Mausam, (1986), 37, 1, 27-38

551.5 : 633 : 551.553.21 (540)

Agroclimatic classification for assessment of crop potential and its application to dry farming tract of India

R. P. SARKER and B. C. BISWAS*

Meteorological Office, New Delhi

(Received 26 September 1985)

सार — किसी क्षेत्र का कृषि जलवायु क्षमता मालूम करने के लिये उसको विभिन्न कृषि-जलवायु क्षेत्रों में वर्गीकृत करना बहुत आवश्यक है। इस लेख में, एक सूचकांक के आधार पर कृषि जलवायु वर्गीकरण के लिये एक सिद्धांत विकसित किया गया है। यह सूचकांक आर्द्रता उपलब्धी सूचकांक (MAI) कहलाता है जिसे निश्चित वर्षा तथा विभव वाष्पोत्सर्जन के बीच अनुपात के रूप में परिभाषित किया गया है। पिछले वर्गीकरण में तीन सुधार किए गए हैं। प्रथम, आर्द्रता उपलब्धी सूचकांक साप्ताहिक आधार पर लिया गया है, द्वितीय, विभिन्न सम्भाव्यता स्तरों पर न्यूनत्तम निश्चित वर्षा पर विचार किया गया है तथा तृतीय, विभिन्न शष्य चरणों के लिये विभिन्न 'MAI' मानों और उनकी अवधियों को बिलकुल ठीक माना गया है तथापि 50% सम्भाव्यता स्तर पर आर्द्रता उपलब्धी सूककांक के आधार पर वर्गीकरण की सिफारिश की गई है जिसे अधिकत्तम मान समझा जाता है। जल प्रतिबल अवधि की लम्बाई के आधार पर मुख्य वर्गीकरण के और उप-वर्ग किए गए हैं।

इस प्रकार विकसित किया गया यह सिद्धांत पहले भारत के शुष्क कृषि क्षेत्रों पर तथा बाद में महाराष्ट्र पर लाग किया गया।

ABSTRACT. To find out agroclimatic potential of a region, it is necessary to classify it into different agroclimatic zones. In this paper, a theory has been developed for agroclimatic classification on the basis of an index called 'Moisture Availability Index (MAI)', which is defined as the ratio of assured rainfall to potential evapotranspiration. Three improvements have been made on earlier classifications. First, moisture availability index has been taken on weekly basis; second, minimum assured rainfall has been considered at different probability levels, and third, the different values of MAI and their duration have been taken as appropriate to various crop phases. The classification, however, has been recommended on the basis of moisture availability index at 50% probability level, which is considered to be an optimum value. The main classification has been further sub-divided depending upon the length of water stress period.

The theory so developed has been applied first to the dry farming tract of India and then to Maharashtra.

1. Introduction

With the ever increasing need for food, shelter and energy, the subject of maximising the produce from land by agriculture and silviculture has become the most important problem for the entire human race. The problem is all the more important and, perhaps, belongs to priority number one for an agricultural country like India.

The saying that farmers learn to live with the limitations of their local climatic conditions through trial and error over generations is no more wholly true. No doubt past experience provides them with very broad information on rainfall and on flood and drought prone areas. Yet for modern agriculture this is not enough. It is now patently clear that for deriving the maximum yield from agriculture (including horticulture) and silviculture, one must have a proper knowledge of agroclimatic conditions without which the most effective cropping pattern and development of supplemental irrigation necessary for different zones cannot be planned. It is not surprising that so much work has been done on this subject for finding a yardstick or at least some kind of a system as can be used with benefit by the agricultural community.

In this paper, we develop a theory of agroclimatic classification and apply the same to the dry farming tract of India. The area bounded by annual rainfall between 40 and 100 cm and practically with no irrigation facilities is known as the "dry farming tract". There are 105 districts under this category of annual rainfall and 18 of these districts have good irrigation facilities. The dry farming tract, therefore, comprises 87 districts and is spread over Punjab, Haryana, Rajasthan, Gujarat, Uttar Pradesh, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil

*Meteorological Office, Pune-411005.

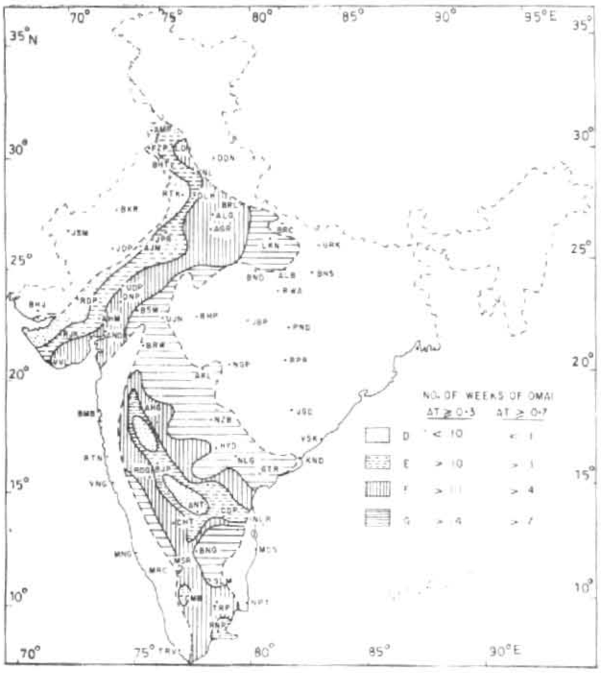


Fig. 1. Agroclimatic classification (Dry Farming Tract of India)

Nadu (Fig. 1). The area under dry farming tract is more than 60 per cent of the total cultivable land in the country and about 40 per cent of the total food production of the country comes from this area. It is, therefore, but natural that increased attention is being given to dry land agriculture.

It is hoped that the agroclimatic classification presented here will provide the agricultural scientists a rational guide for practical agricultural planning.

2. Review of literature

The earlier attempts to classify climate mainly centred round the identification of average annual, seasonal or monthly rainfall and/or temperature regimes that naturally produced some typical types of vegetation of crops in abundance (Koppen 1936; Prescott 1938, Trewartha 1954, Burgos 1958, etc). Thornthwaite (1948) used the concept of average monthly potential evapotranspiration as developed by him, along with the corresponding rainfall to classify climate. He and Mather (1955) improved upon this classification by introducing the various degrees of water deficit and water surplus and called it "Rational Classification". Subrahmanyam (1956) made a "Rational Classification" of India's climate following this method. For assessing agricultural potential of various countries, Papadakis (1961, 1975) used a very simple water balance technique along with average maximum and minimum temperatures. Although Thornthwaite and Mather and Papadakis used some kind of comparison between the moisture required by plants and that is available from precipitation, the results obtained by them are not quite satisfactory as the respective empirical formulae, used by them to compute evapotranspiration are not found suitable for universal application. Moreover, the period used by them is too long in comparison with the entire life cycle of an agricultural crop. Also their methods do not help the users to assess the element of risk involved if agriculture of a country is planned using their classifications.

Cocheme and Franquin (1967) computed water balance following the simple book-keeping procedure of Thronthwaite and Mather (1955) and tried a classification based on different degrees of monthly ratio of P'/PE, where P' is the sum of rainfall and ground storage (available water in the root zone) and PE is the potential evaporation. The ratios of P'/PE equal to 1/8, 1/4, 1/2 and 1 were successively computed and the intervals between the successive limits were defined as Dry (D), Moderately Dry (MD), Moist (M) and Humid (H) respectively. The condition $P'/PE \geqslant 1$ was called Humid (H). This approach has some definite merits in that the length of the growing season could be determined for crop planning at a particular location. They used this method in interpreting the semi-arid areas in south of Sahara and in West Africa. However, the method appears rather difficult for global classification of climates. They also suggested to include risk factor from probability of rainfall determined by semi-logarithmic distribution.

