STUDIES ON THE EFFECT OF PLANTING DENSITIES, CANOPY MANAGEMENT AND FERTIGATION ON GROWTH, YIELD AND FRUIT QUALITY OF APPLE (*Malus × domestica* Borkh.)

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled, **“Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)”** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) - 173230 is a bonafide research work carried out by **Ms Tanzin Ladon (H-2017-18-D)** daughter of Shri Gautam Singh under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Nauni, Solan | **(Dr J S Chandel)**
Date: | **Major Advisor**

CERTIFICATE - II

This is to certify that the thesis titled, **"Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)"** submitted by **Ms Tanzin Ladon (H-2017-18-D)** daughter of Shri Gautam Singh to the Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP) –173 230 India in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY FRUIT SCIENCE** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Fxaminer.

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CONTENTS

LIST OF ABBREVIATIONS

%	:	Per cent
/	:	Per
^0C	:	Degree celsius
AD	:	Adhoc dose
ANOVA	:	Analysis of Variance
cm	:	Centimeter
cm^2	:	Centimeter square
cm^3	:	Cubic centimeter
CD	:	Critical difference
cv.	:	Cultivar
dSm^{-1}	:	deci Siemens per meter
DAFB		Days after full bloom
EC	:	Electrical conductivity
ETc	:	Crop evapo-transpiration
et al.	:	Co-workers
FYM	:	Farm Yard Manure
Fig	:	Figure
g	:	Gram
$g\ kg^{-1}$	:	Gram per kilogram
ha	:	Hectare
HDP	:	High density planting
HP	:	Himachal Pradesh
ICP-OES	:	Inductively coupled plasma atomic emission spectroscopy
Kg/cm^2	:	Kilogram per centimeter square
$kg\ ha^{-1}$	:	Kilogram per hectare
$kg\ tree^{-1}$	:	Kilogram per tree
kg	:	Kilogram
LAI	:	Leaf area index

m^3	:	Cubic metre
m	:	Meter
mg	:	Milligrams
mm	:	Millimetre
ml	:	Millilitre
MT	:	Metric tons
MOP	:	Muriate of Potash
NS	:	Non Significant
OC	:	Organic carbon
PAR	:	Photosynthetically Active Radiation
pH	:	*Puissance de Hydrogen*
ppm	:	Parts per million
RBD	:	Randomized Block Design
RD	:	Recommended dose
t ha^{-1}	:	Tonnes per hectare
TCSA	:	Trunk cross sectional area
TSS	:	Total soluble solids
var.	:	Variety
viz.	:	Videlicet (namely)
WSP	:	Water soluble fertilizer

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Chapter-1

INTRODUCTION

Apple (*Malus* × *domestica* Borkh.) is one of the most important and widely grown fruit crops in temperate regions of the world. In India, it is predominantly grown in the states of Jammu and Kashmir, Himachal Pradesh and hills of Uttarakhand, accounting for about 90 per cent of the total production of the country. Its cultivation has also been extended to Arunachal Pradesh, Sikkim, Nagaland and Meghalaya in north-eastern region and Nilgiri hills in Tamil Nadu. The total area under apple cultivation in India is 3,01,040 ha with an annual production of 23,26,900 MT and productivity of 7.7 MT/ha (Anonymous, 2018).

In Himachal Pradesh apple is cultivated in an area of 1,13,154 ha with a production of 3,68,603 MT (Anonymous, 2019). The state of Himachal Pradesh is also known as apple bowl of country and has made remarkable progress in the apple industry during the last few decades. Under lower elevations, the colour development is a major problem in standard Red Delicious cultivar. However, during last few decades, the introduction of some high colouring strains and spur type varieties have further increased the scope for its commercial cultivation in mid hills of the state. Though the apple production has made significant strides in the state but the average productivity of these orchards is 3.94 MT ha^{-1} (Anonymous, 2018), which is much lower than the productivity obtained in high density orchards (40-60 MT/ ha) in the developed countries of the world.

Most of the existing apple orchards in the state are on seedling rootstocks and planted under low density at a spacing of 7.5 × 7.5 m (standard varieties) with a planting density of 178 trees/ha and at a spacing of 5.0 × 5.0 m (spur type varieties) with a planting density of 400 plants/ha. This results in longer juvenile phase, higher labour cost and lower yield with poor quality fruits. In addition, peculiar location of orchards on slopy lands having shallow, unirrigated and less fertile soils under low density with poor orchard management, inadequate technological up-gradation and adoption by the growers are the reasons behind the low productivity in apple, but low planting density is the major one. Under low density plantation, huge canopy size of seedling trees and its poor management result in poor light penetration and distribution within the canopy, which further leads to production of poor quality fruits.

Under present scenario, the continued decline in the availability of cultivable land, rising energy and land costs together mounting with the demand for apple produce, have given thrust to adoption of high density planting in apple. Therefore, the maximum yields through efficient utilization of land, light, water and nutrition management can be obtained only through high density planting system.

High density planting was largely established in apple in Europe since 1960's, which aims at planting more number of plants per unit area through manipulation of tree size for achieving enhanced productivity and better fruit quality by maintaining a balance between vegetative and reproductive load without impairing the plant health (Heinicke, 1975). Now majority of orchards in Europe, America, Australia and New Zealand have intensive system of production on dwarfing and semi dwarfing rootstocks. However, the concept of high density planting in India is new and it offers a great scope, especially in valley areas and less sloppy land to improve the productivity and quality of fruits. Heinicke (1975) has defined four planting densities in apple viz. low (less than 100 trees/acre); moderate (100-200 trees/acre); high (200 to 500 trees/acre) and ultra high (more than 500 trees/acre), and observed that with increase in planting density, yield may increase but beyond a certain density, the quality deteriorates and may not be profitable in terms of market returns. In high density plantings, trees are planted 1.0 to 1.5 m in a row and 3.0 to 4.5 m row to row depending upon rootstock and scion and accommodating about 3000 to 4444 trees per hectare.

Training system and pruning are two important horticultural practices of canopy architecture that plays significant role in quality fruit production (Jackson and Palmer, 1977). The selection of training form depends on several factors like kind and vigour of rootstock, variety, soil fertility and climatic conditions. The aim of training system is to shape canopy architecture to improve light interception and distribution for optimizing fruit quality and yield. Thus, the choice of the training system plays a critical role in orchard profitability.

Over the past two or three decades, a large number of new intensive training systems for high-density apple orchards have been developed and recommended in

Europe, America and New Zealand such as Tall Spindle, Central Leader, Fruiting Wall, Palmette, Slender Pyramid, Slender Axis, Slender Spindle, Solaxe, Super Spindle, Vertical Axis, V-shaped and Y-trellis (Robinson, 2003). One of the important factors affecting fruit tree productivity is light interception. Tree height and canopy shape affect total light interception and distribution within the canopy (Robinson, 1997)**,** influencing leaf development, flower initiation process and bud differentiation as well as fruit growth and quality particularly the colour and size (Jackson *et al*. 1971). The shaded areas of the canopy generally reduced fruit size, colour, soluble solids and capacity of the tree to sustain marketable yield (Robinson *et al.* 1991; Palmer *et al.* 1992). The canopy which absorbs all the incoming light has maximum assimilation potential (Wagenmakers and Callesen, 1995) and there is a positive correlation between light interception and fruit yield per ground unit area (Palmer, 1989). Thus light interception can be increased by high density planting and canopy shape. High density planting systems with dwarf trees make a better use of the available light than conventional low density planting systems with vigorous trees because light interception with orchard age is greater and light distribution within the canopy is better.

Fertigation is another important key aspect for improving productivity and quality of fruits in high density plantation in apple. It permits close synchronization of nutrient application with plant demand as the nutrients are delivered directly to the root system, therefore, the uptake of nutrients is more efficient and their leaching and run off are limited (Haynes, 1985; Raina *et al.* 2011). The rate of uptake and usage of different nutrients vary throughout the season in apple trees (Neilsen *et al.* 2009). Although, some work on the high density planting in apple has been done in our country, but the precise information on integrated effect of planting density, training system and fertigation level is lacking. Keeping these facts in view, the present investigation was carried out to study the effect of planting densities, training systems and fertigation levels on growth, yield and fruit quality of apple with the following objectives:

i. To assess the integrated effect of planting densities, training systems and fertigation on growth, yield and fruit quality of apple

ii. To study their effect on light interception, photosynthetic efficiency and leaf nutrient status of apple

Chapter-2

REVIEW OF LITERATURE

Apple orcharding plays an important role in the economic prosperity of the people of temperate region of India. However, its commercial cultivation is mostly done with a traditional system of planting accommodating less number of trees per unit area, resulting in to low production and productivity. High density planting system is the accommodation of the maximum possible number of the trees per unit area to get the maximum possible profit per unit of the tree volume without impairing the soil fertility status (Goswami *et al.* 2001). This system is more efficient since it accounts for precocity, easy management, higher yield potential with better quality fruits and higher returns per unit area. A successful orchard system is the result of a designed integration of a group of component parts viz. tree density, tree arrangement, tree quality, support system, canopy and nutrient management, training and pruning as well as cultural management techniques. The tree canopies are managed by using dwarf rootstocks with specialized training systems under high density planting.

Drip irrigation is one of the important components of high density planting and is used worldwide in orchards especially in regions where water supply is limited. Application of irrigation water and fertilizers through drip are most efficient way of supplying water and nutrients to roots, satisfying the plants total and temporal requirements of these two inputs. The right combination of water and nutrients is the key for high yield and quality fruit production. The use of trickle irrigation system is gaining acceptance among growers even in the humid climates with the transition from conventional low-density orchards to high-density systems as it allows more precise management of water and fertilizer applications than other conventional systems.

Attempts have been made by various workers to study the effect of planting densities, canopy management and fertigation levels on tree growth, fruiting and fruit quality of different fruit crops. Therefore, efforts have been made to compile comprehensive review of literature on effect of planting densities, training systems and fertigation levels on growth, yield, light interception and fruit quality of fruit crops in general and apple in particular under the following sub-heads:-

2.1 EFFECT OF PLANTING DENSITY, CANOPY MANAGEMENT AND FERTIGATION ON TREE GROWTH

Pfammatter and Evequoz (1983), while working on planting density and canopy management in apple reported that vegetative growth of trees was more vigorous as spacing increased. They recorded more tree height, shoot growth and spread in trees trained with Palmette system and planted in single row with a density of 1665 trees/ha. Similarly, Ogata *et al*. (1989) conducted studies to assess the performance of apple cv. Fuji on M9 and M26 rootstocks at different planting densities (900, 1250 and 2000 trees/ha) and concluded that tree height did not affected significantly by planting densities. However, tree growth and vigour of apple cv. Golden Delicious were significantly influenced by training system (Ferree, 1980) and, Pyramid hedge row trees planted at 425 trees/ha had highest trunk circumference, height, spread and canopy volume than Slender Spindles or Trellis system trees, planted at much higher densities.

