Mausam, (1993), 44, 1, 53-60

551 . 586 : 633 (540)

Agroclimatic classification in India

A. CHOWDHURY, H. P. DAS and S. S. SINGH

Meteorological Office, Pune

(*Received 2 May 1990, Modified 28 April 1992*)

सार — वर्तमान अध्ययन में, भारत को खरीफ की फसलों के लिये समांग कृषि जलवायुविक क्षेत्रों में विभाजित करने के लिये, कृषि जलवायुविक प्राचलों को मूल अवयव विश्लेषण में प्रयोग किया गया है। अध्ययन के लिये मृदा नमी, फसलों के लिये जल की आवश्यकता, वर्षा के दिन तथा सौर विकिरण नामक प्राचलों को चुना गया। इनमें से कुछ घटकों की क्षेत्रीय परिवर्तिता के बारे में चर्चा की गई है। प्राचलों के तीन अलग-अलग समुच्चय बनाए गये और प्रत्येक के लिये सदिश–1 और सदिश–2 के मान ज्ञात किये गये। इन मानचित्रों के अध्यारोपण की विधि द्वारा कृषि जलवायुविक क्षेत्रों का वर्गीकरण किया गया है।

इस अध्ययन से ज्ञात हुआ है कि भारत को 15 कृषि जलवायुविक क्षेत्रों में बांटा जा सकता है। फसल विभव की दृष्टि से प्रत्येक क्षेत्र के संभावित प्रभाव पर चर्चा की गई है। प्रत्येक क्षेत्र के लिये उपयुक्त फसल की किस्म और अवधि के बारे में भी चर्चा की गई है।

ABSTRACT. In the present study, principal component analysis has been applied to agroclimatic variables for delineating India into homogeneous agroclimatic zones for kharif crops. The variates chosen were soil moisture, water need of the crops, number of rainy days and radiation. Spatial variability of some of these factors has been discussed. Vector 1 and vector 2 were obtained for each of the three seperate sets of the variates and plotted to obtain grid maps. Through a process of successive superimposition of these maps, agroclimatic zones have been obtained.

The study revealed that India could be divided into 15 agroclimatic zones. Implication of each zone from crop potential point of view has been discussed. Crop variety and duration appropriate for each zone have been indicated.

Key words — Agroclimatic zones, Principal component analysis, Eigen vectors, Crop pattern, Kharif crops.

1. Introduction

Crops in different parts of India are raised mostly traditionally, following age-old practices. Suitabilities of areas, the crops and the strains ideal for the agroclimatic environment of the crop, has unfortunately not attracted much attention. Naturally, this had resulted in persistent poor crop yields from areas having maximum untapped crop potential. Till recently agroclimatic resources have hardly been used in agriculture planning and operation in different parts of the world. In order to optimise and stabilise the crop production, it is, therefore, essential to delineate agroclimatic zones and evaluate the response of crops and their varieties prevalent to the climatic conditions. In view of this, the present study has been taken up, so that crop production can be enhanced through a more scientific planning.

2. Past studies

As early as 1936 Koppen, derived a scheme of climatic classification. Thonthwaite (1948), Subrahmanyam (1956), Bharucha and Shanbagh (1957), Rao *et al.* (1972) etc also attempted climatic zoning. These were basically climatic classifications and hence, had little utility in agriculture. Interest in agriculture homoclimes generated during last three decades (Papadakis 1961, 1970, 1975, Hargreaves 1971, Burgos 1982, etc). Moisture availability index has been use by Sarker & Biswas (1980, 1986), etc in dividing India into various agroclimatic zones.

No attempt appears to have been made in applying principal component method for dividing the country into different agroclimatic zones, to exploit the climatic potential. Gadgil and Joshi (1980), however, applied this technique and identified natural cluster of stations homogeneous with respect to rainfall profiles in India. Patterson *et al.* (1978) used the agroclimatic variables and demarcated southeast Australia in 52 homogeneous zones from principal component analysis. In the present paper an attempt has been made to find out efficacy of the eigen vectors in delineating agroclimatic zones in India.

