



Thermal indices and heat use efficiency of apricot cultivars in Himachal Himalayas

Mohan Singh¹, Suman Jangra²

1.Department of Environment Science, Dr. Y S Parmar University of Horticulture & Forestry, Nauni-Solan- 173 230 (HP), India

2.Department of Environment Science, Dr. Y S Parmar University of Horticulture & Forestry, Nauni-Solan- 173 230 (HP), India, Email: jangra_ms@live.com

Article History

Received: 25 January 2018

Accepted: 3 March 2018

Published: April-June 2018

Citation

Mohan Singh, Suman Jangra. Thermal indices and heat use efficiency of apricot cultivars in Himachal Himalayas. *Climate Change*, 2018, 4(14), 224-234

Publication License



© The Author(s) 2018. Open Access. This article is licensed under a [Creative Commons Attribution License 4.0 \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/).

General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate.*

ABSTRACT

Field experiment was conducted during 2015-2017 in the research farm of Dr. YS Parmar University of Horticulture & Forestry located at Horticultural Research Station, Seobag (32°N, 77°E and 1350 m amsl) in Kullu valley of Himachal Pradesh to assess the chilling and thermal time requirements for different phenophases of three apricot cultivars. Average chilling hours accumulated before bud break of apricot varieties was 696 CH for Angelo Errani with 18.2 per cent of coefficient of variation, 721 CH for Harcot with 8.1 per cent and 709 CH for Canino Tardivo with 6.1 per cent, respectively. On an average from bud burst to maturity Angelo Errani required 1191.9 GDD with 7.99 percent of CV, Harcot 1424.8 GDD with 8.87 percent CV and Canino Tardivo required 1712.4 GDD with 1.95 percent. The photothermal index for whole growing period from was highest (13.6) for Harcot in 2015 and lowest (12.0) for Angelo Errani. The mean thermal use efficiencies were observed highest for Harcot followed by Angelo Errani and Canino Tardivo with higher variability in Canino Tardivo followed by Angelo Errani and lowest in Harcot. Thermal indices explained more than 98 percent variation in fruit yield of Harcot, Angelo Errani and 95 per cent variation in Canino Tardivo. Harcot and Angelo Errani were observed precocious and fruiting was recorded in the fifth year after plantation. They were showing better utilization of heat

units and hence, suitable for diversification in apricot cultivation under changing and prevailing climatic conditions of mid hills region of Himachal Himalayas.

Key words: Chilling ours, Growing degree days, Apricot cultivars, Kullu valley

1. INTRODUCTION

In recent years, much research has been devoted to estimating the implications of climate change for agricultural production (Lobell *et al.*, 2007; Walker and Schulze, 2008), with most research scenarios including a doubling of the atmospheric carbon dioxide concentration (Kim *et al.*, 2007; Marhan *et al.*, 2008) and reflecting the most likely future climate estimates proposed by the Intergovernmental Panel on Climate Change (IPCC, 2007) and other climate modelling efforts. While the challenges in producing sufficient amounts of field crops in the future will be enormous (Lobell *et al.*, 2011) but tree crops, in contrast, is much more difficult, because of the long term investments involved in such enterprises. Moreover, the pattern of climatic dependency of perennial crops is much more complex than that of most annuals. One of the major determinants of good yields in many temperate fruit trees is the availability of winter chill and thermal time for different phenophases (Chmielewski *et al.*, 2011). Thermal time effect has been described as the independent variable to delineate plant growth and development (Dwyer and Steward, 1986). Temperature based agrometeorological indices like GDD, HTU, PTU and HYTU are based on the concept that real time to attain the phenological stages is linearly related to temperature in the range between base temperature and the optimum temperature (Monteith, 1981). This concept is widely used for assessing growth, phenological development and yield of different crops (Rajput *et al.*, 1987; Shanker *et al.*, 1996; Swan *et al.*, 1989). Such work has been done in many field crops elsewhere (Rao *et al.*, 1999) but has rarely hitherto been reported from mid hills of Himachal Himalayas especially on fruit crops.

1.2. Apricot

Apricot (*Prunus armeniaca* var. *nucipersica*) is an important fruit crop of midhills and dry temperate regions of India. Cultivated apricot has its origin in North-Eastern China, whereas wild apricot, popularly known as zardalu, appears to be indigenous to India. Apricot is grown commercially in the hills of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh and to a limited extent in north eastern hills. Apricots are a versatile fruit that can be dried, made into fruit leather, frozen, canned/bottled, made into jam/jelly, or eaten fresh. Hence, the present investigation was carried out to assess the response of phenology and fruit yield of three apricot cultivars (Angelo Errani, Harcot and Canino Tardivo) in mid hills of Himachal Himalayas.

1.2.1. Angelo Errani: It is an early-maturing cultivar of apricot which come in last week of May. It has yellowish attractive blush with bitter kernels. It produces good yield, mature early and hence, come early in the market which fetch good price to the growers.

