Jour. Agric. Physics, Vol. 5, No. 1, pp. 71-78 (2005)

Characterizing Thermal Environment Under Semiarid Conditions in Relation to Growth and Development of Bottle Gourd and Tomato

K.M. SUNIL AND K.S. SUNDARA SARMA

Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi-110 012

ABSTRACT

A field study was conducted during both the summer and winter seasons of 2004-2005, to characterize thermal environment of air and soil on crop growth and yields of bottle gourd and tomato. Summer bottle gourd (cv. Pusa Naveen) was sown on three dates at 10 days intervals starting from March 10th 2004, while winter tomato (cv. Pusa Hybrid 2) was transplanted at 10-day intervals starting 25th November 2004. Study revealed that bottle gourd required about 2000 thermal degree days to reach final harvest and late sown crops experienced 1-2°C higher temperature as compared to early sown crops. The heat use efficiency was higher for March 10th sown crop (1.13 g/m^2/°C day) followed by March 20th (0.95) and March 30th (0.69) sown summer crop. The study also revealed that crop growth parameters, LAI, biomass and final yield were significantly correlated with growing degree-days. In case of tomato, the plants in all the three transplantings accumulated more than 140, 180, 250 and 450-degree days during vegetative, flowering, fruiting and harvesting stages, respectively. November 25th planted crop recorded highest HUE (1.71 g/m^2/°C day). All the three transplanted crops suffered soil temperature stress almost during the same period in which they suffered air temperature stress.

Key words: Bottle gourd, tomato, growing degree-days, heat use efficiency

Among the various weather parameters, temperature is considered as the most influential as every chemical, physiological and biological processes in plants are dependent on temperature. Plants of different species vary quite widely in their adaptability to temperature, but, within a species, they are restricted to rather narrow limits. Most plants live and grow in a temperature range of 0 to 50°C. The occurrence of different phenological events during a growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat units (growing degree days). The idea is based on the fact that plants have a definite temperature requirement before they attain certain phenological stages and they need a definite amount of accumulated heat to meet their requirement for phenological development.

A highly significant positive correlation (r = 0.87 to 0.88) between biomass of soybean crop and accumulated heat units was reported by Uchijima (1975) and for wheat crop by Chakravarty (1980). Sastry and Chakravarty (1982) derived heat use efficiency whose values ranged from 0.69 to 4.00 g/m^2 degree-day^{-1} in different wheat varieties. Patel *et al.* (1999) reported that in potato, late sown plants accumulated lower number of growing degree days during establishment and vegetative phases while during reproductive they required higher GDD. This leads to low yield in late planting. Hundal *et al.* (2003) observed an exponential relationship of leaf area development and a power function relationship of dry matter accumulation with GDD, HTU and PTU for soybean.

Materials and Methods

The experiment was conducted at the research farm of I.A.R.I. (28°35'N, 77°10'E and 288.7 m AMSL), New Delhi. The climate of the station is semi-arid with hot summers and cold winters. The weather parameters during crop period are given in Fig. 1 a and b.

The experiment was laid out in a randomized block design with three replications, size of each

