Mausam, (1980), **31**, 1, 157-164

551.579.5:633.1(545)

The behaviour of moisture adequacy index and its utilization for exploiting the agricultural potential in Punjab and Haryana

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(*Received 28 August 1978*)

ABSTRACT. The moisture adequacy indices, the ratios of actual evapotranspiration to the potential evapotranspiration, have been found to follow closely the Beta distribution. The goodness of fit of the Beta distribution to the moisture index frequency distribution was tested using the Kolmogorov-Smirnov test for 144 station-months and 36 seasonal curves. 25 moisture adequacy curves failed the K-S tests. The probability distribution of moisture adequacy indices has been further used to assess irrigation requirement, optimum evapotranspiration, water management, land-use pattern and crop planning aspects for optimum utilization of available natural resources in the region.

1. Introduction

The crop failure resulting from flood or drought, or from both in a single year, is not uncommon in Punjab and Haryana, and therefore, the functional relationship of moisture supply (A_E) with the potential plant water requirement (P_E) can be of great use in crop production aspects. Some of the relationships between A_E and P_E have been earlier reported by Lemon (1956), Holmes and Robertson (1959), Van Bavel (1955), Thornthwaite and Mather (1958), Marlatt (1958), Hide (1954). Baier (1959) critically examined the five different types of relationships between available soil moisture and A_E/P_E ratio (I_{MA}), and concluded that, if the soil moisture observations are not available for comparison, the linear relationship between I_{MA} and available soil moisture appears to be a realistic assumption.

Holmes and Robertson (1963) attempted to make use of the relationship between and P_E to explain variations in wheat yield under arid or semi-arid conditions. Major (1963) considered the relationship between the two as the key to the distribution of zonal vegetation, with soil and topographic anomalies responsible for the occurrence of zonal types. Zahner and Stage (1966) applied the relationship to estimate daily moisture stress on trees and resulting effect on growth. De Wit (1958) used I_{MA} to explain yield variations in crop plants. Albrecht (1971) stated I_{MA} as the best correlated with yield of the practically available indices of the moisture factor in the climate, and the one most nearly representative of the operations of the moisture factor in plants. Therefore, I_{MA} becomes an obvious choice for use as a tool for explaining or for exploiting the agricultural potential. Subrahmanyam *et al.* (1963) correlated the distribution I_{MA} for the spread of rice, wheat and jowar over India. Yao (1968, 1974) indicated the moisture adequacy index as a measure of plant water requirement to estimate the agricultural potential.

In the present paper, the moisture adequacy indices have been shown to follow the Beta distribution and how these can be utilized for irrigation requirement, optimum evapotranspiration, land-use planning and formulating better cropping patterns to make best use of available natural resources.

2. Data used

The monthly I_{MA} values were determined utilizing Thornthwaite and Mather (1955, 1957) approach using climatic variables for the following stations for the period for which data was available from the India Meteorological Department, Pune.

Station	*Period of data used*
(1)	(2)
Pathankot	1952-76
Ludhiana, Ambala, Hissar, New Delhi	1933-76
Amritsar, Patiala	1949-76

