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Research Article

Energy Summation Indices and Heat Use Efficiency in Mango Cv Dashehari under Subtropical Indian Condition

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ABSTRACT

The study was aimed with the objective of assessing energy summation indices and heat use efficiency in mango under subtropical climatic condition, Lucknow region of Uttar Pradesh, India following a fertigation experiment. Changes in energy summation indices (in terms of growing degree days, heliothermal and photothermal) at different critical phenological stages of mango were inferred. The values were in increasing trend with the onset of phenological stages. Mean value of GDD were recorded as 701.7, 817.1, 1094.2 and 1517.8°Cd at the flowering, fruiting (pea and marble stages) and physiological maturity stages respectively. The corresponding values for HTU ranged between 1462.2 to 14652.7°Cd h and in case of PTU, 2600.2 to 20233.5°Cd h. The heat use efficiency (HUE) using GDD was varied between 3.91 to 5.14 g/m^2/°Cd while in case of HTU and PTU, it was 0.47-0.62 and 0.36 to 0.59 g/m^2/°Cd h, respectively. Significant variations in mango yield were recorded and this might be due to variations in energy summation at different critical phenological stages. Analysis of such kind of information is urgently required owing to develop dynamic crop simulation model for precise prediction of climate change impacts on mango production.

Key words: Energy summation indices, heat use efficiency, mango, yield, subtropical climate

Introduction

Mango, the king of fruit is widely grown in tropical and subtropical climatic condition across globe (Mukherjee, 1972). Its potential yield is much higher than observed under Indian climatic condition. Even, the productivity of the fruit, which is a function of crop-climate-soil interactions, is somewhat lower in Indian states as compared to global average (Rajan, 2012). Any crop needs specific thermal heat accumulation to attain its critical phenological stages. A change in such energy requirement often hastens or delays events of phenological stages which in turn may impacts on production and its heat use efficiency (Maiti *et al*., 1978; Perry *et al*., 1987; Kamkar *et al*., 2012). Nagarajan *et al.* (1994) recorded differential thermal heat accumulation in potato crops at its different phenological stages under Northern Indian Hilly condition. Adak *et al*. (2010) observed changes in energy accumulation over different sowing and seasons at different critical phenological crop events. Delayed sowing in case of annual crop, reduced energy accumulation at different stages. Shift in crop phenological stages were recorded over the years as a result of weather dynamics. Rajan (2012) found that changes in rainfall and temperature influence the mango phenology in a bigger way than initially thought. Under the climate change scenario, shifts in rainfall pattern, quantity, and its frequency along with temperatures across globe have further contributes to the complexity in mango production under

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diverse soil-climate conditions. Mishra *et al.* (2014) observed the adverse impacts of weather dynamics on critical stages of guava, particularly at its flowering and fruit set events in Lucknow region.

Under any agroecosystem, understanding the amount of solar energy received is very important for photosynthesis to take place. Variations in energy received will ultimately influence the photosynthate produce and may imbalance the source-sink relationship. The assessment of energy in terms of extraterrestrial radiations, incoming solar radiation are thus very crucial component to have an idea about the solar energy regimes. This energy regime mostly impacts the hydro-thermal regimes under any agroecological region and at a particular event of crop phenophases. All these energy-matter interactions ultimately have a bearing on the crop, irrespective of orchard management system adopted. Thus, a detailed analysis of such kind of energy regimes and its associated summation indices are essentially required to understand the impacts on productivity and heat use efficiency in mango. Keeping all these in view, the present study was aimed with the objective of quantifying the energy summation indices and heat use efficiency in mango under subtropical climatic condition.

