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Requirement of heat unit and agrometeorological indices in selected wheat growing zones

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सार— शुष्क से आर्द्र जलवायविक क्षेत्रों में स्थित गेहूं की उपज वाले ई टी केन्द्रों (नामतः जोरहाट, वाराणसी, नई दिल्ली, लुधियाना, रायपुर, जबलपुर, अकोला, बेल्लारी, बांसवाड़ा तथा जोधपुर) को चुना गया। प्रत्येक केन्द्र के लिए अद्यतन उपलब्ध पांच वर्षों के आंकड़ों का उपयोग करते हुए गेहूं की फसल की वृद्धि की विभिन्न अवस्थाओं में हीट यूनिट और तीन कृषि मौसम वैज्ञानिक सूचकों नामतः ए आर आई (कृषि जलवायविक वर्षा सूचक), वाई एम आई (उपज नमी सूचक) तथा ए आई (शुष्कता सूचक) का आकलन किया गया। अध्ययन से पता चला कि फसल अंश दिनों में खेत की जुताई और दाना बनने की अवस्थाओं में अधिकतम मांग 1580 (जोरहाट) से 2350 (अकोला) तक भिन्न थी। सभी केन्द्रों (जोरहाट को छोड़कर) में एस आर आई मान 25 प्रतिशत से कम रिकार्ड किया गया, जबकि प्रायद्वीपीय और पश्चिमी भारत के केन्द्रों में ये मान 10 प्रतिशत से भी कम थे। प्रायद्वीपीय और पश्चिमी भारत में संचयी वाई एम आई मान निम्न प्राप्त हुए, जबकि पूर्वी भारत में उच्च मान प्रेक्षित किए गए। सभी केन्द्रों में (बेल्लारी तथा बांसवाड़ा को छोड़कर) गेहूं के खेत की जुताई से लेकर पौधों में फूल बनने तक की अवस्थाओं के दौरान शुष्कता नहीं पाई गई। अगेती और पछेती फसल में वृद्धि की अवस्थाओं में ए आई के उच्च मान प्रेक्षित किए गए। नई दिल्ली में उच्चतम मान (-0.89) के साथ ए आई तथा ए आर आई के बीच नकारात्मक संबंध रहा। इस अध्ययन के आधार पर, गेहूं की उपज वाले क्षेत्रों को पांच क्षेत्रों में विभाजित किया गया है।

ABSTRACT. Wheat growing ET-stations (*viz.*, Jorhat, Varanasi, New Delhi, Ludhiana, Raipur, Jabalpur, Akola, Bellary, Banswara and Jodhpur) situated in arid to per humid climatic zones were selected. Heat unit and three agrometeorological indices, *viz.*, ARI (agroclimatic rainfall index), YMI (yield moisture index) and AI (aridity index) were computed at various growth stages of wheat crop using latest available five years data for each of the stations. The study revealed that the crop degree days requirement varied from 1580 (at Jorhat) to 2350 (at Akola) with the maximum requirement at tillering and milk stages. All the stations (except Jorhat) recorded ARI values less than 25%, while for the stations in peninsular and western India, the values were even below 10%. Low cumulative YMI values were obtained in peninsular and western India, while high values were observed over eastern India. The wheat crop did not experience any aridity during tillering to flowering stages for all the stations (except Bellary and Banswara). High values of AI were observed at early and late crop growth stages. Negative correlation was obtained between AI and ARI with the highest value (-0.89) observed at New Delhi. Depending upon this study, the wheat growing areas were divided into five zones.

Key words - Heat unit, ARI, YMI, AI, Growth stages, Degree days, Tillering, Flowering.

1. Introduction

Wheat is one of the most important staple food crop (very close to rice) of the world population, grown in *rabi* season in India and occupy 27.0% of the irrigated area of the country (Michael 1990). The crop can tolerate temperature from extremely low to fairly high. Environmental conditions cause wide fluctuations in its growth and development. The critical crop growth stages are germination, crown root initiation (CRI), tillering, elongation, flowering, milk stage, dough stage and harvest maturity. Depending upon fluctuations in meteorological parameters in different locations, the crop requirements for heat unit, agroclimatic rainfall index (ARI), yield moisture index (YMI), aridity index (AI), varies widely. In the present work both the spatial and temporal distributions of heat unit and various agrometeorological indices are computed, summarized and critically analysed to get an idea about the crop condition in various locations.