Palmer *et al.* (1992) studied the influence of planting density on tree spread in Golden Delicious and reported that the maximum tree spread (2.6 m) was with planting spacing of 3.5 × 1.43 m and minimum (1.7 m) was with planting spacing of 1.5 × 0.8 m, accommodating 2000 and 8333 trees ha^{-1}, respectively.

Costa *et al*. (1997) conducted a trial on apple cultivars Golden Reinders, Jonagored, Staymared, Braeburn and Fuji grafted on M9 and planted at densities of 2778 (3.0 × 1.20 m), 4444 (3.0 × 0.75 m) and 6667 (3.0 × 0.50 m) trees/ha. The results indicated that trunk cross-sectional area of Fuji was maximum (15.9 cm^2) for the lowest planting density of 2778 tree/ha and minimum (9.2 cm^2) in highest planting density of 6667 trees/ha. There was no large variation in trunk cross-sectional area of other cultivars, however the trend was: the lower the planting density the higher the trunk cross-sectional area.

Influence of training systems and planting densities on the growth and cropping of apple cv. Sampion grafted on P2 rootstock and cv. Gloster on M9 was studied by Szczygie *et al*. (2001). The trees were trained to Vertical Axis with a spacing of 2.5 × 0.50 m and 2.5 × 0.75 m (8000 and 5333 trees/ha) and Slender Spindle with a spacing of 3.5 × 1.0 m, 3.5 × 1.25 m and 3.5 × 1.50 m (2858, 2285 and 1904 trees/ha). They reported that trees trained to Vertical Axis under high density planting suppressed growth expressed by trunk cross-sectional area compared to trees trained with Slender Spindle under low density planting. Similarly, Buler *et al*. (2001) studied the effect of planting densities (4.0 × 1.3 m and 4.0 ×1.8 m) and new training systems (Hytec, Solen, Mikado and Spindle) on trunk cross sectional area (TCSA) of cv. Elstar grafted on P22 rootstock and Sampion on M26 rootstock. They observed that the trees planted at closer spacing and trained with Spindle system had maximum increase in TCSA in both the cultivars.

Granelli and Eccher (2006) conducted an experiment to study the performance of four Golden Delicious (clone B, Smoothee, Reinders and Crielaard), three Fuji (Naga-fu 6, Red Sport and Mori Hofu 3A) and three Braeburn (B. standard, Red Braeburn and B. CTIFL) clones grafted on M9 rootstock, planted at a spacing of 75, 100, 150 and 200 cm within rows and 4.5 m between rows, accommodating 2962, 2222, 1481 and 1111 trees/ha, respectively. They reported that trunk cross sectional area obtained under high density is one half of that at the lowest density. Similarly, maximum trunk cross sectional area and crown volume per tree were recorded at wider spacing of 4 × 3 m under high density in apple cv. Jonagold grafted on MM 106 rootstock (Kiprijanovski *et al.* 2009).

Dorigoni *et al.* (2011), while studying the effect of planting density and training system on growth in Toshiro Fuji apple grafted on M9. They observed that the trunk cross sectional area at the base was higher in the Bi-axis than Spindle, whereas annual shoot growth of 1-year-old shoots was almost halved in the Bi-axis than Spindle. The influence of five training systems viz. Slender Spindle, Vertical Axis, Hytec, L-Super Spindle and H-Super Spindle, and planting density with a spacing of 3.0 × 0.7 m, 3.0 × 1.0 m, 3.5 × 1.5 m, 2.0 × 1.0 m and 2.0 × 0.5 m on growth in apple cv. Jonagold grafted on MM 106 rootstock was studied by Ozkan *et al.* (2012). They concluded that the maximum trunk cross sectional area (14.85 cm^2) and canopy volume (4.13 m^3) were recorded in Hytec (3.5 × 1.5 m) and minimum trunk cross sectional area (7.17 cm^2) and canopy volume (1.45 m^3) were in H-Super Spindle (2.0 × 0.5 m), during the third year of cropping. Similarly, Kucuker *et al.* (2015) reported higher trunk cross sectional area (TCSA) and tree height with Super Spindle system of training in Cooper 39 cultivar planted in a density of 10,000 trees/ha.

Srivastava *et al.* (2017) conducted a trial to study the effect of planting densities [2.5 × 2.5 m (1600 plants/ha), 2.5 × 3.5 m (1142 plants/ha) and 3.0 × 3.5 m (952 plants/ha)], and apple varieties (Starkrimson, Cooper IV, Red Chief and Mollies Delicious) grafted on MM 106 (semi-dwarfing rootstock), on tree growth and yield in Kashmir Valley. The highest mean TCSA was reported in Mollies Delicious at all the densities (77.06, 92.61 and 103.79 cm^2) and lowest (67.01, 75.65 and 80.33 cm^2) in Cooper IV. Trees planted at a high density attained less height as compared to those planted at low density.

Dhiman *et al.* (2018) studied the performance of Jeromine cultivar on M9 rootstock planted at four densities viz. 5333 trees/ha (2.5 × 0.75 m), 4000 trees/ha (2.5 × 1.0 m), 3200 trees/ha (2.5 × 1.25 m) and 2666 trees/ha (2.5 × 1.5 m) and trained with Tall Spindle training system. They reported that maximum annual shoot growth (44.58 cm) and increase in tree height (42.55 cm), tree spread (27.06 cm), tree volume (5.68 m^3), stock girth (4.38 cm) and scion girth (4.37 cm) were obtained under low planting density (2666 trees/ha) and minimum was noted under high planting density of 5333 trees/ha.

Reig *et al.* (2019) evaluated the performance of Gala, Fuji and Honeycrisp apple cultivars on different rootstocks, trained with Slender Pyramid, Vertical Axis, Slender Axis and Tall Spindle training systems accommodating 840 (2.44 × 4.88 m), 1284 (1.83 × 4.27 m), 2244 (1.22 × 3.66 m) and 3262 (0.91 × 3.35 m,) trees ha^{-1}, respectively. They observed that among all the training systems, Tall Spindle trees were the least vigorous and the trunk cross sectional area of Tall Spindle trees was 25 and 19 per cent lower than Vertical Axis and Slender Axis trees, respectively in Fuji. In Gala and Honeycrisp, the trunk cross sectional area of Tall Spindle trained trees was 20 per cent lower and, 18 and 14 per cent lower than Vertical Axis and Slender Axis trees, respectively. The largest trees were produced by the combination of Slender Pyramid on M7 followed by Slender Pyramid on M26, G210 and G30 in Fuji and Gala, however Slender Pyramid trained on G935 produced largest trees in Honeycrisp. The smallest trees were recorded with Tall Spindle trained on B9 and M9 in Fuji and Honeycrisp, whereas in Gala the smallest trees were with Tall Spindle trained on B9 and G11.

Sander *et al.* (2019) studied the effect of different training systems on the growth of apple cultivar Maxi Gala from 2014-2017. The Maxi Gala cultivar was planted at a spacing of 0.6 × 4.0 m accommodating 4167 plants per hectare with Tall Spindle, Solaxe and Vertical Axis training system. They recorded the maximum canopy volume of 4.53 m^3, 4.57 m^3 and 6.04 m^3 with Vertical Axis and minimum canopy volume of 3.21 m^3, 3.83 m^3 and 5.10 m^3 with Tall Spindle in 2015, 2016 and 2017, respectively. There was no significant effect of training systems on internodal length and plant height.

Mallikaarjuna (2020) studied the influence of four training systems viz. Tall Spindle, Vertical Axis, Slender Spindle and Mini Center and planting densities with a spacing of 2.5 × 1.50 m (2666 trees/ha), 2.5 × 1.25 m (3200 trees/ha) and 2.5 × 1.00 m (4000 trees/ha) on growth in apple cv. Jeromine grafted on M9 rootstock. The highest tree height (36.91 cm), spread (16.61 cm), volume (5.12 m^3), annual shoot growth (35.45 cm) and scion girth (2.54 cm) was recorded in trees trained with Mini Center system. The growth of the trees increased significantly with decreasing planting densities and the maximum tree height (42.50 cm), spread (17.16 cm), volume (6.58 m^3), annual shoot growth (43.62 cm) and scion girth (2.72 cm) were observed in trees planted at a spacing of 2.5 × 1.50 m (2666 trees/ha).

The fertigation of 17.5 g of P via eight weekly applications immediately after planting rather than a single annual application at planting time was more effective in increasing leaf P and tree vigour during first year for McIntosh and Jonagold apple on M26 rootstock (Neilsen *et al.* 1993).

Buban and Lakatos (2000) evaluated variable effects of fertigation with fertilizer having different forms of nitrogen on growth and yield of young apple trees. Trunk diameter and number of shoots increased markedly where fertigation was done with higher rates of NH_4-N in the first half and NO_3-N in the second half of the season, compared to the treatments where same ratio of NH_4-N and NO_3-N was used during the whole season.

The effectiveness of fertigation using a N fertilizer and a complete nutrient fertilizer containing all macronutrients over traditionally used surface application (broadcasting) of such fertilizers in apple cv. Gala grafted on M9 rootstock was studied and 10 per cent increase in growth of apple trees was recorded with fertigation over surface application (Treder, 2006).

Raina *et al.* (2013) observed 35 per cent greater annual shoot growth, tree height, spread and canopy volume under fertigation of 100 % of RD (NPK) with drip irrigation at 100 % ETc over conventional fertilization.

The positive effect of fertigation on enhanced effectiveness of fertilization in apple cv. Super Chief was studied by Thakur *et al.* (2020). The maximum increase in tree height (34.57 %), trunk girth (31.51 %), and EW-tree spread (237.5 cm) and NS-tree spread (276.3 cm), tree volume (14.90 m^3), and annual extension growth (80.69 cm) were recorded with the application of 100 % of AD (NPK) fertigation dose, followed by 75 % of AD (NPK) and the minimum increase in tree height (28.19 %), trunk girth (26.39 %), and EW-tree spread (121.4 cm) and NS-tree spread (179.5 cm), tree volume (4.96 m^3), and annual extension growth (56.79 cm) were in control (no fertilizer application).

Chauhan and Chandel, (2008) recorded that fertigation with recommended dose and ¾ of RD (NPK) fertilizer induced better vegetative growth in kiwifruit vines. The maximum shoot growth (155.24 and 168.50 cm) and trunk girth (2.26 and 2.31 cm) were recorded in fertigation with recommended dose of NPK fertilizers.

