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Relationship Between Heat Unit Requirement and Growth and Yield of Mulberry, *Morus indica* L.

A. Sarkar[1], M. Rekha* and K. Keshavacharyulu

Central Sericultural research and Training Institute, Mysore - 570 008. India.
[1]Central Sericultural research and Training Institute, Berhampore - 742101. India.

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Growth and development of a plant over a growing season is closely related to the daily accumulation of heat. Heat unit measured by accumulated growing degree days (GDD) is becoming increasingly popular to estimate the growth of a plant or even in insect. GDD or heat accumulation per day is measured by calculating average daily temperature and then subtracting the base temperature below which growth does not occur. Heat accumulation per day is added for the desired period and accumulated GDD is determined. The present study was conducted in five seasons in an established garden with K-2, S-36 and V-1 mulberry varieties belonging to *Morus indica* L. grown under completely irrigated condition at the farm of CSRTI, Mysore during 2001 - 2002. Plants were pruned in each season and the growth of the plant measured by total shoot length and fresh leaf yield was recorded at an interval of 5 days starting from 30 days of pruning (DAP) to 70 days when all the plants were pruned. The accumulated GDD for the corresponding days were recorded and used for analysis. Accumulated growing degree days (GDD) have been found to be perfectly correlated with both growth and yield in all the seasons in all the varieties studied. The high R^2 values indicated a strong relationship between the accumulated GDD and, growth and yield of mulberry.

Key words: Heat units, Growing degree-days, Mulberry

*To whom correspondence should be addressed.
Central Sericultural Research and Training Institute, Srirampura, Mysore- 570 008. India. Tel: 91-821-2362406;
E-mail: rmoodbidri@hotmail.com

Introduction

Mulberry, the host plant of silkworm, *Bombyx mori* L. is cultivated in many tropical, subtropical and temperate areas of the world. Plant growth is a complex process. It involves an increase in plant weight or size, usually brought about by the expansion of plant parts and by the use of products of photosynthesis to make the new parts or to increase the size of the old parts. It has been observed that the primary factor governing growth of mulberry is temperature (Anonymous, 1972). Although moisture stress strongly interacts with temperature in plant growth process, it had little effect on the growth of mulberry under completely irrigated condition. Temperature is also considered as primary factor for controlling leaf appearance rate and growth in grass (Van Esbroeck *et al.*, 1997); soybean, *Glycine max* (Sinclair, 1984); pea, *Pisum sativum* (Truong and Duthion, 1993); cowpea, *Vigna unguiculata* (Ney and Turc, 1993) and in wheat (Tripathi *et al.*, 2004). Temperature influences the growth of plants in many ways like root growth, nutrient uptake and water absorption, photosynthesis respiration and translocation of photosynthetes (Ram Niwas *et al.*, 1990)

The effect of temperature on the development has been described using a thermal type concept called heat unit. As the plant develops over a growing period, its development is closely related to the daily accumulation of heat. A certain amount of heat is required to provide enough energy to move to the next development stage (Anonymous, 2003). Bonhomme (2000) used GDD to estimate harvest maturity and to predict the duration between two developmental stages. A thermal type concept (heat unit) assumes that phenological development is constant per degree of temperature between a base temperature and an upper threshold temperature, below and above which the development rate is zero. Different thermal indices have been used to predict maturity in crops

(Coelho and Dale, 1980; Mitchell *et al.*, 1997; Van Esbroeck *et al.*, 1997). The most commonly used heat unit is growing degree - days. In this study we considered accumulated growing degree - days (GDD) from complete pruning to particular development stage till the harvest at maturity at 70 days after pruning (DAP) in different seasons. The GDD unit for a given day is defined as the difference between the daily mean temperature and a growth threshold temperature (Gilmore and Rogers, 1958; Lu *et al.*, 2001). A GDD index is obtained by summing the daily GDD up to the phase of ontogeny desired.

Accumulated GDD is becoming popular to estimate the growth of a plant and even in insects (Zalom *et al.*,1985; Verma *et al.*, 1990; Caron, 2004) due to its simplicity in calculation. A linear relationship between accumulated GDD and rate of plant development was reported by Wang (1960).

The objective of this study was to find out the relationship of GDD to yield and growth of mulberry and to discuss the possibility of developing a GDD calendar for uniform maturity in mulberry.

