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Role of Changing Climate on Chilling Unit Accumulation and Yield for Apple (*Malus* X *domestica* Borkh) Cultivation at Shimla, Himachal Pradesh, India

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__ABSTRACT:__ The area in and around Shimla in Himachal Pradesh (India), is strictly not a temperate zone region, however, because of its altitude (1900 – 2600 m ASL) it is able to support a fairly good production of temperate pome and stone fruits. Erratic winter chilling in some apple growing areas of late has raised alarming concerns about the continued sustenance of productivity of temperate fruits, particularly of apple, in the region. It will be pertinent to determine the extent of climate change in the region and its impact on productivity of apple trees.

Climate change with particular reference to occurrence of warmer winters is a matter of concern to the temperate fruit grower as this means not being able to satisfy the chilling requirement of the fruit trees. There is therefore a need to continuously monitor the chill unit accumulation during winters to be able to suggest appropriate corrective measures that the fruit grower may adopt to maintain the productivity. Chill Unit estimation models are available but they are not applicable universally. Location specific chill unit estimation ready reckoners are needed. In this study a ready reckoner has been developed for the apple growing Shimla region, H.P. It overcomes some of the drawbacks of the estimation models that have been developed previously. It was found when the chill unit was low (300hr) then days taken to bud break was 50 whereas, increased chill units (1500hr) reduced the days taken for bud break i.e.13.

The low productivity of apple has become a serious concern for the farmers, research workers and development agencies at national and state level for the last two decades. Several factors can be attributed to the declining trend in productivity like expansion of apple cultivation to marginal areas, monoculture of Delicious varieties, declining standards of orchard management and the fluctuating abnormal climatic conditions in different phonological stages.

Perusal of the total chill units received in Shimla during the last five years of the study showed that in none of the years the accumulation was less than 1000 chill units. This is well within the range for cultivation of apples. However, the year to year fluctuations are a matter of concern and a further long term study should be continued to fully understand the impact of global warming at Shimla, Himachal Pradesh.

INTRODUCTION

The area in and around Shimla in Himachal Pradesh (India), is strictly not a temperate zone region, however, because of its altitude (1900 – 2600 m ASL) it is able to support a fairly good production of temperate pome and stone fruits. Erratic winter chilling in some apple growing areas of late has raised alarming concerns about the continued sustenance of productivity of temperate fruits, particularly of apple, in the region. It will be pertinent to determine the extent of climate change in the region and its impact on productivity of apple trees.

The temperate fruit production lies mostly within latitudes 30^0 and 50^0 north and south latitudes , respectively the world over. However, its cultivation is further extended into higher latitudes with the moderating influence of nearby large water bodies and into the lower latitudes by the cooling influences of higher elevations. In India, the temperate fruits including apple are grown, in the areas near to the lower limits of the temperate zone due to the cooling,

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influence of Himalayas. Apple is the predominant temperate fruit crop of India and. it accounts for about three percent of the total fruit production of the country. India stands Fifth in apple production in the world; however, in terms of productivity it stands at fifty second position.

The rapid expansion in area in the last five decades of post-independence era has not kept pace with the productivity of apple due to various factors and it is much lower than the average yields obtained in advanced countries, *viz. France* (42.8 t/ha), Italy (38.1 t/ha) and Brazil (33.1 t/ha). The average productivity of major apple growing states of India, viz: J&K, Himachal Pradesh and Uttrakhand is 10.2, 6.5 and 2.0 t/ha, respectively. In Himachal Pradesh, apple is, grown commercially from 1,524 to 2,472 m above mean sea level (amsl) and has played, an important role in boosting the economic status of the farmers. It accounts for about 85 percent of the total fruit production of the state. In spite of increased production, there is a big gap between the area under apple and its productivity. Moreover, in last three decades there has been a gradual decline in apple productivity from 10.84 t/ha in 1981-82 to 6.35 t/ha in 2003-04 and in 2012-13, it was, 6.15 t/ha.

MATERIAL AND METHODS

Mostly apple cultivars in congenial conditions (location A) require 1000 or more chilling hours before flowering, however some require around 250 chilling hours. To meet the bulk requirements of processing units and its diversification, low chill apple cultivation can be extended to mid hills (location B) by planting suitable cultivars.