Troll (1965) proposed a classification called the seasonal climate of the earth using monthly rainfall and potential evapotranspiration calculated by Peman's method. His classification, was based on the duration of arid and humid months. The month having mean rainfall more than mean potential evapotranspiration is defined as a humid month, otherwise it is an arid month. He divided the climate of the world into six groups and each was associated with some type of vegetation. For example, the semi-arid area is defined as one where the humid months are from 2 to 7. It appears the method is quite satisfactory in delineating areas in very broad terms but cannot provide the kind of detailed and small scale information needed for agriculture.

Troll's classification done for India is found to suffer from a number of defects. For example, the Kutch area and western extremity of west Rajasthan have been brought under semi-arid which is actually arid. A number of stations, like Jodhpur, Hyderabad and Jalgaon have been brought under the same group which is difficult to accept from the point of vegetation. The same method has been applied by ICRISAT (1978) by utilising data for about 300 locations. The map produced by ICRISAT does not also appear to be satisfactory. In this map, areas around Saurashtra and central parts of east Rajasthan have been brought under arid zone. But it is well known that groundnut and other oil-seeds, sorghum and pearl millet are grown in these areas. Similarly, areas in part of Karnataka and Rayalaseema and parts of Madhya Maharashtra have been brought under arid zone, where seasonal crops are produced in most of the areas. Another large area in Orissa, West Bengal, Bihar and Andhra Pradesh has been categorised as semi-arid, where the rainfall is more than 150 cm and rice is grown in plenty. Some of these points have been mentioned in *Agroclimatology Progress Report*-2 of ICRISAT (1978).

In view of the above, one would hesitate to accept Troll's classification, particularly for tropical areas. It seems a combination of humid and arid months would give a better classification (Chowdhury *et al.* 1980).

Another important classification is due to Hargreaves (1974). He gave a classification based on monthly moisture availability index (MAI) which he defined as the ratio of monthly precipitation at 75% probability level to monthly potential evapotranspiration. He introduced the risk factor by taking probabilistic rainfall value instead of the monthly average. He also assumed that rainfall at the 75% probability of occurrence is very much deficit if it does not meet more than a third of potential evapotranspiration requirements. He emphasised the importance of continuity of the period when MAI $\geqslant$ 0.34. Although Hargreaves has taken account of risk factor which is very necessary for crop planning, still according to us, his classification has there shortcomings, *i.e.,*

(*i*) only one risk factor has been taken into account,

(*ii*) month is too long a period for modern cereal crops, and

(*iii*) MAI value $\geqslant$ 0.34 has been considered adequate for all the growth stages of the crops.

3. Present study

In this paper, we wish to develop the methodology for agroclimatic classification using Moisture Availability Index (MAI). We, however, introduce the following three modifications in the methodology developed by Hargreaves (1974) :

(*i*) weekly MAI rather than monthly,

(*ii*) different risk factors, instead of one, so that the planner could choose his own risk level, and

(*iii*) MAI $\geqslant$ 0.3 and $\geqslant$ 0.7 depending upon crop growth phase.

On the basis of the MAI, we make broad classification which we further sub-divide depending upon the length of the water stress period. On this we superimpose soil types to get real agroclimatic classification.

3.1. *Moisture Availability Index (MAI)*

For our specific classification, we first obtained the Moisture Availability Index (MAI) which is defined as follows :

$$\text{MAI} = \frac{\text{Assured rainfall}}{\text{Potential evapotranspiration}}$$

3.2. *Assured rainfall at different probability levels*

It goes without saying that the planner, be he a farmer or a hydrologist, must know the risk he is going to take in his endeavour. The study by using average or normal rainfall cannot include this risk factor. In the dry farming tract or low rainfall areas, there is considerable year-to-year deviation from the normal. In such low rainfall areas, the normal rainfall (Monthly, Seasonal or Annual) quite often is far too short of the water requirements of the crops. But experience shows that on a number of occasions crops are successfully raised. Apparently, in such years the rainfall is more than the normal values and meets the water demand of the crops. So, for any crop planning purpose, one should know from long records what is the chance of meeting the water requirement of the crops. Accordingly, the planning has to be done on a probabilistic basis, which eventually takes into account the chance of success or failure. This minimum assured rainfall (AR) at different probability levels has been computed by Sarker *et al.* (1982) by incomplete gamma distribution for dry farming tract of India and forms the basis of our study.

The equations used for computation of minimum assured rainfall (Sarker *et al.* 1982) are the mixed Gamma distribution :

$$G(X) = q + p\,F(X) \qquad (1)$$

where $F(X)$ is the Gamma distribution and q is the probability of zero precipitation and $p = 1 - q$. $F(X)$ is given by :

$$F(X) = \int_0^X \frac{x^{\gamma-1}\, e^{-x/\beta}}{\beta^{\gamma}\, \Gamma(\gamma)}\, dx \qquad (2)$$

where $x, \gamma, \beta > 0$

$$F(X) = 0 \text{ when } x \leqslant 0$$

γ and β are shape and scale parameters respectively of the distribution and $\Gamma(\gamma)$ is the Gamma function of γ. The distribution is bounded at the left side by zero. $G(X)$ is the probability of rain $< X$.

The parameters γ and β have been estimated from observed data by maximum likelihood method.

$P(X)$, the probability of rain $\geqslant X$ is given by

$$P(X) = 1 - G(X) = 1 - q - (1-q)\,F(X)$$

$$= (1-q)\left[1 - \int_0^X \frac{x^{\gamma-1}\, e^{-x/\beta}}{\beta^{\gamma}\, \Gamma(\gamma)}\, dx\right] \qquad (3)$$

The above equation was solved on electronic computer for probabilities of rainfall exceeding specified amounts X_1, X_2, etc. Alternatively the minimum assured rainfall (AR) was obtained by solving the above equation by iteration process for X. For $P(X) = 0.10, 0.20, 0.30, \ldots\ldots, 0.90$ respectively.

3.3. *Range of MAI used*

Water required by a plant growing under natural conditions mainly consists of three parts, namely, (*i*) transpiration for maintenance of its life process, (*ii*) evaporation from soil and (*iii*) the part that enters into its body building. The first two together is known as evapotranspiration. The last one is so small compared to the sum of the first two that it is neglected in agrometeorological studies and actual evapotranspiration is taken as a good measure of the water requirement of crop plants.

