STANDARDIZATION OF FERTIGATION DOZE FOR OPEN AND PROTECTED CULTIVATION OF PAPAYA IN PUNJAB

A

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ABSTRACT

The gynodioecious papaya cultivars 'Red Lady 786' and 'Surya' have great potential to utilize water and nutrient resources under protected cultivation when supplemented with fertigation treatment. Both the cultivars were planted in two growing conditions *viz.* poly-net house and open field and were applied with four fertigation (60, 80, 100 and 120 percent recommended fertilizer dose) and one conventional fertilization (100 percent recommended fertilizer dose with conventional means) treatment. The experiment was conducted in completely randomized block design (factorial) with the objectives to standardize fertigation dose and to evaluate papaya performance in protected and open fields. The study resulted in increased plant height, stem girth, plant spread, number of functional leaves, height of first flowering, final harvest duration, fruit yield, fruit TSS and fruit sugar content in both the cultivars that were under fertigation, while the poly-net house growing conditions revealed superior plant height, number of functional leaves, average fruit size, fruit weight, fruit yield, edible portion percentage, TSS/acid ratio and fruit sugar content. A significant advancement in flower initiation, fruit set initiation and first fruit maturity of 'Red Lady 786' as well as 'Surya' papaya was observed due to fertigation and green house combination. Among various macro and micro-nutrients, the foliar status of N, K, Ca, Mg, Fe, Zn, Mn and Cu in 'Red Lady 786' and 'Surya' papaya was improved with fertigation. However, the protected field conditions resulted in increased leaf concentration of N, Mg, Zn and Mn as compared to open field in both papaya varieties. It can be concluded that in sub-tropical climatic conditions, papaya production under protected conditions accompanying the application of 80 percent recommended fertilizer dose through drip irrigation was the best treatment in both ‘Red Lady 786’ and ‘Surya’ papaya cultivars resulting in earlier fruit maturity and bearing bigger size fruits ultimately causing adequate fruit yield along with superior quality fruit production in terms of fruit edible portion, total soluble solids and sugars content.

Keywords: Red Lady 786, Surya, fertigation, sub-tropics, nutrition.

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CHAPTER I

INTRODUCTION:

Papaya (*Carica papaya* L.) belonging to family *Caricaceae*, is an important fruit of tropical world and has been known with the name of 'wonder fruit of tropics'. *Carica papaya* is the only species which is grown for edible fruits, out of all 48 species known in *Caricaceae* family. Wide varietal diversity in cultivated papaya exists, which may be monoecious, dioecious and hermaphrodite. Papaya is believed to be originated in tropical America. The Spanish and Portuguese sailors took papaya crop to Caribbean and South East Asia during Spanish exploration in 16^{th} century. Further, it rapidly got distributed to India, Oceania, Africa and now is widely grown in tropical and warmer sub-tropical regions of the world between 32° north and 32° south latitudes. In different languages, papaya is known by different names as papita (Hindi), papaiya (Gujarati), pepe (Bengali), pharangi (Kannad), omakai (Malayalam), papai (Marathi), boppayi pandu (Telgu) and pappali (Tamil).

Papaya is a single stemmed plant growing from 2 to 5 meter height with large and lobed leaves confined to top of the plant. The flowers appear on the axils of the leaves which further develop into fruits. Papaya has highest productivity among fruit crops, which lead to increased commercial area under this crop during last few decades.

Globally papaya is extensively grown in countries like India, Brazil, Indonesia, Nigeria, Mexico, Australia, Hawaii, SriLanka, Malaya, Myanmar, Taiwan, Peru, Puerto Rico, Florida, Texas, California, South Africa and Kenya. India and Brazil are the major producers of papaya contributing 57% of the world's total production of 12.4 million tonnes (Anonymous, 2016).

In India, papaya is commercially grown in Andhra Pradesh, Gujarat, Karnataka, West Bengal, Madhya Pradesh and Maharashtra. It is grown on an area of 1.38 lakh ha with a production of 5.989 million tonnes (Anonymous, 2017). The productivity of papaya in India is low (43.39 tonnes/ha) as compared to Indonesia (85.8 tonnes/ha) and Brazil (54.5 tonnes/ha). This could be attributed to inherent low production capacity of local cultivars, problems of biotic and abiotic stresses, root rot, water logging and flooding, lack of knowledge and support for the quality production and poor adoption of post harvest handling and management practices. Thus, there is a vast scope to improve the productivity of papaya in the country through appropriate measures. In Punjab state, papaya occupies only a very small un-noticeable area due to the above listed factors that are contradictory to papaya growth.

Its limited commercial cultivation in northern plains of India is mainly attributed to adverse affects of various abiotic and biotic factors like low temperature, frost and viral diseases. The low temperature also hampers the fruit quality in addition to fruit yield. The fruit quality is mainly affected due to non-availability of sufficient heat units. The market value of affected fruits is lowered that incurs heavy losses to the farmers.

Papaya ranks fourth in production after banana, oranges and mango among tropical region fruits. In past, India was a leading producer of papaya fruit in the world but its production had gone up dramatically in other countries whereas in India this rise was at a much slower rate (Kumar *et al*., 2008). It is primarily grown for its delicious taste and for extraction of its digestive constituent papain. Papaya has multiple uses from unripe to ripe fruits. The ripe fruits are consumed as table fruit and may be used as ingredient in many products such as jams, jellies, candies, preserves, etc. It contains digestive acid that acts as an aid for dieting and to reduce fat. The unripe fruits have antimicrobial and antioxidant activities and these unripe fruits are cooked as vegetable. They are used in the treatment of blood pressure and as an aphrodisiac. Young papaya plant leaves are consumed as spinach after cooking. Papain extracted from its fruits is being used in beverages, food, pharmaceutical industries, manufacturing easy digestible children foods and in chewing gums. Due to its multiple uses, it is referred as ‘IInd *Kalpataru*’.

Papaya is named as ‘most nutritious fruit’ by the Centre for Science, USA and Christopher Columbus called it ‘the fruit of angles’. It is a wholesome fruit and has more carotene as compared to apple, guava, sitaphal and plantains. Papaya is a rich source of nutrition particularly in terms of vitamins and minerals. It contains 2500 IU (International units) vitamin A with 85 mg vitamin C per 100 g pulp and is also rich in calcium, potassium and magnesium. Papaya fruit constitutes of 90.8% moisture, 0.6% protein and 7.2% carbohydrates. Besides papain, papaya fruit is also a rich source of many other naturally occurring compounds like alkaloids, pectins, volatile compounds, proteolytic enzymes and growth inhibitors. Even the roots of papaya plant have medicinal value.

Water is an important resource gifted by nature for sustainability of life. Any irrelevant use or misuse of this precious natural resource will definitely lead to demolition of civilization and this is very clear from present scenario. It is forecasted that an annual global water shortage of 640 billion cubic meters will be there by year 2050 (Spears, 2003). All over the world, agriculture is the major sector that consumes fresh water. Therefore, it is the need of hour to divert our focus from per unit area production towards production per unit water consumption (Fereres and Soriano, 2007).

The irrigated agricultural area in India is approximately 807 lakh hectares and in Punjab almost all the agricultural area is irrigated but only a small area is under precision irrigation. In relation to micro-irrigation, the states Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh lead all other states of the country.

The papaya crop dominantly responds to irrigation and fertilizer application in terms of fruit yield. It is a crop having shallow roots and is highly sensitive to soil moisture fluctuations. The irrigation intensity to papaya crop solely depends upon soil texture and climatic conditions of the specific area. Papaya plants show sterility and androecious floral characters due to low soil moisture levels, whereas in high soil moisture conditions, the plants develop undesirable carpelloid types resulting in production of mis-shapened fruits (Singh and Singh, 2002). Where water is in direct contact with the trunk, plant becomes more prone to disease occurrence especially collar rot.

Most efficient method of water application is micro-irrigation especially through drippers (Srinivas, 1996 a). By adopting this system, the water is applied slowly but at frequent intervals over long time period using low pressure delivery system just to meet the evapo-transpirational loss from the crop. Drip system of irrigation is beneficial due to 45-50, 40-50 and 25-30 percent reduction, respectively in water, labour and fertilizer requirement (INCID, 1994). A 54 percent saving of water and 28.84 percent increase in fruit yield has been seen in papaya by using drip irrigation over surface irrigation (Biswas *et al*., 1999). The sensitivity of this crop to soil moisture levels necessitates the use of drip irrigation.

Adjustable fertilizer dozing and its precise application is another favourable edge of micro-irrigation. Fertilizer application through drip irrigation facilitates the availability of nutrients near to root zone and hence improves the nutrient uptake and use efficiency (Elfving, 1982). Chaudhri *et al*. (2001) noticed a substantial increase in papaya fruit yield using drip fertigation with 53 and 50 percent water and fertilizer saving, respectively.

In addition, the protected cultivation technology has a capability to produce good quality fruits. Higher temperatures inside the greenhouse like protected structures aids in fruit quality improvement especially during winters in sub-tropics.

Consequently, in the light of precious merits of micro-irrigation, protected cultivation and to counter day by day reducing underground water table in Punjab, the adoption of drip fertigation system on large scale is necessary. Hence, this experiment is being planned to standardize fertigation doze for most popular papaya cultivars *viz.* 'Red Lady 786' and 'Surya' grown under protected and open field conditions.

OBJECTIVES

The objectives for undertaking the proposed study were:

1. To standardize the fertigation dose for 'Red Lady 786' and 'Surya' papaya cultivars.
2. To compare the performance of papaya cultivars under open and protected conditions.
3. To evaluate the quality parameters of papaya grown under sub-tropical climatic conditions.
4. To evaluate the nutritional status of papaya plant under different fertigation treatments.

CHAPTER II

REVIEW OF LITERATURE

The present investigation entitled "Standardization of fertigation doze for open and protected cultivation of papaya in Punjab" was carried out during the time period of year 2016-2018 in poly-net house unit and open fields available at Centre of excellence for fruits, village- Khanaura in the vicinity of Hoshiarpur district. The literatures considering drip irrigation, fertigation and protected cultivation of papaya and other fruit crops have been reviewed for all parameters under study and have been discussed here, under the following headings and sub-headings:

2.1 Drip irrigation

2.1.1 Effect of drip irrigation on vegetative growth

2.1.2 Effect of drip irrigation on yield and related attributes

2.1.3 Effect of drip irrigation on fruit quality attributes

2.1.4 Effect of drip irrigation on leaf nutrient content

2.2 Fertigation

2.2.1 Effect of fertigation on vegetative growth

2.2.2 Effect of fertigation on yield and related attributes

2.2.3 Effect of fertigation on fruit quality attributes

2.2.4 Effect of fertigation on leaf nutrient content

2.3 Protected cultivation

2.3.1 Effect of protected cultivation on vegetative growth

2.3.2 Effect of protected cultivation on yield and related attributes

2.3.3 Effect of protected cultivation on fruit quality attributes

2.3.4 Effect of protected cultivation on disease/pest incidence

2.1 Drip irrigation

In a future forecast, it has been concluded that an annual global water deficit of 640 cubic meters will be there by year 2050 (Spears, 2003). Worldwide major consumption of fresh water is under agriculture sector, which alarms us to think about it and focus upon production per unit water consumption instead of production per unit area in each and every crop (Feres and Soriano, 2007). Although many areas in the world are irrigated with plenty of water resources, but true value of fresh water can only be judged where scarcity arises and significantly interferes with the human life. For sustainability of life, irrelevant and misuse of precious natural resources should be prohibited, which if done, may cause threat to human life definitely leading to demolition of civilization.

Banker *et al.* (1993) has explained drip system of irrigation as an efficient precise water application system that delivers moisture very close to the root zone of plants. Moreover, Shivanappan (1985) elaborated drip irrigation as a positive role playing system for improving production and ultimately leading to increased income for farmers in addition to be beneficial in water scarcity areas. Mishra and Pyasi (1993) also studied water distribution in soil through irrigation by drip method and found more uniform water distribution within 10 cm radius of drip emitter. The non-uniformity of water increased with distance with maximum uniformity at zero. The movement of water was observed to be rapid immediately after discharge through dripper while this movement slowed down with time. Moreover, Vaidyanathan *et al.* (1994) elaborated the cruciality of adequate and timely application of irrigation and the need of precision irrigation technologies for countries like India where intensive cultivation is already practiced limiting more scope for area expansion. They reported improvement of irrigation methodology as a leading input for enhancing productivity of agricultural crops. Singh *et al.* (2000) especially were working on management strategies for dry land farming, compared the fruit crops performance under drip irrigation and surface irrigation, where, they found drip irrigation to be the best method giving higher yields with low irrigation requirement and improved water efficiency.

Padhye (1990) reported drip irrigation to be significantly effective in saving water, power, labour and annual maintenance cost in comparison to sprinkler system. These savings were found to the extent of 458 kwh, 53 percent and 65 percent respectively in terms of power, water and labour. In another study, Brahmanand and Singadhupe (2000) reported improved fruit yield of pomegranate, guava and custard apple along with maximum water saving in drip irrigation method. Similarly, Srinivas (1999) reported increased fruit yield in mango with drip irrigation done at the rate of 60 litres per plant per week. However, in grapes, Muthuchamy *et al.* (1998) reported highest fruit yield under drip irrigation at the rate of 48 litres per tree per day along with a saving in water upto the extent of 48 percent. Similarly, Singh (2004) also experimented on some vegetable crops and reported a positive response in terms of plant growth and flowering when drip system of irrigation was used. Panigrahi and Srivastava (2017) performed an experiment on mandarins to find out the optimum water and fertilizer requirement. They reported improved fruit plant growth and better quality fruits with high yield in most of the drip irrigation and fertigation combinations in comparison to combination of basin irrigation with band placement of fertilizers. Drip irrigation at 75 percent pan evaporation with 75 percent recommended fertilizer dose application was observed to be promising among all treatments in terms of fruit yield, water use efficiency and fertilizer use efficiency.

2.1.1 Effect of drip irrigation on vegetative growth

Srinivas (1996a) carried out research experiment on papaya cv. 'Coorg honey dew' using drip irrigation. He recorded maximum plant height and stem girth using two emitters per plant and giving daily irrigation at 0.6 PEF (pan evaporation) in comparison to one emitter per plant and alternate day irrigation. In another study, Srinivas (1996b) evaluated papaya crop and water usage at variable evaporation- replenishment rates starting from 20 upto 120 percent of USWB class A pan evaporation. Maximum plant height and stem girth of papaya was seen at 120 percent evaporation-replenishment rate and these parameters were seen escalating with an increase in evaporation-replenishment rate starting from 20.

Santana *et al.* (2008) performed a three year trial to evaluate papaya plant response to different quantities of water applied through drip-trickle irrigation. Among various irrigation levels varying from 0.2 evaporation pan to 1.1 evaporation pan, maximum vegetative growth was observed in 0.8 and 1.1 evaporation pan irrigation. Zimmerman (2010) studied papaya growth and other attributes in a double row spaced planting system. This field study was conducted on three papaya cultivars- 'Maradol', 'Tainung 5' and 'Yuen nong'. Double row growing system with 1 x 2 m spacing accompanied with drip irrigation and grass-hay mulch was found best in terms of plant height, stem diameter and fruits as compared to 1 x 1 m double row spacing in all the cultivars under study. While, Carvalho *et al.* (2014) found contrasting results during evaluation of papaya growth grown under various configurations of trickle irrigation system. Under a comparison of different drip irrigation levels and micro-sprinkler system, crop growth parameters were found superior in micro-sprinkler system that irrigated at a discharge rate of 43 litres per hour.

2.1.2 Effect of drip irrigation on yield and related attributes

A study on papaya variety 'Coorg honey dew' was carried out by Srinivas (1996a) to find out best irrigation frequency and number of emitters per plant. Results revealed maximum number of fruits, fruit weight and yield from plants that received daily drip irrigation with two emitters per plant. However, in another experiment, Srinivas (1996b) compared sub-surface drip irrigation with surface drip irrigation and observed higher fruit yield where plants received sub-surface irrigation. In the same experiment, fruit number and yield showed an increasing trend from 20 to 120 percent evaporation-replenishment rates, however, this improvement in fruiting and yield was non-significant above 60 percent rate of evaporation-replenishment. Similarly, Biswas *et al.* (1999) studied the effect of drip irrigation on cultivation of papaya cultivar 'Honey dew'. This research study revealed maximum yield of papaya plant under daily drip irrigation at 0.8 PEF as compared to the minimum yield levels obtained through conventional irrigation done at 1.0 PEF.

Suresh and Saha (2004) did experimentation of drip irrigation accompanied with mulching on papaya variety 'Pusa dwarf'. They reported maximum number of fruits per plant when irrigation was done through drip line at 0.8 PEF level, however, the same reporting shows maximum fruit weight and yield of papaya with drip irrigation at 1.0 PEF level. In another study, Pandey *et al.* (2005) reported 25 micron black plastic mulching along with drip irrigation at 0.6 v (v= Ep x Kp x Kc Sp Sr x Wp) in papaya crop to give benefits of yield enhancement along with water saving. This improvement in yield and yield attributing characters of papaya resulted in better production of marketable fruits.

Santana *et al.* (2008) also evaluated the fruit yield response in papaya with varying intensity of irrigation for three years. Application of various irrigation levels varying from 0.2 evaporation pan to 1.1 evaporation pan, the highest irrigation levels of 1.1 E_o (evaporation pan) were found promising in terms of fruit yield. In another experiment on 'Pusa delicious' cultivar of papaya the effect of irrigation system and their frequencies on its growth and yield was studied by Jain and Tiwari (2012). Daily dripping resulted in development of maximum feeding roots, highest number of fruits, fruit weight and yield per plant as compared to alternate day dripping and other irrigation frequencies. Carvalho *et al.* (2014) while evaluating the yield attributes of papaya grown under various configurations of trickle irrigation system compared drip-irrigation levels and micro-sprinkler system. The discharge rate of 43 litres per hour was found to be the best performing for enhancement of fruit yield.

2.1.3 Effect of drip irrigation on fruit quality attributes

The improvement in fruit weight, size, pulp and juice content of sweet lime was recorded by Sepaskhah and Kashefipour (1994) in frequently irrigated citrus plants, whereas, TSS and ascorbic acid content was reduced significantly as compared control plants. Srinivas (1996a) compared routine drip irrigation with third day drip irrigation in 'Coorg honey dew' variety of papaya and revealed maximum total soluble solids level in the fruits produced on plants that received drip irrigation every third day at 0.6 PEF. Rana (1998) studied the influence of different irrigation levels on fruit growth and quality in "Allison" cultivar of kiwifruit where he reported that basin irrigation at 80 % field capacity significantly resulted in increased fruit size, weight and quality. In another experiment on guava, Manjunatha *et al.* (2001) observed highest average TSS (11.7ºB), Vitamin C (211.4 mg^{-1} 100 g pulp) and total sugar (10.71%) in the fruits harvested from winter crop under drip irrigation than flood irrigation.

In grapes, Gurovich (2002) observed a positive effect on cluster weight, berry weight, berry diameter, total soluble solids and juice pH content when irrigation at 75 % ETc (evapo-transpiration) was maintained through drip irrigation throughout the growth season. However, Chandel *et al.* (2004) noted significant improvement in fruit size, weight and quality of kiwifruit produced under drip irrigation at 100% ETc. Similarly, the effect of drip irrigation on strawberry fruit yield and quality was studied by Yuan *et al.* (2004) under plastic green house and they revealed that fruit size and weight was enhanced as irrigation water was increased from 0.75 Ep to 1.25 Ep. Sharma *et al.* (2005) elucidated the effect of drip irrigation on strawberry cv. Chandler fruit quality under mid hill conditions of Himachal Pradesh and observed significantly higher fruit weight, size and volume when plants were drip irrigated. They further mentioned significant improvement in berry weight and volume by 75.5 and 43.5 %, respectively in the plants irrigated with drip 'V' volume than under rainfed plants.

Hoppula and Salo (2007) also worked on the tensiometer based irrigation scheduling in perennial strawberry and reported enhanced fruit juice soluble solids content and reduced fruit firmness with an increase in soil moisture content. Influence of drip irrigation and plant spacing on fruit yield and quality in guava fruit was studied by Mandal *et al.* (2007) where they revealed that average fruit weight for rainy and winter season crop was higher (154.9-161.3 g) under drip irrigation in comparison to flood irrigation (110.2-158.3 g). However, Terry *et al.* (2007) working on strawberry plants reported that carbohydrates content were increased while organic acids gets decreased under water stress conditions. In another study on grape vines, Taisheng *et al.* (2008) documented the effect of drip irrigation on berry quality and noted significant improvement in vitamin C content by the use of alternate drip irrigation on both the sides of root zone with half applied water.

Kim *et al.* (2009) reported that the quality characteristics of 'Maehyang' and ‘Seolhyang’ strawberry cultivars got affected by water stress, while, total organic acid contents decreased under water stress treatments. Furthermore, Chauhan and Chandel (2010) studied the comparative performance of drip irrigation and conventional basin irrigation in kiwifruit and found their impact on fruit quality. Fruit TSS and titratable acid content were decreased with reduction in the volume of water supplied. Maximum TSS (16.4 %) and acid content (1.27%) were recorded in drip irrigation with ‘V’ volume of water and minimum TSS (13.54%) in basin irrigation at 80% field capacity, juice acid content (1.12%) in drip irrigation with 0.6 ‘V’ volume of water. Maximum total sugars and reducing sugars (9.87 and 6.59%) were recorded in drip irrigation with 0.6 ‘V’ volume of water and minimum total sugars and reducing sugars to the tune of 9.10 and 5.80 percent in basin irrigation with ‘V’ volume of water. Reducing sugars were maximum (3.31%) in fruits harvested from vines which were irrigated with 0.8 ‘V’ volume of water through drip irrigation. Minimum reducing sugars (2.76%) were recorded in basin irrigation at 80% of field capacity. Similarly, Tejero *et al.* (2010) found positive impact of drip irrigation on fruit quality in citrus and recorded significantly higher fruit weight at 100% ETc and lowest at severe deficit irrigation at 50 % ETc.

Kumar *et al.* (2012) observed comparatively higher TSS (8.31%), ascorbic acid (55.3 mg/100g), reducing sugar (2.84%) and anthocyanin content (25.7 mg/100g) in strawberry fruits harvested from drip irrigation (1.0 IW/CPE) than those harvested from other irrigation treatments. Panigrahi *et al.* (2012) evaluated the effect of drip and basin irrigation on fruit quality in ‘Nagpur’ mandarin and obtained significantly higher fruit weight and TSS under drip irrigation at 80% cumulative pan evaporation as compared to basin irrigation.

2.1.4 Effect of drip irrigation on leaf nutrient content

In avocado grown under drip irrigation, a significant increase in leaf manganese and chlorine content was seen by Heinz and Norman (1975). These elemental contents were double in the leaves harvested from drip irrigated trees than flood irrigated fruit plants. Furthermore, leaf phosphorus content was found higher in microjet irrigated apple trees, whereas, in same plants, higher leaf potassium concentration was found over basin irrigation (Intrigliolo *et a.,* 1988).

In another experimental study on 'Dashehari' mango trees, Chandel and Singh (1992) examined the effect of different irrigation levels on growth, cropping and mineral composition and concluded that trees irrigated at 20 and 40 percent depletion of available soil moisture had statistically high leaf nitrogen, phosphorus, potassium, calcium, magnesium, iron and manganese contents than under both irrigated at 60 percent depletion of available soil moisture and un-irrigated the control. Neilsen *et al.* (1995) concluded that apple leaf phosphorus content was effected with different irrigation methods rather by number of irrigations and its value was improved. Layne *et al.* (1996) also observed that drip irrigated plants at low fertigation levels significantly had higher leaf magnesium content than rest of the treatments.

In aonla, Shukla *et al.* (2001) summarized the effect of drip irrigation on plant growth and leaf nutrient status. They observed augmentation in foliar nutrients content (N, P, K, Ca and Mg) in the plants irrigated after two days interval with drip system and lower under basin irrigation. Shirgure *et al.* (2004) also noted that leaf N, P & K contents were affected significantly at different pan evaporation based irrigation treatments. The highest leaf N (2.09% and 2.18%), P (0.14% and 0.12%) and K (2.12% and 1.94%) was attained with 0.8 pan evaporation which was significantly higher than 0.7 and 0.9 pan evaporation irrigation treatments.

Koszanski *et al.* (2006) observed that different irrigation treatments in strawberry cultivars 'Elsanta', 'Elkat' and 'Senga Sengana' and found substantially increased leaf phosphorus, potassium and vitamin C contents, however, leaf nitrogen and magnesium were decreased. Similarly, Panigrahi *et al.* (2012) studied the effect of drip and basin irrigation on leaf nutrients in Nagpur mandarin and reported improvement in leaf elemental content (1.92-2.37 percent nitrogen, 0.095-0.152 percent phosphorus and 1.58-1.98 percent potassium) in all the drip irrigation regimes under 40% ECP to 100% ECP as compared to basin irrigated plants (1.73% N, 0.092% P and 1.49% K). Micronutrients were also significantly (Fe 99.1-108.1 ppm, Mn 48.2-57.3 ppm, Cu 8.7-13.1 ppm and Zn 10.3-14.2 ppm) found better under drip irrigation at 100% ECP. However, micronutrients concentrations under basin irrigation were Fe (98.4 ppm), Mn (46.3 ppm), Cu (8.2 ppm) and Zn (9.9 ppm). Kachwaya and Chandel (2015) while studying the performance of drip and conventional basin irrigation on leaf nutrients content in strawberry observed that leaf nutrients content were significantly higher in drip irrigated plants with 'V' volume of water applied, than conventional basin irrigation.

The above literatures include studies of drip irrigation on different fruits. However, the effects of drip irrigation on different papaya cultivars have been summarized and listed in Table 2.1.

Table 2.1: Various irrigation treatments in papaya as found promising by different researchers

Reference	Variety	Location	Best treatment	Parameters observed
Srinivas (1996a)	Coorg honey dew	Bangalore, India	Daily drip irrigation with two emitters per plant	Plant girth, height, fruit number, weight and yield
			Drip irrigation every third day at 0.6 PEF	Fruit total soluble solids content
Srinivas (1996b)	Coorg honey dew	Bangalore, India	Sub-surface drip irrigation at 60 to 120 evaporation replenishment rate	Plant girth, height, fruit number and yield
Biswas *et al.* (1999)	Honey dew	India	Daily drip irrigation at 0.8 PEF	Fruit yield and water use efficiency
Suresh and Saha (2004)	Pusa dwarf	Bihar, India	Drip irrigation at 0.8 and 1.0 PEF	Fruit number, weight, yield and benefit:cost ratio
Pandey *et al.* (2005)	--	India	Drip irrigation at 0.6 v along with 25 micron black plastic mulch	Fruit yield and cost: benefit ratio
Anonymous (2008a)	Co2	Tamil Nadu, India	Drip irrigation at 0.6 PEF	Cost: benefit ratio
Santana *et al.* (2008)	Baixinho of santa amalia	Spain	Drip Irrigation at 1.1 pan evaporation	Vegetative growth and fruit yield
Zimmerman (2010)	Maradol, Tainung 5 and Yuen nong	USA	Drip irrigation in Double row growing system	Plant height and girth
Jain and Tiwari (2012)	Pusa delicious	Madhya Pradesh, India	Daily irrigation	Roots, fruits, highest fruit weight and yield
Carvalho *et al.* (2014)	Sunrise solo	Brazil	Micro-sprinkler irrigation	Growth parameters and fruit yield

2.2 FERTIGATION

Although many researchers have defined and explained the term ‘fertigation’, Goldberg and Shmueli (1970) described fertigation as a technique that initiated in Israel for water and fertilizer application in the form of droplets directly on to the root zone of the plants. Fertigation technique refers to the fertilizer application through irrigation water applied by low pressure delivery system by the means of dripline ejecting through drippers. This efficient method of irrigation and fertigation is applied just to meet the evapo-transpirational water losses from the crop. Adjustable fertilizer dozing and its precise application are another favourable factors of micro-irrigation *i.e.* fertigation. Fertilizer application through micro-irrigation technique facilitates availability of nutrients very near to the root zone, hence improving the nutrient uptake and its use efficiency (Elfving, 1982). Similarly, Magen (1995) described fertigation as a method of applying solid or liquid fertilizers *via* pressurized irrigation technology which resulted in simultaneous application of water and nutrients, whereas, Sneh (1995) described fertigation as a helpful technique for judicial use of crucial natural resource *i.e.* water resulting in enhancement of yield, quality and net income of farmers without altering anyother production means. In another form, Hagin *et al.* (2000) described fertilizer application through drip irrigation for effective fertilizer usage instead of soil application of fertilizers independently followed or succeeded by drip irrigation. Likewise, Brad Lewis (2001) also explained fertigation as helpful in fertilizer usage, minimum leaching loss and reducing irrigation intensity. Moreover, he also reported that fertigation allows flexibility in fertilizer application timings in addition to reduction in labour requirement.

In an experiment, Broyer *et al.* (2001) observed mango cultivar ‘Tommy Atkins’ under drip fertigation and reported improved fruit weight, productivity and total soluble solids where 30 percent nitrogen was applied through fertigation technique. However, Manohar *et al.* (2001) experimented on grapes, sapota and cashew plants and reported fertigation technique to be best in terms of fertilizer use efficiency with upto 25 percent saving of fertilizers. Timely availability of recommended fertilizer doses at critical fruit growth stages greatly improves the plant vigour and fruit quality (Farooqui *et al.*, 2005). Singh (2002) revealed fertigation as a best technique for economical and intensive crop production by exploiting synergism of simultaneous availability of water and nutrients to plants. Fertigation improves the productivity with minimum losses of essential elements. Moreover, Nanda (2010) while exploring the benefits of fertigation reported the conventional fertilizers to be unsuitable for fertigation and in replacement he recommended use of water soluble fertilizers in fertigation. This system resulted in improved fertilizer and water usage from 40 to 60 percent. This fertigation in banana enhanced yield by 60 to 70 percent. Yamanishi and Zuffo (2011) commented upon application of fertilizers by means of irrigation system. They found fertigation as a viable and economical technique but to have maximum efficiency of fertigation, it required adequate management of soil, water and fertilizers in relation to nutritional demands of plants. Shirgure *et al.* (2016) worked on Nagpur mandarin and found application of 80 percent recommended dose of fertilizers and irrigation scheduling at 80 percent evaporation rate to be the best in terms of canopy volume, fruit yield, fruit quality, juice percentage, total soluble solids and lowest acidity. In contrast, Nirgude *et al.* (2016) observed the fertigation impact on four years old citrus cultivar 'Mosambi' under high density plantation and found 120 percent recommended dose of fertilizers to be the best in improving total soluble solids, sugars, ascorbic acid, total phenolics and flavonoids content in the fruits.

In another study, Carneiro *et al.* (2017) fertigated the mango cultivar 'Tommy Atkins' with different doses of potassium chloride and potassium sulphate to find impact of changed electrical conductivity, exchangeable ionic content and pH on plant production parameters. Sulphate form of potash was found to be more efficient in fertigation as compared to chloride form of potash. In another study on guava cultivar 'Sardar', Mahadevan *et al.* (2018) reported significant effect of fertigation treatments on morphological characters of plant. Gomand *et al.* (2018) worked on fertigation in pear cultivar 'Conference' and found that potassium content in soils is optimum and requires no fertilizer input till first eight years. They recommended application of nitrogen and potassium nutrients only after proper soil analysis to avoid their detrimental effect on fruit quality, if present in excess. However, in another experiment, Vilanova *et al.* (2019) observed the fertigation impact on chemical composition on *Vitis vinifera* cultivar 'Albarino' but recorded in-significant effect on non-volatile compounds, whereas, among the volatile compounds, terpenes and C_{13}-nor-isoprenids were most significantly altered with fertigation having maximum concentrations at 60 percent fertigation. Villar *et al.* (2018) performed an experiment to assess the effect of nitrification inhibition 'DMPP' usage on peach plants and found its usage effective to minimize external fertilizer requirement of plant. The use of nitrification inhibitor improved the peach tree canopy area and nitrogen content in leaves and fruits.

