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Evaluation of phenophasic models of soybean *(Glycine max L.)* based on growing degree-days and photothermal units

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ABSTRACT

In field studies over four crop seasons, soybean (*Glycine max* L.) cv. PK 416 attained physiological maturity in 131 to 137 days under climatic conditions of Ludhiana. The growing degree-days and photothermal units required to attain different phenophases were worked out. From emergence to maturity the crop required growing degree days of 2291 to 2450 °C days with coefficient of variation of 2.7% and photothermal units of 29924 to 32117 °C day hrs with coefficient of variation of 3.1%. Two linear regression models were derived based on the phenophase-wise data pooled over four crop seasons for predicting the onset of a particular phenophase of the crop using either growing degree days or photothermal units. Onset of a particular phenophase depended upon the available growing degree-days or photothermal units which accounted for 99% of the total variation in each case.

***Key Words*:** Growing degree days, Phenophases, Photothermal units, Soybean

Soybean (*Glycine max* L.) is a short day plant and is sensitive to photothermal regime. This influences the area of its adoption and the time of maturity of different cultivars. Temperature alongwith photoperiod affects the flowering time, but temperature alongwith humidity affects initiation and normal pod development. Bhatia *et al* (1997) reported that initiation of flowering and the start of pod development stages were the most susceptible to variation in photoperiod. Initiation as well as duration of crop phenophases are an essential component of weather-based dynamic crop growth and yield simulation models. Crop phenology can be used to specify the most appropriate date and time of specific development process. The duration of each phenophase determines the accumulation and partitioning of dry matter in different organs (Dalton, 1967). Wang (1960) reported that the duration of particular stage of growth was directly related to temperature and this duration for particular species could be predicted using the sum of daily air temperatures. The application of agroclimatic indices provides a scientific basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of the crop. Although these techniques are yet to be tried in India on a regional scale, a few studies have been conducted at local level (Sastry & Chakravarty, 1982). Keeping in view the significance of phenological studies in crop-weather interactions, field studies on soybean were conducted to develop phenology predictive models based on growing degree-days and photothermal units.

MATERIALS AND METHODS

Field studies with soybean cv. PK 416 were conducted during *kharif* 1995, 1997, 1998 and 1999 at the experimental farm, Department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana (30°54'N; 74°48'E & 247m above mean sea level). The soil of the experimental site was loamy sand in texture in the 0-15cm depth and sandy loam in the 15-120cm depth. The crop was sown on 9th, 13th, 4th and 7th June during 1995, 1997, 1998 and 1999, respectively using row to row spacing of 45cm and plant to plant spacing of 5cm. The treatments consisted of four irrigation regimes in four replications, however, no phenological differences were noticed due to irrigation levels as the crop was grown during the rainy season. The crop was fertilized with 30 kg N and 80 kg P_2O_5 per ha.

Growing degree-days (GDD) and photothermal units (PTU) were computed by taking a base temperature of 10°C. The total sum of growing degree-days for each phenophase was obtained by using the following formulae :

$$\text{Accumulated GDD} = \sum_{1}^{N} [(T_{max}+T_{min})/2] - T_b$$

Where,

Tmax, Tmin: daily maximum and minimum temperature (°C)

T_b : base temperature (°C)

1 : date of sowing or start of phenophase

N : date of harvest or the end of phenophase

Accumulated Photothermal Units

$$PTU = \sum_{1}^{N} (GDD) * (\text{Day length})$$

Five plants from the net plot of each replicate were selected randomly for periodic identification of phenological events. Whenever more than three plants from each plot attained a particular stage, the date was considered as the one for attainment of stage. The phenological stages described by IBSNAT (1988) for soybean were followed. Linear regression models based on the phenophase-wise data pooled over four crop seasons were derived for predicting the onset of a particular phenophase based on GDD or PTU.