TABLE 1
Details of ET - stations

Items	ET - Stations									
	Jorhat	Varanasi	New Delhi	Ludhiana	Raipur	Jabalpur	Akola	Bellary	Banswara	Jodhpur
Agroclimatic zone No.s	2	4	5	6	7	8	9	10	13	14
Data studied	81-82 to 85-86	85-86 to 89-90	85-86 to 89-90	84-85 to 86-87, 88-89 89-90	83-84, 84-85, 86-87, 90-91, 91-92	85-86 to 89-90	85-86 to 89-90	85-86 to 89-90	85-86 to 89-90	75-76** to 79-80
Soil types	Sandy loam	Sandy clay loam	Loam	Loamy sand	Silty loam	Sandy clay	Clay	Clay	Loamy clay	Loamy fine sand
Location (lat./long.)	26.78°N 94.20°E	25.30°N 83.05°E	28.67°N 77.17°E	30.93°N 75.87°E	21.27°N 81.60°E	23.15°N 79.97°E	20.70°N 77.03°E	15.15°N 76.85°E	23.55°N 74.45°E	26.30°N 73.02°E
Average yield (q/ha)	23.5	24.5	35.5	48.2	26.4	31.8	30.0	24.9	19.2	21.9

* Agroclimatic zones are according to the Planning Commission, Govt. of India, 1989. Zone nos are: 2 - Eastern Himalayan Region, 4 - Middle Gangetic Plains, 5 - Upper Gangetic Plains, 6 - Trans Gangetic Plains, 7 - Eastern Plateau and Hills, 8 - Central Plateau and Hills, 9 - Western Plateau and Hills, 10 - Southern Plateau and Hills, 13 - Gujarat Plains and Hills and 14 - Western Dry Region.

** Recent meteorological data for the wheat crop was not available.

2. Methodology

2.1. *Selection of zones*

Ten wheat growing ET-stations were selected from each of the ten zones (zoning by the Planning Commission, Govt. of. India, 1989 was used) *viz.*, Jorhat (in eastern Himalayan region), Varanasi (in middle Gangetic plains), New Delhi (in upper Gangetic plains), Ludhiana (in trans Gangetic plains), Raipur (in eastern plateau and hills), Jabalpur (in central plateau and hills), Akola (in western plateau and hills), Bellary (in southern plateau and hills), Banswara (in Gujarat plains and hills) and Jodhpur (in western dry region). The crop was mainly rainfed in all the stations except at New Delhi, Ludhiana and Jabalpur (where it was irrigated). The details of ET-stations along with their wheat yield performance is presented in Table 1. The zone numbering is similar to that given by the Planning Commission, Govt. of India, 1989.

