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Assessment of thermal heat requirement, radiation energy, water use efficiency, and yield of mango cv Dashehari using fertigation method

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ABSTRACT

Thermal heat requirement as well as energy components depend on weather parameters. Critical phenological stages was taken into consideration for the thermal heat requirement during 2013-15 under fertigation treatment (25, 50 and 75 per cent of recommended fertilizer dose) in mango cv Dashehari at Lucknow region. Mango productivity varied from 4.54-11.84 t ha^{-1} across different fertigation regimes as a result of differential thermal heat accumulation. In the treatment 25 per cent RDF, productivity of 5.23, 11.13 and 6.12 t ha^{-1} was recorded during 2013, 2014 and 2015 while in 50 per cent RDF, 6.23, 11.84 and 7.76 t ha^{-1} was observed. The maximum yield reduction (37.5, 14 and 26.1%) was found in control plot. A significant variation in radiation energy received during the field experiment was revealed and a range of 8.97 to 16.27 mm day^{-1} extraterrestrial radiation was observed at different critical phenological stages. The heat use efficiency (HUE) varied between 2.54-6.78 g m^{-2}°Cd^{-1} across seasons and treatments. Water use efficiency (WUE) of 10.8, 14.1, 13.5 and 11.7 kg fruits m^{-3} was recorded in different fertigated treatments. The highest reduction in WUE was noted in control (23.9%) followed by 17.2 and 4.8% in 25 and 50 per cent as compared to 75 per cent fertigation regimes.

Keywords: Agroclimatic indices, radiation dynamics, water use efficiency, productivity, mango,

Mango (*Mangifera indica*) is economically one of the most important fruit crop in India and UP being the important states in the country for earning good economic returns through mango export. The information on abiotic stresses like temperature, moisture, radiation, evaporation, during fruit developmental stages are the key factors for orchard sustainability and securing farmer's livelihood. The crop is immensely influenced by climatic factors during fruiting season (Rajan, 2012). Differential moisture regimes particularly fertigation plays a pivotal role in improving the productivity of mango and thus responsible for variations in energy use in terms of water use efficiency. Generally, higher evaporation from the soil surface and absence of rainfall, with high wind velocity and temperature makes a drier environment, the obvious results being fruit drop, forced maturity, resulting into low quality fruit production (Ravishankar *et al.,* 2011; Adak *et al*., 2013). Additionally, extended cold periods, severe cold (-0.2^{0}C to -1.2^{0}C during 2013) also impacted fruit production. Quantification of thermal heat requirements of fruit crop like mango is essentially important to worked out to mitigate abiotic stresses. Daily maximum and minimum temperatures undergoes great variation and seasonal dynamism also influences fruits production, application of heat unit accumulation is a better option for relating changes in energy use efficiency (Perry *et al*., 1993; Singh *et al.,* 2000; Umber *et al*., 2011). Since the information on all these aspects particularly its energy use across seasons and hydrothermal regimes in mango production under subtropical climatic condition is lacking, hence, a detailed study is therefore set out to quantify the energy requirements and its use efficiency using fertigation scheduling method.

MATERIALS AND METHODS

A field experiment on different fertigation scheduling was carried out on a 30 years old mango cv Dashehari (10×10 m spacing) in the experimental farm of Central Institute for Subtropical Horticulture (26.54^{0}N Latitude, 80.45^{0}E Longitude and 127 m above mean sea level), Rehmankhera, Lucknow, Uttar Pradesh during 2013, 2014 and 2015 to generate the information on energy use efficiency across fruiting seasons. The area falls under subtropical region and soils were characterized under the category of Indo-Gangetic alluvium. Four treatments were placed in a randomized complete bock design using five replications (Table 1). The irrigation was given through drippers having capacity of 8 l h^{-1} on every alternate days and the quantity was decided on the basis of open pan