RESULTS AND DISCUSSION

Crop phenology

Soybean crop took 133, 137, 131 and

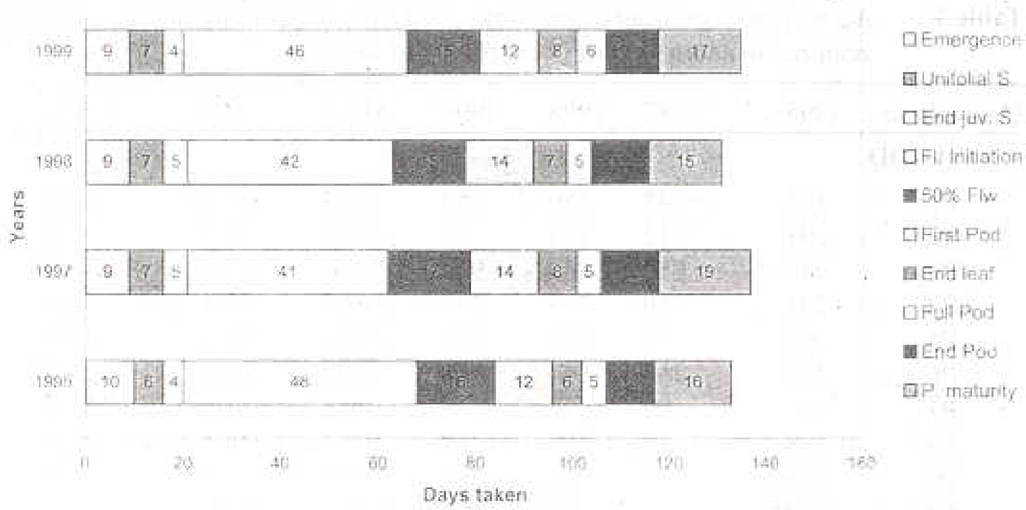

Fig. 1 : Phenology of soybean cv.PK 416 during four years of study

135 days to attain physiological maturity during 1995, 1997, 1998 and 1999, respectively. The calendar for different phenophases observed during the four crop seasons (Figure 1) showed a few little variations in the number of days taken by the crop for completion of each phenophase. Crop sown in 1997 took the highest number of days, whereas the crop sown during 1998 consumed the lowest number of days to attain physiological maturity. This could be attributed to the prevalence of comparatively higher temperatures at the time of physiological maturity in 1998 as compared to 1997.

Growing degree days, photothermal units and crop maturity

Growing degree-days is widely used for describing the temperature responses to growth and development of crops. Both GDD and PTU requirement for completion of different phenophases of soybean were worked out and are presented in Table 1. Soybean crop availed GDD of 2291 to 2450 °C days and PTU of 29924 to 32117°C day hrs from emergence to physiological maturity. The average value of GDD for the same period was 2372 °C days with coefficient of variation of 2.7%, whereas the corresponding values for PTU was 31081 °C day hrs and 3.1%, respectively. When longer periods were considered for accumulation (e.g. phenophase P_{10}, P_{11} or P_{12}) standard deviation was high with relatively low coefficient of variation.

Table 1 : Accumulated growing degree days (AGDD) and photothermal units (APTU) required to attain various phenophases of soybean

Phenophase	1995	1997	1998	1999	Mean	SD	CV%
AGDD							
P1	105	145	150	153	138.3	19.4	14.0
P2	91	112	119	93	103.8	12.0	11.6
P3	946	814	860	929	887.3	53.2	6.0
P4	291	319	303	297	302.5	10.4	3.5
P5	201	276	285	231	248.3	34.1	13.7
P6	113	163	144	158	144.5	19.5	13.5
P7	97	99	85	118	99.8	11.8	11.9
P8	188	167	209	209	193.3	17.4	9.0
P9	259	235	262	262	254.5	11.3	4.5
P10	1142	1071	1130	1175	1129.5	37.6	3.3
P11	890	1023	1025	1013	987.8	56.6	5.7
P12	2291	2328	2417	2450	2371.5	64.4	2.7
APTU							
P1	1489	2054	2128	2166	1959.3	274.5	14.0
P2	1292	1579	1692	1321	1471.0	169.6	11.5
P3	13038	11207	11970	12849	12266.0	732.3	6.0
P4	3783	4130	4027	3901	3960.3	130.6	3.3
P5	2532	3536	3674	2948	3172.5	459.4	14.5
P6	1388	1998	1817	1967	1792.5	243.4	13.6
P7	1173	1187	1050	1439	1212.3	141.4	11.7
P8	2241	1967	2529	2504	2310.3	228.0	9.9
P9	2988	2663	3066	3022	2934.8	159.3	5.4
P10	15819	14840	15790	16336	15696.3	540.0	3.4
P11	11117	12828	13096	12759	12450.0	779.8	6.3
P12	29924	30330	31952	32117	31080.8	966.3	3.1