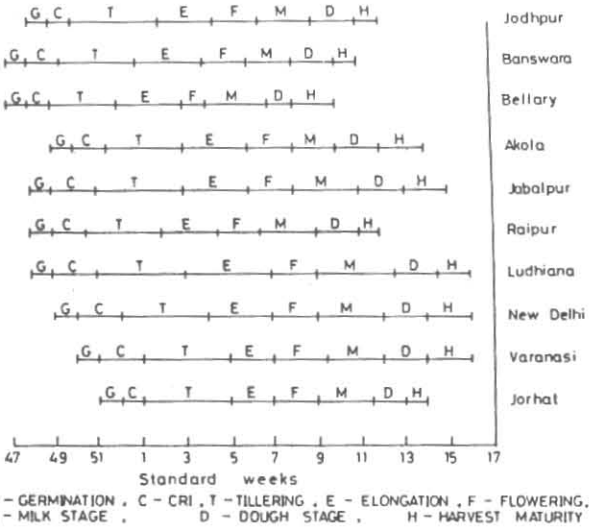

Fig.1. Duration - wise growth stages at different ET-stations

2.2. *Data*

The mean span (in standard weeks) for each of the eight critical growth stages (*viz.*, germination, CRI, tillering, elongation, flowering, milk stage, dough stage and harvest maturity) of wheat crop are determined and presented in Fig.1. Daily data on rainfall, the maximum and minimum temperatures, bright hours of sunshine and actual evapotranspiration were collected from all the ten stations for five years and the mean values were obtained for each of the growth stages which were used for computation of heat unit requirement and for evaluation of different agrometeorological indices at various growth stages of the crop. Existing maximum, minimum temperatures, bright sunshine hours [Fig.2(a)], rainfall, actual and potential evapotranspiration [Fig.2(b)] available at various growth stages for all the stations are determined and presented.

2.3. *Heat unit computation*

The basic assumption that there is a linear and direct relationship between temperature and growth of a plant and below a particular minimum (base) temperature (3.3°C for

TABLE 2

Growth stage-wise average heat unit requirement (degree days) of wheat crop at different ET-Stations

Crop growth stages	ET - Stations									
	Jorhat	Varanasi	New Delhi	Ludhiana	Raipur	Jabalpur	Akola	Bellary	Banswara	Jodhpur
Germination	72.6	98.0	82.6	81.9	97.8	96.6	102.0	118.8	104.4	102.0
Crown root initiation	115.0	147.6	161.0	155.4	156.0	201.6	205.2	172.8	162.0	176.0
Tillering	294.4	334.8	306.0	284.8	375.0	369.6	444.6	426.8	397.8	403.0
Elongation	235.8	268.2	254.1	247.2	291.6	306.6	340.2	342.0	297.0	262.8
Flowering	182.4	243.0	205.5	196.2	246.4	231.0	275.8	234.0	232.4	198.8
Milk stage	304.2	408.0	361.2	351.9	333.0	386.4	388.8	351.9	306.0	334.8
Dough stage	183.0	273.6	271.6	263.2	232.1	301.0	290.4	220.0	179.3	238.8
Harvest maturity	191.0	312.0	333.2	352.8	259.6	337.4	302.4	231.0	210.1	251.9
Total	1578.4	2085.2	1975.2	1933.4	1991.5	2230.2	2349.4	2097.3	1889.0	1968.1

TABLE 3

Average agroclimatic rainfall index at various growth stages at different ET - stations

Crop growth stages	ET - Stations									
	Jorhat	Varanasi	New Delhi	Ludhiana	Raipur	Jabalpur	Akola	Bellary	Banswara	Jodhpur
Germination	55.2	9.9	6.6	11.4	0.0	0.0	1.8	0.0	0.0	0.0
Crown root initiation	15.9	35.6	32.3	9.6	10.2	5.0	9.0	0.0	0.0	0.0
Tillering	25.7	16.2	37.0	56.8	33.1	32.0	19.1	15.9	2.2	0.0
Elongation	85.0	35.8	36.8	16.1	20.8	13.3	1.1	7.1	0.9	2.7
Flowering	42.5	19.0	41.8	17.8	9.5	65.0	8.5	6.8	0.0	1.7
Milk stage	52.5	5.5	21.1	29.1	10.1	30.8	4.4	0.3	0.0	10.6
Dough stage	53.3	0.2	9.9	9.5	10.9	6.9	2.9	0.8	0.2	0.0
Harvest maturity	188.5	0.0	1.4	3.6	0.3	0.0	5.9	0.0	0.0	0.0

wheat), there is no crop growth (Kakde 1985), based on which growing degree days (GDD) or heat unit is determined by the following formula :

$$GDD = \sum_{i=1}^{n} \left(\frac{T\,\text{max.} + T\,\text{min.}}{2.0} - T_t \right) \qquad (1)$$

where, $\frac{T\,\text{max.} + T\,\text{min.}}{2.0}$ is the average daily temperature (°C) obtained from Fig.2(a) and T_t is the minimum threshold temperature (3.3°C) for the crop. The computed daily heat unit values were summed up, growth stage-wise for all the stations (Table 2).

2.4. *Agrometeorological indices computation*

The agrometeorological data of all the ET-stations are presented through agrometeorological indices which expressed the relationship between climate and agricultural production. The different indices computed are agroclimatic rainfall index, yield moisture index and aridity index.