Kumar and Ahmed (2014) studied the effect of fertigation on growth of almond cv. Wasris. During the course of their study they reported that fertigation treatment significantly affected the growth of the tree and the highest TCSA of main trunk (72.67 and 90.28 cm^2), primary, secondary and tertiary branches (16.75 and 24.26 cm^2, 3.83 and 7.49 cm^2, and 0.47 and 1.23 cm^2, respectively) and canopy volume (7.15 and 8.11m^3) during the year 2011 and 2012, respectively were found in trees fertigated with 100 % of RD (NPK).

Verma *et al*. (2017), while studying the influence of drip irrigation and fertigation on growth of peach cv. Redhaven reported that fertigation at 100 % RD (NPK) and drip irrigation at 100 % ETc significantly increased tree height (18.61 %), tree spread (16.97 %), trunk girth (14.80 %) and annual shoot growth (116.80 cm).

2.2 EFFECT OF PLANTING DENSITY, CANOPY MANAGEMENT AND FERTIGATION ON CROPPING

Palmer *et al.* (1992) studied the effect of apple tree spacing viz. 3.5 × 1.43 m, 2.75 × 0.8 m, 2.0 × 1.25 m and 1.5 × 0.8 m with corresponding planting densities of 2000, 4545, 4000 and 8333 trees ha^{-1} on yield in cultivars Golden Delicious and Karmijn de Sonnaville grafted on M9 rootstock. The maximum yield of 83 and 60 t ha^{-1} was recorded at planting density of 8333 trees ha^{-1} in Golden Delicious and Karmijn, respectively and the minimum yield of 35 and 36 t ha^{-1} was at planting density of 2000 trees ha^{-1} in Golden Delicious and Karmijn, respectively.

Costa *et al*. (1997) studied yield performance of apple cultivars Golden Reinders, Jonagored, Staymared, Braeburn and Fuji grafted on M9 under different planting densities of 2778 (3.0 × 1.20 m), 4444 (3.0 × 0.75 m) and 6667 (3.0 × 0.50 m) trees/ha, and Red Chief and Red Delicious spur-type clone grafted on M26 under different planting densities of 4167 (3.0 × 0.80 m), 6667 (3.0 × 0.50 m) and 9524 (3.0 × 0.35 m) trees/ha. The highest yield at all the three planting densities was recorded in Braeburn followed by Fuji, Staymared, Jonagored and Golden Reinders and the lowest in Red Chief at all the planting densities. In Braeburn and Staymared, yield increased with density, however, there was no significant difference in yield of Golden Reinders, Jonagored and Fuji planted at two higher densities. Fuji planted at highest density produced the highest cumulative yield, whereas, Jonagored and Braeburn produced highest cumulative yield when planted at lowest density.

Meland and Hovland (1997) evaluated five planting systems (free Spindle/M9, Slender Spindle/M9, Y trellis/M26, V-system/M9 and Vertical Axis/M26) in 'Summerred' apples. They reported that yield per hectare was positively correlated with tree density and cumulative yield per hectare was highest in V-system trees.

Widmer and Krebs (2001) conducted a trial with different planting densities and training systems on apple varieties Royal Gala and Golden Delicious. V-system with planting densities of 3,000, 4,000, 5,000 and 6,000 trees/ha, single row systems (2,400, 3,000 and 5,000 trees/ha), Drilling-system (2,000 trees/ha) and Mikado-system (1,500 trees/ha) were compared. They reported that the doubling of the density from 3,000 to 6,000 trees per hectare in Spindle System produced 30 to 40 per cent higher yields per hectare up to the seventh year, however, planting density of 6,000 trees per hectare resulted in slight reduction of fruit size. The orchard yields of the Drilling-system (3 branch elements/tree) and the Mikado-system (4 branch elements/tree) with 6,000 trees per hectare were lower in the first years, but after that yield per hectare were equal to those of Spindles with higher planting densities. The open tree form of the Drilling and Mikado systems allows optimal light interception and produced good quality fruits.

Hampson *et al.* (2002) established Royal Gala on M9 rootstock to determine whether angled-canopy training systems could improve orchard tree performance relative to Slender Spindles. The trees were trained in one of five ways: Slender Spindle, Geneva Y-trellis, Solen Y-trellis or V-trellis (LDV) and planted at a spacing of 1.2 × 2.8 m (2976 trees/ha). In addition, a higher density (7143 trees/ha) version of the V-trellis (HDV) was also planted to gauge the performance of this system at densities approaching those of local Super Spindle orchards. The plots were drip-irrigated and hand-thinned. After 8 years, Y-shaped training systems had 11 to 14 per cent greater cumulative yield per hectare than the Slender Spindle, but did not intercept significantly more light at maturity. Relative to the LDV, the HDV yielded less per tree but far more per hectare, particularly in the first 3 years. After 8 years, the cumulative yield per hectare was still 65 per cent greater than with LDV. Yield efficiency was unaffected by tree density. Fruit size on HDV ranked lowest among the systems nearly every year but was still commercially acceptable.

Robinson (2007), while working on high density studied the effect of eight tree planting densities viz. 598 (3.1 × 5.1 m), 840 (2.4 × 4.9 m), 1026 (2.1 × 4.6 m), 1283 (1.8 × 4.3 m), 1655 (1.5 × 4.0 m), 2243 (1.2 × 3.7 m), 3262 (0.9 × 3.4 m) and 5382 (0.6 × 3.1 m), and two tree shapes conic (Slender Pyramid, Vertical Axis, Tall Spindle and Super Spindle) and V (Y-trellis, V-Slender Axis, V-Tall Spindle and V-Super Spindle) in four apple cultivars (Gala, McIntosh, Empire and Fuji) on cropping of apple. The trees were grafted on M7 and M26 rootstocks at the lowest two densities, while M9 rootstocks were used in higher densities. They recorded the maximum (50 t/ha) and minimum (25 t/ha) yield in highest and lowest density, respectively, in the fourth year. Tree density had a highly significant negative effect on cumulative yield per tree, but had a highly significant positive effect on yield per hectare. The cumulative yield of the highest tree density was three times greater than the lowest density. There was a significant interaction of tree shape and tree density on cumulative yield. Under high density planting, conic shape trees produced higher cumulative yield than V-shape trees, whereas, at lower tree densities the V-shape was superior to the conic shape.

Dorigoni *et al.* (2011) recorded higher yield (55.6 kg/tree) in Bi-axis than Spindle (20.6 kg/tree) at densities of 3.6 × 1.2 m and 4.0 × 0.9 m in Ravenna and Ferrara (lowlands orchards), respectively, and higher yield (17.0 kg/tree) was recorded in Bi-axis than Spindle (14.8 kg/tree) at densities of 3.2 × 1.0 m and 3.5 × 1.2 m in Non Valley and Adige Valley (upland orchards), respectively. They concluded that the Bi-axis trained trees appeared to be less prone to biennial bearing than Spindle with only a 20 per cent reduction in yield of Bi-axis trees compared to 31 per cent in Spindle, in the following year.

Ozkan *et al.* (2012) studied the effect of five training systems having different planting densities on yield of apple cv. Jonagold grafted on MM 106 rootstock. The trees were trained with Slender Spindle, Vertical Axis, Hytec, L-Super Spindle and H-Super Spindle and planted at a spacing of 3.0 × 0.7 m, 3.0 × 1.0 m, 3.5 × 1.5 m, 2.0 × 1.0 m and 2.0 × 0.5 m, accommodating 4,761, 2,857, 1,904, 5,000 and 10,000 trees/ha, respectively. The highest cumulative yield (15.05 kg/tree) was recorded in trees trained with Hytec (3.5 × 1.5 m) and lowest (9.13 kg/tree) was in trees trained with H-Super Spindle (2.0 × 0.5 m), whereas highest cumulative yield efficiency (1.47 kg/cm^2) was recorded in L-Super Spindle trained trees and lowest (1.02 kg/cm^2) in Hytec due to higher trunk cross sectional area. The effect of high density planting on cumulative yield/ha was evident as the highest cumulative yield (91.24 t/ha) was recorded in H-Super Spindle systems accommodating 10,000 trees/ha and lowest (33.46 t/ha) in Hytec systems accommodating 1,904 trees/ha during first three cropping years.

Asadollah and Mohsen (2016) compared the yield of apple cultivar Golden Delicious grafted on clonal rootstock under different training systems. They observed that Palmette and Solen training forms accounted for low yield as compared with other training forms. However, the Slender Spindle training form produced the highest fruit yield on MM106 rootstocks. Similarly, Gandev *et al.* (2016), while studying the effect of three training systems on the reproductive habits of the apple cultivar Braeburn grafted on M9 rootstock recorded the highest average and cumulative yields per hectare with Vertical Axis training system, which was due to the better reproductive habits of the trees in that variant and more number of trees per hectare.

A field trial was conducted to study the effect of different planting densities on yield in 3-year-old apple cv. Jeromine by Dhiman *et al*. (2018). The trees were planted at a spacing of 2.5 × 0.75 m (5333 trees/ha), 2.5 × 1.00 m (4000 trees/ha), 2.5 × 1.25 m (3200 trees/ha) and 2.5 × 1.50 m (2666 trees/ha). The highest fruit set and yield per tree were recorded in planting density of 2666 trees/ha (2.5 × 1.5 m), however, productivity increased with the increase in planting density and maximum productivity of 17.50 MT/ha was reported in planting density of 5333 trees/ha (2.5 × 0.75 m).

Lordan *et al.* (2018) studied the effect of eight tree planting densities (598, 840, 1026, 1283, 1655, 2243, 3262, and 5382 trees/ha), and two tree shapes (conic and V) with four apple cultivars (Empire, Fuji, Gala and McIntosh) on yield and fruit quality. At the lowest two densities, trees were planted on M7 rootstock (598 trees/ha) and M26 rootstock (840 trees/ha), whereas, M9 was used in higher density planting. They observed that under higher density planting, Fuji and Gala were more appropriate with conic tree shapes than V-shapes. On the other hand, with Empire and McIntosh, high planting density was not found much beneficial. The highest yields from 'McIntosh' were realized at less than 3000 trees/ha with V tree shapes, or 3500 trees/ha with conic tree shapes.

Reig *et al.* (2019) conducted a trial on Gala, Fuji and Honeycrisp apple cultivars grafted on Geneva® rootstocks (CG4210, G11, G16, G41, G30, G210 and G935), one Budagovsky series clone (B9), and three Malling series clones (M7EMLA, M9 and M26EMLA) trained with Slender Pyramid, Vertical Axis, Slender Axis and Tall Spindle training systems. They reported that the trees trained with Tall Spindle planted at a spacing of 0.91 × 3.35 m were most productive system for all cultivars with the highest cumulative crop load and partitioning index values. The combinations of Tall Spindle with G11 and G16 rootstocks in Fuji, G11 and G41 rootstocks in Gala, and G16 and M9 rootstocks in Honeycrisp produced the highest cumulative yield, yield efficiency and crop loads with low biennial bearing, whereas, the lowest yield was observed in combination of Slender Pyramid with M7, M26, G210 and G935 in both Fuji and Gala.