Materials and Methods

The experiment was conducted in the farm of Central Sericultural Research and Training Institute, Mysore with three varieties of mulberry *viz.,* K-2, S-36 and V-1, all belonging to *Morus indica* L. All these varieties were developed gradually in the Institute in different years and at present widely cultivated in South India with an yield potentiality of 30, 46 and 70 tons per hectare per year, respectively (Sarkar *et al.*, 2000). The soil of the experimental site is red loam with a pH of 7.8. The study was conducted under complete irrigated condition during the year 2001 - 2002 involving five harvests with the duration of 70 days each in an established mulberry garden with a spacing of 60 × 60 cm. After pruning at ground level during each harvest, the plants were maintained as per recommended package of practices (Sarkar *et al.,* 2001). While the record of maximum and minimum temperature initiated immediately after pruning, the record of growth and leaf yield on fresh weight basis at particular time was initiated at 30 days after each pruning and continued till 70 days at an interval of five days. The increment in leaf yield of selected five plants was estimated by using the mean fresh weight of unit shoot length of another five plants (sample) of similar size sacrificed at each harvest. The growth and leaf yield of the experimental plants of each variety at each scheduled harvest was continuously monitored from five sample plants of similar type pruned at particular harvest. At each harvest five sample plats were pruned at schedule harvest days of 30, 35, 40, 45, 50, 55, 60, 65 days after pruning and total length of effective shoots per plant were measured. Leaves were separated and average weight of leaves per unit length of shoot was calculated from the sample plants by:

$$\frac{\text{Total weight of leaves}}{\text{Total length of shoots}}$$

At the same day of harvesting, the total length of shoots of the experimental plants from each variety was measured. The leaf yield at particular harvest for individual varieties was calculated from the sample plants and used to estimate the leaf yield of the experimental plants at different harvests. Growth and yield of the plants at 70 days were recorded directly by pruning the experimental plants. The GDD for each day was calculated considering the base temperature for mulberry as 13°C, below which the growth of mulberry is virtually zero (Anonymous, 1972; Rangaswamy *et al.*, 1976). GDD index or the accumulated GDD was calculated using the following formula:

$$\sum GDD = \{[T_{max} + T_{min}]/2 - T_b\}$$

where,

T_{max} = Maximum daily temperature in °C,
T_{min} = Minimum daily temperature in °C,
T_b = Base temperature for mulberry.

If the average temperature is equal to or less than the base temperature, no degree-days are accumulated and the GDD for the particular day is considered as zero. However, this situation did not arise during this experiment. Accumulated GDD was used to find out its relationship with growth and yield of mulberry.

Results and Discussion

The daily maximum, minimum and average temperature and accumulated GDD for the different seasons during the experimental period are presented in Table 1. It is observed that highest accumulated GDD was recorded in the month of April - May (Summer) and lowest in January - February (Winter) (Table 1). This indicates that uniform calendar day presently recommended for performing harvesting in different seasons may not be justified as it does not corroborate with the uniform maturity. A close examination of the table indicated that the cumulated GDD for 70 days varied from 678.3 in January - February (Winter) to 1021.3 in April - May (Summer).

Growth of mulberry was found to be dependent on variety and season and hence the correlation study was carried out separately for different varieties and in different sea-

Table 1. Daily maximum, minimum and average temperature along with accumulated GDD in different season during the growth period of 70 days after pruning in Mulberry

Crop no.	Temperature (°C)				Accumulated GDD
	Season	Maximum	Minimum	Average	
1.	July - August	28.6	20.9	23.7	847.4
2.	Aug - Sept	29.1	19.7	24.1	781.2
3.	Oct - Nov	28.2	19.4	23.6	797.5
4.	Jan - Feb	30.0	17.2	23.1	678.3
5.	April - May	33.3	22.0	26.9	1021.3

sons. Correlation coefficients between the growth of mulberry measured by total length of shoots and GDD is presented in Table 2. It is observed that there exists a very strong linear relationship between the GDD and rate of plant development (Table 2). Hence it appears possible to develop a GDD calendar for entire cultural operation that would replace the calendar day operation for uniform maturity in all the seasons.