3. Choice of parameters and data used

Selection of suitable climatic parameters which exert direct influence on agriculture is a pre-requisite in any agroclimatic classification. The choice of variables should also reflect appropriate cultural practices and cropping patterns in agroclimatological zoning. Chief factor that affects vegetation growth in tropical regions is the soil moisture availability, since temperature vary within narrow limits during the year in these areas. Use of rainfall alone as an index in agroclimatic classification, does not seem sound as it does not take into account the moisture available in the soil in relation to demand. Moreover, plants extract moisture from the soil surface. We have, therefore, used available soil moisture in each of the five months (June to October) of the kharif crop season. The computation has been done following the modified water balance technique of Thornthwaite and Mather (1957).

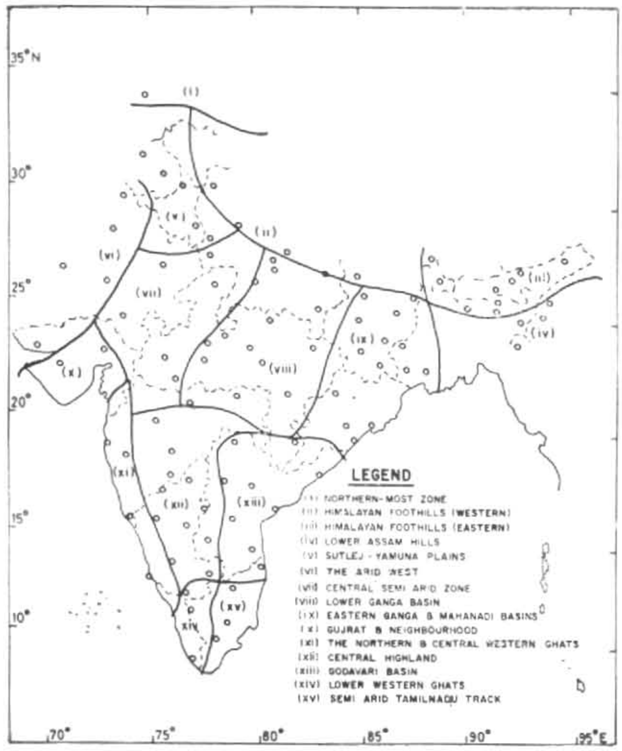

Fig. 1. Network of stations and agroclimatic classification of India

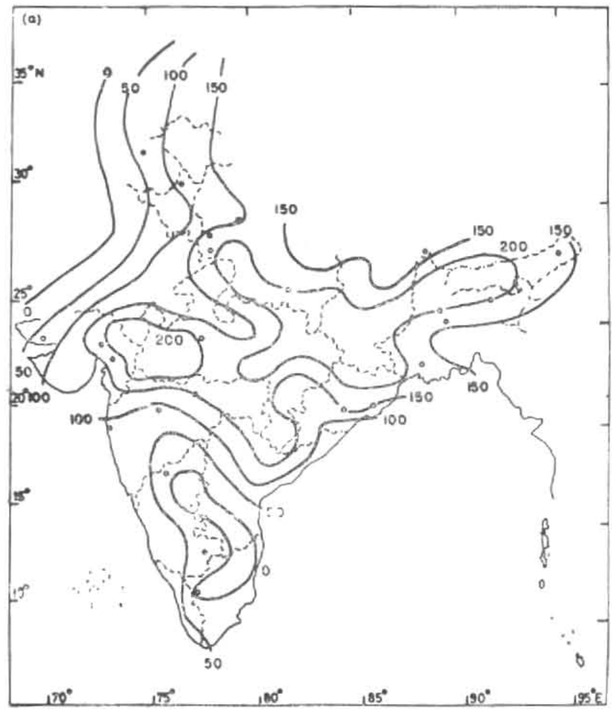

Fig. 2(a). Distribution of soil moisture (mm) in August

Crop water requirements are relevant in demarcating agroclimatically homogeneous areas. Achieving full production potential in a given crop growing environment depends very much on this factor. The phenological growth of the crop was divided into three phases, *viz.*, crop development (from 10% of ground cover to 70-80% of the ground covered by the crop), mid-season (up to grain formation) and late season which covered period up to physiological maturity (Doorenbos and Pruitt 1977). These phases were determined after discussion with agricultural experts and from crop weather calendars prepared by Agrimet Division, India Meteorological Department, Pune. Length of growing period, an important component in the scheme of agroclimatic classification hitherto not much used by research workers, has similarly been collected from the crop weather calendars (Anonymous 1987) and taken into consideration. Radiation (which represents energy available to plants for photosynthesis) is a single important variable that combine the effect of one or more variables. Data on radiation and rainy days have been collected from the publications of India Meteorological Department. Besides the total quantity, distribution of rainfall is another factor which can make or mar crop prospects. In the present study number of rainy days (rainfall 2.5 mm or more per day) has been introduced as a variable. The set of 11 variables thus chosen in the study, appears relevant and a logical set to the analysis.