Mallikaarjuna (2020) evaluated the influence of different planting densities (2666, 3200, 40000 and 5333 trees/ha) and training systems (Tall Spindle, Vertical Axis, Slender Spindle and Mini Center) on yield of apple cv. Jeromine grafted on M9 rootstock and concluded that the trees planted at density of 2666 trees/ha and trained with Tall Spindle system recorded the highest yield/tree with good quality fruits. However, the highest productivity of 29.90 and 30.17 MT/ha was reported in trees under planting density of 4000 trees/ha and Tall Spindle training system, respectively.

Kumar (2004) conducted an experiment to evaluate the effect of drip fertigation on fruit yield of apple. The full dose of N, P, K through drip produced the highest yield (12.62 kg/tree). Fallahi *et al*. (2010) observed that the application of 15 kg K/tree/year through drip fertigation significantly increased the yield and they reported maximum yield of 5.34 kg/tree and minimum of 4.53 kg/tree in fertigated and non fertigated trees, respectively.

Banyal and Sharma (2011) studied the influence of fertigation and rootstocks on yield of 6-years-old apple under high density plantation and recorded maximum fruit yield (12.19 and 12.62 kg/plant) with full dose of N, P and K through drip and minimum (11.11 and 10.47 kg/plant) fruit yield with full dose of N, P and K as soil fertilization during 1^{st} and 2^{nd} year of study, respectively.

The significant influence of drip fertigation on yield in apple was recorded by Raina *et al.* (2013). They reported that the treatment combination of 100 % RD (NPK) with irrigartion at 100 % ETc produced the highest fruit set (34.01 %), yield (14.2 t ha^{-1}) and lowest fruit drop (11.41 %) as compared to other treatments.

Thakur *et al.* (2020) conducted a trial to study the influence of fertigation doses on yield in apple cv. Super Chief under high density planting. They reported the highest yield (25.53 t ha^{-1}) in trees subjected to fertigation dose of 100 % of AD (NPK) and the lowest (19.19 t ha^{-1}) in non-fertigated trees.

Kumar and Ahmed (2014) conducted an experiment to study the response of nitrogen and potassium fertigation in almond cv. Waris under Northwestern Himalayan region of India. They recorded that application of recommended dose of fertilizers through fertigation increased nut number in almond. The maximum nut number (990 and 3083 /tree) and yield was reported under the treatment of 100 % of RDF through fertigation, closely followed by treatment of 75 % of RDF through fertigation (split application) treatment, which was significantly superior as compared to other treatments.

Chauhan and Chandel (2008) compared the effect of drip fertigation and soil fertilization on yield in kiwifruit under mid hill conditions of Himachal Pradesh and observed that the application of ferigation with 100 % of RD (NPK) and ¾ of 100 % of RD (NPK) produced highest fruit yield of 88.00 and 69.65 kg/vine, respectively.

Fallahi *et al*. (2010), while studying the effect of potassium fertigation on yield in apple, recorded significantly higher yield (5.34 kg/tree) in fertigated trees than non fertigated trees (4.53 kg/tree).

Verma *et al.* (2017), while studying the performance of fertigation and conventional soil fertilization on yield of peach cv. Redhaven reported highest yield of 15.50 kg/tree and productivity of 19.37 tonnes/ha in treatment combination of fertigation at 100 % of RD (NPK) and drip irrigation at 100 % ETc.

Sharma *et al*. (2013) evaluated the influence of fertigation on yield of guava and reported that the 120 % of RD of N fertigation produced highest yield of 21.6 t/ha, which was found at par with 100 % RD of N fertigation (21.2 t/ha). Similarly, Ramniwas *et al*. (2013) studied the effect of drip fertigation scheduling on yield and fruit quality of guava cv. Shweta under meadow orcharding. They reported the highest yield (30.04 t/ha) in F_3 (60, 30, 30 g NPK WSF), which was found at par with the F_2 (45, 20, 20 g NPK/plant/year through WSF) and lowest in basal application of fertilizers.

2.3 EFFECT OF PLANTING DENSITY, CANOPY MANAGEMENT AND FERTIGATION ON FRUIT QUALITY

Planting density and canopy management significantly affect the fruit quality indirectly by affecting the light interception and penetration in the tree canopies.

Heinicke (1966), while studying the influence of light intensity on quality characteristics of apple noticed that fruits growing in parts of trees receiving less than 30 per cent of full sunlight, resulted in lower colouration of fruit skin and accumulation of dry matter and sugars compared to those fruits which received full sunlight in apple. Red colouration in apple increased with light intensity upto atleast 50 per cent of full sunlight, whereas, few small and green fruits were produced in areas receiving less than 30 per cent of full sunlight. Similarly, Ogata *et al.* (1989) reported that illuminations of less than 50 per cent of solar radiation resulted in poorly coloured apples with reduced fruit size under higher densities. The small size fruits were obtained under densest spacing in apple as fruit size was negatively correlated with plant density. The higher densities also resulted in lower percentage of good coloured fruits probably due to reduced illumination.

In apple, fruit quality is basically a function of light distribution with in the canopy (Jackson and Palmer, 1977). Similarly, Sansavini *et al*. (1980) reported that the fruits from the upper part of the canopy had higher soluble solids, low acidity and ripened earlier than the lower portion of the canopy in apple under high density planting.

Kim *et al*. (1988) carried out an investigation to study the effect of planting densities on tree growth, fruit size and yield in Fuji and Jonagold apple trees on M27 rootstocks. They noticed that fruit weight was not affected by higher tree density but more number of poor size fruits were produced under high density planting. Similarly, Robinson *et al*. (1991) reported poor quality fruits in terms of total soluble solids and total acids due to poor light interception in closely planted apple trees of cv. Empire trained to Y-trellis.

Costa *et al.* (1997) studied the effect of planting densities on yield and fruit quality of apple and noticed that fruits were greener in colour, poor in quality, smaller in size and weight under highest tree density, however, sweetness was highest at medium density. Hudina *et al.* (2001), while investigating the effect of different planting densities on the contents of sugars, sorbitol and organic acids in cvs. Golden Delicious, Jonagold, Idared, Elstar, Gloster and Gala observed that lower density of 6000 trees/ha produced best quality fruits having better size, weight, TSS and sugars content.

Widmer and Krebs (2001) carried out an investigation to study the influence of planting densities on fruit quality and yield of apple cvs. Royal Gala and Golden Delicious. They concluded that planting density of 6,000 trees per hectare resulted in slight reduction in fruit size, whereas, there was no significant effect of planting density on internal fruit qualities like fruit firmness, soluble solids, titratable acidity. Similarly, Szczygie *et al.* (2001) also reported that large size fruits were obtained from low density planting as compared to ultra high density plantings.

Buler and Mika (2006), while studying the effect of training systems on fruit yield and quality of Sampion apple reported that Mikado system significantly affected the fruit colour and produced higher coloured fruits over Solen system, however, fruit size did not differ significantly among the different systems of training.

Granelli and Eccher (2006) carried out investigation on the performance of four Golden Delicious (clone B, Smoothee, Reinders and Crielaard), three Fuji (Naga-fu 6, Red Sport and Mori Hofu 3A) and three Braeburn (B. standard, Red Braeburn and B. CTIFL) clones on M9 rootstocks planted at 1111, 1481, 2222 and 2962 trees/ha and reported that highest planting density (2962 trees/ha) significantly reduced the fruit size and soluble solids content.

Dorigoni *et al.* (2011) conducted two sets of field trials with Toshiro Fuji apple grafted on M9 to study the cropping traits of Bi-axis system against the standard Spindle in high density plantings. During first, two to three years of planting there was no significant differences in crop quality, but after four to five years, large shaded lower scaffolds developed in the Spindle trees resulting in poor green coloured fruits in the lower parts of the trees and excellent quality fruits only at the top, whereas, Bi-axis trees produced better fruit red overcolour throughout the canopy.

Stehr (2011), while studying the effect of planting density concluded that with increasing planting densities, the average fruit size at harvest decreased slightly by about 1 mm diameter and fruit colour was also inferior at higher densities in apple.

Ozkan *et al.* (2012) reported that the apple cv. Jonagold grafted on MM 106 rootstock produced the largest fruits with Hytec trained trees planted at a spacing of 3.5 × 1.5 m in 2009, however in 2010, the Slender Spindle and Vertical Axis trained trees planted at a spacing of 3.0 × 0.7 m and 3.0 × 1.0 m, respectively produced largest fruits. Similarly, the maximum average fruit weight was with Hytec trained trees in 2009 but Vertical Axis trained trees produced maximum average fruit weight in 2010. The trees trained with Vertical Axis and Hytec under low density planting resulted in larger fruit weight. Similarly, Pramanick *et al*. (2012) also reported highest fruit weight, volume and TSS under low density of 625 trees/ha.

Arsov *et al*. (2013) recorded highest fruit size and weight from Slender Spindles and Solex system of training and lowest from V-system in apple. While working on high density in apple, Musacchi *et al*. (2014) reported that trees trained to Bi-axis produced fruits with high sugar content in comparison to other training systems. Robinson *et al*. (2013) conducted a trial to assess the effect of training systems on yield and fruit quality in apple and concluded that trees trained with Tall Spindle produced better quality fruits than other training systems.

Csima *et al*. (2015) carried out an investigation to study the effect of different trellises (Slender Spindle, V-system and an experimental Y-shape trellises) on quality parameters of fresh market fruits of apple cv. Regal Prince (Syn. Gala Must). They noticed that large size fruits with higher colour and total soluble solid contents were obtained under Y-shape trellis system. Similarly, Ozkan *et al.* (2016) also reported that trees trained to Vertical Axis produced fruits with high titratable acidity and soluble solid, followed by Hytec and Slender Spindle training systems in apple.

Srivastava *et al.* (2017) conducted an experiment to study the effect of planting densities and varieties on fruit yield and quality of apple. Four apple varieties viz. Starkrimson, Cooper IV, Red Chief, and Mollies Delicious grafted on MM 106 (semi-dwarfing rootstock) were planted at three planting densities 2.5 × 2.5 m, 2.5 × 3.5 m and 3.0 × 3.5 m accommodating 1600, 1142 and 952 trees/ha in Central Institute of Temperate Horticulture, Srinagar, Jammu and Kashmir. They recorded that fruit size and weight increased with the decrease in plant density. Similarly, Dhiman *et al.* (2018) also recorded highest fruit size, weight, TSS and sugars in trees planted at lower planting density of 2666 (2.5 × 1.50 m) trees/ha in comparison to 3200 (2.5 × 1.25 m), 4000 (2.5 × 1.00 m) and 5333 (2.5 × 0.75 m) trees/ha.