P_1 - emergence to unifolial stage
P_2 - unifolial to endjuvenile stage
P_3 - end juvenile to flower initiation stage
P_4 - flower initiation to 50% flowering stage
P_5 - 50% flowering to first pod stage
P_6 - first pod to end leaf stage
P_7 - end leaf to full pod stage
P_8 - full pod to end pod stage
P_9 - end pod to physiological maturity
P_{10} - emergence to flower initiation stage
P_{11} - flower initiation to end pod stage
P_{12} - emergence to physiological maturity

Table 2 : Actual (Act), predicted (Pre) and deviation (Dev) of predicted from actual calendar days required to attain various phenophases of soybean based on accumulated growing degree days

Phenophase		1995	1997	1998	1999	Mean	SD	CV%
P_1	Act	6.0	7.0	7.0	7.0	6.8	0.43	6.42
	Pre	5.6	7.7	7.9	8.1	7.3	1.01	13.73
	Dev	-0.4	0.7	0.9	1.1	0.6		
P_2	Act	4.0	5.0	5.0	4.0	4.5	0.50	11.11
	Pre	4.9	5.9	6.3	5.0	5.5	0.59	10.74
	Dev	0.9	0.9	1.3	1.0	1.0		
P_3	Act	48.0	41.0	42.0	46.0	44.3	2.86	6.47
	Pre	49.2	42.4	44.7	48.3	46.2	2.74	5.94
	Dev	1.2	1.4	2.7	2.3	1.9		
P_4	Act	16.0	17.0	15.0	15	15.8	0.83	5.26
	Pre	15.2	16.7	15.9	15.5	15.8	0.56	3.56
	Dev	-0.8	-0.3	0.9	0.5	0.1		
P_5	Act	12.0	14.0	14.0	12	13.0	1.00	7.69
	Pre	10.6	14.5	14.9	12.1	13.0	1.76	13.53
	Dev	-1.4	0.5	0.9	0.1	0.0		
P_6	Act	6.0	8.0	7.0	8	7.3	0.83	11.44
	Pre	6.0	8.6	7.6	8.3	7.6	1.01	13.99
	Dev	0.0	0.6	0.6	0.3	0.4		
P_7	Act	5.0	5.0	5.0	6	5.3	0.43	8.25
	Pre	5.2	5.3	4.5	6.3	5.3	0.64	12.05
	Dev	0.2	0.3	-0.5	0.3	0.1		
P_8	Act	10.0	12.0	12.0	11	11.3	0.83	7.37
	Pre	9.9	8.8	11.0	11	10.2	0.91	8.96
	Dev	-0.1	-3.2	-1.0	0	-1.1		
P_9	Act	16.0	19.0	15.0	17	16.8	1.48	8.83
	Pre	13.6	12.3	13.7	13.7	13.3	0.59	4.45
	Dev	-2.4	-6.7	-1.3	-3.3	-3.4		
P_{10}	Act	58.0	53.0	54.0	57	55.5	2.06	3.71
	Pre	59.4	55.7	58.8	61.1	58.8	1.95	3.32
	Dev	1.4	2.7	4.8	4.1	3.1		
P_{11}	Act	49.0	56.0	53.0	52	52.5	2.50	4.76
	Pre	46.3	53.2	53.3	52.7	51.4	2.94	5.72
	Dev	-2.7	-2.8	0.3	0.7	-1.1		
P12	Act	123.0	128.0	122.0	126	124.8	2.38	1.91
	Pre	119.0	120.9	125.5	127.2	123.2	2.32	2.70
	Dev	-4.0	-7.1	3.5	1.2	-1.6		

Standard deviation was the highest for P_{12} phenophase, whereas coefficient of variation was the highest for the P_1 phenophase.