Nieuwolt (1981) proposed agroclimatic rainfall index (ARI) which is given by :

$$ARI = 100 \times \frac{P}{PET} \qquad (2)$$

where, P and PET are the growth stage-wise rainfall (mm) and potential evapotranspiration (mm), respectively obtained from Fig.2(b). The values computed are presented in Table 3.

Yield moisture index (YMI) pertained to the specific crop under agroclimatic assessment (Steyaert *et al.* 1981) is defined as :

$$(YMI)_j = \sum_{i=1}^{n} C_{ij}\, P_i \qquad (3)$$

where, $(YMI)_j$ is the yield moisture index for the *j*th crop. P_i is the rainfall (mm) during the *i* th crop growth stage and C_{ij} is the appropriate crop coefficient (*i.e.* the ratio of actual to potential evapotranspiration) obtained from Fig.2(b). Crop coefficient computed by Kashyapi and Dubey (1996) for wheat at various growth stages in different agroclimatic zones was used. Computed YMI values are presented in Table 4.

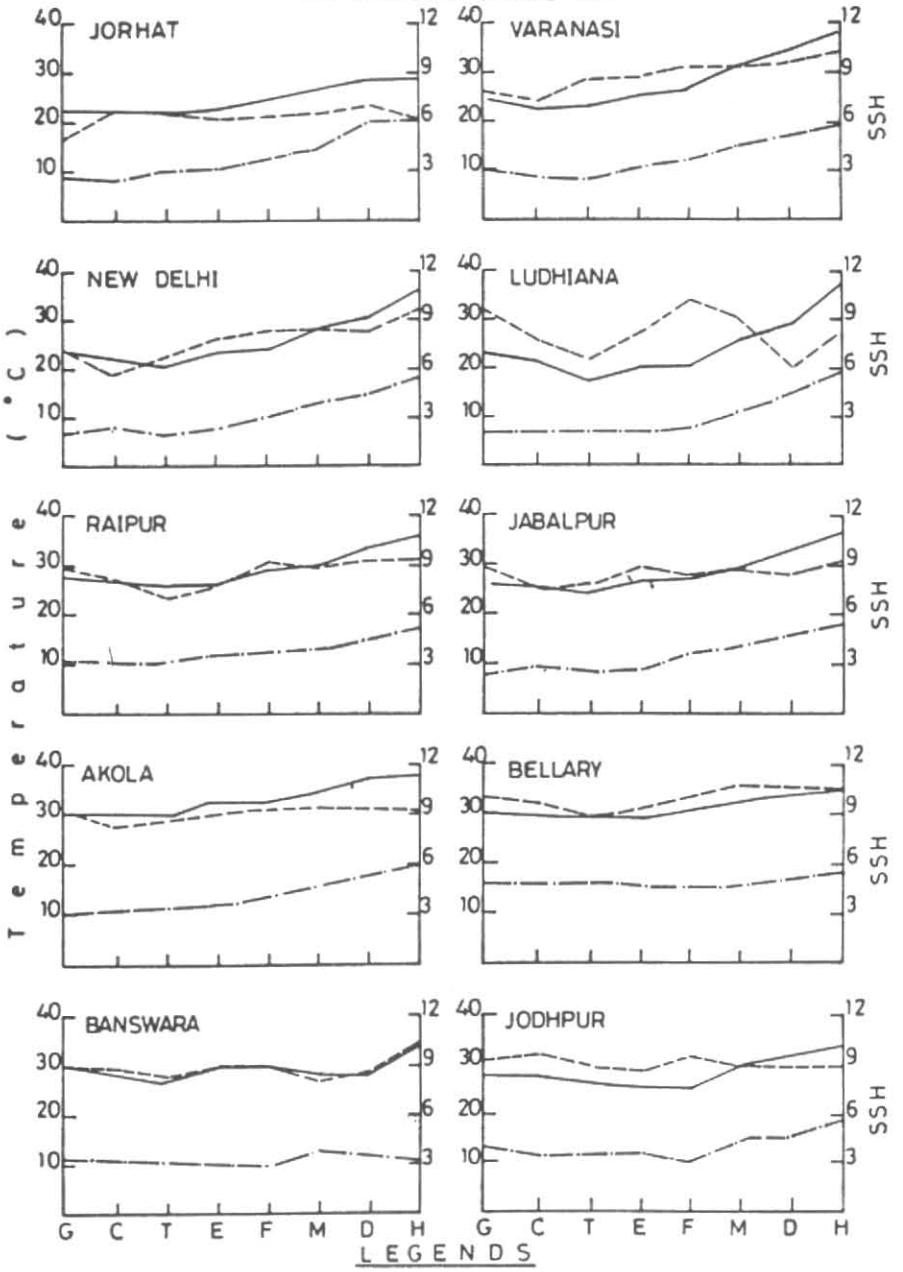

Fig. 2(a). The maximum, minimum temperatures and bright sun-shine hours at various growth stages of wheat crop in different locations

Aridity index (AI) as proposed by Thornthwaite (1948) is based on the values of water deficiency at various growth stages, is computed by the formula :

$$AI = \frac{PET - AET}{PET} \times 100 \qquad (4)$$

where, PET and AET are the potential and actual evapotranspiration (mm), respectively, at various growth stages obtained from Fig.2(b). The AI values are summarized in Table 5.

Correlation coefficient between AI and ARI was determined for all the stations and t-test was tried for indicating the test of significance.

3. Result and discussions

Heat unit and different agrometeorological indices, their spatial and temporal variations are discussed under this heading.

