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Effect of different regimes of deficit irrigation and drip fertigation on quality and economics of mango (*Mangifera indica* L.) cv. dashehari under rainfed conditions

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Abstract
This study addresses water-saving irrigation strategies, including regulated deficit irrigation (RDI) at 75% and 50% crop ETc and partial root-zone drying (PRD) at 75% and 50% ETc to investigate the response of the mango (*Mangifera indica* L.) drip system in the field on a sandy loam soil during years 2017 and 2018. Results revealed that the date of appearance of panicle, full bloom was recorded earlier in the treatments T_6 i.e (RDI $_{75\%\ ETc}$ + F) as compared to the treatments not subjected to fertigation i.e both T_2 (RDI $_{75\%\ ETc}$), T_3 (RDI $_{75\%\ ETc}$), T_4 (RDI $_{75\%\ ETc}$) and T_5 (RDI $_{75\%\ ETc}$) whereas, panicle appearance and full bloom was last (100% ETc) respectively in plants treated with full irrigation (T_1) as compared both fertigated and non fertigated plants during both the years, respectively whereas longest duration of flowering was recorded in treatments receiving fertigation i.e T_6 (RDI $_{75\%\ ETc}$ + F). The panicle length (26.57 cm and 25.18 cm) and panicle breadth (13.53 cm and 11.78 cm) was recorded maximum under T_7 comprising of PRD $_{75\%\ ETc}$ + F and minimum panicle length (18.52 cm and 17.37 cm) and breadth (10.88 cm and 9.52 cm) was recorded under T_{10} i.e no irrigation whereas tree height, spread and stock girth and scion girth was found maximum at $T_{1\ 100\%\ ETc}$. The maximum fruit weight, volume and size was recorded in T_7 PRD $_{75\%\ ETc}$ + Fertigation and minimum was recorded in treatment T_{10} no irrigation. The benefit cost ratio was found maximum under treatment T_7 comprising of PRD $_{75\%\ ETc}$ + F.

Keywords: Regulated deficit irrigation, partial root zone drying, mango

Introduction

Available water resources for agriculture have been decreasing in recent years with the increased demands for irrigation and other non agricultural water uses. For sustainable water use in agriculture, crop-specific and water-saving irrigation techniques that do not negatively affect crop productivity must be developed. Worldwide, successful attempts have been documented regarding the use of deficit irrigation methods, namely regulated deficit irrigation (RDI) and partial rootzone drying (PRD) to improve water use efficiency (WUE) in various tree crop species (Arzani *et al.*, 2000 in apricot; Hutton, 2000 in citrus, Grant *et al.*, 2004 in raspberries; Romero *et al.*, 2004 in almond; Van Hooijdonk *et al*., 2004 in apple) [3, 16, 15, 38, 50].
Deficit irrigation strategies present an interesting alternative to common irrigation practices for increasing water use efficiency (WUE), wherever water is a limiting factor to production. "Drip fertigation" a pooled method of drip irrigation with standardized dose of nutrients for the specific crop overcomes the problem with surface irrigation and has number of advantages. Applying fertilizers through an efficient irrigation system, termed as fertigation, offers a vast potential for more accurate and timely crop nutrition. Fertigation increases the efficiency in the application of the fertilizers, which also allows reducing the amount of applied fertilizers. This not only reduces the production cost but also lessens the potential of ground water pollution caused by the fertilizer leaching. Fertigation allows adopting the amount and concentration of the applied nutrients in order to meet the actual nutritional requirement of the crop throughout the growing season (Raina, 2002, Raina *et al*., 2005 and Kachwaya, 2018) [35, 34, 18].
The mango (*Mangifera indica* L.) belonging to family Anacardiaceae is the most important commercially grown fruit crop of India. It is called as king of the fruits and is said to have originated in the Indo-Burma region.

Although grown widely, mango prefers a warm, frost-free climate with a well-defined winter dry season. Rain and high humidity during flowering and fruit development reduces fruit yields. In India, it is grown in Uttar Pradesh, Maharashtra, Gujarat, Madhya Pradesh, Haryana, Andhra Pradesh, West Bengal, Karnataka, Bihar, Uttarakhand and Jammu Kashmir. The current area and production of mango in India is 2288 thousand hectares and production 21253 thousand million tones (Anonymous, 2018) [1] whereas, in Jammu province of J&K union territory, the total area under mango cultivation is 13037 ha with the total production of 30478 metric tones, respectively (Anonymous, 2019) [2]. In India, mangoes are mainly grown in tropical and sub-tropical regions from sea level to an altitude of 1,500 m. Mango grows well in tropical and sub-tropical climate conditions. The optimum temperature for its growth ranges from 23.9-26.7 °C. The nutritional requirement as well as water requirement of mango depends upon climate, soil type and age of tree. Irrigation management for the mango crop must follow technical criteria, so that water is applied at the right time and in right amount. Mango fruit development takes place during the dry season and irrigation is necessary to ensure stable yields of high quality. Under limited water conditions, it is therefore imperative that water is used judiciously and in a manner to minimize evaporative and other losses and thus improving water use efficiency. The most commonly used method for irrigation scheduling employ empirical estimation of plant water consumption by measurements of evaporation of free water or soil status. The so called class-A pan evaporimeter (U.S. weather Bereau Class A Evaporation Pan) is popular for scheduling irrigation because of the high association between water loss and actual evaporation is easy to monitor and necessary equipment is simple and easy to maintain (Jensen and Middleton, 1970; Doorenbos and Pruitt, 1977) [17, 9]. Among major nutrient element, nitrogen has major effect on the growth and development of branches, leaves and fruits, while phosphorous help in better root as well as fruit development and timely ripening. Potassium imparts biotic and abiotic stress tolerance and also improves fruit quality including better shelf life. Keeping in view the above facts it seemed to be essential to evaluate deficit irrigation strategies combined with fertigation and their impact on fruit quality of mango cv. Dashehari.