Fertigation combines the fertilization and irrigation techniques for precise and consistent application of nutrients to the base of plant where intense feeder roots are available. Ultimately it increases the fertilizer use efficiency upto 80 to 90 percent preventing nutrients loss that may occur through leaching or volatilization. In the same aspect, Arshad *et al.*

(2014) reported optimistic impact of nutrient application through drip irrigation on fruit yield along with efficient utilization of nutrients.

In the past, various researchers have studied the effect of fertigation on different parameters of fruit production such as plant growth, fruit yield, quality, leaf elemental content, etc. A brief discussion of the results obtained has been reviewed here under following headings:

2.2.1 Effect of fertigation on vegetative growth

In an experimental study on apple, Hipps (1992) recorded a higher shoot growth in fresh plantation supplied with fertigation using 20 g/tree nitrogen in comparison to conventional fertilization system. Similarly, Spayd *et al.* (1993) also revealed an improvement in shoot growth and pruned wood weight in grapes when higher nitrogen doses were applied through fertigation. Experiments of nitrogen fertigation on oranges done by Guazzelli *et al.* (1995) revealed improved average growth, trunk size and leaf dry weight when nitrogen dose was used at the rate of 200 mg per litre through fertigation. A significant improvement in fruit plant growth was also seen by Neilsen *et al.* (1995) when they compared conventional fertilizer application with fertigation. Richard *et al.* (1996) observed the effect of different combinations of irrigation methods with fertilizer application and reported largest trunk cross sectional area under highest fertigation treatment in comparison to band placed fertilizers without any irrigation. A significant enhancement in plant height, tree girth and canopy volume in mandarin trees was revealed with irrigation when scheduled at 20 percent depletion of available water along with application of 500, 140 and 70 g nitrogen, phosphorous and potassium per plant, respectively. However, in acid lime, maximum increase in plant height, girth and canopy volume was recorded with fertigation using 100 percent followed by 80 percent nitrogen (Shirgure *et al.,* 1999). Similarly, Buban and Laktos (2000) also reported an increase in trunk area and shoot number in apple trees during assessment of different nitrogen fertilizers through drip irrigation. Best treatment effect was reported when higher ammonium doses were applied in first half followed by nitrate form in second half of growing season in comparison to simultaneous application of both nitrogen forms throughout the season.

Murthy *et al.* (2001) also corroborated the effects of fertigation on grapes variety 'Bangalore blue' and reported 80 percent drip irrigation accompanied with water soluble fertilizers to be the best treatment in terms of maximum leaf area production, whereas, highest shoot growth and trunk circumference were found maximum with use of recommended fertilizer dose instead of 80 percent fertigation. The increase in mean shoot length was attributed to the total shoot extension caused by use of nitrogen fertilizer. The observations of papaya crop response to varying fertigation frequencies was studied by Jeyakumar *et al.* (2002) in which they recorded highest plant height, maximum number of leaves accompanying minimum flowering and bearing height by giving fertigation at the rate of 10 litres water per day along with 13.5 g urea and 10.5 g muriate of potash (MoP) per week in addition to soil application of 278 g super phosphate per plant at bi-monthly intervals. In apricots, Raina *et al.* (2005) reported significantly improved annual shoot growth, tree height and canopy volume as a result of fertigation. Similarly, Sharma *et al.* (2005) did an experiment laid out constituting five fertigation levels in papaya crop of cultivar 'Red Lady' and reported tallest plants with widest girth and maximum functional leaves under 100 percent fertigation level. The same treatment in addition to the above promising growth parameters also resulted in early flowering and fruiting. In another strawberry variety 'Elsanta', Martinsson *et al.* (2006) reported an improvement in leaf number by applying full nutrient package through fertigation when compared to control. In a study on kiwifruit cultivar 'Bruno', Chauhan and Chandel (2008) identified the level of fertilizer effect on plant growth, yield, fruit quality and measured fertilizer use efficiency under fertigation. They reported significantly higher growth of grape vines through fertigation as compared to soil application. In an experiment on 'Korona' cultivar of strawberry, Opstad and Sonsteby (2008) practically assessed the impact of timings and methodology of fertilizer application on flowering and fruit ripening, where they reported earlier flowering and more leaf area in plants under fertigation in comparison to non-fertigated plants. However, in another study, Santos and Chandler (2009) studied the impact of fertigation using only nitrogen fertilizers in strawberry cultivars 'Festival' and 'Winter Down'. They reported a vigorous canopy circumference with higher nitrogen applications upto nitrogen application to the tune of 0.9 kg/ha/day. Singh *et al.* (2009) studied the response of mango cultivar 'Dashehri' to fertigation in terms of plant growth and revealed significantly higher leaf area with combined treatments of irrigation, mulching and 100 % fertigation. Jeyakumar *et al.* (2010) studied the influence of fertigation on nutrient usage and yield enhancement in papaya cultivar 'Co7'. This fertigation assessment was done by using urea and muriate of potash as a source of nitrogen and potassium, respectively, whereas the phosphorus was applied using single super phosphate directly into the soil as conventional method. Significantly superior morphological and fruiting characters were observed in the plants that were applied with 100 percent recommended fertilizer dose i.e. 50 g N and 50 g K_2O through fertigation and 50 g P_2O_5 through soil basal application.

In another experimental study for three continuous years in sandy loam soil texture to evaluate the fertigation effect on papaya plants of cultivar ‘Taiwan 786’, Deshmukh and Hardaha (2014) performed fertigation experiment by collaborating irrigation levels with fertilizer doses. The interaction of irrigation equal to cumulative pan evaporation with 100 percent fertilizer recommendation dose was observed to give optimum growth and fruit production which was approximately 36 percent increased over conventional irrigation method. Likewise, Panigrahi *et al.* (2015) studied the fertigation impact on ‘Red Lady’ cultivar of papaya. Various fertigation treatments were found quite effective in improving plant vigor. These plant growth characteristics were found promising in 80 percent recommended dose of fertilizers through drip irrigation. However, in contrast to these findings, Anderson *et al.* (2017) tried to identify the reason for reduced papaya growth of two cultivars ‘Sunrise golden’ and ‘Uenf-Caliman 01 hybrid’, where they reported reduced plant growth due to decreased osmotic potential in root zone when nutritional requirements of plant were fed through fertigation.

2.2.2 Effect of fertigation on yield and related attributes

Wolf *et al.* (1990) observed highest yield of pear cultivars ‘Conference’ and ‘Doyennedu-Comice’ with fertigation than with broadcast of N, P and K fertilizers. Hipps (1992) reported an increase in fruit set forming terminal flower clusters in trees that were applied with 10 and 20 g nitrogen per tree. In same study, maximum improvement in shoot growth, fruit bud production, fruit set and cumulative fruit yield was seen with 29 g nitrogen per tree fertigation. Likewise, Spayd *et al.* (1993) reported higher fruit yield in grapes as improved by application of 56 kg nitrogen per hectare through fertigation. On the other hand, Robinson and Stiles (1997) observed the fertigation effect on fruit yield of apple cultivars ‘Red chief’ and ‘Oregon Spur’. They reported 22 and 29 percent increase in cumulative yields respectively in both these cultivars. Zydlik and Pacholak (1998) reported enhancement of fruit yield in apple cultivar ‘Golden delicious’.

While experimenting on kiwi fruit cultivar ‘Hayward’, Granelli *et al.* (1994) also revealed higher fruit yield with use of higher fertigation doses when fertigation and soil application was used simultaneously. Bachchhav (1995) documented the effect of fertigation in grapes. He observed enhancement in fruit yield/vine by 25.6 % as compared to soil application in grapes. Hochmuth *et al.* (1996) experimented on strawberry by applying nitrogen fertilizer through drip system of irrigation at weekly intervals and reported enhancement of fruit yield at higher nitrogen doses. Burgess (1997) reported improvement in strawberry fruit yield by application of 40 and 80 kg nitrogen per hectare. Likewise, in 'Chandler' variety of strawberry, Miner *et al.* (1997) reported enhanced fruit yield where nitrogen fertilizer was applied through drip irrigation. Hipps (1997) reported an increase in apple fruit yield to the tune of 18 percent with phosphorus fertigation in comparison to simple water irrigation. In same experiment, it was also observed that phosphorus band placement without irrigation had no significant effect on fruit yield. Similarly, Peterson (1998) also documented highest fruit yield in strawberry with use of fertigation system. Buban and Laktos (2000) experimented on young apple trees to evaluate the effect of various fertigation levels on plant vegetative growth and fruit yield. They reported increased trunk cross sectional area and shoot number where fertigation was done using higher ammonium form of nitrogen in first half and nitrate form of nitrogen in second half of season as compared to simultaneous application of both nitrogen forms during whole season. Ferrara *et al.* (2000) reported considerably increased grapes berry size and bunch weight with N, P and K fertigation.

In a study on the papaya crop to work out its response to varying fertigation frequencies, Chaudhri *et al.* (2001) conducted an experiment and elaborated the effect of fertigation. The fertigation concentrations were varied from 50 to 125 percent of recommended fertilizer dose. According to the observations recorded, 50 percent fertigation dose was found to give normal yield at par to solid fertigation control which showed efficient use of fertilizer to get optimum yield. Jeyakumar *et al.* (2001) also found promising results while comparing the performance of papaya plants under fertigation and conventional fertilization. They reported improved photosynthetic activity in fertigated plants that ultimately resulted in good fruit size and finally better yield in comparison to conventionally fertilized plants. Jeyakumar *et al.* (2002) experimented on papaya cultivar 'Co2' by giving a 278 g per plant application of superphosphate and varying amounts of urea and MoP. They reported maximum number of fruits, fruit weight, length, circumference and volume in the fertigation treatment done with 10 litres water per day including 13.5 g and 10.5 g urea and muriate of potash, respectively per week. In an investigation on banana, Raghupati *et al.* (2002) determined the effect of various nitrogen and potassium fertigation levels and documented maximum fruit yield of banana at 200 g per plant application each of nitrogen and potassium. Reddy *et al.* (2002) observed significantly higher banana yield at higher fertigation levels as compared to soil band placement of fertilizers. Maximum fruit yield was obtained in trees that were applied with 200 g nitrogen and potassium through drip irrigation. In an experiment on Valencia oranges growing on rough lemon rootstock, maximum fruit yield was observed by Alva *et al.* (2003) in trees applied with 180 kg nitrogen per hectare per year as fertigation in comparison to low yield in conventional fertilizer application. Garcia *et al.* (2004) obtained maximum fruit yield and cumulative fresh fruit yield in oranges from fertigated area than broadcasted fertilizer area. Kumar (2004) reported significantly higher yield of apple fruit by applying full nitrogen, phosphorous and potassium dose through drip irrigation. Similarly, Thakur and Singh (2004) recorded maximum fruit yield and fruit number in mango cultivar 'Amrapali' when trees were applied with 75 percent recommended dose of fertilizers through fertigation. Gutal *et al.* (2005) compared five different nitrogen fertigation levels with conventional fertilization and reported an average 15.6 percent increase in fruit yield with 75 percent recommended fertilizer dose through fertigation, which in other words mean a 25 percent saving of fertilizers. In another experiment, Sharma *et al.* (2005) recorded maximum fruit length (31.12 cm), circumference (68.72 cm), number (32.45), weight (1.810 g), pulp thickness (3.21 cm) and yield (140 t/ha) by application of 100 percent of fertilizers through drip irrigation as compared to other fertigation and fertilization treatments. Experimenting on papaya variety 'Maradol' to evaluate its performance under drip irrigation, NPK fertilization, conventional furrow irrigation and soil fertilization, Vazquez *et al.* (2005) reported to promote yield with fertigation treatments giving highest 30.4 t/ha papaya fruit yield against 13.3 t/ha fruit yield under conventional system. Martinsson *et al.* (2006) worked on strawberry cultivar 'Elsanta' and reported enhanced fruit yield to the tune of 186.6 g per plant. Likewise, Singh and Singh (2006) compared three fertigation treatments and cultivation with conventional fertilization while working on papaya variety 'Pusa delicious' in which results revealed significantly superior fruit size, number and weight under fertigation with an average 43 percent increase in fruit yield by 100 percent application of urea through fertigation. Chauhan and Chandel (2008) observed the effect of fertigation on kiwi fruit plant vegetative, fruiting characteristics and fertilizer use efficiency in hills of Himachal Pradesh. They reported improved fruit yield in fertigated vines. Opstad and Sonsteby (2008) studied the impact of varying timing of fertilizer application and different application methods on strawberry variety 'Korona' and revealed a significant improvement in fruit yield in fertigated plants as compared to non-fertigated ones. In apple trees, Fallahi *et al.* (2010) assessed the fruit yield and quality by varying potassium doses and recorded promising yield with 15 g potassium per tree annual application in comparison to lowest yield where no potassium was given. Jeyakumar *et al.* (2010) did yield assessment in papaya cultivar 'Co7' by using urea and muriate of potash as a source of nitrogen and potassium, respectively applied through fertigation , whereas the phosphorus was applied using single super phosphate directly into the soil as conventional method. Significantly superior fruiting and yield attributes were observed in the plants that were applied with 100 percent recommended N and K_2O fertilizer dose i.e. 50 g N and 50 g K_2O through fertigation in addition to 50 g P_2O_5 through soil basal application.

In another experimental study done to standardize the optimum fertigation dose for papaya cultivar 'Red Lady' Sadarunnisa *et al.* (2010) applied fertigation doses constituting 100, 75 and 50 percent of recommended nitrogenous and potash fertilizers where 100 percent dose constitutes 250 g N and 500 g K_2O. Promising yield, fruiting and fruit characteristics were found in plants under fertigation as compared to soil application of fertilizers. 100 and 75 percent fertigation doses were at par to each other in terms of improvement in above fruiting characters, so 75 percent fertigation was concluded as most economical in providing the potential yield.

Banyal and Sharma (2011) studied the impact of fertigation and rootstock type on apple fruit yield and quality under high density planting system. They observed maximum fruit yield in the plants fertigated with full dose of nutrients through drip irrigation in comparison to minimum in plants where nutrients were applied through conventional method of band placement. In apricot, Raina *et al.* (2011) reported fertigation with 100 and 75 percent recommended fertilizer dose to be the best for improvement in fruit yield resulting in 16.4 and 13.7 percent increase in fruit yield respectively in 100 and 75 percent fertigation treatments. Singh and Singh (2011) did fertigation experiment on 'Pusa delicious' variety of papaya in comparison to conventional cultivation keeping it as control. The 100 percent dose used here included 435 g urea, 1250 g single super phosphate and 333 g muriate of potash per papaya plant per year. Among fertigation treatments, only nitrogenous fertilizer *i.e.* Urea was applied through drip irrigation in the concentrations of 100, 80 and 60 percent nitrogenous fertilizer. They found maximum effective roots and highest number of fruits per plant in 100 percent nitrogen fertigation. However, Singh and Singh (2012) also explored the response of same papaya cultivar i.e. 'Pusa delicious' to fertigation in comparison to conventional fertilization. They applied fertigation treatments in which nitrogen concentration was kept variable, while other essential nutrients were applied as basal application apart from the control plants that were totally under conventional fertilization system. Enhanced fruiting and quality fruit characteristics were recorded where 100 percent nitrogen fertigation subsequently followed by 80 and 60 percent nitrogen fertigation. Yield enhancement with fertigation was seen upto 43 percent over control plants. Deshmukh and Hardaha (2014) organised an experimental study for three continuous years in sandy loam soil texture to evaluate the fertigation effect on papaya plants of cultivar 'Taiwan 786'. This fertigation experiment was done by collaborating irrigation levels with fertilizer doses. The interaction of irrigation equal to cumulative pan evaporation with 100 percent fertilizer recommendation dose was observed to give optimum growth and fruit production which was approximately 36 percent increased over conventional irrigation method. Panigrahi *et al.* (2015) studied the fertigation impact on 'Red Lady' cultivar of papaya. Various fertigation treatments were found quite effective in improving flowering, fruit setting and yield. These plant fruiting and fruit quality characteristics were found promising where 80 percent recommended dose of fertilizers was applied through drip irrigation.

2.2.3 Effect of fertigation on fruit quality attributes:

Bachchhav (1995) reported improved fruit thickness, weight and quality in the fertigated plants as compared to soil fertilized plants. Dolega and Link (1998) found in-significant results regarding apple fruit firmness, juice acidity and sugar content during comparison of fruit quality of fertigated and non-fertigated plants. Peterson (1998) reported high quality plants and fruits of strawberry that were under fertigation treatment as compared to non-fertigated plants.

Jeyakumar *et al.* (2001) compared the performance of papaya plants under fertigation and conventional fertilization. They recorded higher nutritional and chlorophyll content in fertigated plants along with improved photosynthetic activity, water use efficiency, fruit size and total soluble solids as compared to plants without fertigation treatment. Mahalakshmi *et al.* (2001) reported maximum bunch weight, number of hands per bunch and number of fingers per bunch in banana as improved by fertigation treatments. Shirgure *et al.* (2001) reported maximum fruit weight, total soluble solids and juice content in the fruits of Nagpur mandarin by applying N:P:K fertilizers in the ratio of 500g :140g :70g per tree through fertigation. However, working on papaya variety 'Co2', Jeyakumar *et al.* (2002) observed highest pulp thickness and total soluble solids content to the tune of 12.4° Brix in the fruits developing on plants receiving nutrition through fertigation. Rana and Chandel (2003) studied the fertigation effect on strawberry cultivar 'Chandler' in hilly region and found significantly higher total soluble solids and sugars in the fruits harvested from plants applied with 100 kg nitrogen per hectare. In banana, Kavino *et al.* (2004) did an experimental study to assess the effect of fertigation on fruiting and in the results they reported highest bunch weight, hands per bunch, fingers per bunch and fingers weight in fertigated plants as compared to control treatment. Neilsen *et al.* (2004) observed the effect of nitrogen fertigation on apple cultivar 'Gala' and reported an diminished titratable acid content and decreased flesh firmness, whereas, total soluble solids and starch content were recorded higher in fruits that were under nitrogen fertigation treatment. Park *et al.* (2004) reported an increase in average fruit weight, total soluble solids and fruit firmness in apple cultivar 'Delicious' with fertigation treatments. The fruit colour was also found better in fruits harvested from fertigated plants. Thakur and Singh (2004) reported maximum fruit weight, pulp ratio, fruit size, total soluble solids and reducing sugars by applying 100 percent fertigation. Fertigation had been reported to increase fruit juice vitamin C and anthocyanin content in strawberries (Moor *et al.,* 2005). Similarly, Sharma *et al.* (2005) observed highest average TSS of 12.38° Brix where 100 percent fertigation treatment was given in comparison to other levels of fertigation.

Taghavi *et al.* (2006) did an experimental study on strawberry cultivar 'Selva' by applying fertigation using nitrate and ammonium forms of nitrogen. They reported highest fruit juice pH and vitamin C concentrations in the fruits harvested from plants that received ammonium form of nitrogen, whereas, total soluble solids and titratable acidity content showed a declining trend with increase in ammonium content in the fertigation solution. Wold and Opstad (2007) reported an improvement in strawberry fruit juice vitamin C and acid concentration in the fruits that were harvested from plants supplied with 80 kg nitrogen per hectare per year as compared to fruits harvested from plants that got lower nitrogen dose. Maldonado and Pritts (2008) reported an improved starch, glucose, sucrose and total non-structural carbohydrate levels in strawberries harvested from plants under fertigation as compared to conventional fertilization.

Raina *et al.* (2011) studied the fertigation effect on fruit yield and quality of apricot fruit and documented highest fruit weight in the plants applied with 100 percent fertigation as compared to soil application. Ramniwas *et al.* (2012) studied the impact of fertigation scheduling on plant growth and yield parameters in guava growing as meadow orchard and observed significantly higher fruit weight (182.2 g) under fertigated treatments. Singh and Singh (2012) also explored the response of another papaya cultivar 'Pusa delicious' to fertigation in comparison with conventional fertilization. Among fertigation treatments only nitrogen concentration was variable, while other essential nutrients were applied as basal application apart from the control plants that were totally under conventional fertilization system. Enhanced fruiting and quality fruit characteristics were recorded with 100 percent nitrogen fertigation subsequently followed by 80 and 60 percent nitrogen fertigation. In another study, the impact of fertigation on 'Red Lady' papaya was studied by Panigrahi *et al.* (2015). Various fertigation treatments were found effective in improving papaya fruit quality. These fruit quality characteristics were found promising in 80 percent recommended dose of fertilizers through drip irrigation in comparison to other fertigation levels.

2.2.4 Effect of fertigation on leaf nutrient content

Klein *et al.* (1989) applied 150 kg nitrogen per hectare and reported significant increase in leaf nitrogen concentration. In addition to increased nitrogen content, this also had impact over other nutrient concentrations in which leaf phosphorous and potassium levels were decreased and magnesium level was enhanced with increased nitrogen levels. In apples, Wolf *et al.* (1990) observed higher leaf nitrogen concentrations by fertigation with N:P:K (19:6:6) fertilizer. In an experimental study on banana, Hedge and Srinivas (1991) assessed the impact of different nitrogen and potassium levels on nutrient uptake and reported an enhanced nitrogen, potassium and magnesium content with enhanced nitrogen doses in fertigation. Intrigliolo *et al.* (1992) compared performance of plants under fertigation with conventional fertilization method and reported a significant improvement in nutritional and physiological status of plant that were under fertigation. A fertigation experiment on pear resulted in significant improvement of leaf phosphorous content as reported by Meimon *et al.* (1995). Noe *et al.* (1995) observed significantly higher leaf elemental concentrations *viz.* 2.49 percent nitrogen, 1.81 percent calcium and 0.27 percent magnesium when plants were applied with fertigation as compared to non-fertilized plants. Hochmuth *et al.* (1996) also reported a linear increase in leaf nitrogen content when increasing dose of nitrogen was used in various fertigation treatments. In an fertigation experiment on acid lime, an increase in leaf nitrogen content with increased nitrogen fertigation was seen but to a limit of 80 percent nitrogen fertigation. The maximum value of leaf nitrogen content was seen to the tune of 27.5 percent followed by 24.3, 20.2 and 7.5 percent respectively in 100, 60 percent nitrogen fertigation and fertilizer band placement (Shirgure *et al.,* 1999).

Comparing the performance of papaya plants under fertigation and conventional fertilization, Jeyakumar *et al.* (2001) recorded higher nutritional and chlorophyll content in leaves of fertigated plants along with improved photosynthetic activity as compared to plants without fertigation treatment. Murthy *et al.* (2001) experimented on grapes variety ‘Bangalore blue’ and reported that application of 100 percent recommended fertilizers dose through fertigation with 80 percent water soluble fertilizers resulted in highest leaf potassium and calcium contents. Likewise, Jeyakumar *et al.* (2002) observed significantly higher leaf nitrogen and potassium content, whereas, phosphorus content in leaves was insignificantly effected with fertigation treatments in papaya plant. Chen and Cheng (2004) reported some contrasting facts that the nitrogen content in leaves decreased with diminishing nitrogen dose in fertigation. Ibrahim *et al.* (2004) experimented on strawberry plants and also reported gradual increase in leaf chloride content when the potassium requirement of plants was fed through fertigation using potassium chloride (KCl) as a source of nutrient in discussion. Neilsen *et al.* (2004) studied the response of nitrogen and potassium fertigation in apples and in the results they reported an enhancement in leaf potassium, magnesium and boron content.

Wold and Opstad (2007) reported significantly higher N:P:K nutrient content in the leaves to the tune of 2.51 % : 0.33 % : 1.41 % in the plants that were under fertigation with 80 kg nitrogen per hectare per year. In another experimental study on kiwi fruit, Chauhan and Chandel (2008) did fertigation trials under temperate climate zone and documented significantly higher leaf nutrients *viz.* 3.05 percent nitrogen, 0.31 percent phosphorous, 2.37 percent potassium and 0.55 percent magnesium in the trees fertigated with full recommendation of nutrients in comparison to soil band placements. Maldonado and Pritts (2008) worked on the strawberry plants and reported higher leaf nitrogen content in fertigated plants to the tune of 12.7 mg/g as compared to non-fertigated plants. Jeyakumar *et al.* (2010) compared the performance of fertigation and soil application on leaf nutrient content in papaya and revealed that leaf nutrients content (1.72% N, 0.41% P and 2.91% K) were significantly higher in the plants applied with 100% recommended doses of N and K_2O fertilizers through drip irrigation. WeiJun *et al.* (2011) did an experimental study on apricot plants and reported significantly higher leaf nitrogen and phosphorous content respectively to the tune of 9.1 and 0.6 percent in fertigated plants as compared to non-fertilized and deep ditch fertilization.

The above literatures include studies of fertigation related to different fruits. However, the effects of fertigation on different cultivars of papaya have been summarized and listed in Table 2.2.

Table 2.2: Various fertigation treatments in papaya as found promising by different researchers

Reference	Variety	Location	Best treatment	Parameters observed
Chaudhri *et al.* (2001)	--	Maharashtra, India	Fertigation with 50 percent RDF (100g:100g:100g $N:P_2O_5: K_2O$ per plant)	Fruit yield
Jeyakumar *et al.* (2001)	--	Tamil Nadu, India	Fertigation	Fruit size, yield, total soluble solids, leaf nutritional and chlorophyll content
Jeyakumar *et al.* (2002)	Co2	India	Irrigating with 10 litres water per day using 13.5 g urea and 10.5 g	Plant height, leaf number, flowering, bearing height, pulp

			MoP per week	thickness, TSS, fruit number, size, weight, volume and leaf N and K_2O content
Sharma *et al.* (2005)	Red Lady	India	100 percent fertigation	Plant height, girth, functional leaves, fruit number, size, weight, yield, TSS and cost:benefit ratio
Vazquez *et al.* (2005)	Maradol	Mexico, USA	Fertigation	Fruit yield
Singh and Singh (2006)	Pusa delicious	India	100 urea application through fertigation	Fruit number, size and weight
Anonymous (2008b)	Co7	India	100 percent nitrogen (50 g N) and potash (50 g K_2O) application through drip irrigation	Benefit: cost ratio
Jeyakumar *et al.* (2010)	Co7	India	Fertigation with 100 percent RDF (50 g N and 50 g K_2O)	Morphological characters, fruiting, yield attributes and benefit: cost ratio
Sadarunnisa *et al.* (2010)	Red Lady	Andhra Pradesh, India	75 percent RDF through fertigation (RDF used was 250 g N and 500 g K_2O)	Yield, fruit characteristics and benefit: cost ratio
Singh and Singh (2011)	Pusa delicious	Bihar, India	100 percent nitrogen (435 g urea) application through fertigation	Maximum roots and fruits
Singh and Singh (2012)	Pusa delicious	Bihar, India	100 percent nitrogen application through fertigation (435 g urea per plant)	Fruiting and fruit quality characters
Deshmukh and Hardaha (2014)	Taiwan 786	Madhya Pradesh, India	100 percent RDF through fertigation (250g:250g:500g $N:P_2O_5: K_2O$ per plant	Growth parameters and fruit production
Panigrahi *et al.* (2015)	Red Lady	Chhattisgarh, India	80 percent RDF through fertigation	Plant vigour Fruit setting, quality and yield
Anderson *et al.* (2017)	Sunrise golden and Uenf-Caliman 01 hybrid	Brazil	Low nutrient concentration in drip line to maintain osmotic potential of soil	Plant growth

2.3 PROTECTED CULTIVATION

As a new challenge to feed ever growing population, cultivation system needs improvement to produce more from a limited area. Protected cultivation acts as one of the best growing environment in some of the crops to get high yield in addition to protection from some biotic and abiotic factors. The advantages of protected cultivation include low expenditure with easier management practices (irrigation, weeding, pest control, harvesting, etc), less yield loss, off-season weather alteration, increase in marketable quality yield, all these leading to higher profitability. India adds a major share of fruit production among total world's production but export is limited due to some inferiority in quality. The protected cultivation adds to quality fruit production in addition to making it possible to grow some tropical fruits in sub-tropical and temperate climate. At initial stages, most of the countries adopted protected cultivation to decrease dependency on imports by producing off-season quality fruits on their own. Guvvali *et al.* (2017) stated that greenhouse or protected cultivation is a latest and best eco-friendly technology available to protect crops from various biotic, abiotic factors and natural calamities in addition to fruit yield and quality enhancement and eventually turning to deliver good benefit: cost ratio. The studies regarding protected cultivation of fruits have been reviewed here under:-

2.3.1 Effect of protected cultivation on vegetative growth

Saucov *et al.* (1992) studied the influence of environment variations by the use of protected structures on banana plant morphology. They worked specifically on "Dwarf Cavendish" variety of banana in the Canary Islands. They reported that the plants under greenhouse conditions were superior to open field plants in terms of all plant growth characteristics. Hirokazu *et al.* (2001) experimented on custard apple to study the effect of various shade levels on plant growth. Maximum shoot length and leaf number were reported in low shade conditions allowing 64 percent light interception. However, maximum shade increased the inter-nodal and specific stem length. In contrast, stem diameter, leaf and stem dry weight were found higher in light shading conditions. More shady conditions suppressed the tissue dry weights producing thinner and larger leaves. Although these larger leaves in maximum shady conditions had more leaf area but total leaf area on shoots was reduced, whereas specific leaf area was improved due to reduced thickness. Kamiloglu *et al.* (2011) did an experimental study on different varieties of grapes and reported enhanced shoot growth under protected cultivation in comparison to open fields. Among the varieties under experiment, "Uslu" variety was found to grow most rapidly under both field conditions as compared to "Yalova incise" and "Perlette" that had lowest growth under open field conditions.

Gubbuk and Pekmezci (2004) worked on "Dwarf Cavendish" variety of banana and studied its performance under open and protected conditions. They reported an improved vegetative growth in terms of pseudostem height, girth and total number of leaves at the time of flowering in the crop grown under net house as compared to open cultivation. The highest mean pseudostem height, pseudostem circumference and total number of leaves recorded were 1.8 m, 78.3 cm and 17.2, respectivelty in protected structure as compared to 1.7 m plant height, 68.5 cm plant circumference and 13.30 leaves in outer fields. Santos *et al.* (2008) studied the growth of papaya and passion fruit nursery seedlings in protected structure and reported uniform height in all treatments upto 31 days after sowing, however, after 38 days of sowing, plant height was maximum under monofilament net and aluminizada shading. The improvement in height was attributed to the low transpirational losses under modified environment. Medany *et al.* (2009) studied the effect of white greenhouse net on growth of mango variety "keitt" and reported a significant increase in number of green leaves in two seasons with average maximum number of total leaves in trees under net as compared to open orchard. Overall vegetative growth of trees was also better under white net which was computed from plant height, number of leaves and stem circumference. This improvement in vegetative growth was attributed to crop favourable environmental conditions usually maintained under net house protection. These favourable crop growth factors were adequate relative humidity, lower maximum temperature, lower light irradiance, lower evapo-transpiration, higher maximum temperature and lower wing speed that are not available in open field conditions.