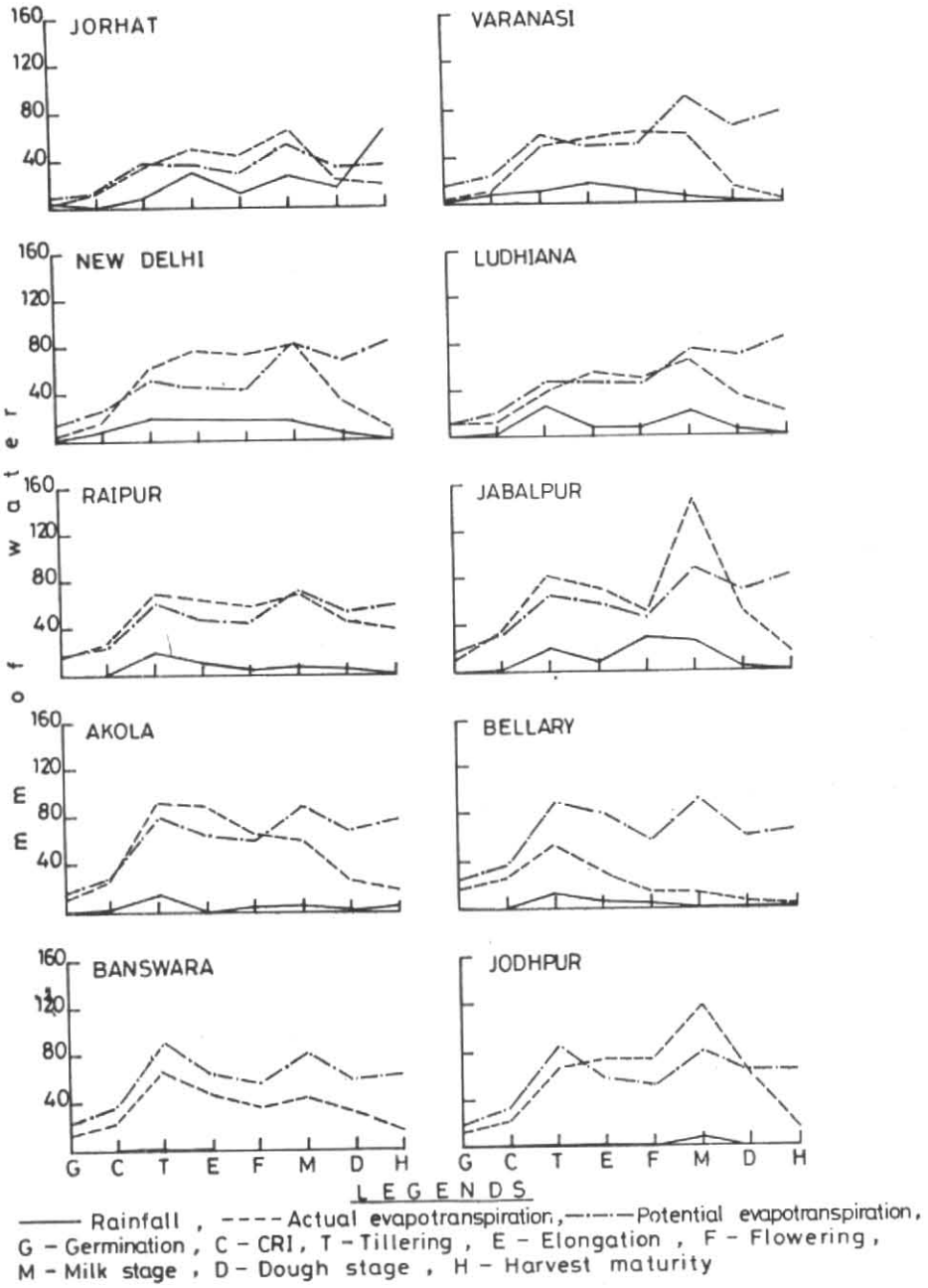

Fig. 2(b). Rainfall, potential evapotranspiration and actual evapotranspiration at various growth stages of wheat crop in different locations

3.1. *Heat Unit*

The spatial and temporal distribution of heat unit for wheat crop are shown in Table 2. The mean total heat unit requirement for the crop throughout its life span was around 2000 degree days (the values varied from 1578 degree days at Jorhat to 2349 degree days at Akola). The heat unit requirement for the early pheno-phases was low which increased rapidly with the ageing of the crop and afterwards it became constant. The mean degree days requirement obtained at various growth stages showed the primary peak at tillering stage (364 degree days), closely followed by a secondary peak at milk stage (353 degree days). ET-stations

TABLE 4

Average yield moisture index at the end of various growth stages at different ET-stations

Crop growth stages	ET - Stations									
	Jorhat	Varanasi	New Delhi	Ludhiana	Raipur	Jabalpur	Akola	Bellary	Banswara	Jodhpur
Germination	2.50	0.30	0.27	1.12	0.00	0.00	0.17	0.00	0.00	0.00
Crown root initiation	4.45	4.33	5.58	2.36	3.00	1.74	2.69	0.00	0.00	0.00
Tillering	13.19	12.49	28.74	24.15	26.58	27.94	20.40	8.58	1.42	0.00
Elongation	56.33	32.50	57.64	32.95	39.88	37.38	21.37	10.80	1.85	2.05
Flowering	75.06	44.34	88.55	41.51	45.47	70.74	26.93	11.66	1.85	3.30