Reig *et al*. (2019), while studying the response of training systems on fruit quality of different cultivars viz. Gala, Fuji and Honeycrisp of apple under New York state environmental conditions concluded that Tall Spindle showed greater effect on flesh firmness, fruit weight and soluble solids contents, followed by Slender Axis and Vertical Axis.

Mallikaarjuna (2020) evaluated the influence of different planting densities and training systems on fruit quality of apple cultivar Jeromine and reported that the highest fruit size, weight, TSS, fruit firmness and sugars content were found in high density planting of 2666 (2.5 × 1.50 m) trees/ha and Tall Spindle training system.

Kappel and Brownlee (2001) conducted a trial to evaluate the early performance of Conference pear on four training systems and noticed that highest fruit weight and size were obtained on Slender Spindle trained trees and the smallest on Y-trellis system. The effect of different training systems on yield and quality of pear was studied by Musacchi (2008). He reported that fruit size for Bibaum (Y-shape) trees was slightly larger (275 g) than the Spindle trees (271 g) and fruit sugars content was also higher in the Bibaum system, however, there was no substantial differences in yield.

Robinson and Dominguez (2014), while studying the effects of training systems on fruit quality of cherry reported that the trees trained to Tall Spindle produced higher quality fruits with higher yield efficiency than Modified Spanish Bush system.

Neilsen *et al*. (2000), while studying the response of N fertigation at different rates (12, 24, 48 g N/tree) on apple cv. Gala reported that total soluble solids and starch content increased with higher level of N applied through fertigation, whereas flesh firmness and titratable acidity decreased. However, in the findings of Dolega and Link (1998), there were no differences in fruit firmness, acidity and sugar content between fertigated and non fertigated plots of apple plants. Park *et al.* (2004) also reported that the application of liquid fertilizers increased the average fruit weight, total soluble solids and hardness of fruit with brighter colouring .

Raina *et al*. (2011) evaluated the effect of drip fertigation with different fertilizer on fruit quality of apricot and found that drip fertigation with 100 per cent recommended dose of NPK fertilizers produced highest fruit weight (16.8 g/fruit) in comparison to soil fertilization with 100 per cent recommended dose of conventional fertilizers. The response of nitrogen and potassium fertigation to almond cv. Waris under North-Western Himalayan Region of India was studied by Kumar and Ahmed (2014). They reported that maximum nut weight was obtained with 75 % RDF through fertigation (split application), which got enhanced by 16.66 and 7.18 per cent nut weight during the year 2011 and 2012, respectively. In the similar manner, nut dry matter content was also enhanced with 75 % RDF through fertigation (split application) treatment.

Banyal *et al*. (2015) conducted an experiment to study the effect of nitrogen fertigation on yield and fruit quality of low chilling cultivars of peach under sub-tropical conditions of Himachal Pradesh. The application of full dose of recommended NPK through drip produced highest fruit weight (61.92 g), fruit length (47.58 cm) and fruit diameter (47.64 cm), which was however, found statistically at par with 2/3rd dose of recommended dose of NPK through drip than control.

Verma *et al.* (2017), while studying the response of fertigation and drip irrigation on fruit quality of peach cv. Redhaven concluded that treatment combination of fertigation at 100 and 80 % of RD (NPK) and drip irrigation at 100 % ETc significantly increased fruit length, diameter, weight and volume, TSS, total sugars, reducing sugars and non-reducing sugars content.

2.4 EFFECT OF PLANTING DENSITY, CANOPY MANAGEMENT AND FERTIGATION ON LIGHT INTERCEPTION AND LEAF NUTRIENT CONTENT

2.4.1 Light interception

Wertheim *et al.* (1986) noticed that Y-trellis trained trees intercepted about 70 per cent of available PAR (Photosynthetically Active Radiation) at maturity, whereas, Slender Spindle system intercepted only 55 per cent of PAR despite of 30 per cent greater tree density in apple.

Robinson *et al.* (1991), while working on high density apple planting found that total light interception during the 7th to 10th years had the best correlation with the yields of the different systems and the average light interception was the strongest with the Y-trellis method of both cultivars and exceeded 70 per cent of the available PAR with Empire cultivar and the central leader had the lower light interception with both cultivars.

Palmer *et al.* (1992) studied the influence of different densities on leaf area distribution and light interception of apple cultivar Golden Delicious grafted on M9 and planted at a spacing of 3.5 × 1.43 m (2000 trees ha^{-1}), 2.75 × 0.8 m (4545 trees ha^{-1}), 2.0 × 1.25 m (4000 trees ha^{-1}) and 1.5 × 0.8 m (8333 trees ha^{-1}). They reported that leaf area index (LAI) and light interception varied from 1.4 to 3.3 and 49 to 83 per cent at a density of 2000 and 8333 trees ha^{-1}, respectively in Golden Delicious. Higher tree densities resulted in higher LAI and light interceptions, intercepting 83-84 per cent of the incoming light. Similarly, in high density systems Wertheim *et al.* (1986) with the planting of Jonagold on M9 at 3559 and 4566 trees ha^{-1} and Palmer (1989) with the planting of Crispin on M27 at 8889 trees ha^{-1} reported more than 80 per cent light interception. The closer row spacing in high density planting resulted in more uniform distribution of light over the orchard floor with much less wasted light in the alleyway than with the single row.

Sharma and Chauhan (1992), while studying the effect of different rootstocks and training systems on photosynthetic efficiency and fruit quality of Delicious apple revealed that the higher photosynthetic efficiency was observed in the trees trained on Spindle Bush as compared to Modified Central Leader system.

Cropping efficiency is highly influenced by the canopy architecture. Structure of a tree and its leaf distribution are primarily affected by training system which strongly affects the light interception and distribution with in the canopy. The total light interception of an orchard can be increased by increasing the tree density (LAI of the canopy increases) and tree height (Lakso, 1994).

Robinson (1997) compared the effect of tree forms (Y-shaped, Slender Spindle and Palmette) on light interception and yield efficiency of Jonagold, Delicious and Empire cvs. of apple and found that trees trained with Y-shaped had more light interception, rate of photosynthesis and were 11 and 18 per cent more productive than Slender Spindle and Palmette trees, respectively.

Tustin *et al.* (1998), while studying the influence of orchard row canopy discontinuity on irradiance and leaf area distribution in apple trees stated that total daily photosynthetic photon flux (PPF) within canopies was higher in the wider spaced trees. This is due to attenuation of PPF from mid to lower canopy regions was less pronounced than with closely spaced trees under both diffuse and direct light conditions in apple.

High level of light interception at maturity in apple trees trained with V-system under high tree densities was observed by Robinson (2000). V-system allows light penetration direct in the center of the canopy. Similarly, Hampson *et al.* (2002) compared Slender Spindle, Geneva Y-trellis, Modified Solen, V-trellis and high density V-trellis training systems in apple and reported the higher light interception in Slender Spindle and the high density V-trellis trained trees.

Buler and Mika (2009) studied the effect of canopy architecture on light interception and distribution in apple cv. Sampion. They reported that light transmission within the canopy of the plant was the most effective in the Mikado training system. Mikado trained trees had higher total leaf area and leaf area index resulting into high level of light interception.

Robinson (2007) compared eight tree planting densities ranged from 598-5382 trees/ha and two training forms conic (Slender Pyramid, Vertical Axis, Tall Spindle and Super Spindle) and V (Y-trellis, V-slender Axis, V-Tall Spindle and V-Super Spindle). They reported a positive relationship between tree density and canopy light interception. In 2^{nd} year, 25 per cent light interception was recorded in highest tree density, whereas 12 per cent light interception was in lowest tree density. About 60 and 70 per cent of light interception was recorded in 5^{th} and 7^{th} year, respectively in highest density orchards, whereas 50 per cent of light interception was recorded in lowest density systems after 7^{th} year. There was no effect of tree shape on canopy light interception until year four, after which all the V-shape forms surpassed the conic shape systems at similar densities. All of the training systems exceeded 50 per cent light interception after seven year, whereas Super Spindle and Tall Spindle systems with more than 3000 trees/ ha exceeded 70 per cent light interception, followed by 60 per cent light interception in trees grafted on M9 and planted at densities more than 1000 trees /ha. They concluded that 70 per cent light interception should be the goal of all orchard systems to optimize light interception and suggested high density planting of more than 3000 trees/ha. It was also concluded that cumulative yield was a function of light interception.

Trees trained to transverse Y system reported high values of leaf area per unit of ground area (LAI) and better utilized the available solar radiation as compared to delayed vase in peach cv. Springcrest (Nuzzo *et al.* 2002). However, Lu *et al.* (2003), while studying the effect of training systems on yield, fruit quality and light penetration reported that the better light distribution and good quality fruits were obtained in trees trained with slanting central leader system compared to Y- system in peach cv. Ruipan 5.

According to Matei *et al.* (2013), the trees trained with Tatura trellis and V-system planted at a spacing of 4.0 × 1.0 m and 4.0 × 1.5 m, respectively resulted in best light interception ratio and had a balanced ratio between tree growth and yield, whereas, Sibari Y and Vertical Axis trained trees planted at a spacing of 4.5 × 1.5 m and 4.0 × 1.5 m, respectively intercepted less light in peach.

Mallikaarjuna (2020) studied the effect of training systems and planting densities on light interception. The Jeromine cultivar was planted at a spacing of 2.5 × 0.75 m, 2.5 × 1.00 m, 2.5 × 1.25 m and 2.5 × 1.50 m accommodating 5333, 4000, 3200 and 2666 trees per hectare, respectively and trained with Tall Spindle, Vertical Axis, Slender Spindle and Mini Center training system. The trees planted at a spacing of 2.5 × 1.50 m and trained with Tall Spindle exhibited maximum light interception of 839.94 and 960.36 $\mu mol/m^{-2}/s^{-1}$, respectively, while trees planted at spacing of 2.5 × 0.75 m and trained with Slender Spindle noticed minimum light interception of 709.55 and 747.34 $\mu mol/m^{-2}/s^{-1}$, respectively.

2.4.2 Leaf nutrients content

Schneider *et al.* (1978) carried out an experiment to study the effects of rootstock, tree spacing, and cultivar on tree size, yield and foliar mineral composition of apple cv. Red spur and reported that more phosphorus and potassium content of the leaves from widest spaced trees and more calcium, magnesium and manganese contents of leaves from closely spaced trees, however, tree spacing did not affect nitrogen, iron, zinc and copper contents of the leaves.

Barrera and Slowik (1980), while working on high density in apple reported that planting density had no significant effect on leaf phosphorus and calcium content, however, leaf nitrogen content decreased and potassium and iron content increased with increasing tree density in apple. Similarly, Wertheim (1985) also concluded that mineral composition of leaves was not influenced by the planting density. On the other hand, Olszewski and Mika (1986) reported significant effect of planting density on mineral composition of leaves and fruits of “Macspur” apples. They observed that higher content of phosphorus and potassium was with leaves from triple rows.