Casierra-Posada *et al.* (2011) analysed the growth of strawberry plants exposed to different shading and light environments in Columbia. Different light quantity regimes were maintained using polypropylene films of different colours *viz.* yellow, green, blue, red and transparent along with a naked control. Only the green cover resulted in significant difference among root to shoot ratio which was higher under covered conditions, while other covers did not show any significant difference in any parameter as compared to control. Schettini *et al.* (2011) analysed the plant growth of cherry and peach fruit trees under two photoselective and three photoluminescent greenhouse plastic films. They reported a significant improvement in shoot growth of both the plants growing under plastic films and attributed this enhancement to modified spectral distribution of solar radiations. Kaur and Kaur (2017) compared the performance of "Red Lady" papaya under protected cultivation and open fields. They revealed an improved vegetative growth under protected cultivation with maximum plant height: 214.05 cm, leaf number: 20.46 and 876.5 cm^2 leaf area.

2.3.2 Effect of protected cultivation on yield and related attributes

Furukawa *et al.* (1990) assessed the effect of protected cultivation on peach fruit. They reported 13 to 20 days advancement in fruiting of peach when grown under protected conditions in comparison to open field orchard. This earliness in fruiting was promoted by earliness in anthesis. Despite this earliness of fruiting, the overall mean yield assessed was maximum in open orchard as compared to protected structure. The assessed yield factor was in terms of yield per unit trunk crossectional area and yield per unit of canopy volume. Galan Saucov *et al.* (1992) studied the influence of environment variations by the use of protected structures on banana plant morphology. They worked specifically on "Dwarf Cavendish" variety of banana in the Canary Islands. They reported that the plants under greenhouse conditions gave higher yields having more bunch weight and good finger size as compared to open field plants. Eckstiin and Joubfrt (1998) compared the performance of banana under protected cultivation and open field conditions, where they reported shorter harvesting period with earliness in anthesis and shooting under protected conditions. Although, the crop duration from planting to harvest was shorter, but the duration from flowering to harvest was enlarged under protected conditions. Finger number and finger size were measured as a factor to identify the yield estimates. Protected cultivation was reported to produce more number of fingers per bunch with highest fruit circumference and fruit length to the tune of 251, 10.9 cm and 21.0 cm, respectively as compared to 185, 8.3 cm and 16.6 cm in open fields banana production. These fruiting characters resulted in overall 53 percent yield enhancement under protected conditions. Specifically, the individual improvement in above yield attributing characters was upto 10 percent in terms of number of hands per bunch, 14 mm in finger length and 8 to 26 percent in bunch weight.

Kamiloglu *et al.* (2011) experimented on grapevines by growing them under protected conditions and open fields, where they recorded earliness in phonologic periods of vines grown under protected structures. The factors which were reported to be advanced by protective covering were bud break stage, full bloom, veraison and fruit maturity. Blooming occurred 14 days early than open field grapes due to 9 day early bud break of fruiting vines. Similarly, the fruit maturity was noticed 17 days early under protective cover due to 16 days advancement in veraison stage as compared to open vine orchard. Medany *et al.* (2009) compared the open field mango orchard performance with mango plants grown under white net. They reported an increase in fruit yield of mango by the use of white net. This yield enhancement was attributed to white net affect on irradiation. The reduced radiations under the white net affected photosynthetic capacity of leaves resulting in low light saturated photosynthesis rate as compared to the tree leaves growing in open fields.

Reddy and Gowda (2014) studied the influence of protected cultivation on flowering, fruit yield and quality of "Red Lady" papaya. The green house cultivation of papaya resulted in precocity in flower initiation and bearing ending up in higher yield levels. The plants under green house started flowering in 84.69 days producing higher number of flowers per plant to the tune of 48.88 percent leading to maximum fruit setting upto 74.38 percent. Earliness in flowering and fruiting lead to advanced maturity with average 166.81 days and prolonged harvest period contributing to 31.58 harvests. This advancement in fruiting and enhancement in harvesting period was attributed to improved hormonal metabolism and photosynthesis in plant due to favourable environmental conditions under protected structure. In the same experiment, papaya fruit length, breadth, circumference, weight, yield per plant and yield per hectare were reported to be 20.63 cm, 14.03 cm, 31.90 cm, 962.70 g, 33.11 kg and 102.18 tones in the plants grown under protected conditions. These values were significantly superior to the levels obtained in open field conditions (fruit length 15.24 cm, breadth 11.71 cm, circumference 27.06 cm, weight 806.16 g and yield per plant 10.42 kg). These promising yield attributes were produced by availability of continuous and healthy disease/ pest free growth and maximum leaf area. Tyagi *et al.* (2015) studied the papaya plants production under poly-net house by evaluating five different cultivars. They reported "Red Lady" cultivar of papaya to give earliest harvesting in 295 days. Kaur and Kaur (2017) compared the performance of "Red Lady" papaya under protected cultivation and open fields. They revealed an improved flowering, fruiting and yield under protected cultivation with maximum bisexual flowers (51.32 flowers, 49.52 fruits per plant and 45.39 kg/ plant fruit yield).

2.3.3 Effect of protected cultivation on fruit quality attributes:

Furukawa *et al.* (1990) compared the performance of peach under protected cultivation and open fields. They reported significant differences among total soluble solids and pH when fruits from protected structure were compared with outer fields. Although total soluble solids, pH and acidity were higher in protected cultivation fruits, but the acid content variations were non-significant. Hirokazu *et al.* (2001) assessed the influence of shading conditions on custard apple and noticed enhancement in leaf chlorophyll content as a result of low light intensity under shady conditions. This higher level of chlorophyll was recorded in pre-shade leaves, whereas in post-shade leaves, the chlorophyll content was higher at 24 percent sunlight perception *i.e.* middle shading conditions. They also explained that leaves performed higher carbon dioxide assimilation rate with increased stomatal conductance under light and middle shading conditions. This carbon dioxide assimilation rate was uniformly higher under light shading all day long except during mid day when stomatal conductance and leaf water potential were minimum. Higher light perception resulted in higher leaf temperature that ultimately caused high leaf vapor pressure deficit resulting in low gas exchange rate. Specifically, the custard apple fruit quality and weight were inferior under higher shady conditions and also the maturity was delayed. Cherimoya production was also nil under heavy shade conditions. This cherimoya production was found optimum with light environment created by use of 50 to 70 percent shading.

Gubbuk and Pekmezci (2004) studied the influence of protected cultivation on banana production and reported an increase in bunch stalk circumference and total number of hands per bunch in comparison to open field production. These parametric values were 25.4 and 12.9, respectively in comparison to 22.2 and 10.6 noted in open fields. Kamiloglu *et al.* (2011) performed an experimental study on five grape varieties by growing them under two types of conditions *viz.* open fields and protected conditions. Overall performance of grapes was reported to be better under protected conditions in comparison to outer fields. The parameters that were found significantly different among two growing conditions were grape cluster weight, cluster width, cluster length, total soluble solids content, titrable acidity, pH and maturity index. Although the cluster length was reported maximum in variety “Uslu”, whereas, the cluster width and weight was maximum in cultivar “Ergin cekirdeksizi”. The total soluble solids content varied from 14.68 percent in open fields to 14.82 percent in protected cultivation, whereas the pH value was at par under both growing conditions. The acidity in berries was higher in protective farming, however, the maturity index was least in same field as compared to open cultivation. Vool *et al.* (2013) also compared the grapes performance under protected structures and open fields. The parameters identified to evaluate the performance were total soluble solids, acidity, phenolics and anthocyanins in grape berries. Among these biochemical characteristics, total soluble solids content, phenolics and anthocyanin content were found promising in the berries produced under protected cultivation with the maximum values to the tune of 25.4 °brix, 540 mg per 100 gram and 480 mg per 100 gram, respectively. However the acid content of 1.2 g per 100 gram was lowest in the protected cultivation berries as compared to 1.6 g per 100 gram in openly cultivated berries.

Jiang *et al.* (2013) used protected cultivation as rain shelter for grape vines and evaluated the quality of grapes where they reported an overall decrease in anthocyanin content in grape berries skin. This reduced pigment content was attributed to lower sunlight availability and risen temperature effect that have major influence on accumulation of anthocyanins. Moreover, the higher levels of air moisture were found non-favourable for above pigment accumulation. These anthocyanins were reported to occur in different predictable forms such as monomers and oligomers or polymers that occur in grape stem, berries seed and skin. A procyanidin dimer and trimer namely flavan 3-ols oligomer was estimated to be highest in all berries produced under both cultivation systems, whereas, pro-anthocyanidin had low concentrations in berries produced under shelter. It was concluded that solar radiations and air moisture had major influence on anthocyanin accumulation during maturation than air temperature. Reddy and Gowda (2014) studied the influence of protected cultivation on "Red Lady" papaya production. Among different fruit quality aspects, maximum pulp weight (813.46 g), least peel weight (76.56 g), more pulp:peel ratio (10.63), highest total soluble solids content (13.92 °brix), total sugars (12.64 %), reducing sugars (9.53 %), non-reducing sugars (3.11 %), sugar/acid ratio (105.33), carotene content (2.42 mg/100 g) with least acidity (0.12 %) and ascorbic acid content (96.18 mg/ 100 g pulp) were observed in fruits produced under green house conditions. In addition to these biochemical characteristics, fruit firmness (2.82 kg/cm^2), shelf life (7.92 days) and organoleptic score (19) were also found promising in green house conditions. The improvement in fruit quality characteristics was related to the favourable climatic factors such as temperature, light intensity and humidity that promoted the chlorophyll content and ultimately photosynthesis in leaves. As a result there might be more translocation of carbohydrates for cell division and elongation of plant and fruits. Adequate timely translocation of carbohydrates accompanied with more leaf area and number might have promoted development of sweeter fruits with low acidity at maturity.

2.3.4 Effect of protected cultivation on disease/pest incidence

Jiang *et al.* (2013) used protected cultivation as rain shelter for grape vines and evaluated the quality of vines. They reported a far lower fruit disease incidence under rain-shelter technology. However, the vines in open fields got infected with downy mildew, anthracnose and white berries rot. This infection in open fields was upto the extent of 75 percent which alters the fruit yield and quality very seriously, thereby causing economical losses. Reddy and Gowda (2014) studied the influence of protected cultivation on incidence of papaya ring spot virus in "Red Lady" papaya. Under open field conditions, they revealed

163.23 days for virus appearance with 100 percent infected plants, whereas in protected environment no virus incidence was seen upto end of the investigation. This absence of infection under covered conditions was attributed to the exclusion of virus vectors *i.e.* aphids by the use of insect-net on outer walls of the growing structure.

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled "Standardization of fertigation doze for open and protected cultivation of papaya in Punjab" was carried out during the time period of year 2016-2018 in poly-net house unit and open fields available at Centre of Excellence for Fruits, village- Khanaura in the vicinity of Hoshiarpur district. The materials and methods employed during the investigation are described as under:

3.1 Planting material

The studies were carried on two papaya cultivars namely "Red Lady 786" and "Surya". Both the varieties were planted in poly-net house unit as well as in open fields during the month of September. All the plants were planted at a distance of 1.5 x 1.5 m. The description of varieties is as under:

3.1.1 Red Lady 786

This variety is also known as Taiwan 786. It is a gynodioecious variety grown for table as well as processing purpose. The plants start bearing at a height of 100 cm above ground level. The fruits are oblong, weighing 1-3 kg and have good keeping quality. The average yield of the variety is 50 kg/ plant.

3.1.2 Surya

It is a hybrid variety which was derived from the cross between 'Sunrise Solo' and 'Pink Flesh Sweet', followed by selection from F_{14} generation. The plants are gynodioecious in nature with no male plants. The fruits are medium sized weighing 600 to 800 g with a small central cavity. In ideal conditions, the yield is approximately 55 to 65 kg per plant.

3.2 Experimental details

The experiment was laid out by Factorial Randomized Block Design (FRBD) with two papaya cultivars studied under two factors as described below:

Factor 1 : Fertilizer application (F) at five levels consisting four fertigation and one control treatment.

F_1 : Fertigation with 60 percent recommended dose of fertilizers

F_2 : Fertigation with 80 percent recommended dose of fertilizers

F_3 : Fertigation with 100 percent recommended dose of fertilizers

F_4 : Fertigation with 120 percent recommended dose of fertilizers

F_5 : Fertilizer application through conventional method using 100 percent recommended dose of fertilizers

Factor 2 : Growing conditions (C) at two levels.

C_1 : Poly-net house growing condition

C_2 : Open field growing condition

Each treatment was replicated three times with three plants in each replication. Total ten treatment combinations were formulated by using both factors that have been shown below:

F_1C_1 : Fertigation with 60 percent recommended dose of fertilizers under poly-net house

F_2C_1 : Fertigation with 80 percent recommended dose of fertilizers under poly-net house

F_3C_1 : Fertigation with 100 percent recommended dose of fertilizers under poly-net house

F_4C_1 : Fertigation with 120 percent recommended dose of fertilizers under poly-net house

F_5C_1 : Fertilization through conventional means with 100 percent recommended dose of fertilizers under poly-net house

F_1C_2 : Fertigation with 60 percent recommended dose of fertilizers in open fields

F_2C_2 : Fertigation with 80 percent recommended dose of fertilizers in open fields

F_3C_2 : Fertigation with 100 percent recommended dose of fertilizers in open fields

F_4C_2 : Fertigation with 120 percent recommended dose of fertilizers in open fields

F_5C_2 : Fertilization through conventional means with 100 percent recommended dose of fertilizers in open fields

The experimental layout of study has been listed below:

Number of cultivars under study	=	2 ('Red Lady 786' and 'Surya')
Number of growing conditions	=	2 (Protected cultivation and open fields)
Number of treatments	=	5 (4 fertigation + 1 control treatments)
Number of plants per replication	=	3
Number of replications per treatment	=	3
Total number of experimental plants	=	180 (90 plants of each cultivar)

3.3 Methodology

The healthy seedlings of ‘Surya’ variety were produced from seeds that were bought from Indian Institute of Horticultural Research, Bangalore, whereas, the healthy nursery plants of ‘Red Lady 786’ variety were procured from fruit plant nursery of Punjab Agricultural University, Ludhiana. These plants were planted in poly-net house unit and open fields and were given fertigation treatments which consisted of applying N:P:K (0:52:34) and ammonium sulphate fertilizers along with drip system of irrigation. The control treatment was applied in the form of conventional fertilization system using urea, single super phosphate and muriate of potash. The recommended dose of fertilizers used here consisted of 375 g urea, 750 g superphosphate and 125 g muriate of potash (Anonymous 2018). The experimental plants under above treatments were further periodically used to record various vegetative, fruiting, physico-chemical characteristics and leaf nutrients status in both the papaya cultivars. The amount of nutrients calculated for various treatments was as under:

Nutrient dose	60 percent	80 percent	100 percent	120 percent
N (gram)	104.00	139.00	173.00	208.00
P_2O_5 (gram)	72.00	96.00	120.00	144.00
K_2O (gram)	47.00	63.00	78.00	94.00

Fertilizer dose (gram)	60 percent	80 percent	100 percent	120 percent
N:P:K	138.00	185.00	230.00	277.00
Ammonium sulphate	400.00	535.00	665.00	800.00

3.4 Fertigation scheduling

The drip line consisted of drippers having individual discharge capacity of 2 to 2.4 litres per hour. The drip irrigation was scheduled every third day, whereas, fertigation was done at seven days interval starting from 45 days after transplanting. However, in control plants the fertilizers were applied in the month of February and August (Anonymous 2018).

3.5 Observations recorded

The methods used to analyze various growth, yield, fruit quality, leaf nutrient and soil nutrient parameters during this experimental study are listed here:

3.5.1 List of recorded observations:

3.5.1.1 Plant growth parameters

3.5.1.1.1 Plant height (cm)

3.5.1.1.2 Stem girth (cm)

3.5.1.1.3 Plant spread (cm)

3.5.1.1.4 Average number of functional leaves per plant

3.5.1.1.5 Height of first flowering (cm)

3.5.1.2 Yield and related attributes

3.5.1.2.1 Days taken to flower initiation

3.5.1.2.2 Days taken to initiation of fruit set

3.5.1.2.3 Days taken to first fruit maturity

3.5.1.2.4 Days taken to final harvest

3.5.1.2.5 Average no. of fruits per node

3.5.1.2.6 Average no. of fruits per plant

3.5.1.2.7 Average fruit length (cm)

3.5.1.2.8 Average fruit circumference (cm)

3.5.1.2.9 Average fruit weight (g)

3.5.1.2.10 Average fruit yield (kg/tree)

3.5.1.2.11 Colour development

3.5.1.2.12 Central cavity diameter (cm)

3.5.1.3 Fruit quality parameters

3.5.1.3.1 Edible portion (percent)

3.5.1.3.2 Fruit firmness (lb)

3.5.1.3.3 TSS (°Brix)

3.5.1.3.4 Titratable acidity (%)

3.5.1.3.5 TSS/acid ratio

3.5.1.3.6 Sugars (%)

3.5.1.4 Leaf elemental content

3.5.1.4.1 Macro-nutrients (N, P, K, Ca, Mg)

3.5.1.4.2 Micro-nutrients (Fe, Zn, Mn, Cu)

3.5.1.5 Soil parameters (at 0-15, 15-30, 30-60 and 60-90 cm depth) before and after experiment

3.5.1.5.1 pH

3.5.1.5.2 Electrical conductivity (dSm^{-1})

3.5.1.5.3 Organic carbon (percent)

3.5.1.5.4 Available N (percent)

3.5.1.5.5 Available P (percent)

3.5.1.5.6 Available K (percent)

3.6 Description of recorded observations:

3.6.1 Plant growth parameters

3.6.1.1 Plant height (cm)

The plant height was measured in centimeters from the ground level to the tip of uppermost leaf using the measuring tape and average was worked out.

3.6.1.2 Stem girth (cm)

The stem girth was measured in millimeters at a height of 10 centimeters from the ground level.

3.6.1.3 Plant spread (cm)

The plant spread was measured in centimetres using measuring tape by spreading the widest leaves adjacent to each other and measuring plant spread in the form of distance between tips of both the selected leaves.

3.6.1.4 Average number of functional leaves per plant

The number of mature fully developed functional leaves per plant was counted on all the three plants in each replication and the average was worked out in terms of number of leaves per plant.

3.6.1.5 Height of first flowering (cm)

The height of first flowering was measured as soon as the flower emergence started. It was measured from ground level to first flower with the help of measuring tape and average height of all the experimental plants of each variety was calculated and recorded in centimeters.

3.6.2 Yield and related attributes

3.6.2.1 Days taken to flower initiation

The experimental plants of both varieties were regularly observed for the advent of anthesis. The number of days taken from transplanting to opening of first flower bud was recorded as the time taken for initiation of flowering.

3.6.2.2 Days taken to initiation of fruit set

The number of days taken from transplanting to first fruit set was recorded following the advent of flowering in each variety.

3.6.2.3 Days taken to first fruit maturity

The number of days taken from transplanting to beginning of harvest in each variety was recorded when fruits started showing yellowish colored streaks over the surface and became ready for harvest.

3.6.2.4 Days taken to final harvest

The days taken from transplanting to last mature fruit harvest in each variety was recorded as final harvest period.

3.6.2.5 Average number of fruits per node

The number of fruits borne on each node was counted at maturity and the average fruit number from all replications was worked out for each treatment under observation.

3.6.2.6 Average number of fruits per plant

The total number of fruits borne on each plant of both the varieties was counted at harvesting stage and average value was worked out from all the replications which were expressed as average number of fruits per plant.

3.6.2.7 Average fruit length (cm)

Three ripened fruits were randomly selected from each replication plant and their length was measured with the help of an ordinary scale (marked in cm). Thereafter, the average fruit length for each treatment was worked out and is expressed in centimeters.

3.6.2.8 Average fruit circumference (cm)

The same randomly selected fruits used for determining the length were also taken for the estimation of circumference. The fruit circumference was measured with an ordinary scale in centimeters from the middle of fruit where the fruit breadth was maximum and the average of each treatment was worked out.

3.6.2.9 Average fruit weight (g)

The ripened fruits randomly selected for observing fruit size were further weighed with the help of an electronic balance for recording fruit weight. The average weight of all the treatments was calculated and expressed in kilograms.

3.6.2.10 Average fruit yield (kg/plant)

The average yield per plant in each treatment was determined by multiplying the average fruit weight per plant with the total number of fruits borne on same plant. The average data for all three replications in each treatment was expressed in terms of kg per plant.

3.6.2.11 Colour development

Fruit skin colour at maturity was analysed using Royal Horticultural Society Colour Chart (Wilson, 1963) in each experimental plant.

3.6.2.12 Central cavity diameter (cm)

The central cavity diameter of the same fruits used for recording size and weight was determined using an ordinary centimetre scale. For this, the fruit was cut into two equal halves and thereafter the readings were taken at its maximum breadth. The average of each treatment was worked out in centimeters.

3.6.3 Fruit quality parameters

3.6.3.1 Edible portion (percent)

To determine the edible portion percentage, the weight of edible portion was worked out after removing the peel and placental tissue. Both, total fruit weight and weight of edible portion (pulp) was taken with the help of electronic weighing balance. Thereafter, percentage of edible portion of fruit was calculated by applying the following formula:

$$\text{Edible portion (\%)} = \frac{\text{Weight of edible portion (pulp)}}{\text{Total fruit weight}} \times 100$$

3.6.3.2 Fruit firmness (lbs)

Three fruits per replication plant were used for testing the firmness. About one square centimeter of the peel in each fruit from the shoulder end on both sides was removed with the help of a peeler and firmness of pulp was recorded with the help of a penetrometer. The pressure readings were recorded in lbs and average value was calculated for each treatment.

3.6.3.3 TSS (°Brix)

For determining total soluble solids content, the juice of three randomly selected fruits per plant was extracted and strained through muslin cloth. The strained juice was stirred properly. A drop of this juice was placed on the prism of Erma Hand refractometer and value of total soluble solids was obtained from direct reading (AOAC, 1990). The refractometer was washed and cleaned with distilled water before taking each reading.

3.6.3.4 Titratable acidity (Percent)

To determine acidity, 10 ml of juice was extracted and diluted to 100 ml in a volumetric flask. Then, it was titrated against N/10 NaOH solution using phenolphthalein as an indicator. The end point was noted with the change in colour from colourless to light pink.

The percentage of acid content was determined and estimated in terms of citric acid using the following formula (AOAC 1990):

$$\text{Juice acidity (\%)} = 0.0064 \times \frac{\text{0.1 N NaOH used}}{\text{Juice taken}} \times 100$$

3.6.3.5 TSS/acid ratio

TSS/acid ratio was calculated by dividing TSS with respective titratable acidity values.

3.6.3.6 Sugars (%)

For determination of total sugars, 25 g of fruit flesh was macerated with distilled water and the final volume was made to 100 ml. To this solution, 1 g lead acetate was added to precipitate the extraneous material. It was mixed thoroughly and the solution was allowed to stand for 10 minutes. Then 1 g potassium oxalate was added to it, for removing excess lead and the obtained solution was filtered through a filter paper and the filtrate was further diluted with distilled water up to 250 ml. This aliquot was further used for sugar estimation. In 25 ml of aliquot, 5 ml of 60 per cent concentrated HCl was added and the solution was left for acid hydrolysis for 24 hours at room temperature. Thereafter, the excess of HCl was neutralized with 10 % NaOH in initial stages and then with 0.1 % NaOH near the point of neutralization. A mixture of Fehling solution A and B (5 ml each) was titrated with the above produced neutralized solution using methylene blue as an indicator. Appearance of brick red colour indicated the end point. The percentage of total sugars was calculated by the following formula:

$$\text{Total sugar (\%)} = \frac{\text{Fehling solution factor (0.05)}}{\text{Volume of filterate used}} \times \frac{\text{Dilution made}}{\text{Weight of sample taken}} \times 100$$

3.6.2.5 Leaf elemental content

For determination of leaf elemental content, sixth leaf from top, six months after transplantion was collected from each experimental plant. These collected leaves were thoroughly washed first in tap water, then with distilled water and afterwards with a mixture of 0.01 N HCl and then with teepol solutions. Leaf samples were firstly dried in the shade and finally in an oven at 60°C at least for 48 hours. The dried samples were ground in the Willy Mill fitted with all components of stainless steel and the ground samples were passed through 40 mesh sieves. These ground samples were stored in butter paper bags and later were used for leaf nutrients analysis. Before analysis, the ground leaf samples were once again oven dried for 24 hours at 60°C.

3.6.2.5.1 Macro-nutrients (N, P, K, Ca, Mg) and micro-nutrients (Fe, Zn, Mn, Cu)

The 0.5 gram material from each ground sample was taken and 6 ml of concentrated nitric acid (HNO_3) was added in each HF vessel. The samples were then placed in rotors and rotors in microwave. After irradiating with microwaves, the solutions were cooled down for 20 minutes and the venting screws of vessels were opened under the fume hood. The solutions were further diluted to 50 times and the diluted samples were fed to inductively coupled plasma spectrophotometer (ICP) for analyzing various macro and micro-nutrients. The concentration of leaf elements was worked out as under:

Leaf elements (ppm) = dilution factor x ICP leaf elements value (ppm)

Where, dilution factor = volume made / weight of sample taken

3.6.2.6 Soil parameters (at 0-15, 15-30, 30-60 and 60-90 cm depth) before and after experiment:

To assess the initial fertility and after experimental status of soil, representative soil samples (0-90 cm depth) from three spots from each treatment site were collected, composited and air dried. 10 gram dried soil sample was mixed with 20 ml ammonium bicarbonate diethylene triamine pentaacetic acid (AB-DTPA) and shaken for half hour to mix it thoroughly. After that by adding 1 ml of 5 percent nitric acid, the above solution was filtered. The filtered solution was further fed to inductively coupled plasma spectrophotometer (ICP) for analyzing soil pH, electrical conductivity, organic carbon, nitrogen, phosphorus and potassium.

3.7 Statistical analysis

The experiment was be laid out by following factorial Randomized Block Design (RBD) and data was analyzed as per standard statistical procedures using suitable analysis software OPSTAT.

CHAPTER IV

RESULTS AND DISCUSSION

The research study entitled "Standardization of fertigation doze for open and protected cultivation of papaya in Punjab" was carried out on two gynodioecious varieties of papaya namely "Red Lady 786" and "Surya". In this chapter, results obtained on different parameters of the crop are illustrated and discussed under the respective heads:

4.1 Plant growth parameters

4.1.1 Plant height (cm)

Table 4.1: Effect of fertigation and growing conditions on plant height (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	313.53	230.42	**271.98[cd]**	206.17	168.76	**187.47[d]**
F_2	315.27	232.85	**274.06[c]**	213.86	177.81	**195.84[c]**
F_3	320.74	235.06	**277.90[b]**	240.35	181.07	**210.71[b]**
F_4	328.11	236.93	**282.52[a]**	280.66	186.93	**233.80[a]**
F_5	313.92	225.79	**269.86[d]**	212.93	166.45	**189.69[d]**
Mean (C)	**318.31[a]**	**232.21[b]**		**230.79[a]**	**176.20[b]**	
CD ($p \leq 0.05$)						
F	**2.38**			**5.11**		
C	**1.51**			**3.23**		
F x C	**3.37**			**7.22**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

It is clear from data presented in Table 4.1 that in both the papaya varieties, plant height was significantly improved in all the fertigation treatments. Also among different field conditions, the plant height was significantly different with maximum mean plant height under poly-net house conditions.

In variety 'Red Lady 786', the plant height was maximum (282.52 cm) where 120 percent RDF (recommended dose of fertilizers) was given through fertigation technique. Whereas, among both the growing conditions, the plant height was found maximum under poly-net house conditions as compared to open fields. The interactions were also statistically significant, analysing the 120 percent RDF fertigation under poly-net house (F_4C_1) to be the highest value (328.11) followed by 320.74 cm average height in F_3C_1 (100 percent RDF fertigation under poly-net house) and minimum average height (225.79 cm) was observed in open field with conventional fertilization (F_5C_2).

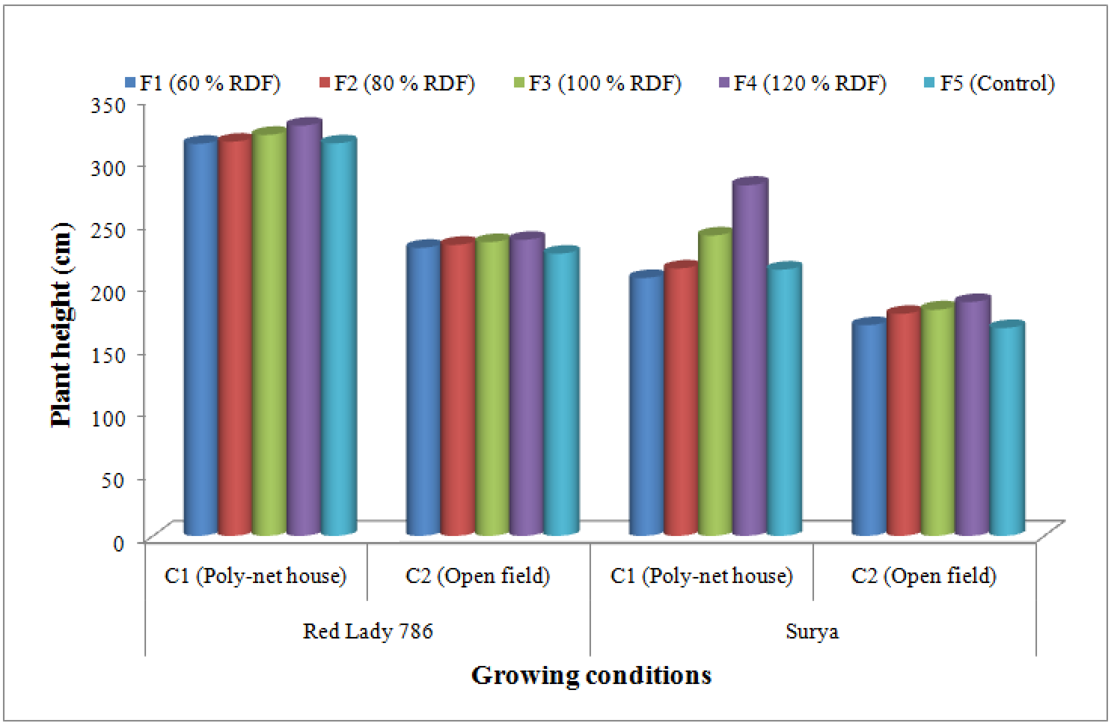

Figure 4.1: Effect of fertigation and growing conditions on plant height (cm) of papaya.

In papaya variety 'Surya', the mean plant height was highest (233.80 cm) where 120 percent RDF was applied through fertigation *i.e.* F_4 treatment followed by 210.71 cm in F_3 (100 percent fertigation) and was minimum (187.47 cm) in F1 (60 percent fertigation). Among two growing conditions, maximum mean plant height (230.79 cm) was recorded in plants growing under poly-net house as compared to 176.20 cm in plants grown in open fields. The interaction between fertigation and cultivation field treatments had also significantly affected the average plant height recording maximum average plant height of 280.66 cm followed by 240.35 cm respectively in F_4C_1 and F_3C_1, whereas, the minimum plant height was observed in F_5C_2 (conventional fertilization in open fields).

In treatments where plants were grown under poly-net house conditions and fertigation was applied, an increase in height was obviously expected due to availability of favourable growing environment under green house and due to constant nutrients availability in soil regime very near to root zone than normal growing plants in open fields and conventionally fertilized. These results are corroborated with the findings of Santos *et al.* (2008) who attributed the improvement in papaya plant height to low transpirational losses under modified environment. Similar results of increasing papaya plant height with increase in fertigation dose were also obtained by Deshmukh and Hardaha in 2014. Saucov *et al.* (1992), Kamiloglu *et al.* (2011) and Gubbuk and Pekmezci (2004) have also reported an improvement in plant vegetative growth under protected structures respectively in banana, grapes and banana crops.

4.1.2 Stem girth (cm)

The plant stem girth was significantly affected by growing conditions and various fertigation treatments in both papaya cultivars as shown in Table 4.2. Moreover, the interactions between these two independent factors were found significant only in 'Red Lady 786' variety.

