MAUSAM, **54**, 3 (July 2003), 711-716

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Assessment of phenology, heat and radiation use efficiency, thermal growth rate and phenophasic development model of chickpea at Peninsular India

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(*Received 7 September 2001, Modified 13 August 2002*)

सार – 1987–88 से 1995–96 के दौरान की अवधि में शोलापुर के विकास और आई.सी.आर.आई.एस.ए.टी. की अनागिरी चने की किस्मों के कृषि मौसम वैज्ञानिक आँकड़ों का उपयोग तापीय समय, उष्मा और विकिरण के उपयोग की क्षमता से संबंधित घटना विज्ञान का निर्धारण करने के लिए किया गया है। क्रिया विज्ञान संबंधी परिपक्वता को लाने के लिए ताप एकक की आवश्यकता आई.सी.आर.आई.एस.ए.टी. की अपेक्षा शोलापुर में अधिक है। उष्मा एकक की आवश्यकता के फेनोफेज़ वार विश्लेषण से यह ज्ञात हुआ है कि बाद की पुनरूत्पादन अवस्था (फली के आने से उसके आकार लेने तक की परिपक्वता तक) में फसल की बढ़ोतरी के समय चरम के प्रारंभ के बाद चरम गौंण अवस्था आती है। उष्मा उपयोग क्षमता (एच.यू.ई.) और विकिरण उपयोग क्षमता (आर.यू.ई.) भी समय काल में परिवर्तन दिखाते है जो पहले बोई गई फसलों में उच्चतर पाई गई थी। प्रत्येक स्थान की फसल की विशेष घटना को जानने के समय का पूर्वानुमान करने के लिए ताप एकक आवश्यकताओं के घटनावार पर अरैखिक समश्रयण निदर्श तैयार किया गया है।

ABSTRACT. Agrometeorological data over chickpea varieties Vikas at Solapur and Annigeri at ICRISAT for the period 1987 - 88 to 1995- 96 were used for assessing the phenological development in relation to thermal time, heat and radiation use efficiency. Heat units required to attain physiological maturity were higher at Solapur than that of ICRISAT. Phenophasewise analysis of heat unit requirement revealed that the primary peak at vegetative stage followed by secondary peak at late reproductive phase (pod initiation to physiological maturity). Heat use efficiency (HUE) and radiation use efficiency (RUE) also showed variations in time and space which were higher in early sown crops. A linear regression model based on the phenophasewise heat unit requirements was derived for predicting the time to attain the particular phenophase of the crop at each locations.

Key words – Heat unit, HUE, RUE, Phenophase, Vegetative, Reproductive, Pod initiation, Physiological maturity, Linear regression model.

1. Introduction

Chickpea is an important legume crop of India, grown mostly on residual soil moisture with extensive root proliferation. In India, two distinct agroclimatic regions are recognised for chickpea. In cold winters of north India, long duration crop (160 to 170 days) is grown on alluvial soils (entisols) which contain 200 mm available water in 120 cm deep soil profile. Whilst in peninsular India, where winters are warm and potential evapotranspiration is high, short duration varieties (90 to 110 days) are grown on black cotton soils (vertisols) which retain 250 mm water at 100 cm soil depth.

In peninsular India, the principal agroclimatic constraints for productivity and production of chickpea are hot and dry seedbeds at seedling establishment stage followed by temperatures above 30° C and soil moisture scarcity during vegetative stage to flowering and seed formation stage.

The objectives of the present studies were to assess phenology, heat and radiation use efficiencies, thermal growth rate and phasic development model of Chickpea under semi-arid environments of peninsular India.