1.2.2. Harcot: It is medium to large fruit, firm, sweet, and juicy. Early harvest compared to Canino Tardivo but later than Angelo Errani with an attractive red blush. It has good fruit quality for roadsides markets and direct fruit sales, but unsuitable for shipping or processing. Harcot has a sweet kernel, but this characteristic has been inconsistent at Vineland.

1.2.3. Canino Tardivo: It is a late-maturing cultivar and ripens almost in the first week of July. It is poor in taste, colour, quality and yield. Due to late maturing it fetch poor price to the growers.

1.2.4. Agroecology: In its native range, apricot is found in sparse forests on mountain slopes, slopes, gullies from 700-3000 m altitude. Apricot is a cool temperate climate species although it can grow in a Mediterranean climate. It is winter hardy enough to survive to temperatures down to -30°C, they prefer stable winter temperature and are sensitive to winter temperature fluctuations. Apricot requires chilling requirements to break winter dormancy of 600-1270 chilling units and a heat requirement for flowering of 4078-5879 growing degree hours (Ruiz *et al.*, 2007). Prevailing weather conditions during the whole crop growing season (Fig 1) have direct bearing upon the phenological events of the crop which ultimately affect the crop yield.

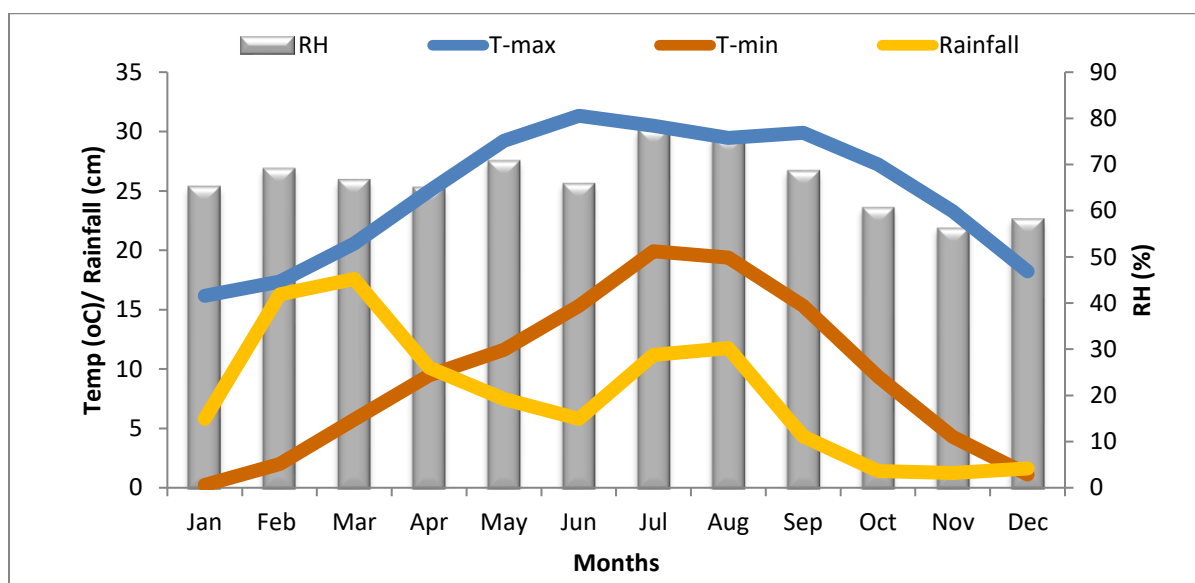


Figure 1 Weather during the crop growth period (average of three years)



Dormant



Pink Bud



White bud



Full bloom



Petal fall



Maturity

Plate 1 Important phenophases recorded in apricot in Kullu valley

2. MATERIAL AND METHODS

Field experiment was conducted during 2015-2017 in the research farm of the Dr. YS Parmar University of Horticulture & Forestry located at Horticultural Research Station, Seobag (32°N, 77°E and 1350 m amsl) at Kullu valley of Himachal Pradesh to assess the

chilling and thermal time requirements for different phenophases of three apricot cultivars. These Italian apricot varieties were planted in spring 1985-86 with a spacing of 6m x 6m (275 trees per ha). Initiation and duration of five important phenophases (Plate 1) from dormancy to maturity like bud break (BB), pink bud (PB), white bud (WB), full bloom (FB), petal fall (PF) and physiological maturity (PM) were recorded at two days' interval from five randomly selected branches of the marked trees with three replications. The meteorological data was collected from the Agromet Observatory situated in the research farm.