The network of stations chosen in the analysis is shown in Fig. 1.

4. Principal component method and analysis

Most of the variable used in crop-weather analysis are not independent of each other. As such, each describes variations common to one or more of the other, besides providing some additional information. It is, thus, desirable to combine or group these variables so that each variate accounts for information independent of that accounted for by any other. This could be achieved in such a way that sum of variance of a new variable is equal to the total variance of the original ones. Such a transformation is accomplished through principal component analysis.

Let A be a co-variance matrix of order $n \times n$. If I is an identify matrix, it is possible to form a singular matrix $(A - \lambda I)$ such that the determinant $|A - \lambda I| = 0$. Solution to the determinant yields eigen values of the matrix A which are elements of λ called characteristics or latent roots. There is one set of special multipliers ν corresponding to each value of λ derived from the matrix A. These sets of ν are called the latent vectors or eigen vectors or principal components. Mathematically these results can be expressed as :

$$(A - \lambda I)\, \nu = 0$$

or as the determinant $|A - \lambda I| = 0$

Since the variance-covariance matrix is always symmetrical, the eigen vectors are orthogonal, *i.e.*, they are oriented at right angles to one another. Orthogonal here means that the "correlation" between any two patterns in a set is exactly zero.

In the above λ represents that part of total variance accounted for by the principal components. Also each of the n principal components of A would account for unequal proportion of total variance.

An advantage of the principal component method is that it enables the dimentionality of the data to be reduced with little loss of information by dropping one or more of the small sized components or vectors which provide little interpretable information.

For details of the technique, a reference to Seal (1964) may be made.

Three sets of agroclimatic variables were considered in the analysis. The first set included soil moisture from June to October, while the second set called crop characteristic parameters had four crop parameters comprising three crop growth phases and the fourth length of crop season. In the last set, the remaining two parameters, *i.e.*, number of rainy days and radiation were analysed.

The analysis for each set was restricted to determining first two principal components, *viz.*, vector 1 and vector 2. The latent roots or the characteristic coefficients of the variables and the percentage variation explained have been determined and discussed.

5. Geographical distribution of climatic variables

Before subjecting the data to principal component analysis a discussion on the geographical distribution of some of the selected parameters appears relevant and necessary. Only three variables, *i.e.*, soil moisture during August — the month which is marked by frequent 'breaks' (sometimes leading to premature withdrawal) but crucial from the crop growth point of view, water need during mid-season and the growth duration, have been chosen for discussion.

5.1. *Soil moisture*

In the heart of the Thar desert and also over interior areas of Karnataka and Tamil Nadu, there is hardly any moisture in August [Fig. 2 (a)]. In most parts of north India over 200 mm of moisture is available during the month whereas in Peninsula, the moisture does not exceed 100 mm.

5.2. *Water need*

As may be seen in Fig. 2(b) during the mid-season stage, water need in west Rajasthan is very large (more than 200 mm). Over the country as a whole plants needs 100-200 mm of moisture during mid-season.

5.3. *Growing days*

The crop growing days are characteristically low (less than 100 days) in the traditionally millet growing areas of Rajasthan and Gujarat [Fig. 2 (c)]. The growing days progressively increase eastward and southward. In the humid eastern India, the period may exceed 5 months.

6. Relative variations and agroclimatic conditions

The 11 parameters when subjected to correlation analysis in groups yielded interesting results. The inter-correlation within each group is shown in Table 1. Inspite of large variations in the mean values of a number of agroclimatic elements of various combinations the results indicate that these variations are highly correlated among themselves. The moisture in July and August each appear highly (positively) correlated with that in September and October. Similarly water needs in different stages tend to be significantly related with one another. The number of days of the three crop growth stages are each found to be negatively correlated with the number of days of the entire growth period (from sowing to physiological maturity). The negative correlation between rainy days and radiation observed in the analysis is not surprising.