2. Materials and methods

The study pertains to Solapur observatory (location 17° 04' N, 75° 54' E, 476 m.a.s.l.) and ICRISAT observatory(location 17° 32' N, 78° 16 ' E, 545 m.a.s.l.). Meteorological and phenological observations were recorded at the experimental field adjoining to the observatories. Daily data on maximum and minimum

TABLE 1

Heat unit (°C day) required to attain various phenophases of chickpea at Solapur and ICRISAT

Solapur					ICRISAT			
Emergence to flowering	Flowering to pod initiation	Pod initiation to physiological maturity	Emergence to physiological maturity	Year	Emergence to flowering	Flowering to pod initiation	Pod initiation to physiological maturity	Emergence to physiological maturity
831	353	516	1700	1987-88	636	299	597	1532
725	288	541	1554	1988-89	662	295	534	1491
686	321	551	1558	1989-90	629	287	538	1454
640	256	523	1419	1990-91	644	288	529	1461
656	267	439	1362	1991-92	N.A.	N.A.	N.A.	N.A.
641	266	542	1449	1993-94	485	303	565	1353
790	331	493	1614	1994-95	463	246	536	1245
765	389	531	1685	1995-96	584	289	575	1448
717	309	517	1543	Mean	586	287	553	1426
68	44	34	116	SD	74	17	24	89
9.5	14.4	6.6	7.5	CV %	12.7	6.1	4.3	6.3

N.A. - Not Available

TABLE 2

Heat use efficiency (HUE) and radiation use efficiency (RUE) of chickpea at Solapur and ICRISAT

Solapur						ICRISAT				
Yield (kg/ha)	Heat unit (° C day)	HUE (kg ha^{-1} degree day^{-1})	PAR (M J m^{-2})	RUE (g M J^{-1})	Year	Yield (kg/ha)	Heat unit (° C day)	HUE (kg ha^{-1} degree day^{-1})	PAR (M J m^{-2})	RUE (g M J^{-1})
1125	1700	0.66	390	0.29	1987-88	965	1532	0.63	368	0.26
1093	1554	0.70	422	0.26	1988-89	1012	1491	0.68	411	0.25
1017	1558	0.65	370	0.27	1989-90	932	1454	0.64	359	0.26
915	1419	0.65	377	0.24	1990-91	879	1461	0.60	349	0.25
1029	1362	0.76	317	0.32	1991-92	N.A.	N.A.	N.A.	N.A.	N.A.
1005	1449	0.69	353	0.28	1993-94	811	1353	0.60	358	0.23
1113	1614	0.69	362	0.31	1994-95	834	1245	0.67	366	0.23
1109	1685	0.66	398	0.28	1995-96	873	1448	0.60	373	0.23

temperature, bright hours of sunshine were collected for eight years from Solapur and seven years from ICRISAT (1987-96) for computation of heat unit measurement, heat use efficiency and radiation use efficiency during growing season of the crop. Similarly crop yield data and phenological informations were also collected and presented in Tables 1 and 2. The phenological stages described by Piara. Singh *et al*. (1990) for chickpea were adopted for preparation of phenological calender of the chickpea crop at Solapur (var. VIKAS) and ICRISAT (var. ANNIGERI) and presented in Fig. 1.

A linear regression model, based on the phenophasewise data pooled over eight years for Solapur and seven years for ICRISAT, was derived for predicting the time required for particular phenophases.

The heat units were computed using mean daily air temperature minus the base (threshold) temperature to correlate and predict the phenological development and maturity of the chickpea crop (Swan *et al*., 1987, Shankar *et al*., 1996) and the base temperature below which chickpea doesn't grow is about 8° C (Huda and Virmani, 1987) was used in the study for characterising thermal response in chickpea.