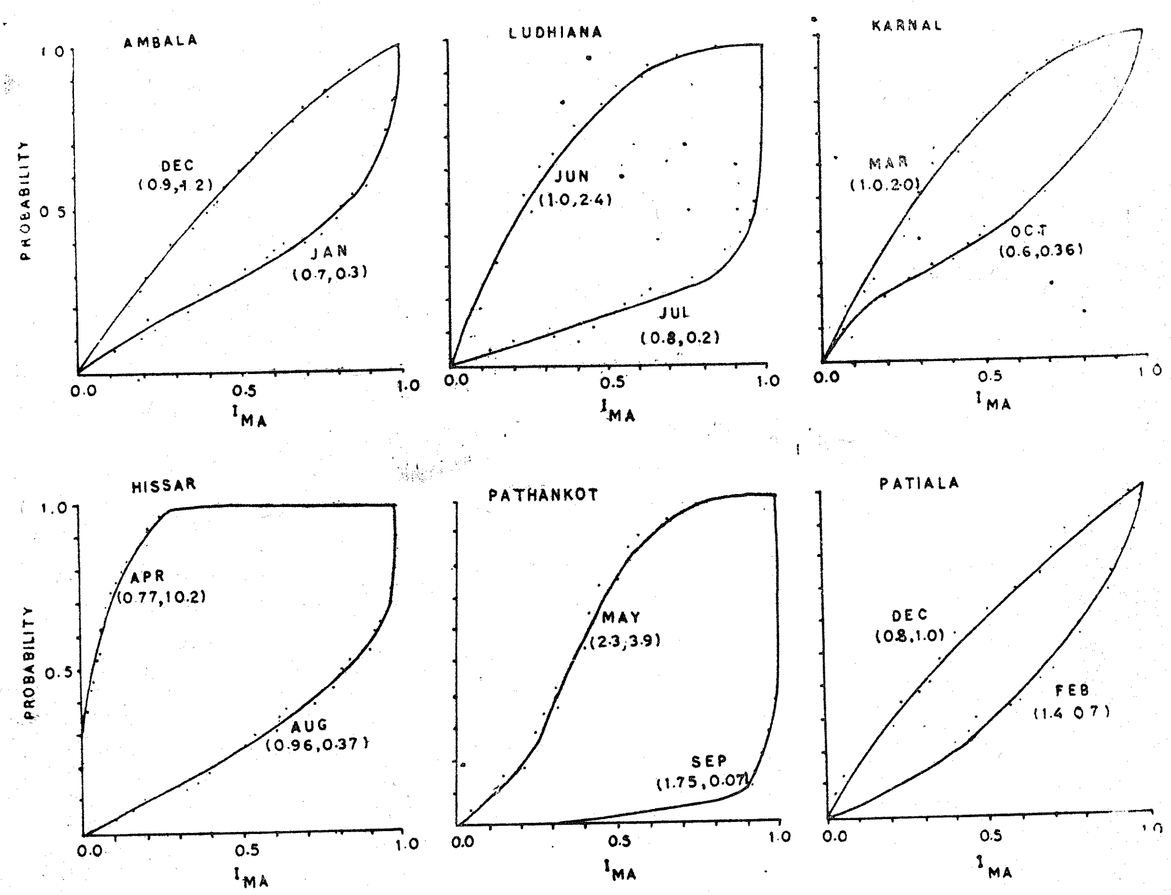

Fig. 1

(1)	(2)
Ferozepur, Karnal	1950-76
Chandigarh	1954-76
Sriganganagar	1937-76
Alwar	1956-76

3. Beta function

The incomplete Beta function is defined by :

$$\beta_x(p, q) = \int_0^x t^{p-1}(1-t)^{q-1}\, dt$$

For $x=1$, the complete Beta function :

$$\beta(p, q) = \int_0^1 t^{p-1}(1-t)^{q-1}\, dt$$

$$= \frac{\Gamma(p)\,\Gamma(q)}{\Gamma(p+q)}$$

In order that the function $\beta_x(p, q)$ may represent a cumulative distribution of a variable x over range $0 \leqslant x \leqslant 1$, $\beta_x(p, q)$ is divided by $\beta(p, q)$ to obtain the standardised incomplete Beta function ratio as:

$$I_x(p,q) = \frac{\beta_x(p,q)}{\beta(p,q)} = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} \int_0^x t^{p-1}(1-t)^{q-1}\, dt$$

where p and q are two positive parameters. This distribution function represents a two parameter family of distributions and tables are provided (Pearson 1934) for various p and q values.

The estimates of the parameters p and q of the Beta distribution came from the first two moment coefficients as given by Pearson (1934):