Standard Delicious apple trees were grown at two locations, an ideal site (1980 m amsl) and the marginal site (1375m amsl), designated as location A and B respectively. Weather data were collected from the two locations which were at variance from each other with respect to their altitudes. Data were also collected from the agro-meteorological section of the Central Potato Research Institute, Shimla.

The temperature and full bloom data was recorded for both the sites (Jindal and Mankotia, 2004; Mankotia *et al*., 2004). Two techniques were used to compare the chilling requirement of Starking Delicious apple- i) accumulation of chilling hours below 7.2^{o}C ii) determination of effective chill units to break the rest period by adopting Utah Model (Richardson *et al*., 1974; Ashcroft *et al*., 1977; Kishore *et al*., 2013). Effective chill unit accumulations (based on Utah Model), winter precipitations and summer precipitation were measured and chill unit was obtained as described by Linsley-Noakes, *et al*., (1995) and Anonymous (2012) respectively.

The chilling units on a daily basis were ascertained from the hourly temperature data on the basis of the conclusions drawn from the Utah Model (Richardson *et al*., 1974; Linvil, 1990). The number of chill units allotted for a particular maximum-minimum temperature combination in the ready reckoner was based on computed values of hourly temperatures. The hourly temperatures were computed on the basis of modal times of maximum and minimum temperatures during the 24-hour period of winter months over the five year period of the study.

RESULTS AND DISCUSSION

The average apple productivity of Himachal Pradesh was 6.94 t/ha (Period I) which increased to 7.19 t/ha (Period II) then declined to 4.17 t/ha (Period III)and again increased to 6.5 t/ha (Period-IV) , whereas the average productivity of other temperate fruits (plum, peach and pear accounts for about 86 percent of total production) was maximum at 1.24 t/ha (Period I), declined to 1.02 t/ha (Period II) and then slightly increased to 1.10 t/ha during Period III and 1.25 t/ha in period IV (Table1). This revealed that the apple productivity increased from Period I to Period II by 3.6 percent, but declined drastically by 42 percent in Period III in comparison to Period II and again increased by 64 percent. There were no significant difference in the productivity of other temperate fruits during the course of four periods.

Table 1
Changes in the average productivity of apple and Other Temperate Fruits (O.T.F.) in Himachal Pradesh

	Productivity (t/ha)	
Period	*Apple*	*O.T.F.*
Period-I	6.94	1.24
Period-II	7.19	1.02
Period-III	4.17	1.10
Period-IV	6.50	1.25

Changes in average winter conditions under both locations indicated a gradual decline in ECU accumulations during the course of periods under investigation (Table 2). In Location A, the average ECU accumulations were 2,949 chill units (Period I) declined to 2,529 chill units (Period II) and finally reduced to 1,841 chill units (Period III) and 1519 in period IV. Under Location B, the ECU-accumulations were 1576 chill units(Period I) then 1229 chill units

(Period II) and decline to 870 chill units (Period III) and 800 chill units in Period-IV. This revealed that the decline in apple productivity (4.17 t/ha) in the Period it might be due to lack of sufficient chill units accumulation to break rest period of dormant buds under lower elevations of apple growing region of the state. Mankotia (1987) reported that the chill unit requirement of Starking Delicious apple was 1,208 chill units under Mashobra and 1130 chill units under Solan conditions (1,375 m amsl) based on Utah Chill Unit Model. Similarly, Ashcroft *et al*., (1977) reported that the Delicious apples required 1,234 chill units to complete rest under Utah conditions. Skinner (1964) observed that the warm winters resulted in shortage of spurs capable of forming flower buds, delayed and protracted flowering season with poor fruit development and irregular ripening.

Data presented in Table 2 further indicate that there was decline in snowfall and total precipitations from Period I to Period III and slight increase in Period-IV at location A, whereas rainfall increased between Period I and Period II, then declined in Period III and slight increase in Period-IV. Under Location B, there was decline in all three parameters from Period-II to Period III and slight increase in Period-IV. This revealed that the declining trends of rainfall and snow during Period III in both the locations might· have adversely affected the flowering and ultimately productivity, especially under lower elevations of apple growing region of the state, as reported earlier.