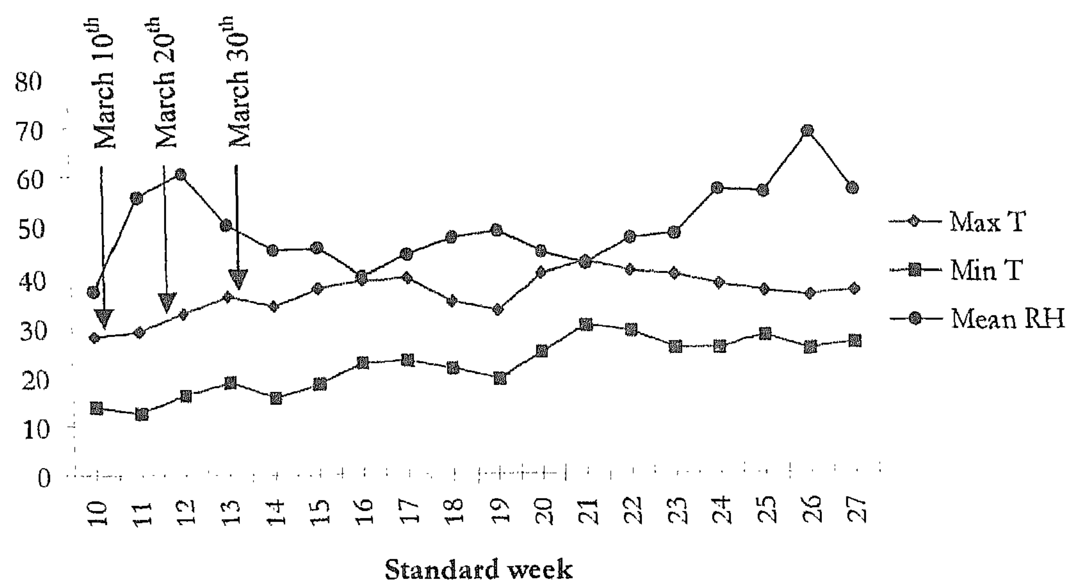

Fig.1a. Weekly weather parameter prevailed during 2004-'05 summer season (crop: bottlegourd)

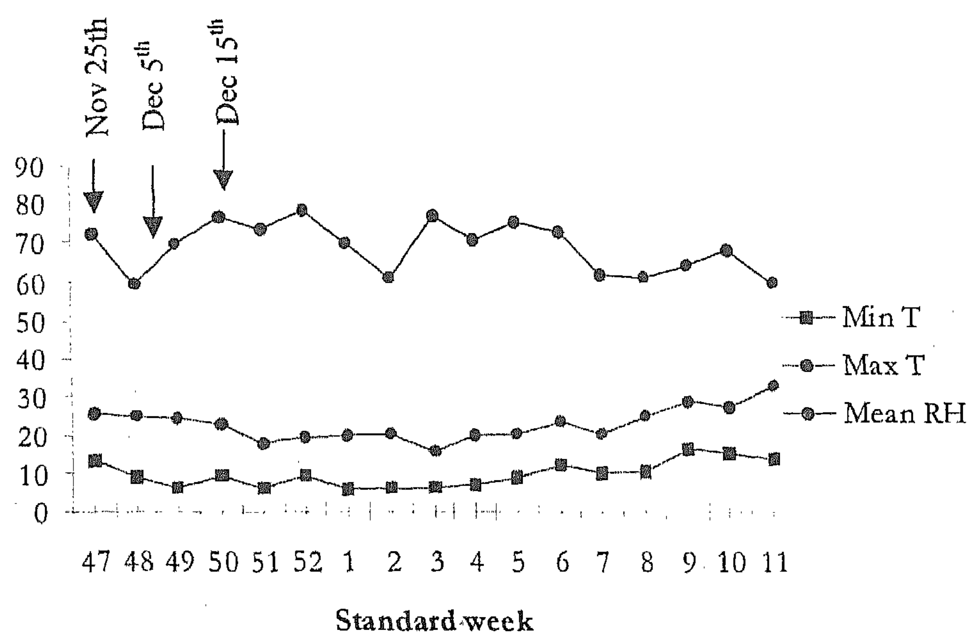

Fig. 1b. Weekly weather parameter prevailed during 2004-'05 winter season (crop: tomato)

plot being 30 × 1 m. The cultivars used were Pusa Naveen for bottle gourd and Pusa Hybrid 2 for tomato. The recommended package of practices were followed under non-limiting water conditions. Crops were sown on three different dates at 10 days interval starting from March 10th for bottle gourd and November 25th for tomato to create different thermal environment. Computerized drip irrigation was given, which work in accordance with the evaporative demand of the atmosphere. Fertilizers solution of 5:3:5 ratio of N: P: K was applied through drip irrigation @ 5-8 liters solution /m^3 of water according to growth and season of the crop. The fertilizers used were ammonium nitrate 80 kg/ ha, phosphoric acid 50 kg/ha) and potassium nitrate 80 kg/ha for bottle gourd and the quantity of fertilizer applied for tomato were 60, 40 and 60 kg, respectively.

In order to relate crop growth parameters with thermal indices, three plant samples were collected at weekly intervals from each replication and average values of leaf area index (LAI) and above ground biomass were recorded.

Growing degree day was computed using the following formula:

$$GDD = (T_{max} + T_{min})/2 - T_b \ ^\circ C$$

Where, T_{max} and T_{min} represent the daily maximum and minimum temperatures and T_b is the base temperature. For bottle gourd, T_b is considered as 10°C, while for tomato it was 5°C. Heliothermal units were computed following the method (Sastry and Chakravarty, 1982). The product of the actual bright sunshine hours and degree days accumulated from the base temperatures (10°C for bottle gourd and 5°C for tomato) on any day was termed as Heliothermal units.