Similarly, the relationship between the leaf yield and GDD was computed through correlation coefficients and presented in Table 3. A perusal of Table 3 indicated that the growth and leaf yield in mulberry was highly correlated with the GDD in all the varieties studied in all the seasons. In general, growth of mulberry is poor in winter season (Jan - Feb) and high in summer season. In the calendar day model that is now in vogue does not consider the differential maturity in different seasons but restricts to particular day after pruning. In the GDD model the mulberry crop during winter should get a longer duration to get the uniform maturity as the accumulated GDD is less in comparison to summer month. More study is still required to identify the range of optimum GDD for mulberry growth suitable to different stages of silkworm.

The high correlation between accumulated GDD with growth and yield of leaves in mulberry prompted us to develop a regression model for the estimation of yield and growth of mulberry in different seasons. Apart from the seasonal variation, the growth and yield is also dependent on the genotype. The relationship between GDD and growth of mulberry measured by total length of shoot and

Table 2. Correlation coefficients between total length of shoots and accumulated GDD in different varieties of mulberry in different seasons

Season	Mulberry variety		
	K-2	S-36	V-1
July - August	0.998**	0.997**	0.998**
Aug - Sept	0.994**	0.997**	0.993**
Oct - Nov	0.997**	0.987**	0.993**
Jan - Feb	0.996**	0.997**	0.982**
April - May	0.998**	0.998**	0.996**

**Significant at 1% level of significance.

Table 3. Correlation coefficient between leaf yield and accumulated GDD in different varieties of mulberry in different seasons.

Season	Mulberry variety		
	K-2	S-36	V-1
July - August	0.989**	0.991**	0.991**
Aug - Sept	0.987**	0.952**	0.984**
Oct - Nov	0.946**	0.956**	0.959**
Jan - Feb	0.988**	0.986**	0.976**
April - May	0.966**	0.994**	0.993**

**Significant at 1% level of significance.

Table 4. Relationship of growth of mulberry measured by length of total shoots with growing degree days in different varieties

Season	Regression equation	R^2
	K-2	
July - August	Y = 1.07X - 223	0.99
Aug - Sept	Y = 1.16X - 136	0.98
Oct - Nov	Y = 0.90X - 111	0.99
Jan - Feb	Y = 0.98X - 109	0.99
April - May	Y = 0.92X + 12	0.99
	S-36	
July - August	Y = 1.24X - 2056	0.99
Aug - Sept	Y = 1.33X - 201	0.99
Oct - Nov	Y = 0.84X - 97	0.97
Jan - Feb	Y = 0.97X - 154	0.99
April - May	Y = 0.82X - 20	0.99
	V-1	
July - August	Y = 1.96X - 310	0.99
Aug - Sept	Y = 1.68X - 114	0.98
Oct - Nov	Y = 1.15X - 160	0.98
Jan - Feb	Y = 1.25X - 84	0.96
April - May	Y = 1.42X - 134	0.99

Y = Total shoot length; X = Accumulated GDD.

Table 5. Relationship of leaf yield in mulberry with growing degree days in different varieties

Season	Regression equation	R^2
	K-2	
July - August	Y = 0.37X - 110	0.97
Aug - Sept	Y = 0.44X - 98	0.97
Oct - Nov	Y = 0.75X - 237	0.89
Jan - Feb	Y = 0.38X - 84	0.97
April - May	Y = 0.47X - 129	0.93
	S-36	
July - August	Y = 0.76X - 223	0.98
Aug - Sept	Y = 0.78X - 205	0.90
Oct - Nov	Y = 1.08X - 355	0.91
Jan - Feb	Y = 0.60X - 136	0.97
April - May	Y = 0.65X - 180	0.98
	V-1	
July - August	Y = 1.42X - 493	0.98
Aug - Sept	Y = 1.13X - 291	0.96
Oct - Nov	Y = 1.64X - 575	0.92
Jan - Feb	Y = 0.84X - 1851	0.95
April - May	Y = 0.96X -3536	0.98

Y = Leaf yield; X = Accumulated GDD.

leaf yield are explained through regression equation and presented in Table 4 and 5 along with the respective R^2 values.

It is clear from the table that coefficient of determination (R^2) of all regression equations with respect to growth and yield of leaves are mostly ≥ 0.90 which suggests that the regressions developed will be useful in simplifying communication on growth and relative maturity of mulberry in different seasons and in different varieties.

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