2.1. Chilling hours: The Chilling Hours Model is the oldest method to quantify winter chill that is still widely used. It considers all hours with temperatures between 0 and 7.2°C as equally effective for winter chill accumulation. All models developed for chilling hour's computation requires hourly temperature data which are rarely available. In the present study the Linvill (1990) model was used who proposed a method for simulating hourly observations for day and night from daily maximum and minimum temperature. The temperature wave from sunrise to sunset can be described as:

$$T(t) = T_{\max} - T_{\min} \times \sin [(\pi \times t) / (DL + 4)]$$

Where, $T(t)$ = Temperature at time t after sun-rise

$T_{\max}$ = Maximum temperature

$T_{\min}$ = Minimum temperature

DL = Day length (h).

Assuming that minimum temperature occurs at sunrise, the night time cooling temperature wave from sunset to sunrise can be described as:

$$T(t) = T_s - [(T_s - T_{\min}) / (24 \ln - DL)] \times \ln(t)$$

Where, $T(t)$ = Temperature at time $t > 1$ hr after sunset

T_s = The sunset temperature obtained from day time temperature wave.

The chilling hour model is simple and widely used, chilling hours are calculated using this model in this study as:

Chilling hours = $\sum -2^\circ \text{C} < CH < 7^\circ \text{C}$ Where, CH is a chilling hour

2.2. Agrometeorological indices: Different agrometeorological indices and heat use efficiencies were calculated on daily basis and accumulated from bud burst to maturity/harvesting taking 4°C as base temperature (Singh and Bhatia, 2011).

1. Growing degree days (GDD) = $(T_{\max} + T_{\min}) / 2 - 4^\circ \text{C}$
2. Photothermal unit (PTU) = GDD * Day Length
3. Heliothermal unit (HTU) = GDD * Sunshine Hours
4. Hydrothermal unit (HYTU) = GDD * RH

2.3. Energy use efficiency: The energy use efficiencies were computed ((kg ha⁻¹ per degree) to compare the relative performance of different cultivars with respect to utilization of heat unit using the following formulae:

1. Heat use efficiency (HUE) = Fruit yield (kg ha⁻¹) / GDD °C day.
2. Photothermal use efficiency (PTUE) = Fruit yield (kg ha⁻¹) / PTU °C hour.
3. Heliothermal use efficiency (HTUE) = Fruit yield (kg ha⁻¹) / HTU °C hour.
4. Hydrothermal use efficiency (HYTUE) = Fruit yield (kg ha⁻¹) / HYTU °C day %

2.4. Photothermal Index: Phenothermal index (PTI) for each phenophases was calculated as per following formula (Sastry and Chakravarty, 1982).

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

Predictive regression relation model was also worked out between thermal indices and yield. of different root stocks. The plant height, plant girth, annual extension growth, per cent fruit set and physical parameters like fruit weight, fruit length & breadth were also observed for evaluation of performance.

3. RESULTS AND DISCUSSION

3.1. Descriptive statistics of chilling hours

In Kullu valley the chilling hour (CH) started accumulating from November and continued up to March. The nineteen years (1999-2017) average of CH was highest during January (306 CH) followed by December (232 CH) and the lowest was received during March (62 CR) followed by November (Table 1). The accumulation of CH was most variable during March (78.1 %CV) followed by February (41.5 %CV) and lowest during December (20.1 %CV) followed by January (21.1 %CV). A decreasing trend in CH was observed in all the months except November in which half an hour of CH was increasing per years. Among the months the decreasing rate in CH was observed highest (2.1 CH/year) during March. The annual value of chilling hours at Seobag was 908 CH with 21 per cent of coefficient of variation and showing a decreasing rate of 4 CH per year (Fig 2). The decreasing trend in chilling hour could be ascribed for the shifting in temperate fruit belt towards higher altitudes (Chmielewski *et al.*, 2011) in want of chilling hours' requirement (Darbyshire *et al.*, 2011) and apple cultivation expanded in the cold desert in recent decades (Conceicao *et al.*, 2011). Similar trend was also observed by Rana *et al.* (2008) for Himachal Pradesh.