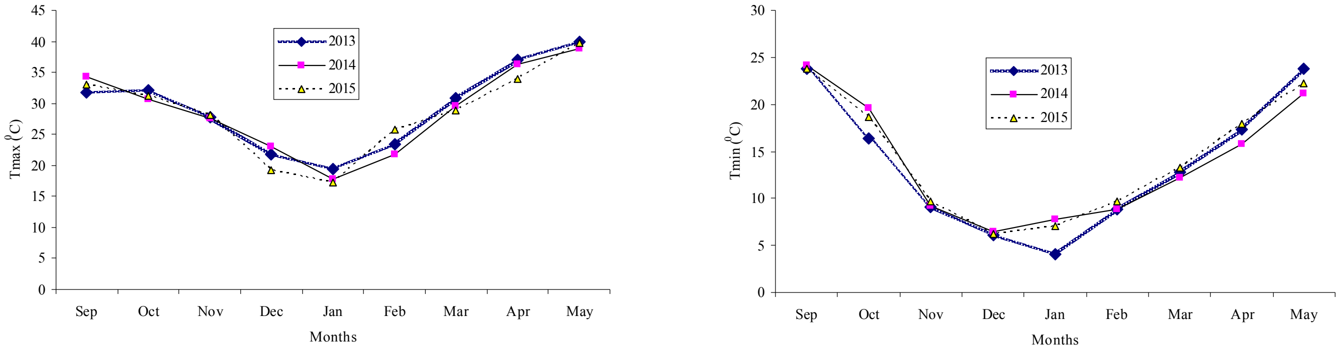

Fig. 1: Monthly average temperatures during mango growing season

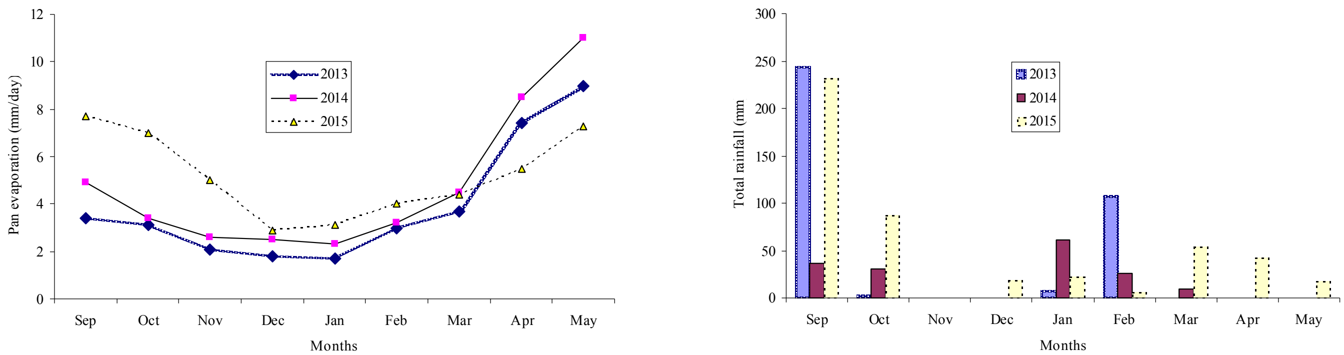

Fig. 2: Monthly average pan evaporation and total rainfall during mango growing season

evaporation data. Fruit productivity was recorded at full maturity stage by quality parameters like Total Soluble solid, acidity and ascorbic acid. The heat unit indices *viz*., growing degree days (GDD), heliothermal unit (HTU), and photothermal units (PTU) were calculated to quantify the thermal heat requirements. All these indices were calculated as follows:

Growing degree days (GDD) = $\Sigma(T_{Max} + T_{Min})/2 - T_{Base}$

Heliothermal units (HTU) = GDD × actual bright sunshine hour (n)

Photothermal units (PTU) = GDD × day length (N)

where T_{Max} and T_{Min} are the maximum and minimum temperatures (°C) of the day and T_{Base} is base temperature which was taken as 15°C (Whiley *et al.,* 1991). N indicates maximum possible bright sunshine hours or day length and calculated as