Materials and Methods

A field experiment was laid out during three consecutive years (2013-15) under subtropical climatic condition of Uttar Pradesh (Lucknow region), India in mango cv Dashehari (30 yrs old) spaced at 10 ×10 m. The experiment was conducted on different fertigation scheduling *viz.*, T_1 (Control), T_2 (75 % RDF), T_3 (50 % RDF), T_4 (25 % RDF). Recommended fertilizer dose (RDF) was 1 kg N, 0.5 kg P_2O_5 and 1 kg K_2O per tree and it was applied in the month of September in basin (control plots). Fertilizer through drip was applied in four split dose at two days interval at each stage. In T_2, 25% (N), 50% (P), 15% (K) fertilizer was applied through drip after harvest while 20% (N), 25% (P), 15% (K) during flowering. In the marble size stage, only N (30%) and K (45%) were applied through drip. In T_3 treatment, 20% (N), 30% (P), 10% (K) fertilizer was applied through drip after harvest. During flowering, a dose of 20% (N), 20% (P), 10% (K) and in marble stage, N (10%) and K (30%) were applied through drip. In T_4 treatment, only N (5%) and K (15%) were applied in the marble size stage through drip whereas in flowering stage, 10% (N), 10% (P), 5% (K) and after harvest 10% (N), 15% (P), 15% (K) were applied. Irrigation water was given @ 60% of the evaporation rate through drippers (8 l/h). The treatments were replicated five times in a randomized block design. The soil of the area falls in the Indo-Gangetic alluvium category having a texture of sandy loam.

The solar radiation (extraterrestrial radiation Ra) received at the experimental site is a function of latitude, date and time of day. Moreover, the amount of incoming solar radiation (Rs) reaching the place as a function of (photosynthetically active shortwave) is also quantified. Thus, mean daily values of extraterrestrial radiation and incoming shortwave solar radiation were estimated with the following equation-

$$Ra = [(24\times60)/\pi \times Gsc \times dr \times \{Ws \times \sin(\Phi) \times \sin(\sigma) + \cos(\Phi) \times \cos(\sigma) \times \sin(Ws)\}]$$

Where,

Ra = Extra terrestrial radiation ($MJ/m^2/day$)

Gsc = Solar Constant = 0.082 $MJ/m^2/min$

dr = Inverse relative distance earth-sun

Ws = Sunset hour angle

Φ = Latitude (radian)

σ = Solar declination

dr was estimated by the following equation

$$dr = \{1+0.033 \times \cos(2\pi/365 \times J)\}$$

Where J is the Julian day

The incoming shortwave solar radiation (Rs) was calculated by the Angstrom's formula

$$Rs = Ra \times (0.32 + 0.46 \times n/N)$$

Where, n = Actual bright sunshine hours for a day and N = Maximum possible sunshine hours for the same day.

Where, $N = (24/\pi) \times Ws$

Ws is the sunset hour angle (Radian) = Arc Cosine [-tan (Φ) × tan (σ)]

Φ= Latitude in radian,

For CISH, Lucknow Φ= (26.54 × π)/ 180

σ = Solar declination angle, calculated as follows:

σ = 0.409 × Sine [(2 × π × J)/d-1.39]

Where J= Julian days (1 to 365/366) and d = No. of days in the year

Daily weather data of temperature (maximum and minimum), relative humidity (morning and evening), rainfall, wind speed, bright sunshine hours and evaporation rates were recorded in the Agrometeorological Observatory located within the experimental site. All these data were used for deriving the energy summation indices. These indices were computed on daily basis taking 1st September as base for each year since mango is harvested during June and July in Northern India and post harvest vegetative phase started. During the month of September to mid December, vegetative phases prevail after which reproductive phase started. Differential time periods in mango phenological stages were revealed during this study period (2013-15). As per the study on mango phenological stages by Rajan *et al.*, (2011), extended BBCH scale (BBCH = Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) applied for inflorescence emergence (BBCH scale 510) consisted from 1st week of January and lasts about 1st, 2nd and 3rd week of February in 2013, 2014 and 2015 respectively. In case of BBCH scale 519 (end of panicle development), the stage exited between 4th week of February and last week of March. Flowering periods (BBCH scale 610-619) extended from last week of February up to march in three different seasons. Fruit developmental stages (fruit setting, pea nut size, marble size and physiological maturity) prevailed from April to end of May (scale 711-719, 810). Different time periods (weeks) for occurrences of phenological studies were computed stage wise for calculation and reference purpose in each year.