Milk stage	109.41	47.59	105.80	60.04	52.50	115.78	29.77	11.70	1.85	15.83
Dough stage	121.92	47.61	109.06	63.29	57.60	119.48	30.53	11.74	1.90	15.83
Harvest maturity	157.37	47.61	109.19	64.01	57.73	119.48	31.50	11.74	1.90	15.83

TABLE 5

Average aridity index at various growth stages at different ET - stations

Crop growth stages	ET - Stations									
	Jorhat	Varanasi	New Delhi	Ludhiana	Raipur	Jabalpur	Akola	Bellary	Banswara	Jodhpur
Germination	48.3	80.1	70.1	20.3	11.3	45.2	44.0	31.7	45.3	36.8
Crown root initiation	15.2	52.1	36.2	41.1	0.0	0.0	13.3	29.0	39.2	37.2
Tillering	8.8	15.0	0.0	19.4	0.0	0.0	0.0	40.0	28.6	22.9
Elongation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.2	29.1	0.0
Flowering	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77.6	37.3	0.0
Milk stage	0.0	34.8	2.3	14.8	5.5	0.0	28.8	86.3	45.2	0.0
Dough stage	32.5	79.1	52.0	50.1	12.0	23.3	61.9	91.9	46.4	9.2
Harvest maturity	46.8	94.7	88.9	76.2	34.3	80.7	78.7	94.6	75.6	76.2

viz., Raipur, Akola, Bellary, Banswara and Jodhpur recorded the pattern as mentioned above. Stations like Jorhat, Varanasi and Jabalpur showed the primary peak at milk stage, followed by the secondary peak at tillering stage, while New Delhi and Ludhiana recorded the peaks at milk stage (primary), at harvest maturity stage (secondary) and also at tillering stage (tertiary).