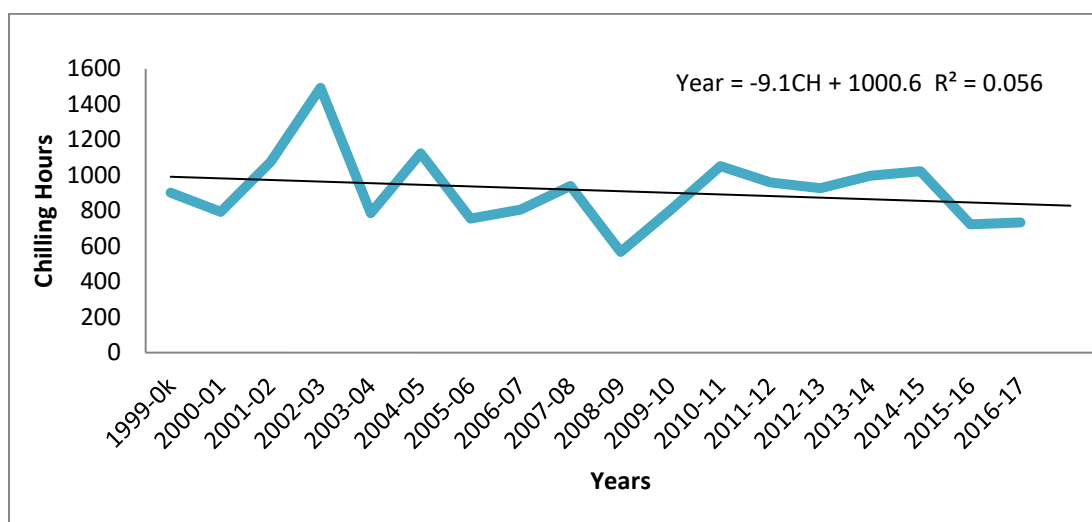


Figure 2 Trend in chilling hours in Kullu valley

The three years' average chilling hours accumulated before bud break of apricot varieties was 696 CH for Angelo Errani with 18.2 per cent of coefficient of variation, 721 CH for Harcot with 8.1 per cent of coefficient of variation and 709 CH for Canino Tardivo with 6.1 per cent of coefficient of variation, respectively. Similar results were obtained in different cultivars of apricot by Ruiz *et al.* (2007), Viti *et al.* (2010) and Campoy *et al.* (2012) in Spain. Based on three years data all the three varieties were showing a decreasing trend in CH with highest rate for Angelo Errani (117 CH/year) at the study area. For three year's data the mean value of CH for three cultivars was 709 CH with 10.6 percent CV and a decreasing rate of 73 CH per year (Table 1). Different chilling requirements are required for apricot cultivars to overcome dormancy.

Table 1 Statistical measures of chilling hours in Kullu valley

Months	Value	SD	CV (%)	Intercept	Trend per year	R ²
Month wise						
November	121.7	27.9	23.0	115.9	0.59	0.013
December	232.3	48.4	20.8	243.4	-1.06	0.014
January	306.5	66.7	21.8	312.6	-0.55	0.002

February	181.2	75.3	41.5	198.9	-1.61	0.015
March	62.2	48.6	78.1	84.2	-2.11	0.056
Annual	907.5	188.8	20.8	946.7	-4.13	0.013
Variety wise						
Angelo Errani	696.0	126.8	18.2	931.0	-117.5	0.859
Harcot	721.3	58.8	8.1	838.3	-58.5	-0.991
Canino Tardivo	708.7	43.2	6.1	794.9	-43.0	0.989
Mean	708.7	74.8	10.6	854.7	-73.0	0.953

3.2. Descriptive statistics of thermal indices

Among the three varieties of apricot the bud burst started first in Angelo Errani cultivar which took place in second week of February followed by Canino Tardivo and Harcot in the first week of March during 2015, 2016 and 2017, respectively. Days taken (DT) to complete growth stages from dormant to petal fall (fruit set) via bud burst and white bud were found highest (35 DT) in Angelo Errani followed by Harcot and Canino Tardivo both were at par (28 DT). But, highest numbers of days were taken by Canino Tardivo followed by Harcot to attain the maturity after fruit setting and lowest in case of Angelo Errani which showed it is an early maturing variety. Similar trend was observed in agrometeorological indices like GDD, HTU, PTU, and HYTU etc. (Table 2).

Total numbers of GDD for Angelo Errani cultivar from completion of dormancy to bud burst, pink bud, white bud, full bloom, fruit set and physiological maturity were 53, 40, 66, 64 and 969 with coefficient of variation of 15.5, 33.2, 18.8, 37.2, 6.2 per cent, respectively. For Harcot 41, 40, 67, 106 and 1170 GDD with a coefficient of variation of 17.0, 14.2, 30.0, 14.2 and 8.7 per cent, respectively were taken. Similarly for Canino Tardivo they were 37, 39, 54, 108 and 1476 with a coefficient of variation of 3.2, 12.7, 29.1, 19.1 and 1.3 per cent, respectively. Similar trend was observed in HTU, PTU and HYTU indices for all the three cultivars of apricot (Table 2).

Table 2 Agrometeorological indices and days taken to attain different phenophases in three apricot cultivars