Materials and Methods

The field experiment was carried out on 12 year old, healthy, disease free and bearing mango plants of Cv. Dashehari during the years 2017-18 and 2018-19 on farmer's field located at Akhnoor, Jammu under subtropical rainfed conditions. Akhnoor is situated in the sub-tropical zone at latitude of 32.89^0 North and longitude of 74.74^0 East. The altitude of the place is 301 meters from the sea level. Annual precipitation is about 1200 mm mostly coinciding during July to October (about 70 per cent). The mean annual maximum and minimum temperatures are 29.6 ^{0}C and 16.7 ^{0}C, respectively. Summer months are hot with temperature and humidity ranging from 23.5^0C to 35.5^0C and 53.0 to 73.5 per cent, respectively. The winter months experience mild temperature ranging from 6.5^0C to 21.7^0C. December is the coldest month, when minimum temperature touches to 4^0C. The highest temperature is recorded in the month of June (45 ^{0}C). The meteorological data was collected from the University Agrometrology Centre on various climate parameters namely, air temperature, relative humidity, pan evaporation and rainfall throughout the growing season. Plant to plant spacing was 8m × 8m. The soil of the study was lighter in texture along with presence of rocks; which characteristically are of highly permeable soil, low water holding capacity, low organic carbon content, and invariably possesses very low soil nutrients.

The drip line was installed in two lateral lines and spaced at 60 cm away from tree trunk. Around each tree there was 4 numbers of drippers having discharge rate of 8 litres/dripper. A venturi assembly was used for mixing fertilizers with irrigation water. Based on the water requirement of mango trees, the duration of irrigation through drip system per day was worked out. The trees were organized in a randomized block design.

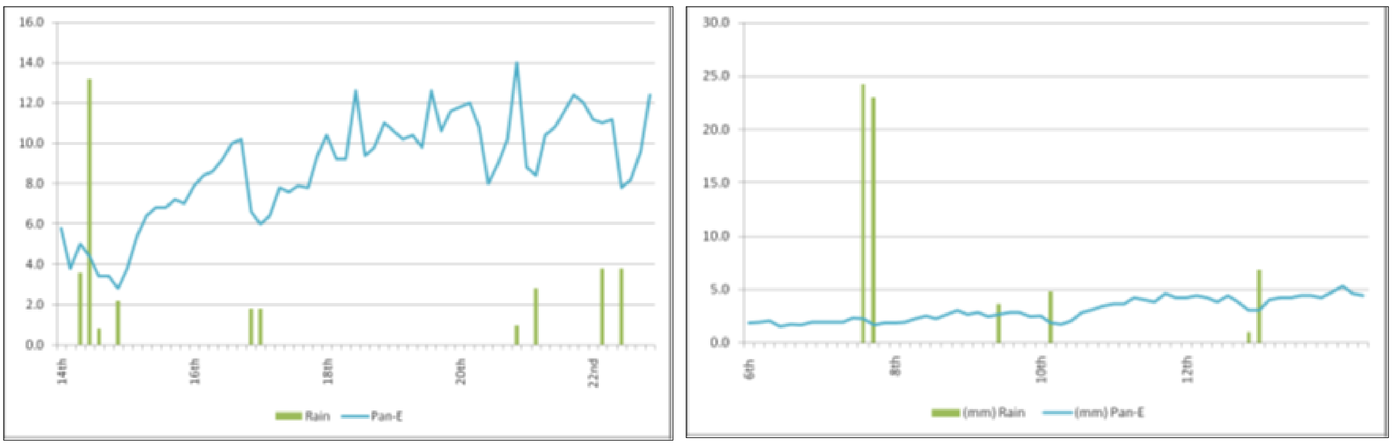

Fig 1a: Rainfall and pan evaporation during the flowering and fruit growth of mango during the year 2017

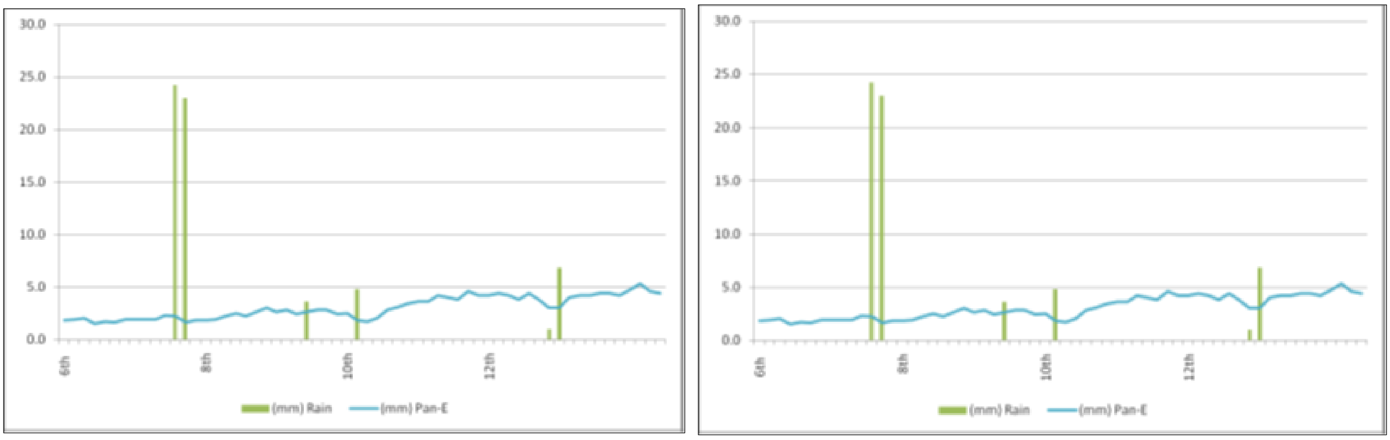

Fig 2a: Rainfall and pan evaporation during the flowering and fruit growth of mango during the year 2018

Table 1: Treatments

T_1	**100% ETc**
T_2	RDI 75% ETc evenly applied under the canopy
T_3	PRD 75% ETc applied to alternating sides of the root system
T_4	RDI 50% ETc evenly applied under the canopy
T_5	PRD 50% ETc applied to alternating sides of the root system
T_6	RDI 75% ETc evenly applied under the canopy + Fertigation with K_2SO_4 (0.5%), H_3BO_3(0.5%) and $Ca(NO_3)_2$(1%)
T_7	PRD 75% ETc applied to alternating sides of the root system + fertigation with K_2SO_4 (0.5%), H_3BO_3 (0.5%) and $Ca(NO_3)_2$(1%)
T_8	RDI 50% ETc evenly applied under the canopy + fertigation with K_2SO_4 (0.5%), H_3BO_3 (0.5%) and $Ca(NO_3)_2$ (1%)
T_9	PRD 50% ETc applied to alternating sides of the root system + fertigation with K_2SO_4 (0.5%), H_3BO_3 (0.5%) and $Ca(NO_3)_2$ (1%)
T_{10}	No Irrigation

ETc- Crop evapotranspiration
F- Fertigation
RDI- Regulated deficit irrigation
PRD- Partial root zone drying

Phenological observation

Date of appearance of panicle

The date of panicle appearance was recorded when maximum panicle emergence took place.