Heat use efficiency (HUE) of the crop production per unit degree day with respect to economic (pod) yield has been computed using the following formula to compare the relative performance of the crop with respect to utilization of heat (Rao *et al*., 1999).

$$\text{Heat use efficiency (HUE) (kg ha}^{-1}\text{ degree day}^{-1}) = \frac{\text{Economic (pod) yield (kg ha}^{-1})}{\text{Accumulated heat units (degree days)}}$$

Radiation use efficiency (RUE) of the crop in terms of above ground dry matter production (here economic / pod yield) per unit of photosynthetically active radiation (PAR) absorbed by the crop was also estimated (Rosenthal and Gerik 1991) using the following formula :

$$\text{RUE (g MJ}^{-1}) = \frac{\text{Economic (Pod) yield (g m}^{-2})}{\text{Cumulative absorbed PAR (MJ m}^{-2})}$$

$$Rs = R_A\left(\mathrm{a} = \mathrm{b}\,\frac{n}{N}\right)$$

$$\text{PAR} = Rs \times 0.45 \quad \text{(Meek } et\ al.\text{, 1984)}$$

Where

Rs = Incoming solar radiation in MJm^{-2}

R_A = Theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere.

n = Actual duration of sunshine hours

N = Maximum possible duration of sunshine

a and b = Constants

The values of a and b are 0.25 and 0.45 respectively for the latitude of the study area concerned (Mani and Rangarajan, 1982).

3. Results and discussion

3.1. *Crop phenology*

Actual duration and cumulative heat units of different phenophases of the crop at Solapur and ICRISAT were recorded (Table 1). The duration of various phenophases with respect to season, varieties and sowing dates (Fig. 1) showed wide variations and the number of days taken by the crop for completion of emergence to physiological maturity also varied with the date of sowing. The crop had maturity period ranging from 101 to 110 days at Solapur (average 106 days) and 98 to 108 days at ICRISAT (average 103 days) with variability about 3 percent each.

The early sowing lengthened mainly vegetative period which in turn has extended the total growing period. The early sown Vikas variety at Solapur took longest time 110 days in 1987-88 and at ICRISAT for Annigeri variety, it was 108 days in 1988-89 for attainment of physiological maturity. Similarly, the late sown curtailed the vegetative period as well as reproductive period in both locations. The shortest maturity period of the crop was 101 days at Solapur (1990-91) and 98 days at ICRISAT during 1993-94 due to late sowing. This is mainly attributed to the prevailing temperature and sunshine hours during the growing season.

3.2. *Thermal environment, crop maturity and yield*

Heat unit is widely used for describing the temperature responses to growth and development of crops. Degree day based phenology *i.e*. the thermal time requirement for completion of different phenophases of chickpea at two locations were worked out and recorded in Table 1. It was noted that sowing date could have marked influence on degree days accumulated. For different sowing days Growing degree days (GDD) for emergence to maturity ranged between 1362° Cd (1991 - 92) to 1700° Cd (1987-88) at Solapur and 1245° Cd (1994-95) to 1532° Cd (1987-88) at ICRISAT. Patel *et al*., (1999) observed a decreasing trend in accumulated GDD with delayed sowing for pigeon pea at Anand, Gujarat. Both varieties Vikas and Annigeri were sown in the first fortnight of October, having almost same duration, but required different GDD to attain maturity which was varied 1554° Cd to 1700° Cd at Solapur (during 1987-88,