$$p = \frac{\mu_1'(\mu_1' - \mu_2')}{(\mu_2' - \mu_1')}$$

$$q = \frac{(1-\mu_1')(\mu_1' - \mu_2')}{(\mu_2' - \mu_1'^2)}$$

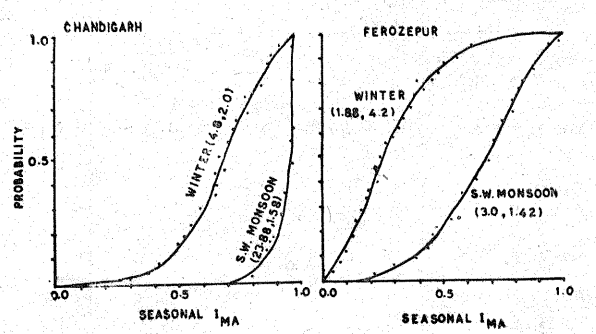

Fig. 2

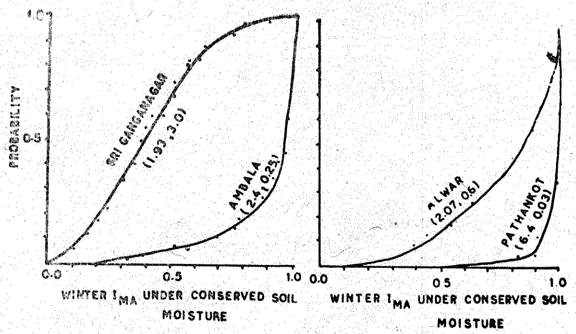

Fig. 3

The estimaters for μ_1' and μ_2' are $\hat{\mu}_1'$ and $\hat{\mu}_2'$ respectively,

where,

$$\hat{\mu}_1' = \sum_{i=1}^{n} I_{MAi}/n$$

$$\hat{\mu}_2' = \sum_{i=1}^{n} I_{MAi}^2/n$$

Simpson's rule of approximation provides the probabilities under the Beta distribution.

The basic characteristics of I_{MA} index and the Beta distribution are similar. The variables X and I_{MA} both have a range from 0 to 1 and are continuous in this range. Beta distribution has two positive parameters, which determine the shape of the curve, while the distribution of I_{MA} may also be regarded as a distribution characterized by two factors, moisture supply and moisture demand. These analogies suggest that the Beta distribution can be suitable probability model for the variability of I_{MA}. This hypothesis is supported by Yao (1969) studies and data examined in this paper for northwest Indian region.

4. Moisture adequacy index curves

The frequency distribution of I_{MA} values was plotted against the Beta distribution curves computed as described above for monthly and seasonal values. The seasonal I_{MA} values were computed by dividing the accumulated values of A_E and P_E during the rainy (July to September) and the winter (October to March) seasons for the 12 stations under study. The I_{MA} values were also computed for the rainy season fallow soils (conserved soil moisture status) as it is utilized for winter crops due to the erratic nature of rainfall in this region; in the southwestern region of Punjab and Haryana, this is a common practice. Therefore, the accumulated soil moisture storages were computed from daily rainfall amounts utilizing Bishnoi (1975) method and then recomputing the A_E values by Thornthwaite and Mather (1955) procedure. These 36 seasonal I_{MA} frequency curves were also found to follow closely the Beta distribution. A few monthly and seasonal I_{MA} frequency curves and Beta distribution curves have been plotted in Figs. 1-3 respectively.

6. Agricultural resources utilization: Methodology

(a) *Potential crop yields*—The crop yields are found to have a close relationship to the optimum evapotranspiration rate. Denmead and Shaw (1962), Dale and Shaw (1965) have suggested the moisture stress concept, in which the days on which P_E is expressed as the per cent of available soil moisture necessary to prevent plant from losing its turgor. Therefore, it is necessary to find optimum evapotranspiration level to retain turgidity of crop plants. Yadav (1973) and Rajput (1977) have presented the data on I_W / C_{PE} ratios for potential crop yields and the stage at which irrigation becomes essential so as to avoid the substantial reduction of crop yields of various crops over a good network of research stations in India in the I.C.A.R. coordinated Project on Water Management and Soil Salinity. I_W is the quantity of irrigation water (water supply) and C_{PE} is the cumulative open pan evaporation (maximum evaporative demand). The I_W / C_{PE} are the optimum evapotranspiration rates for potential crop yields and critical evapotranspiration rates where supplementary irrigation are essential for light and medium alluvial soils in

TABLE 1

Probabilities of getting I_{MA} for optimum evapotranspiration during the *Kharif* season