Heliothermal unit (HTU) = Degree days × actual bright sunshine hours

The heat use efficiency (HUE) was computed to compare the relative performance on different dates of sowings with respect to heat energy utilization, using the following formula:

$$HUE = \frac{\text{Maximum biomass (g/m}^2)}{\text{Accumulated heat unit corresponding to the day of maximum biomass accumulation}} \ (\text{g/m}^2/\text{degree - day})$$

The temperature stress factor was computed with the equation (Williams *et al.* 1989)

$$TS = \text{Sin}\left[\frac{\pi}{2}\,\frac{Ta - Tb}{To - Tb}\right]$$

Where TS is the temperature stress factor (0-1), Ta is the average daily temperature (°C), Tb is the base temperature for the crop (°C), and To is the optimum temperature for the crop (25°C for bottle gourd and 20°C for tomato).

For determining the leaf area index in tomato, four plants were randomly cut above ground from each plot. This sampling was done at weekly interval. The green leaf portions were separated and the area was measured using leaf area meter (LI-3100). LAI was derived using the formula:

$$LAI = \frac{\text{Measured leaf area (cm}^2)}{100 \times 100 \ (\text{cm}^2)}$$

In bottle gourd, the leaf area is estimated by using a regression equation developed by Mohammad and Murthy (2001) for bottle gourd.

$$\text{Leaf area} = 43.96 + 0.72\ LW$$

Where, L and W represent maximum length and width of leaf.

Results and Discussion

Effect of thermal environment on yield and yield components

During 2004 summer season, the fruit yield of bottle gourd varied between 224.3 q ha^{-1} in March 10^{th} sown crop to 189 q ha^{-1} in March 30^{th} sown crop, respectively. The average yield reduction was about 4.5 q ha^{-1} day^{-1}. The thermal environment under the different dates of sowing significantly affected crop yield and other yield components. Except percent fruit set, all other yield components were affected significantly by the differences in thermal environment (Table 1). The reduction in yield and other yield parameters was because of relatively high temperature during flowering and early fruit development stages in late sown crops.

Rapid rate of respiration due to high temperature and evaporative demand at later stage of crop growth restricted the partitioning of photosynthates towards fruits, resulting in a considerable decrease in total fruit weight in the late sowings.

The fruit yield of tomato ranged between, 351.1 q ha^{-1} in November 25^{th} transplanted crop to 306.7 q ha^{-1} in 5^{th} December, 2004 and 261.0 q ha^{-1} in 15^{th} December, 2004 transplanted crop, respectively. The different transplanting dates significantly affected crop yield and other yield components by the altered thermal environment created. Except fruit weight, all other yield components were affected significantly. While the number of fruits per plants was reduced to 27 from 31 with delayed sowing. Towards to full onset of winter the number of days to reach flowering was enhanced by two days. (Table 2). The reduction in yield and other yield attributes was because of low temperatures

Table 1. Yield and yield components of bottle gourd under different dates of sowing

Yield and yield components	March 10	March 20	March 30	SE	LSD
Days to first flowering	31[b]	28[a]	2[a]	0.76	2.21
Days to 50% flowering	48[b]	46[a]	45[a]	0.74	1.15
Fruit weight (g)	762.2[a]	621[b]	492[c]	18.6	79.1
Per cent of fruit set	75.03[a]	76.04[a]	73.77[a]	4.13	17.5
Number of fruit per plant	8.33[a]	7.33[b]	6.4[c]	0.25	0.97
yield (q/ha)	224.3[a]	200[b]	189[c]	2.58	10.9

Table 2. Yield and yield components of tomato under different dates of planting

Yield and yield components	Nov. 25	Dec. 05	Dec. 15	SE	LSD
Days to first flowering	49[a]	55[b]	55[b]	0.56	2.37
Days to 50% flowering	64[a]	62[b]	62[b]	0.57	1.43
Number of fruit per plant	31.7[a]	27.1[b]	22.7[c]	0.65	2.74
Fruit weight (g)	43.8[a]	43.5[a]	43.6[a]	0.31	1.32
Per cent fruit set	55.4[a]	52.9[b]	46.1[c]	0.35	1.52
yield (q/ha)	351.1[a]	306.7[b]	261.0[c]	1.59	6.77

that prevailed in the initial stages of crop growth which led to reduced vegetative growth and leaf area in late planted crops (December 05th and 15th planted crops).