In case of 'Red Lady 786' papaya, maximum (42.63 cm) stem circumference was recorded in 60 percent RDF fertigation (F_1 treatment) followed by second highest (42.26 cm) in 80 percent RDF fertigation (F_2) and minimum (33.44 cm) mean stem circumference in 120 percent RDF fertigation (F_4). However, F_1 treatment was at par with F_2 treatment. In same variety, mean plant stem girth (39.85 cm) was maximum in open fields as compared to minimum (37.14 cm) under poly-net house conditions. However, among various interactions, 60 percent RDF fertigation in poly-net house unit resulted in maximum average stem girth (47.53 cm) followed by 43.02 cm and 41.50 cm respectively in 80 percent RDF fertigation under poly-net house (F_2C_1) and open field (F_2C_2) with minimum stem girth (26.52 cm) in F_4C_1 (120 percent fertigation under protected conditions).

In 'Surya' variety of papaya, among different fertigation treatments, the mean stem girth was higher (33.39 cm) in 100 percent fertigation (F_3) which was at par with 33.22 cm in 80 percent fetigation (F_2) and was recorded minimum (29.51 cm) in 60 percent fertigation (F_1). Among two different growing conditions, open field (C_2) resulted in statistically higher mean stem girth of 33.75 cm, whereas it was at 30.03 cm in protected conditions (C_1). The interactions (F x C) resulted in higher average stem circumference (35.07 cm) in 80 percent fertigation doze in open field (F_2C_2) which was followed by 34.80 cm and 33.66 cm, respectively in 100 (F_3C_2) and 120 (F_4C_2) percent fertigation both done in open fields. These interactions recorded minimum average stem girth of 26.50 cm in 60 percet fertigation level under poly-net house conditions (F_1C_1).

Table 4.2: Effect of fertigation and growing conditions on stem girth (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	47.53	37.72	**42.63[a]**	26.50	32.52	**29.51[c]**
F_2	43.02	41.50	**42.26[a]**	31.36	35.07	**33.22[a]**
F_3	33.57	41.01	**37.29[b]**	31.97	34.80	**33.39[a]**
F_4	26.52	40.35	**33.44[c]**	29.74	33.66	**31.70[b]**
F_5	35.06	38.68	**36.87[b]**	30.58	32.69	**31.64[b]**
Mean (C)	**37.14[b]**	**39.85[a]**		**30.03[b]**	**33.75[a]**	
CD (p≤0.05)						
F	**1.49**			**1.30**		
C	**0.94**			**0.82**		
F x C	**2.11**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The greenhouse fertigated plants that showed lanky or elongated growth tends to have somewhat narrow stem in comparison to medium height plants. These results may be attributed to a combined effect caused by fertigation and shady conditions of protected greenhouse that diverted most of the plant energy for elongation of plants in search of more light. These findings are in line with the conclusions drawn by Panigrahi *et al.* (2015) who also reported a lower stem girth in large height papaya plants that were under fertigation.

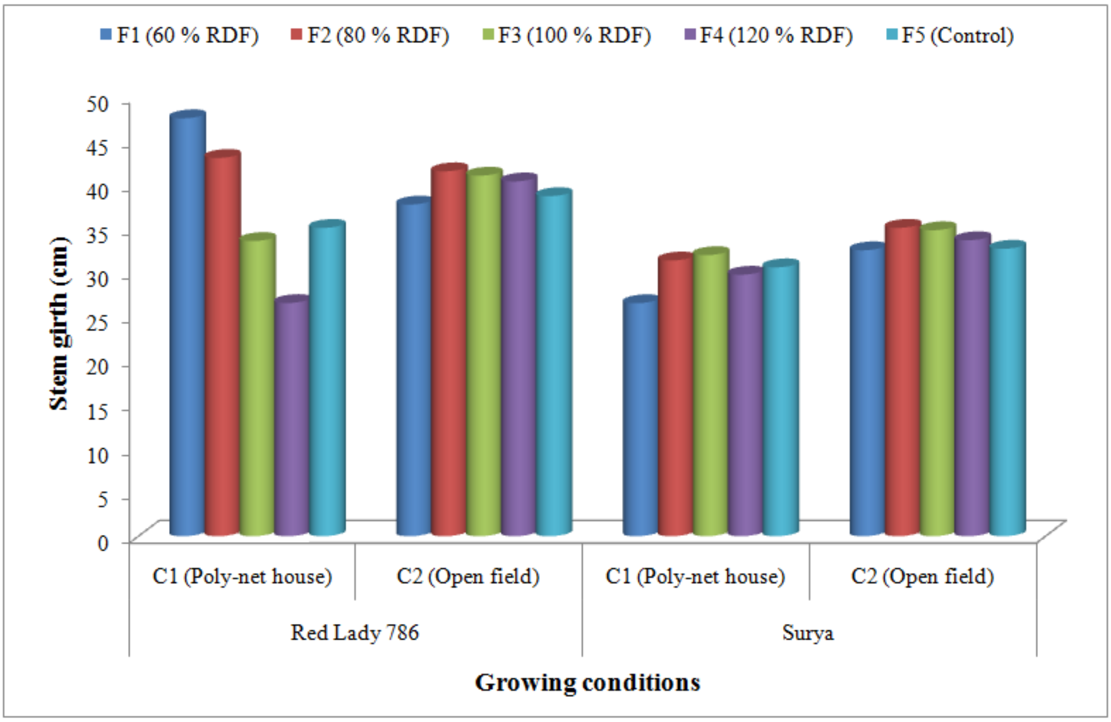

Figure 4.2: Effect of fertigation and growing conditions on stem girth (cm) of papaya.

4.1.3 Plant spread (cm)

The affect of various fertigation treatments and growing conditions on plant spread is shown in Table 4.3 for two papaya varieties 'Red Lady 786' and 'Surya'. The data represent that both the factors; fertigation and growing conditions, had significantly affected the plant spread individually as well in interaction.

In cultivar 'Red Lady 786', maximum mean plant spread (292.57 cm) was recorded in F_2 *i.e.* 80 percent fertigation that was at par with 289.55 cm in F_1 (60 percent fertigation) and was lowest (252.35 cm) in F_5 (100 percent conventional fertilization). Among different growing conditions, maximum mean plant spread (283.42 cm) was observed in open fields in contrast to minimum mean spread (272.54 cm) in plants growing under protected conditions. The interaction between fertigation treatments and growing conditions confrms the highest mean plant spread (296.41 cm) in 80 percent RDF fertigation when applied under poly-net house (F_2C_1) followed by 294.62 cm in 60 percent RDF fertigation under same growing conditions (F_1C_1) and lowest average plant spread (219.72 cm) in conventional fertilization system followed under protected conditions (F_5C_1).

Table 4.3: Effect of fertigation and growing conditions on plant spread (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	294.62	284.47	**289.55[a]**	211.43	233.58	**222.51[d]**
F_2	296.41	288.73	**292.57[a]**	240.50	239.40	**239.95[a]**
F_3	279.34	278.75	**279.05[b]**	216.00	237.93	**226.97[c]**
F_4	272.63	280.16	**276.40[b]**	221.76	240.76	**231.26[b]**
F_5	219.72	284.98	**252.35[c]**	206.89	227.29	**217.09[e]**
Mean (C)	**272.54[b]**	**283.42[a]**		**219.32[b]**	**235.79[a]**	
CD ($p \leq 0.05$)						
F	**5.95**			**0.94**		
C	**3.76**			**0.59**		
F x C	**8.41**			**1.33**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In ‘Surya’ cultivar of papaya, highest plant spread (239.95 cm) was noted in the plants that were under 80 percent fertigation (F_2). The second highest average plant spread (231.26 cm) was recorded in 120 percent fertigation (F_4), whereas, minimum plant spread (217.09 cm) was observed in conventional fertilization system *i.e.* control plants. The plants grown under open field had highest mean spread (235.79 cm) than plants grown under protected conditions (219.32 cm). Further, among all treatment combinations, the highest (240.76 cm) plant spread was reported in F_4C_2 followed by F_2C_1 (240.50 cm), while minimum plant spread (211.43 cm) was observed in 60 percent RDF fertigation done under protected conditions (F_1C_1).

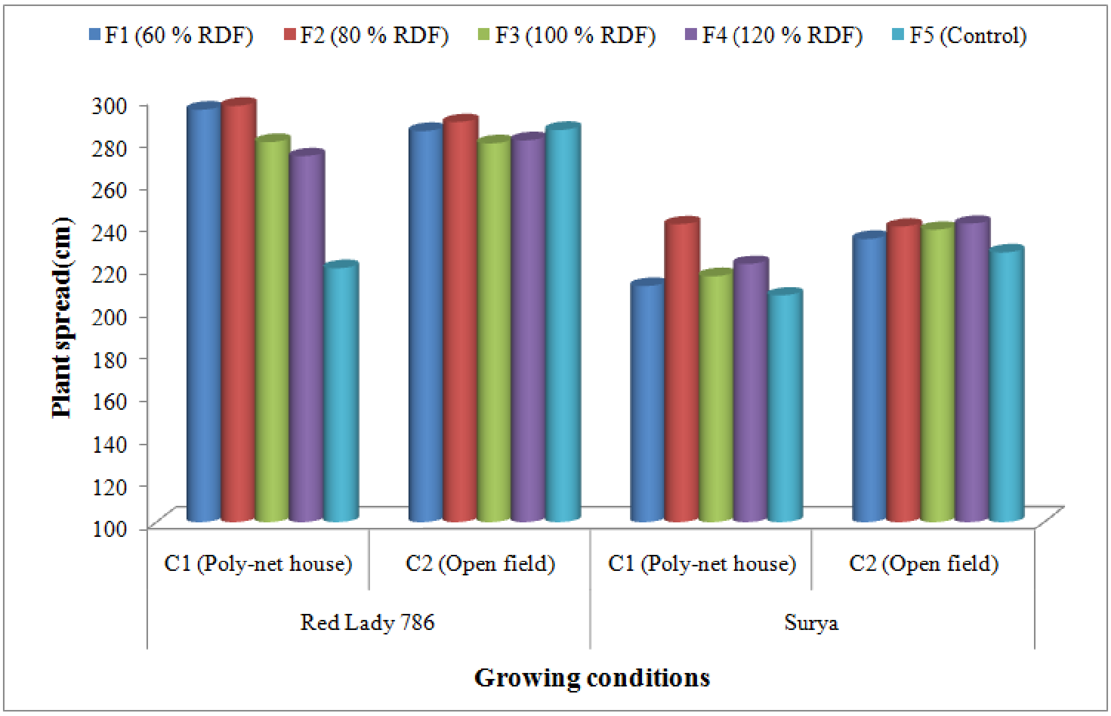

Figure 4.3: Effect of fertigation and growing conditions on plant spread (cm) of papaya.

The fertigation treatments resulted in increased foliage stretch that may ultimately had affected photosynthates development useful for sink *i.e.* developing fruits. Similarly, the open field plants might have stretched out the leaves more widely as compared to green house plants which had more internal energy diversion towards elongation rather than horizontal growth. These plant spread findings are in line with that of Singh *et al.* (2010) who had also reported improved canopy spread in litchi with increased fertigation levels

4.1.4 Average number of functional leaves per plant

It is clear from the data presented in Table 4.4 that total count of functional leaves on a plant is significantly affected by different fertigation and cultivation treatments in both the cultivars of papaya *viz.* ‘Red Lady 786’ and ‘Surya’. The interaction effect of both the factors also significantly influenced the attribute.

The fertigation treatments applied in ‘Red Lady 786’ variety resulted in maximum 26.50 mean number of leaves per plant in F_1 treatment (60 percent RDF fertigation) followed by 23.67 and 22.50 mean leaf number in F_2 (80 percent RDF fertigation) and F_5 (basal application of fertilizers), respectively, that were at par to each other. Whereas, minimum mean number (20.50 and 20.67) of functional leaves per plant were recorded, respectively in F_4 (120 percent RDF fertigation) and F_3 (100 percent RDF fertigation) treatment. Maximum mean functional leaves per plant (26.0) were under poly-net house conditions (C_1) as compared to minimum (19.53) in open fields (C_2). Among various treatment combinations, 60 percent RDF fertigation under protected conditions (F_1C_1) resulted in highest (32.0) average leaf number followed by 26.0 in both F_2C_1 (80 percent fertigation under poly-net house) and F_5C_1 (conventional fertilization under poly-net house), whereas, F_4C_2 (120 percent fertigation in open field) recorded least average leaf number (17.0).

Table 4.4: Effect of fertigation and growing conditions on average number of functional leaves per plant in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	32.0	21.0	**26.50^a^**	22.58	15.76	**19.17^c^**
F_2	26.0	21.3	**23.67^b^**	29.47	18.93	**24.20^a^**
F_3	22.0	19.3	**20.67^c^**	29.31	18.08	**23.70^a^**
F_4	24.0	17.0	**20.50^c^**	18.62	15.29	**16.96^d^**
F_5	26.0	19.0	**22.50^b^**	23.92	16.47	**20.20^b^**
Mean (C)	**26.0^a^**	**19.53^b^**		**24.78^a^**	**16.91^b^**	
CD (p≤0.05)						
F	**1.74**			**0.61**		
C	**1.10**			**0.38**		
F x C	**2.46**			**0.86**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In ‘Surya’ papaya, highest mean per plant leaf count (24.20) was observed in F_2 (80 percent fertigation) followed by 23.70 in F_3 (100 percent fertigation) and minimum mean leaf count (16.96) was recorded in F_4 (120 percent fertigation). However, F_2 was at par with F_3. Comparing two field conditions, the highest leaf number mean (24.78) was under protected conditions in comparison to 16.91 in open fields. The interactions of various factors revealed the highest leaf average count (29.47) in F_2C_1 followed by 29.31, 23.92 and 22.58 in F_3C_1 (100 percent fertigation inside protected structure), F_5C_1 (conventional fertilization under poly-net house) and F_1C_1 (60 percent fertigation inside protected structure), respectively. However, in open conditions highest (18.93) number of leaves were reported in F_2 (80 percent fertigation) followed by 18.08 in F_3 (100 percent fertigation) and was lowest (15.29) in F_4 (120 percent fertigation).

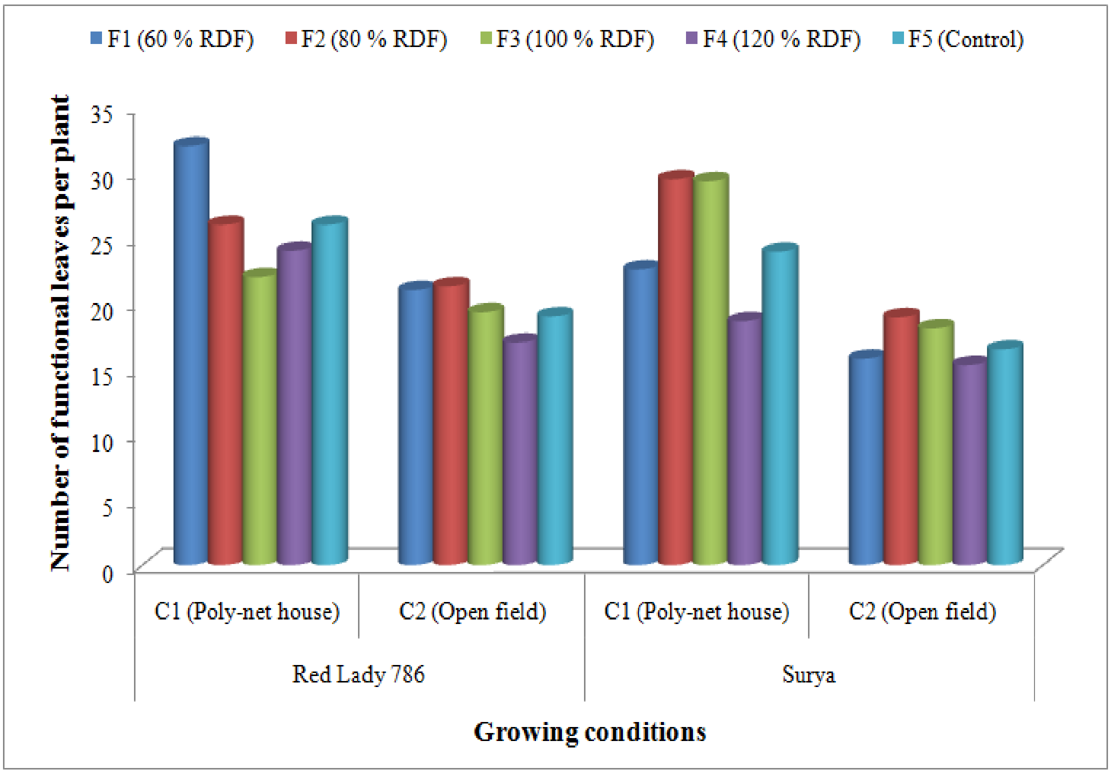

Figure 4.4: Effect of fertigation and growing conditions on number of functional leaves per plant in papaya.

Average number of leaves per plant was more in most of the fertigation doses that may be attributed to higher nutrients uptake and reserving them in leaf tissues for greater photosynthesis. However, excess of fertigation had not been effective to increase number of leaves which confirms the maximum FUE (fertilizer use efficiency) at RDF. These results are related with the banana crop findings by Senthilkumar *et al.* (2013) who stated maximum leaves retention at lowest fertigation level combined with consortium of fertilizer application. Similarly, Ghanta *et al.* (1995) and Panigrahi *et al.* (2015) had also reported an enhancement in intensity of functional leaves retained on papaya plants by using fertigation technique.

4.1.5 Height of first flowering (cm)

The lower height of flowering in papaya plant is accountable for earliness in flowering, so, this attribute is contributor towards high yield. The data presented in Table 4.5 reveals that different levels of fertilizer application and varied growing conditions significantly improved the height of first flowering in papaya. Similarly, the interactions among various nutrition levels and environmental factors also had significantly affected the flowering height of papaya plants in both the cultivars.

Table 4.5: Effect of fertigation and growing conditions on height of first flowering (cm) in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	87. 00	77.65	**82.33^{a}**	155.47	134.82	**145.15^{a}**
F_2	89.00	78.93	**83.97^{b}**	172.61	132.57	**152.59^{b}**
F_3	98.30	80.74	**89.52^{c}**	180.53	150.63	**165.58^{d}**
F_4	103.50	82.06	**92.78^{d}**	189.37	161.16	**175.27^{e}**
F_5	83.50	83.30	**83.40^{ab}**	147.49	164.38	**155.94^{c}**
Mean (C)	**92.26^{b}**	**80.54^{a}**		**169.09^{b}**	**148.71^{a}**	
CD						
($p \leq 0.05$)	**1.46**			**1.12**		
F	**0.92**			**0.71**		
C	**2.07**			**1.58**		
F x C						

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The first flowering in 'Red Lady 786' papaya occurred at lowest height (82.33 cm) from base of plants that were given 60 percent fertigation (F_1) followed by 83.40 and 83.97

cm in 100 percent conventional fertilization and 80 percent fertigation, respectively. The poly-net house controlled environmental conditions also increased the height of flowering to the mean level of 92.26 cm as compared to 80.54 cm in plants growing in open fields. However, among various interactions, maximum average flowering height was 103.50 cm in 120 percent fertigation in protected conditions (F_4C_1) which was followed by 98.30 cm in 100 percent fertigation in same growing conditions (F_3C_1). However, 60 percent fertigation treatment in open fields (F_1C_2) resulted in lowest flowering level of 77.65 cm.

In papaya cultivar 'Surya', the fertigation treatments (F_3 @ 100 percent fertigation and F_4 120 percent fertigation) increased the flowering height (175.27 and 165.58 cm, respectively) as compared to 155.94 cm in control (F_5). However, the F_1 fertigation treatment resulted in minimum height of flowering at the level of 145.15 cm. Among two growing conditions, the green house structure (C_1) recorded higher height of flower initiation as compared to open field (C_2) grown plants. Collaborative affect of both independent factors (fertigation and growing environment treatments) recorded 189.37 cm to be the highest average flowering height in 120 percent fertigation in protected structure (F_4C_1) followed by 180.53 in 100 percent green house fertigation (F_3C_1) and flowering occurred at lowest level of 132.57 cm in 80 percent open field fertigation (F_2C_2).

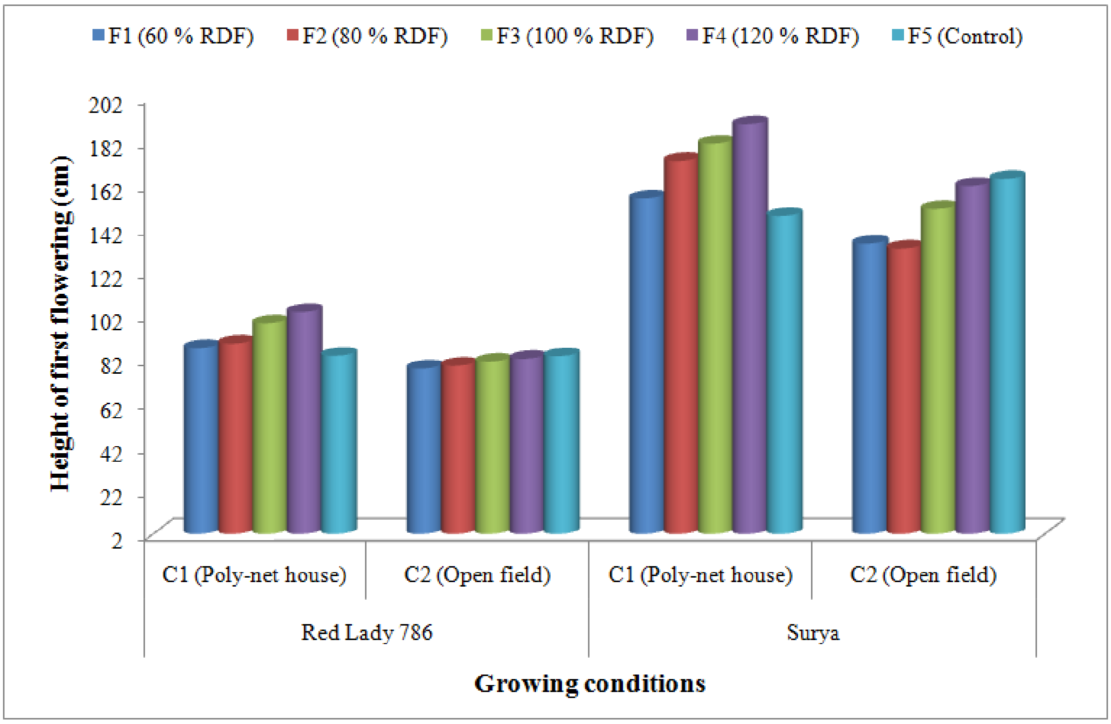

Figure 4.5: Effect of fertigation and growing conditions on height of first flowering (cm) in papaya.

In protected cultivation, along with increased height of plants, the bearing height of first fruit might also have moved upwards. Although, the lower flowering height in papaya crop is considered desirable but here the elongated upward growth of plants with greenhouse environment may have slightly moved the flowering level upwards. However, various fertigation levels have decreased the flower initiation height in comparison to control in open fields that may be a result of early diversion to reproductive phase in fertigated plants. The results obtained are in contrast to the inferences worked out by Singh and Singh (2012) in papaya variety 'Pusa delicious', where an increase in height of flowering was reported in the plants that were under fertigation.

4.2 Yield and related attributes

4.2.1 Days taken to flower initiation

It is evident from the data presented in Table 4.6 that varying fertigation levels from 60 to 120 percent under protected and open environmental conditions significantly reduced the days taken for flower initiation in 'Red Lady 786' and 'Surya' papaya. The analysis also confirms significant individual and interactional effect of both factors over number of days taken to flower initiation.

The data for 'Red Lady 786' papaya manifested that the plants under 60 percent RDF fertigation took least number of days (192.9) followed by 195.9 days in 80 percent RDF fertigated plants as compared to control plants (100 percent conventional fertilization) which took maximum duration to flower *i.e.* 203.7 days. Moreover, the plants growing in protected environment started flowering earlier in 196.0 days as compared to 201.9 days taken by plants under open field. Overall F x C interactions also significantly advanced the flower initiation with earliest flowering (189.0 days) in 60 percent RDF fertigation under poly-net house (F_1C_1) followed by 193.0 days in 80 percent RDF fertigation plants growing under same conditions (F_2C_1).

Similarly, in papaya cultivar 'Surya', the F_1 treatment (60 percent fertigated plants) resulted in earliest flowering within 231.0 days of transplanting as compared to late flowering in 236.7 and 236.8 days in F_5 (100 percent conventional fertilization) and F_4 (120 percent fertigated plants), respectively. Comparing the plants under two growing conditions, the plants under poly-net house initiated flowering approximately 10 days (within 229.0 days of transplanting) before flower initiation in open field plants. The data analyzed for various interactions revealed that flowering in poly-net house plants under 60 percent fertigation (F_1C_1) initiated within least 226.0 days followed by 227.0, 230.0 and 230.3 days under same growing conditions in 80 percent fertigation (F_2C_1), control (F_5C_1) and 100 percent fertigation (F_3C_1) plants, respectively. However, the open field plants under F_3C_2, F_4C_2 and F_5C_2 treatments started flowering very late within 240.3, 242.0 and 243.3 days after transplanting, respectively.

Table 4.6: Effect of fertigation and growing conditions on flower initiation (days) in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	189.0	196.7	**192.9^{a}**	226.0	236.0	**231.0^{a}**
F_2	193.0	198.7	**195.9^{b}**	227.0	235.7	**231.4^{a}**
F_3	197.0	202.3	**199.7^{c}**	230.3	240.3	**235.3^{b}**
F_4	202.0	203.6	**202.8^{d}**	231.6	242.0	**236.8^{c}**
F_5	199.0	208.3	**203.7^{d}**	230.0	243.3	**236.7^{bc}**
Mean (C)	**196.0^{a}**	**201.9^{b}**		**229.0^{a}**	**239.5^{b}**	
CD (p≤0.05)						
F	**1.74**			**1.45**		
C	**1.10**			**0.92**		
F x C	**2.46**			**2.05**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

It is pertinent to mention here that the green house plants applied with fertigation tend to show precocity in bearing i.e. earlier shifting from vegetative to reproductive phase. Reddy and Gowda (2014) related this earliness in fruiting with the increased hormonal metabolism and photosynthesis in the papaya plant due to presence of most favourable climatic conditions inside poly-net house. Sameway, Ahmed *et al.* (2010) had documented an earlier flowering in banana crop grown under drip irrigation as compared to surface irrigation.

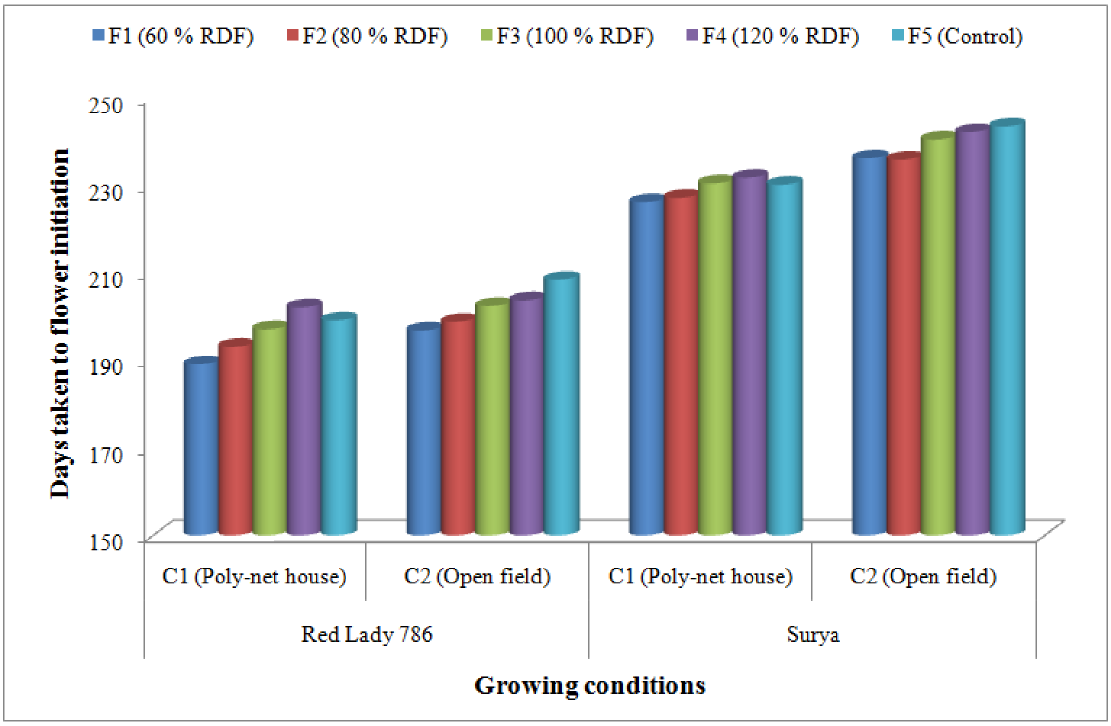

Figure 4.6: Effect of fertigation and growing conditions on flower initiation (days) in papaya.

4.2.2 Days taken to initiation of fruit set

The data related to fruit set initiation in 'Red Lady 786' and 'Surya' varieties of papaya as influenced by different fertigation and growing conditions is presented here in Table 4.7. It appears that fruit setting initiation was significantly affected by fertigation and growing condition treatments as well as by their interaction effect.

The mean number of days taken for initiation of fruit shows that 'Red Lady 786' papaya plants under F_1 fertigation treatment started fruit setting in 196.7 days, whereas in F_2 treatment (80 percent fertigation), the fruit set has taken 198.4 days after transplanting as compared to maximum 207.2 days in F_5 (control). The modification of environment because of protected conditions also advanced the fruit setting in 'Red Lady 786' papaya causing it to occur within 199.6 days i.e. approximately 5 days earlier to plants under open field where fruiting took 204.9 days to start. The interaction effect of fertigation and growing conditions resulted in least number of days requirement for fruit setting i.e. 194.0 days in F_1C_1 (60 percent RDF fertigation under poly-net house) followed by 196.0 and 199.3 days in F_2C_1 (80 percent RDF fertigation under poly-net house) and F_1C_2 (60 percent RDF fertigation in open fields), respectively. However, the F_4C_2 (120 percent fertigation in open fields) and F_5C_2

(conventional fertilization in open fields) treatment interactions revealed the maximum time period requirement for fruit setting to the level of 207.0 and 212.3 days, respectively.

Table 4.7: Effect of fertigation and growing conditions on fruit set initiation (days) in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	194.0	199.3	**196.7^a**	226.7	237.3	**232.0^a**
F_2	196.0	200.7	**198.4^b**	229.3	239.3	**234.3^a**
F_3	201.0	205.3	**203.2^c**	232.3	242.0	**237.2^b**
F_4	205.0	207.0	**206.0^d**	236.3	248.3	**242.3^c**
F_5	202.0	212.3	**207.2^d**	230.3	250.3	**240.3^c**
Mean (C)	**199.6^a**	**204.9^b**		**231.0^a**	**243.4^b**	
CD ($p \leq 0.05$)						
F	**1.61**			**2.52**		
C	**1.02**			**1.59**		
F x C	**2.28**			**3.56**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The lowest mean number of days (232.0) taken for fruit set in 'Surya' papaya was in F_1 (60 percent fertigation) treatment followed by 234.3 days in F_2 (80 percent fertigation) treatment as compared to 242.3 days (maximum days taken for fruit setting) in F_4 (120 percent fertigation). Nearly 3.5 days difference was reported for fruit setting under poly-net house (231.0 days) in comparison to open field grown papaya plants (243.4 days). Similarly, the interaction effect of fertigation done in different growing conditions revealed the minimum days (226.7) required for fruit setting in 60 percent RDF fertigated plants in protected fields (F_1C_1) followed by 229.3 days in 80 percent RDF fertigated plants in poly-net house (F_2C_1) and maximum 250.3 days taken for fruit set in control treatment i.e. F_5C_2 (100 percent conventional fertilization in open fields).