Growth Stages	GDD		HTU		PTU		HYTU		DT	
	Value	CV (%)	Value	CV (%)	Value	CV (%)	Value	CV (%)	Value	CV (%)
Angelo Errani										
BB-PB	52.9	15.5	263.0	30.9	585.8	14.9	3528.5	10.2	7.7	7.5
PB-WB	40.4	33.2	135.3	17.4	457.1	33.3	2760.4	34.2	6.0	16.7
WB-FB	65.8	15.8	154.7	9.6	761.6	15.3	4814.7	16.0	10.0	10.0
FB-PF	64.3	37.2	180.3	74.9	765.2	37.8	4274.0	37.0	7.3	20.8
PF-PM	968.5	6.2	6175.9	10.4	12756.6	7.0	69038.3	8.6	68.3	3.0
Harcot										
BB-PB	40.7	17.0	128.9	28.6	476.7	17.4	2879.5	13.0	7.7	7.5
PB-WB	40.4	14.2	77.5	48.9	478.5	14.6	2683.7	20.4	6.7	12.9
WB-FB	67.1	30.0	295.9	34.2	806.5	29.9	4460.6	27.6	11.3	13.5
FB-PF	106.1	14.2	817.5	16.0	1299.4	14.6	5863.8	13.8	9.3	34.4
PF-PM	1170.6	8.7	7396.0	9.3	15810.0	9.5	85845.7	8.4	77.3	7.1
Canino Tardivo										
BB-PB	36.6	3.2	89.8	21.8	425.9	3.4	2735.5	2.5	8.3	6.9
PB-WB	38.7	12.7	119.0	11.1	456.8	12.5	2522.2	16.6	7.3	20.8
WB-FB	53.7	29.1	138.1	89.4	642.6	29.5	3753.3	24.5	13.7	11.2
FB-PF	107.6	19.1	783.5	26.4	1312.7	19.7	6127.7	13.6	11.2	24.1
PF-PM	1475.7	1.3	9414.5	1.6	20166.1	1.3	107210.4	1.4	93.7	1.6

Table 3 Accumulated GDD, DT and growth rate for different phenophases of apricot cultivars in Kullu valley

Growth Stages	Angelo Errani			Harcot			Canino Tardivo		
	CGDD	CDT	Rate	CGDD	CDT	Rate	CGDD	CDT	Rate
2015									
PB	44.0	8.0	0.125	46.5	8.0	0.125	37.9	8.0	0.125
WB	91.4	14.0	0.167	93.5	13.0	0.200	71.5	15.0	0.143
FB	145.6	22.0	0.125	153.0	22.0	0.111	121.9	26.0	0.091
PF	199.3	29.0	0.143	267.7	30.0	0.125	233.6	36.0	0.100
PM	1175.5	98.0	0.014	1541.8	113.0	0.012	1731.0	131.0	0.010
2016									
PB	54.7	7.0	0.167	42.7	8.0	0.125	36.5	8.0	0.125
WB	79.6	12.0	0.200	79.7	15.0	0.143	79.9	14.0	0.167
FB	153.8	19.0	0.143	131.6	23.0	0.125	119.9	23.0	0.111
PF	201.2	25.0	0.167	220.3	30.0	0.143	205.3	32.0	0.111
PM	1105.9	91.0	0.015	1290.8	102.0	0.014	1673.8	126.0	0.011
2017									
PB	60.0	9.0	0.125	33.1	7.0	0.143	35.6	9.0	0.111
WB	108.9	16.0	0.143	70.2	15.0	0.125	74.7	18.0	0.111
FB	177.9	25.0	0.111	160.1	25.0	0.100	145.4	28.0	0.100
PF	269.6	33.0	0.125	274.8	34.0	0.111	271.2	39.0	0.091
PM	1294.2	103.0	0.014	1441.9	111.0	0.013	1732.5	131.0	0.011
Annual									
PB	52.9	8.0	0.139	40.7	7.7	0.131	36.6	8.3	0.120
WB	93.3	14.0	0.170	81.1	14.3	0.156	75.4	15.7	0.140
FB	159.1	22.0	0.126	148.2	23.3	0.112	129.1	25.7	0.101
PF	223.4	29.0	0.145	254.3	31.3	0.126	236.7	35.7	0.101
PM	1191.9	97.3	0.015	1424.8	108.7	0.013	1712.4	129.3	0.011
CV (%)	7.99	6.19	3.09	8.87	5.39	7.09	1.95	2.23	2.13

To attain the white bud phenophases after bud break Angelo Errani required higher numbers of CGDD in all the three years except Harcot in 2015 but, up to petal fall higher number of CGDD were recorded in case of Harcot followed by Canino Tardivo during all the three years (Table 3). Similar results were observed by Singh and Bhatia (2011) in apple. On an average from bud burst to maturity Angelo Errani required 1191.9 GDD with 7.99 percent of CV, Harcot 1424.8 GDD with 8.87 percent and Canino Tardivo required 1712.4 GDD with 1.95 percent. Similar trend was observed in CDT to attain these phenophases (Table 3). Growth rate was observed highest from pink bud to white bud stage in all the varieties during all the years which indicated less numbers of days required to attain this stage. Low growth rate was observed from petal fall to physiological maturity i.e. it required longer period to attain the maturity in all the three cultivars during three years.

The growth period of all the cultivars was almost one week shorter during 2016 as compared to 2015 and 2017 which might be due to the dry weather conditions in 2016 resulting in higher temperature and early accumulation of thermal units for different phonological stages. Singh and Bhatia (2011) also reported similar works for apple under mid hill region of Himachal Pradesh.