It is very difficult to have data on actual evapotranspiration which varies with the growth of plant and also perhaps, to some extent, from crop to crop. How-

TABLE 1

MAI and AAR in weekly and bi-weekly period

Probability level	Weekly No. of weeks MAI ⩾.3	⩾.5	⩾.7	⩾.9	Accumulated assured rainfall (mm) for period when MAI ⩾0.3	Bi-weekly No. of weeks MAI ⩾.3	⩾0.5	⩾.7	⩾.9	Accumulated assured rainfall (mm) for period when MAI⩾0.3
Hissar (Lat. 29°10′N, Long. 75°44′ E)										
40	10	7	3	0	214	12	10	6	0	277
50	8	3	0	0	119	10	6	0	0	180
60	2	0	0	0	25	8	0	0	0	108
70	0	0	0	0	0	2	0	0	0	23
New Delhi (Lat. 28°35′N, Long. 77°12′E)										
40	12	11	9	7	396	18	12	12	8	503
50	11	8	7	3	255	12	10	8	4	338
60	8	5	3	0	141	10	8	4	2	226
70	5	0	0	0	061	8	4	2	0	142
Banaras (Lat. 25°18′N, Long. 83° 01′E)										
40	17	16	15	13	849	18	16	16	14	839
50	16	14	13	12	625	16	16	14	12	760
60	14	12	11	9	441	16	14	12	12	615
70	12	10	9	6	286	16	12	12	10	479
Bhopal (Lat. 23°16′N, Long. 77° 25′E)										
40	16	15	14	13	980	16	16	14	14	1068
50	15	14	13	12	738	16	16	14	12	877
60	14	12	12	11	539	16	12	12	12	709
70	12	11	10	8	367	14	12	12	12	548
Rajkot (Lat. 22°18′N, Long. 70°47′E)										
40	15	9	5	5	398	16,	14	10	6	489
50	10	5	3	1	203	14	10	6	4	322
60	5	1	0	0	82	10	4	2	0	182
70	1	0	0	0	12	6	0	0	0	86
Barsi (Lat. 18°14′N, Long. 75°42′E)										
40	19	16	10	5	478	22	18	14	6	552
50	15	8	4	1	288	18	14	6	2	404
60	11	2	1	0	142	18	8	2	2	302
70	3	0	0	0	34	10	2	0	0	139
Bellary (Lat. 15°09′N, Long. 76°51′E)										
40	14	6	4	3	241	20	8	6	6	342
50	6	3	3	1	103	12	6	6	2	189
60	4	2	0	0	48	6	6	2	0	101
70	2	0	0	0	20	6	2	0	0	69
Kovilpatti (Lat. 09°10′N, Long. 77°52′E)										
40	16	12	8	8	410	22	12	10	6	513
50	12	8	5	5	247	14	10	6	6	331
60	8	5	4	1	146	12	6	6	4	238
70	5	3	1	1	75	8	4	4	2	153

ever, it is assumed in all the agrometeorological studies that potential evapotranspiration covers the maximum requirement of fully grown crop plants (the peak period of their moisture demand) covering the soil surface completely. It has been found that during its early stage of growth (first 3 to 4 weeks) actual evapotranspiration is about one-quarter of the potential rate due to small and sparse foliage and that the maximum demand may even slightly exceed the potential rate if the size of the field is not too large and there is considerable advection of sensible heat into the crop field (Riplay 1966). But experiments have shown that due to its built in natural protective capacity, a plant can narrow down its stomatal openings to restrict transpiration when there is moisture stress and grow almost normally as long as the moisture supply does not fall below about three-quarter of the potential rate (Arnon 1972). After completion of grain formation, the water demand falls off rapidly becoming small at the ripening stage (Holmes and Bomertson 1963).

In view of the above, the classification in the present study has been made on the basis that a crop will be nearly normal if it gets moisture varying from 0.3 to 0.7 of potential evapotranspiration commencing from germination to completion of grain formation stage.

3.4. *Choice of interval*

As mentioned earlier, a month is too long a period compared to the entire crop life. This is particularly so as the plant breeders are constantly evolving short duration varieties with a view to producing more number of crops per year. Use of monthly rainfall suffers from another defect also. There are areas where even during the height of the wet season the daily rainfall varies immensely in amount, so much so, that a month's average rainfall may be realised only in a few days (say, a week or even less), while the rest of the month may go dry. If this happens during the early part of the life of a crop, it may cause irreparable damage to it. In the tropics where the rainfall is showery and highly freakish in intensity, amount and distribution (both in time and space), it is necessary to use the week as the unit of time, at least for the early part of the crop life, and not more than two weeks at a later stage.

3.5. *Optimum Moisture Availability Index (OMAI)*

An index called the Optimum Moisture Availability Index (OMAI) has been calculated for respective area units and it is defined as the ratio of assured rainfall (weekly, bi-weekly or monthly) at 50% probability level to potential evapotranspiration of the correspondign period. The MAI index has, however, been calculated for 40, 50, 60 and 70 per cent probability levels, although the climatic classification has been done on the basis of the index at 50% level.

The reason for choice of the 50% probability is this that since in calculating MAIs at a certain probability level the minimum assured rainfall figures have been used, in actuality the MAIs of many individual years will have higher values than indicated by that particular probability and will have really a better chance of agricultural success. Hence use of assured rainfall at 50% probability level indicates a chance of agricultural success higher than 50%.

It has been observed that MAI for many weeks for most of the stations is 1.0 or more and very small or zero for 40 and 70% levels of probability respectively. Hence use of these probabilities will lead to unrealistic results. An examination of the MAIs for the remaining two probability levels (50 and 60%) shows that all of them give almost the same relative gradation.

It is accepted that 40% is too low a probability for planning. On the other hand, with 60% level of probability, duration of MAIs in the group 0.7, the minimum necessary for certain period for most of the crop becomes too little. The probability 50% satisfies the criterion of MAI values of 0.3 for early and 0.7 for subsequent growth stages of the crop life.

Table 1 gives the MAIs of weekly and bi-weekly assured rainfall at different probability levels for a few selected stations. It is seen that classification based on weekly MAIs at 50% probability level remains practically same as that of bi-weekly at 60% level. In other words, for the purpose of classification, use of weekly MAIs at 50% probability level is equivalent to using bi-weekly MAIs at 60% probability, both in duration and accumulated rainfall during the period when MAI is more than 0.3. An examination of MAIs and assured accumulated rainfall (AAR) at various levels leads to the conclusion that, in general, dependability increases by 10% if one switches over from weekly to bi-weekly analysis. But as mentioned earlier, it should be kept in the mind that though the minimum water requirement for the crop in its early stage is low, it is very susceptible to moderately prolonged moisture deficiency. Hence, choice of a bi-weekly assured rainfall is not desirable for the early growth stage, particularly in areas where time variability of rainfall is high. Therefore, choice of weekly assured rainfall at 50% probability level seems to be the optimum criterion for classification of areas on the basis of moisture availability index, as it also covers 60% probability with bi-weekly rainfall for that growth stage when the crop has already developed the capacity to stand moisture stress for a week or so. The MAIs obtained by using assured weekly rainfall at 50% may, therefore, be called the Optimum Moisture Availability Index (OMAI) which has been used in the method applied here.

Using the OMAI mentioned above, for the period 23rd to 42nd week (4 June-21 October), the area under study has been classified into following broad agroclimatic zones. Increasing OMAI both in duration and magnitude has been denoted in alphabetical order of the English capital letters starting from 'D'.

Classification	*No. of weeks when OMAI at 50% level at least*	
	0.3	*0.7*
D	<10	<1
E	⩾10	⩾1
F	⩾11	⩾4
G	⩾14	⩾7

Some letters A to C at the beginning have been kept reserved for classification for arid zone where annual rainfall is less than 40 cm. Similarly, letters after G will be used for classification of high rainfall zones where annual rainfall is more than 100 cm. These classifications will be reported in a subsequent paper.

3.5.1. *Sub-divisions due to water stress period*

The mid-monsoon season water stress, *i.e.,* when OMAI is less than 0.3 which is called water stress period has been designated by the use of numerical suffixes in the ascending order of duration to the above broad classification. Suffix 1 indicates that there is hardly one week's water stress period, while suffixes 2, 3 and 4 indicate 2-3 weeks; 4-5 weeks and more than 5 weeks water stress respectively.

Deliberately we have not given any further subdivision on the basis of temperature, as practically the entire country comes under one category according to temperature classification.