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

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

Φ = Latitude in radian,

σ = Solar declination in radiation, calculated as follows

$\sigma = 0.409 \times \text{Sine}\,[(2 \times \pi \times J)/d - 1.39]$

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

The extraterrestrial radiation (Ra) and incoming short wave radiation (Rs) were estimated using Allen *et al*., (1998). After harvesting in June-July, during the month of September, post harvest vegetative phases started. The events for phenological stages described as flower bud differentiation (December to January), flowering (Feb to March) and fruit set, development to maturity (April to May-June). The energy use efficiency in terms of heat or water energy was also derived. Heat use efficiency was estimated as productivity (g m^{-2}) per unit of agroclimatic indices and water use efficiency was calculated as productivity per (kg) m^3 of water applied. These indices were calculated on daily basis taking 1st September as base for each year since mango is harvested during June-July in northern India. The calculation was considered up to physiological maturity (end of May in each year). The data was statistically analyzed and significance was concluded at 5% level of significance using SPSS version 16.0.

RESULTS AND DISCUSSION

Meteorological condition during the mango growth cycle

The mean monthly meteorological parameters observed during mango growth and developmental is

Table 1: Details of different ferigation scheduling applied in mango cv Dashehari

	T_1	T_2			T_3			T_4		
Stages		N	P	K	N	P	K	N	P	K
After harvest	100% NPK in basin	25	50	15	20	30	10	10	15	5
during flowering	-	20	25	15	20	20	10	10	10	5
marble size stage	-	30	-	45	10	-	30	5	-	15
		75%	75%	75%	50%	50%	50%	25%	25%	25%