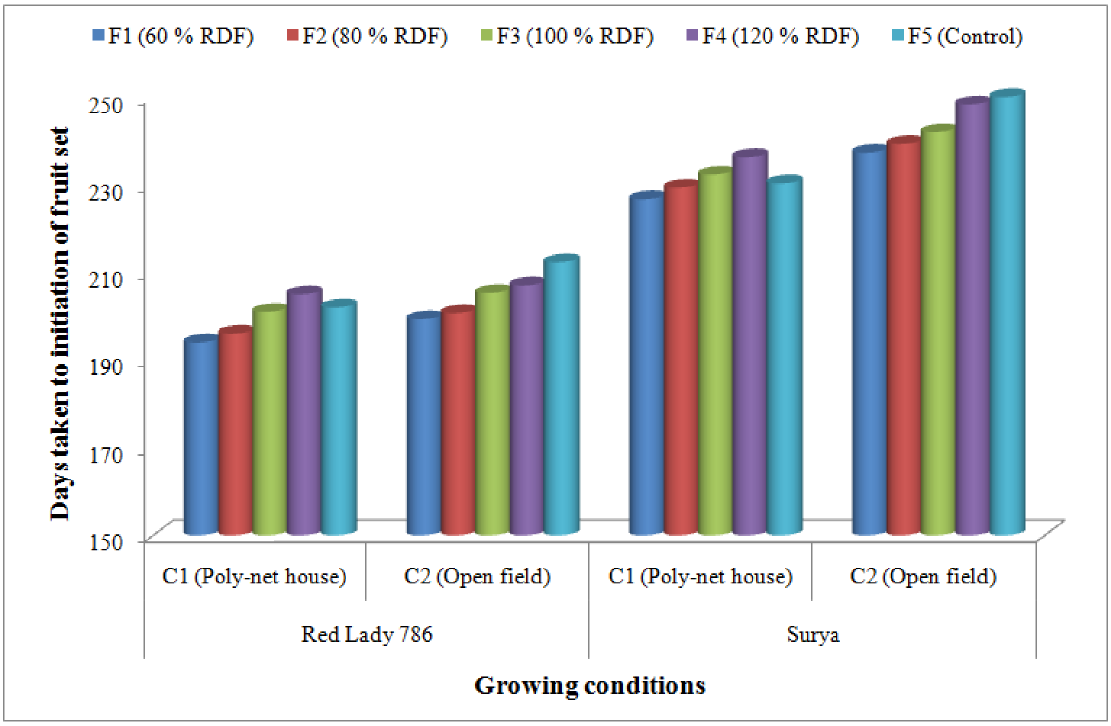

Figure 4.7: Effect of fertigation and growing conditions on fruit set initiation (days) in papaya.

This earliness in fruit setting was simply a result of advanced flowering in fertigated and green house grown plants. These results are in accordance with the observations of Galan (2002), Rodriguez (2002) and Galan and Rodriguez (2007). Furukawa *et al.* (1990) also reported 13 to 20 days advancement in fruiting of peach when grown under protected conditions in comparison to open field orchard.

4.2.3 Days taken to first fruit maturity

The data regarding effect of fertigation treatments *viz.* F_1 (60 percent fertigation), F_2 (80 percent fertigation), F_3 (100 percent fertigation), F_4 (120 percent fertigation) and F_5 (100 percent conventional fertilization) and growing conditions *i.e.* C_1 (poly-net house) and C_2 (open fields) and their interactions on fruit maturity in 'Red Lady 786' and 'Surya' papaya had shown statistically significant results as given in Table 4.8.

The most advanced maturity (304.5 days) in 'Red Lady 786' papaya was caused by 80 percent RDF fertigation *i.e.* F_2 treatment which was at par with 306.8 days in 60 percent RDF fertigation *i.e.* F_1 treatment as compared to 322.0 days taken for fruit maturity in control fertilization treatment *i.e.* F_5. Similarly, the second factor of modified environment (protected conditions) also resulted in advance maturity of fruits within 309.2 days as compared to 315.5 days in C_2 (open fields). The interaction effect of both factors were also significant with earliest (302.3 days) in F_2C_1 followed by 303.3 days in F_1C_1 and 306.7 days in F_2C_2, while it was maximum (327.7 days) in F_5C_2.

In 'Surya' papaya, fruit maturity was advanced by 4 to 12 days with various fertigation treatments and maximum earliness of 12 days was recorded in F_2 (80 percent fertigation) followed by 10 days in F_1 (60 percent fertigation) over control (382.2 days). The environmental modifications resulted in approximately 12 days advancement in fruit maturity *i.e.* 370.1 days in protected conditions as compared to 382.0 days in open fields. Overall, least number of days (366.0) taken for first fruit maturity was in F_2C_1, while maximum days (390.0) were taken in F_5C_2.

Table 4.8: Effect of fertigation and growing conditions on first fruit maturity (days) of papaya.

Treatments	**Varieties**					
	Red Lady 786			**Surya**		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
F_1	303.3	310.3	**306.8[a]**	367.7	376.3	**372.0[b]**
F_2	302.3	306.7	**304.5[a]**	366.0	374.3	**370.2[a]**
F_3	309.3	313.7	**311.5[b]**	371.0	383.3	**377.2[c]**
F_4	315.0	319.0	**317.0[c]**	371.7	386.0	**378.9[c]**
F_5	316.3	327.7	**322.0[d]**	374.3	390.0	**382.2[d]**
Mean (C)	**309.2[a]**	**315.5[b]**		**370.1[a]**	**382.0[b]**	
CD ($p \leq 0.05$)						
F	**1.15**			**1.68**		
C	**0.73**			**1.06**		
F x C	**1.62**			**2.37**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The advancement in fruit maturity may be attributed to the early flowering, fruiting, continuous nutrition availability and more photosynthates accessibility for the sink. These results are corroborated with the findings of Reddy and Gowda (2014), who reported precocity in bearing of green house cultivated papaya and attributed the advanced maturity character to earliness in flowering and fruiting. Similarly, Kamiloglu *et al.* (2011) working on grapevines, recorded earliness in phonologic periods of vines grown under protected structures. They documented 17 days early fruit maturity under protective cover due to 16 days advancement in veraison stage as compared to open vine orchards.

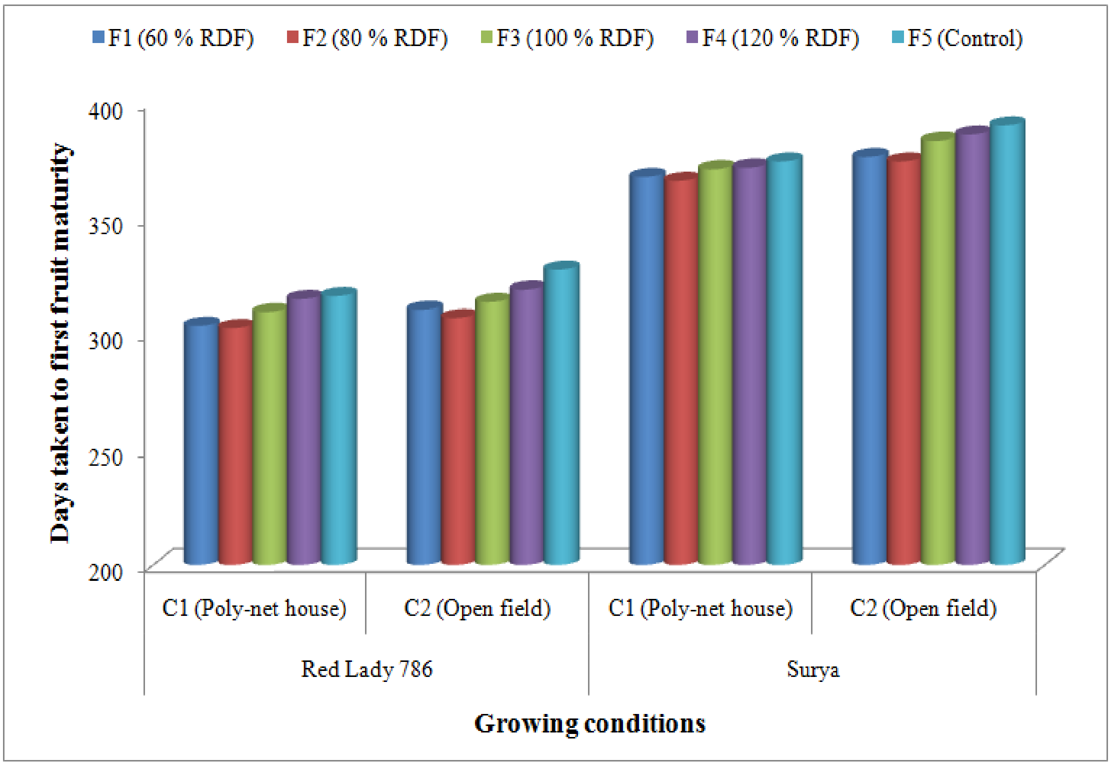

Figure 4.8: Effect of fertigation and growing conditions on first fruit maturity (days) of papaya.

4.2.4 Days taken to final harvest

The data pertaining to number of days taken for final harvest of papaya fruits has been presented in Table 4.9. The analysis of data revealed a significant impact of each factor and their interaction on final harvest of 'Red Lady 786' and 'Surya' papaya fruits.

In 'Red Lady 786' papaya, the 120 percent RDF fertigation treatment recorded with mean maximum number of days (416.8) for final harvest followed by 416.5 days in 100 percent fertigation treatment. The fruit under conventional fertilization treatment took least 412.4 days to complete harvest. In open field, the fruit harvesting took more days (417.0

days) from transplanting as compared to protected conditions (413.1 days). Among different F x C combinations, the order of number of days taken for fruit maturity was: $F_4C_2 > F_3C_2 > F_1C_2 > F_5C_2 > F_4C_1 > F_2C_2 > F_3C_1 > F_2C_1 > F_1C_1 > F_5C_1$.

In 'Surya' cultivar, maximum mean number of days taken for final harvest was around 428.2 in 100 percent RDF fertigation treatment followed by 420.4 days in 120 percent fertigation and minimum (414.9 days) in lowest fertigation treatment i.e. 60 percent fertigation. The papaya plants growing under modified environment took less number of days (415.4 days) to final harvest as compared to open cultivated plants (425.8 days). However, within various interactions, the 100 percent RDF fertigation and conventional fertilization took maximum average number of days (433.5 and 428.6 days respectively in F_3C_2 and F_5C_2) for harvesting completion.

Table 4.9: Effect of fertigation and growing conditions on final harvest (days) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
F_1	411.2	417.3	**414.3^c**	411.4	418.4	**414.9^e**
F_2	414.8	415.9	**415.4^b**	414.4	421.1	**417.8^d**
F_3	415.5	417.4	**416.5^a**	422.9	433.5	**428.2^a**
F_4	416.0	417.6	**416.8^a**	413.5	427.3	**420.4^c**
F_5	408.1	416.7	**412.4^d**	414.8	428.6	**421.7^b**
Mean (C)	**413.1^b**	**417.0^a**		**415.4^b**	**425.8^a**	
CD ($p \leq 0.05$)						
F	**0.99**			**0.41**		
C	**0.63**			**0.26**		
F x C	**1.40**			**0.58**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

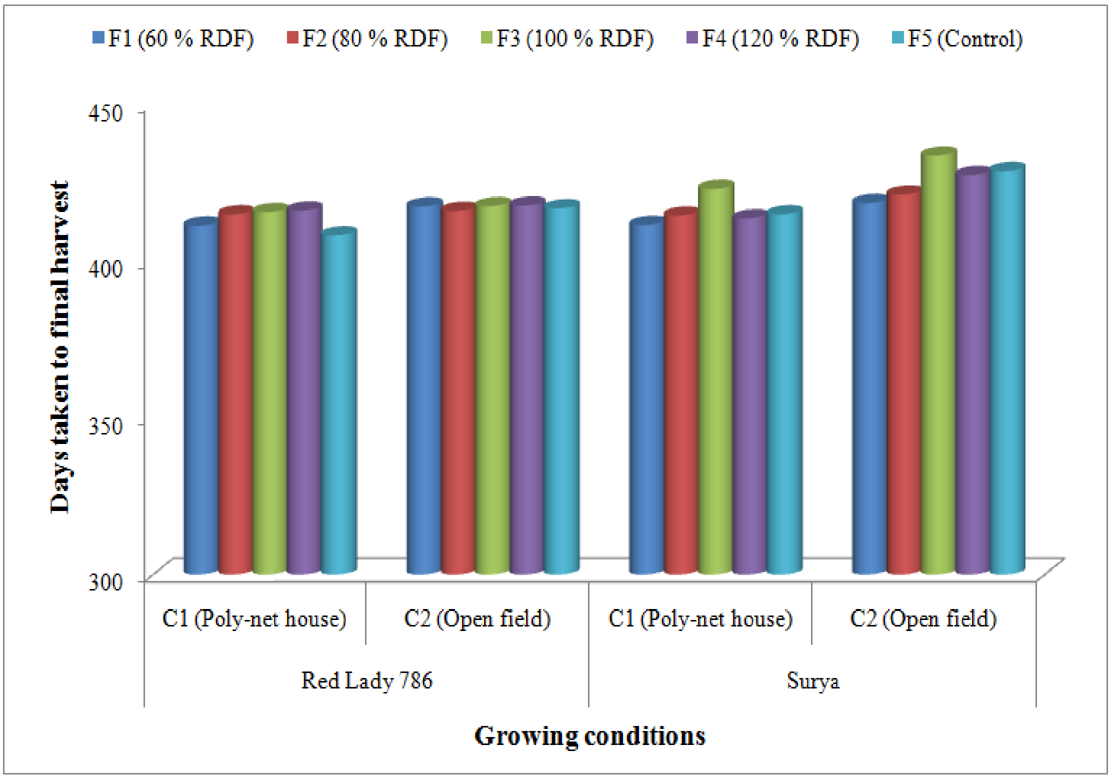

Figure 4.9: Effect of fertigation and growing conditions on final harvest (days) of papaya.

4.2.5 Average number of fruits per node

The data representing the intensity of papaya fruits on a single node is given in Table 4.10. The statistical analysis revealed that the fertigation and growing condition treatments did not have significant effect on fruits borne per node. In case of 'Red Lady 786' papaya, numerically the 60 percent fertigation treatment (F_1) resulted in maximum mean number of fruits (1.55) growing on a single node followed by F_2 treatment (1.51). Among growing conditions, open field papaya gave more mean fruit number per node as compared to protected conditions. In contrast, the 'Surya' papaya had fruit retention to the extent of one fruit on each node in all the experimental plants. This character of per node bearing can be related to the genetic behavior of the varieties that was not altered by any of the treatment under experimentation.

Table 4.10: Effect of fertigation and growing conditions on average number of fruits per node in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	1.66	1.43	**1.55**	1.00	1.00	**1.00**
F_2	1.12	1.89	**1.51**	1.00	1.00	**1.00**
F_3	1.00	1.14	**1.07**	1.00	1.00	**1.00**
F_4	1.00	1.00	**1.00**	1.00	1.00	**1.00**
F_5	1.00	1.24	**1.12**	1.00	1.00	**1.00**
Mean (C)	**1.16**	**1.34**		**1.00**	**1.00**	
CD ($p \leq 0.05$)						
F	**NS**			**NS**		
C	**NS**			**NS**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

4.2.6 Average number of fruits per plant

The data pertaining to average number of fruits per plant, tabulated in Table 4.11, reveals that fertigation treatments had significant effect on fruits retention on a plant upto maturity, however, growing condition and interaction effect was not significant.

In 'Red Lady 786' papaya, maximum number of fruits were recorded to the extent of 46.00 in 80 percent fertigation (F_2) followed by 43.63 and 42.59 fruits per plant in control (F_5). However, 120 percent fertigation (F_4) treatment recorded minimum fruits per plant with a mean value of 41.01.

Table 4.11: Effect of fertigation and growing conditions on average number of fruits per plant in papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	43.30	41.88	**42.59^{bc}**	31.41	32.05	**31.73^{c}**
F_2	46.26	45.73	**46.00^{a}**	35.90	35.57	**35.74^{a}**
F_3	41.50	41.39	**41.45^{c}**	30.77	30.62	**30.70^{d}**
F_4	41.25	40.77	**41.01^{c}**	29.86	30.03	**29.95^{d}**
F_5	44.90	42.36	**43.63^{b}**	33.03	33.28	**33.16^{b}**
Mean (C)	**43.44**	**42.43**		**32.19**	**32.31**	
CD ($p \leq 0.05$)						
F	**2.14**			**0.88**		
C	**NS**			**NS**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Similarly, the mean maximum fruits (35.74) of 'Surya' were recorded in 80 percent fertigation (F_2) treatment followed by 33.16 in control (F_5) treatment, while maximum fertigation level of 120 percent reduced the fruit bearing to minimum level of 29.95. Overall, the number of fruits of 'Red Lady 786' was ranged from 41.25 in F_4C_1 to 46.26 in F_2C_1, while of 'Surya' cultivar ranged as 29.86 in F_4C_1 to 35.90 in F_2C_1.

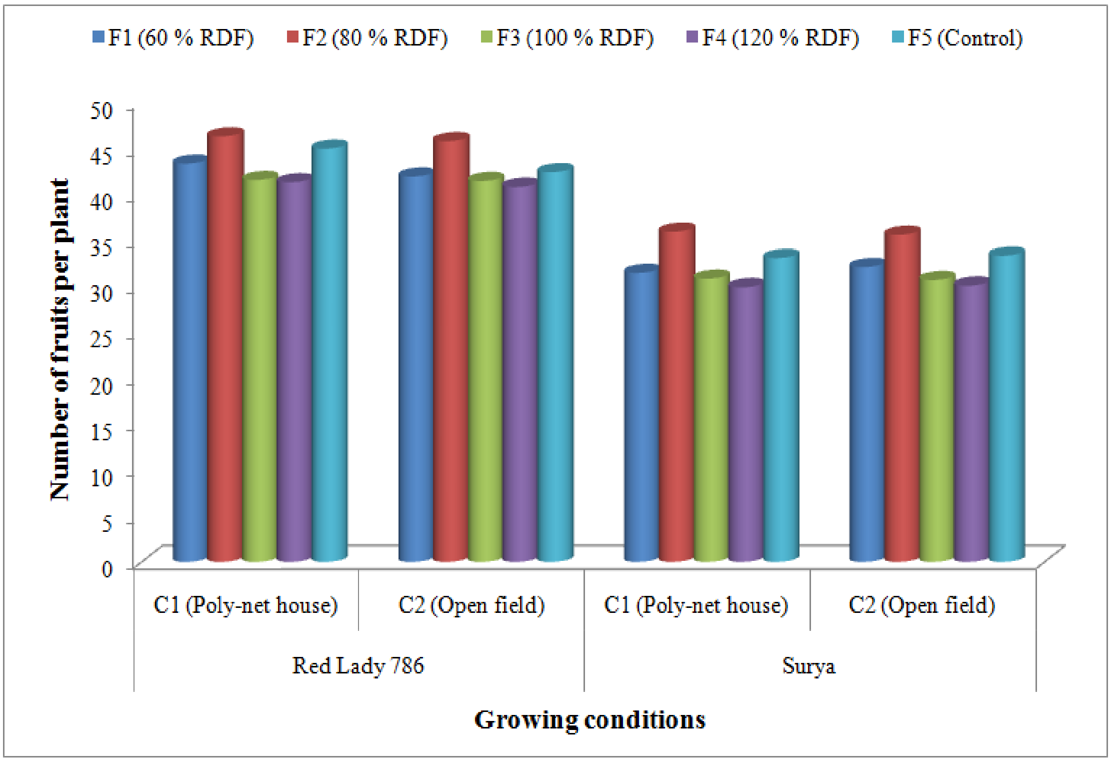

Figure 4.10: Effect of fertigation and growing conditions on average number of fruits per plant in papaya.

The fruit number per plant might be related to the simultaneous ratio of vegetative and reproductive growth of a plant especially in papaya. Extensive fertigation might have provided vigorous vegetative growth to plants that resulted in lesser fruit retention. The plants getting adequate nutrition as per requirement maintained a balance among both the growth stages *i.e.* vegetative and reproductive. These results are somehow in line with the reportings of Panigrahi *et al.* (2015), who mentioned an increased fruit set in papaya by use of fertigation but not in excess of recommended dose.

4.2.7 Average fruit size (cm)

The perusal of data given in Table 4.12 and 4.13 complies that various environmental modifications accompanied with different levels of fertigation had a significant impact over fruit size (fruit length and circumference) in both the varieties under experimentation. However, the interaction effect was not significant.

The mean values worked out for different fertigation levels in ‘Red Lady 786’ papaya elaborates F_2 treatment (80 percent fertigation) to be the best in terms of maximum fruit size development (length= 18.78 cm and circumference= 38.66 cm). The control treatment where

100 percent RDF was given through conventional fertilization, the fruit size obtained was 17.90 cm mean length and 37.47 cm mean circumference. Overall mean fruit size was maximum (length- 19.26 cm and circumference= 38.03 cm) in plants growing under protected conditions as compared to fruits (length= 15.90 cm and circumference= 35.59 cm) borne on plants in open field. The joint impact of fertigation and growing condition revealed large sized fruits in F_2C_1 (80 percent fertigation in poly-net house) measuring average length of 20.67 cm and circumference of 40.53 cm. The second largest fruits were borne on the plants applied with conventional fertilization under protected conditions (F_5C_1). These fruits measured around 19.44 cm in length and 38.75 cm in circumference which was at par with the size of fruits (19.25 cm length and 38.55 cm circumference) borne on plants that were under 60 percent fertigation in green house unit (F_1C_1).

Table 4.12: Effect of fertigation and growing conditions on average fruit length (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	19.25	16.01	**17.63[ab]**	12.15	11.88	**12.02[a]**
F_2	20.67	16.89	**18.78[a]**	12.03	11.73	**11.88[b]**
F_3	18.50	15.48	**16.99[b]**	11.69	11.24	**11.47[d]**
F_4	18.46	14.77	**16.62[b]**	11.87	11.58	**11.73[c]**
F_5	19.44	16.36	**17.90[ab]**	12.02	11.79	**11.91[ab]**
Mean (C)	**19.26[a]**	**15.90[b]**		**11.95[a]**	**11.64[b]**	
CD ($p \leq 0.05$)						
F	**1.41**			**0.13**		
C	**0.89**			**0.09**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Table 4.13: Effect of fertigation and growing conditions on average fruit circumference (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	38.55	35.66	**37.11^{b}**	29.70	29.54	**29.62^{b}**
F_2	40.53	36.79	**38.66^{a}**	31.80	30.87	**31.34^{a}**
F_3	36.38	34.74	**35.56^{c}**	30.44	29.66	**30.05^{b}**
F_4	35.92	34.57	**35.25^{c}**	27.66	27.37	**27.52^{d}**
F_5	38.75	36.18	**37.47^{ab}**	28.19	28.08	**28.14^{c}**
Mean (C)	**38.03^{a}**	**35.59^{b}**		**29.56^{a}**	**29.10^{b}**	
CD ($p \leq 0.05$)						
F	**1.45**			**0.56**		
C	**0.92**			**0.36**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The fruit size analysis for papaya cultivar 'Surya' represents that maximum fruit size was obtained in F_1 in terms of fruit length and F_1, F_2 and F_3 in terms of fruit circumference as compared to respective controls. The inference drawn from analysis of data revealed large sized fruits under protected conditions (11.95 cm length and 29.56 cm circumference) in comparison to 11.64 cm length and 29.10 cm circumference of fruits produced in open field. The interactive affect of various F x C treatments observed maximum fruit length of 12.15 cm and 12.03 cm in F_1 and F_2 under poly-net house conditions. However, in case of fruit circumference, the plants under 60, 80 and 100 percent fertigation in both the growing conditions (F_1C_1, F_1C_2, F_2C_1, F_2C_2, F_3C_1 and F_3C_2) produced large sized fruits. In terms of fruit length, the 100 percent fertigation (F_3C_1 and F_3C_2) and in terms of fruit circumference, F_4C_1 and F_4C_2 resulted in smallest average sized fruits.

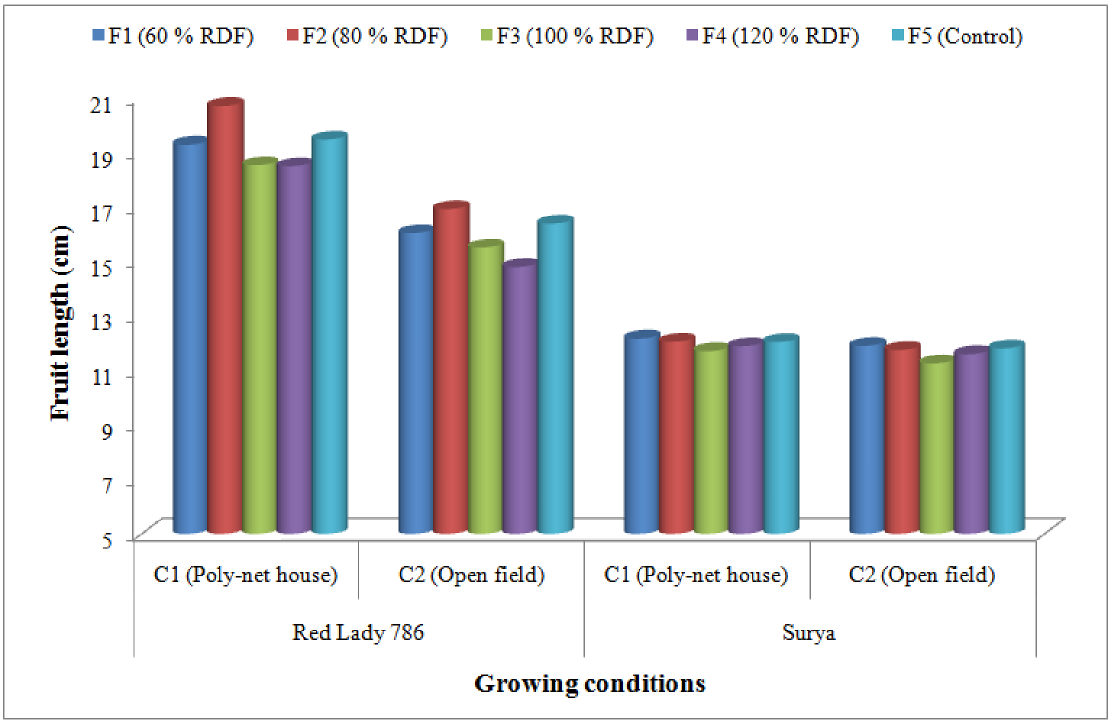

Figure 4.11: Effect of fertigation and growing conditions on average fruit length (cm) of papaya.

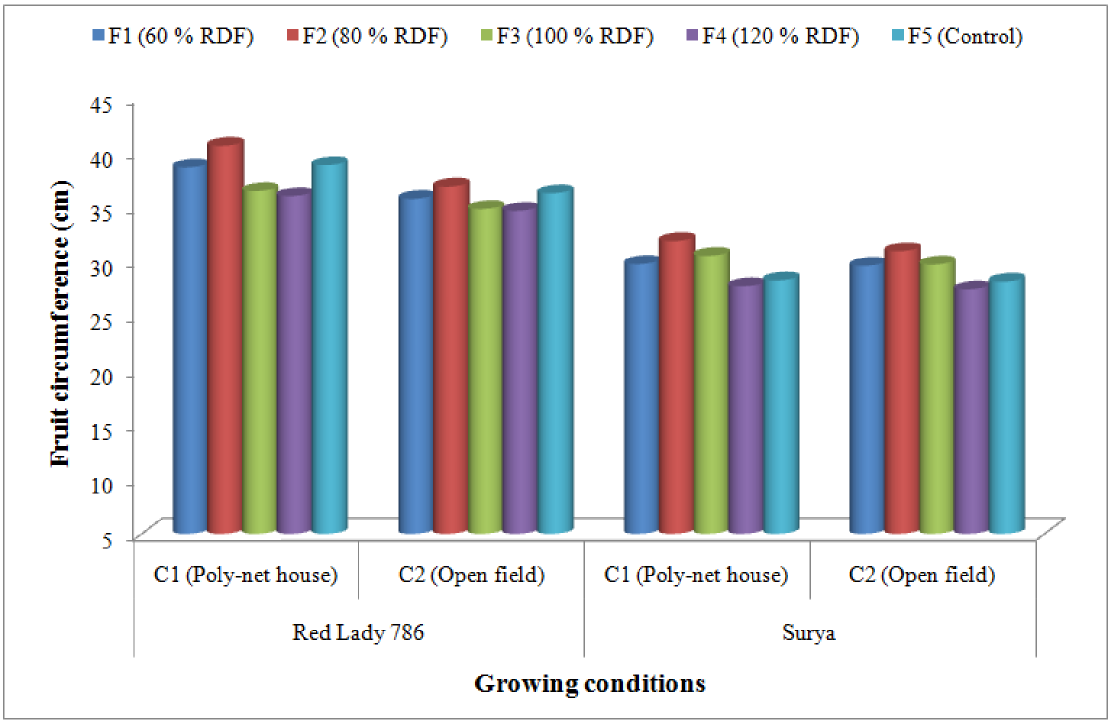

Figure 4.12: Effect of fertigation and growing conditions on average fruit circumference (cm) of papaya.

The fruit size might have improved due to more photosynthesis that resulted in higher accumulation and utilization of reserves for fruit development. These findings are supported with the reportings of Deshmukh and Hardaha (2014) regarding papaya who have also reported an increased fruit size with fertigation. Similarly, Chepinski *et al.* (2010) and Kachwaya and Chandel (2015) had also declared an improvement in fruit phenology characters of strawberry with fertigation. However, the results are not in line with the findings of Kaur and Kaur (2017) who found a better size papaya fruits in open fields as compared to green house fruits.

4.2.8 Average fruit weight (g)

Table 4.14: Effect of fertigation and growing conditions on average fruit weight (g) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	781.53	745.43	**763.48^{bc}**	457.67	401.50	**429.58^{ab}**
F_2	925.47	774.53	**850.00^{a}**	499.60	428.87	**464.23^{a}**
F_3	772.47	693.77	**733.12^{d}**	411.63	352.63	**382.13^{cd}**
F_4	775.73	711.50	**743.62^{cd}**	385.73	337.53	**361.63^{d}**
F_5	846.40	721.40	**783.90^{b}**	439.47	369.53	**404.50^{bc}**
Mean (C)	**820.32^{a}**	**729.33^{b}**		**438.82^{a}**	**378.01^{b}**	
CD ($p \leq 0.05$)						
F	**22.47**			**37.75**		
C	**14.21**			**23.88**		
F x C	**31.77**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The data presented in Table 4.14 illustrate that average fruit weight had followed similar trend as of fruit size and was significantly affected by fertilizer treatments and growing conditions, however, interaction effect was not significant in 'Surya'cultivar.

In 'Red Lady 786' papaya, the mean average fruit weight was maximum (850.00 g) in 80 percent fertigation (F_2) as compared to other treatments. However, the control (F_5) and 60 percent fertigation treatment (F_1) were observed at par with mean fruit weight of 783.90 and 763.48 g, respectively. Poly-net house conditions produced more weighted fruits (820.32 g) as compared to plants of open field (729.33 g). The fertigation and other treatment interactions had a significant impact over fruit weight resulting in 925.47 g to be maximum in 80 percent fertigation in poly-net house (F_2C_1) followed by 846.40 and 781.53 g, respectively in F_5C_1 and F_1C_1. However, the lowest fruit weight of 693.77 g and 711.50 g was observed in F_3C_2 and F_4C_2, respectively.

