MAUSAM, **63**, 3 (July 2012), 449-454

551.525.5 : 633/635

Thermal indices in relation to crop phenology and fruit yield of apple

MOHAN SINGH and H. S. BHATIA

Dr. Y. S. Parmar University of Horticulture and Forestry, Seobag, Kullu, (HP), India

(*Received 15 December 2010, Modified 13 April 2011*)

e mail : jangra_ms@live.com

सार – कुल्लू घाटी में सिओबाग के बागवानी अनुसंधान केन्द्र की अनुसंधान फार्म की पथरीली बलुआई मिट्टी में उगाई जाने वाली सेब की दस प्रजातियों पर तीन मौसमों में (2008–2010) स्थलीय प्रयोग किए गए। फसल के पहले मौसम में सभी प्रजातियों के फल 157 से 188 दिनों में पक गए जबकि दूसरे और तीसरे मौसम में क्रमशः 159 से 179 दिनों में और 156 से 187 दिनों में फल पके। वृक्षों में फूल लगने से फल बनने तक का औसत जी. डी. डी. 382 से 419 डिग्री डी. का होता है और फलों के पकने तक 2310 से 2957 डिग्री डी. का समय लगता है। सभी प्रजातियों में भिन्न–भिन्न मौसमों में पौधों के विकास होने में मोलीस प्रजाति में सबसे कम जी. डी. डी. और स्टारक्रीमसन प्रजातियों में अधिकतम जी. डी. डी. लगता है। परन्तु कॉमर्शियल एवं टाइडमैन प्रजाति के फल तैयार होने में क्रमशः न्यूनतम और अधिकतम जी. डी. डी. लगते हैं। सभी प्रजातियों में और मौसमों में प्रकाशीय ऊष्मा सूचकांक (पी. टी. आई.) 7.2 से 16.8 तथा 13.2 से 18.4 डिग्री डी./दिन क्रमशः पुष्पित होने और फल लगने की अवस्था में होता है।

ABSTRACT. Field experiments were conducted on gravel sandy soil of research farm of Horticultural Research Station, Seobag in Kullu valley with ten varieties of apple for three seasons (2008-2010). In the first crop season all the varieties matured within 157-188 days, while in the second and third seasons the crop matured with 159-179 and 156-187 days, respectively. The mean GDD accumulation from bud burst to fruit set was from 382 to 419° D and to maturity 2310 to 2957° D. The varieties, Mollice and Starkrimson consumed the lowest and highest GDD for attaining physiological maturity in different seasons among all varieties. But Commercial and Tydeman consumed the lowest and highest GDD for fruit setting. The photo thermal index (PTI) in all the varieties and seasons varied from 7.2 to 16.8 and 13.2 to 18.4° D/day at flowering and reproductive stages respectively.

Key words – Apple, GDD, PTI and HUE.

1. Introduction

In Himachal Himalayas the era of prosperity was initiated through the cultivation of apple following stepwise replacement of the traditional coarse grain based farming system. Apple is temperate deciduous thermal sensitive long day plant. The crop remains in dormancy from October to March and bud beak takes place from last week of March to first week of April after completing the chilling requirements. Though its growth and development are influenced by many weather parameters, the temperature is identified as one of the most important factors which affect its growth development. The rate of growth and development of a crop is a function of the energy receipt and thermal regime in any given crop growth season. Wang (1960) reported that the duration of a particular stage of growth was directly related to temperature and this duration for particular species could be predicted using the sum of daily air temperature. Thermal time effect has been described as the independent variable to delineate plant growth and development (Dwyer and Stewart, 1986). Temperature based indices like growing degree days (GDD), Photothermal units (HTU) and Photothermal index (PTI), Heat use efficiency (HUE) can successfully be used for describing phonological behaviour and other growth parameters like leaf area development, biomass production, yield etc. in relative terms (Swan *et al*., 1989; Neog and Chakravarty, 2005; Singh *et al*., 2007). These indices are based on the concept that real time to attain the phonological stages is linearly related to temperature in the range between base temperature and the optimum temperature (Monteith, 1981). This concept widely used for growth, phonological development and yield of different crops (Rajput *et al.*, 1987; Shanker *et al.*, 1996). Such works have been done elsewhere (Rao *et al.*, 1999) it has not hitherto been reported from Himachal Pradesh for apple. Hence, the present investigation was carried out to assess the relationship between thermal time, phenophases and fruit yield.