Date of full blossom

The day on which more than 70-80 percent flowers were opened was considered as date of full bloom. The record was made date-wise for each treatment.

Length of panicle (cm)

The length of the panicle was recorded and expressed in centimetres. The panicle lengths of ten randomly selected (North, South, East and West directions) shoots were recorded and the mean was calculated.

Breadth of panicle (cm)

The breadth of the panicle was recorded and expressed in centimetres. The panicle breadths of ten randomly selected (North, South, East and West directions) shoots were recorded and the mean was calculated.

Duration of flowering (days)

The duration of flowering was calculated by counting the total number of days from commencement of flowering to end of flowering.

Date of maximum fruit set

The date of fruit set was recorded when 70-80 per cent fruit set took place. The record was made date-wise for each treatment.

Date of harvest

The date on which more fruit were harvested was considered as date of harvest. The record was made date-wise for each treatment.

Tree growth characteristics

Tree height (m)

Height of the tree was recorded with the help of a graduated staff from the ground surface to the maximum height attained by the plant and means height was worked out and expressed in meter.

Tree spread (m)

Spread of the tree was measured by putting the graduated staff horizontally with the tree from east-west and north-south and mean spread was worked out and expressed in meter.

Stock girth (cm)

The stock girth was measured with the help of measuring tape at a height of 20 cm above the ground level and expressed in centimeter.

Scion girth (cm)

The scion girth was measured just above the graft union with measuring tape and was expressed in centimeter.

Physical characteristics

Fruit weight (g): The weight of ten randomly selected fruits from each treatment of each replication was taken by electronic balance. Subsequently, the average fruit weight was calculated and expressed in gram (g).

Fruit size (cm)
Length and breadth of ten randomly harvested fruits from each treatment of each replication was measured by using vernier callipers. Mean length was computed and expressed in centimeter (cm).

Fruit volume (cm^3)
Volume of fruit was measured by water displacement method. The average of ten fruits from each replication was calculated and expressed in cubic centimeter (cc).

Economic analysis
Benefit cost ratio
The benefit to cost ratio for each treatment was calculated by using the following formula.

$$\text{Benefit to cost ratio} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

The experiment consisted of 10 treatments and laid out in randomized block design with three replications for each treatment. The data of both the years were pooled and analyzed to Duncan's multiple-ranged test was performed using SPSS v. 16 software.

Results and Discussion
Date of appearance of panicle and Full bloom
The presented in Table 2 revealed that in year 2017 the date of appearance of panicle (13th February), full bloom (6th March) was recorded earlier in the treatments T_6 i.e (RDI $_{75\%\ ETc}$ + F) as compared to the treatments not subjected to fertigation i.e both T_2 (RDI $_{75\%\ ETc}$), T_3 (RDI $_{75\%\ ETc}$), T_4 (RDI $_{75\%\ ETc}$) and T_5 (RDI $_{75\%\ ETc}$) whereas, panicle appearance (19th February) and full bloom (11th March) was last (100% ETc) respectively in plants treated with full irrigation (T_1) as compared both fertigated and non fertigated plants. During the second year (2018), the date of panicle appearance (15th February), full bloom (8th March), was recorded earlier in the treatments receiving fertigation i.e T_6 (RDI $_{75\%\ ETc}$ + F) as compared to the treatments not subjected to ferigation i.e both T_2 (RDI $_{75\%\ ETc}$), T_3 (RDI $_{75\%\ ETc}$), T_4 (RDI $_{75\%\ ETc}$) and T_5 (RDI $_{75\%\ ETc}$) whereas, panicle appearance (21st February) full bloom (15th March) was last respectively, in plants treated with full irrigation T_1 (100% ETc) as compared both fertigated and non fertigated plants. Sharma *et al.*, 2015 [41] found that under water stress condition the initiation of flowering is earlier and this might be due to accumulation of maximum photosynthesis favoring fast growth in tomato. These results are supported by findings of Cuevas *et al.*, 2008 who reported that more severe the water stress was, the earlier the blooming resulted. Similarly in mango, water stress also advance bloom date (Nunez-Elisea and Davenport, 1994; Lu and Chacko, 2000) [31, 23]. Sidhu and Bal (2009) [45] reported that ber plants irrigated at stress condition (cumulative Epan 150 mm) were first to flower, attain full bloom and first to complete flowering phase as compared to the plants which were irrigated at 50, 75, 100 and 125 pan cumulative evaporation. Early flowering under drip fertigation had been documented by Prabhakar *et al.* (2001) [32], Meenakshi and Vadivel (2003) [28] and Kavitha (2005) [19] in tomato. This indicated that nutrient availability at regular intervals in water soluble form and judicious water availability might have helped early flowering and harvesting of the crop.
In the present studies, potassium nitrate showed a very positive effect on the panicle emergence. The higher per cent of panicle appearance in KNO_3-1% treated trees might be due to the fact that KNO_3 acts as a bud dormancy breaking agent (Tongumpai *et al.*, 1989) [48]. Potassium nitrate is a universal rest-breaking agent in deciduous fruit trees (Erez and Lavee, 1974) [11] that may simply hasten flower emergence of a differentiated, but dormant, mango bud.