3.3 Phenothermal index (PTI)

The mean value of photothermal index steadily increased from pink bud stage to physiological maturity for all the cultivars which indicated that the coming phenophases required somewhat higher numbers of GDD (Table 4). The photothermal index for whole growing period from bud burst to harvesting was highest (13.6) for Harcot in 2015 and lowest (12.0) for Angelo Errani in the same years. Among the different phenophases PTI was highest from fruit set to maturity and lowest from bud burst to pink bud for all the cultivars but among the cultivars Canino Tardivo observed highest PTI and lowest in Angelo Errani. Higher coefficient of variation

was observed for Angelo Errani and lower in Canino Tardivo. On an average the PTI for Angelo Errani was 6.9, 6.7, 7.8, 9.2 and 14.2 for pink bud, white bud, full bloom, petal fall and physiological maturity, respectively. The corresponding values of PTI for Harcot were 5.3, 6.1, 7.5, 13.3 and 15.1 whereas for Canino Tardivo 4.4, 5.3, 5.4, 10.4 and 15.8, respectively (Table 4).

Table 4 Photothermal index (PTI) during various phenophases of apricot in Kullu Valley

	PB	WB	FB	PF	MT	Total
Angelo Errani						
2015	5.5	7.9	6.8	7.7	14.1	12.0
2016	7.8	5.0	8.9	7.9	13.7	12.2
2017	7.5	7.0	7.7	11.5	14.6	12.6
Mean	6.9	6.7	7.8	9.2	14.2	12.2
CV(%)	2.1	2.0	1.3	2.6	2.0	1.3
Harcot						
2015	5.8	9.4	6.6	14.3	15.4	13.6
2016	5.3	5.3	6.5	12.7	14.9	12.7
2017	4.7	4.6	9.0	12.8	15.2	13.0
Mean	5.3	6.1	7.5	13.3	15.1	13.1
CV(%)	2.3	0.6	2.7	1.1	1.2	1.6
Canino Tardivo						
2015	4.7	4.8	4.6	11.2	15.8	13.2
2016	4.6	7.2	4.4	9.5	15.6	13.3
2017	4.0	4.3	7.1	11.4	15.9	13.2
Mean	4.4	5.3	5.4	10.8	15.8	13.2
CV(%)	0.5	0.6	2.9	1.9	0.8	0.9

3.4. Thermal use efficiency

The efficiency of thermal, heliothermal (HTUE), photothermal (PTUE) and hydrothermal (HYTUE) energy conversion for yield and dry matter depend upon genetic factors of crop and time of breaking of bud, after, the completion of the rest period. Thermal use efficiency was highest for the cultivar which required lower amount of thermal units for producing higher grain and biological yields. The mean HUE, HTUE, PTUE and HYTUE was observed highest for Harcot followed by Angelo Errani and Canino Tardivo cultivar whereas the coefficient of variation was highest for Canino Tardivo followed by Angelo Errani and lowest in Harcot (Table 5). Singh and Bhatia (2011) reported similar works for apple. For Harcot they were 9.463, 1.547, 0.715 and 0.133 kg ha⁻¹/degree day with coefficient of variation of 4.61, 3.79, 3.92 and 5.07 per cent, respectively. Similarly for Angelo Errani 9.03, 1.56, 0.71, 0.13 kg ha⁻¹/degree day with coefficient of variation of 8.9, 10.3, 8.8 & 9.1 per cent and for Canino Tardivo 3.5, 0.57, 0.26, 0.05 with coefficient of variation of 22.1, 20.8, 21.9 and 22.2 per cent, respectively were observed. Among the years the thermal use efficiencies were observed better during 2015 followed by 2017 and 2016 (Table 5).

Table 5 Thermal use efficiencies of apricot cultivars in Kullu Valley

Years	HUE kg ha ⁻¹ / degree day	HTUE kg ha ⁻¹ / degree day	PTUE kg ha ⁻¹ / degree day	HYTUE kg ha ⁻¹ / degree day
Angelo Errani				
2015	9.925	1.714	0.770	0.140
2016	8.791	1.581	0.688	0.127
2017	8.371	1.394	0.648	0.116
Mean	9.029	1.563	0.702	0.128

CV (%)	8.906	10.29	8.843	9.109
	Harcot			
2015	9.909	1.610	0.743	0.139
2016	9.038	1.494	0.688	0.126
2017	9.440	1.538	0.713	0.132
Mean	9.463	1.547	0.715	0.133
CV (%)	4.607	3.791	3.921	5.066
	Canino Tardivo			
2015	4.172	0.671	0.310	0.059
2016	2.655	0.439	0.198	0.037
2017	3.688	0.595	0.274	0.051
Mean	3.505	0.568	0.261	0.049
CV (%)	22.10	20.80	21.89	22.16