Thermal indices on crop phenology and biomass production

Accumulated heat units to attain different phenological stages for three different sowing dates are given in Table 3. The bottle gourd crop required a definite unit of accumulated heat for passing on to the next phenological stage. In all the three dates of sowing crops accumulated more than 500, 800, 900 and 2000 degree days during vegetative, flowering, fruiting and harvesting stages, respectively. Crop sown on March 10th took more number of days to complete all the developmental stages, followed by crop sown on March 20th and March 30th. During the entire crop growth period, (from sowing to final harvest) the HTU attained a value of 15352 units in case of March 10th sown crop where as March 20th and March 30th sown crops accumulated 15369 and 14640 units, respectively.

Results indicated that delayed sowings took less number of days to final harvest. It may be because of relatively higher temperature of the order of 32°C (mean temperature) experienced by the crop throughout the growing period as compared to crops planted on March 10th and 20th.

Tomato crop also required a definite unit of accumulated heat to pass on to the next phenological stage. The plants in all the three transplantings accumulated more than 140, 180, 250 and 450 degree days during vegetative, flowering, fruiting and harvesting stages, respectively. During all the growth stages except in the harvesting stage, plants transplanted on December 15th had taken more number of days to complete the developmental stages. November 25th planted crop took more days to attain final harvest stage (96 DAP) followed by December 05th (94) and December 15th (92) planted crop. This was because of the occurrence of low temperature experienced by November 25th planted crop in the flowering and fruit development stage. The mean temperature during that period was 16.7°C for November 25th planted crop whereas December 05th and 15th sown

Table 3. Accumulated heat unit (GDD) and Heliothermal unit (HTU) at different growth stages of bottle gourd

Growth stages	GDD			HTU		
	March 10	March 20	March 30	March 10	March 20	March 30
Vegetative	505.8 (31)	502.0 (28)	518.6 (27)	4201.0 (31)	4058.8 (28)	3786.6 (27)
Flowering	844.3 (48)	834.2 (46)	816.5 (45)	6581.2 (48)	6243.9 (46)	6142.3 (45)
Fruiting	822.8 (52)	909.95 (59)	921.8 (48)	7084.4 (52)	6976.5 (50)	6903.5 (48)
Harvesting	2135.8 (107)	2166.8 (106)	2234.0 (106)	15352.0 (107)	15369.2 (106)	14639.9 (106)

(Duration of phenological stages in days are shown in parentheses.)

Table 4. Accumulated heat unit (GDD) and Heliothermal unit (HTU) at different growth stages of tomato

Growth stages	GDD			HTU		
	Nov.25	Dec.05	Dec.15	Nov.25	Dec.05	Dec.15
Vegetative	206.8 (32)	160.1 (36)	144.7 (38)	672.7 (32)	377.6 (36)	379.9 (38)
Flowering	259.0 (49)	206.6 (55)	189.3 (55)	797.1 (49)	604.0 (55)	582.8 (55)
Fruiting	311.4 (69)	287.5 (71)	275.7 (71)	1066.1 (69)	1043.0 (71)	1106.6 (71)
Harvest	460.4 (96)	460.5 (94)	488.9 (92)	2029.8 (96)	2169.7 (94)	2733.0 (92)

Duration of phenological stages in days are shown in parentheses.

crops recorded 18.5 and 19.7°C, respectively. From the above results, it is clear that length of growing period correlated closely with accumulated temperature and the low temperature after flowering extent the length of fruit development stage.

During the entire crop growth period from transplanting to final harvest, HTU attained a value of 2030 units in case of November 25th planted crop where as December 05th and December 15th planted crops accumulated 2170 and 2733 HTU, respectively. It showed that tomato required more than 2000 units of HTU to complete its life cycle (Table 4).

HUE of all the three bottle gourd crops at maximum biomass accumulation level as influenced by sowing dates are computed and presented in Table 5. It was observed that March 10th sowing recorded the highest HUE (1.13 g/m^2/°C days), while March 20th and March 30th sown crop, the HUE values were 0.95 and 0.69 g/m^2/°C day, respectively. This may be attributed to higher biomass and LAI in the former than the latter. It can be observed from the study that the above ground biomass accumulation was affected by late sowing. Late sown crop (March 30th) experienced higher temperatures than first sown crop (March 10th) during fruit development period which might have resulted in reduction of fruit weight.

In case of tomato, November 25th planted crop recorded highest HUE (1.71 g/m^2/°C day), while December 05th and December 15th planted crop, the HUE values were marginally lower, 1.60 and 1.38 g/m^2/°C day, respectively (Table 6). This may be due to higher biomass and LAI recorded by the November 25th planted crop. It can be observed that late planted crops experienced high temperature during fruit development stage which increased the respiration rate and there by reduced the assimilate translocation to the fruits. Sowing on different dates caused variation in thermal units resulting in variation in yield as reported by Mukherjee (2000) in brinjal and Haider *et al.* (2003) in wheat.