Table 2: Effect of different irrigation regimes and fertigation on date of appearance of panicle and date of full blossom of mango cv. Dashehari

	Date of appearance of panicle		Date of full blossom	
Treatment	**2017**	**2018**	**2017**	**2018**
T_1: 100% ETc	19th of Feb	21st of Feb	11th of March	15th of March
T_2: RDI 75% ETc evenly applied under the canopy	16th of Feb	18th of Feb	9th of March	12th of March
T_3: PRD 75% ETc applied to alternating sides of the root system	16th of Feb	18th of Feb	9th of March	12th of March
T_4: RDI 50% ETc evenly applied under the canopy	18th of Feb	19th of Feb	10th of March	14th of March
T_5: PRD 50% ETc applied to alternating sides of the root system	18th of Feb	19th of Feb	10th of March	14th of March
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	13th of Feb	15th of Feb	6th of March	8th of March
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	13th of Feb	15th of Feb	6th of March	8th of March
T_8: RDI 50% ETc evenly applied under the canopy + Fertigation	15th of Feb	17th of Feb	8th of March	11th of March
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	15th of Feb	17th of Feb	8th of March	11th of March
T_{10}: No Irrigation	14th of Feb	15th of Feb	7th of March	7th of March

Length and Breadth of panicle
The data presented in Table 3 during both the year 2017 and 2018 respectively revealed that panicle length (26.57 cm and 25.18 cm) and panicle breadth (13.53 cm and 11.78 cm) was recorded maximum under T_7 comprising of PRD $_{75\%\ ETc}$ + F and minimum panicle length (18.52 cm and 17.37 cm) and breadth (10.88 cm and 9.52 cm) was recorded under T_{10} i.e no irrigation and similar trend was followed in pooled data. The results are in line with Sarker and Rahim (2013) [39] who reported that there were significant differences in terms of terminal shoot length, number of leaves per terminal shoot, leaf area, length and breadth of panicle and number of secondary branches per panicle as influenced by different irrigation treatments and this might be due to the uptake of sufficient nutrient elements from the soil. Kumar and Jaiswal (2004) [20] stated that possible cause of difference in panicle length and width may be due to environmental conditions. The results were in accordance with the findings of Majumder *et al.* (2011) [25] and Kundu *et al.* (2009) [22]. Garad *et al.* (2013) [12] who stated that the maximum panicle length (34.41 cm) was observed by spraying of KNO_3 1%.

Table 3: Effect of different irrigation regimes and fertigation on length of panicle (cm) and breadth of panicle (cm) of mango cv. Dashehari

	Length of Panicle (cm)			Breadth of Panicle (cm)		
Treatment	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: 100% ETc	19.89ef	18.62ef	19.25ef	12.54ab	10.27bc	11.40ab
T_2: RDI 75% ETc evenly applied under the canopy	20.38de	19.24def	19.81ef	12.58ab	12.31abc	12.44ab
T_3: PRD 75% ETc applied to alternating sides of the root system	20.71de	19.57de	20.14de	12.71ab	10.65abc	11.68ab
T_4: RDI 50% ETc evenly applied under the canopy	19.27ef	18.03gh	18.65fg	12.32ab	10.01bc	11.65bc
T_5: PRD 50% ETc applied to alternating sides of the root system	19.64ef	18.28gh	18.96efg	12.39ab	10.13bc	11.26bc
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	24.38b	23.71b	24.04b	13.34a	11.72a	12.53ab
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	26.57a	25.18a	25.87a	13.53a	11.78a	12.65a
T_8: RDI 50% ETc evenly applied under the canopy + Fertigation	21.88cd	20.36d	21.12d	12.96a	10.82abc	11.89ab
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	22.96bc	21.57c	22.26c	13.25a	11.34ab	12.29ab
T_{10}: No Irrigation	18.52f	17.37h	17.94g	10.88b	9.52c	10.20c

Table 4: Effect of different irrigation regimes and fertigation on duration of flowering and date of maximum fruit set of mango cv. Dashehari

	Duration of flowering		Date of maximum fruit set		Date of harvest	
Treatment	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
T_1: 100% ETc	24	23	29th of March	30th of March	20th of June	22nd of June
T_2: RDI 75% ETc evenly applied under the canopy	25	25	26th of March	28th of March	18th of June	19th of June
T_3: PRD 75% ETc applied to alternating sides of the root system	25	25	26th of March	28th of March	18th of June	19th of June
T_4: RDI 50% ETc evenly applied under the canopy	22	24	28th of March	29th of March	19th of June	20th of June
T_5: PRD 50% ETc applied to alternating sides of the root system	22	24	28th of March	29th of March	19th of June	20th of June
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	25	27	22nd of March	24th of March	14th of June	15th of June
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	25	27	22nd of March	24th of March	14th of June	15th of June
T_8: RDI 50% ETc evenly applied under the canopy +Fertigation	23	26	24th of March	26th of March	17th of June	18th of June
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	23	26	24th of March	26th of March	17th of June	18th of June
T_{10}: No Irrigation	22	21	23rd of March	25th of March	14th of June	15th of June

Duration of flowering, Date of maximum fruit set and Date of harvest

Data in Table 4 showed that longest duration of flowering was recorded in treatments receiving fertigation i.e T_6 (RDI $_{75\%\ ETc}$ + F) on (25 and 27 days) during both the years 2017 and 2018 as compared to the treatments not subjected to fertigation, whereas, shortest duration of flowering was recorded in T_{10} i.e no irrigation. So far as the start of flowering as well as its duration is concerned with KNO_3- 1% flowered earlier and thus reduced the duration of flowering period. Early initiation of panicle, flowering and lesser duration in these processes are in line with Ubale and Banik (2017a) [49] who observed shortest flowering duration in the trees treated with KNO_3 2% (14 days) whereas longest (20 days) was perceived with T_7 (Control - water spray) and T_8 (Control, without water), respectively. Earlier flowering in mango promoted by foliar spray of KNO_3, which promotes ethylene biosynthesis has also been reported by Mosqueda-Vazquez and Avila-Resendiz (1985) [31]. The data presented in Table 4 also showed that the date of maximum fruit set and date of harvest was recorded earlier (22nd March and 14th June, respectively) in the treatments T_6 i.e (RDI $_{75\%\ ETc}$ + F) as compared to the treatments T_2 (RDI $_{75\%\ ETc}$), T_3 (RDI $_{75\%\ ETc}$), T_4 (RDI $_{75\%\ ETc}$) and T_5 (RDI $_{75\%\ ETc}$) whereas, date of maximum fruit set and date of harvest was last (100% ETc) i.e, 29th March and 20th June, respectively in plants treated with full irrigation (T_1) as compared both fertigated and non fertigated plants during the year 2017 while during the second year (2018), the date of maximum fruit set and date of harvest was recorded earlier (24th March and 15th June, respectively) in the treatments T_6 (RDI $_{75\%\ ETc}$ + F) as compared to the treatments not subjected to ferigation i.e both T_2 (RDI $_{75\%\ ETc}$), T_3 (RDI $_{75\%\ ETc}$), T_4 (RDI $_{75\%\ ETc}$) and T_5 (RDI $_{75\%\ ETc}$) whereas, date of maximum fruit set and date of harvest was last (30th March and 22nd June, respectively) in plants treated with full irrigation T_1 (100% ETc) as compared both fertigated and non fertigated plants. Sharma *et al.*, 2015 [41] found that under water stress condition the initiation of flowering is earlier and this might be due to accumulation of maximum photosynthesis favoring fast growth in tomato. These results are supported by findings of Cuevas *et al.*, 2008 [7] who reported that more severe the water stress was, the earlier the blooming resulted.