4. End of the growing season

On the basis of computation of MAI discussed above one will be tempted to think that the growing season is over when MAI comes below 0.3. But cessation of rainy season does not mean the end of crop season. Crop can thrive on stored moisture. It is, therefore, necessary to examine and find out the amount of moisture stored in the soil at the end of the season when MAI is just 0.3. This could be done by water balance technique which is not within the scope of

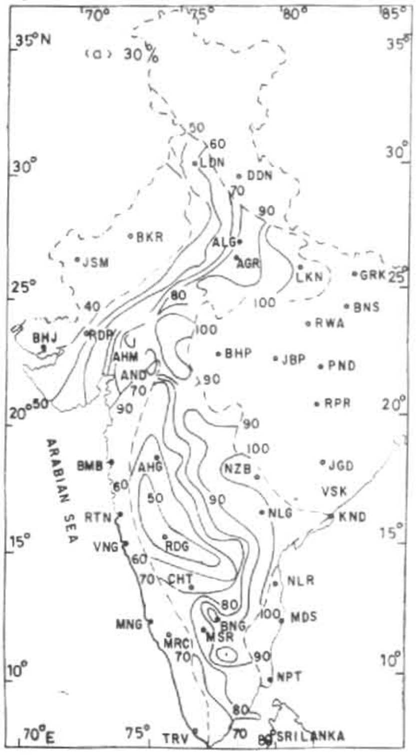


Fig. 2

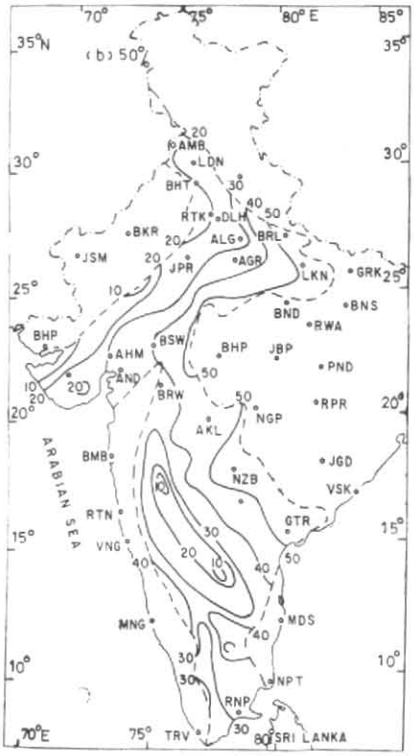


Fig. 3

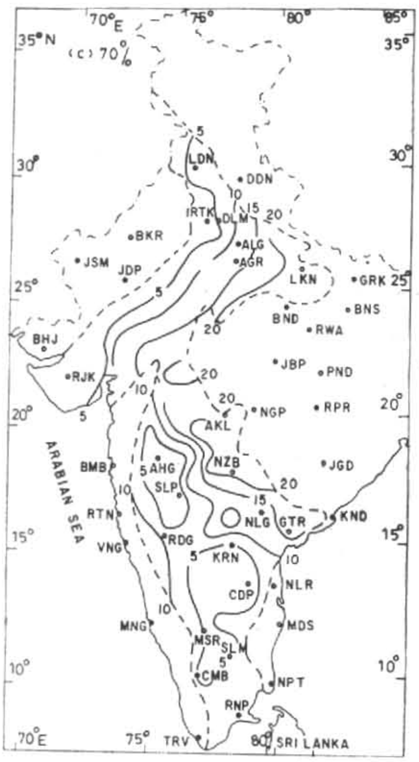


Fig. 4

Figs. 2-4. Accumulated assured rainfall (cm) at 30% level (Fig. 2), at 50% level (Fig. 3) and at 70% level (Fig. 4)

TABLE 2

MAI, PET and accumulated assured rainfall (AAR)

State	Station	At 40% probability level						At 50% probability level						Agroclim. class.
		No. of weeks MAI				AAR (mm)	PET (mm)	No. of weeks MAI				AAR (mm)	PET (mm)	
		≥.3	≥.5	≥.7	≥.9			≥.3	≥.5	≥.7	≥.9			
Punjab	Jullundur	12	10	9	8	395	415	10	8	5	4	254	341	E_1
	Ferozpur	8	7	—	—	157	299	6	—	—	—	89	222	D_2
Haryana	Karnal	12	11	10	8	444	424	10	9	7	6	279	347	E_1
	New Delhi	12	11	9	7	396	426	11	8	7	3	255	380	F_1
Rajasthan	Amjer	12	10	9	7	329	402	9	9	3	2	189	293	D_1
	Uadipur	16	13	11	10	473	450	13	11	10	8	295	344	F_1
	Banswara	15	14	13	13	725	393	14	12	11	10	484	353	G_1
Madhya Pradesh	Shivpuri	15	14	12	11	719	481	14	11	10	10	514	434	G_1
	Neemuch	15	13	13	10	606	470	13	12	10	10	399	378	F_1
	Indore	16	16	14	13	741	518	16	14	13	11	535	518	G_1
Gujarat	Deesa	11	10	9	6	329	352	10	8	3	2	181	277	D_1
	Idar	15	13	11	11	736	475	11	11	9	9	460	325	F_1
	Anand	14	13	12	11	636	408	12	11	11	8	399	310	F_1
	Baroda	15	14	12	12	664	454	13	12	11	8	427	382	F_1
	Amreli	14	10	8	4	321	446	9	7	3	1	173	286	D_1
Maharashtra	Ahmednagar	19	14	7	4	387	491	15	7	2	1	214	410	E_2
	Jalgaon	16	14	13	11	539	562	14	11	9	6	401	476	G_1
	Solapur	17	16	13	6	443	542	17	12	4	2	303	542	F_1
	Tasgaon	21	13	8	4	404	629	15	8	2	0	234	434	E_3
	Malsiras	12	6	3	2	249	397	7	2	2	2	129	232	D_4
	Barsi	19	16	10	5	468	652	15	8	4	1	288	515	F_2
	Akola	18	15	8	8	411	510	15	8	6	3	267	472	F_3
Andhra Pradesh	Hyderabad	19	15	15	13	551	622	16	15	11	6	381	520	G_1
	Anantpur	17	5	4	3	217	629	5	4	2	—	87	156	D_1
	Cuddappah	20	20	12	3	454	785	18	13	2	2	307	660	E_1
Karnataka	Gulburga	19	18	14	9	536	661	18	14	6	3	367	629	F_1
	Bellary	11	6	4	3	215	451	6	3	3	1	103	179	D_1
	Tumkur	28	23	18	9	644	835	27	17	5	4	369	707	E_1
Tamil Nadu	Tiruchirapalli	18	14	12	7	486	664	14	9	6	2	296	473	F_1
	Dharampuri	29	19	14	9	607	898	19	13	7	3	334	644	G_1

Agroclim. class. = Agroclimatic classification

TABLE 3

MAI, PET and accumulated assured rainfall (AAR)