Sharma and Chauhan (1991) studied the effect of training systems on mineral composition of apple leaves and reported that the trees trained to Spindle Bush system had higher micro nutrient contents in comparison to Modified Central Leader trained trees.

According to Hassan *et al*. (2010), the nitrogen level was greatly affected by the tiller training system, however, the potassium level of the central leader trained trees decreased significantly in the leaves relative to that of the tiller training system of apple cv. Anna. However, effect of training system was not significant on the percentage of phosphorus content of leaves but in both experimental seasons it tended to decrease significantly in the open central leader system as compared to the tiller training system.

Pramanick *et al.* (2012) carried out an investigation to assess the effect of high density planting on nutrients levels of apple cv. Red Spur. They recorded that the density of 1111 trees per hectare had significantly higher leaf nutrient levels. Similarly, Kumar *et al.* (2013), while working on planting density found significantly higher leaf nitrogen, phosphorus and potassium contents (N: 1.17 %, P: 0.149 % and K: 1.69 %) in the wider spacing compared to the closer spacing.

Mallikaarjuna (2020) studied the influence of training systems (Tall Spindle, Vertical Axis, Slender Spindle and Mini Center) and planting densities (2666, 3200, 4000 and 5333 trees/ha) on leaf nutrient content of apple cv. Jeromine and reported that the trees trained with Tall Spindle training system and trees planted at wider spacing of 2.5 × 1.50 m (2666 trees/ha) obtained highest leaf nutrients content.

Klein *et al*. (1989) studied the effect of drip nitrogen fertigation on leaf nutrient content of Starking Delicious apple trees and reported that application of N at 150 kg ha^{-1} through fertigation significantly increased concentration of leaf nitrogen.

Neilsen *et al*. (2004) studied the influence of fertigation in apple and observed that fertigation significantly increased K, Mg and B contents in leaves and N, P, Mg, K and Ca content in fruits. Similarly, Wolf *et al*. (1990) also recorded significant increased in leaf N content with drip fertigation.

Neilsen *et al*. (2009) conducted a trial to study the effect of N fertigation on leaf nutrient contents in apple (cvs. Ambrosia, Cameo, Fuji, Gala and Silken) grafted on M9 rootstock. The daily application of 28 mg nitrogen L^{-1} (low) and 168 mg nitrogen L^{-1} (high) at 0-4, 4-8 and 8-12 weeks after full bloom (wafb) was performed. They reported that under high N inputs, all cultivars had increased mid-summer leaf nitrogen concentrations. Leaf nitrogen was also affected by timing of N application and after 4-weeks of fertigation resulted in to highest leaf N concentration, however, concentrations declined over the growing season, reaching minimum at harvest.

Raina *et al.* (2013) studied the effect of drip fertigation on 7-years-old apple plantation raised on seedling rootstock planted at a spacing of 3.5 × 3.5 m and reported that fertigation significantly increased the leaf N and K contents (2.37 and 1.65 %, respectively) over conventional soil fertilization under both drip irrigated (1.99 and 1.35 %, respectively) and rainfed (1.74 and 1.19 %, respectively) conditions.

Meland *et al.* (2016), while working on 2-years-old apple cv. Summerred grafted on M9 knip trees and fertigated with established three fertigation schemes viz. Zero; low N-0.15 g N m^{-1} row day^{-1} and high N-0.30 g N m^{-1} row day^{-1}. They observed that all fertigation treatments resulted in adequate mineral nutrient concentrations. N-fertigation significantly increased the leaf nitrogen content during the whole season, which was more than or equals to the standard adequacy range (1.5-2.0 %).

Thakur *et al.* (2020) evaluated the effect of fertigation in apple cv. Super Chief under high density planting and observed that the fertigation dose at 100 % of AD (NPK) significantly increased leaf nitrogen (3.17 %), phosphorus (0.29 %), potassium (1.80 %), and sulfur (0.53 %) content over control (no fertilizer application) with 2.57 per cent of leaf nitrogen, 0.16 per cent of phosphorus, 1.55 per cent of potassium and 0.27 per cent of sulfur.

2.5 EFFECT OF PLANTING DENSITY, CANOPY MANAGEMENT AND FERTIGATION ON SOIL NUTRIENT STATUS

Raina *et al.* (2013) carried out an investigation to study the effect of drip fertigation with and without mulch on soil hydrothermal regimes and nutrient status in apple and reported that the drip fertigation had significant influence on the nutrient status of soil. The highest available N content in soil layers 0-10 (150.8 mg kg^{-1}), 10-20 (142.4 mg kg^{-1}) and 20-30 cm (121.3 mg kg^{-1}) was recorded with drip fertigation (100 % Recommended dose of NPK) and the lowest was with conventional soil fertilization with surface irrigation. The precise, frequent, and direct application of fertilizers in the root zone through drip fertigation resulted in higher available N in the surface (0-30 cm deep). The maximum available P at the 0-10 cm soil layer (50.00 mg kg^{-1}) was reported with drip fertigation of 100 % of RD (NPK) and lowest was with conventional soil fertilization with surface irrigation. Drip fertigation significantly increased the available N, P and K at the 0-10 and 10-20 cm depth of soil.

Kumar *et al.* (2016) studied the influence of method and rate of fertilizer application on soil nutrient status in apple and reported that higher available nitrogen, phosphorus and potassium content in 0-30 cm soil layers was obtained under drip fertigation with 100 % of RD (NPK), which was found statistically at par with 80 % of RD (NPK).

Chapter-3

MATERIALS AND METHODS

The present investigation titled **"Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)"** was carried out during the years 2019 and 2020 at the experimental orchard of Department of Fruit Science, Dr YS Parmar University of Horticulture & Forestry, Nauni, Solan (HP).

3.1 GEOGRAPHICAL FEATURES OF EXPERIMENTAL SITE

The experiment was laid out at the experimental orchard of Department of Fruit Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, located at 30° 51´ North latitude and 77° 88´ East longitude. The location is 1256 m above mean sea level and climate of the area is typically sub-temperate. The annual rainfall of this area is about 125-130 cm and major amount of which is received during July to September.

3.2 SOIL STATUS

Physico-chemical properties of soil were determined before the start of experiment and detailed information is presented in Table 3.1.

Table 3.1: The physico-chemical characteristics of the experimental soil before the start of experiment

Sr. No.	Soil properties	Contents (0-30 cm soil depth)
1	pH	7.24
2	EC (dSm^{-1})	0.249
3	Organic carbon ($g\ kg^{-1}$)	19.68
4	N ($kg\ ha^{-1}$)	304.1
5	P ($kg\ ha^{-1}$)	81.76
6	K ($kg\ ha^{-1}$)	291.2

3.3 LAYOUT OF THE EXPERIMENT

Field trial was conducted during the years 2019 and 2020 on 4-year-old apple trees of cultivar Jeromine grafted on M9 rootstock having uniform size and vigour. The plantation was done with three planting densities viz. 4000 trees/ha (2.5 × 1.00 m) (Plate 1), 3200 trees/ha (2.5 × 1.25 m) (Plate 2) and 2666 trees/ha (2.5 × 1.50 m) (Plate 3) and trees were trained to Tall Spindle (Plate 4) and Vertical Axis (Plate 5) systems of training. The experiment was laid out in a randomized block design (factorial) with treatment combinations of three planting densities, two training systems and two levels of fertigation and each replicated three times having two trees per replication. The experimental trees were subjected under drip irrigation consisting of two online emitters per plant, placed at a distance of 15 cm away from the tree trunk at an angle of 180^0 to each other with a discharge rate of 4.2 lh^{-1}. The experimental trees were pruned every year during January to remove dead, diseased and unwanted branches and kept under uniform cultural practices with permanent support system during the course of investigation. The details of the experiment are as under:

Experiment: Effect of planting densities, training systems and fertigation levels on growth, yield and fruit quality of apple.

1.	Planting densities (D)	: 3 viz. 4000 (2.5 x 1.00 m), 3200 (2.5 x 1.25 m) and 2666 (2.5 x 1.50 m)
2.	Training systems (T)	: 2 viz. Tall Spindle and Vertical Axis
3.	Fertigation levels (F)	: 100 % of AD (NPK) and 75 % of AD (NPK)
4.	Treatment combinations	: 12
5.	Number of replications	: 3
6.	Cultivar	: Jeromine
7.	Age of tree	: 4-years-old
8.	Time of fertigation	: From third week of March to July in 15 equal splits at weekly intervals
9.	Experimental design	: Randomized Block Design (Factorial)

Plate 1: Planting density of 4000 trees ha^{-1} (2.5 × 1.00 m)

Plate 2: Planting density of 3200 trees ha^{-1} (2.5 × 1.25 m)

Plate 3: Planting density of 2666 trees ha^{-1} (2.5 × 1.50 m)

Plate 4: Tall Spindle training system

Plate 5: Vertical Axis training system

Plate 6: Fertigation system

Treatment details:

Treatment No.	Treatment code	Planting density (D) (trees/ha)	Training system (T)	Fertigation level (F)
T_1	$D_1T_1F_1$	4000 (2.5 × 1.00 m)	Tall Spindle	100 % of AD (NPK)
T_2	$D_2T_1F_1$	3200 (2.5 × 1.25 m)	Tall Spindle	100 % of AD (NPK)
T_3	$D_3T_1F_1$	2666 (2.5 × 1.50 m)	Tall Spindle	100 % of AD (NPK)
T_4	$D_1T_1F_2$	4000 (2.5 × 1.00 m)	Tall Spindle	75 % of AD (NPK)
T_5	$D_2T_1F_2$	3200 (2.5 × 1.25 m)	Tall Spindle	75 % of AD (NPK)
T_6	$D_3T_1F_2$	2666 (2.5 × 1.50 m)	Tall Spindle	75 % of AD (NPK)
T_7	$D_1T_2F_1$	4000 (2.5 × 1.00 m)	Vertical Axis	100 % of AD (NPK)
T_8	$D_2T_2F_1$	3200 (2.5 × 1.25 m)	Vertical Axis	100 % of AD (NPK)
T_9	$D_3T_2F_1$	2666 (2.5 × 1.50 m)	Vertical Axis	100 % of AD (NPK)
T_{10}	$D_1T_2F_2$	4000 (2.5 × 1.00 m)	Vertical Axis	75 % of AD (NPK)
T_{11}	$D_2T_2F_2$	3200 (2.5 × 1.25 m)	Vertical Axis	75 % of AD (NPK)
T_{12}	$D_3T_2F_2$	2666 (2.5 × 1.50 m)	Vertical Axis	75 % of AD (NPK)

RDF- Recommended dose of fertilizer:

Recommended dose of NPK for traditional system of planting - 70:35:70 g $tree^{-1}$ yr^{-1} ($N:P_2O_5:K_2O$)

100 % of adhoc dose (AD) taken for high density plantation - 35:17.5:35 g $tree^{-1}$ yr^{-1} ($N:P_2O_5:K_2O$)

3.4 Training and Pruning

3.4.1 Tall Spindle system

Tall Spindle system is the most recently developed training system from a combination of Slender Spindle, Vertical Axis and Super Spindle systems (Robinson *et al*. 2006). The procedure of training and pruning to develop Tall Spindle system is presented in Table 3.2.