2. Materials and methods

Field experiments were conducted in three seasons (2008-2010) on gravel sandy soil of research farm of Horticultural Research Station of Dr. Y. S. Parmar

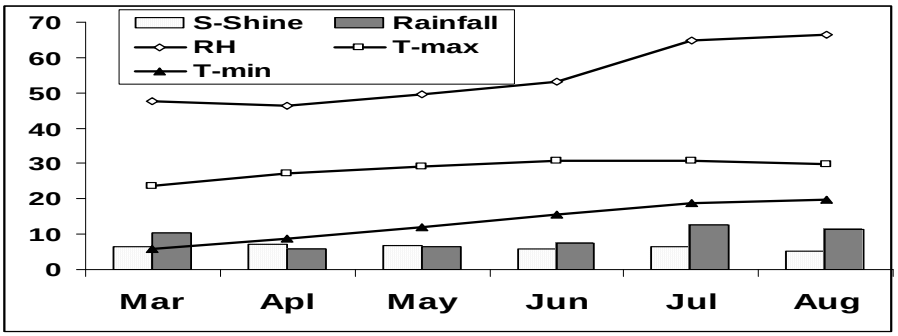

Fig. 1. Average weather during the crop growing period

University of Horticulture and Forestry at Seobag (32° N, 77° E and 1350 m amsl) in the Kullu valley of Himachal Pradesh to assess the thermal unit requirements for fruit set and maturity of apple. Pomologists have identified about 21 different phenophases in apple from dormancy to physiological maturity. Two important phenophases (fruit set and maturity) were visually observed by visiting the plant of ten apple cultivars (Starking Delicious, Vance Delicious, Top Red Delicious, Oregon Spur, Red Chief, Red Spur, Starkrimson, Tydeman' Early Worcester, Commercial and Mollice) at one day interval.

Daily weather data was collected from Agromet Observatory situated in the same farm. The average maximum, minimum temperatures, relative humidity sunshine hours and total rainfall were 28.6° C, 13.5° C, 54.6 %, 6.3 hours and 536.9 mm, respectively during the crop growing period from March to August (Fig. 1). Growing degree days accumulated for attaining different phonological events were calculated with base temperature as 4° C. Phenothermal index (PTI) expressed as degree days per growth day for flowering stage (from bud burst to fruit set) and reproductive growth (fruit set to physiological maturity) stages of the crop were calculated as per following formula (Sastry and Chakravarty, 1982).

PTI = (GDD)/No. of days taken between two phenophases

Heat use efficiency (HUE) defined as the biomass accumulation during the given period per day was computed (kg ha^{-1} per degree) for fruit yield to compare the relative performance of different cultivars with respect to utilization of heat as:

HUE = Fruit yield (kg ha^{-1})/accumulated heat units.

3. Results and discussion

3.1. *Crop phenology*

Numbers of days taken to attain any phenological events varied in all the varieties and among the seasons (Table 1). On an average the crop took 35.6 (CV = 3.65 %) and 177.7 (CV = 5.9 %) days to attain fruit set and physiological maturity in all varieties and seasons. For attaining the fruit set stage the variation was lowest in case of Commercial (CV = 4.68%) followed by Mollice (CV = 6.93 %) whereas it was highest in case of Red Chief (CV = 14.71 %) followed by Tydeman and Starkrimson with CV value of 13.48 and 13.37 per cent, respectively. This variation was at par among all the varieties for attaining the physiological maturity. In three seasons Red Chief took minimum days for fruit set and Mollice to mature as compared to other varieties in different seasons. It was observed that the cultivars Tydeman, Commercial and Mollice took 4-8 days more as compared to the other for fruit setting, but they mature 15-30 days earlier than the remaining cultivars. These three are the pollinizer cultivars so we can say that the pollinizer required more number of days for attaining the fruit set stage and less for the physiological maturity as compared to standard and spur type of cultivars. The year 2008 was a normal years, 2009 was a poor year and the 2010 was bumper year for apple production. During the 2010 there was good rainfall with good distribution as compared to the other two seasons.