Tree Height

Data presented in Table 5 showed that during both the years 2017 and 2018 respectively, the tree height and spread were recorded maximum under treatments receiving fertigation as compared to the treatments not subjected to fertigation. It was also observed that the treatments receiving deficit irrigation at 75% ETc recorded higher tree height and spread as compared to treatments receiving irrigation at 50% ETc and no irrigation. The optimum and continuous availability of water to the plants under 75% ETc drip irrigation treatments may be accounted for better vegetative and reproductive growth of plants. Tree height (5.97 cm and 6.18 cm) and spread east-west (4.91 cm and 5.22 cm), north south (4.64 cm and 4.93 cm) was higher in case of full irrigation i.e 100% ETc (T_1) followed by T_7 (PRD $_{75\%\ ETc}$ + F) during both the years. However, lowest tree height (4.78 cm and 4.95 cm) and spread east-west (2.72 cm and 3.18 cm) was recorded under no irrigation (T_{10}). These results are in conformity with those of Yuan *et al.* (2004) [51], who obtained significantly higher plant growth attributes and more number of leaves with increasing the amount of irrigation water from Ep 0.75 to Ep

1.25 in strawberry. Similar results were obtained by Kumar *et al*. (2012) [21] in strawberry, who found that irrigation at 1.0 IW/CPE ratio, significantly increased crown height, plant spread, than other irrigation levels. Further, they also observed that limited water availability decreased plant growth attributes. The plants irrigated at 50% ETc and no irrigation attained less vegetative growth than those of 75% ETc. The plants irrigated at 50% ETc through drip attained less vegetative growth in terms of plant height, during both the years of study. Irrigation at 50% ETc results into water stress condition in the soil during the active growing period due to more evaporation of water and limited application of irrigation water which resulted in the reduction of uptake of nutrients and may have accounted for poor vegetative and reproductive growth. These results are in agreement with the findings of Rolbiecki *et al*. (2004) [37], who observed significant reduction in vegetative growth of strawberry under no irrigation treatments. Further they concluded that reduction in vegetative growth of strawberry under no irrigation treatment was due to water stress condition in the soil during active growing period.

Different fertilization methods gave a variable impact on vegetative growth characteristic of mango. The maximum vegetative growth in terms of tree height, tree spread were observed in plants fertigated with K_2SO_4 (0.5%), H_3BO_3 (0.5%) and $Ca(NO_3)_2$(1%) The increased nutrients content might have increased the rate of various physiological and metabolic processes in the plant system, ultimately resulted in higher vegetative growth parameters. These results are in accordance with the findings of Martinsson *et al*. (2006) [27]. The higher growth parameters recorded under these fertigation treatments may be due to increased nutrient use efficiency by minimizing the leaching losses through drip.

Stock girth and scion girth

The analysis data on stock girth and scion girth of mango has been presented in Table 6. In first and second year of study, stock girth was highest in case of full irrigation i.e 100% ETc (T_1) (63.53 cm and 65.72 cm) during 2017 and 2018, respectively, than plants treated at 50% ETc i.e T_4 and T_5. Highest stock girth was observed when deficit irrigation was supplemented with fertigation under treatment T_7 i.e. PRD $_{75\%\ ETc}$ + F with 63.37 cm and 65.58 cm during 2017 and 2018, respectively. However, the lowest stock girth was recorded under no irrigation (T_{10}) with 54.36 cm and 56.67 cm during first and second year of experimental study, respectively. A similar pattern was observed in the pooled data of stock girth. Whereas in case of scion girth was higher in plants treated with 100% ETc i.e T_1 (53.95 cm and 55.89 cm) during 2017 and 2018, respectively, than plants treated at 50% ETc i.e T_4 (RDI $_{50\%\ ETc}$) 53.69 cm and 55.56 cm in 2017 and 2018, respectively and T_5 i.e (PRD $_{50\%\ ETc}$) 51.24 cm and 53.68 cm during 2017 and 2018, respectively. Maximum scion girth was recorded when deficit irrigation was provided with fertigation under T_7 i.e PRD $_{75\%\ ETc}$ + F with values of 59.81 cm and 62.70 cm during 2017 and 2018, respectively, whereas minimum scion girth was observed under T_{10} i.e no irrigation (48.34 cm and 50.83 cm) during first and second year of experiment. A similar pattern in scion girth was observed in pooled data. The reduction in trunk girth either due to deficit or surplus water availability to the plants in the present study can be attributed to the fact that the reduced water potential might have resulted in low uptake of water and nutrients. The observations made during the present study are in conformity with the findings of Bhardwaj *et al.* (2010) [5] who reported that apple tree had 12 per cent increased trunk girth and 92 per cent increased shoot growth under drip irrigation, whereas in basin irrigation trunk girth increased only up to 6 per cent and shoot growth up to 32 per cent as compared to plant grown under rainfed conditions. Dolker *et al.* (2017) [8] also that reported maximum plant height, stock girth, scion girth and plant volume were recorded under plants supplied with RDI at 100% ETc whereas, the minimum value were with plants treated with no irrigation and this might be due to the fact that plants grown under rainfed conditions or water stress conditions might have saturated the root zone, thereby reduced the oxygen level and respiration rate resulting into low uptake of nutrients and inhibited proper growth and vigour of plants. The similar type of observations were also recorded in the earlier studies on irrigation scheduling in Nagpur mandarin (Shirgure *et al.*, 2014) [42], kinnow mandarin by Panigrahi *et al.* (2014) and Nagpur mandarin by Shirgure *et al.* (2016) [43]. Mills *et al.* (1996) [29] also reported that the higher trunk girth obtained with availability of water might be due to higher absorption of water and nutrient from soil, better translocation of assimilates and production of harmones from roots and better unloading through phloem.