The calculation was considered up to physiological maturity (end of May in each year). The energy summation indices *viz*., thermal heat accumulation (GDD), heliothermal unit and photothermal units for this region were calculated as per Shukla *et al.* (2016). The pooled data was statistically analyzed and significance was concluded at 5% level of significance using SPSS version 12.0. Required graphs were generated using MS Excel software.

Results and Discussion

Weather dynamics during the study periods

The analysis of weather prevailed during the mango growing season is important from view point of assessing the impact of weather dynamics on the production and quality of fruits. Dinesh and Reddy (2012) explained narrow variations in temperature and relative humidity impacting on mango yield and quality components. Ambient temperature directly influencing the flowering and fruiting behaviour in a season and thereby yield outcome. Sometimes higher temperature hastens the fruit maturity and often forced maturity reduces the fruit quality. Differential environmental factors may impact the quality fruit production (Peng *et al.*, 2000; Hutton and Landsberg, 2000; Hoppula and Karhu, 2006). Thus, agroclimatic analysis at the experimental sites is valuable for evaluating crop-weather interaction. The mean monthly weather parameters were tabulated in Table 1. The agroclimatic analysis indicated that maximum and minimum temperatures (T_{max} and T_{min}) were varied between 18.1-39.5°C and 6.3-23.9°C respectively across different stages. The relative humidity was ranged between 53.3-84.9%. The bright sunshine hours and wind speed was varied between 3.2-9.6 h and 1.0-3.7 km h^{-1}, respectively. Highest rainfall of 511.4 mm was received during the months of September followed by 139.6 mm and 122.2 mm in the months of February and October respectively. Lowest amount (18.0 mm) was in May. Unseasonal rainfall was also received during winter months of December and January (19.4 and 90.7 mm respectively). The pan evaporation ranged between 2.4-9.1 mm d^{-1}. A pan evaporation of 2.5-4.5 mm d^{-1} was noted during the initial mango growth cycle (flower bud

Table 1. Mean (2013-2015) meteorological conditions during mango growth cycle

Month	Temperature (°C)		Relative humidity (%)	Bright sunshine hours (h)	Wind velocity (km h^{-1})	Total rainfall (mm)	Pan evaporation (mm)
	Max	Min					
September	33.0	23.9	81.3	6.6	3.1	511.4	5.3
October	31.4	18.2	79.9	7.0	1.6	120.2	4.5
November	27.8	9.3	75.3	6.5	1.0	0.0	3.2
December	21.4	6.3	78.3	4.8	1.7	19.4	2.4
January	18.1	6.3	84.9	3.2	2.3	90.7	2.4
February	23.6	9.2	81.8	6.2	2.6	139.6	3.4
March	29.7	12.8	73.6	8.1	3.2	64.0	4.2
April	35.7	17.0	53.3	8.6	3.7	41.8	7.1
May	39.5	22.4	55.0	9.6	3.5	18.0	9.1

differentiation, flowering stages). Higher (7.1-9.1 mm d^{-1}) pan evaporation was recorded during fruit developmental (marble) stages.

Radiation dynamics during the study periods

The radiating dynamics during the fertigation experiment was presented in Fig. 1. It was observed that the extraterrestrial radiation decreases as winter season advances and it gains its momentum increase as summer season advances. A range of 21.79-40.51 MJ m^{-2} d^{-1} Ra was recorded during the entire fruit growth and developmental cycle. The Rs was also assessed at different critical crop phenological stages and results revealed that the values started increasing with the advancement of growth stages (post flowering to fruit development). The mean values of 15.89, 20.80, 23.59 and 26.03 MJ m^{-2} d^{-1} were recorded in the months of February to May coinciding with flowering, fruiting (pea and marble stages) and physiological maturity respectively (Fig. 1) while lowest as 10.75 and 11.76 MJ m^{-2} d^{-1} in Jan-Dec (flower bud differentiation stage). Similarly, maximum possible bright sunshine hours are widely varying during the crop growth stages and a range of 11.85 to 13.55 h in post flowering stages were recorded. Knowledge of radiation dynamics in quantifying the dry matter produce is of prime importance. Briston and Campbell (1984) had developed the relationship of incoming solar radiations from ambient temperature in order to quantify with the radiation regimes. Abraha and Savage (2008) also estimated the radiation dynamics in order to use in crop simulation models. Adak et al. (2014) recorded wide-spared differentiation in the radiation dynamics across mango growing seasons in Lucknow. All these information may be useful as an important input in developing dynamic crop simulation model to assess the impact of changes in radiation regimes on mango crop.