3.5. Predictive model

Regression models were developed for fruit yield prediction using thermal units consumed during the active growing period. Strong linear regression relationship was observed between fruit yield (FY) and Heat Units (HU) for all the three cultivars and the pooled data. This prediction model holds good for all the other three thermal units (PTU, HTU and HYTU) as well. The equations for forecast of fruit yield are as under:

- **For Angelo Errani:** $FY = 972.2 \text{ HU} + 8796.3$ ($R^2 = 0.993$)
- **For Harcot:** $FY = 1805.6 \text{ HU} + 9907.4$ ($R^2 = 0.998$)
- **For Canino Tardivo:** $FY = 1388.9 \text{ HU} + 3240.7$ ($R^2 = 0.949$)
- **For pooled data:** $FY = 1388.9 \text{ HU} + 7314.8$ ($R^2 = 0.987$)

Although all the three cultivars and the pooled data showed a good relation at par even then Harcot showed better thermal use efficiencies and relation in comparison with other two cultivars and the pooled model. Thermal indices explained more than 98 percent variation in fruit yield of Harcot, Angelo Errani and the pooled data and 95 per cent variation in Canino Tardivo. Similar works on developing agroclimatic models based on temperature, photoperiod and day length for mustard (Hundal *et al.*, 2003) for wheat (Hundal *et al.*, 1997) have been reported under Punjab conditions and for apple fruit (Singh and Bhatia, 2011) under mid hill region of Himachal Pradesh.

4. DISCUSSION

Climate change has affected winter chill and heat accumulation in recent decades with increasing temperature (Jangra and Singh, 2011; Luedeling *et al.*, 2015). We used the Modified Utah Model (Linvill, 1990) for quantifying chilling Hours. In Kullu valley a decreasing trend in CH was observed in all the months except November in which half an hour of CH was increasing per years. In a global context, warm growing regions might experience severe reductions in winter chill as global temperatures increase. For individual cultivars, chilling requirements can vary among site/year combinations (Viti *et al.*, 2010). Also with a similar methodology, Campoy *et al.* (2012) evaluated chilling requirements of twelve apricot cultivars in Murcia, Spain, based on 4 years of observation. Darbyshire *et al.* (2011) report a declining winter chill trend in response to warming at most sites in Australia and Luedeling *et al.* (2009) detected decreases chilling hours by 1.2– 9.5 h per year between 1983 and 2008. Decreasing winter chilling hours (5–26 h per year) were also found for the Central Valley of California (Baldocchi and Wong, 2008). Luedeling *et al.* (2009) also observed and projected substantial decreases in winter chill for this region with different chilling models and climate change scenarios, and pointed out that production of some fruits might no longer be possible in the future. In temperate zones, winter chill is likely to remain relatively stable, while cold climate might see increasing chill due to lower incidence of freezing temperature events, which the chill model does not consider effective for chill accumulation (Luedeling *et al.*, 2015).

Trends in available heat accumulation have, to our knowledge, not been studied. In our analysis, warming during the chilling period apparently led to an increasing tendency in chill accumulation of apricot over the past 16 years, which was, however, not

statistically significant. The need to anticipate and adapt to climatic changes is much more urgent for growers of fruit crops than for farmers engaging in annual crop production, careful selection of cultivars that are adapted to the particular climate conditions of a production site. Modern breeding techniques, as well as advances in mapping the genetic determinism of chilling are required to speed up the breeding process, so that appropriate cultivars can be developed for all major fruits within a reasonable time frame. Microclimate manipulation can also affect chill and heat accumulation. Campoy *et al.* (2011) indicated that shading during endodormancy can slightly advance bloom dates of apricots in Spain.

5. CONCLUSION

The range of chilling requirements for the greater part of the cultivars studied was between 600 and 800 CH. Angelo Errani showed the lowest chilling requirements around 696 CH. The apricot cultivars showed a range of heat requirements between 968 GDD, in the case of Angelo Errani, and 1475 GDD, for Canino Tardivo. A decreasing trend in chilling hour and an increasing trend in GDD were observed in the study area. Harcot and Angelo Errani were showing better utilization of heat units and hence, suitable for diversification in apricot cultivation Kullu valley in particular and mid hill region of Himachal Himalayas in general under changing and prevailing climatic conditions. Our results do not clarify whether the heat requirements for flowering are an intrinsic characteristic of the cultivar. Temperate orchards are in urgent need of climate change adaptation strategies because of the high investments incurred in orchard development and the long productive life span of trees. For complex agricultural systems, searching for future climates among present-day locations and extracting adaptation lessons from such sites, may be the most promising strategy for ensuring that production remains viable in a climatically changing future.