Table 5. Heat units, maximum biomass and heat use efficiency (HUE) of different dates of sowing in bottle gourd

Treatments	Max. biomass (g/m^2)	Heat units at max. bio mass (°C day)	HUE (g/m^2/ °C day)
March 10	2418.3	2135.7	1.13
March 20	2078.3	2192.0	0.95
March 30	1574.5	2258.5	0.69

Table 6. Heat units, maximum biomass and heat use efficiency (HUE) of different dates of planting in tomato

Treatments	Biomass	GDD	HUE
Nov.25	788.60	460.45	1.71
Dec.05	736.89	460.50	1.60
Dec.15	675.41	488.92	1.38

Temperature stress based on both air and soil temperatures were calculated and presented in Table 7. The value of temperature stress varied between 0-1 and lower value indicated higher stress. In the case of air temperature stress, the bottle gourd crop sown on March 20th and March 30th suffered stress during early stages of fruit development (63 and 70 DAS, respectively) whereas March 10th sown crop suffered the same at picking stage (84 DAS). All the three crops suffered soil temperature stress one week ahead of air temperature stress i.e., during 77, 63 and 56 DAS for crops sown on March 10th, 20th and 30th, respectively.

The optimum temperature for fruit development in most of the cucurbits was around 25°C (Lorenz and Maynard, 1980) and the rate of fruit development was mostly influenced by the temperature during the initial stages of fruit development. It may be due to the above reason, the crops which experienced stress in the early fruit development stages (March 20th and 30th sown crops) recorded lower yield as compared to March 10th sown crop.

In the case of tomato, the crop planted on December 05th suffered air temperature stress during early stages of growth (7 to 49 DAP), whereas early planted crop (November 25th) suffered stress in between 28 and 63 DAP and late planted crop (December 15th) was subjected to stress in a period between 14 and 56 DAP. All the three crops suffered soil temperature stress almost during the

Table 7. Temperature stress at different days after sowing in bottle gourd

Days	Air temperature			Soil temperature		
	March 10	March 20	March 30	March 10	March 20	March 30
7	0.90	0.99	0.96	0.97	0.96	0.96
14	0.90	0.96	0.99	0.96	0.99	0.86
21	0.99	0.99	0.95	0.98	0.89	0.79
28	0.96	0.95	0.82	0.95	0.84	0.87
35	0.99	0.82	0.79	0.85	0.76	0.92
42	0.95	0.79	0.94	0.79	0.92	0.84
49	0.82	0.94	0.99	0.88	0.96	0.38
56	0.79	0.99	0.72	0.93	0.57	0.39
63	0.94	0.72	0.38	0.79	0.28	0.76
70	0.99	0.38	0.53	0.35	0.68	0.66
77	0.72	0.53	0.71	0.44	0.61	0.79
84	0.38	0.71	0.76	0.72	0.83	0.77
91	0.53	0.76	0.74	0.70	0.69	0.83
98	0.71	0.74	0.85	0.77	0.85	0.58
105	0.76	0.85	0.79	0.81	0.69	0.68

Table 8. Temperature stress at different days after planting in tomato

Days	Air temperature			Soil temperature		
	Nov.25	Dec.05	Dec.15	Nov.25	Dec.05	Dec.15
7	0.65	0.61	0.27	0.82	0.52	0.65
14	0.53	0.47	0.40	0.52	0.46	0.40
21	0.60	0.31	0.28	0.59	0.30	0.28
28	0.22	0.31	0.36	0.21	0.30	0.35
35	0.44	0.32	0.12	0.43	0.32	0.12
42	0.27	0.26	0.31	0.27	0.26	0.31
49	0.33	0.19	0.37	0.33	0.18	0.36
56	0.33	0.27	0.74	0.11	0.27	0.74
63	0.45	0.65	0.40	0.32	0.65	0.40
70	0.72	0.63	0.65	0.44	0.61	0.64
77	0.37	0.44	0.93	0.71	0.43	0.92
84	0.71	0.85	0.89	0.71	0.89	0.97
91	0.95	0.91	0.98	0.95	0.93	0.99

same period in which they suffered air temperature stress (Table 8).