Station	Probabilities of getting I_{MA} greater than or equal to 0.6			0.7			0.8			0.9		
	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep	Jul	Aug	Sep
Sriganganagar	17	44	8	11	37	7	6	30	6	2	1	4
Ferozepur	78	84	44	73	77	37	67	67	30	59	58	21
Hissar	48	71	64	41	64	60	32	56	55	23	45	49
Alwar	83	89	75	80	88	72	75	87	68	69	82	63
New Delhi	60	91	85	58	90	81	54	88	76	50	85	65
Amritsar	63	82	46	55	75	40	45	64	30	32	47	14
Patiala	93	90	78	76	89	73	66	87	67	50	85	59
Karnal	66	96	79	62	95	77	58	94	73	52	93	70
Ambala	92	95	86	90	93	82	88	91	78	86	88	73
Ludhiana	82	91	69	79	91	69	76	89	64	71	81	54
Chandigarh	100	99	98	99	98	96	97	97	91	93	95	80
Pathankot	100	100	97	98	100	96	97	100	95	95	100	90

TABLE 1(a)

Cropping patterns at various stations

Station	Cropping Patterns: Throughout the year				Intensity of cropping %	Kharif fallow—winter crops under conseved moisture				Intensity of cropping
Pathankot	(PMA) 0.9	(J GR) 0.05	W 0.2	G 0.5	165	W 1.0				100
Chandigarh	(PMA) 0.8	(J GR) 0.11	W 0.1	G 0.3	131	W 1.0				100
Ambala	(PMA) 0.7	(J GR) 0.08	G 0.25	RO 0.25	128	W 0.75	BA 0.1	G 0.1	RO 0.05	100
Ludhiana	M 0.55	(J GR) 0.1	G 0.2	RO 0.1	95	W 0.6	BA 0.15	G 0.15	RO 0.08	98
Patiala	M 0.5	(J GR) 0.16	G 0.3	RO 0.15	111	W 0.7	BA 0.1	G 0.1	RO 0.05	95
Karnal	M 0.5	(J GR) 0.1	G 0.3	RO 0.2	110	W 0.75	BA 0.1	G 0.1		95
Alwar	M 0.6	(J GR) 0.1	B 0.1		80	BA 0.4	W 0.2	G 0.2	RO 0.1	90
New Delhi	M 0.4	(J GR) 0.1	RO 0.35		85	BA 0.4	W 0.2	G 0.2	RO 0.1	90
Amritsar	B 0.4	G 0.25	KP 0.06	RO 0.15	86	W 0.5	BA 0.2	G 0.02	RO 0.05	95
Hissar	B 0.4	KP 3 0.1			50	G 0.5	RO 0.25			75
Ferozepur	B 0.35	KP 0.1			45	G 0.5	RO 0.25			75
Sriganganagar	—				—	RO 0.45				45

this region. These evapotranspiration rates are given below :

Crops	Evapotranspiration rates	
	Optimum	Critical
S. W. monsoon season (Jul to Sep)		
Moong & Cowpeas	0.6	0.4
Bajra	0.7	0.5
Jowar, Groundnut	0.8	0.5
Maize, Arhar	0.9	0.6
Paddy	1.0	0.75
Winter season (Oct to Mar)		
Taramira, Raya	0.4	0.3
Sarson	0.5	0.4
Gram	0.6	0.4
Barley, Desi Wheat	0.8	0.5
Wheat	0.9	0.6

The probability of getting I_{MA} greater than their requisite values at the various growth stages will reflect the level of optimum evapotranspiration attained and thereby showing the potentiality of growing various crops in the region.

(b) *Irrigation requirement and water management*

The probalities of getting I_{MA} less than the values of the critical evapotranspiration rates for various crops during their growth stages will indicate the essential irrigation requirement and also decision on distribution of water for various crops can be made so as to make the best use of available water.

(c) *Land utilization and crop planning*

The likelihood of water supply for crop growth can be used to judge the degree of land utilization with reference to its climatic potential. The probabilities of I_{MA}. for various levels corresponding to the different crops mentioned above, will indicate the differences in crop-moisture conditions during the growth period. These crop-moisture conditions will reflect the differences in agronomic practices, thus indicating the suitability of crops in the region. The distribution of crops has been decided with the seasonal probability levels of various crops with the following criteria :

	I_{MA}	Seasonal prob. of getting I_{MA}	Crops
(1)	0.95	90	Paddy (P)
(2)	0.9	70	Maize (M), Wheat (W)
(3)	0.8	70	Barley (Ba), Jowar (J) Groundnut (Gr)
(4)	0.7	50	Bajra (B)
(5)	0.6	50	Moong, Cowpea (KP) Gram (G)
(6)	$\leqslant 0.5$	50	Rabi Oilseeds (RO)

The criterion is also applied to the distribution of rabi crops grown under conserved stored moisture of Kharif fallow.