State	Station	At 60% probability level						At 70% probability level					
		No. of weeks MAI				AAR (mm)	PET (mm)	No. of weeks MAI				AAR (mm)	PET (mm)
		⩾.3	⩾.5	⩾.7	⩾.9			⩾.3	⩾.5	⩾.7	⩾.9		
Punjab	Jullundur	8	5	3	—	154	271	5	3	—	—	77	174
	Ferozepur	—	—	—	—	—	—	—	—	—	—	—	—
Haryana	Karnal	8	7	3	—	139	274	5	2	—	—	76	176
	New Delhi	8	5	3	—	141	270	5	—	—	—	61	168
Rajasthan	Ajmer	8	2	—	—	106	262	1	—	—	—	12	34
	Udaipur	11	8	6	—	177	290	7	3	—	—	80	182
	Banswara	11	10	9	9	302	268	9	9	7	3	171	214
Madhya Pradesh	Shivpuri	11	10	9	8	339	323	9	8	7	2	206	264
	Neemuch	12	10	9	4	254	349	9	7	1	—	134	253
	Indore	14	13	10	6	354	436	13	9	4	2	221	389
Gujarat	Deesa	6	3	—	—	80	192	1	—	—	—	3	29
	Idar	10	9	9	6	259	286	9	6	4	2	161	256
	Anand	11	9	6	5	255	310	10	5	3	2	124	194
	Baroda	12	9	6	5	264	344	8	5	3	—	125	223
	Amreli	7	1	1	—	83	220	1	—	—	—	13	34
Maharashtra	Ahmednagar	9	1	1	0	121	342	1	—	—	—	11	27
	Jalgaon	11	9	6	4	259	365	9	6	2	—	119	307
	Solapur	15	14	1	—	185	480	5	—	—	—	47	157
	Tasgaon	9	3	—	—	130	257	2	—	—	—	63	54
	Malsiras	2	2	1	0	29	60	2	—	—	—	24	60
	Barsi	10	2	1	—	142	335	3	—	—	—	34	94
	Akola	9	5	2	—	142	293	5	1	—	—	56	134
Andhra Pradesh	Hyderabad	15	12	4	1	261	474	12	4	—	—	149	373
	Anantpur	3	1	—	—	34	93	—	—	—	—	—	—
	Cuddappah	12	2	1	—	131	375	2	—	—	—	20	60
Karnataka	Gulburga	15	6	1	—	217	508	6	—	—	—	67	195
	Bellary	3	2	—	—	48	91	2	—	—	—	21	62
	Tumkur	17	5	3	—	223	505	3	1	—	—	35	145
Tamilnadu	Thiruchirapalli	9	5	1	—	165	350	5	1	—	—	63	160
	Dharampuri	13	5	1	1	178	408	4	1	—	—	46	114

present study. However, the cumulative seasonal evapotranspiration for dry land crops like sorghum etc even under relatively favourable moisture conditions may be only 65% of PET (Jenson 1968). Riplay (1966) observed that in many farm crops seasonal water use may range from 55% to 75% of PET.

India Meteorological Department installed about 35 lysimeters in various soil and climatic zones of the country to find out water requirement to different crops. Venkataraman *et al.* (1976) found that cumulative seasonal ET is about 70% of PET. It has, therefore, been taken for this study that difference between seasonal total assured rainfall and two-third of PET of corresponding period will go into stored soil moisture and plant can use it even after the end of the rainy season.

5. Application of the methodology to Dry Farming Tract of India

The theory of agroclimatic classification developed here has been applied to the Dry Farming Tract of India comprising 87 districts and has also been applied separately for Maharashtra.

In case of the entire dry farming tract we have taken one station for each district and thus the analysis is based on 87 locations. In the case of Maharashtra, a district has been represented by 5 to 10 stations. Thus we have 84 stations for Maharashtra.

The weekly assured rainfall (AR) values have been taken from Sarker *et al.* (1982) and Biswas & Khambete (1979). The corresponding weekly potential evapotranspiration (PET) values were taken from the monthly average values worked out by Rao *et al.* (1971) using Penman's method (1948).

On the basis of the above analysis, the dry farming tract of India has been divided into four agroclimatic zones — D, E, F and G (Fig. 1). Accumulated assured rainfall (AAR) at 30, 50 and 70 per cent levels is depicted in Figs. 2 to 4 respectively. Tables 2 and 3 give the duration of MAI at various probability levels of selected 30 stations along with AAR, PET and classification.

In the following paragraphs, we discuss the zones and their crop potential. Before we do so, it is necessary to have an idea about the water requirements of crops of various durations. Information on this aspect is really lacking. However, it has been recognised that about 325 to 525 mm of water is necessary in low rainfall zone for raising a summer crop like Sorghum, Pearl Millet, Cowpea, etc. Our present analysis shows that accumulated assured rainfall (AAR) for 10 to 12 weeks during which MAI $\geqslant 0{\cdot}3$ (of which during 3 to 6 weeks MAI is more than 0.7), varies from 220 to 270 mm. It is, therefore, believed that a short duration crop (10 to 12 weeks) requires about 250 mm of AAR. Similarly a medium duration crop of 12 to 16 weeks would require about 350 mm and a long duration crop of more than 16 weeks would require more than 400 mm. Our discussion in the following paragraphs regarding crop potential at different probability levels has been based on these assumptions.

5.1.. *Different crop potential zones*

5.1.1. *Area 'D'* — This is the low crop potential area of dry farming tract. Fig. 1 shows that there are three parts of area 'D' in the tract. The first part comprises western part of the dry farming tract extending from Jamnagar district of Gujarat to Ferozepur in Punjab. The second area includes the parts of Ahmednagar, Pune, Satara, Solapur and Sangali districts of Maharashtra. The third part falls in Karnataka and is having the portions of the districts of Bijapur, Raichur, Bellary, Kurnool and Anantpur.

In the area 'D', there may be a break of OMAI of one week duration and in many cases it may be of 4-5 weeks. Assured rainfall is of the order of 80-100 mm in the western part of the tract in Gujarat and 200-225 mm in Punjab at 50% probability level (Fig. 3). Crop production without irrigation is almost a speculaton. However, in some stations where AAR is of the order of 200-250 mm and there is hardly any break in OMAI, a short duration crop may be raised.

At 40% probability level accumulated rainfall is low and it is of the order of 220-250 mm over Pali area of Rajasthan, Dhond in Pune district of Maharashtra and Bellary district of Karnataka. A short duration crop may be raised from most parts of the area 'D'.

Crop prospect is high at 30% probability level as assured rainfall is as high as 500 mm at some of the stations (Fig. 2).

As rainfall is the limiting factor of crop production, all sorts of commercial crops may be discouraged in this region. The areas where break is more than two weeks are suitable for pasture development and cattle rearing.

5.1.2. *Area 'E'* — Fig. 1 shows that the area 'E' is extending from Rajkot in Gujarat along the east side of the area 'D' upto Punjab through Rajasthan and Haryana. The second part is spread from Ahmednagar district in Maharashtra upto coastal area of Cudappa district in Andhra Pradesh through Satara, Pune, Solapur and Sangali districts of Maharashtra and Bijapur, Bellary and Tumkur districts of Karnataka. Crop potential of this area is not very high because the duration of OMAI more than 0.3 and 0.7 ranges for 10-13 and 1-5 weeks respectively. Fig. 3 shows that assured rainfall is about 200 mm in the Sirohi district and adjacent area of Rajasthan and it is of the order of 350-375 mm in Karnataka and Andhra Pradesh at 50% probability level. A short to medium duration crop may be raised from most of the stations.

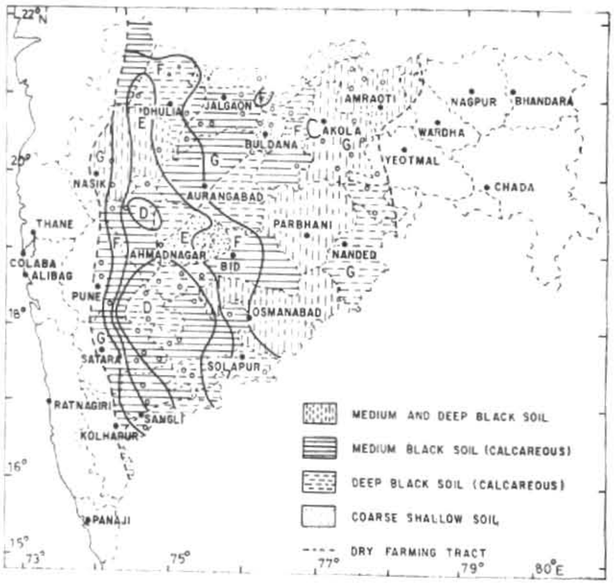


Fig. 5. Agroclimatic classification of Maharashtra

Many stations get accumulated assured rainfall as high as 460 mm at 40% probability level (Table 2). So, some soil moisture may be available at the end of rainy season. A medium to long duration crop may be raised from this area as crop can thrive on stored moisture for a few weeks even after cessation of rainy season.