Table 3.2: Simplified training and pruning plan for the Tall Spindle system

First year	
At planting	Whip plants are headed back to 60 cm above grafting point to encourage the development of feathers. Adjust graft union at 15 cm above soil level. Do notching by giving a deep cut above the bud about 15 days before sprouting of buds for the emergence of more feathers
Spring	Remove any branches within 45 cm of the soil surface
Summer	At 1-2 cm shoot growth: Rub off second and third buds below the new leader. Attach clothes pins to new side shoots on leader at 5-10 cm shoot growth to promote wide crotch angles and pinch off the terminal portion of the shoots to restrict the growth
July	Spread or tied down the branches below horizontal planes

Second year	
8-15 cm growth	Pinch back all the shoots in the top half of last year's growth. Repeat pinching as new shoots appear or previously shoots regrow
Early June	Hand thin fruits to single fruit 15-20 cm apart
Dormant	Single the leader by removing any competitive shoots. Remove uprights, weak hanging shoots, suckers and all broken branches. Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut. Single the leader by removing any competitive shoots
Third year	
8-15 cm growth	Pinch back new shoots in the top half of last year's leader. Repeat pinching as new shoots appear or previously shoots regrow
Early summer (15-20 DAFB)	Hand thin fruits to single fruit 15-20 cm apart. Tie tree to stakes with permanent tree tie at the top of the stake to help support crop load on the leader
July	Light summer pruning to remove water sprouts, open canopy and optimize fruit quality
Dormant	Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut. Single the leader by removing any competitive shoots. Remove uprights, weak hanging shoots, suckers and all broken branches
Fourth year	
Early summer (15-20 DAFB)	Chemical thinning and follow up with hand thinning if desired
July	Light summer pruning to remove water sprouts, open canopy and optimize fruit quality
Dormant	Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut. Single the leader by removing any competitive shoots. Remove uprights, weak hanging shoots, suckers and all broken branches
Mature tree	
Dormant	Limit tree height to 3 m by cutting leader back to fruitful side branch. Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut. Single the leader by removing any competitive shoots
Early summer (15-20 DAFB)	Hand thin fruits to single fruit 15-20 cm apart. Tie tree to stakes with permanent tree tie at the top of the stake to help support crop load on the leader
July	Light summer pruning to remove water sprouts, open canopy and optimize fruit quality

3.4.2 Vertical Axis system

The Vertical Axis system was developed in the late 1970's by Lespinasse (1980) in southern France. The procedure of training and pruning to develop Vertical Axis system is presented in Table 3.3.

Table 3.3: Simplified training and pruning plan for the Vertical Axis system

First year	
At planting	Adjust graft union to 10 cm above soil level. Remove all scaffolds below 60 cm, using a flush cut. Trees with three or more scaffolds (25 cm long) should be headed at 110 cm above the soil line, with all scaffolds headed by removing one-third their length. Trees with fewer than three feathers should be headed at 90 cm and all feathers removed, using a bevel cut, leaving a 2 cm stub
1-2 cm growth	Rub off second and third buds below the new leader bud to eliminate competitors to the leader shoot
5-10 cm growth	Attach clothes-pegs to new side-shoots on leader to promote wide crotch angles
Early summer	Attach tree to support system with a permanent tree tie above first tier of scaffolds, leaving a 5 cm diameter loop to allow for trunk growth
July	Tie developing leader to support pole with permanent tie. Remove clothes-pegs
Second year	
10-15 cm growth	Pinch lateral shoots in top one-quarter of last year's leader growth, removing about 5 cm of growth (the terminal bud and four or five young leaves)
Mid-June	Repinch all lateral shoots in top one-quarter of last year's growth. Tie developing leader to support system with permanent tie. Remove all fruit on 1-year-old wood and hand-thin remaining fruits to 15 cm apart
Mid-July	Repinch vigorous lateral shoots in top one-quarter of last year's growth. Tie down four or five permanent lower scaffold branches to the horizontal. Attach permanent trellis clips to tree to support fully second-year crop
Dormant	Do not head leader. Remove uprights, weak hanging shoots, suckers and all broken branches
Third year	
10–15 cm growth	Pinch lateral shoots in top one-quarter of last year's leader growth removing about 5 cm of growth (the terminal bud and four or five young leaves)
June 15	Repinch all lateral shoots in top one-quarter of last year's growth. Tie developing leader to support system with a permanent tie. Hand-thin to single fruits spaced 10 cm apart
Mid-July	Repinch vigorous lateral shoots in top one-quarter of last year's growth
August	Tie up lower scaffolds not expected to support the crop. Alternatively, do not tie up but prune back scaffolds to prevent limb breakage and preserve tree structure
Dormant	Do not head leader. Remove uprights, weak hanging shoots, suckers and all broken branches. Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut

Fourth year	
Late May	Chemical thinning and follow up with hand thinning if desired
July	Lightly summer-prune to encourage light penetration and maintain pyramidal tree shape. Tie leader to support system with a permanent tie at the top of the pole
Dormant	Do not head leader. Remove uprights, weak hanging shoots, suckers and all broken branches. Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut.
Mature tree	
Dormant	Limit tree height to 3 m by cutting leader back to fruitful side branch. Remove scaffolds that are more than ½ the diameter of the leader using a Bevel or Dutch cut
July	Summer-prune to encourage light penetration and maintain pyramidal tree shape

3.5 Fertigation

Fertigation was done through venturi (Plate 6) starting from third week of March of each experimental year and continued till July in fifteen equal split applications at weekly intervals. The water soluble fertilizer (WSF-19:19:19) was used for fertigation, fulfilling its phosphorus requirement and rest of the nitrogen and potassium requirement were supplemented with urea and muriate of potash (MOP). Considering the solubility and compatibility of WSF, urea and MOP (Waterman, 2001), a 25 litres of stock solution having all the three fertilizers was prepared fresh for each fertigation. The quantity of WSF, urea and MOP was computed to be 24.56, 10.14 and 7.77 g tree^{-1} split^{-1}, respectively with the application of 100 % of AD (NPK) and 18.17, 7.50 and 5.75 g tree^{-1} split^{-1}, respectively with 75 % of AD (NPK) on 4-years-old tree in the year 2019, whereas for 5-years-old plants during the year 2020, the quantity came out to be 30.70, 12.67 and 9.71 g tree^{-1} split^{-1}, respectively with 100 % of AD (NPK) and 22.71, 9.37 and 7.18 g tree^{-1} split^{-1}, respectively with 75 % of AD (NPK).

The details of N, P and K fertilizers applied during the years 2019 and 2020 are presented in Table 3.4.

Table 3.4 Fertigation schedule of water soluble N, P and K fertilizers at different levels for apple in high density planting

Year / Date	2019						Year / Date	2020					
	100 % of AD (NPK)			75 % of AD (NPK)				100 % of AD (NPK)			75 % of AD (NPK)		
	NPK (19:19:19) g/tree	Urea (46:0:0) g/tree	MOP (0:0:60) g/tree	NPK (19:19:19) g/tree	Urea (46:0:0) g/tree	MOP (0:0:60) g/tree		NPK (19:19:19) g/tree	Urea (46:0:0) g/tree	MOP (0:0:60) g/tree	NPK (19:19:19) g/tree	Urea (46:0:0) g/tree	MOP (0:0:60) g/tree
23/03/19	24.56	10.14	7.77	18.17	7.50	5.75	23/03/20	30.70	12.67	9.71	22.71	9.37	7.18
30/03/19	24.56	10.14	7.77	18.17	7.50	5.75	30/03/20	30.70	12.67	9.71	22.71	9.37	7.18
06/04/19	24.56	10.14	7.77	18.17	7.50	5.75	07/04/20	30.70	12.67	9.71	22.71	9.37	7.18
12/04/19	24.56	10.14	7.77	18.17	7.50	5.75	15/04/20	30.70	12.67	9.71	22.71	9.37	7.18
20/04/19	24.56	10.14	7.77	18.17	7.50	5.75	23/04/20	30.70	12.67	9.71	22.71	9.37	7.18
29/04/19	24.56	10.14	7.77	18.17	7.50	5.75	30/04/20	30.70	12.67	9.71	22.71	9.37	7.18
07/05/19	24.56	10.14	7.77	18.17	7.50	5.75	08/05/20	30.70	12.67	9.71	22.71	9.37	7.18
15/05/19	24.56	10.14	7.77	18.17	7.50	5.75	16/05/20	30.70	12.67	9.71	22.71	9.37	7.18
23/05/19	24.56	10.14	7.77	18.17	7.50	5.75	23/05/20	30.70	12.67	9.71	22.71	9.37	7.18
31/05/19	24.56	10.14	7.77	18.17	7.50	5.75	01/06/20	30.70	12.67	9.71	22.71	9.37	7.18
07/06/19	24.56	10.14	7.77	18.17	7.50	5.75	09/06/20	30.70	12.67	9.71	22.71	9.37	7.18
15/06/19	24.56	10.14	7.77	18.17	7.50	5.75	17/06/20	30.70	12.67	9.71	22.71	9.37	7.18
23/06/19	24.56	10.14	7.77	18.17	7.50	5.75	25/06/20	30.70	12.67	9.71	22.71	9.37	7.18
01/07/19	24.56	10.14	7.77	18.17	7.50	5.75	03/07/20	30.70	12.67	9.71	22.71	9.37	7.18
09/07/19	24.56	10.14	7.77	18.17	7.50	5.75	11/07/20	30.70	12.67	9.71	22.71	9.37	7.18

*** 100 % adhoc dose (AD) of N, P and K through drip.**

3.5 OBSERVATIONS RECORDED

3.5.1 Vegetative growth parameters

3.5.1.1 Tree height

The tree height was measured with the help of graduated flag staff from the soil surface to the top of a tree, once before the start of the experiment in January and again after the end of growing season. The increase in height over the growing season was calculated and expressed in centimetre (cm).

3.5.1.2 Tree spread

The spread of the tree was measured in two directions i.e. East-West and North-South once before the start of experiment and again at the end of growing season (December) with the help of a measuring tape at a height where the spread was maximum. Average of East-West and North-South directions was taken as spread and increase in tree spread was calculated, which was expressed in centimetre (cm).

3.5.1.3 Annual shoot growth

Five shoots from the current season’s growth were randomly selected from all around the periphery of each experimental tree and their length was measured with measuring tape at the end of growing season and average annual shoot growth was expressed in centimetre (cm).