3.2. *Growing degree days (GDD)*

The GDD or thermal time concept assumes that the amount of heat would be more or less same for a crop to

TABLE 1

Days to attain fruit set and physiological maturity in apple cultivars during different years

Cultivars	Fruit set (days)				Maturity (days)			
	2008	2009	2010	Mean	2008	2009	2010	Mean
Commercial	38	38	35	37.0	188	178	187	185.7
Starkrimson	37	39	30	35.3	188	179	182	183.0
Vance	38	39	31	36.0	188	179	181	182.7
Oregon Spur	35	38	31	34.7	186	178	183	182.3
Red Spur	36	37	31	34.7	187	177	183	182.3
Top Red	36	37	31	34.7	186	177	183	182.0
Red Chief	34	39	29	34.0	185	179	181	181.7
Starking Delicious	35	38	31	34.7	185	178	182	181.7
Tydeman	38	42	32	37.3	159	162	154	158.3
Mollice	36	39	34	36.3	157	159	156	157.3

TABLE 2

Heat unit accumulation at fruit set and physiological maturity of apple cultivars during different years

Cultivars	Fruit set				Maturity			
	2008	2009	2010	Mean	2008	2009	2010	Mean
Starking Delicious	396	393	359	383	3152	2863	2832	2949
Vance	404	403	359	389	3160	2873	2832	2955
Top Red	396	403	359	386	3152	2873	2832	2952
Oregon Spur	395	403	359	385	3160	2873	2832	2955
Red Chief	395	403	359	385	3160	2873	2832	2955
Red Spur	395	403	359	385	3160	2873	2832	2955
Starkrimson	401	403	359	388	3167	2873	2832	2957
Tydeman	439	453	366	419	2518	2384	2377	2426
Commercial	427	391	341	386	2459	2323	2352	2378
Mollice	407	403	359	390	2429	2227	2274	2310

reach a particular phenological stage or maturity. The accumulated GDD to reach fruit set stage and physiological maturity varied in all the varieties and in three seasons Table 2). This variation was observed highest in Commercial and Tydeman (CV = 11.23 & 11.16 %), lowest in Starking Delicious (CV = 5.46 %) remaining varieties having this variation at par (CV = 6.12 to 6.93 %) for fruit set. The variation in GDD for attaining maturity was lowest in Commercial and Tydeman with coefficient of variation ranging from 3.0 to 3.3 per cent followed by Mollice and Top Red (CV = 4.6 to 5.9 %). Reaming cultivars required almost same numbers of GDD (CV = 6.0 to 6.2 per cent). The total GDD requirement for attaining fruit set and maturity ranged from 340.6 to 452.7° D (with mean 389.5° D and CV = 2.72 %) and 2226.8 to 3167.1° D (with mean 2779.2^{o} D and CV = 10.2 %), respectively among all varieties and seasons. On an average the crop took total 406, 406 and 357 GDD for fruit set and 2952, 2703 and 2682 GDD for maturity during 2008, 2009 and 2010 respectively.