Like 'Red Lady 786', maximum mean fruit weight of 'Surya' variety (464.23 g) was recorded in 80 percent fertigation (F_2) followed by 429.58 g and 404.50 g in 60 percent fertigation (F_1) and control (F_5), respectively. The protected cultivation resulted in a mean maximum (438.82 g) fruit weight, whereas, the fruits from open fields recorded a mean value of 378.01 g. The F x C interactions in 'Surya' confirms F_2C_1 (499.60 g) and F_1C_1 (457.67 g) as the best treatment combinations in terms of higher fruit weight. However, F_4C_2, F_3C_2 and F_5C_2 had resulted in lowest fruit weight production (337.53, 352.63 and 369.53, respectively).

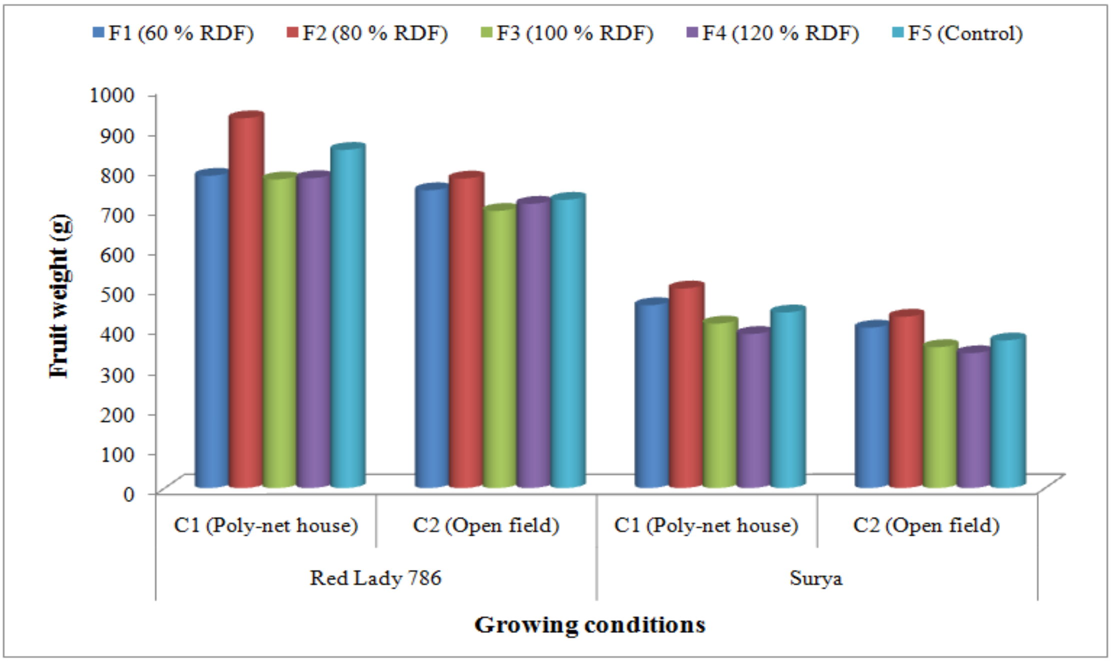

Figure 4.13: Effect of fertigation and growing conditions on average fruit weight (g) of papaya.

The increased fruit weight has a direct relationship with the enhanced fruit size. These superior fruit weight observations as compared to control may be a result of greater plant spread and efficient fertilizer usage in combination with effective photosynthesis. These factors in combination might have accumulated more carbohydrates for the fruits development and ultimately translocating higher carbohydrates to the sink, promoting cell division and thus enhancing fruit size and weight. These results are in accordance with the reportings of Singh and Singh (2012) and Panigrahi *et al.* (2015) for papaya fruit that have evidenced heavy weight papaya fruits as compared to control as a result of fertigation. Similarly, Bachchhav (1995) had also confirmed better fruit weight in fertigated plants. Protected cultivation had also improved papaya fruit weight as compared to open field environment as reported by Reddy and Gowda (2014) and Kaur and Kaur (2017).

4.2.9 Average fruit yield (kg/plant)

Table 4.15: Effect of fertigation and growing conditions on average fruit yield (kg/plant) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	33.77	31.17	**32.47^b**	14.34	12.84	**13.59^b**
F_2	42.79	35.38	**39.09^a**	17.91	15.21	**16.56^a**
F_3	32.03	28.66	**30.35^b**	12.64	10.77	**11.71^c**
F_4	31.92	28.97	**30.45^b**	11.48	10.11	**10.80^c**
F_5	38.09	30.53	**34.31^b**	14.48	12.27	**13.38^b**
Mean (C)	**35.72^a**	**30.94^b**		**14.17^a**	**12.24^b**	
CD ($p \leq 0.05$)						
F	**3.05**			**0.93**		
C	**1.93**			**0.59**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The data related to fruit yield of two papaya varieties namely 'Red Lady 786' and 'Surya' is presented in Table 4.15 showing influence of various growing environment and fertigation treatments. The perusal of data shows a significant impact of treatments applied independently while interaction effect was not significant.

In 'Red Lady 786' papaya cultivar, 80 percent fertigation treatment produced highest fruit yield per plant (39.09 kg) as compared to 34.31 kg/ plant in control (F_5). The minimum mean yield (30.35 kg/ plant) was reported in 100 percent fertigation treartment (F_3). Among two types of growing environments, mean highest yield (35.72 kg/ plant) was reported in poly-net house in comparison to 30.94 kg/ plant in plants grown in open field. Although not significant but highest (42.79 kg/ plant) yield was reported in F_2C_1 followed by 38.09 and 35.38 kg/ plant yield in F_5C_1 and F_2C_2, respectively. The 100 and 120 percent fertigation treatments in open fields (F_3C_2 and F_4C_2) recorded minimum fruit yields of 28.66 and 28.97 kg/ plant.

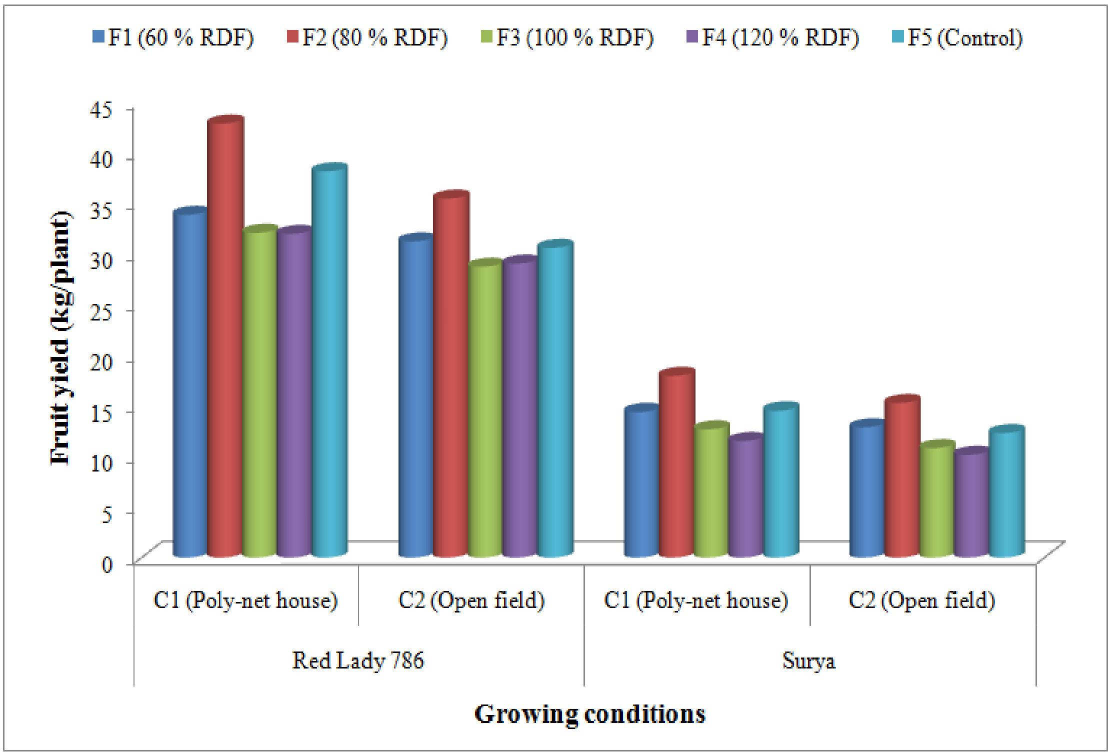

Figure 4.14: Effect of fertigation and growing conditions on average fruit yield (kg/plant) of papaya.

The fruit yield analysis of 'Surya' papaya cultivar shows a highest mean fruit yield of 16.56 kg/ plant in 80 percent fertigation (F_2) treatment followed by 13.59 kg/ plant in 60 percent fertigation (F_1) treatment and least fruit yield of 10.80 kg/ plant in 120 percent fertigation (F_4).

A significant enhancement of papaya fruit yield was observed in protected environment with a mean value of 14.17 kg/ plant as compared to low yield of 12.24 kg/ plant in open fields. Various F x C combinations also improved the fruit yield, being highest (17.91 kg/ plant) in 80 percent fertigation under poly-net house (F_2C_1) followed by 15.21 kg/ plant in 80 percent fertigation level when applied in open fields (F_2C_2). However, the 100 and 120 percent fertigation treatments in open fields (F_3C_2 and F_4C_2) resulted in lowest average fruit yields of 10.77 and 10.11 kg/ plant values.

The fruit yield character is simply an observation based on fruit bearing intensity and average fruit weight per plant. As fertigation and modified growing environment has improved the above characters in some of the treatments, the same has been responsible for promising yields of papaya. Protected environment might also have improved the yield by limiting the biotic factors like vectors for viruses. Similar results of improved fruit yield in papaya with fertigation had also been computed by Singh and Singh (2012), Deshmukh and Hardaha (2014) and Panigrahi *et al.* (2015). Reddy and Gowda in 2014 and Kaur and Kaur in 2017 have observed promising papaya fruit yields inside green house units as compared to open field grown papaya.

4.2.10 Colour development

The data regarding colour development of fruits is presented in Table 4.16. It is clear from the data that no significant difference among various treatments has been seen in both the varieties under study. Among different growing conditions, both ‘Red Lady 786’ and ‘Surya’ appeared to present more coloured complexion under protected environment as compared to fruits produced under open environment.

Table 4.16: Effect of fertigation and growing conditions on colour development of papaya fruits.

Treatments	Red Lady 786		Surya	
	C_1 (Poly-net house)	C_2 (Open field)	C_1 (Poly-net house)	C_2 (Open field)
F_1	Orange group 24A	Orange group 24B	Orange group 24A	Orange group 24B
F_2	Orange group 25B	Orange group 24B	Orange group 24A	Orange group 24B
F_3	Orange group 23B	Orange group 23C	Orange group 25B	Orange group 24B
F_4	Orange group 23B	Orange group 23C	Orange group 24C	Orange group 24B
F_5	Orange group 24B	Orange group 24B	Orange group 24C	Orange group 24C

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

4.2.11 Central cavity diameter (cm)

The perusal of data presented in Table 4.17 shows the significant effect of various fertigation treatments and growing conditions on central cavity diameter of 'Red Lady 786' and 'Surya' papaya fruits.

In 'Red Lady 786' papaya fruits, largest central cavity (7.15 cm) was seen in 80 percent fertigation treatment (F_2) followed by 6.55 and 6.38 cm in F_5 (control) and F_1 (60 percent fertigation), respectively. The poly-net house plants comparatively measured a higher central cavity mean diameter of 6.83 cm in comparison to 6.22 cm in fruits from open field. The fertigation and growing environment interactions had also positively affected the central cavity diameter of fruits with maximum values of 7.90, 6.79, 6.53 and 6.48 cm in F_2C_1, F_5C_1, F_1C_1 and F_4C_1, respectively. However, 120 percent fertigation treatment in open fields (F_4C_2) produced smallest central cavity fruits with average value of 6.01 cm.

Table 4.17: Effect of fertigation and growing conditions on central cavity diameter (cm) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	6.53	6.23	**6.38[c]**	5.64	5.25	**5.45[b]**
F_2	7.90	6.39	**7.15[a]**	5.77	5.46	**5.62[a]**
F_3	6.43	6.15	**6.29[d]**	5.29	5.32	**5.31[c]**
F_4	6.48	6.01	**6.25[d]**	5.03	5.00	**5.02[d]**
F_5	6.79	6.31	**6.55[b]**	5.41	5.12	**5.27[c]**
Mean (C)	**6.83[a]**	**6.22[b]**		**5.43[a]**	**5.23[b]**	
CD (p≤0.05)						
F	**0.08**			**0.09**		
C	**0.05**			**0.06**		
F x C	**0.11**			**0.13**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In variety 'Surya', among various fertigation treatments, 80 percent fertigation resulted in 5.62 cm mean diameter of fruit cavity followed by 5.45 and 5.31, cm in 60 and 100 percent fertigation treatments, respectively. Similar to 'Red Lady 786' papaya, the fruits of 'Surya' produced under protected conditions measured a little higher cavity size (5.43 cm) as compared to 5.23 cm under open cultivation. Various fertigation and modified environment combinations recorded a significant and highest central cavity diameter of 5.77, 5.64 and 5.46 cm in F_2C_1, F_1C_1 and F_2C_2, respectively. However, 120 percent fertigation resulted in least average cavity size of 5.00 and 5.03 cm in open field and protected environment papaya (F_4C_2 and F_4C_1) , respectively.

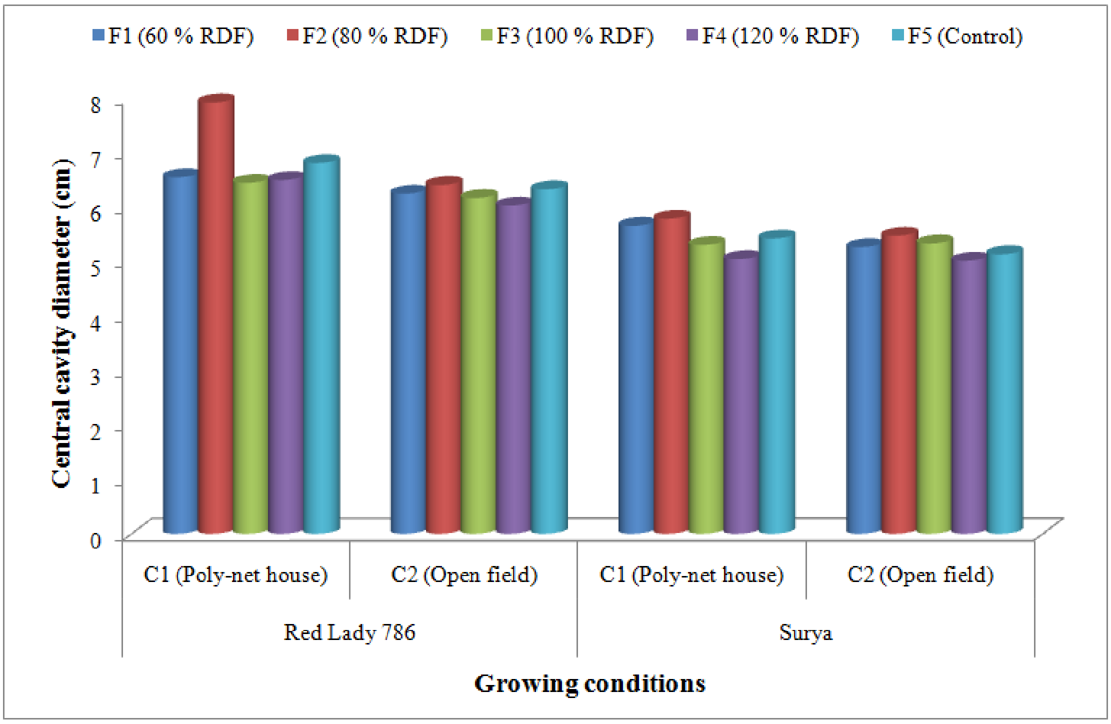

Figure 4.15: Effect of fertigation and growing conditions on central cavity diameter (cm) of papaya.

The results of fruit cavity size evidence the overall more diameter of fruits *i.e.* bigger size fruits. Tyagi *et al.* (2015) had also published the higher papaya fruit cavity results for 'Red Lady 786' and 'Surya' varieties as compared to others.

4.3 Fruit quality parameters

4.3.1 Edible portion (percent)

It is clear from Table 4.18 that in both papaya cultivars various treatments significantly affected the percentage of fruit edible portion, however, interaction effect was not significant.

In 'Red Lady 786', highest edible portion of fruits was found in F_2 (80 percent fertigation) to the extent of 85.68 percent followed by 85.25 and 84.98 percent in F_5 (control) and F_1 (60 percent fertigation), respectively. A slightly higher edible portion percentage was seen in the fruits developing under modified green house environment (85.24 percent) in comparison to 84.96 percent in open fields. Different fertigation x cultivation condition interactions resulted in higher edible pulp portion (85.86 and 85.49 percent) in the fruits produced on 80 percent fertigated plants in both the environments (F_2C_1 and F_2C_2). However, 120 and 100 percent RDF fertigation in protected fields recorded minimum fruit edible portion percentage of 84.52 and 84.78 percent, respectively.

Table 4.18: Effect of fertigation and growing conditions on edible portion (percent) of papaya.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	85.03	84.93	**84.98^c**	84.98	85.03	**85.01^b**
F_2	85.86	85.49	**85.68^a**	85.57	85.29	**85.43^a**
F_3	84.98	84.78	**84.88^c**	84.18	84.22	**84.20^d**
F_4	84.91	84.52	**84.72^d**	84.42	84.38	**84.40^c**
F_5	85.43	85.06	**85.25^b**	85.19	85.06	**85.13^b**
Mean (C)	**85.24^a**	**84.96^b**		**84.87^a**	**84.80^b**	
CD (p≤0.05)						
F	**0.14**			**0.12**		
C	**0.09**			**0.06**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In 'Surya' papaya, highest edible portion of pulp (85.43 percent) was recorded in 80 percent RDF fertigation (F_2) followed by 85.13 percent in control (F_5) that was at par with 85.01 percent in F_1. The 100 percent RDF fertigation treatment recorded the minimum percentage of edible portion (84.20 percent). Numerically more edible portion percentage was seen in protected environment fruits to the extent of 84.87 percent and least 84.80 percent in open field fruits. Although, interaction was not significant but maximum fruit edible pulp was reported as 85.57 percent in F_2C_1 and 85.29 percent in F_2C_2 followed by 85.19 and 85.06 percent in F_5C_1 and F_5C_2, respectively. However, F_3C_1 treatment (100 percent fertigation in poly-net house) and F_3C_2 (100 percent fertigation in open fields) plants observed minimum percentage of edible fruit portion *i.e.* 84.18 percent in F_3C_1 and 84.22 percent in F_3C_2.

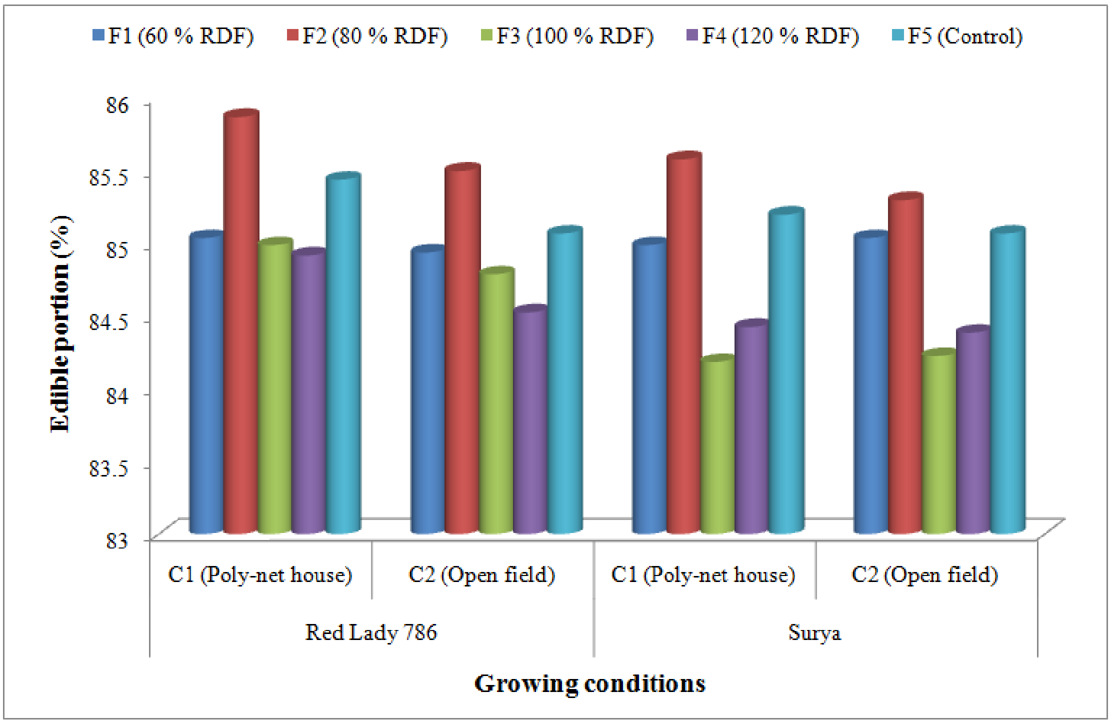

Figure 4.16: Effect of fertigation and growing conditions on edible portion (percent) of papaya.

The fruit edible portion is more or less related to the fruit weight. The continuous availability of nutrients and presence of higher chlorophyll content in leaves of fertigated plants growing under polyhouse conditions promoted carbohydrates manufacturing and translocation towards the developing fruits resulting in more pulp: peel ratio. Senthilkumar *et al.* (2013) documented a higher banana fruit edible portion as a result of fertigation in comparison to normal fertilization. Similarly, Sharma *et al.* (2005) recorded maximum fruit pulp thickness by application of fertilizers through drip irrigation as compared to other fertilization treatments.

4.3.2 Fruit firmness (lb)

The data related to fruit firmness as influenced by various treatments has been represented in Table 4.19. Although, the fruit firmness was not significantly affected by any factor or their interactions, however, the congenial climatic conditions maintained under the green house might have affected the bio-chemical reactions responsible for softening of fruits at maturity. The fruit firmness of papaya cultivars under all treatments were ranged between

1.17 lb (F_1C_1) in 'Surya' to 1.22 lb (F_4C_2) in 'Red Lady 786'. These results are contradictory to the findings of Reddy and Gowda (2014) and Kaur and Kaur (2017) who have reported more firm papaya fruits under protected conditions.

Table 4.19: Effect of fertigation and growing conditions on firmness (lb) of papaya fruits.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	1.19	1.22	**1.21**	1.17	1.19	**1.18**
F_2	1.20	1.21	**1.21**	1.18	1.19	**1.19**
F_3	1.20	1.21	**1.21**	1.18	1.19	**1.19**
F_4	1.21	1.23	**1.22**	1.19	1.20	**1.20**
F_5	1.18	1.21	**1.20**	1.18	1.21	**1.20**
Mean (C)	**1.20**	**1.22**		**1.18**	**1.20**	
CD ($p \leq 0.05$)						
F	**NS**			**NS**		
C	**0.02**			**NS**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

4.3.3 TSS (°Brix)

The data regarding papaya fruit TSS of varieties 'Red Lady 786' and 'Surya' is presented in Table 4.20.

In 'Red Lady 786' papaya, maximum TSS (13.23 °brix) of fruits was recorded in 80 percent fertigation followed by 13.01°brix in F_1 (60 percent fertigation) and 12.81 in F_5 (control). A significantly higher mean TSS (13.34 °brix) was observed in fruits produced inside green house in comparison to open fields (12.29 °brix). The analysis of interactions among factors confirms highest average TSS (13.63 °brix) in F_2C_1 followed by 13.55 °brix in F_1C_1 and 13.40 °brix in F_5C_1. However, the lowest TSS was estimated in F_4C_2 and F_3C_2 to the extent of 11.93 and 12.01 °brix, respectively.

Table 4.20: Effect of fertigation and growing conditions on TSS (°Brix) of papaya fruits.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	13.55	12.47	**13.01^b**	13.30	12.53	**12.92**
F_2	13.63	12.83	**13.23^a**	13.45	12.76	**13.11**
F_3	13.13	12.01	**12.57^c**	13.02	12.29	**12.66**
F_4	13.00	11.93	**12.47^c**	12.97	12.17	**12.57**
F_5	13.40	12.22	**12.81^b**	12.73	12.03	**12.38**
Mean (C)	**13.34^a**	**12.29^b**		**13.09^a**	**12.36^b**	
CD (p≤0.05)						
F	**0.21**			**NS**		
C	**0.13**			**0.34**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In variety 'Surya', fertigation treatments F_2 and F_1 recorded numerically highest fruit TSS *i.e.* 13.11 and 12.92 °brix, respectively in comparison to lowest 12.38 °brix in control. Protected cultivation of papaya had also recorded significantly higher fruit TSS (13.09 °brix) as compared to 12.36 °brix in open fields. The TSS content was ranged from 12.03 °brix in F_5C_2 to 13.45 °brix in F_2C_1.

The improvement in fruit total soluble solids content among fertigated and protected cultivation of fruits might be a result of high photosynthetic efficiency allocating more soluble sugars towards the sink. The present results are corroborated with the findings of Panigrahi *et al.* (2015) in papaya, Senthilkumar *et al.* (2013) in banana and Singh *et al.* (2010) in litchi, who documented an increased fruit TSS with fertigation treatments in respective fruit plants. Similarly, Reddy and Gowda (2014), Parkash *et al.* (2015) and Kaur and Kaur (2017) have reported papaya fruit production with superior TSS under protected conditions in comparison to the open fields.

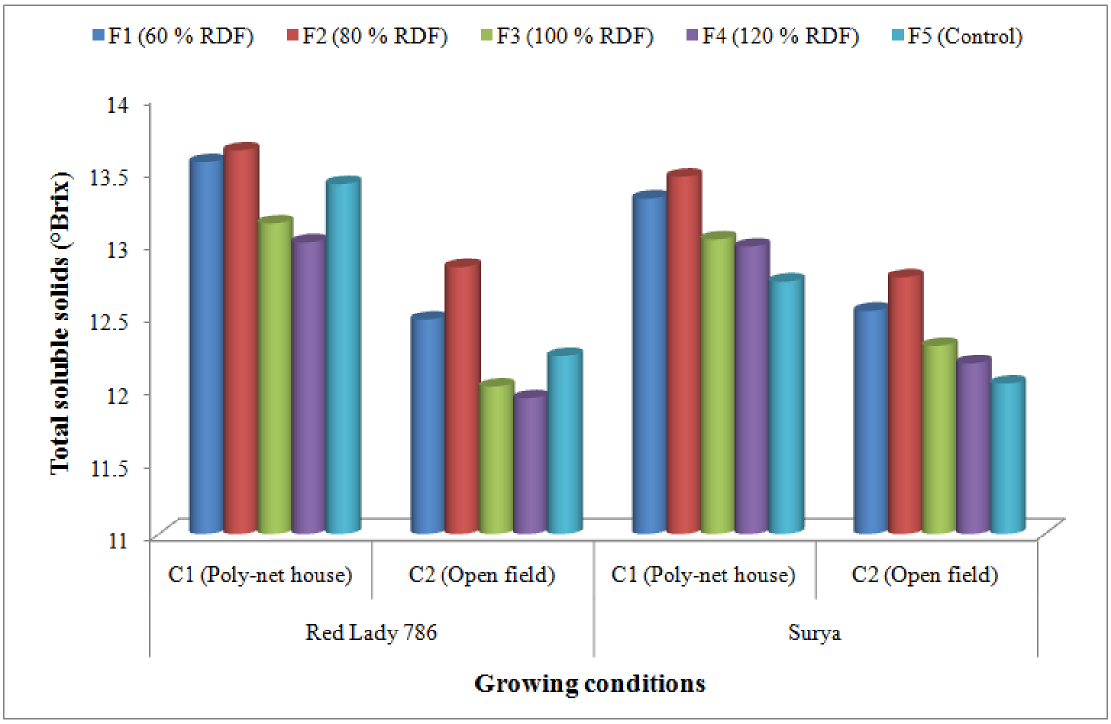

Figure 4.17: Effect of fertigation and growing conditions on TSS (°Brix) of papaya fruits.

4.3.4 Titratable acidity (%)

The statistical analysis of data pertaining to acid content in papaya fruits (Table 4.21) makes it pertinent to mention that acidity of fruits was not significantly affected by any of the treatment and their combinations except F x C interactions in 'Red Lady 786' papaya.

The titratable acidity observed in 'Red Lady 786' papaya fruits numerically ranged from 0.09 to 0.10 percent among various fertigation and growing condition treatments. Various F x C interactions shows a significant effect on acid content of fruits resulted in least acidity of 0.08 percent value in F_2C_2 (80 percent fertigation in open fields), whereas, the treatments F_1C_1, F_2C_1, F_5C_1, F_3C_2 and F_4C_2 produced fruits with maximum acid content (0.10 percent). The titratable acidity content in fruits of 'Surya' variety ranged from 0.06 to 0.09 percent in various fertigation treatments and growing conditions.

Table 4.21: Effect of fertigation and growing conditions on titratable acidity (%) of papaya fruits.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
F_1	0.10	0.09	**0.10**	0.07	0.07	**0.07**
F_2	0.10	0.08	**0.09**	0.06	0.07	**0.07**
F_3	0.09	0.10	**0.10**	0.06	0.07	**0.07**
F_4	0.09	0.10	**0.10**	0.08	0.09	**0.09**
F_5	0.10	0.09	**0.10**	0.07	0.09	**0.08**
Mean (C)	**0.10**	**0.09**		**0.07**	**0.08**	
CD ($p \leq 0.05$)						
F	**NS**			**NS**		
C	**NS**			**NS**		
F x C	**0.01**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The fruit acid content was not significantly altered in many of the treatments. These results are contradictory to the reporting's of Singh *et al.* (2010) in litchi and Neilsen *et al.* (2004) in apple that delivers a significant decrease in fruit acidity with the use of fertigation as compared to conventional fertilization. Also Reddy and Gowda (2014) reported a significant decline in papaya fruit acid content that was produced under green house instead of open fields.

4.3.5 TSS/acid ratio

The TSS/acid ratio presented in Table 4.22 makes it pertinent to mention that various fertigation treatments had significantly affected the ratio in comparison to control in both the cultivars. However, growing conditions and F x C interactions had contradictory results among two varieties.

Table 4.22: Effect of fertigation and growing conditions on TSS/acid ratio of papaya fruits.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	140.57	138.56	**139.57^{ab}**	189.99	188.87	**189.43^{a}**
F_2	137.29	160.38	**148.84^{a}**	213.37	192.36	**202.87^{a}**
F_3	147.09	120.10	**133.60^{c}**	217.00	185.25	**201.13^{a}**
F_4	139.56	119.30	**129.43^{c}**	156.09	140.11	**148.10^{b}**
F_5	134.93	135.78	**135.36^{c}**	174.21	139.19	**156.70^{b}**
Mean (C)	**139.89**	**134.82**		**190.13^{a}**	**169.16^{b}**	
CD ($p \leq 0.05$)						
F	**11.67**			**14.71**		
C	**NS**			**9.30**		
F x C	**16.50**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Highest TSS/acid ratio in 'Red Lady 786' papaya fruits was recorded to be 148.84 in F_2 (80 percent fertigation) among all fertigation treatments with least (129.43) in F_4 (120 percent fertigation). Same way, among two growing conditions, numerically maximum ratio of 139.89 was observed in fruits that developed under poly-net house. Among various interactions of treatments, F_2C_2 recorded maximum TSS/acid ratio (160.38) followed by 147.09 in F_3C_1. However, F_4C_2 recorded the minimum ratio (119.30) among all interactions.