Table 2
Changes in average winter conditions at two locations under different periods

Period	*ECU*	*Rain (mm)*	*Snow (cm)*	*Total precipitation (mm)*
Location A				
Period-I	2949	197.10	165.10	1,848.4
Period-II	2529	228.4	130.6	1,534.4
Period-III	1841	148.40	82.80	976.40
Period-IV	1519	195.60	91.10	1010.5
Location B				
Period-I	1576	307.01	50.51	905.15
Period-II	1229	259.90	35.50	614.90
Period-III	0870	102.10	27.30	375.10
Period-IV	0800	131.30	30.35	425.25

Based on productivity, Thirty production years (1980-81 to 2010-2011) were classified into three groups based on the apple productivity of Himachal Pradesh. In good crop years (average productivity 8.25 t/ha), under Location A, the ECU accumulations up to January and -March were 1,873 and 2,785 chill units, respectively, whereas the poor crop years (average productivity, 3.52 t/ha) had 1496 and 2180 chill unit accumulation for the respective months. Maximum average rains of 131.3 and 274.5 mm, and maximum average snowfalls of 91.1 and 124.8 cm were recorded up to January and March in good crop years. It declined to 55.7 and 101.9 cm in poor crop years. Similar trends were observed in respect of total precipitations by Byrne, 1992.

Under the controlled conditions study on the effect of different chilling units on bud break, the maximum days taken for bud break of potted apple plants were under 300 chill units (CU) treatment and minimum under 1500 CU treatment. It was observed that with the increase in chill units, there was reduction in number of days required for bud break (Table 3).

Table 3
Effect of chilling units (CU) on bud break of apple in artificial conditions

Chill units	*Days for bud break*	*Average buds sprouted*
300	50	1.0
500	48	1.2
750	30	2.2
1000	18	2.4
1250	16	3.2
1500	13	4.2
Mean ± SE (M)	**25.2 ± 6.34**	**2.64 ± 0.50**

Earlier, Felker and Robitaille (1985) observed that the forcing time for bud break in sour cherry decreased steadily as chilling hours increased. The number of buds sprouted after the plants were subjected to growing conditions indicated that with the increase in chilling units there was an increase in number of sprouted buds. Young and Werner (1985) also observed similar results in apple.

The data on chilling clearly shows that as the chill units (CU) increased from 300 to 1500 at site A, the number of days taken for bud break decreased from 53 to 14 and average number of buds that sprouted rose from 1.3 to 4.3 where as in site B, which is a marginal site also showed variation as regards chill units accumulated (or low chill cultivars) and days for bud break and average number of buds sprouted (Table 4). When about 750 CU were accumulated cultivars took about 23 days for bud break and 4.5 buds sprouted on an average. The two locations showed distinct variation and clear cut indication of climate on chill unit accumulation.

Table 4
Effect of chilling unit (CU) on bud break of apple at two different locations

Site A			Site B		
CU	*Days for bud break*	*Avg. no. of buds sprouts*	*CU*	*Days for bud break*	*Avg. no. of buds sprouts*
300	53	1.3	300	45	1.8
500	47	2.2	400	39	2.7
750	34	2.7	500	30	3.8
1000	22	3.5	750	23	4.5
1250	16	4.7			
1500	14	4.3			
Mean±SE(M)	31.0±3.25	3.1±0.79		34.2±2.80	3.2±0.51

In an earlier study some *Malus* species and apple rootstocks were categorized into eight groups, according to their chilling requirement (Kishore and Randhawa,1984). This was based on dates of *in-vitro* bud burst studies. This categorization was revisited and actual chill unit accumulation for each of these accessions was obtained from the hourly temperature data available from the Central Potato Research Institute, Shimla, India. On the basis of the chill units accumulated till the date of *in-vitro* bud burst the categorization of these accessions has been narrowed down to five groups.

Perusal of the total chill units received in Shimla, H.P, India during the last five years of the study show that in none of the years the accumulation was less than 1000 chill units. This is well within the range for cultivation of apples. However, the year to year fluctuations are a matter of concern and a further long term study should be continued to fully understand the impact of global warming on chilling units' accumulation at Shimla, Himachal Pradesh.