A long duration crop may be raised from most of the stations of this area once in three years as AAR ranges from 530 mm at Ahmednagar in Maharashtra to 940 mm at Tumkur in Karnataka (Fig. 2) and crop can use stored moisture at the end of the rainy season.

5.1.3. *Area 'F'* — Like the region 'E', the area 'F' has also two parts. The northern part comprises vast areas of Gujarat, Rajasthan, Uttar Pradesh and a small portion of Haryana and Punjab (Fig. 1). The southern part stretches from Nasik district of Maharashtra to Kanya Kumari in Tamil Nadu. A large portion of Karnataka and Andhra Pradesh also comes under this agroclimatic zone.

Fig. 3 gives AAR at 50% probability level. As there is hardly any break of OMAI and assured rainfall is of the order of 230 to 450 mm around Sangli area of Maharashtra and Madhpura of Rajasthan, a medium duration crop may be raised from most of the stations once in two years.

At 40% probability level crop prospect is high as AAR ranges 330 mm at Sangli (Maharashtra) to 730 mm at Idar (Gujarat). Two short duration crops or a mixed crop may be raised from this region at this level.

A short duration crop may be raised at 60% probability level from some of the stations where AAR is of the order of 225-250 mm (Table 3).

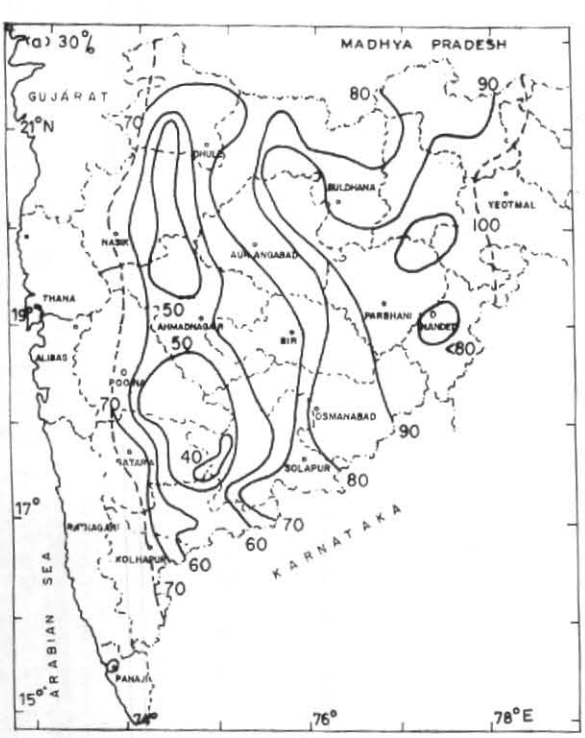


Fig. 6. Accumulated assured rainfall (cm) at 30 per cent probability level

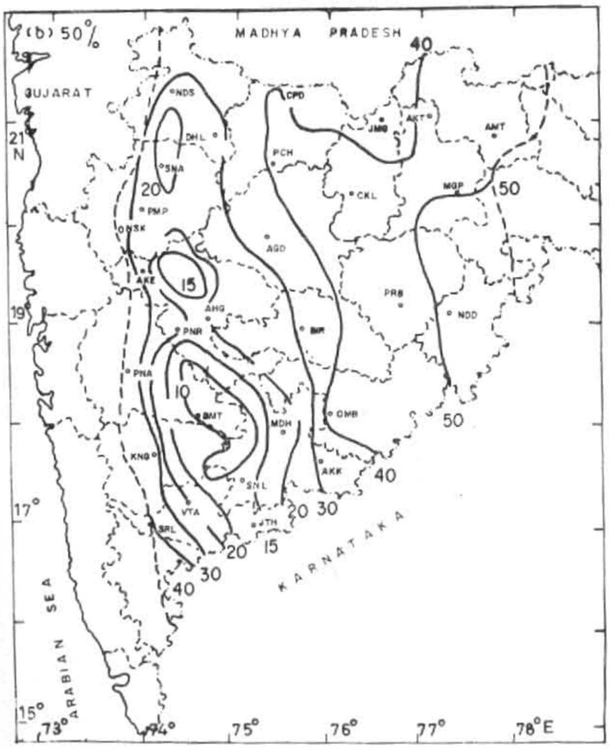


Fig. 7. Accumulated assured rainfall (cm) at 50 per cent level

5.1.4. *Area 'G'* — This is the highest crop potential zone of dry farming tract. This area consists of small portions of Uttar Pradesh, Madhya Pradesh and Gujarat and Tamil Nadu and considerable parts of Maharashtra and Andhra Pradesh (Fig. 1). The portion in Tamil Nadu enjoys the northeast monsoon. Growing season, therefore, differs significantly from rest of the areas of this region.

OMAI $\geqslant 0.3$ and 0.7 range from 14-19 and 7-13 weeks respectively and AAR from 330 to 480 mm. Some stored moisture will be available at some of the stations. A crop of 13-18 week duration may be raised from this reigon in rainfed condition once in two years.

At 60% probability level most of the stations have the potential to grow a medium/short duration crop as assured rainfal ranges from 180 mm at Dharampuri district of Tamil Nadu to 380 mm at Nanded district of Maharashtra.

The AAR at 70% level depicted in Fig. 4, and Table 3 will reveal that it is of the order of 200-250 mm at a number of locations. A short duration crop may, therefore, be raised at these places in 7 out of 10 years.