Dynamics in energy summation indices

The thermal heat accumulation (GDD) was quantified at different critical crop phenological stages (month-wise) during mango fruiting season (Table 2). It was observed that during the initial month, a value of 216.5°Cd in the month of September was recorded. The values started increasing with the advancement of phenological stages. The mean value of 701.7, 817.1, 1094.2 and 1517.8°Cd were recorded in the months of February to May coinciding with flowering, fruiting (pea and marble stages) and physiological maturity respectively. The corresponding values for HTU ranged between 1462.2 to 14652.7°Cd h and in case of PTU, 2600.2 to 20233.5°Cd h. Nagarajan et al. (1994) recorded a range of 260-2253 GDD, 2038-9469 HTU and 3329-13068 PTU at four critical phenological stages in potato under northern Indian hilly condition.

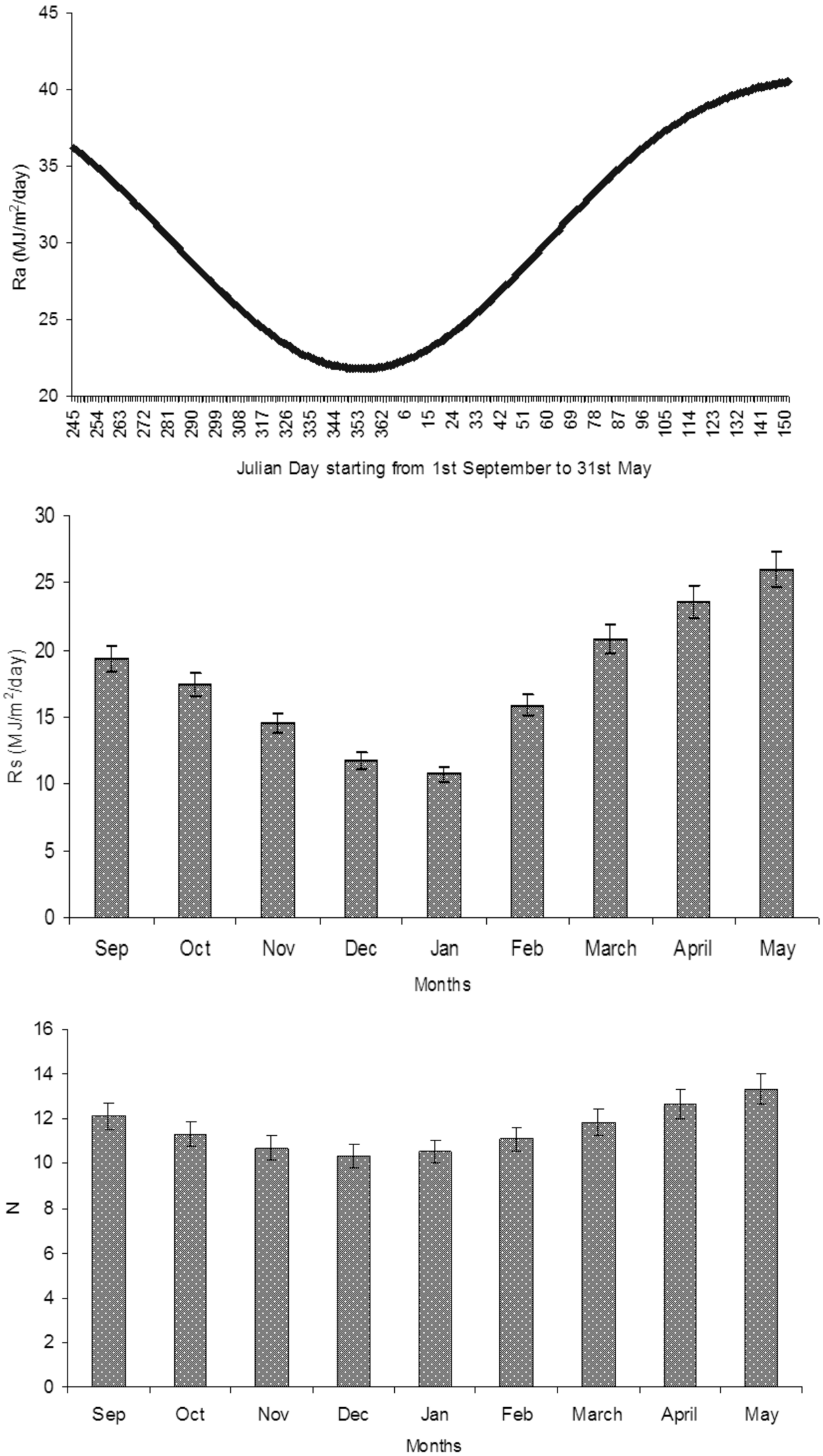

Fig. 1. Dynamics of extraterrestrial radiation (Ra), incoming short-wave radiation (Rs), and maximum possible bright sunshine hours (N) at different crop phenological stages in mango cv. Dashehari under Lucknow condition

Table 2. Energy summation indices at different crop phenological stages in Dashehari mango under subtropical Lucknow, Indian condition

Months	Phenological phases	GDD (^{0}Cd)	HTU (^{0}Cd h)	PTU (^{0}Cd h)
Sep	Vegetative phase	216.5	1462.2	2600.2
Oct		573.7	4007.2	6485.5
Nov		774.7	5072.4	8269.0
Dec	Inflorescence emergence	810.3	3926.5	8400.5
Jan		728.3	2304.9	7678.8
Feb	Inflorescence emergence, beginning of flowering	701.7	4348.0	7793.1
March	Flowering, fruit setting	817.1	6611.3	9698.5
April	fruit developmental stages	1094.2	9420.8	13864.8
May	fruit developmental and physiological maturity	1517.8	14652.7	20233.5