The area under each crop is assigned according to the assured probability levels corresponding to I_{MA} value in the individual months during the growth period. If the assured probability levels for two consecutive I_{MA} values are not much different, then the area has been assigned for both crops as bracketed. The assured probability level has been indicated as area under that crop at the subscript. The cropping pattern is given in Table 1(a).

6. Results and discussion

(a) *Frequency curves*

The K-S tests show that in 25 out of total 180 I_{MA} frequency curves, the absolute distance between the frequency curves and the theoretical curves is significant different at 10/15 per cent level. However, in most cases including monthly and seasonal periods, the frequency curves resemble the theoretical curves with good agreement and the hypothesis shows good promise. Therefore, knowing the behaviour of I_{MA} frequency curves, the properties could further be extended to understand some relations of plant water requirement and formulation of cropping patterns.

(b) *Potential crop yields*

The results of various experimental studies (Sec. 5a) have indicated that the optimum evapotranspiration has close relationship to potential crop yields. The probabilities of getting optimum evapotranspiration, corresponding to the I_{MA} values of various crops, are given in Table 1 for the S. W. monsoon season and in Table 2 for the winter season. Therefore, considering climatic

TABLE 2

Probabilities of getting I_{MA} for optimum evapotranspiration of *Rabi* crops

Station	Probabilities of getting I_{MA} equal to or greater than 0.4, 0. 5, 0. 6, 0. 8 and 0.9 during																	
	Oct	Nov	Dec	Jan	Feb	Mar	Oct	Nov	Dec	Jan	Feb	Mar	Oct	Nov	Dec	Jan	Feb	Mar
	⩾0.4						⩾0.5						⩾0.6					
Sriganganagar	6	2	9	17	19	9	5	1	7	22	15	5	4	1	5	20	11	3
Ferozepur	11	25	26	69	41	37	6	18	23	63	38	29	4	13	20	59	30	23
Hissar	26	11	14	42	37	18	20	7	9	37	29	14	15	4	6	32	23	10
Alwar	63	36	26	37	32	4	61	35	20	29	24	1	58	16	15	23	18	1
New Delhi	65	36	35	68	44	17	60	28	28	60	38	9	55	21	21	52	30	4
Amritsar	57	37	56	74	89	52	50	29	50	71	82	42	10	23	44	66	75	32
Patiala	57	44	51	79	81	43	52	35	42	75	74	79	45	27	33	70	66	18
Karnal	70	60	48	79	69	36	64	50	40	73	53	25	60	40	32	68	42	6
Ambala	70	47	47	77	83	52	63	35	37	22	76	38	54	25	22	67	69	26
Ludhiana	57	30	42	77	75	59	52	22	37	72	70	50	46	16	32	67	72	42
Chandigarh	84	61	71	86	82	68	78	50	63	84	76	55	73	39	54	81	68	45
Pathankot	94	87	76	96	100	94	91	77	72	94	99	91	86	56	66	93	97	19
	⩾0.8						⩾0.9											
Sriganganagar	2	1	2	12	5	1	1	0	1	9	3	0						
Ferozepur	1	4	14	46	15	11	0	1	1	38	7	5						
Hissar	6	1	2	21	11	4	1	0	0	14	5	2						
Alwar	25	4	7	11	18	0	10	1	3	5	5	0						
New Delhi	44	9	9	34	11	1	34	4	4	23	5	0						
Amritsar	7	11	30	55	56	14	9	5	21	45	41	6						
Patiala	30	12	12	61	48	4	22	6	6	55	31	1						
Karnal	48	20	16	53	20	4	40	10	8	44	9	1						
Ambala	35	9	12	56	50	7	23	3	6	50	36	2						
Ludhiana	32	7	23	56	51	24	23	3	14	50	42	14						
Chandigarh	62	18	34	74	49	35	52	7	22	70	35	25						
Pathankot	69	37	55	89	86	66	57	19	48	86	69	49						

factors alone, the occurrence of conditions for maximum crop yields are reflected by the probability levels for various crops in these tables. For example the optimum evapotranspiration for paddy is attained at Pathankot, Chandigarh and Ambala; and for maize at Ludhiana, Patiala, Karnal, New Delhi and Alwar. But the prospects for rainfed paddy at Ludhiana, Patiala, Karnal, New Delhi and Alwar are considerably reduced. At Hissar, Ferozepur and Amritsar, only Bajra and low water requirements Kharif pulses like Moong and cowpeas can be successfully grown.