The analysis suggest that crop variables are the most important among all the variables but are subject to interaction between regions. Since all these variables are highly correlated, the consequence of these conclusions must be further examined by analysing the cropping pattern in relation to soil types and moisture availability. This unfortunately, is beyond the scope of the present study.

It is obvious from this study that agronomically important but reasonably unpredictable climatic variations can be partioned and spatially assigned on the basis of nature and magnitude of its components. Composition of the two vectors for variables in the three sets is given in Table 2. It is seen that the sum of the total roots of the first two principal components (PC) in first set accounts for 91% of the climatic data. Similarly the first two roots of PC in second set accounts for 96%. In the analysis of soil moisture and crop variables vector 1 appears dominant. Vector 2 which has no obvious physical meaning also contributes significantly. Contribution of remaining components were small and were, therefore, not considered. The contribution of vector 1 in the third set (radiation and rainy days) dominates over vector 2 by a ratio of 20 : 1.

The composition of the first vector indicated that 79% of the influence of the five moisture variables is associated with a tendency for all the variables to increase. The second vector accounts 12% of the variance when effect of first vector has been removed. This vector shows that soil moisture in June, July and October each of whose coefficient is negative, operate in a similar direction and oppose August and September soil moisture which have positive coefficients. Moisture coefficient for July, *i.e.*, —0.05 makes negligible contribution.

In the case of crop factors, the composition of first PC show that 76% of the effect is linked with a tendency of water need parameters to operate positively and opposes that of the growing period. In the second vector, which explains 20% variance, all variables operate in the same positive direction. In case of radiation and rainy days both the variables operate in similar fashion for both vectors.

TABLE 1

Inter-correlation matrix

(a) **Soil moisture variables**

Soil moisture during	Jun	Jul	Aug	Sep	Oct	Mean	C.V.
Jun	1.0	0.43	0.28	0.26	0.44	36.2	158.2
Jul	0.43	1.0	0.91	0.85	0.72	114.4	67.3
Aug	0.28	0.91	1.0	0.94	0.75	129.7	63.8
Sep	0.26	0.85	0.94	1.0	0.81	135.1	60.1
Oct	0.44	0.72	0.75	0.81	1.0	116.4	58.1

(b) **Crop variables**

Variable	Crop development stage	Mid season stage	Late stage	Growing period	Mean	C.V.
Crop development stage	1.0	0.91	0.82	−0.57	106.4	23.6
Mid season stage	0.91	1.0	0.86	−0.48	138.8	20.5
Late stage	0.82	0.86	1.0	−0.58	89.6	15.0
Growing period	−0.57	−0.48	−0.58	1.0	147.7	20.4

(c) **Energy variables**

Variable	Rainy days	Radiation	Mean	C.V.
Rainy days	1.0	−0.59	48.5	43.5
Radiation	−0.59	1.0	90.8	9.2

TABLE 2

Agroclimatic coefficients of first two vectors

		Vector 1	Vector 2
(a) **Moisture variables**			
Characteristic roots		21724.9	3247.0
% variance explained		79.3	11.9
Coefficients			
Soil moisture during	Jun	0.16	−0.92
,, ,, ,,	Jul	0.49	−0.05
,, ,, ,,	Aug	0.54	0.23
,, ,, ,,	Sep	0.53	0.25
,, ,, ,,	Oct	0.39	−0.20
(b) **Crop parameters**			
Characteristic roots		1911.2	514.7
% variance explained		75.7	20.4
Coefficients			
Crop growth stage		0.54	0.27
Mid-season stage		0.59	0.47
Late stage		0.27	0.10
Growing period		−0.53	0.84
(c) **Energy variables**			
Characteristic roots		490.3	23.9
% variance explained		95.3	4.7
Coefficients			
Rainy days		0.95	0.32
Radiation		0.32	0.95

7. Agroclimatic zonation, crop potential and cropping pattern

In order to demarcate agroclimatic zones, vectors 1 and 2 for soil moisture parameters were plotted. The spacings of the isopleths for the first set enabled to agroclimatically divide India into 10 regions, each of which was considered homogeneous with respect of the two vectors. Sets 2 and 3 yielded 9 and 8 homogeneous agroclimatic zones respectively. In each case the limit to the agroclimatic changes in these zones depend on the size of the intervals between the isopleths. Superimposing one over the other in succession, it was possible to divide the kharif crop agricultural areas of India (*cf.* Anonymous 1989) into 15 homogeneous zones as shown in Fig. 1. The following paragraphs describe characteristics features of the zones, bring out their crop potential and suggest variety and duration suitable for them.