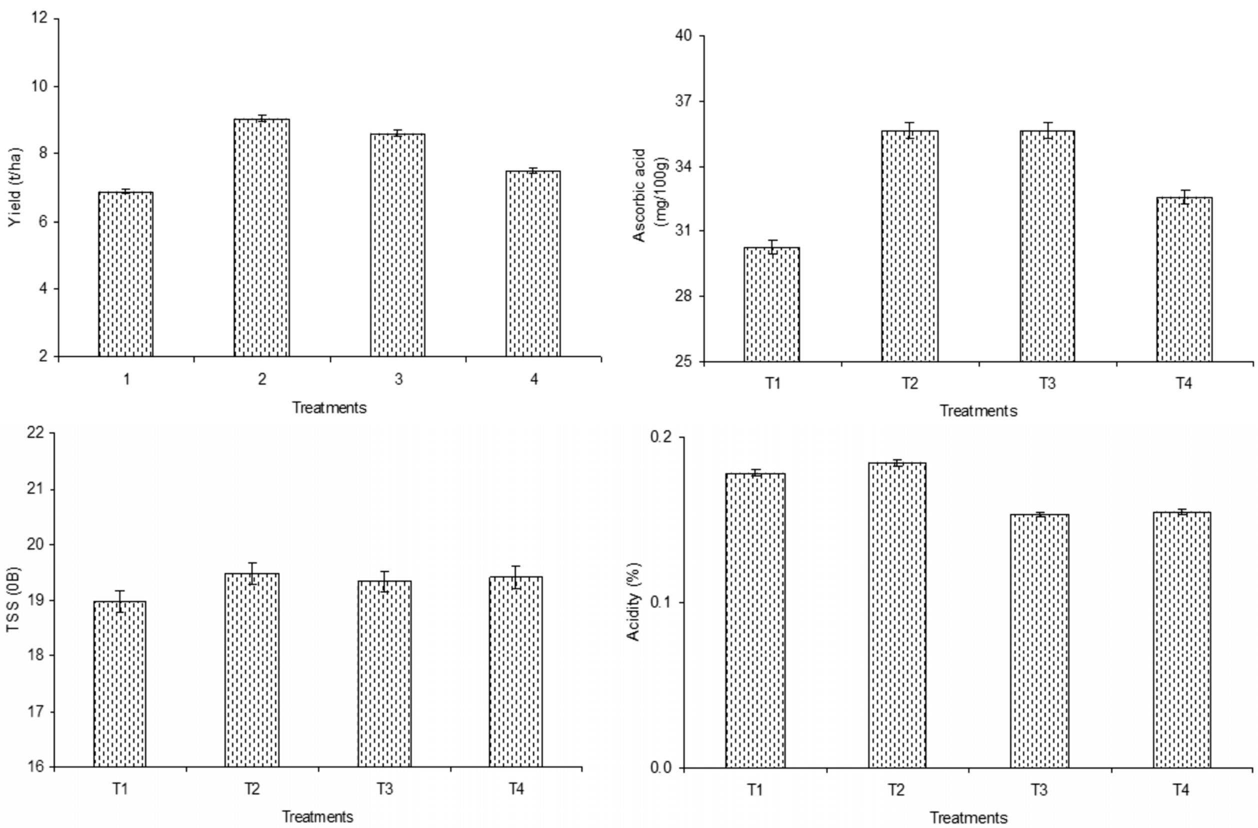

Fig. 2. Variations in yield and quality components in mango cv Dashehari under subtropical climatic condition (TSS = Total dissolved solids)

Variations in yield, quality components and heat use efficiency

Significant variations in fruit yield across different treatments were observed (Fig. 2). The highest and lowest fruit yields were recorded as 6.89 t ha^{-1} in control plot (T_1) and 9.05 t ha^{-1} (T_2). The fruit yields in T_3 and T_4 treatments were recorded as 8.61 and 7.49 t ha^{-1} respectively. It was found that significant variations in vitamin C content exited among the treatments. The mean values were 30.27, 35.65, 35.65 and 32.54 Vitamin C (mg 100^{-1} g) in T_1, T_2 T_3 and T_4

respectively. A non-significant difference in case of total dissolved solids (TSS) and acidity was observed, of course the values ranged from 18.47-19.9°B and 0.14-0.20% respectively. The present study concluded that fertigation with 75 per cent of recommended NPK dose may be applied as split doses at phenological stages for yield improvement with better fruit quality in mango under subtropical conditions of Lucknow.

Wide variations in heat use efficiency (HUE) were inferred from this study. The pooled value indicated a range of 3.91-5.14 g m^{-2} $°Cd^{-1}$ (Fig. 3). The analysis on energy summation indices