The probability levels, given in Tables 1 and 2, also indicate the order of supplemental irrigation required to get potential crop yields if the optimum evapotranspiration conditions are poorly reflected for a particular crop under the prevailing climatic conditions. Thus, these results are also very helpful in designing the experiments under irrigated conditions and managing the available irrigation resources to get potential crop yields. Desi wheat and barley have some

TABLE 3

Seasonal probabilities of I_{MA} for optimum evapotranspiration under conserved soil moisture conditions for *Rabi* crops

Station	Probabilities of getting I_{MA} equal to or greater than				
	0.4	0.5	0.6	0.8	0.9
Sriganganagar	48	31	18	3	0
Ferozepur	79	65	50	14	1
Hissar	78	67	51	20	11
Alwar	93	87	80	59	41
New Delhi	91	86	79	60	44
Amritsar	97	94	90	75	61
Patiala	96	94	90	79	69
Karnal	96	94	92	85	78
Ambala	98	96	93	84	75
Ludhiana	96	92	88	73	59
Chandigarh	100	100	100	100	99
Pathankot	100	100	100	100	99

TABLE 4 (a)

Probabilities of I_{MA} for survival evapotranspiration to estimate the irrigation needs for paddy and low water requirement *Rabi* oilseeds

Station	Probabilities of getting I_{MA} $\leqslant 0.75$ during				$\leqslant 0.3$ during					
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Sriganganagar	99	90	66	94	92	98	89	71	77	85
Ferozepur	99	30	28	66	82	66	70	26	45	55
Hissar	93	64	40	42	68	84	79	52	55	77
Alwar	99	22	13	30	6	51	67	55	60	90
New Delhi	94	50	11	22	32	54	54	24	39	69
Amritsar	99	50	30	65	85	55	37	20	7	38
Patiala	97	29	12	30	36	47	40	17	13	42
Karnal	98	40	5	26	24	30	44	16	25	51
Ambala	83	11	8	20	22	41	41	19	12	24
Ludhiana	96	22	13	38	36	62	52	19	20	29
Chandigarh	87	2	2	7	11	28	21	11	13	20
Pathankot	80	3	0	5	3	8	20	3	0	3

TABLE 4 (b)

Probabilities of getting I_{MA} for survival evapotranspiration to estimate the irrigation needs for low water requirement pulses and medium water requirement oil seeds

Station	Probabilities of getting I_{MA} $\leqslant 0.4$ during								
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Sriganganagar	69	42	90	94	98	91	73	81	91
Ferozepur	13	8	43	89	75	74	31	54	63
Hissar	34	18	28	74	89	86	58	63	82
Alwar	13	10	19	27	74	84	73	78	19
New Delhi	43	5	8	35	63	64	32	76	83
Amritsar	23	8	42	86	63	44	26	11	48
Patiala	7	7	13	43	56	49	21	19	57
Karnal	26	3	15	30	40	52	21	31	64
Ambala	6	3	9	29	53	53	23	17	48
Ludhiana	12	5	24	43	70	58	23	25	41
Chandigarh	0	1	0	16	39	29	14	18	30
Pathankot	0	0	1	6	13	24	4	0	6

TABLE 4 (c)

The probabilities of getting I_{MA} for survival evapotranspi ration to estimate irrigation requirement for maize and wheat during growth period

Station	Probabilities of getting I_{MA} $\leqslant 0.6$ during								
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Sriganganagar	83	56	92	96	99	95	80	89	97
Ferozepur	22	16	56	96	87	80	42	70	77
Hissar	52	29	36	85	96	94	69	77	90
Alwar	17	11	25	53	94	90	77	82	100
New Delhi	56	9	15	45	79	79	48	70	96
Amritsar	37	18	54	90	77	56	34	25	68
Patiala	17	10	22	55	73	67	30	34	83
Karnal	34	4	21	40	60	68	32	58	84
Ambala	8	5	14	46	75	77	33	31	74
Ludhiana	18	9	31	54	84	68	33	28	58
Chandigarh	1	1	2	27	61	46	19	32	50
Pathankot	1	0	3	14	34	34	7	3	10