The optimum temperature for growth and development of tomato is 21-24°C and under low temperature plant growth, flowering, pollination and fertilization were inhibited (Wang-XiaoXuan *et al.* 1996). It might be due to the above reason, the plants which experienced stress in the early development stages (December 05th and 15th planted crops) recorded low growth and yield as compared to November 25th planted crop.

The study also revealed that there was good correlation between different plant parameters and GDD. Maximum biomass and yield were estimated using multiple regression models. GDD and LAI were used as independent variables to develop regression models. The following regression models were developed to predict total biomass and yield of bottle gourd.

Yield (q ha^{-1}) = 276.88 - 0.322 GDD + 116.385 NDVI ($r^2 = 0.82$)

Biomass (gm^{-2}) = 1425.89 - 2.598 GDD + 36.206 NDVI ($r^2 = 0.93$)

The regression models developed for tomato were as follows:

Yield (q ha^{-1}) = 194.509 - 0.0688 GDD + 43.939 LAI ($r^2 = 0.84$)

Biomass (gm^{-2}) = 4012.14 - 1.724 GDD + 68.96 LAI ($r^2 = 0.98$)

The multiple regression models have a significant coefficient of determination. So these models can be used for predicting yield and biomass of bottle gourd and tomato.

The above results show that with rise in temperature, yield will be reduced. The effect of increased temperature on crop production would largely be negative because of increased respiration and shortened vegetative and fruit development period. Whereas in tomato, rise in temperature increased the fruit yield considerably and continuously. This is because of increase in temperature during the winter season brings up the temperature to the optimum limit for crop growth and development of tomato.

The varieties tested were conventional and time tested for the Delhi region as summer crop (bottle gourd) and winter crop (tomato). When the sowing date was towards was more nearer to the severe winter/summer, caused thermal stress and there by lowered crop growth efficiency. While testing these crops/varieties for other regions the above thermal environment data need to be modeled to obtain the crop growth efficiency.

References

Chakravarty, N.V.K. 1980. Crop-weather interactions in wheat *(Triticum aestivum* L.) and mung bean *(Vigna radiata* L. Wilczek) with reference to crop phenology. Ph.D. Thesis. I.A.R.I., New Delhi.

Haider, S.A., Alam, M.Z., Alam, M.F. and Paul, N.K. 2003. Influence of different sowing dates on the phenology and accumulated heat units in wheat. *J. Biological Sciences* 3 (10): 932-939.

Hundal, S.S., Singh, Harpreet, Kaur, Prabhiyot, Dhaliwal, L.K., Singh, H. 2003. Agro-climatic models for growth and yield of soyabean (*Glycine max*). *Indian J. Agrl. Sci.* **73** (12): 668-670.

Lorenz, O.A. and Maynard, D.N. 1980. Knott's Handbook of Vegetable Growers. 2nd edn, J. Wiley, New York.

Mohammad, S. and Murthy, V.R.K. 2001. Rapid, simple and indirect method of leaf area estimation in bottle gourd (*Cucurbitaceae sp*). *Crop Res.* **21**(2): 178-180.

Mukherjee, J. 2000. Evaluation of thermal environment and spectral characteristics of brinjal (*Solanum melongena* L.) and tomato (*Lycopersicon esculentum* Mill.) crops and to develop yield predicting models. Ph.D. thesis, Post Graduate School, Indian Agricultural Research Institute, New Delhi.

Patel, H.R., Patel, G.C. and Shekh, A.M. 1999. Factors associated with reduced yield of delayed planting of potato *(Solanum tuberosum* L.) in middle Gujarat agro-climatic region. *Journal of Agrometeorology* **1** (2): 119-124.

Sastry, P.S.N. and Chakravarty, N.V.K. 1982. Energy summation indices for wheat crop in India. *Agric. Meteorol.* **27**: 45-48.

Uchijima, Z. 1975. Dry matter production of crops in relation to climatic conditions. Collected papers of Agric. Meteorol., No.16. *Nat. Inst. Agric. Sci.*, Japan 2-5.

Wang Xiao-Xuan, Li-shude, Dong-Hui Ru, Gao zhenttua, Dai-Shan Shu, Wang, X.X, Li, S.D., Dong, H.R., Gao, Z.H. and Dai, S.S. 1996. Effect of low temperature stress on several properties of tomato during seedling and florescence. *Acta Hort.* **234**: 349-354.

Williams, J.R., Jones, C.A., Kiniry, J.R. and Spanel, D.A. 1989. The EPIC crop growth model. *Trans. ASAE* **32** (2): 497-511.