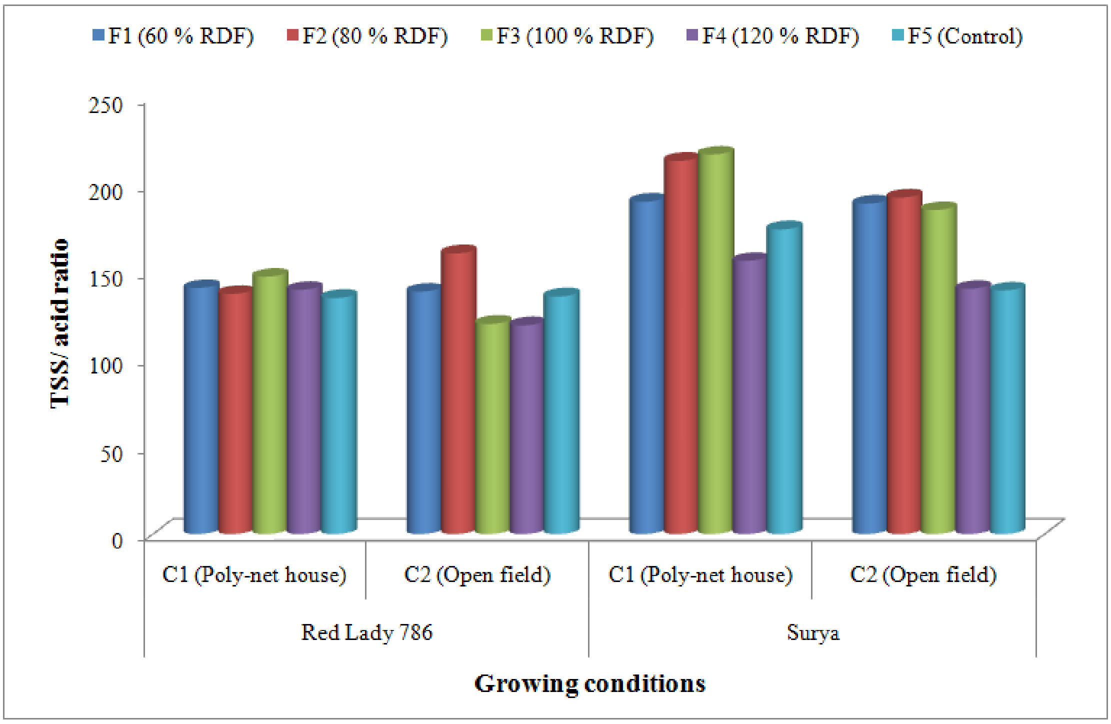

Figure 4.18: Effect of fertigation and growing conditions on TSS/acid ratio of papaya fruits.

Papaya variety 'Surya' revealed maximum TSS/acid ratio of 202.87 and 201.13 in F_2 and F_3 in comparison to other fertigation treatments. Comparison of two growing environments also demarcated poly-net house cultivation with better TSS/acid ratio fruits as compared to open fields. Various F x C interactions observed a maximum ratio of 217.00 and 213.37 in F_3C_1 and F_2C_1, respectively with minimum values of 139.19 and 140.11, respectively in F_5C_2 and F_4C_2.

The TSS/acid ratio signifies organoleptic rating of the fruit. Hence, more TSS and lesser comparative acidity improve this ratio. The same sugars to acid ratio improvement has been seen in papaya fruits growing under poly-net house by Reddy and Gowda (2014).

4.3.6 Sugars (%)

The fruit sugar level data for papaya varieties under experimentation is tabulated in Table 4.23 which reveals a significant influence of various fertigation and growing conditions.

Table 4.23: Effect of fertigation and growing conditions on sugar content (%) of papaya fruits.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	7.95	7.81	**7.88**^{ab}	5.59	5.21	**5.40**^{b}
F_2	8.03	7.87	**7.95**^{a}	5.88	5.37	**5.63**^{a}
F_3	7.82	7.64	**7.73**^{c}	5.21	5.08	**5.15**^{c}
F_4	7.80	7.69	**7.75**^{c}	4.74	4.66	**4.70**^{d}
F_5	7.89	7.73	**7.81**^{bc}	4.32	4.24	**4.28**^{e}
Mean (C)	**7.90**^{a}	**7.75**^{b}		**5.15**^{a}	**4.91**^{b}	
CD ($p \leq 0.05$)						
F	**0.11**			**0.13**		
C	**0.07**			**0.09**		
F x C	**NS**			**0.19**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The ‘Red Lady 786’ fruits have shown significantly higher sugar content (7.95 and 7.88 percent, respectively in F_2 and F_1) as compared to control (7.81 percent). Likewise, the C_1 treatment with modified environment recorded highest fruit sugars (7.90 percent) than in fruits harvested from open fields. Although F x C interactions did not show any significant effect on fruit sugars in variety ‘Red Lady 786’, numerically highest value (8.03 percent) was obtained in F_2C_1 treatment and minimum in F_3C_2 (7.64 percent).

Papaya variety ‘Surya’ recorded significant results with maximum sugar content of 5.63, 5.40, 5.15 and 4.70 percent in fruits harvested from plants that were under F_2, F_1, F_3 and F_4 treatment in comparison to lowest 4.28 percent in control. Among two growing conditions, poly net-house grown plants resulted in mean highest sugars content (5.15 percent) as compared to 4.91 percent in fruits of open field. F_2C_1 and F_1C_1 interactions observed highest fruit sugars to the level of 5.88 and 5.59 percent, whereas, F_5C_2 and F_5C_1 recorded minimum (4.24 and 4.32 percent, respectively) sugar content.

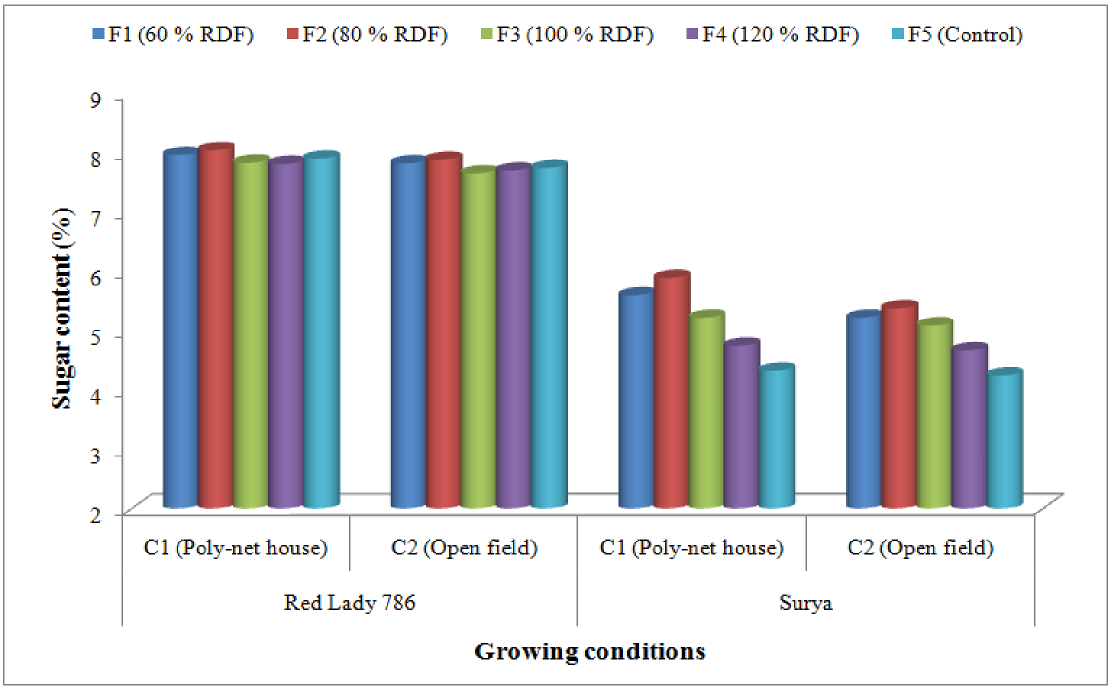

Figure 4.19: Effect of fertigation and growing conditions on sugar content (%) of papaya fruits.

The improvement in fruit total sugar content with fertigation and modified growing environment might be due to more assimilates translocation to the developing fruits causing better physico-chemical activities during maturity of fruits and improving more starch to sugars conversion. The green house environment might also have provided congenial light and temperature conditions for good quality fruit development during physiological maturity. These results are in accordance with the outcomes explained by Reddy and Gowda (2014) in papaya fruit showing maximum sugar level in protected cultivation fruits. Similarly, Rana and Chandel (2003) and Kumar *et al.* (2012) have also evidenced increased sugar content in strawberry fruits with fertigation treatments.

4.4 Leaf elemental content

4.4.1 Macro-nutrients (N, P, K, Ca and Mg)

4.4.1.1 Leaf nitrogen content (percent)

The status of leaf nitrogen content as influenced by various treatments has been presented in Table 4.24. The data revealed a significant effect of both factors and their interaction on leaf nitrogen concentration in both the varieties.

Table 4.24: Effect of fertigation and growing conditions on nitrogen content (percent) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	3.57	2.97	**3.27**^{d}	4.41	4.24	**4.33**^{d}
F_2	3.71	3.09	**3.40**^{c}	4.69	4.59	**4.64**^{c}
F_3	3.85	3.23	**3.54**^{b}	4.97	4.82	**4.90**^{b}
F_4	3.99	3.45	**3.72**^{a}	5.53	5.06	**5.30**^{a}
F_5	3.08	2.91	**3.00**^{e}	3.85	3.89	**3.87**^{e}
Mean (C)	**3.64**^{a}	**3.13**^{b}		**4.69**^{a}	**4.52**^{b}	
CD ($p \leq 0.05$)						
F	**0.06**			**0.07**		
C	**0.04**			**0.04**		
F x C	**0.08**			**0.09**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The leaves of 'Red Lady 786' variety showed presence of maximum nitrogen concentration of 3.72 percent in 120 percent fertigation treatment (F_4) followed by 3.54 percent in 100 percent fertigation (F_3) treatment. The control (F_5) treatment recorded minimum levels (3.00 percent) of mean nitrogen content in papaya leaves. Among two growing conditions, the plants growing under poly-net house unit recorded significantly higher (3.64 percent) nitrogen level as compared to 3.13 percent in open field plants. However, among F x C interactions, F_4C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf nitrogen concentration to the level of 3.99 percent followed by 3.85, 3.71, 3.57 and 3.45 percent, respectively in F_3C_1, F_2C_1, F_1C_1 and F_4C_2. The conventional fertilization in open fields (F_5C_2) and 60 percent RDF fertigation in open fields (F_1C_2) recorded minimum leaf nitrogen concentrations (2.91 and 2.97 percent, respectively).

In variety 'Surya', leaves of plants that were under 120 percent fertigation (F_4) were observed to have maximum nitrogen content (5.30 percent) followed by second maximum (4.90 percent) in 100 percent fertigation treatment (F_3) and minimum content was seen in control i.e. F_5 to the tune of 3.87 percent. Similarly, both growing conditions also differ in terms of leaf N concentrations with higher levels (4.69 percent) in poly-net house as compared to lower level (4.52 percent) in open fields. The interactive affect of various treatments reproduced higher concentration of nitrogen (5.53 percent) in leaves of plants fertigated with 120 percent RDF under green house. The same fertigation level under open cultivation revealed the second highest leaf N content (5.06 percent). However, F_5 treatment *i.e.* conventional fertilization under both growing conditions resulted in least leaf nitrogen content (3.85 and 3.89 percent, respectively in F_5C_1 and F_5C_2).

This increase in leaf nitrogen content might be due to regular availability of nutrients that improves the uptake of plant and its translocation within the plant under various fertigation treatments over the control as observed in 'Co. 7' papaya by Jeyakumar *et al.* (2010). Similarly, Valji (2011) also reported an enhancement in leaf nitrogen content in 'Madhu Bindu' papaya as a result of fertigation.

4.4.1.2 Leaf phosphorus content (percent)

The data pertaining to leaf phosphorus content in 'Red Lady 786' and 'Surya' papaya is presented in Table 4.25, that shows it was not significantly affected by any of the factors or treatment combinations.

However, in 'Red Lady 786' cultivar, numerically higher phosphorus content (0.79 percent) in leaves was recorded in F_4 (120 percent RDF fertigation) and minimum 0.34 percent in F_5 (control). Poly-net house grown plants recorded higher (0.70 percent) leaf phosphorus concentrations as compared to lower (0.36 percent) in open fields.

In 'Surya' cultivar, 100 percent RDF fertigation (F_3) treatment recorded numerically higher values (0.50 percent) of phosphorus level, whereas, F_5 (conventional fertilization) treatment was found to give lowest 0.22 percent mean level of phosphorus. Among two growing environments, poly-net house conditions resulted in higher P content (0.46 percent) as compared to 0.30 percent in open field papaya.

Table 4.25: Effect of fertigation and growing conditions on phosphorus content (percent) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	0.56	0.37	**0.47**	0.44	0.32	**0.38**
F_2	0.68	0.22	**0.45**	0.48	0.18	**0.33**
F_3	0.78	0.44	**0.61**	0.53	0.47	**0.50**
F_4	0.99	0.59	**0.79**	0.51	0.41	**0.46**
F_5	0.51	0.17	**0.34**	0.33	0.10	**0.22**
Mean (C)	**0.70**	**0.36**		**0.46**	**0.30**	
CD ($p \leq 0.05$)						
F	**NS**			**NS**		
C	**NS**			**NS**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

These results obtained in the present studies are similar to the observations of Jeyakumar *et al.* (2010) and Valji (2011) who reported a slight increase in leaf P content due to fertigation in papaya plants but this increase was statistically non-significant.

4.4.1.3 Leaf potassium content (percent)

The data related to leaf concentration of potassium element has been tabulated in Table 4.26. The data analysis revealed a significant effect of treatments on leaf potassium concentrations in both varieties except growing condition influence in 'Red Lady 786'.

The highest leaf potassium content (2.11 percent) was estimated in F_2 treatment (80 percent fertigation) followed by F_1 treatment (60 percent fertigation) and minimum (1.46 percent) in F_5 (conventional fertilization) in 'Red Lady 786' papaya. The poly-net house conditions resulted in numerically higher K content in papaya leaves (1.77 percent) as compared to minutely lower (1.76 percent) in open field grown papaya. Within different interactions, 80 percent fertigation combination with both growing conditions (F_2C_1 and F_2C_2) recorded peak K concentration levels of 2.20 and 2.02 percent, respectively in 'Red Lady 786' and minimum levels (1.42 and 1.47 percent) were estimated in F_5C_1 and F_4C_1 (conventional fertilization and 120 percent fertigation under protected conditions).

Table 4.26: Effect of fertigation and growing conditions on potassium content (percent) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	2.01	1.89	**1.95^{b}**	1.25	1.32	**1.29^{b}**
F_2	2.20	2.02	**2.11^{a}**	1.56	1.39	**1.48^{a}**
F_3	1.77	1.63	**1.70^{c}**	1.24	1.08	**1.16^{c}**
F_4	1.47	1.78	**1.63^{c}**	1.18	1.21	**1.20^{c}**
F_5	1.42	1.49	**1.46^{d}**	1.01	0.95	**0.98^{d}**
Mean (C)	**1.77**	**1.76**		**1.25^{a}**	**1.19^{b}**	
CD ($p \leq 0.05$)						
F	**0.08**			**0.04**		
C	**NS**			**0.03**		
F x C	**0.12**			**0.06**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In case of 'Surya' papaya, F_2 treatment (80 percent fertigation) recorded higher mean potassium content (1.48 percent) in leaves, whereas, minimum concentration (0.98 percent) was estimated in control treatment. Protected cultivation was reported to be superior in accumulation of more leaf potassium (1.25 percent) in comparison to open fields (1.19 percent). Among various F x C combinations, 1.56 and 1.39 percent were the highest leaf potassium levels both found in 80 percent fertigation when grown under poly-net house conditions and open fields, respectively (F_2C_1 and F_2C_2), whereas, conventional fertilization resulted in lowest K content (0.95 and 1.01 percent in F_5C_2 and F_5C_1, respectively).

The observed results showing an increase in leaf potassium concentration are in accordance with the findings of Jeyakumar *et al.* (2010) who reported a significant enhancement in leaf K content in 'Co. 7' papaya due to 75 and 100 percent RDF fertigation. Similarly, Valji (2011) also reported an increase in leaf potassium content when fertigation was done applying 100 percent recommended dose of fertilizers through drip irrigation.

4.4.1.4 Leaf calcium content (percent)

The observations pertaining to leaf calcium levels are shown in Table 4.27. It is clear from data that various treatments except growing conditions, significantly increased the leaf Ca levels in both the cultivars under study.

Table 4.27: Effect of fertigation and growing conditions on calcium content (percent) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	3.03	3.38	**3.21**^{c}	3.27	3.18	**3.23**^{d}
F_2	4.02	3.53	**3.78**^{b}	3.34	3.63	**3.49**^{b}
F_3	3.66	3.97	**3.82**^{b}	4.33	4.07	**4.20**^{a}
F_4	4.08	3.81	**3.95**^{a}	3.39	3.32	**3.36**^{c}
F_5	2.82	3.06	**2.94**^{d}	2.25	2.79	**2.52**^{e}
Mean (C)	**3.52**	**3.55**		**3.32**	**3.40**	
CD ($p \leq 0.05$)						
F	**0.08**			**0.06**		
C	**NS**			**NS**		
F x C	**0.11**			**0.08**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); F_2 (Fertigation with 80 percent recommended dose of fertilizers); F_3 (Fertigation with 100 percent recommended dose of fertilizers); F_4 (Fertigation with 120 percent recommended dose of fertilizers) and F_5 (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

‘Red Lady 786’ leaves analysis had shown higher (3.95 per cent) Ca concentration in 120 percent fertigation (F_4) followed by 100 percent fertigation (F_3) (3.82 per cent) and minimum (2.94 percent) in F_5 *i.e.* control. The interactions between fertigation and growing conditions had recorded significantly higher calcium (4.08 percent) in F_4C_1 followed by 4.02 percent in F_2C_1 as compared to minimum (2.82 percent) in F_5C_1.

The 100 percent RDF fertigation treatments in ‘Surya’ had resulted in highest leaf calcium concentration (4.20 percent) followed by 3.49 percent in 80 percent RDF fertigation and lowest (2.52 percent) in control. Among various treatment combinations, calcium concentration was found maximum (4.33 and 4.07 percent) in F_3C_1 and F_3C_2 and minimum (2.25 percent) calcium was seen in F_5C_1.

In line with the present study, leaf calcium levels were found higher in fertigated plants of apple by Noe *et al.* (1995). Likewise, in another study also, the fertigation treatments increased calcium contents in leaves of grapes variety ‘Bangalore blue’ as reported by Murthy *et al.* (2001).

4.4.1.5 Leaf magnesium content (percent)

The data regarding leaf Mg content in different treated plants is shown in Table 4.28. Different treatments enhanced leaf magnesium percent in both cultivars ‘Red Lady 786’ and ‘Surya’.

In ‘Red Lady 786’, significantly maximum leaf Mg (1.15 percent) was observed in F_4 (120 percent fertigation) followed by 1.11 percent in F_3 (100 percent fertigation) as compared to lowest (0.93 percent) in F_1 (60 percent fertigation) that was at par with 0.98 percent in the control (F_5). The leaf samples taken from plants growing under poly-net house had significantly maximum leaf Mg (1.19 percent) and minimum 0.91 percent in openly cultivated plants. The interactions between fertigation and cultivation treatments were not significant with numerically maximum values (1.29 percent) in F_3C_1 as compared to other F x C combinations.

In ‘Surya’, significantly higher (1.33 percent) magnesium level was observed in 120 percent fertigation which was at par with 1.32 percent in 100 percent fertigated plants. The foliage of plants developed under poly-net house had more Mg concentrations (1.28 percent) as compared to 1.17 percent in open field conditions. 120 percent fertigation performed inside poly-net house (F_4C_1) resulted in peak leaf Mg (1.40 percent) among all F x C interactions, followed by 1.33 and 1.30 percent in F_3C_2 and F_3C_1, respectively. On the other hand, 80 percent RDF fertigation in open field (F_2C_2) had recorded the lowest leaf Mg content (1.02 percent).

Table 4.28: Effect of fertigation and growing conditions on magnesium content (percent) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	1.09	0.77	**0.93^b**	1.24	1.16	**1.20^b**
F_2	1.21	0.98	**1.10^a**	1.25	1.02	**1.14^c**
F_3	1.29	0.93	**1.11^a**	1.30	1.33	**1.32^a**
F_4	1.22	1.07	**1.15^a**	1.40	1.25	**1.33^a**
F_5	1.14	0.82	**0.98^b**	1.23	1.07	**1.15^c**
Mean (C)	**1.19^a**	**0.91^b**		**1.28^a**	**1.17^b**	
CD ($p \leq 0.05$)						
F	**0.09**			**0.03**		
C	**0.06**			**0.02**		
F x C	**NS**			**0.05**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

The increased levels of leaf magnesium concentration in plants that were under fertigation might be due to enhanced nitrogen doses in fertigation as reported by Hedge and Srinivas (1991). Noe *et al.* (1995) also observed significantly higher leaf magnesium concentrations when plants were applied with fertigation as compared to non-fertilized plants. Similarly, Neilsen *et al.* (2004) studied the response of nitrogen and potassium fertigation in apples and in the results they reported an enhancement in leaf magnesium content. In another experimental study on kiwi fruit, Chauhan and Chandel (2008) documented significantly higher leaf magnesium in the trees fertigated with full recommendation of nutrients in comparison to soil band placements.

4.4.2 Micro-nutrients (Fe, Zn, Mn and Cu)

4.4.2.1 Leaf iron content (ppm)

The observations regarding leaf iron content as affected by different treatments are shown in Table 4.29. Most of the treated plants were observed to have significantly increased Fe content as compared to control in both the cultivars.

In 'Red Lady 786' plants, significantly highest amount of iron was observed in 120 percent RDF fertigation (317.8 ppm) followed by 299.8 ppm in F_2 *i.e.* 80 percent RDF fertigation and minimum of 220.4 ppm in F_1 (60 percent RDF fertigation). The results among two growing environments were also significant and recorded maximum Fe in C_1 (poly-net house condition) and minimum in C_2 (open fields). Higher leaf iron content (332.7, 313.9 and 302.9 ppm) was seen in F_4C_1, F_2C_1 and F_4C_2, respectively and minimum (217.0 percent) in F_1C_1.

Table 4.29: Effect of fertigation and growing conditions on iron content (ppm) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	217.0	223.9	**220.5^e**	307.7	339.8	**323.8^e**
F_2	313.9	285.6	**299.8^b**	412.3	423.5	**417.9^b**
F_3	292.5	276.1	**284.3^c**	370.5	406.1	**388.3^c**
F_4	332.7	302.9	**317.8^a**	488.3	452.7	**470.5^a**
F_5	225.9	239.8	**232.9^d**	334.1	366.2	**350.2^d**
Mean (C)	**276.4^a**	**265.7^b**		**382.6^b**	**397.7^a**	
CD						
($p \leq 0.05$)	**5.68**			**3.80**		
F	**3.59**			**2.40**		
C	**8.04**			**5.37**		
F x C						

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In ‘Surya’ plants, 120 percent RDF fertigation (F_4) resulted in higher (470.5 ppm) mean Fe content and lowest (323.8 ppm) in 60 percent fertigated plants *i.e.* F_1 treatment. Different growing conditions also gave significant results and recorded maximum iron (397.7 ppm) in open field plants (C_2) with minimum (382.6 ppm) in poly-net house plants (C_1). Among various F x C interactions, F_4C_1 had highest (488.3 ppm) levels of iron followed by 452.7 ppm in F_4C_2 and minimum (307.7 ppm) in F_1C_1.

The improvement in leaf iron content might also have enhanced the photosynthetic capacity of plants because it is an important part of chlorophyll. These results are corroborated with the observations of Neilsen *et al.* (1995) who noted that leaf K concentrations had synergistic effect on leaf Fe content.

4.4.2.2 Leaf zinc content (ppm)

Different treatments had resulted in increased levels of zinc in leaves of papaya cultivars ‘Red Lady 786’ and ‘Surya’ as shown in Table 4.30. However, the interactions between two factors were not significant.

Maximum zinc (65.81 ppm) in ‘Red Lady 786’ plants was observed under 120 percent RDF fertigation plants (F_4) followed by 62.07 ppm in 80 percent RDF fertigation plants (F_2) and significantly minimum (55.45 ppm) in lowest fertigation i.e. 60 percent (F_1) that was at par with 56.94 ppm in F_5. Significantly higher leaf Zn level of 61.97 ppm was estimated in poly-net house plants as compared to 58.15 ppm in open field plants. Although, the results for various F x C interactions were non-significant, however, numerically topmost zinc content was observed in leaves of plants that were under highest fertigation treatments in both growing conditions (67.65 ppm in F_4C_1 and 63.96 ppm in F_4C_2).

In ‘Surya’ papaya, significantly highest Zn content (57.04 ppm) was recorded in F_4 followed by 52.02 ppm in F_3 and minimum of 47.51 ppm in F_1. Maximum Zn (54.17 ppm) in poly-net house plants was significantly more from 49.13 ppm in open field plants. Although, the F x C interactions were not significant, the maximum observed Zn concentration of 59.42 ppm was in F_4C_1 followed by 54.66 ppm in F_4C_2 and minimum (45.73 ppm) in F_1C_2.

These results of comparatively more zinc element content in fertigated plant leaves are in agreement with those of Kumar and Dey (2011), who also observed higher nutrient uptake in strawberry plants that were under drip irrigation at 1.0 and 0.8 ‘V’ volume of water than those irrigated with surface irrigation.

Table 4.30: Effect of fertigation and growing conditions on zinc content (ppm) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	57.96	52.93	**55.45[d]**	49.28	45.73	**47.51[c]**
F_2	63.05	61.08	**62.07[b]**	54.39	46.91	**50.65[b]**
F_3	61.68	58.39	**60.04[c]**	53.98	50.06	**52.02[b]**
F_4	67.65	63.96	**65.81[a]**	59.42	54.66	**57.04[a]**
F_5	59.50	54.37	**56.94[d]**	53.76	48.29	**51.03[b]**
Mean (C)	**61.97[a]**	**58.15[b]**		**54.17[a]**	**49.13[b]**	
CD (p≤0.05)						
F	**1.53**			**1.48**		
C	**0.97**			**0.93**		
F x C	**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

4.4.2.3 Leaf manganese content (ppm)

The data on manganese content as affected by various treatments are presented in Table 4.31. It is pertinent to mention that fertigation and growing condition treatments given to 'Red Lady 786' and 'Surya' papaya varieties significantly increased the Mn content in leaves with minimum in control plants.

In case of 'Red Lady 786', highest (54.40 ppm) Mn content was recorded in 100 percent fertigation (F_3) followed by 51.87 ppm in 120 percent fertigation (F_4) and minimum (44.19 ppm) in control (F_5). Among open and poly-net house conditions, maximum (50.25 ppm) Mn was observed in C_1 i.e. poly-net house plants and minimum (47.29 ppm) in open field cultivated plants. The interactions between various treatments were significant and recorded higher levels of manganese (58.47 ppm) in F_3C_1 followed by 53.82 ppm in F_4C_2.

Table 4.31: Effect of fertigation and growing conditions on manganese content (ppm) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	47.90	46.63	**47.27[c]**	46.98	45.71	**46.35[c]**
F_2	48.36	43.92	**46.14[c]**	47.95	42.86	**45.41[d]**
F_3	58.47	50.32	**54.40[a]**	57.44	50.27	**53.86[a]**
F_4	49.91	53.82	**51.87[b]**	48.72	53.61	**51.17[b]**
F_5	46.62	41.75	**44.19[d]**	45.51	42.08	**43.80[e]**
Mean (C)	**50.25[a]**	**47.29[b]**		**49.32[a]**	**46.91[b]**	
CD ($p \leq 0.05$)						
F	**1.61**			**0.75**		
C	**1.02**			**0.47**		
F x C	**2.27**			**1.06**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In papaya cv. ‘Surya’, F_3 treatment resulted in highest (53.86 ppm) Mn content which was followed by F_4 (51.17 ppm) and least of 43.80 ppm in control (F_5). Among the growing conditions, maximum (49.32 ppm) manganese concentration was seen in C_1 (poly-net house) and minimum of 46.91 ppm in C_2 (open field). The interactions between treatments were significant giving highest values of 57.44, 53.61 and 50.27 ppm, respectively in F_3C_1, F_4C_2 and F_3C_2 and minimum Mn content of 42.08 in F_5C_2.

The fertigation treatments improved the leaf Mn content in papaya. It is well documented that application of N, P and K fertilizers in different compositions enhanced the optimum uptake of Mg, Fe, Mn and Zn contents from the soils.

4.4.2.4 Leaf copper content (ppm)

The data presented in Table 4.32 shows the significant effect of different fertigation and growing conditions on leaf Cu content.

Table 4.32: Effect of fertigation and growing conditions on copper content (ppm) of papaya leaves.

Treatments	Varieties					
	Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	5.84	5.64	**5.74^d**	8.40	8.31	**8.36^d**
F_2	6.20	5.87	**6.04^b**	8.97	8.67	**8.82^b**
F_3	6.06	5.73	**5.90^c**	8.46	8.54	**8.50^c**
F_4	6.34	6.05	**6.20^a**	9.11	8.96	**9.04^a**
F_5	5.16	5.57	**5.37^e**	7.80	7.93	**7.87^e**
Mean (C)	**5.92^a**	**5.77^b**		**8.55**	**8.48**	
CD (p≤0.05)						
F	**0.13**			**0.13**		
C	**0.08**			**NS**		
F x C	**0.19**			**0.19**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

In 'Red Lady 786', significantly maximum (6.20 ppm) content of Cu was recorded in F_4 followed by F_2 (6.04 ppm) and minimum of 5.37 ppm in F_5 (control). Growing conditions gave significant results with highest values of 5.92 ppm in modified environment (poly-net house) and least 5.77 ppm in open field plants. Likewise, the F x C interactions between various treatments were also significant, where highest leaf Cu concentration (6.34 ppm) was observed in F_4C_1 followed by 6.20 ppm in F_2C_1 and lowest 5.16 and 5.57 ppm in their respective controls (F_5C_1 and F_5C_2).

In 'Surya' papaya, F_4 treatment resulted in significantly maximum copper (9.04 ppm) and minimum (7.87 ppm) in F_5 (control). Although, the results within two growing conditions were not significant, the higher Cu level of 8.55 ppm was seen in poly-net house plants as compared to plants grown in open field. The F x C interactions revealed that F_4C_1, F_2C_1 and F_4C_2 resulted in maximum copper element concentration (9.11, 8.97 and 8.96 ppm, respectively) and minimum Cu content of 7.93 and 7.80 ppm in conventional fertilization under both growing environments (F_5C_2 and F_5C_1, respectively). Kumar and Dey (2011) also found more nutrient uptake in strawberry plants that were under fertigation.

4.5 Soil parameters before experiment:

Table 4.33: Status of soil parameters at different depths before experiment.