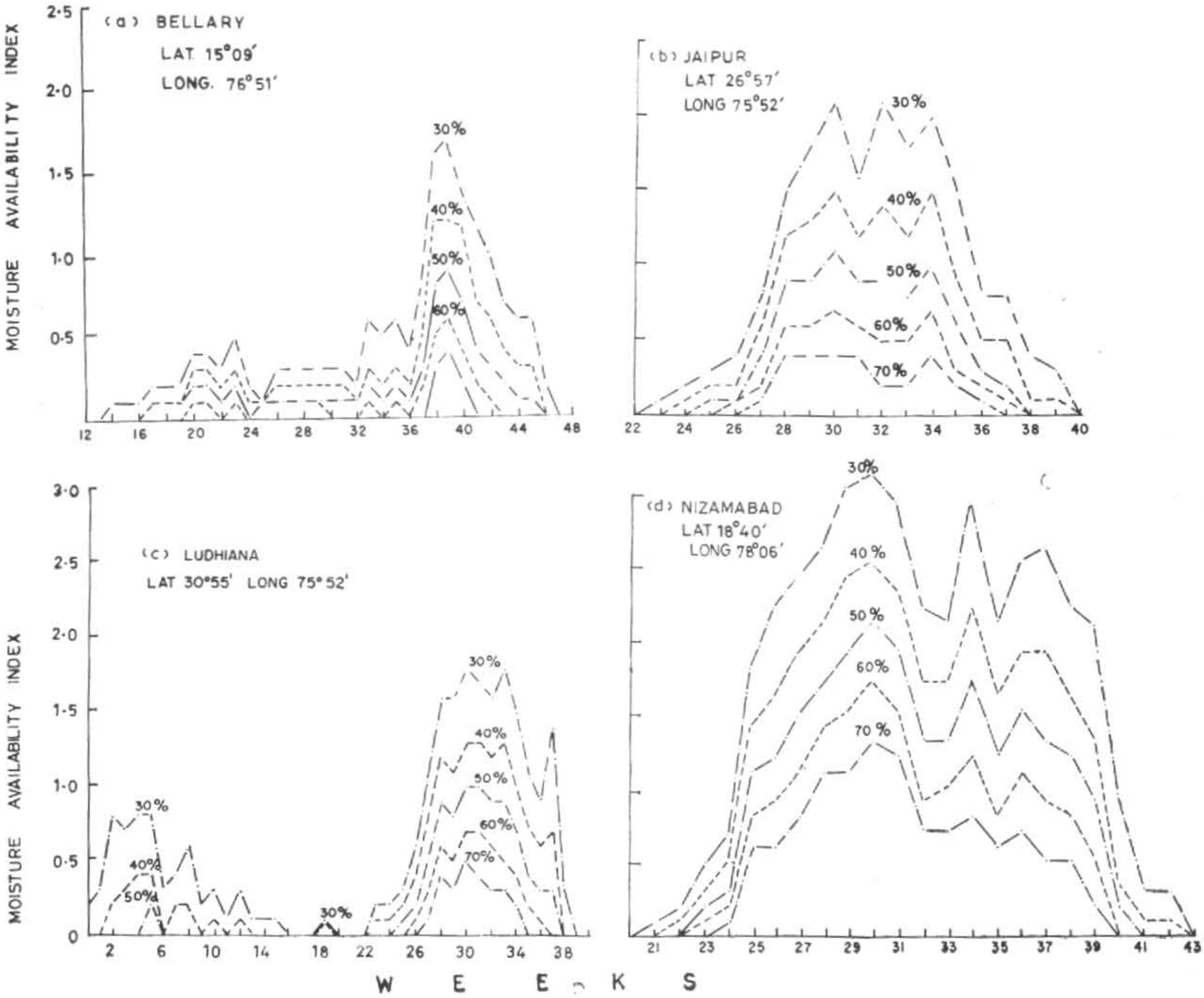
Crop prospect is very high at 40% probability level as the AAR ranges from 460 mm to 850 mm (Table 2). Two short duration crops or a mixed crop may be raised from this region at this level.

Although the classification has been done on the basis of 50% probability level of rainfall, it is seen that some times in a particular area the prospect of planning a crop at this probability level is very dim. For example, in the agroclimatic zone 'D', at many stations, the accumulated assured rainfall at 50% probability level is not sufficient to grow a crop, but there could be sufficient moisture at 30% probability level to grow a crop, which means one could plan a crop once in 3 years. Similarly, in high rainfall zones, *viz.*, 'G', there could be many stations where the assured moisture may be sufficient to grow crop at 60-70% probability level, which means that one could expect to plan a crop in 6 to 7 years out of 10. We have, therefore, given the assured accumulated rainfall at 30, 50 and 70% probability levels in Figs. 2, 3 and 4 respectively.

6. Application to Maharashtra

We have also divided the dry farming tract of Maharashtra into 4 agroclimatic zones, 'D', 'E', 'F', and 'G', by using data of 84 stations. Assured rainfall has been taken from the publication of Biswas and Khambete (1979).

This micro analysis divides the dry farming tract of Maharashtra (Fig. 5) into different agroclimatic zones and brings out many local features that could not be located in the micro analysis of the entire dry farming tract. Fig. 6 and Fig. 7 give the accumulated assured rainfall at 30 and 50% level which have brought out the core of the drought prone areas comprising 6 talukas, *viz.*, Dhond, Baramati, Indapur, Malsiras and parts of Karmala and Dahiwadi Accumulated rainfall during the rainy season in this area is about 125 mm at 50% level (Fig. 7), but at 30%



Figs. 8 (a-d). Moisture availability index at different probability levels (30-70%) for (a) Bellary, (b) Jaipur, (c) Ludhiana and (d) Nizamabad

level it is about 400 mm (Fig. 6). This indicates that crops can be raised from the core of the drought prone area in about 30-40 per cent of the years. On the micro analysis we have superimposed the type of soils (Fig. 5). This has further sub-divided the area into various sub-zones. This analysis has brought out crop potential of each sub-zone in terms of soil, precipitation and atmospheric evaporative demand and also the risk involved in the agriculture. This indicates clearly the necessity of micro analysis to assess the crop potential of small areas.

7. Crop potential at individual stations

In order to examine the crop potential at few individual stations, we have given in Figs. 8(a-d), the moisture availability indices at different probability levels for one station in each agroclimatic zone. The soil characteristics have also been taken into account. These are discussed below:

Bellary (Lat. 15° 09′ N, Long. 76° 51′ E)—Fig. 8(a)

The station falls in the climatic category D_1. This area is dominated by black calcareous soils and depths of the soils vary from medium to deep with complex slopes running at various directions. Soils are poor in available phosphates and generally well supplied with organic matters. Fertility is poor. Field capacity and wilting point are 32-36 and 19-21 per cent of the dry soil respectively.

It is inferred that no rainfed crop may be raised from the area around Bellary, because assured rainfall and the duration of OMAI $\geqslant$ 0.3 are 103 mm and 6 weeks (Fig. 8a) respectively at 50% probability level.

At 40% probability level a short duration rabi crop may be raised with one or two irrigations as AAR is 215 mm, as the rainfall peak is around 39th week (24-30 September).

At 30% duration of MAI more than 0.3 is 23 weeks, but MAI exceeds 0.7 during 7 weeks, *i.e.,* from 36th to 42nd week (3 September-21 October). A medium duration crop may be raised from this region once in three years.

Rabi jowar is the main crop in this area. Oil seeds like sunflower and safflower occupy a considerable area. More pulses may be introduced to boost up total production.

Jaipur (*Lat.* 26° 55′ *N*; *Long.* 75° 50′*E*) — *Fig.* 8(b)

The station comes under agroclimatic zone E_1. Soils at Jaipur are brown; texture is sandy loam. Depths of the soils are medium to deep. There may be some pockets of saline soils. Porosity of soil is good. There is hardly any problem of drainage. Soils are fertile, salinity and alkalinity may develop due to improper management.

Fig. 8(b) depicts the MAIs of Jaipur at different probability levels. One of the important features of the station is that rainfall is mainly confined between 28th & 34th week (9 July-26 August). Duration of OMAI more than 0.3 and 0.7 is 10 and 7 weeks respectively and AAR is 250 mm.

Crop prospect is high at 40% probability level as MAI $\geqslant$ 0.9 during 8 weeks and accumulated assured rainfall exceeds PE. A medium duration crop could be successfully raised in 2 out of 5 years.

At 30% probability level, a long duration crop may be raised as crop can thrive on stored moisture for 3 to 4 weeks after cessation of the rain as AAR is of the order of 550 mm (Fig. 2).

Main crop is Pearl Millet, occupying about 44% of cropped area; barley and pulses occupy 8 and 10 per cent areas respectively. Wheat is also cultivated in about 8% area. Pulses may be given more place to boost up production.

Ludiana (*Lat.* 30°55′*N*, *Long.* 75°52′*E*) — *Fig.* 8(c)

This station belongs to category F_1. The soil around this region is mainly sandy. Depths of the soils vary from medium to deep. Texture is medium coarse. Water holding capacity of the soils is more or less good. Field capacity and permanent wilting point lies between 9-11 and 4-5 per cent respectively. There is hardly any variation in physical and chemical properties of the soils at different layers.