Table 5: Effect of different irrigation regimes and fertigation on tree height (m), Tree spread (East-West (m) and North-South (m)) of mango cv. Dashehari

	Tree height (m)			Tree spread					
				East-West (m)			North-South (m)		
Treatment	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1: 100% ETc	5.97^{a}	6.18^{a}	6.07^{a}	4.91^{a}	5.22^{a}	5.06^{a}	4.64^{a}	4.93^{a}	4.78^{a}
T_2: RDI 75% ETc evenly applied under the canopy	5.26^{ef}	5.39^{fg}	5.32^{ef}	3.58^{cd}	3.95^{bc}	3.76^{def}	3.31^{cd}	3.77^{cde}	3.54^{de}
T_3: PRD 75% ETc applied to alternating sides of the root system	5.35^{de}	5.47^{ef}	5.41^{de}	$3.74b^{cd}$	4.17^{bc}	3.95^{cde}	3.58^{bc}	3.83^{bcde}	3.70^{cde}
T_4: RDI 50% ETc evenly applied under the canopy	5.11^{f}	5.22^{g}	$5.16f^{g}$	2.97^{d}	3.39^{de}	3.18^{fg}	2.72^{d}	3.04^{ef}	2.88^{f}
T_5: PRD 50% ETc applied to alternating sides of the root system	5.18^{f}	5.26^{g}	5.22^{fg}	3.25^{cd}	3.63^{cde}	3.44^{efg}	3.06^{cd}	3.35^{def}	3.20^{ef}
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	5.69^{b}	5.81^{bc}	5.75^{bc}	4.40^{ab}	4.72^{ab}	4.56^{ab}	4.28^{ab}	4.45^{abc}	4.36^{abc}
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	5.76^{b}	5.90^{b}	5.83^{b}	4.63^{ab}	4.95^{ab}	4.79^{ab}	4.39^{ab}	4.68^{ab}	4.53^{ab}
T_8: RDI 50% ETc evenly applied under the canopy +Fertigation	5.48^{cd}	5.59^{de}	5.53^{cd}	3.82^{bcd}	4.25^{bc}	4.03^{cde}	3.66^{bc}	4.01^{bcd}	3.83^{cde}
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	5.60^{bc}	5.70^{cd}	5.65^{cd}	4.16^{abc}	4.49^{abc}	4.32^{bcd}	3.88^{abc}	4.23^{abcd}	4.05^{bcd}
T_{10}: No Irrigation	4.78^{g}	4.95^{h}	4.86^{h}	2.72^{d}	3.18^{e}	2.95^{g}	2.53^{d}	2.76^{f}	2.64^{f}

Table 6: Effect of different irrigation regimes and fertigation on stock girth and scion girth of mango cv. Dashehari

	Stock girth (cm)			Scion girth (cm)		
Treatment	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: 100% ETc	63.53^{a}	65.72^{a}	64.62^{a}	59.81^{a}	62.70^{a}	61.25^{a}
T_2: RDI 75% ETc evenly applied under the canopy	58.79^{de}	60.77^{d}	59.78^{cd}	51.24^{de}	53.68^{e}	52.46^{e}
T_3: PRD 75% ETc applied to alternating sides of the root system	59.67^{bc}	61.39^{c}	60.53^{c}	54.98^{cd}	57.09^{c}	56.03^{cd}
T_4: RDI 50% ETc evenly applied under the canopy	57.47^{d}	59.72^{cd}	58.59^{cd}	52.65^{cd}	54.79^{cde}	53.72^{de}
T_5: PRD 50% ETc applied to alternating sides of the root system	57.54^{d}	60.55^{cd}	59.04^{ef}	52.19^{cde}	55.06^{de}	53.62^{de}
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	62.28^{ab}	63.47^{b}	62.87^{ab}	58.26^{ab}	59.45^{b}	58.85^{b}
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	63.37^{ab}	65.58^{a}	64.47^{ab}	59.35^{a}	61.89^{a}	60.62^{a}
T_8: RDI 50% ETc evenly applied under the canopy +Fertigation	59.44^{cd}	61.82^{c}	60.63^{cd}	54.53^{cd}	56.87^{cd}	55.70^{cde}
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	62.04^{bc}	63.34^{b}	62.69^{b}	58.02^{bc}	59.32^{b}	58.66^{b}
T_{10}: No Irrigation	54.36^{e}	56.67^{e}	55.51^{e}	48.34^{e}	50.83^{f}	49.58^{f}

Physical characteristics

Fruit weight and fruit volume

The perusal of the data presented in Table 7 revealed that fruit weight and fruit volume was significantly affected by different treatments during 2017 and 2018. During both the years, it was observed that fruit weight was higher in plants treated with deficit irrigation with fertigation (T_7) PRD 75% ETc + F and minimum was recorded in treatment (T_{10}) no irrigation. According to Marscher (1995) [26], a balanced supply of nutrients promoted the carbohydrate assimilation and its efficient translocation for the fruit development processes, which would directly influence the enhancement of fruit weight. The increased fruit weight under fertigation might be ascribed to better utilization of water, minimum losses of water through percolation and evaporation, and excellent soil-water-air relationship with higher oxygen concentration in the root zone and higher uptake of nutrients. These results are in agreement with the findings of Gornet *et al*. (1973) [14] in cucumber and Bafna *et al*. (1993) [4] in tomato. Appreciable improvement in fruit weight by borax application had been also reported by Dutta (2004) [10] in mango cv. Himsagar. Boron facilitates sugar transport within the plant and it was also reported that borate react with sugar to form a squgar-borate complex (Gauch and Dugger, 1953) [13]. Increase in fruit weight with the application of borax has been also observed by Raychaudhary *et al.* (1992) [36] in guava.