REFERENCE

- Baldocchi, D., Wong, S., 2008, "Accumulated winter chill is decreasing in the fruit growing regions of California", *Clim. Change*, 87, 153–166.
- Campoy, J.A., Ruiz, D., Egea, J., 2011, "Seasonal progression of bud dormancy in apricot (*Prunus armeniaca* L.) in a Mediterranean climate: a single-node cutting approach", *Plant Biosyst.*, 145, 596–605.
- Campoy, J.A., Ruiz, D., Allderman, L., Cook, N., Egea, J., 2012, "The fulfillment of chilling requirements and the adaptation of apricot (*Prunus armeniaca* L.) in warm winter climates: an approach in Murcia (Spain) and the Western Cape (South Africa)", *Eur. J. Agron.*, 37, 43–55.
- Chmielewski, F.M., Muller, A., Bruns, E., 2004, "Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000" *Agric. Forest Meteorol.*, 121, 1–2, 69–78.
- Chmielewski, F. M., Blümel, K., Henniges, Y., Blanke, M., 2011, "Phenological models for the beginning of apple blossom in Germany", *Meteorol. Z.*, 20, 487–496.
- Conceicao, M. A. F., Nachtigall, G. R., Cargnino, C., Fioravanco, J. C., 2011, "Water requirement and crop coefficients (Kc) for apple trees in Vacaria, Brazil", *Ciencia Rural*, 41, 3, 459–462.
- Darbyshire, R., Webb, L., Goodwin, I., Barlow, S., 2011, "Winter chilling trends for deciduous fruit trees in Australia", *Agric. For. Meteorol.*, 151, 1074–1085.
- 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.
- IPCC, 2007, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
- Jangra, S. and Singh, M., 2011, "Analysis of rainfall and temperatures for climatic trend in Kullu valley", *Mausam*, 62, 1, 77–84.
- Kim, S., Gitz, D., Siche, R., Baker, J., Timlin, D., Reddy, V., 2007, "Temperature dependence of growth, development, and photosynthesis in maize under elevated CO₂", *Environmental and Experimental Botany*, 61, 224–236.
- Linville, D. E., 1990, "Calculating chilling hours and chill units from daily maximum and minimum temperature observations", *Hort. Science*, 25, 14–16.
- Lobell, D. B., Bonfils, C., Duffy, P. B., 2007, "Climate change uncertainty for daily minimum and maximum temperatures: a model inter-comparison", *Geophysical Research Letters* 34: L05715, doi:10.1029/2006GL028726.
- Lobell, D. B., Schlenker, W. S., Costa-Robert, J., 2011, "Climate trends and global crop production since 1980", *Science*, 333, 616–620.
- Luedeling, E., Gebauer, J., Buerkert, A., 2009, "Climate change effects on winter chill for tree crops with chilling requirements on the Arabian Peninsula. *Climatic Change*, 96, 219–237.
- Luedeling E, Blanke M, Gebauer J, 2015, "Chilling Challenges in a Warming World". *Acta Horticulturae*, 1099, 901–907.

19. Marhan S, Derain D, Erbs M, Kuzyakov Y, Fangmeier A, Kandeler E., 2008, "Soil organic matter mineralization and residue decomposition of spring wheat grown under elevated CO₂ atmosphere", *Agric Ecosyst Environ*, 123, 63–68.
20. Monteith J.L., 1981, "Climate variation and growth of crops" *Quart J. Royal Meteorol. Soc.*, 107, 602-607.
21. 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.
22. Rana, R. S., Bhagata, R. M., Vaibhav, K. and Harbans, L., 2008, "Impact of climate change on shift of apple belt in Himachal Pradesh", ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: *Impact of Climate Change on Agriculture*, pp 131-137.
23. Rao, V.U.M., Singh, D. and Singh, R., 1999, "Heat use efficiency of winter crops in Haryana", *J. Agromet.* 1, 143-148.
24. Ruiz, D., Campoy, J.A., Egea, J., 2007, "Chilling and heat requirements of apricot cultivars for flowering" *Environ. Exp. Bot.*, 61, 254–263.
25. Sastry, P.S.N. and Chakravarty, N.V.K., 1982, "Energy summation indices for wheat crop in India" *Agric. Meteorol.*, 27, 45-48.
26. Singh, M. and Bhatia, H.S., 2011, "Thermal time requirement for phenophases of apple genotypes in Kullu valley", *J. Agrometeorology*, 13, 1, 46-49.
27. Shanker, U., Agrawal, K.K. and Gupta, V.K., 1996, Heat unit requirement of rainfed soybean. *Indian J. Agric. Sci.* 66: 401-404.
28. 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.
29. Viti, R., Andreini, L., Ruiz, D., Egea, J., Bartolini, S., Iacona, C., Campoy, J.A., 2010, "Effect of climatic conditions on the overcoming of dormancy in apricot flower buds in two Mediterranean areas: Murcia (Spain) and Tuscany (Italy)", *Sci. Hortic.* 124, 217–224.
30. Walker, N. J. and Schulze, R. E., 2008, Climate change impacts on agro-ecosystem sustainability across three climate regions in the maize belt of South Africa", *Agriculture, Ecosystems and Environment*, 124, 1–2, 114–124.