Vittum *et al.* (1965) reported that the heat unit is a simple means of relating plant growth, development and maturity to air temperature. Every crop requires certain definite quantities of heat regardless of time, for development of each growth stage and final maturity (Kakde 1985). The computed heat unit, according to Gillespie (1985) is an important tool in efficient pest management.

3.2. *Agrometeorological indices*

The computed indices, *viz.*, ARI, YMI and AI, which represents the relationship between climate and agricultural production are discussed under this sub-heading.

3.2.1. *Agroclimatic rainfall index (ARI)*

The *rabi* season rainfall during the study period was not sufficient to meet the PET demand at various growth stages. Thus, the ARI values were always less than 100% (Table 3). Among all the ET-stations studied, Jorhat showed the highest value (65.0%); Varanasi, New Delhi, Ludhiana, Raipur and Jabalpur recorded ARI values between 10.0 to 25.0%, while Akola, Bellary, Banswara and Jodhpur recorded very low percentage (between 0.5 to 7.0%).

At Jorhat throughout the crop growth span medium to high ARI values were recorded with very high ARI at harvest which was detrimental for wheat yield (reflected by low yield as shown in Table 1). Fairly high ARI from CRI to milk stage for New Delhi, Ludhiana and Jabalpur was reflected by reasonably high yield at these stations. Banswara, Jodhpur and Bellary with very low ARI values resulted in poor yield.

3.2.2. *Cumulative yield moisture index (YMI)*

The cumulative YMI values (Table 4) showed wide variations, from as low as 1.90 (at Banswara) to 157.37 (at Jorhat). The cumulative YMI values showed increasing trend mainly upto milk stage of the crop. The contribution of individual growth stage-wise YMI towards cumulative YMI was the maximum between flowering to milk stage, while stages between CRI to tillering, tillering to elongation, elongation to flowering also recorded high YMI values. Low YMI values were obtained at Bellary, Jodhpur. ET-stations, *viz.*, Raipur, Ludhiana, New Delhi, Jabalpur showed moderate to high YMI values.

Prasad and Datar (1990) suggested that YMI is a good drought indicator. Very low YMI values at Banswara, Bellary, Jodhpur as well as very high YMI values at Jorhat, were reflected by poor crop yield at these stations.

3.2.3. *Aridity index (AI)*

Growth stage-wise AI values obtained at different ET-stations during the wheat growing period are presented in Table 5. The general trend observed was, very high AI values during early crop growth stages; as the season advanced, the values gradually decreased and afterwards, in the late season values again increased. At Jorhat, Jodhpur, the crop recorded no aridity during elongation to milk stages; at Varanasi, Ludhiana, the crop recorded no aridity during elongation to flowering stages; at New Delhi, Akola no aridity during tillering to flowering stages were recorded, while at Raipur, Jabalpur the crop did not suffer from aridity during CRI to flowering or milk stage. The crop at Bellary and Banswara suffered due to aridity throughout the whole life span, which was reflected by poor yield performance.

The study of correlation coefficient between AI and ARI revealed that the relation was negative for all the stations (except Jorhat). New Delhi recorded the highest correlation (-0.89), significant at 1.0% level of significance. The correlation coefficient values at Varanasi (-0.62), Raipur (-0.62), Jabalpur (-0.57) and Banswara (-0.55) were also high.

3.3. *Grouping of zones*

The wheat growing ET-stations, depending upon the parameters studied can be grouped into five zones :

(*i*) Jorhat because of its lowest crop heat unit requirement with the highest ARI, YMI values and low AI value formed the first zone, where the wheat yield was low.