Fruit size

Fruit length and Fruit breadth

The data presented in Table 8 revealed that during both the years 2017 and 2018 respectively, the fruit length (10.37 and 10.40 cm) and fruit breadth (6.31 cm and 6.33 cm) was found maximum when plants are treated with (T7) PRD 75% ETc + F and minimum fruit length (8.75 cm and 8.77 cm) and fruit breadth (5.97 cm and 5.99 cm) was recorded in T_{10} no irrigation and Similar pattern was observed in pooled data. The higher fruit size and weight under 75% ETc (RDI and PRD) with fertigation and also in 100% ETc through drip irrigation treatments may be attributed to optimum soil moisture content maintained by frequent irrigations and better nutrients availability during the entire growth period. These results are in line with the findings of Yuan *et al*. (2004) [51], who found that the size and weight of strawberry fruit increased with the increase in amount of irrigation water from Ep 0.75 to Ep 1.25. Similarly, Sharma *et al*. (2005) [40] also noticed significant increase in strawberry fruit size and weight under drip irrigation. They emphasized that increase in size and weight of fruits may be due to availability of optimum soil moisture content throughout entire growth period because of frequent irrigation coupled with better nutrient supply. The possible reason for higher fruit weight under T_7 may be due to water deficit in root zone under this treatment suppressed the vegetative growth of the plants without bringing much effect on leaf photosynthesis rate and the mango plants invested higher quantity of photosynthates towards reproductive growth (fruiting) than vegetative growth. Similarly, Proietti and Antognozzi (1996) [33] in olive reported that larger fruit size was primarily the result of a larger number of cells and the positive effect of water availability on the cell division rather than cell expansion.

Fertigation with nutrients registered a significant higher size and weight of fruits. This may be ascribed to the increased synthesis of metabolites due to higher nutrient levels and their translocation to the fruits. These results are in accordance with the findings of Thakur and Singh (2004) [47] in mango cv. Amarpalli and Mahalakshmi *et al.* (2001) [24] in banana, who observed significant increase in fruit size and weight with Fertigation. Similarly, Martinsson *et al.* (2006) [27] also observed better size and weight of strawberry under fertigation compared to common soil application.

Table 7: Effect of different irrigation regimes and fertigation on fruit weight (g) and fruit volume (cm^3) of mango cv. Dashehari

	Fruit weight (m)			Fruit volume (cm^3)		
Treatment	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: 100% ETc	177.52^{g}	185.72^{g}	181.62^{g}	173.25^{f}	179.87^{f}	176.56^{g}
T_2: RDI 75% ETc evenly applied under the canopy	181.92^{f}	188.41f	185.16^{f}	174.98^{f}	180.72^{f}	177.85^{f}
T_3: PRD 75% ETc applied to alternating sides of the root system	187.38^{e}	190.42^{e}	188.90^{e}	184.79^{e}	187.51^{e}	186.15^{e}
T_4: RDI 50% ETc evenly applied under the canopy	168.76^{i}	180.42^{i}	174.59^{i}	162.98^{h}	174.72^{h}	168.85^{i}
T_5: PRD 50% ETc applied to alternating sides of the root system	172.88^{h}	183.88^{h}	178.38^{h}	169.43^{g}	176.95^{g}	173.19^{h}
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	200.36^{b}	200.52^{b}	200.44^{b}	207.85^{b}	201.75^{b}	204.80^{b}
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	206.45^{a}	208.29^{a}	207.37^{a}	213.87^{a}	216.56^{a}	215.21^{a}
T_8: RDI 50% ETc evenly applied under the canopy +Fertigation	192.64^{d}	194.51^{d}	193.57^{d}	191.29^{d}	191.74^{d}	191.51^{d}
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	196.57^{c}	198.44^{c}	197.50^{c}	199.62^{c}	196.66^{c}	198.14^{c}
T_{10}: No Irrigation	157.76^{j}	175.44^{j}	166.60^{j}	158.95^{i}	173.85^{h}	166.40^{j}

Table 8: Effect of different irrigation regimes and fertigation on fruit weight (g) and fruit volume (cm^3) of mango cv. Dashehari

	Fruit size					
	Fruit length (cm)			Fruit breadth (cm)		
Treatment	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1: 100% ETc	9.58^{ab}	9.60^{ab}	9.59^{ab}	6.09^{b}	6.11^{ab}	6.10^{b}
T_2: RDI 75% ETc evenly applied under the canopy	9.61^{ab}	9.64^{ab}	9.62^{ab}	6.13^{b}	6.15^{ab}	6.14^{b}
T_3: PRD 75% ETc applied to alternating sides of the root system	9.64^{ab}	9.66^{ab}	9.65^{ab}	6.16^{ab}	6.19^{a}	6.17^{b}
T_4: RDI 50% ETc evenly applied under the canopy	9.53^{ab}	9.56^{ab}	9.54^{ab}	6.01^{b}	6.03^{ab}	6.02^{b}
T_5: PRD 50% ETc applied to alternating sides of the root system	9.55^{ab}	9.58^{ab}	9.56^{ab}	6.05^{b}	6.08^{ab}	6.06^{b}
T_6: RDI 75% ETc evenly applied under the canopy + Fertigation	10.34^{a}	10.36^{a}	10.35^{a}	6.27^{ab}	6.29^{a}	6.28^{a}
T_7: PRD 75% ETc applied to alternating sides of the root system + Fertigation	10.37^{a}	10.40^{a}	10.38^{a}	6.31^{a}	6.33^{a}	6.32^{a}
T_8: RDI 50% ETc evenly applied under the canopy +Fertigation	10.28^{a}	10.23^{ab}	10.25^{a}	6.19^{ab}	6.21^{a}	6.20^{ab}
T_9: PRD 50% ETc applied to alternating sides of the root system + Fertigation	10.31^{a}	10.34^{a}	10.32^{a}	6.23^{ab}	6.25^{a}	6.24^{a}
T_{10}: No Irrigation	8.75^{b}	8.77^{b}	8.76^{c}	5.97^{b}	5.99^{b}	5.98^{b}

Economics

Benefit cost ratio as influenced by different irrigation and fertigation levels was calculated and is presented in Table 9, 10, 11 and 12. During both the years of investigation benefit: cost ratio was significantly affected by the treatments as compared to control. During the first year, highest benefit cost ratio (1:2.30) was recorded in fruits harvested from mango plants receiving PRD $_{75\%\ ETc}$ + F i.e T_7 followed by treatment T_6 (1:2.14) (RDI $_{75\%\ ETc}$ + F) whereas lowest benefit cost ratio (1:1.31) was recorded under treatment with T_{10} (no irrigation). The findings of second year also recorded the maximum benefit cost ratio (1:4.87) under treatment T_7 (PRD $_{75\%\ ETc}$ +F) as compared to other treatments whereas, minimum benefit cost ratio (1:3.23) was recorded under treatment with T_{10} (no irrigation). This may be due to the fact that the cost of cultivation increased with the increase in application of irrigation level and due to increased production. The present results are in conformity with the findings of Bhattacharya (2010) [6] found that the benefit cost ratio was the highest in treatment combination of drip irrigation at 0.75 EpR and fertigation with 75 per cent recommended dose of N and K which was closely followed by treatment combination of drip irrigation at 0.75 EpR and fertigation with 100 per cent recommended dose of N and K through drip in banana cv. Barjahaji (AAA)

Sujatha and Haris (2006) [46] indicated that, drip irrigation resulted in realizing a net return of `68,581 ha-1. Similarly the net return per rupee investment was also higher with drip fertigation system in arecanut.