(*i*) *Northernmost zone*

This zone covers Jammu & Kashmir. Here, the Kashmir valley receives 50-75 cm of rainfall while Ladakh is characterised by extreme cold and inadequate moisture, both acting as climatic barrier. The soil is mostly podsolic and consists of sub-montane to mountain meadow.

Agricultural potential appears low/moderate in the zone. Maize, which requires 50% of its total water in a period of 30-35 days after tasseling, is ideally suited in central or western parts. Composite variety of *Amber*

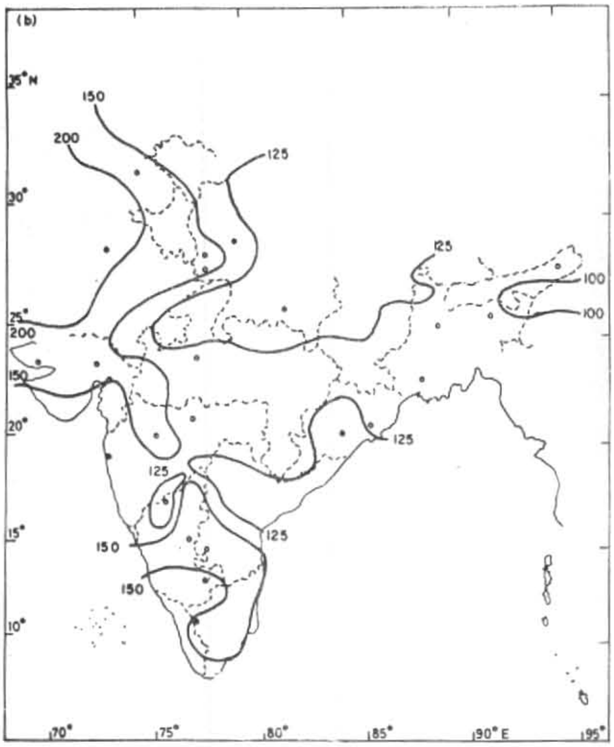

Fig. 2(b). Distribution of water need (mm) in mid-season growth stage

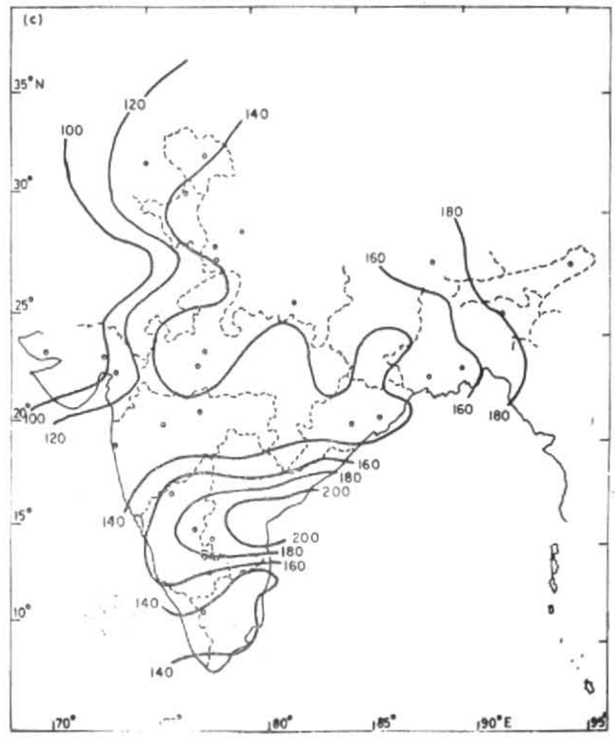

Fig. 2(c). Distribution of crop growing period (days)

which is resistant to leaf blight and downy mildew is recommended. *Jaya* or *Basmati* 370 variety of paddy could be adopted or nutritionally superior medium duration opaque composite, like *Rattan* could be tried in eastern parts.