TABLE 3

Photo thermal index at flowering and reproductive stage of apple cultivars during different seasons (2008-2010)

Cultivars	Fruit set				Maturity			
	2008	2009	2010	Mean	2008	2009	2010	Mean
Starking Delicious	11.3	11.3	14.0	12.2	18.4	17.6	16.4	17.5
Vance	11.1	11.3	12.0	11.5	18.4	17.6	16.5	17.5
Top Red	11.3	11.3	14.0	12.2	18.4	17.6	16.3	17.4
Oregon Spur	11.7	11.3	16.8	13.3	18.3	17.6	16.3	17.4
Red Chief	11.7	11.3	16.8	13.3	18.3	17.6	16.3	17.4
Red Spur	11.7	11.3	16.8	13.3	18.3	17.6	16.3	17.4
Starkrimson	11.7	11.3	16.8	13.3	18.3	17.6	16.3	17.4
Tydeman	10.4	12.7	13.3	12.1	17.2	16.1	16.5	16.6
Commercial	11.6	10.4	7.2	9.8	13.5	13.8	13.2	13.5
Mollice	10.8	11.3	9.4	10.5	16.7	15.2	15.7	15.9

TABLE 4

Fruit yield and Heat use efficiency of apple cultivars during different seasons

Cultivars	Yield (t/ha)				HUE (yield/degree)			
	2008	2009	2010	Mean	2008	2009	2010	Mean
Oregon Spur	22.3	14.3	26.1	20.9	8.67	4.98	9.21	7.62
Red Chief	16.7	8.1	20.6	15.1	6.47	2.81	7.27	5.52
Starkrimson	18.5	11.8	14.3	14.9	5.84	4.11	5.06	5.00
Red Spur	14.6	4.0	21.5	13.4	6.90	1.39	7.59	5.29
Starking Delicious	13.7	8.7	12.9	11.8	4.34	3.03	4.56	3.98
Vance	12.7	6.8	13.9	11.1	4.09	2.37	4.94	3.80
Tydeman	6.6	6.2	8.6	7.1	2.61	2.60	3.63	2.95
Commercial	5.2	7.2	7.5	6.6	2.12	3.09	3.19	2.80
Mollice	6.3	5.2	7.8	6.4	2.59	2.32	3.46	2.79
Top Red	5.9	4.3	6.8	5.7	1.87	1.51	2.39	1.92

3.3. *Phenothermal index (PTI)*

The Phenothermal index gives an idea about the rate of development of the various phenological events with reference to heat units, which will eventually help in evaluating relative performance of different varieties. In three crop seasons, the PTI varied from 7.2 to 16.8° D/day during fruit set stage, while in the reproductive growth stage (fruit development stage) it ranged from 13.2 to 18.4° D/day in all varieties (Table 3). Like days and GDD the PTI during fruit set stage in all the varieties was more variable (CV = 16.9 %) than at reproductive growth stage (CV = 5.2 %). During flowering period of all varieties, the PTI was maximum in 2010 (except in Commercial and Mollice which required longer period for attaining the fruit set stage) which may be due to that the day and night temperature was higher in 2010 at this stage as compared to in 2009 and 2008 respectively. On an average the apple

crop have 12.1 ^{o} D/day (CV = 10.3 %) and 16.8 (CV = 7.61 %) PTI to attain fruit set and physiological maturity in all varieties and seasons. The PTI was lowest and highest for Commercial and Starkrimson, respectively among all the varieties and seasons for fruit setting stage. For development stage it was lowest for Commercial and highest for Vance Delicious genotypes among all the varieties and seasons.

3.4. *Fruit yield*

Fruit yield of all the cultivars of apple in different seasons is given in Table 4. The highest yield (26.1 t/ha) was observed in Oregon Spur in 2010 followed by the same variety in 2008. On an average the highest yield was recorded in 2010 followed by 2008 and lowest in 2009 indicating that during 2010 the weather conditions were more conducive for growth and development of the crop as compared to 2008 and 2009, respectively. The yield was most variable in Red Spur and red Chief (CV = 65.9 & 42.3 %) and lowest in Tydeman, Commercial and Mollice which indicate that the yield is more persisted in pollinizer varieties as compared to other standard and spur types of cultivars.