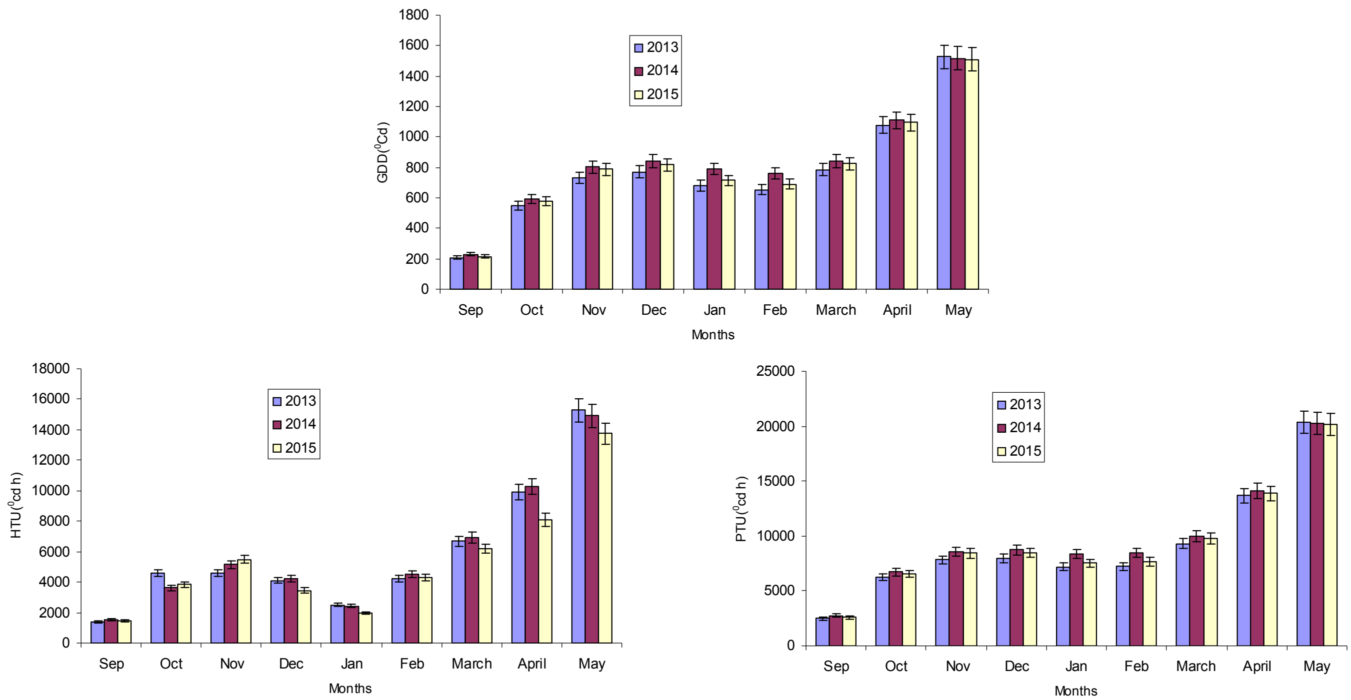

Fig. 3: Quantification of thermal heat requirements at different critical phenological stages in Dashehari mango (month wise)

presented in the Fig. 1-2. The monthly average maximum and minimum temperatures (T_{max} and T_{min}) varied between 19.4-39.9 and 4.1-24.1°C respectively across three seasons. The pan evaporation ranged from 1.8 to 11.0 mm day^{-1}. A range of 3.7-8.5 mm day^{-1} pan evaporation was recorded during the initial fruit growth stages across three seasons. Temporal variation in total amount of rainfall received was depicted. During the month of September a total of 243.2, 36.8 and 231.4 mm of rainfall were received. Unseasonal rainfall of 19.4 mm during December 2015 was received. Similarly, unseasonal rainfall was also received during the months of January and February. During 2015 fruiting season, a total of 54.2, 41.8 and 18.0 mm of rainfall were received during fruit developmental stages (pea and marble stages).

Thermal heat requirement at different phenological stages

Different thermal heat accumulation was revealed with the higher in 2014 than both the years (Fig. 3). During flowering period, 651.8 to 762.4 °Cd while, at fruit growth, 785.0 to 843.0 °Cd heat accumulation was estimated across seasons. The accumulated GDD ranged between 1078.1 and 1527.4, 1110.5 and 1516.9 and 1094.0 and 1509.0°Cd during marble size stage to fruit maturity stages in 2013, 2014 and 2015 respectively. The thermal heat accumulation at different critical crop phenological stages in general indicates the stage-wise heat requirement and also essential for harvesting the economic parts of the crop (Nagarajan *et al.*, 1994; Villordon *et al.,* 2009; Mu˜noz *et al.*, 2012). Suresh *et al.* (2013) observed that a range of 1567-2780 cumulative GDD from anthesis to maturity in oil palm hybrids under Pedavegi, Andhra Pradesh condition.

Energy use efficiency and crop productivity

A range of 10.2-11.8, 5.9-8.04 and 4.5-7.3 t ha^{-1} productivity across different fertigation regimes were noted