At this station, duration of rainfall is short. But it has been seen that once rainfall starts it attains the peak and continues for 7-8 weeks. Some rainfall also occurs during January and February. Although this amount is little, it is beneficial to winter crop due to low evaporation. Fig. 8(c) shows that at 50% probability level duration of OMAIs$\geqslant$ 0.3 and 0.7 are 11 and 7 weeks respectively. As AAR is about 250 mm (Fig. 3), a 12-14 weeks duration crop may be raised from this area.

At 40% probability level crop prospect is high as AAR is 390 mm.

At 30% probability level MAIs $\geqslant$ 0.3 and 0.7 are *14 and 11* weeks respectively and AAR is 610 mm (Fig. 2). A long duration or two short duration crops may be raised.

Maize is the main crop and sunflower occupies the second place in crop rotation. Short duration maize and pulses may be given more place in crop rotation to use the full soil water potential.

Nizamabad (*Lat.* 18°40′*N*, *Long.* 78°06′*E*) — *Fig.* 8(d)

This station falls in the agriclimatic category G_1.

Medium black soil is predominant in this region. Depths of the soil vary from 40 cm to more than a metre. Soils become sticky on wetting and cracks are formed on drying. Salinity and alkalinity may be developed under improper management.

Fig. 8(d) gives MAIs at different probability levels. The duration of OMAI $\geqslant$ 0.3 and 0.7 are 16 and 15 weeks respectively. Accumulated assured rainfall at 50% level is 640 mm (Fig. 3) and PET for the corresponding period is 435 mm. A considerable amount of moisture may be available at the end of rainy season. A long duration crop or two short duration crops may be raised from this region in rainfed condition once in 2 years.

At 60% probability level AAR is 470 mm and some quantity of stored moisture may be available at the time of cessation of rains. A crop of 13-16 weeks duration may be grown from this area.

Even at 70% probability level a short duration crop may be raised as AAR is 320 mm (Fig 4).

The main crops grown are paddy and maize. Sorghum, sugarcane and pulses each occupies 5-7 per cent of cropped area. Double crop may be introduced in place of paddy and sugarcane.

8. Conclusion

The agroclimatic classification of the entire dry farming tract of India has brought out many interesting features. The area could be divided into four agroclimatic zones of different crop potentials. The lowest crop potential area 'D' comprises three parts. Rainfed agriculture does not suit this area. However, a short duration crop may be raised from this area once in three years. Area 'E' has the potential to raise crops in about 40 per cent of years. Rainfed crop can be successfully raised from area 'F', once in two years. Region 'G' is the highest crop potential area where crop may be grown about 60 per cent of years.

The core of low crop potential area or scarcity zone could clearly be identified from the accumulated assured rainfall at 50% level. This comprises three parts. The total seasonal assured rainfall in this area is less than 100 mm at 50% probability level and the assured rainfall exceeds 30 cm at 30% level.

Some areas could also be identified where crop can thrive on stored moisture at the end of the rainy season.

Maharashtra has also been divided into four agroclimatic zones 'D', 'E', 'F' and 'G'. The core of the low potential or scarcity zones has also been clearly brought out by this classification.

The entire dry farming tract being very large and the number of stations chosen being limited, the classification is expected to be quite general and one cannot expect a one to one correspondence between macro and micro analysis. For example, the scarcity zone areas identified in Maharashtra could hardly be located and identified with the large scarcity areas obtained from macro scale analysis. While a macro scale analysis can give some broad aspects of crop potential, it is essential to do the analysis on a micro scale so that the specific areas of varying crop potential and the specific areas of scarcity zone comprising small areas can be identified and specific recommendations drawn up.

Superimposition of soil has further refined the classification of Maharashtra.

It is hoped that the classification given here will enable the agricultural scientists to evolve a suitable cropping pattern for each zone boosting up crop productivity.

Acknowledgements

The authors are thankful to the members of the Dry Farming Research Unit of Agrometeorology Division, Pune for computational help and Shri S. D. Gaur for typing the manuscript.

References

Arnon, I., 1972, *Crop production in dry regions*, **2**, Leonard Hill, London.

Biswas, B.C. and Khambete, N.N., 1979, Distribution of short period rainfall over dry farming tract of Maharashtra, *J. Mah. Agri. Univ.*, **5**(2).

Burgos, J., 1958, Agroclimatic classifications. Doc. 18-WMO Commission for Agricultural Meteorology, Warsaw.

Chowdhary, A. and Sarwade, G.S., 1980, A simple approach for Climatic Classification of India (to be published in *Tropical Ecology*).

Cocheme, J. and Franquin, P., 1967, A study of Agroclimatology of semi-arid area south of Sahara in West Africa. FAO/UNESCO/WMO Interagency Project on Agroclimatology, Tech. Report.

Hargreaves G.H., 1974, Precipitation dependability and potential for agricultural production in Northeast Brazil, EMBRAPA and Utah State University, Publication No. 74-D-159.

Holmes, R.M. and Robertson, G.W., 1963, Application of relationship between actual and potential evapotranspiration in dry land agricultural *Trans, Am. Soc. Agric. Eng.*

Hillel, D., 1971, *Soil and Water*, Academic Press, New York.

ICRISAT, 1978, Approaches used in classifying climates with special reference to dry climates : Agroclimatology Progress Report-2.

Jenson, M.E., 1968, *Water consumption by Agricultural plants, Water deficit and plant growth*, **2**, Academic Press, New York.

Koppen, W., 1936, Das Geographische System der Klimate. In *hand buche der Klimatologie'*, **1**, Part C. (Eds. W. Koppen and R. Geiger). Gelercuder Bonntragen, Berlin.

Papadakis, J., 1966, Climates of the world and their agricultural potentialities, *J. Papadakis*, Buenos Aires, Argentina.

Papadakis, J., 1975, *Climates of the world and their potentialites*, Buenos Aires, Argentina.

Penman, H.L., 1948, Natural evaporation from open water, bare soil and grass, *Proceedings, Royal Society Series A*, **193**, 120-145.

Prescott, J.A., 1938, Indices in Agricultural Climatology, *Aust. Instt. Agric . Sal.*, **4**, 1.

Rao, K.N., George, C.J. and Ramasastri, K.S., 1971, Potential evapotranspiration over India, India Met. Dep., Pre-Publ. Sci. Report No. 136.

Riplay, P.E., 1966, The use of water by crops. Proc. Intern. Comm. Irrigation and Drainage, New Delhi.

Sarker, R.P., Biswas, B.C. and Khambete, N.N., 1982, Probability analysis of short period rainfall in dry farming tract in India, *Mausam*, **33**, 3, pp. 269-284.

Subrahmanyam, V.P., 1956, Climatic types of India according to rational classification of Thronthmaite, *Indian J. Met. Geophys.*, **7**, 3.

Thronthwaite, C.W., 1948. An approach towards a rational classification of Climate, *Geogr. Rev.*, **38**, pp. 55-94.

Thronthwaite, C.W. and Mather, J.R., 1955, The water budget and its use in irrigation. *In water—the year book of agriculture* 1955, USDA, pp. 346-358.

Trewartha, G.T., 1968, *An introduction to climate* (4th Ed.), Mc Graw Hill, New York.

Troll, C., 1965, Seasonal climates of the earth. In. E. Roden Waldt. and H. Jusatz (Eds.) *World maps of Climatology*, Berlin, Springer Venlag.

Venkatarman, S., Sarker, R.P. and Subba Rao, K., 1976, A comparative study of evapotranspiration of wheat at Akola, Pune and New Delhi, India Met. Dep. Pre-Publ. Sci. Rep. No. 76/16.