(*ii* & *iii*) *Himalayan foothills* — The hilly region of western Himalayas (outside Ladakh) and its foothills [zone (*ii*)] offers much diversity in rainfall and agricultural pattern compared to the eastern Himalayas [zone (*iii*)]. Hilly areas of zone (*ii*) generally have brown hilly soil. The Tarai region have rich alluvial soil.

The Himalayan foothills possess markedly high to very high crop potential. Paddy of medium duration (*Jaya, Basmati* etc) or two short duration paddy crops like CH-1034, IR-579 or a sequence of medium and a short duration paddy variety, *e.g., Desai Basmati*, R-575 is suggested. In Tarai belt nutritious superior high protein quality *Shakti* or *Protina* maize is suggested.

Zone (*iii*) received about 250 cm rainfall nearly throughout the year and hence has abundant available soil moisture, in its alluvial and deep black soils. It has a lengthy crop season but reduced radiation.

Very high to high potential marks this zone. Two short duration paddy crops like *Pusa* 2-21, *Kalinga* 1, or one short and one medium duration like blast resistant *Vani, Sona* or one long duration variety like *Mahsuri* is suggested.

(*iv*) *Lower Assam hills* — This zone consists of Tripura, Mizoram and Manipur. It receives nearly same amount of rainfall as zone (*iii*). The soil moisture availability, though high, is restricted to a few months.

It is a zone of high agricultural potential. Early planting paddy of short duration, *viz.*, CH-1039, CH-988 or a medium duration, *Annapurna* or *Ratna* is suggested.

(*v*) *Sutlej-Yamuna alluvial plains* — Haryana, Punjab and adjoining areas in Jammu & Kashmir and Uttar Pradesh called Sutlej-Yamuna plains belong to this zone. They have generally alluvial and calcarious soil. This is among the low rainfall zones in the country and have low potential for rainfed culture.

Short duration paddy like *Palan* 579 or a medium duration like IR-8, *Jaya Basmati* 370 may fetch profitable returns. HKR-120 rice variety which is resistant to brown plant hopper is also a good bet. Since water requirement of cotton is low, introduction of medium (fibre) superior quality or superior long stappled CP 25/1 or extra long superfine variety like *Suvin* or CBS-156 can make a great impact on textile production in the region.

(*vi*) *The arid west* — The Thar desert has been brought out very convincingly in the analysis. In western Rajasthan and adjoining areas, rainfall is highly erratic, uncertain and low (20-30 cm annually) in quantum. Because of sandy soil the moisture retention capacity is low.

Traditionally, it is a bajra growing area. New HB-5 is, perhaps, best suited to this zone due to its disease resistance, higher yields and wide adaptation. Jowar hybrid like CSH-1, CSH-5, variety like CSV-3, CSV-6 which are resistant to shootfly could also be appropriate.

(*vii*) *The central semi-arid zone* — Eastern Rajasthan, west Madhya Pradesh and adjoining areas of Uttar Pradesh and Gujarat with over 75 cm of rains and medium black to red-black soils has been categorised as a separate zone. It has better soils than Thar and experience comparatively higher rainfall but length of growing season and soil moisture availability does not seem much encouraging.

This region has moderate crop potential. Sorghum cultivation is predominant in this zone. Limited intervarietal hybridization can contribute to high level of grain yield with juicy stems and improved forage quality. Hybrid like CSH-1, CSH-5 or variety like CSV-4, CSV-6 are ideal. Maize (*Shakti* hybrid) can conveniently fit into crop rotation with jowar.

(*viii*) *Lower Ganga basin* — In the north, it comprises of Ganga basin in Uttar Pradesh and in the south have hills and plains of east Madhya Pradesh. This zone gets moderate rainfall and has soil similar to zone (*vii*) but receives fairly large rainfall (100-150 cm) in comparison. In hilly terrain, run-off are large, offsetting the large rainfall.

It is a predominantly paddy growing area, endowed with high agricultural potential. Early maturing paddy variety like *Kranti*, *Pusa* 33 or medium duration crop like *Jaya*, IR-20 or long duration one like *Mahsuri* or *Jalmagan* appears ideal. Scented paddy like *Dubraj* can also thrive well in southern parts of the region.