Development of phenophasic models

Two linear regression models taking the phenophase -wise data pooled over four crop seasons were derived for predicting the

Table 3 : Actual (Act), predicted (Pre) and deviation (Dev) of predicted from actual calendar days required to attain various phenophases of soybean based on accumulated photothermal units

Phenophase		1995	1997	1998	1999	Mean	SD	CV%
P1	Act	6.0	7.0	7.0	7.0	6.8	0.43	6.42
	Pre	6.2	8.5	8.7	8.9	8.1	1.09	13.52
	Dev	0.2	1.5	1.7	1.9	1.3		
P2	Act	4.0	5.0	5.0	4.0	4.5	0.50	11.11
	Pre	5.5	6.6	7.0	5.6	6.2	0.64	10.39
	Dev	1.5	1.6	2.0	1.6	1.7		
P3	Act	48.0	41.0	42.0	46.0	44.3	2.86	6.47
	Pre	51.3	44.1	47.1	50.1	48.2	2.79	5.80
	Dev	3.3	3.1	5.1	4.1	3.9		
P4	Act	16.0	17.0	15.0	15.0	15.8	0.83	5.26
	Pre	15.2	16.5	16.1	15.7	15.9	0.48	3.03
	Dev	-0.8	-0.5	1.1	0.7	0.1		
P5	Act	12.0	14.0	14.0	12.0	13.0	1.00	7.69
	Pre	10.3	14.2	14.8	11.9	12.8	1.80	14.10
	Dev	-1.7	0.2	0.8	-0.1	-0.2		
P6	Act	6.0	8.0	7.0	8.0	7.3	0.83	11.44
	Pre	5.9	8.2	7.5	8.1	7.4	0.92	12.39
	Dev	-0.1	0.2	0.5	0.1	0.1		
P7	Act	5.0	5.0	5.0	6.0	5.3	0.43	8.25
	Pre	5.0	5.1	4.5	6.1	5.2	0.58	11.22
	Dev	0.0	0.1	-0.5	0.1	-0.1		
P8	Act	10.0	12.0	12.0	11.0	11.3	0.83	7.37
	Pre	9.2	8.1	10.3	10.2	9.5	0.89	9.42
	Dev	-0.8	-3.9	-1.7	-0.8	-1.8		
P9	Act	16.0	19.0	15.0	17.0	16.8	1.48	8.83
	Pre	12.1	10.8	12.4	12.2	11.9	0.63	5.31
	Dev	-3.9	-8.2	-2.6	-4.8	-4.9		
P10	Act	58.0	53.0	54.0	57.0	55.5	2.06	3.71
	Pre	62.1	58.3	62.0	64.1	61.6	2.09	3.40
	Dev	4.1	5.3	8.0	7.1	6.1		
P11	Act	49.0	56.0	53.0	52.0	52.5	2.50	4.76
	Pre	43.8	50.5	51.5	50.2	49	3.04	6.21
	Dev	-5.2	-5.5	-1.5	-1.8	-3.5		
P12	Act	123.0	128.0	122.0	126.0	124.8	2.38	1.91
	Pre	117.1	118.7	125.1	125.7	121.7	3.05	2.53
	Dev	-5.9	-9.3	3.1	-0.3	-3.1		

onset of any particular phenophase based on growing degree days or photothermal units as shown below :