	Before experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
Treatments	C_1 (Poly-net house)	C_2 (Open field)	Mean	C_1 (Poly-net house)	C_2 (Open field)	Mean	C_1 (Poly-net house)	C_2 (Open field)	Mean	C_1 (Poly-net house)	C_2 (Open field)	Mean
	0-15 cm soil depth						15-30 cm soil depth					
pH	8.18	8.18	**8.18**	8.15	8.14	**8.15**	8.24	8.22	**8.23**	8.24	8.25	**8.25**
EC (dSm^{-1})	0.23	0.24	**0.24**	0.26	0.28	**0.27**	0.21	0.22	**0.22**	0.23	0.24	**0.24**
OC (percent)	0.53	0.54	**0.54**	0.54	0.55	**0.55**	0.50	0.51	**0.51**	0.52	0.51	**0.52**
N (kg/ha)	272.45	275.97	**274.21**	273.51	277.08	**275.30**	236.41	237.18	**236.80**	238.96	239.42	**239.19**
P (kg/ha)	42.67	43.95	**43.31**	45.27	45.84	**45.56**	37.66	38.24	**37.95**	37.59	38.41	**38.00**
K (kg/ha)	335.46	336.54	**336.00**	336.18	336.87	**336.53**	285.42	286.36	**285.89**	286.57	287.18	**286.88**
	30-60 cm soil depth						60-90 cm soil depth					
pH	8.37	8.39	**8.38**	8.36	8.38	**8.37**	8.41	8.40	**8.41**	8.40	8.40	**8.40**
EC (dSm^{-1})	0.31	0.30	**0.31**	0.30	0.30	**0.30**	0.25	0.26	**0.26**	0.27	0.28	**0.28**
OC (percent)	0.49	0.49	**0.49**	0.49	0.47	**0.48**	0.48	0.47	**0.48**	0.48	0.48	**0.48**
N (kg/ha)	230.58	231.43	**231.01**	231.87	232.61	**232.24**	226.19	226.82	**226.51**	227.68	228.51	**228.10**
P (kg/ha)	30.84	30.72	**30.78**	30.15	30.33	**30.24**	26.08	26.28	**26.18**	26.19	26.78	**26.49**
K (kg/ha)	288.71	288.18	**288.45**	289.25	288.97	**289.11**	289.64	289.37	**289.51**	289.43	288.99	**289.21**

4.6 Soil parameters after experiment:

4.6.1 pH

The data illustrated in Table 4.34 shows that various fertigation and growing conditions did not significantly influence the soil pH in any of the varieties under study. In both the varieties, highest pH was observed in the lowest soil layer (60-90 cm) and minimum in the uppermost layer upto 15 cm soil depth. Although the data analysis results were not significant, the highest pH range was recorded in maximum fertigation levels i.e. 120 percent RDF fertigation in almost all the soil depths. A very minute and non-significant enhancement of soil pH was reported with fertigation treatments.

4.6.2 Electrical conductivity (dSm^{-1})

It is clear from the conductivity values tabulated in Table 4.35 that treatments of two factors under study were not significantly affected the soil electrical conductivity in any papaya variety under discussion. The initial and final soil status regarding conductivity levels of soil were at par at all soil depths. The electrical conductivity level numerically showed an decreasing trend from upper soil layer (0-15 cm) to second layer (15-30 cm), but moving further downwards, the conductivity levels were seen to rise up to a depth of 60 cm and again a diminishing trend from 60 to 90 cm soil depth. The overall range of soil electrical conductivity was 0.20 to 0.31 dSm^{-1}.

4.6.3 Organic carbon (percent)

The data presented in Table 4.36 revealed that soil organic carbon content was neither improved nor depleted with any of the treatments given to papaya varieties ‘Red Lady 786’ and ‘Surya’. The overall trend of organic carbon percentage seems to be decreasing as we move to the deep layers of soil. The range of observed soil carbon content varied from approximately 0.57 percent in upper soil layers to 0.47 percent in deep layers of soil. The non-significant effect of various fertigation treatments on soil organic carbon content is line with the findings of Singh (2018) in strawberry who also reported the same soil organic carbon status in fertigation treatments.

Table 4.34: Status of soil pH at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			**Surya**			**Red Lady 786**			**Surya**		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
	0-15 cm soil depth						**15-30 cm soil depth**					
F_1	8.15	8.10	**8.13**	8.06	8.19	**8.13**	8.14	8.16	**8.15**	8.15	8.25	**8.20**
F_2	8.22	8.14	**8.18**	8.15	8.10	**8.13**	8.16	8.25	**8.21**	8.29	8.15	**8.22**
F_3	8.13	8.25	**8.19**	8.13	8.16	**8.15**	8.25	8.28	**8.27**	8.25	8.30	**8.28**
F_4	8.23	8.15	**8.19**	8.20	8.15	**8.18**	8.27	8.25	**8.26**	8.30	8.25	**8.28**
F_5	8.27	8.15	**8.21**	8.15	8.17	**8.16**	8.30	8.23	**8.27**	8.22	8.29	**8.26**
Mean (C)	**8.20**	**8.16**		**8.14**	**8.15**		**8.22**	**8.23**		**8.24**	**8.25**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		
	30-60 cm soil depth						**60-90 cm soil depth**					
F_1	8.30	8.40	**8.35**	8.35	8.34	**8.35**	8.30	8.47	**8.39**	8.37	8.38	**8.38**
F_2	8.32	8.43	**8.38**	8.42	8.37	**8.40**	8.43	8.42	**8.43**	8.39	8.43	**8.41**
F_3	8.37	8.42	**8.40**	8.36	8.39	**8.38**	8.52	8.33	**8.43**	8.42	8.40	**8.41**
F_4	8.40	8.42	**8.41**	8.38	8.40	**8.39**	8.47	8.44	**8.46**	8.38	8.44	**8.41**
F_5	8.45	8.38	**8.42**	8.33	8.42	**8.38**	8.47	8.45	**8.46**	8.43	8.37	**8.40**
Mean (C)	**8.37**	**8.41**		**8.37**	**8.38**		**8.44**	**8.42**		**8.40**	**8.40**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Table 4.35: Status of soil electrical conductivity (dSm^{-1}) at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
	0-15 cm soil depth						15-30 cm soil depth					
F_1	0.22	0.23	**0.23**	0.25	0.26	**0.26**	0.21	0.22	**0.22**	0.23	0.21	**0.22**
F_2	0.23	0.24	**0.24**	0.28	0.27	**0.28**	0.23	0.21	**0.22**	0.23	0.23	**0.23**
F_3	0.24	0.22	**0.23**	0.26	0.28	**0.27**	0.22	0.22	**0.22**	0.24	0.22	**0.23**
F_4	0.24	0.23	**0.24**	0.25	0.28	**0.27**	0.20	0.21	**0.21**	0.25	0.23	**0.24**
F_5	0.23	0.22	**0.23**	0.26	0.25	**0.26**	0.21	0.23	**0.22**	0.25	0.24	**0.25**
Mean (C)	**0.23**	**0.23**		**0.26**	**0.27**		**0.21**	**0.22**		**0.24**	**0.23**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		
	30-60 cm soil depth						60-90 cm soil depth					
F_1	0.30	0.31	**0.31**	0.30	0.31	**0.31**	0.25	0.27	**0.26**	0.25	0.28	**0.27**
F_2	0.30	0.28	**0.29**	0.31	0.30	**0.31**	0.27	0.26	**0.27**	0.27	0.25	**0.26**
F_3	0.31	0.29	**0.30**	0.30	0.29	**0.30**	0.24	0.26	**0.25**	0.26	0.28	**0.27**
F_4	0.30	0.29	**0.30**	0.29	0.31	**0.30**	0.25	0.25	**0.25**	0.28	0.27	**0.28**
F_5	0.31	0.30	**0.31**	0.30	0.30	**0.30**	0.24	0.26	**0.25**	0.26	0.28	**0.27**
Mean (C)	**0.30**	**0.29**		**0.30**	**0.30**		**0.25**	**0.26**		**0.26**	**0.27**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

$\mathbf{F_1}$ (Fertigation with 60 percent recommended dose of fertilizers); $\mathbf{F_2}$ (Fertigation with 80 percent recommended dose of fertilizers); $\mathbf{F_3}$ (Fertigation with 100 percent recommended dose of fertilizers); $\mathbf{F_4}$ (Fertigation with 120 percent recommended dose of fertilizers) and $\mathbf{F_5}$ (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Table 4.36: Status of soil organic carbon (percent) at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
	0-15 cm soil depth						15-30 cm soil depth					
F_1	0.55	0.54	**0.55**	0.55	0.52	**0.54**	0.49	0.52	**0.51**	0.51	0.49	**0.50**
F_2	0.53	0.55	**0.54**	0.56	0.53	**0.55**	0.52	0.51	**0.52**	0.50	0.50	**0.50**
F_3	0.54	0.56	**0.55**	0.56	0.53	**0.55**	0.51	0.51	**0.51**	0.52	0.50	**0.51**
F_4	0.56	0.55	**0.56**	0.57	0.56	**0.57**	0.50	0.51	**0.51**	0.53	0.49	**0.51**
F_5	0.55	0.53	**0.54**	0.55	0.54	**0.55**	0.52	0.50	**0.51**	0.52	0.50	**0.51**
Mean (C)	**0.55**	**0.55**		**0.56**	**0.54**		**0.51**	**0.51**		**0.52**	**0.50**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		
	30-60 cm soil depth						60-90 cm soil depth					
F_1	0.48	0.49	**0.49**	0.48	0.50	**0.49**	0.46	0.47	**0.47**	0.47	0.47	**0.47**
F_2	0.46	0.51	**0.49**	0.49	0.48	**0.49**	0.47	0.48	**0.48**	0.48	0.48	**0.48**
F_3	0.49	0.50	**0.50**	0.51	0.48	**0.50**	0.48	0.46	**0.47**	0.47	0.48	**0.48**
F_4	0.50	0.50	**0.50**	0.50	0.47	**0.49**	0.48	0.47	**0.48**	0.47	0.48	**0.48**
F_5	0.47	0.49	**0.48**	0.49	0.50	**0.50**	0.47	0.46	**0.47**	0.48	0.47	**0.48**
Mean (C)	**0.48**	**0.50**		**0.49**	**0.49**		**0.47**	**0.47**		**0.47**	**0.48**	
CD ($p \leq 0.05$)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

$\mathbf{F_1}$ (Fertigation with 60 percent recommended dose of fertilizers); $\mathbf{F_2}$ (Fertigation with 80 percent recommended dose of fertilizers); $\mathbf{F_3}$ (Fertigation with 100 percent recommended dose of fertilizers); $\mathbf{F_4}$ (Fertigation with 120 percent recommended dose of fertilizers) and $\mathbf{F_5}$ (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

4.6.4 Available N (kg/ha)

The data pertaining to available nitrogen content in soil is presented in Table 4.37. The analysis of data revealed that the nitrogen content in upper layers of soil was significantly influenced by various fertigation and growing conditions and their combinations in both the cultivars. However, the deep layer of 60 to 90 cm had not shown significant variation. The general trend followed by the nitrogen content in soil was an increasing concentration when we follow lowest to highest level of fertigation.

Highest level of available nitrogen was recorded in soils applied with highest fertigation level (120 percent RDF fertigation) with decrease in trend towards soil depth under both cultivars. The highest estimated value of available nitrogen at successive depths (0-15, 15-30, 30-60 and 60-90 cm) was 330.43, 286.64, 250.83 and 238.77 kg/ha in 'Red Lady 786', while 332.69, 288.68, 251.30 and 239.66 kg/ha in 'Surya' cultivar. However, the lowest value was reported in conventional fertilizer application (F_5). Further, the soil nitrogen content under poly-net house was statistically lower as compared to open field. Interaction effect (F x C) had revealed highest value in F_4C_2 and F_4C_1 for both cultivars.

These increased levels of N content with more fertigation are corroborated with the findings of Valji (2011) who had also observed the same trend of enhanced soil nitrogen content by various fertigation treatments in papaya.

4.6.5 Available P (kg/ha)

The available phosphorus concentration elaborated in the Table 4.38 revealed various treatments to be non-effective in changing its soil levels. In both the papaya cultivars under discussion, the available phosphorus content showed a diminishing trend from topmost soil layer to the deep soil layer (i.e. moving from soil surface to 90 cm deep). However, the overall highest estimates of P was recorded in F_4C_2 (51.83 kg/ha) followed by F_4C_1 (51.32 kg/ha) under 'Surya' cultivar and F_4C_2 (49.29 kg/ha) followed by F_3C_2 (48.88 kg/ha) under 'Red Lady 786' cultivar. The lowest value was recorded in plants applied with conventional treatment (F_5C_1 and F_5C_2). Further, the soil beneath open cultivated plants had more available phosphorus levels as compared to modified environment papaya plants. These results are in accordance with the in-significant effect of fertigation on soil mineral composition under papaya plants as documented by Valji (2011).

4.6.6 Available K (kg/ha)

The data given in Table 4.39 illustrated that all the fertigation treatment levels exerted a significant influence on available soil K (kg/ha) in both the cultivars. It is clear from the data that F_4 (fertigation @ 120 percent RDF) had the maximum soil K content (362.35, 317.28 and 299.16 kg/ha in 'Red Lady 786' and 360.27, 316.80 and 301.07 kg/ha in 'Surya', respectively) at soil depths of 0-15, 15-30 and 30-60 cm in both the cultivars. The minimum soil K content (293.75 kg/ha in cultivar 'Red Lady 786' and 296.12 kg/ha in 'Surya') was recorded at 30 to 60 cm soil depth in F_5 treatment (conventional fertilization treatment). In general, the deepest soil layers had least K elemental content as compared to the richest concentrations in top soil. These findings are in line with the results reported by Valji (2011) in papaya crop listing a significant enhancement of soil K concentrations in available form under the influence of various fertigation levels.

Table 4.37: Status of soil available nitrogen (kg/ha) at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
	0-15 cm soil depth						**15-30 cm soil depth**					
F_1	292.34	293.46	**292.90**	294.91	295.66	**295.29**	252.37	253.29	**252.83**	254.82	255.63	**255.23**
F_2	299.56	302.17	**300.87**	300.56	304.37	**302.47**	261.66	262.54	**262.10**	263.45	264.45	**263.95**
F_3	315.68	322.46	**319.07**	318.72	325.46	**322.09**	273.46	274.17	**273.82**	275.67	276.91	**276.29**
F_4	328.28	332.58	**330.43**	330.45	334.92	**332.69**	285.45	287.83	**286.64**	287.79	289.57	**288.68**
F_5	290.46	290.72	**290.59**	291.31	292.04	**291.68**	248.96	248.63	**248.80**	250.45	250.64	**250.55**
Mean (C)	**305.26**	**308.28**		**307.19**	**310.49**		**264.38**	**265.29**		**266.44**	**267.44**	
CD (p≤0.05)												
F	1.46			1.06			1.22			1.05		
C	0.73			0.41			0.08			0.06		
F x C	1.92			1.77			1.33			1.16		
	30-60 cm soil depth						**60-90 cm soil depth**					
F_1	241.75	242.33	**242.04**	241.97	243.53	**242.75**	234.45	234.87	**234.66**	235.14	235.29	**235.22**
F_2	243.82	244.57	**244.20**	244.16	245.87	**245.02**	235.72	235.96	**235.84**	235.94	236.57	**236.26**
F_3	248.64	249.42	**249.03**	248.59	250.74	**249.67**	237.61	238.97	**238.29**	237.87	239.43	**238.65**
F_4	250.93	250.72	**250.83**	251.27	251.32	**251.30**	238.74	238.79	**238.77**	239.17	240.15	**239.66**
F_5	240.46	240.87	**240.67**	240.75	240.98	**240.87**	232.49	232.57	**232.53**	232.89	232.96	**232.93**
Mean (C)	**245.12**	**245.58**		**245.35**	**246.49**		**235.80**	**236.23**		**236.20**	**236.88**	
CD (p≤0.05)												
F	**0.18**			**0.34**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Table 4.38: Status of soil available phosphorus (kg/ha) at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
	0-15 cm soil depth						15-30 cm soil depth					
F_1	45.72	46.36	**46.04**	46.33	46.87	**46.60**	39.47	39.23	**39.35**	39.84	39.77	**39.81**
F_2	46.15	47.53	**46.84**	48.92	48.54	**48.73**	40.25	41.32	**40.79**	40.37	40.65	**40.51**
F_3	47.57	48.88	**48.23**	49.86	49.92	**49.89**	42.36	42.78	**42.57**	41.63	41.84	**41.74**
F_4	48.76	49.29	**49.03**	51.32	51.83	**51.58**	42.96	43.15	**43.06**	42.78	42.96	**42.87**
F_5	45.43	45.67	**45.55**	45.43	46.02	**45.73**	39.05	38.64	**38.85**	39.13	39.57	**39.35**
Mean (C)	**46.73**	**47.55**		**48.37**	**48.64**		**40.82**	**41.02**		**40.75**	**40.96**	
CD (p≤0.05)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		
	30-60 cm soil depth						60-90 cm soil depth					
F_1	31.74	31.54	**31.64**	31.13	31.45	**31.29**	27.43	27.84	**27.64**	26.78	26.89	**26.84**
F_2	31.92	32.37	**32.15**	32.42	32.79	**32.61**	27.38	28.29	**27.84**	27.32	27.57	**27.45**
F_3	33.44	33.68	**33.56**	33.27	33.62	**33.45**	28.56	29.11	**28.84**	28.47	28.64	**28.56**
F_4	34.26	34.46	**34.36**	33.86	34.14	**34.00**	29.13	30.24	**29.69**	29.58	29.93	**29.76**
F_5	31.05	31.29	**31.17**	30.87	31.08	**30.98**	26.94	27.25	**27.10**	26.05	26.25	**26.15**
Mean (C)	**32.48**	**32.67**		**32.31**	**32.62**		**27.89**	**28.55**		**27.64**	**27.86**	
CD (p≤0.05)												
F	**NS**			**NS**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

Table 4.39: Status of soil available potassium (kg/ha) at different depths after experiment.

Treatments	After experiment											
	Red Lady 786			Surya			Red Lady 786			Surya		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
	0-15 cm soil depth						15-30 cm soil depth					
F_1	349.85	350.64	**350.25**	351.12	351.34	**351.23**	304.28	305.63	**304.96**	304.38	305.14	**304.76**
F_2	351.38	352.19	**351.79**	353.26	353.79	**353.53**	308.37	310.72	**309.55**	307.59	308.87	**308.23**
F_3	355.79	357.81	**356.80**	356.48	358.03	**357.26**	311.45	313.86	**312.66**	310.46	312.61	**311.54**
F_4	361.16	363.54	**362.35**	359.57	360.97	**360.27**	315.61	318.95	**317.28**	315.84	317.75	**316.80**
F_5	348.47	347.52	**348.00**	347.75	348.16	**347.96**	295.32	295.64	**295.48**	296.78	297.86	**297.32**
Mean (C)	**353.33**	**354.34**		**353.64**	**354.46**		**307.01**	**308.96**		**307.01**	**308.45**	
CD (p≤0.05)												
F	**1.84**			**2.51**			**1.67**			**1.82**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		
	30-60 cm soil depth						60-90 cm soil depth					
F_1	294.18	294.85	**294.52**	297.24	297.83	**297.54**	290.44	290.88	**290.66**	289.27	290.16	**289.72**
F_2	295.89	296.16	**296.03**	297.54	298.76	**298.15**	291.35	291.76	**291.56**	290.57	291.32	**290.95**
F_3	297.23	297.92	**297.58**	299.82	300.09	**299.96**	291.87	292.48	**292.18**	291.79	292.57	**292.18**
F_4	298.75	299.57	**299.16**	300.67	301.46	**301.07**	293.56	294.15	**293.86**	292.62	293.74	**293.18**
F_5	293.36	294.13	**293.75**	295.86	296.37	**296.12**	290.12	290.42	**290.27**	289.06	289.36	**289.21**
Mean (C)	**295.88**	**296.53**		**298.23**	**298.90**		**291.47**	**291.94**		**290.66**	**291.43**	
CD (p≤0.05)												
F	**0.84**			**0.91**			**NS**			**NS**		
C	**NS**			**NS**			**NS**			**NS**		
F x C	**NS**			**NS**			**NS**			**NS**		

F_1 (Fertigation with 60 percent recommended dose of fertilizers); **F_2** (Fertigation with 80 percent recommended dose of fertilizers); **F_3** (Fertigation with 100 percent recommended dose of fertilizers); **F_4** (Fertigation with 120 percent recommended dose of fertilizers) and **F_5** (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers).

CHAPTER V

SUMMARY

The present investigation entitled "Standardization of fertigation doze for open and protected cultivation of papaya in Punjab" was carried out in two gynodioecious papaya cultivars "Red Lady 786" and "Surya". Both the varieties were planted at a spacing of 1.5 x 1.5 m under poly-net house unit (C_1) as well as in open field (C_2) during the month of September. These plants were then applied with various fertigation treatments and one conventional fertilization treatment *i.e.* control. The experimental plants under above treatments were further periodically analyzed to record various vegetative, fruiting, physico-chemical characteristics and leaf nutrients status in both the papaya cultivars. The results described in chapter - iv have been summarized below:

5.1 Plant growth parameters

The results depicted that tallest plants (282.52 and 233.80 cm height, respectively in 'Red Lady 786' and 'Surya') initiating flowering at highest length from plant base in both the varieties were observed in 120 percent RDF (recommended dose of fertilizers) fertigation treatment (F_4). However, stem girth was seen to show somewhat inverse relation to plant height with maximum stem circumference in F_1 (42.63 cm) and F_3 (33.39 cm), respectively in 'Red Lady 786' and 'Surya'. Greenhouse plants (C_1) measured higher plant (318.31 and 230.79 cm in 'Red Lady 786' and 'Surya') and flowering height (92.26 and 169.09 cm in 'Red Lady 786' and 'Surya') with narrow stem as compared to open field plants (C_2) having short height with broad stem girth and low level flowering. Maximum fertigation treatment applied inside the protected environment (F_4C_1) resulted in long statured plants flowering at higher position in both the varieties. On the other hand, stem girth of 'Red Lady 786'and 'Surya' papaya was higher in F_1C_1 and F_2C_2, respectively. The leaf spreading alongside the plant stem was greater (292.57 and 239.95 cm, respectively in 'Red Lady 786' and 'Surya') in plants fertigated with 80 percent recommended fertilizer dose in both the cultivars. Likewise, maximum plant spread with minimum functional leaf count was recorded in open cultivation plants in comparison to lowest leaf spread accompanying higher leaf count in green house plants. Contrarily, number of functional leaves was maximum (26.50) in 'Red Lady 786' plants fertigated with least fertilizer dose (60 percent) and in 80 percent fertigation in variety 'Surya' (24.20).

5.2 Yield and related attributes

The analysis of data pertaining to flowering and fruiting characteristics of papaya cultivars under experiment revealed that least time taken for commencement of anthesis (*i.e.* 192.9 and 231.0 days, respectively in 'Red Lady 786' and 'Surya') and foremost fruit setting

was within 196.7 days in 'Red Lady 786' and 232.0 days in 'Surya' was observed in plants that were applied with least fertilizer dose (60 percent) through fertigation, whereas, fertigation with 80 percent recommended fertilizer dose resulted in earliest fruit maturity initiation (304.5 and 370.2 days, respectively in 'Red Lady 786' and 'Surya'). However, final harvest completion time was seen to be maximum 416.8 days in 'Red Lady 786' plants applied with 120 percent fertigation and 428.2 days in 'Surya' applied with 100 percent fertigation treatment. However, the green house cultivated plants appeared to produce earlier flowering and fruiting ultimately resulting in early maturity and short final harvest time period as compared to flowering and fruiting in open field papaya plants. Irrespective of the in-significant results obtained in respect to number of fruits per node in both the experimental varieties, the mean total fruits retained on a single plant were maximum (46.00 and 35.74 fruits, respectively in 'Red Lady 786' and 'Surya') in fertigation treatment supplying 80 percent of recommended dose fertilizers. However, the single plant fruit count results were in-significant in green house and open cultivation plants comparison.

Different fertigation levels also significantly enhanced the fruit size, weight and yield in both 'Red Lady 786' and 'Surya' papaya. Large sized 'Red Lady 786' fruits (length = 18.78 cm and circumference = 38.66 cm) were produced on plants that were applied with 80 percent fertilizer fertigation. However, in contrast, maximum length (12.02 cm) and circumference (31.34 cm) of 'Surya' fruits was seen, respectively where least fertilizer (60 percent) and 80 percent fertigation dose was given. Likewise, the modified environment treatments also improved the fruit size resulting in bigger size papaya fruits under poly-net house (19.26 and 38.03 cm, respectively in 'Red Lady 786' and 'Surya') in comparison to open environment fruits. Although, the F x C interactions were in-significant in context of fruit size, however, overall superior size fruits were observed in green house cultivated plants applied with 80 percent RDF fertigation (F_2C_1) in both the cultivars. It is pertinent to mention that with the improvement of papaya fruit size under various treatments, the average fruit weight was also significantly enhanced in both papaya varieties. The best treatments in terms of superior fruit weight production in 'Red Lady 786' (850.00 g) as well as 'Surya' (464.23 g) were F_2 (80 percent RDF fertigation) and protected cultivation environment (820.32 and 438.82 g, respectively in 'Red Lady 786' and 'Surya') among all fertigation and cultivation treatments, respectively. Consequently, in comparison to control, the fruit yield was also significantly superior to the tune of 39.09 kg/plant in 'Red Lady 786' and 16.56 kg/plant in 'Surya' in the treatment that resulted in maximum fruit retention and fruit weight *i.e.* 80 percent RDF fertigation (F_2) in both papaya cultivars. Among both growing conditions, protected environment recorded higher fruit yield (35.72 and 14.17 kg/plant, respectively in

'Red Lady 786' and 'Surya') than open field plants. 80 percent fertigation accompanied with modified environment was the best treatment combination to get optimum potential yields of 'Red Lady 786' (42.79 kg/plant) and 'Surya' (17.91 kg/plant). Although, the fruit colour was in-significantly affected by various treatments, however, the fruit internal cavity measurements showed an increasing trend similar to the improvement of fruit size.

5.3 Fruit quality parameters

Among different fruit quality parameters, the fruit firmness did not show any major significant influence of various treatments. The comparative fruit pulp: peel ratio or edible fruit portion percentage in both cultivars was seen to show some significant improvement revealing maximum edible portion in F_2 treatment (85.68 and 85.43 percent, respectively in 'Red Lady 786' and 'Surya'), whereas, protected cultivation also recorded somewhat higher edible fruit portion percentage (85.24 and 84.87 percent, respectively in 'Red Lady 786' and 'Surya') in comparison to open field produced fruits. On the other hand, various F x C interactions did not show any significant influence on fruit edible portion percentage. Various treatments were able to significantly improve papaya fruit TSS, TSS/ acid ratio and total sugars content, whereas, fruit acidity was insignificantly affected. The F_2 fertigation (80 percent RDF) among various fertilizer application treatments was the dominating treatment promoting levels of fruit TSS, TSS/acid ratio and sugars content sequentially to the tune of 13.23 °brix, 148.84 and 7.95 percent in 'Red Lady 786' and 13.11 °brix, 202.87 and 5.63 percent in 'Surya'. Moreover, the modified environment fruit quality was superior resulting in 13.34 and 13.09 °brix average TSS, 139.89 and 190.13 average TSS/ acid ratio and 7.90 and 5.15 percent average sugars content, respectively in 'Red Lady 786' and 'Surya' cultivars.

5.4 Leaf elemental content

The papaya leaf nutrient analysis revealed a significant effect of various experimental treatments on some of the macro (nitrogen, potassium, calcium and magnesium) and micro-nutrients (iron, zinc, manganese and copper). The leaf nitrogen and magnesium content (3.72 and 5.30 percent N and 1.15 and 1.33 percent Mg, respectively in 'Red Lady 786' and 'Surya') was found maximum in F_4 (120 percent fertigation) treatment in comparison to all other fertilizer application treatments applied in both the cultivars. However, the leaf potassium concentration in 'Red Lady 786' (2.11 percent) as well as 'Surya' (1.48 percent) was observed maximum in plants that were under 80 percent RDF fertigation. Whereas, the calcium concentration in papaya leaves was maximum (3.95 percent in 'Red Lady 786') in F_4 and (4.20 percent in 'Surya') in F_3 treatments. Among two growing environment variants, the mean leaf nitrogen, potassium and magnesium content was higher in green house conditions as compared to open fields. In contrast, although the calcium content was in-significantly affected by environment variations, numerically more Ca level to the tune of 3.55 and 3.40 percent, respectively in 'Red Lady 786' and 'Surya' was seen in open field plants. The leaf micro-nutrients were also observed to show significant influence of experimental treatments recording maximum Fe, Zn and Cu concentrations in papaya leaves of both cultivars that were under 120 percent RDF fertigation treatment. The concentration of Mn element was higher in the leaves of F_3 treatment (100 percent RDF fertigation) in both varieties under discussion. In 'Red Lady 786' papaya, the plants under green house unit recorded more content of leaf iron (276.4 ppm), zinc (61.97 ppm), manganese (50.25 ppm) and copper (5.92 ppm) as compared to open field plants. However, in 'Surya' papaya the average leaf zinc (54.17 ppm), manganese (49.32 ppm) and copper (8.55 ppm) concentrations were more in protected cultivation, but, the iron content (397.7 ppm) was significantly more in open cultivated plants.

5.5 Soil parameters

The data analysis showed that various fertigation and growing environment treatments did not significantly influence the soil pH, electrical conductivity and organic carbon percentage in any of the varieties under discussion. The data pertaining to available nitrogen, phosphorus and potassium content in soil revealed that the nitrogen content in upper layers of soil (upto 60 cm) was significantly influenced by various fertigation and growing environment treatments and their combinations in both the cultivars. However, the soil potassium concentrations were only significantly influenced by different levels of fertigation, whereas, available phosphorus level was not influenced by any of the treatment. In comparison to the control treatment, the mean N level was maximum in open fields where maximum nutrition was given through fertigation (120 percent RDF). Likewise, the soil potassium availability was recorded maximum in the highest fertigation level (F_4 @ 120 percent RDF fertigation). Although, the soil phosphorus content before and after experiment did not differ significantly, however, numerically it showed a diminishing trend from topmost soil layer to the deep soil layer (0 to 90 cm depth) in both the papaya cultivars under discussion.

5.6 Conclusion

From the present investigation, it can be concluded that 80 percent of the recommended fertilizer dose applied through the fertigation technique was the best treatment for both the cultivars *viz.* 'Red Lady 786' and 'Surya' resulting in earlier fruit maturity and bearing bigger size heavy fruits ultimately causing adequate fruit yield. Under sub-tropical climatic conditions of Punjab, the papaya production under protected conditions resulted in high yield of superior fruits in terms of fruit edible portion percentage, total soluble solids and sugars content as compared to open field. Likewise, it was estimated that under these climatic conditions the quality characteristics of papaya fruit were adequate for edible purpose. The nutritional status of papaya plants was optimum in 80 percent fertigation treatment signifying efficient uptake and utilization of soil nutrients with quality fruit production.

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LIST OF PUBLICATION OF PAPERS

S. No.	TITLE OF PAPER WITH AUTHOR NAMES	NAME OF JOURNAL / CONFERENCE	PUBLISHED DATE	ISSN NO/ VOL NO, ISSUE NO
1.	Impact of fertigation on Papaya crop under protected conditions. Damandeep Singh, Shailesh Kumar Singh and Lal Bahadur Damathia	Ecology, Environment and Conservation	2019	ISSN 0971–765X / Volume 25(1): 2019
2.	Efficient Usage of Water and Fertilizers for Papaya Production – A Review Damandeep Singh and Shailesh Kumar Singh	Annals of Biology	Accepted on 04.04.2019	ISSN: 0970-0153

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