(*ix*) *Eastern Ganga and Mahanadi basin* — Gangetic plains in Bihar and West Bengal, the Bihar plateau and Mahanadi basin, form this zone. The soils are rich alluvial intercepted by red, yellow and laterite soils. Heavy soils in the north have large water holding capacity. The Mahanadi estuary has deltaic sandy formations with little water retention capacity and hence low crop yields.

It is mainly a paddy growing region, with a few pockets in West Bengal receiving silt from annual floods, growing jute. High yielding *Swarna* which tillers profusely, and moderately resistant to blast, is suitable for lowland areas of West Bengal (Mondal *et al.* 1990). Since paddy has a poor water use efficiency factor and is a poor utiliser of nutrients, yields could be increased by using short duration variety like *Ratna*, or medium duration IR-26 or medium late duration, *Patnai*-23, *Pankaj*. In places where jute is grown JRC-212 (*Sabujsona*) is suitable. JRC-7447 (*Shyamali*) is suitable where water logging occurs during monsoon.

(*x*) *Gujarat and neighbourhood* — This consists of most of Gujarat and some parts of Maharashtra. This zone receives low rainfall (50-70 cm). The soils are rich in diversity and have about 6 soil grades out of 10 in the world. In this zone, prospects are low over Saurashtra and moderate over the rest of the area. Areas with sandy loam to loamy soils offer ideal conditions for groundnut as a parential in rotation with jowar, bajra or cotton.

The variety GAUG-10 which gives about 50% of oil or KG-61-240 (*Jyoti*) which gives large number of pods are recommended. In the red sandy loam/loamy soils, cotton hybrid MCU-5 or CBS-156 following groundnut can give 15-20% higher yield than that following jowar.

(*xi*) *The northern and central Western Ghats* — Coastal areas of Maharashtra and Karnataka which are characterised by heavy rainfall belong to this zone. Unandation by sea water during monsoon restricts cultivation over affected areas.

Though a heavy rainfall zone, the region offers a moderate crop potential as soil is acidic (pH=3 or less). Short duration paddy like *Palghar*-60, *Pusa*-33, *Mangal* or medium duration variety like IR-22, *Karjat* 35-3 or long duration *Pankaj* or SR-30 are best suited. For highly saline areas, SR-26B may be a useful variety.

(*xii*) *Central highlands* — This area lies on the leeward side of Western Ghats and is traditionally drought-prone and hence a low potential zone. Soils are medium black in north and red sandy in south, with patches of deep black. Moisture retention is low, and length of growing season though fairly large is variable in tune with variable rainfall.

Hybrid CSH-1, CSH-5, CSH-6 or variety CSV-1 of jowar can thrive well in this region. Cotton is preponderant in red sandy loam/loams, where *Vanalaxmi*, *Mahalaxmi*, MCU-7, or extra long stapled hybrid-4 or ELS-250 are recommended. In groundnut growing areas, improved Spanish peanut which gives nearly 1000 pods/ha with 50% oil and matures early (95 days) is best suited as perrenial.

Ragi is an important cereal in red loam, black and sandy loams soils. IE-28, which is resistant to mosaic under field conditions, highly resistant to blast and borer and has wide adaptability, or white grained varieties like CO-9 or *Hansa* is most suitable.

(*xiii*) *Godavari basin* — Most of Andhra belongs to this type. The soils vary from sandy coastal alluvial to red soils. Compared to zone (*xii*), rainfall is large and is more assured.

It has medium crop potential. Paddy is grown in coastal parts and groundnut and jowar in areas of limited rainfall. Medium duration paddy variety like *Surekha*, *Vikram*, IR-20 or late variety like *Pankaj*, NLR 9674, *Gautama* are suggested. A cross between IR-8 and IR-5, *i.e.*, TRRNR-21 (*Hari*) which combines the dwarf and high yielding traits of IR-8 and has long slender kernel, is suitable. *Kakatiya* variety which is resistant to gall midge can also be tried (Sastry *et al.* 1990). Where jowar is grown, hybrids CSH-1, CSH-6 variety CSV-3, CSV-6 are suggested.

(*xiv*) *Lower Western Ghats* — Kerala and adjoining hills of Tamil Nadu and Karnataka, with abundant rainfall most parts of the year, belong to this zone. Inspite of abundant rainfall, high slopes with large run-off acts as a constraint for the crop to reach its genetic potential.