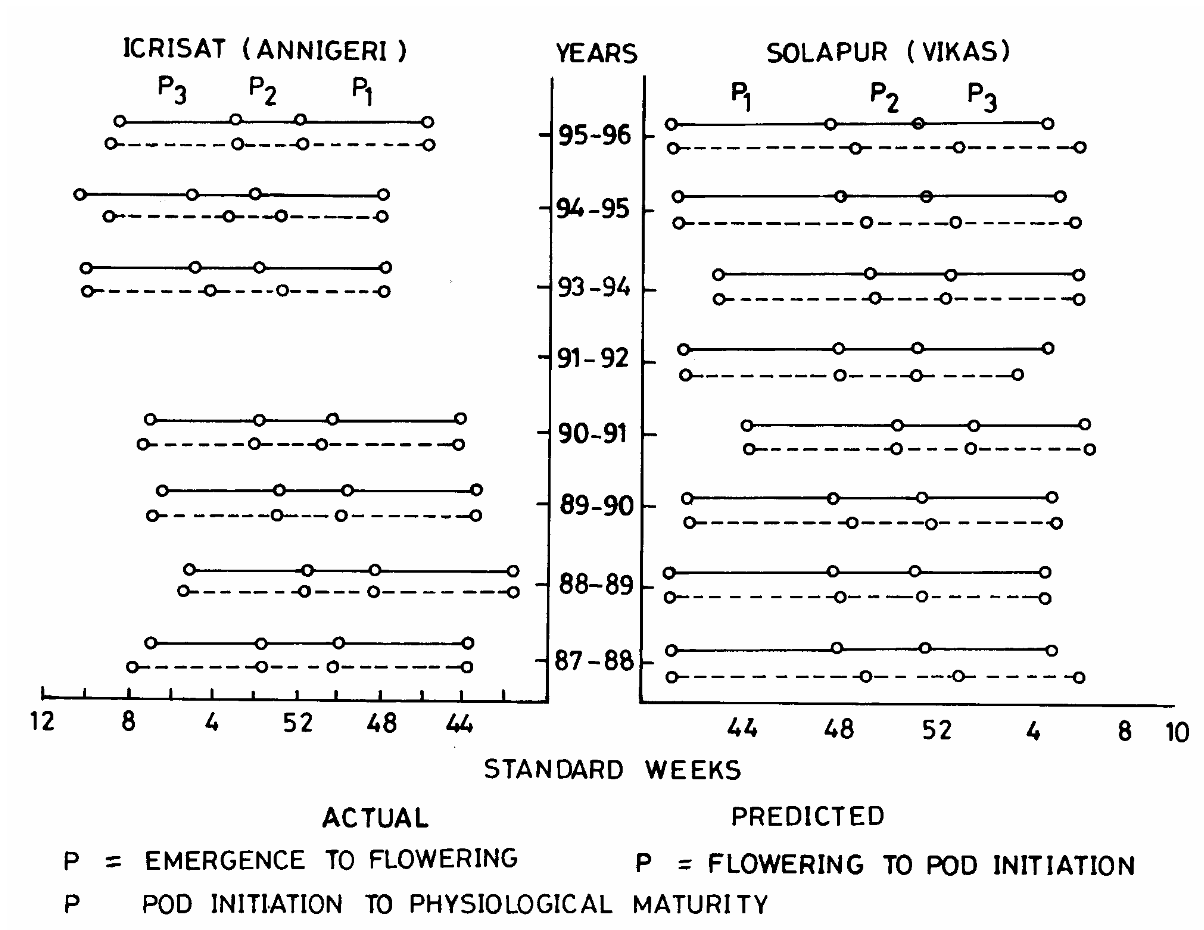

Fig. 1. Phenological calender of chickpea at Solapur and ICRISAT

1988-89 and 1995-96) and 1491° Cd at ICRISAT (during 1988-89). The average value of GDD was 1543° Cd with a variability of 7.5% at Solapur and the same for ICRISAT was 1426° Cd and 6.3% respectively. Rao *et al.* (1999) obtained the GDD of Chickpea ranging from 2122° Cd to 2678° Cd at Hisar, Haryana, taking a base temperature of 5° C. The mean GDD also worked out at various phenophases, showed the primary peak at vegetative stage (emergence to flowering) which was 717 and 586 for Solapur and ICRISAT, followed by secondary peak at late reproductive phase (pod initiation to physiological maturity) which was 517 and 553 respectively for two locations.

Differences in pod yield in two locations were greatly influenced for different varieties and dates of sowing which could be inferred that weather elements *e.g.* temperature, sunshine hours or radiation played a great role either directly in the expression of maturity as well as yield of the crop (Table 2 and Fig. 1). In general, late sown crop matured earlier gave poor pod yield. This could probably be attributed to relatively higher temperature that prevailed at pod filling and maturity phase of late sown chickpea crop at both locations.