The results showed that mean temperatures (Table-5) during dormant period at location A, winters were relatively long as compared to those at location B (Table-6), i.e. the mean temperatures of October, November, February, March and April were much higher as compared to location A. The average number of hours below 7.2°C under location A ranged from 1173.5 to 1892.5, whereas it varied from 960 to 1030 at location B (Table 5 and 6). Under the location B enough chill units were accumulated for low chill cultivars to flower and fruit, but cultivar Red Delicious at same location with higher chilling units requirement did not perform satisfactory as required chill units conditions were not met with as reported in case of cherry (Kuden & Kuden, 2004).

Bud dormancy is a characteristic feature of temperate fruit trees that has helped them to escape cold injury to vegetative and floral organs (Peereboom Soller, 1986). These crops require some critical amount of winter chilling to break the dormant stage (Saure, 1985). Early dormancy is the period when it becomes increasing difficult to force the buds to grow when transferred to optimum growth temperatures – until finally it becomes impossible to force growth.

Table 5
Chill units based on daily maximum and minimum temperature (°C) difference for high chill congenial conditions at Location A

Month	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*
August	0	0	0	0	0	0
September	0	0	0	0	0	0
October	32.5	1.5	13.0	9.0	6.0	11.0
November	219.0	124.0	64.5	112.5	68.5	65.0
December	464.5	449.0	226.5	496.0	369.0	425.5
January	430.5	525.0	403.5	459.0	526.0	476.0
February	446.5	431.5	325.5	438.0	400.0	365.5
March	299.5	28.0	96.5	14.0	169.0	89.5
April	0	0	44.0	0	100.0	33.5
Total chill units	1892.5	1559	1173.5	1519.5	1638.5	1436

Table 6
Monthly average maximum and minimum temperature (°C) at Location B

	2006-07		*2007-08*		*2008-09*		*2009-10*		*2010-11*		*2011-12*	
Month	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*
Jan	17.2	2.3	21.0	1.5	19.8	1.8	17.9	2.6	18.0	2.7	18.8	2.2
Feb	20.0	3.0	30.6	3.7	19.9	5.0	22.4	4.8	17.9	4.7	22.2	4.3
Nov	25.2	5.0	22.2	6.1	24.4	4.9	23.8	5.9	24.6	5.0	24.1	5.3
Dec	24.0	1.9	19.2	1.2	19.9	3.5	22.5	4.1	21.8	1.4	21.5	2.4
Total chill units	960		986		1026		1006		1030		999	

Table 7
Annual variations in chilling, productivity of apple and mean winter temperatures at Shimla (1980 m Above Mean Sea Level), India

Year	*RR*	*DM*	*Productivity (tones/ha)*	*Mean Annual Winter Temperatures (°C)*
1983-84	1590	82	6.5	11.1
2006-07	1656	82	7.0	11.6
2007-08	1314	67	10.4	12.0
2008-09	1181	51	7.6	13.7
2009-10	1553	70	6.7	12.4
2010-11	1638	78	9.9	12.3

Nb: RR: Ready Reckoner, DM: Dynamic Model.

Comparison of the ready reckoner and the dynamic model along with productivity of apple is presented in Table 7. During the period under study minimum accumulation in chilling was recorded in the year 2008-09 while productivity of apple trees during the period was the lowest in the year 1983-84. Lack of chilling during the period of the study is not an issue, as chilling units recorded were well above 1000 units, while the adequate range for apple varies between 800 – 1000 units (Erez, 2000). The productivity of apple in the region was also not adversely affected in any of the years under study. This was in spite of the fact that a sharp fall in chilling portion accumulation was observed in 2008-09 though productivity was the highest in that year. The optimum values for the chilling portion of the Dynamic Model for different apple cultivars have not been determined as yet. However, cultivars like Golden Delicious and cultivars of the Delicious group that are grown extensively in Shimla region have been characterized as high chill requiring cultivars. The corresponding chilling portion requirement of these cultivars should ideally be in the range of 60 to 80 units. It is however, worth noting that there has been a steady rise in mean winter temperatures from 11.1°C in 1983-84 to13.7°C in 2008-09. The variation in chilling appears to be closely related to the mean winter temperature.