The predominant crops are plantations followed by topioca and paddy. Among the plantation, coconut is grown in coastal plains. Dwarf X, which is early bearer and tolerant to the root (wilt) diseases is suited. Indigenous collection like *San Ramon* or *Kappadom* are high yielding and can be tried. Cloves like RRIM or *Glenshiel* which gives 2000-3000 kg/ha are recommended. In arecanut growing areas, semi-tall early bearing variety like *Mangal* is suited.

Short duration *Jyoti*, *Rohini* or medium duration IR-8, *Jaya*, *Sabari* or long duration *Mahsuri* or H-4 paddy are suggested.

(*xv*) *Semi-arid Tamil Nadu tract* — Areas of Tamil Nadu which receives hardly any rainfall in southwest monsoon but are more affected by northeast monsoon can be categorised as a separate agroclimatic zone in itself. This semi-arid tract has red sandy to deltaic alluvial soils. In kharif, the crop potential is low due to low soil moisture.

Jowar hybrids CSH-7R, *Kovilpatti* (tall), CSH-8R and groundnut *Pol* 2 variety which gives about 1500 kg pods/ha are suggested. Short duration CO-39, ADT-32, medium duration *Pusa* 2-21, ASD-14 or long duration CO-40 can also be tried.

8. Conclusion

The method of principal component analysis has been used for agroclimatic classification of India during the kharif crop season. The parameters are on soil moisture, crop and radiation. The country has been divided into 15 agroclimatic zones. The crop potential for each zone has been discussed and the crops and their varieties suggested. It is hoped agricultural scientists will find this study useful.

Acknowledgements

The authors are grateful to the Additional Director General of Meteorology (Agricultural Meteorology), Pune for his interest in the work and encouragement. They wish to record their appreciation to the unknown referee for his very constructive and positive comments. Thanks are also due to Miss Geeta Ramachandran for neatly typing the text.

References

Anonymous, 1987, *Handbook of Agricultural*, Indian Council Agr. Res., New Delhi.

Anonymous, 1989, Agroclimatic Regional Planning, Planning Commission, New Delhi.

Bharucha, F.R. and Shanbhag, G.Y., 1957, *Botanical Memoirs*, No. 3, Univ. of Bombay.

Burgos, J., 1982, *OMM-PNUD*, Sudan, 93.

Doorenbos, J. and Pruitt, W.O., 1977, FAO Irrigation and Drainage, Paper No. 24, FAO, Rome.

Gadgil, S. and Joshi, N.V., 1980, Consultants meeting on climatic classification, ICRISAT, pp. 17-26.

Hargreaves, G.H., 1971, Publ. No. 74-D-158, EMBRAPA and Utah State Univ., USA.

Koppen, W., 1936, *Das Geographische system der klimate* 1, Part C, Berlin, Germany.

Mondal, B., Das, C.S. and [illegible]aduri, B., 1990, *Indian Farming*, 40, pp. 21-24.

Papadakis, J., 1961, *Climate Tables for the World*, Buenos Aires.

Papadakis, J., 1970, *Agricultural potentialities of world climates*, Ac Cordoba 4564, Buenos Aires, Argentina.

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

Patterson, J.G., Goodchild, N.A. and Boyd, W.J.R., 1978, *Agric. Met.*, **19**, pp. 349-360.

Rao, K.N., Gerorge, C.J. and Ramasastry, K.S., 1972, Met. Monogr. Agromet. No. 4, India Met. Dept., Pune.

Sarker, R.P. and Biswas, B.C., 1980, Consultants Meeting on Climate Classification — ICRISAT, Hyderabad, India.

Sarker, R.P. and Biswas, B.C., 1986, *Mausam*, **37**, pp. 27-38.

Sastry, M.V.S., Kalode, M.B. and Venkataraman, S., 1990, *Indian Farming*, **40**, pp. 11-14.

Seal, H., 1964, *Multivarial Statistical Analysis for Biologists*, Methuen, London.

Subrahmanyam, V.P., 1956, *Indian J. Met. Geophys.*, **7**, pp. 253-264.

Thornthwaite, C.W., 1948, *Geogr. Rev.*, **38**, pp. 55-94.

Thornthwaite, C.W. and Mather, J.R., 1957, *Publ. in Climatology*, **10**, pp. 185-311.