$$Y = 0.1328 + 0.05188 \text{ AGDD} \quad (R^2 = 0.996;\ n = 48)$$

$$Y = 0.4394 + 0.0039 \text{ APTU} \quad (R^2 = 0.989;\ n = 48)$$

Where,

Y = number of days predicted

AGDD = accumulated growing degree days for the particular phenophase

APTU = accumulated photothermal units for the particular phenophase

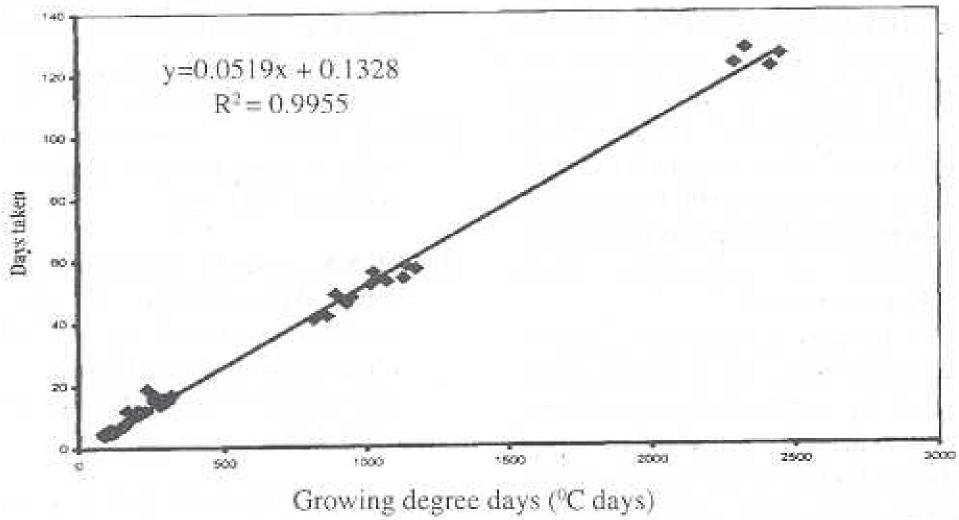

Fig. 2: Relationship between days taken and Growing degree days required to attain various phenophases

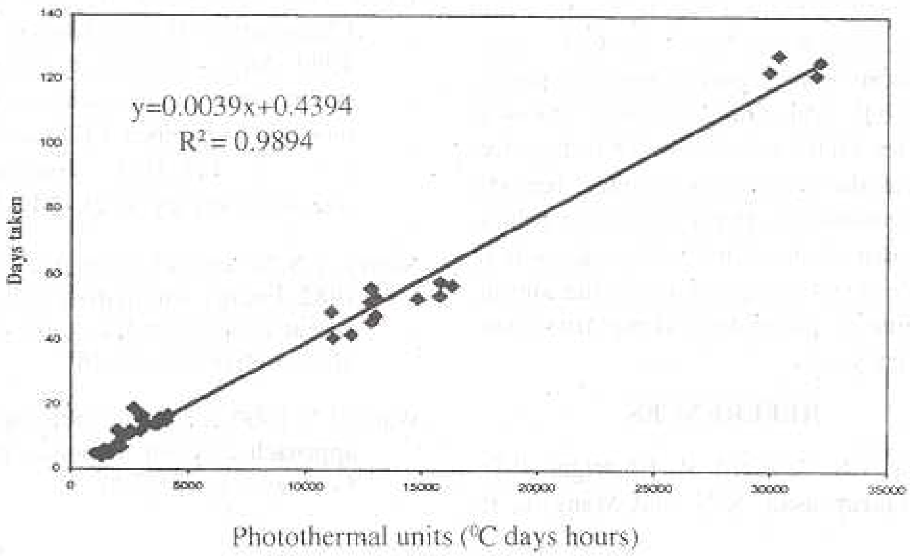

Fig. 3: Relationship between days taken and Photothermal units required to attain various phenophases

The model indicated that both the GDD and PTU accounted for 99% variation in the onset of different phenophases for soybean. Hundal *et al* (1997) also reported AGDD as the best index to predict various phenophases in wheat crop under Punjab conditions. Patel *et al* (1999) formulated a similar type of model to predict the phasic development of pigeonpea from accumulated heat units.

By using these models, the dates of occurrence of various phenophases can be predicted by accumalating real time temperature data. The actual and predicted days for each phenophase as obtained by the models are given in Table 2 and 3 and Figures 2 and 3. The deviations remained in the range of -3.2 to +2.7 days upto P_8 stage when the predictions were based on GDD and -3.9 to +5.1 days when the predictions were based on PTU. The deviations were higher in the later stages of P_{10} to P_{12} which ranged from-7.1 to +4.8 days for GDD and -9.3 to +8.0 days for PTU, as these stages cover longer periods for accumulation. Higher deviation values were also observed in the P_9 stage, which may be due to temperature fluctuations at the time of physiological maturity over different years.

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