Three types of ready reckoners have been developed for estimating chilling units received at any particular location. One is in tabular format which estimates daily positive chill units (PSU) on the basis of maximum and minimum temperatures (Linsley-Noakes *et al.*, 1995); the second is in a graph format from which total chill units perceived in a region are estimated on the basis of average temperature during the coldest month(s) (Byrne and Bacon, 1992). Both

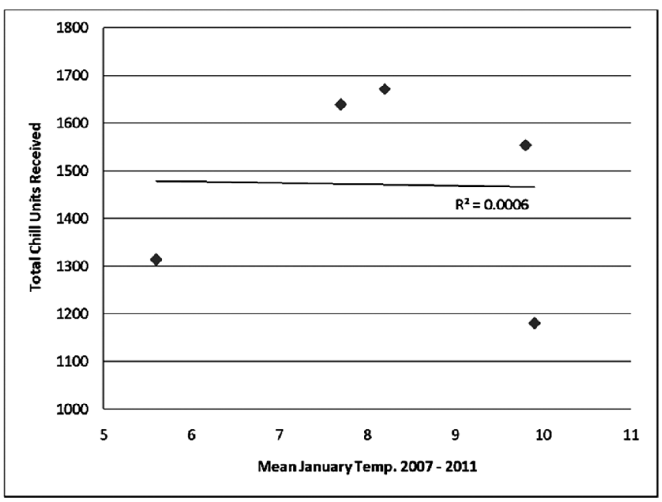

Figure 1: Correlation between Mean Temperatures of the coldest month (January) and Total Chill units received at Shimla (1980 m Above Mean Sea Level), India

these chill unit estimation models do not conform to the temperature range encountered in the apple growing regions of Shimla. The annual variation of mean temperatures during the coldest month i.e. January in Shimla condition is also very weakly correlated with the total chill units received at Shimla (R^2 = 0.0006, Fig. 1). Moreover though it is widely acknowledged that during the initial stages of dormancy negative chilling can accrue, yet no provision for this has been made in these two models.

Apple production in India and subsequent growth rate is depicted in Table 8 for knowing the fluctuating climate particularly chill unit accumulation.

Table 8
Fresh Apples Production in India by Year and subsequent Growth Rate

Market Year	*Production*	*Unit of Measure*	*Growth Rate*
2001	1160000	(MT)	NA
2002	1470000	(MT)	26.72%
2003	1521600	(MT)	3.51%
2004	1739000	(MT)	14.29%
2005	1814000	(MT)	4.31%
2006	1624000	(MT)	-10.47%
2007	2001000	(MT)	23.21%
2008	1985000	(MT)	-0.80%
2009	1777200	(MT)	-10.47%
2010	2891000	(MT)	62.67%
2011	2203400	(MT)	-23.78%
2012	2200000	(MT)	-0.15%
2013	2200000	(MT)	0.00%

Source: United States Department of Agriculture.

CONCLUSIONS

It is concluded that the quantum of chill unit accumulation is location specific and cannot be accurately estimated by any generalized estimation model. Perusal of the total chill units received in Shimla during the last five years of the study show that in none of the years the accumulation was less than 1000 chill units. This is well within the range for cultivation of apples. However, the year to year fluctuations are a matter of concern and a further long term study should be continued to fully understand the impact of global warming at Shimla particularly damaged by hail storm which is an alarming situation.

It is also suggested to go for horticultural diversification with different crops and varieties to fulfil the chilling requirement and to avoid hail damage during flowering and fruit setting stages in some of the crops and varieties.

It is clearly reflected that standard apple cultivar along with pollinizers in site A and Delicious Group in site B would not flower and fruit when chilling units are not adequately fulfilled. Hence there is an urgent need to select appropriate low chill cultivars for plantation at location B so that consistent yields are obtained and crop failures avoided. To meet the bulk requirements of the processing units and horticultural diversification, apple cultivation can be extended to mid hills by planting suitable low chilling cultivars. The effect of various chilling units (300 to 1500 CU) on bud break in young potted-apple plants was studied under- controlled conditions. It was observed that with the increase in the chilling exposure, the bud break was advanced and improved.

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