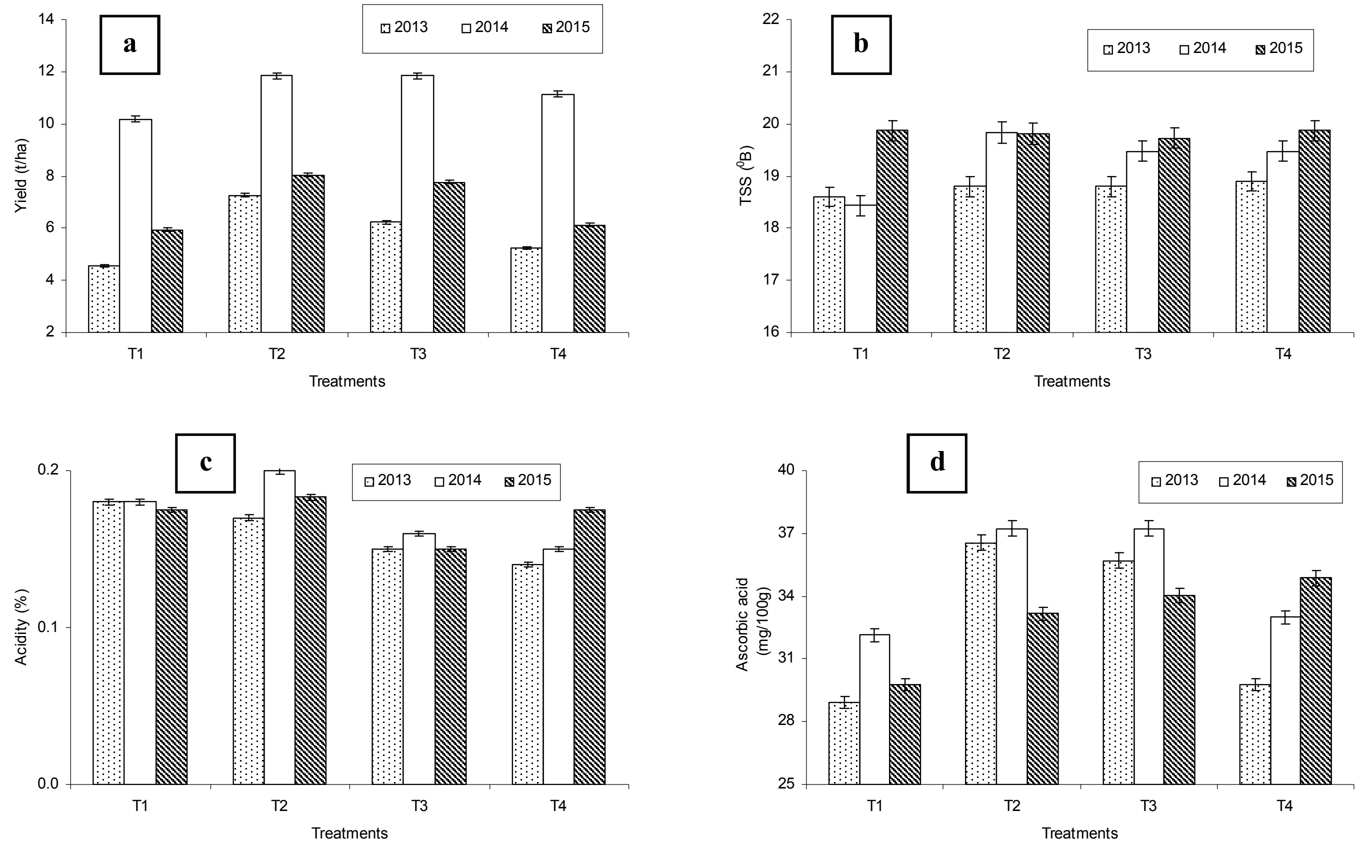

Fig. 4: Changes in productivity and quality parameters under different fertigation regimes in mango cv Dashehari

(Fig. 4a). Mango productivity was higher in 2014 followed by 2015 and lowest in 2013years. A 25 per cent recommended dose of fertilizer (T4) exhibited a productivity of 5.2, 11.1 and 6.1 t ha^{-1} in 2013, 2014 and 2015 season while 50% RDF (T3), 6.23, 11.84 and 7.76 t ha^{-1} was observed (Fig. 4). The maximum yield reduction (37.5, 14 and 26.1%) was found in control plot during experimental periods. Yield reduction in T_4 as compared to T_2, was estimated as 28.0, 6.0 and 23.9 per cent in 2013, 2014 and 2015 respectively while in case of T_3, 14.2 per cent in 2013 and 3.5 per cent in 2015 was observed. Fruit quality parameters like TSS and acidity did not vary significantly across different fertigation treatments. In case of ascorbic acid content, a significant change was observed and a range of 28.91-36.56, 32.54-37.22 and 29.76-34.86 mg/100g was estimated in 2013, 2014 and 2015 (Fig. Fig. 4 b,c,d).Optimum soil moisture is required for obtaining sustainable yield in mango as soil moisture content at fruit set to developmental periods is key factors for determining the quantity as well as quality production. Higher yield and quality in T_2 treatment may be because of higher nutrients applied at critical phenological stages with higher percentage of K during marble stage. Lower yield in other treatments may be because of low fertigation regime. Such kind findings in productivity variations under different fertigation regimes across different agroecological regions were also observed (Panwar *et al*., 2007; Bhriguvanshi *et al*., 2012; Adak *et al*.,2014),