TABLE 4 (d)

Probabilities of getting I_{MA} for survival evapotranspiration to estimate irrigation needs for low water requirement cereals and high water requirement pulses and oilseeds

Station	Probabilities of getting I_{MA} $\leqslant 0.5$ during								
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Sriganganagar	77	48	91	99	93	78	86	95	100
Ferozepur	18	15	50	94	82	77	37	62	71
Hissar	46	23	32	80	93	91	63	71	86
Alwar	15	10	22	39	85	85	71	76	99
New Delhi	50	6	11	40	72	72	40	62	91
Amritsar	29	13	48	88	71	50	29	18	58
Patiala	11	8	18	48	65	58	25	26	71
Karnal	30	4	18	36	50	60	27	47	75
Ambala	7	4	12	37	65	63	28	24	62
Ludhiana	15	7	27	48	77	63	28	30	50
Chandigarh	0	1	1	23	50	37	16	24	40
Pathankot	0	0	2	9	23	29	6	1	10

promise (30 to 40 per cent) as a second crop at Pathankot and Chandigarh. Gram can be taken as a second crop at Pathankot. Chandigarh, Ambala, Patiala, Ludhiana, Karnal and Amritsar. Possibilities of taking a second crop at Hissar, Ferozepur, Sriganganagar and Alwar are very poor and therefore winter crops are grown in these areas on conserved moisture stored during the rainy season. Probabilities of getting optimum evapotranspiration for various crops during the winter season are given in Table 3. Under the conserved moisture conditions, potential crop yields of wheat, barley can be obtained at Pathankot, Chandigarh, Ludhiana, Ambala, Ferozepur, Karnal, Patiala and Amritsar. Supplemental irrigations are required under stored moisture at Sriganganagar, Ferozepur, Hissar, Alwar and New Delhi.

(c) *Irrigation resources*

Based on the experimental results of various studies indicated in Sec. 5(b) the values will indicate the critical water requirement at the various growth stages to avoid the substantial loss in crop yields. To maintain the optimum crop yields, the probabilities can be utilized to understand the irrigation needs to assure ample moisture supply for optimum growth and these are presented in Tables 4(a) to (d). Knowing these probability levels being essential for optimum crop yields at various growth stages, the moisture requirement at critical stages can be met with the other resources of supplemental irrigations. The irrigation resources can also be managed and scheduled according to variability of these probability levels for various crops which are suitable under existing soil and environmental conditions. For example at Karnal, Ludhiana, Amritsar, New Delhi, etc, supplemental irrigation is highly desired in July and September months.

(d) *Land utilization and crop planning*

With the criterion described in Sec. 5(c) for utilizing the various probability levels of water supply to judge the land utilization pattern, the crops to be grown in the order of preference at each stations are given below.

The area covered under each crop has been indicated as a subscript figure or for a number of crops bracketed if the probability levels for individual crops do not vary much. These subscript figures are the minimum assured probability levels attained in the months during the growing season so as the crops are not required to go under moisture stress under the climatic conditions. The crops satisfying optimum evapotranspiration has been given the main emphasis. The area under subsequent crops indicated by the subscripts has been taken as the assured increase in probability level with respect to the first crop. Adding up these subscript assigned areas will indicate the intensity of cropping for optimum evapotranspiration and the potential crop yields. Pathankot, Chandigarh, Ambala, Patiala and Karnal have more than 100 per cent intensity of cropping. Only 45 to 50 per cent intensity of cropping exists at Hissar and Ferozepur during the rainy season, where as at Sriganganagar feasibility of growing even low water requirement crops is practically *nil.* At Sriganganagar, the minor millets and the low water requirement and drought resistant grasses can be taken. However, in the southwestern tract, due to higher variability of rainfall, the optimum evapotranspiration conditions and intensity of cropping are better reflected for winter crops under conditions of stored moisture conserved during the rainy season and therefore area under winter crops is higher as compared to the crops grown during the rainy season.

Acknowledgements

The author is grateful to Prof. V. P. Subrahmanyam for kindly going through the manuscript and rendering helpful suggestions. The author is also highly thankful to Council of Scientific and Industrial Research, New Delhi for sanctioning Senior Research Fellow at Andhra University, Waltair during the period 1976-79.

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