Table 9: Effect of different irrigation regimes and fertigation on Cost benefit ratio of mango cv. Dashehari in the year 2017

S. No.	Treatment/Particular	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
1	Cost of system for 3 trees	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	-
2	Interest cost@ 12%	126	126	126	126	126	126	126	126	126	
3	Operation coste. Repair & Maintenance @ 1%	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	
4	Cost of basin preparation /tree (Rs)	135	135	135	135	135	135	135	135	135	135
5	Cost of FYM/tree (Rs)	420	420	420	420	420	420	420	420	420	420
6	Cost of Urea/tree (Rs.)	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
7	Cost of DAP/tree (Rs)	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50
8	Cost of MOP/tree (Rs)	27	27	27	27	27	27	27	27	27	27
9	Cost of fertigation	-	-	-	-	-	1075.89	1075.89	1075.89	1075.89	-
10	Miscellaneous (plant protection measures, harvesting of fruits etc.) (Rs)	500	500	500	500	500	500	500	500	500	500
11	Total cost/treatment(for three trees)	2304.5	2304.5	2304.5	2304.5	2304.5	3380.39	3380.39	3380.39	3380.39	1118
12	Total cost/Tree	768.16	768.16	768.16	768.16	768.16	1123.45	1123.45	1123.45	1123.45	372.66
13	Total cost/ha	119832.96	119832.96	119832.96	119832.96	119832.96	175258.20	175258.20	175258.20	175258.20	58134.96

Table 10: Effect of different irrigation regimes and fertigation on Cost benefit ratio of mango cv. Dashehari in the year 2017

S. No.	Treatment/Particular	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
1	Average yield/tree(2017)	29.19	32.62	34.24	26.18	27.24	43.86	47.02	36.57	39.88	19.63
2	Average yield/ha	4553.64	5088.72	5341.44	4084.08	4249.44	6842.16	7335.12	5704.92	6221.28	3062.28
	Price/kg (Rs.)	40	40	40	40	40	55	55	55	55	25
3	Gross return/tree(Rs.)	1167.6	1304.8	1369.6	1047.2	1089.6	2412.3	2586.1	2011.35	2193.4	490.75
4	Cost of cultivation/tree (Rs.)	768.16	768.16	768.16	768.16	768.16	1298.08	1298.08	1119.20	1119.20	372.66
5	Net returns/tree (Rs.)	399.44	536.64	601.44	279.04	321.44	1114.22	1288.02	713.27	895.32	118.09
6	Net returns/ha (Rs.)	62312.64	83715.84	93824.64	43530.24	50144.64	173818.32	200931.12	111270.12	139669.92	18422.04
7	Benefit Cost ratio	1:1.51	1:1.69	1:1.78	1:1.36	1:1.41	1:2.14	1:2.30	1:1.79	1:1.95	1:1.31

Table 11: Effect of different irrigation regimes and fertigation on Cost benefit ratio of mango cv. Dashehari in the year 2018

S. No.	Treatment/Particular	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
1	Cost of system for 3 trees	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	-
2	Interest cost@ 12%	126	126	126	126	126	126	126	126	126	
3	Operation coste. Repair & Maintenance @ 1%	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	
4	Cost of basin preparation /tree (Rs)	135	135	135	135	135	135	135	135	135	135
5	Cost of FYM/tree (Rs)	420	420	420	420	420	420	420	420	420	420
6	Cost of Urea/tree (Rs)	11.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
7	Cost of DAP/tree (Rs)	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50	25.50
5	Cost of MOP/tree (Rs)	27	27	27	27	27	27	27	27	27	27
8	Cost of fertigation	-	-	-	-	-	985.62	985.62	985.62	985.62	-
9	Miscellaneous (plant protection measures, harvesting of fruits etc.) (Rs)	500	500	500	500	500	500	500	500	500	500
10	Total cost/treatment(for three trees)	2304.5	2304.5	2304.5	2304.5	2304.5	3290.12	3290.12	3290.12	3290.12	1118
11	Total cost/Tree	768.16	768.16	768.16	768.16	768.16	1096.70	1096.70	1096.70	1096.70	372.66
12	Total cost/ha	119832.96	119832.96	119832.96	119832.96	119832.96	171085.20	171085.20	171085.20	171085.20	58134.96

Table 12: Effect of different irrigation regimess and fertigation on Cost benefit ratio of mango cv. Dashehari in the year 2018

S. No.	Treatment/Particular	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
1	Average yield/tree	76.85	78.90	80.45	71.73	73.42	92.42	97.11	84.20	90.12	60.32
2	Average yield/ha	11988.6	12308.4	12550.2	11189.8	11453.52	14417.52	15149.16	13135.2	14058.72	9409.92
	Price/kg (Rs.)	35	35	35	35	35	55	55	55	55	25
3	Gross return/tree(Rs.)	2689.75	2761.5	2815.75	2510.55	2569.7	5083.1	5341.05	4631	4956.6	1508
4	Cost of cultivation/tree (Rs.)	768.16	768.16	768.16	768.16	768.16	1273.48	1273.48	1198.27	1198.27	372.66
5	Net returns/tree (Rs.)	1921.59	1993.34	2047.59	1742.39	1801.54	3809.62	4067.57	3432.73	3758.33	1135.34
6	Net returns/ha (Rs.)	299768.04	310961.04	319424.04	271812.84	281040.24	594300.72	634540.92	535505.88	586299.48	177113.04
7	Benefit Cost ratio	1:3.50	1:3.59	1:3.66	1:3.26	1:3.34	1:4.63	1:4.87	1:4.22	1:4.51	1:3.23

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