The efficiency with which the mango fruit was produced was studied in terms of its energy use and presented in Fig. 5. The heat use efficiency (HUE) varied between 2.54 and 4.06, 5.83 and 6.78 and 3.38 and 4.57 g m^{-2} °Cd^{-1} in 2013, 2014 and 2015 respectively (Fig. 5a). The highest HUE was recorded in T2. Moreover, the reduction in HUE was also quantified and it was observed that maximum reduction in energy use efficiency was 37.5 per cent in control plot (T_1), followed by 28 and 14.2 per cent in T_4 and T_3 treatments during 2013. . Considering HTU, it was inferred that the HUE exhibited 0.30-0.47, 0.68-0.79 and 0.43-0.58 g m^{-2} °Cd h^{-1} in 2013, 2014 and 2015 years across different fertigation treatments (Fig. 5b). The heat use efficiency using PTU as an index showed higher value of 0.50-0.59 g m^{-2} °Cd h^{-1} during 2014 as compared to 2013 (0.22-0.36 g m^{-2} °Cd h^{-1}) and 2015 (0.30-0.40 g m^{-2} °Cd h^{-1}) years (Fig. 5c). Higher HUE in 2014 indicated higher thermal heat accumulation and better utilization of energy.

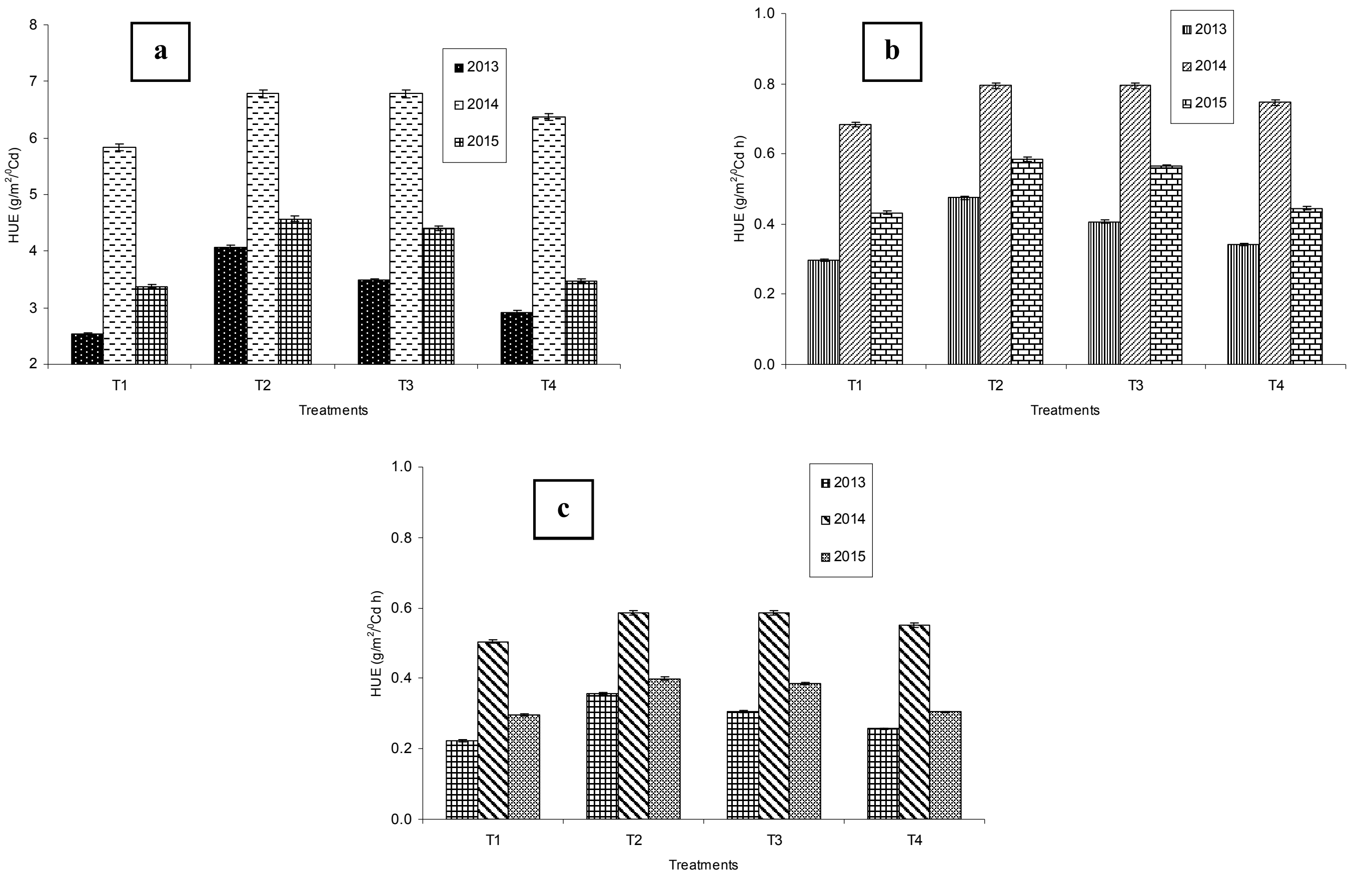

Fig. 5: Significant changes in heat use efficiency in mango cv Dashehari using different thermal indices (GDD-a, HTU-b , PTU-c)

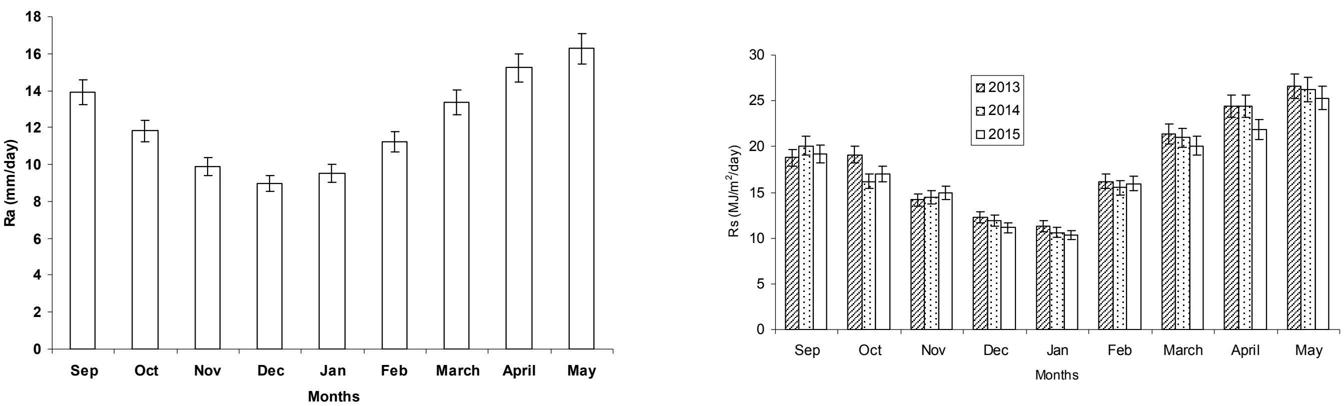

Fig. 6: Variations in extraterrestrial radiation and Incoming short wave radiation during mango growing season

Changes in radiation energy and water use efficiency

A significant change in terms of radiation energy received during the field experiments was revealed (Fig. 6). Extraterrestrial radiation (Ra) received during the critical phenological stages ranged from 8.97 to 16.27 mm day^{-1}. Radiation energy was estimated to be 8.97-9.53, 11.23, 13.28, 15.23 and 16.27 mm day^{-1} during FBD (Flower bud differentiation), flowering, pea stage of fruit, marble size stage and finally at physiological maturity. A critical analysis of Rs (incoming shortwave solar radiation as a function of PAR) indicated wide variations across different phenological stages of the mango fruit. It was also found that highest Rs was received in 2013 fruiting season while 2014 and 2015 fruiting season received comparatively lower value (Fig. 6). This information is very crucial to have an idea about how the fruit crop responses under low radiation conditions. Highest and lowest value was estimated as 6.97 and 28.43 MJ m^{-2} day^{-1}. The Rs assessed at different critical crop phenological stages (month wise) during three consecutive mango fruiting seasons revealed that during the initial