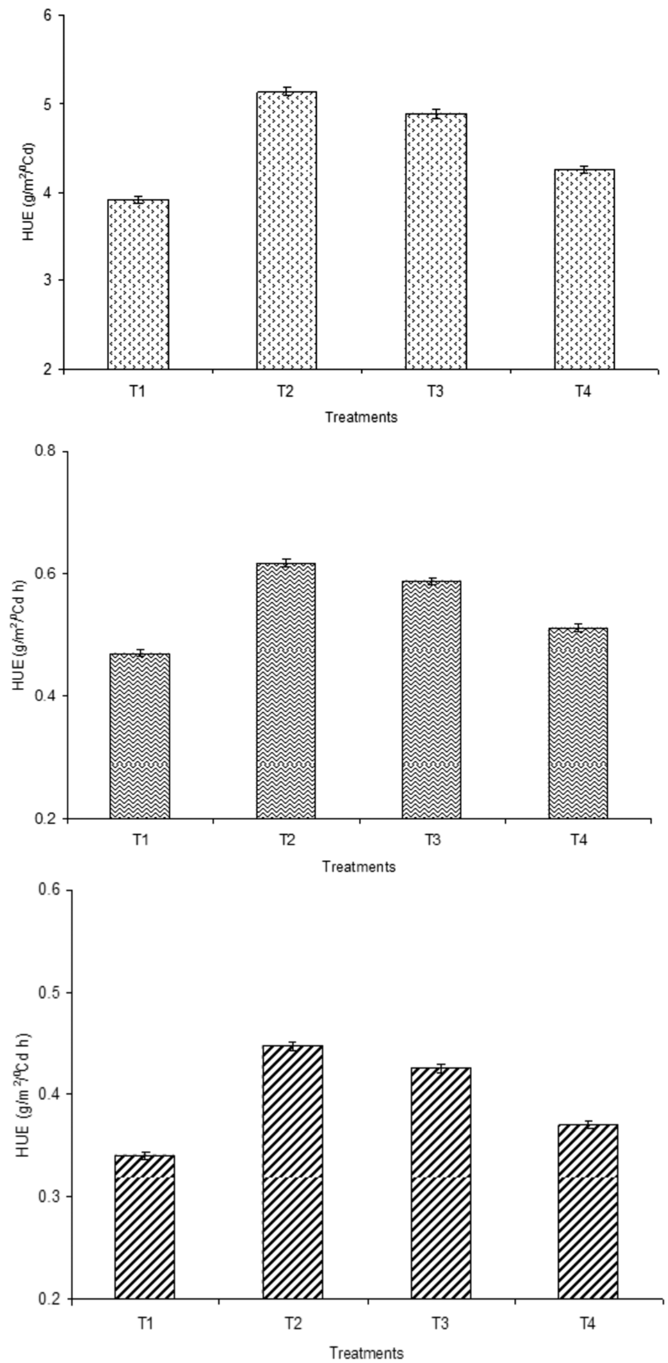

Fig. 3. Variations in heat use efficiency (HUE) in mango cv Dashehari using GDD, HTU and PTU respectively under subtropical climatic condition

using GDD indicated highest heat use efficiency (HUE) in mango cv Dashehari during the year 2014, followed by 2015 and least in 2013 fruiting season. Similarly, considering the HTU indices, a range of 0.30-0.79 g m^{-2} °Cd h^{-1} heat use efficiency in mango cv Dashehari was inferred. Cutting across the seasons, HUE was estimated as 0.47, 0.62, 0.59 and 0.51 g m^{-2} °Cd h^{-1} in T_1, T_2 T_3 and T_4 respectively. In this content, PTU was also employed to quantify the HUE and highest was quantified as 0.36, 0.59, 0.40 g m^{-2} °Cd h^{-1} in 2013, 2014 and 2015 season respectively with a pooled highest as 0.45 g m^{-2} °Cd h^{-1} (T_2).

Changes from optimum environmental condition during growth and development stages influence the tree physiology, productivity level and quality production. Kliewer (1977) observed that very high temperature during critical developmental stages is detrimental for the crop. Chmielewski and Rotzer (2001) recorded differential response of tree phenology towards climatic changes while Rajan (2008) found the implication of such changes in mango also. All these responses are indicating the fact that impacts on phenology and yield of various tree crops act as a function of differential hydrothermal and radiation regimes prevailed. Lass *et al*. (1993) forecasted the harvest date using some complex regression models. Nagarajan *et al*. (1994) estimated 1.52-1.61, 0.30-0.28 and 0.32-0.46 heat use efficiency in potato using these energy summation indices under Northern Indian Hilly condition. Energy summation indices or in turn the concept of thermal heat accumulation is widely applied in predicting the harvest date of a number of horticultural crops (Perry *et al*., 1996; Jenni *et al*., 1998; Hueso *et al*., 2007).

Conclusion

Differential energy regimes were prevailed during the study periods across mango growing seasons. A significant change in energy summation at different critical phenological stages of mango was revealed. Highest fruit yield (9.05 t ha^{-1}) in mango was recorded in fertigation with 75% recommended dose of NPK. The fertigation should be applied @ 25% (N), 50% (P), 15% (K) after harvest, 20% (N), 25% (P), 15% (K) during flowering and only N (30%) and K (45%) in marble size stage. The yield improvement over basin/untreated irrigation was 31.3, 20.8 and 11.3 per cent in 75, 50 and 25% RDF respectively. Wide variations in heat use efficiency (HUE) were also inferred from this study.

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