3.3. *Phasic development model*

Linear regression models, based on the phenophasewise data pooled over eight years of Solapur and seven years of ICRISAT, were derived for predicting the time to attain particular phenophases. The regression model so developed for two locations was given below :

Y_1 = $2.219 + 0.066\,X_1$ (R^2 = 0 .98)

Y_2 = $1.0923 + 0.071\,X_2$ (R^2 = 0 .99)

Y_1 and Y_2 = Number of days predicted for Solapur and ICRISAT.

X_1 and X_2 = Accumulated GDD for that particular phenophase for above two locations.

From the above model, the days taken for various phenophases can be predicted by using minimum of GDD required to reach that particular phenophase. The actual and predicted days for each phenophases for two locations as obtained by the model are presented in Fig. 1. The mean differences between actual and predicted days for different phenophases ranged from +1.4 days (at pod initiation to physiological maturity) to –4.7 days (at emergence to flowering) for Solapur and for ICRISAT +1.4 days (at flowering to pod initiation) to –3.1 days (at pod initiation to physiological maturity). However, the mean deviation for the same (between actual and predicted) for emergence to physiological maturity remained +1.3 days at ICRISAT and +2.2 days at Solapur. Hundal *et al*. (1997) reported accumulated GDD as the best index to predict various phenophases in wheat under Punjab conditions. Patel *et al*. (1999) also formulated similar type of model to predict the phasic development of pigeonpea from accumulated heat units at Anand, Gujarat.

3.4. *Heat and radiation use efficiency*

Heat use efficiency of Vikas at Solapur and Annigeri variety at ICRISAT was calculated to determine the number of GDD required to produce unit amount of economic grain/pod yield. At Solapur, HUE was varied from 0.65 kg ha^{-1} degree day^{-1} (1989-90 and 1990-91) to 0.76 kg ha^{-1} degree day^{-1} (1991-92) and at ICRISAT, from 0.60 kg ha^{-1} degree day^{-1} (1990-91, 1993-94 and 1995-96) to 0.68 kg ha^{-1} degree day^{-1} (1988-89). Rao *et al*. (1999) obtained HUE of 0.44 kg ha^{-1} degree day^{-1} at Hisar. The higher HUE at both locations may be attributed to higher economic yield in early sown crop as seen in Table 2. In the late sown crop the reduction of HUE was not so high, probably the economic yield was not affected very much due to late sowing and recorded modest heat units upto maturity level (Table 2).

Crops sown in different dates and locations are exposed to different solar elevation during the growing season and this may influence RUE through its effect on radiation transmission. The RUE of chickpea in terms of economic seed/pod yield for each locations varied from year to year in the range of 0.24 g MJ^{-1} (1990-91) to 0.32 g MJ^{-1} (1991-92) at Solapur .The same was found to vary from 0.23 g MJ^{-1} (1993-94 to 1995-96) to 0.26 g MJ^{-1} (1987-88 , 1989-90) at ICRISAT. The variations in RUE for each location may be attributed to the different varieties of plant species and varying environments in different years. When water does not limit plant growth the total dry matter production per unit of intercepted solar radiation is assumed to have a constant value of 0.67 g MJ^{-1} of solar radiation as reported by Piara Singh *et al.* (1990) in his growth and yield model of chickpea.

4. Conclusions

The following conclusion are drawn :

(*i*) Heat unit requirement during total growth period of chickpea was comparatively higher at Solapur than ICRISAT. Delayed sowing resulted in lesser GDD, whereas early sown plants accumulated higher GDD during crop growth period in each locations.

(*ii*) Analysis of phenophasewise heat units showed that the primary peak at vegetative stage followed by secondary peak at late reproductive phase (pod initiation to physiological maturity) in both locations.

(*iii*) HUE and RUE revealed variation in time and space and were higher in early sown crops.

(*iv*) The time required to attain various phenophases can be predicted by the linear regression model based on phasewise requirements of heat units.

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