3.5. *Heat use efficiency (HUE)*

Among different varieties and seasons the heat use efficiency varied from 1.87 to 8.67 kg/ha/degree during 2008, from 1.39 to 4.98 kg/ha/degree during 2009 while during 2010 it varied from 2.39 to 9.21 kg/ha/degree with coefficient of variation of 28.8 % as a whole. The values of heat use efficiency were slightly higher in third crop season in most of the cases (40 to 80%) as compared to second season and first season, respectively which indicate that the thermal environment was favourable in second and first season. This index can be used to asses seed yield in relative terms. It may be inferred that growing degree days, Phenothermal index and heat use efficiency indices may be used to assess the crop performance in assessing suitability of the variety to a particular locality depending on the thermal environment.

3.6. *Predictive model*

Regression model was developed for fruit yield prediction. A linear regression model taking into account the phasic development data pooled over different varieties in three cropping seasons on the basis of thermal unit requirement was developed as under.

$$Y = 0.059 \text{ AGDD} - 13.57 \qquad (R^2 = 0.98)$$

Where, *Y* is the number of days predicted AGDD the accumulated growing degree days for the particular phenophases. This model indicated that accumulated thermal units account for nearly 98 per cent variation of the occurrence/onset of different phenophases in apple. Similar work on developing agroclimatic models for mustard (Hundal *et al*., 2003) and for wheat (Hundal *et al*., 1997) have been reported under Punjab conditions.

4. Conclusion

During the first crop season all the varieties matured within 157-188 days, while in the second and third season the crop matured with 159-179 and 156-187 days, respectively. Thus the crop took 9 days less during the second season (2009). The mean GDD accumulation from bud burst to fruit set ranged from 382 to 419 ^{o} D and to maturity 2310 to 2957° D. The varieties, Mollice and Starkrimson consumed the lowest and highest GDD for attaining physiological maturity in different seasons. But Commercial and Tydeman consumed the lowest and highest GDD for fruit setting. The photo thermal index (PTI) in all the varieties and seasons varied from 7.2 to 16.8 and 13.2 to 18.4° D/day in flowering and reproductive stage, respectively. This model indicated that accumulated thermal units account for nearly 98 per cent variation of the occurrence/onset of different phenophases in apple.

References

Dwyer, L. M. and Steward, D. W., 1986, "Leaf area development in field grown maize", *Agron. J.*, **78**, 334-348.

Hundal, S. S., Prabhjyot Kaur and Malikpuri, S. D. S., 2003, "Agroclimatic models for prediction of growth and yield of Indian Mustard", *Indian J. Agric. Sci.*, **73**, 3, 142-144.

Hundal, S. S., Singh, R. and Dhaliwal, L. K., 1997, "Agro-climatic indices for predicting phenology of wheat in Punjab", *Indian J. Agric. Sci.*, **67**, 6, 265-268.

Monteith, J. L., 1981, "Climate variation and growth of crops", *Quart J. Royal Meteorol Soc*., **107**, 602-607.

Neog, P. and Chakrvarty, N. V. K., 2005, "Thermal indices in Brassica grown under a semi arid environment", *Ann. Agirc. Res.*, (New series), **26**, 2, 291-296.

Rajput, R. P., Deshmukh, M. R. and Paradker, V. K., 1987, "Accumulated heat units and phenology relationship in wheat as influenced by planting dates under late sown conditions", *J. Agron. Crop Sci.*, **159**, 345-349.

Rao, V. U. M., Singh, D. and Singh, R., 1999, "Heat use efficiency of winter crops in Haryana", *J. Agromet.*, **1**, 143-148.

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

Shanker, U., Agrawal, K. K. and Gupta, V. K., 1996, "Heat unit requirement of rainfed soybean", *Indian J. Agric. Sci.*, **66**, 401-404.

Singh, I. A., Rao, U. V. M., Singh, D. and Singh, R., 2007, "Study on agrometeorological indices for soybean crop under different growing environment", *J. Agrometeorol.*, **9**, 1, 81-85.

Swan, J. B., Schneider, E. C., Moncrief, J. E., Paulson, W. H. and Peterson, A. E., 1989, "Estimating crop growth yields and grain moisture from air growing degree days and residue cover", *Agron. J.*, **79**, 53-60.

Wang, J. Y., 1960, "A critique of the heat units approach to plant response studies", *Ecology*, **40**, 785-790.