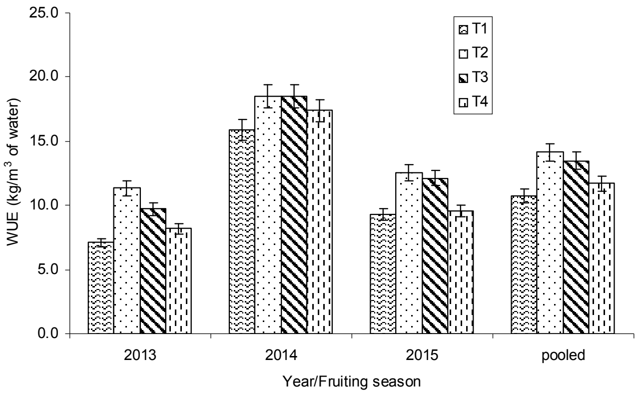

Fig. 7: Dynamics of water use efficiency in mango cv Dashehari under different fertigation system

month a value of 18.8-20.08 MJ m^{-2} day^{-1}in the month of September was recorded across the seasons. The lowest value was observed to be 10.04-12.22 with a mean value of 10.75 MJ m^{-2} day^{-1} during winter months from December-January. The maximum possible sunshine hours during the critical mango growth period was calculated and it was found in the range of 10.34 to 13.55 hours with a standard deviation of 0.98 and coefficient of variation of 8.5 per cent. It decreased from September to December and after that started increasing with the advancement of summer seasons (clear sky). Differential solar and micro environmental regimes are reported to affect on productivity of different crops (Adak *et al*., 2012 and 2013). Highest water use efficiency (WUE) was noted in T_2 across three consecutive seasons. In other fertigation treatments (T_3 and T_4), WUE of 8.2-9.7, 17.4-18.5 and 9.6-12.1 kg fruits m^{-3} was recorded during 2013, 2014 and 2015 respectively (Fig. 7). A pooled value of 10.8, 14.1, 13.5 and 11.7 kg fruits m^{-3} was inferred in T_1 to T_4 respectively. The WUE decreased in other fertigation treatments as compared to T_2. Maximum reduction observed in T_1 (23.9%) followed by T_4 (17.2%) and T_3 (4.8%) treatments. Variations in WUE under different hydro thermal regimes across different agroecological regions were also observed by Spreer *et al*., (2007) and Bhriguvanshi *et al*., (2012). Such variations may be due to irrigation regimes applied coupled with weather parameters dynamics particularly pan evaporation, radiation and evapotranspiration (Adak *et al*., 2014; Mehta and Pandey, 2015).

CONCLUSION

Wide variations in thermal heat requirement in mango cv Dashehari at different critical phenological stages during 2013, 2014 and 2015 fruiting season was inferred.. Higher heat accumulation was observed in 2014 mango growing season. The highest productivity was recorded in 2014 followed by 2015 and lowest in 2013. A range of 10.18-11.84, 5.94-8.04 and 4.54-7.26 t ha^{-1} productivity across different fertigation regimes was noted in the respective years. Higher heat and water use efficiency were recorded in the treatment where 75 per cent of recommended fertilizer doses were applied at critical phenological stages. A range of 2.54 to 6.78 g m^{-2} °Cd^{-1} HUE and 8.2 to 18.5 kg fruits m^{-3} was estimated across three seasons with higher value in 2014 seasons. Lower heat and water use efficiency was recorded in the treatments wherever 25 and 50% of recommended fertilizer doses were applied.

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