(*ii*) New Delhi, Ludhiana, Varanasi and Raipur formed the second zone because of their medium to high crop heat unit requirement, moderate values of ARI and YMI. The wheat yield was medium to very high in this zone.

(*iii*) Jabalpur with its very high crop heat unit requirement, medium values of ARI, YMI and low AI value, represented the third zone, where high wheat yield was obtained.

(*iv*) Jodhpur due to its medium crop requirement of heat unit, low ARI and YMI values with moderate AI represented the fourth zone, where very poor crop yield was obtained.

(*v*) Akola, Bellary and Banswara with their medium to very high crop heat unit requirement, low ARI, YMI values and moderate to very high AI values formed the fifth zone. The wheat yield in this zone was very low to medium.

4. Conclusions

The present study revealed the following conclusions :

(*i*) The total crop requirement of heat unit was around 2000 degree days. With the advancement of pheno-phases the degree days requirement increased rapidly and at the late growth stages it became constant.

(*ii*) Two main peaks of heat unit requirement by the wheat crop were noticed at tillering and milk stages, while New Delhi and Ludhiana observed another peak at harvest maturity stage.

(*iii*) ET stations, *viz.*, Varanasi, New Delhi, Ludhiana, Raipur and Jabalpur recorded ARI between 10.0 to 25.0%. Jorhat recorded very high ARI values, while for Akola, Bellary, Banswara and Jodhpur the values were very low (0.5 to 7.0%). Both too high or too low ARI values resulted in poor wheat yield.

(*iv*) Banswara, Bellary, Jodhpur observed low cumulative YMI values; Raipur, Ludhiana, New Delhi, Jabalpur recorded moderate to high YMI values, while Jorhat recorded very high YMI value.

(*v*) Aridity as indicated by AI was severe at the commencement of the wheat growing season. As season advanced, the severity gradually decreased and increased, again, at the late season. The crop did not suffer from any aridity between tillering to flowering stages for all the stations (except Bellary, Banswara).

(*vi*) Negative correlation was observed between AI and ARI. New Delhi recorded the highest correlation (-0.89), significant at 1.0% level of significance, while ET-stations *viz.*, Varanasi (- 0.62), Raipur (-0.62), Jabalpur (-0.57), and Banswara (-0.55) recorded very good correlation.

(*vii*) Based on the study, wheat growing ET-stations can be clubbed into five groups, *viz.*, (a) Jorhat, (b) New Delhi, Ludhiana, Varanasi and Raipur, (c) Jabalpur, (d) Jodhpur and (e) Akola, Bellary and Banswara.

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References

Gillespie, T.J., 1985, "Agrometeorological aspects of crop protection against pests and diseases". A lecture note for the WMO workshop on the application of operational techniques in agrometeorology, Pune, India, 21 Nov. - 6 Dec., 1985.

Kakde, J.R., 1985, *Agricultural Climatology*, Metropolitan book company (P) Ltd., New Delhi, First edn. (1985), 1-387.

Kashyapi, A. and Dubey, R.C., 1996, "A critical study on parameters controlling water requirement of wheat (*Triticum aestivum* L.) at various growth stages in ten different agroclimatic zones", *Mausam*, **47**, 4, 409-418.

Michael, A.M., 1990, *Irrigation - Theory and Practice*, Vikas publishing house Pvt. Ltd., New Delhi, 1 - 801.

Nieuwolt, S., 1981, The agricultural rainfall index (a mimeograph), MARDI, Agrometeorological unit, Malaysia, 15p.

Prasad, Rajendra and Datar, S.V., 1990, "Qualitative agroclimatic assessment of rainfed crops", *Mausam*, **41**, 1, 65-68.

Steyaert, L.T., Achutuni, V.R. and Todorov, A., 1981, "Agroclimatic assessment method for drought/food shortages in south and southeast Asia" - Proposed early warning programme, Final report.

Thornthwaite, C.W., 1948, *George. Rev.*, **38**, 1, 55-94.

Vittum, M.T., Dethier, B.E. and Lesser, R.C., 1965, "Estimating growing degree days", *Proc. Am. Soc. Hort. Sci.*, **87**, 449-452.