3.5.1.4 Scion diameter

The scion diameter was measured at 10 cm above the graft union with the help of digital Vernier callipers. The diameter was measured before the start of experiment and again at the end of growing season. The increase in scion diameter was expressed in milimetre.

3.5.1.5 Stock diameter

The stock diameter was measured at 10 cm below the graft union by using digital Vernier callipers once before the start of experiment and again at the end of growing season. The values of increase in stock diameter was calculated and expressed in milimetre.

3.5.1.6 Tree volume

The tree volume was calculated from height and spread measurements once before the start of the experiment and after the completion of the experiment during the years 2019 and 2020, as per method suggested by Westwood (1993).

1. For a tree which was taller than its width:
   Volume (m^3) = 4/3 π ab^2
2. For a tree which was wider than its height:
   Volume (m^3) = 4/3 π a^2b

Where:

π = 3.1428

a = ½ the major axis (height)

b = ½ the minor axis (spread)

The increase in tree volume was worked out and expressed in cubic metre (m^3).

3.5.1.7 Leaf area

Twenty fully expanded leaves were collected randomly from each experimental tree in the month of August and the leaf area was recorded with LI-3000 CAP Leaf Area Meter and the values were expressed as an average leaf area/leaf in square centimetre (cm^2).

3.5.1.8 Leaf area Index

LAI (Leaf area index) is the area of leaves per unit area of soil surface and was recorded with Flour PEN-PSI Canopy Analyzer in the month of June.

3.5.1.9 Pruning wood weight

The pruning was performed after the complete cessation of growth in the month of January. After pruning, all the pruned woods were collected and weighed on electronic balance. The weight of pruned wood was expressed in gram/tree.

3.5.2 Cropping parameters

3.5.2.1 Spur density

Ten shoots of uniform growth were selected around the tree periphery and marked with paint. Before flowering, number of spurs were counted on these shoots and expressed as number of spurs/cm length of the shoot.

3.5.2.2 Blossom density

All the blossom clusters on each tree were counted and blossom density was calculated by dividing the number of blossom clusters by TCSA.

3.5.2.3 Fruit set

Four branches were selected on each tree in all the directions and were marked with paint. The number of flowers present on these branches was counted and the number of fruits was also counted 20 days after petal fall stage. The per cent fruit set was calculated as per the method given by Westwood (1978):

$$\text{Fruit set (\%)} = \frac{\text{Total number of fruits set}}{\text{Total number of flower buds}} \times 100$$

3.5.2.4 Fruit drop

Total number of fruits retained till harvest on marked branches were counted and per cent fruit drop was calculated as under:

$$\text{Fruit drop (\%)} = \frac{\text{Total number of fruits set - fruit retained at maturity}}{\text{Total number of fruit set}} \times 100$$

3.5.2.5 Fruit yield

The final yield of fruits under different treatments was recorded at the time of harvest by weighing the total fruits retained in particular tree. The yield was expressed in kilogram per tree (kg/tree). Yield per hectare was calculated by multiplying the average fruit yield per tree with the total number of trees per hectare in each of the planting densities and training systems. The yield was expressed as metric tonnes per hectare (MT/ha).

3.5.2.6 Yield efficiency

The yield efficiency of each treatment was calculated as per the method given by Westwood (1978) and expressed in kilogram per square centimetre of trunk cross sectional area (kg/cm^2) using the formula:

$$\text{Yield efficienty } (kg/cm^2) = \frac{\text{Fruit yield}}{\text{Trunk cross sectional area}}$$

3.5.3 Fruit quality parameters

The fruit samples for physico-chemical analysis were collected when the fruits had attained full maturity. Ten fruits were collected randomly from all sides of trees and then were brought to the laboratory for analysis.

3.5.3.1 Fruit length

Ten fruits were selected randomly from each experimental tree at the time of fruit harvest and the polar length of selected fruits was measured with the help of Vernier callipers between calyx and styler end and the mean value was worked out and expressed in millimetre (mm).

3.5.3.2 Fruit diameter

The diameter of the same fruits, which were used for measuring length, was measured in terms of diameter of cheeks with the help of Vernier callipers and was expressed in millimetre (mm).

3.5.3.3 Fruit volume

The volume of fruits was computed by water displacement method. Ten fruits which were selected for recording fruit weight were immersed in a measuring cylinder filled with water to obtain certain graduation. The difference between initial and final readings gave the measurement of volume of fruit samples. The results were averaged and expressed in cubic centimetres per fruit (cm^3/fruit).

3.5.3.4 Fruit weight

Fruit weight was computed by considering average weight of ten fruits (which were taken for recording fruit length and diameter), weighed on electronic top pan balance and expressed in gram per fruit (g/fruit).

3.5.3.5 Fruit firmness

The fruit firmness was determined by digital pressure tester (FHP-802) which recorded the pressure necessary for the plunger to penetrate the peeled flesh of fruits. Five fruits were tested from each tree and results were expressed in kilogram per square centimeters (kg/cm^2).

3.5.3.6 Total soluble solids (TSS)

The total soluble solids content in fruits was determined by "Erma-Hand Refractometer" (0 to 32^0B). The refractometer was calibrated with distilled water before use. A few drops of fruit juice were placed on the prism and reading was recorded. The values of total soluble solids were expressed as per cent of the fresh juice.

3.5.3.7 Titratable acidity

Standard procedure as described by Ranganna (1995) was used to estimate titratable acidity in the fruits. Twenty five gram of fruit pulp was thoroughly homogenized with distilled water in an electric blender and volume was made to 250 ml in a volumetric flask. Out of it, 50 ml extract was taken for the estimation of acidity and the rest used for determining the total and reducing sugars. The 50 ml extract was then filtered through Whatman No. 1 filter paper as obtained above. Subsequently, 25 ml of this discolored juice was titrated against N/10 NaOH solution using phenolphthalein as an indicator until the end point was pink. The total titratable acidity was calculated in terms of malic acid on the basis of one ml of NaOH equivalent to 0.0067 g of anhydrous malic acid (AOAC, 1980) and expressed in percentage.

$$\text{Titratable acidity (\%)} = \frac{\text{Titre value} \times \text{Normality of NaOH} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of sample taken} \times \text{Volume of aliquat taken} \times 1000}$$

3.5.3.8 Total sugars

The sugar content of the fruit was measured by volumetric method based on the principle of quantitatively hydrolyzing the sucrose content of the fruit to glucose and fructose in the presence of hydrochloric acid as proposed by Ranganna (1995).

The remnant of the 200 ml extract left from titratable acidity was taken in a 250 ml volumetric flask and 5 ml of 45 per cent standard lead acetate was added. After 5-10 minutes, 5 ml of 22 per cent potassium oxalate was added to precipitate the excess of lead acetate and volume was made 250 ml followed by the filtration of the solution. Afterwards, 50 ml of the filtrate was taken and hydrolyzed by adding 5 ml of concentrated HCl. The solution was left overnight for hydrolysis at room temperature. In next day, the excess of HCl was neutralized with saturated NaOH solution and final volume of 250 ml was made with distilled water. The total sugar content was then estimated by titrating boiling mixture of 5 ml each of Fehling A and Fehling B against hydrolyzed solution using methylene blue as an indicator. The end point was indicated by the appearance of brick red colour. The total sugar was expressed as percentage of fresh weight of fruit pulp.

$$\text{Total sugars (\%)} = \frac{\text{*Factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight or Volume of sample taken}} \times 100$$

*Factor = 0.05

3.5.3.9 Reducing sugars

The remaining unhydrolyzed, deleaded and clarified solution was titrated against a boiling solution of 5 ml each of Fehling A and Fehling B using methylene blue as an indicator (Ranganna, 1995). Reducing sugars content was expressed as percentage of fresh pulp weight.

$$\text{Reducing sugars (\%)} = \frac{\text{*Factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight or Volume of sample taken}} \times 100$$

*Factor = 0.05

3.5.3.10 Non-reducing sugars

The amount of non-reducing sugars was calculated by subtracting the reducing sugars from total sugars and multiplying the difference by a standard factor i.e. 0.95. The results were expressed as per cent sugars.

$$\text{Non-reducing sugars (\%)} = (\text{total sugars} - \text{reducing sugars}) \times 0.95$$

3.5.3.11 Ascorbic acid

The quantitative estimation of ascorbic acid was done according to the method given in A.O.A.C. (1980) as:

(A) Reagents

Fifteen grams of metaphosphoric acid pellets were dissolved in 40 ml glacial acetic acid and 200 ml of distilled water. The volume was made 500 ml with distilled water. The solution was filtered through Whatman No.1 filter paper and stored in coloured bottles in a refrigerator.

(B) Standard ascorbic acid

One hundred milligrams of analytical grade ascorbic acid (reference standard) were accurately weighed on electronic balance and dissolved in 10 ml of metaphosphoric acid extraction solution. The content was transferred to a 100 ml volumetric flask and volume was made to 100 ml by addition of metaphosphoric acid solution. Now this solution was diluted to one litre before use with metaphosphoric acid solution so as to reduce the consumption of dye.

(C) Indophenol standard solution

Fifty milligrams of 2, 6-dichlorophenol indophenols sodium salt was dissolved in 50 ml distilled water in a beaker. Forty-two mg of sodium bicarbonate was added to it. The contents were shaken vigorously and when 2,6-dichlorophenol indophenols was dissolved, it was diluted to 200 ml with distilled water, filtered and stored in dark coloured bottle in a refrigerator.

(D) Procedure

Twenty five grams of pulp was homogenized in metaphosphoric acid extraction solution and the volume was made to 100 ml in a volumetric flask. This solution was titrated against 2, 6-dichlorophenol indophenols dye. Appearance of light pink colour indicated the end point. The amount of ascorbic acid in milligrams per hundred grams of juice was calculated using formula:

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titre value} \times \text{Dye Factor} \times \text{Dilution}}{\text{Weight of sample taken} \times \text{Volume taken for estimation}} \times 100$$

3.5.3.12 Anthocyanin content

Anthocyanin pigment in apple skin was determined by the method given by Harborne (1973). One gram of skin was macerated in a known quantity of methanol containing 1 per cent hydrochloric acid. The content was kept overnight at 0°C temperature in a deep freezer. The absorbance of red coloured solution was recorded at 530 nm on Spectronic-20 colorimeter. The amount of anthocyanin was expressed at 530 nm per gram of fresh apple skin as absorption units.

3.5.4 Light interception

Light interception was measured in the month of June using an AccuPAR/LAI Ceptometer. Measurements were done above and below the canopy of tree. Light interception was calculated by using the following formula given by Purcell (2000):

$$IPAR\ (\%) = [1- (PAR_b/PARa)] \times 100$$

Where,

IPAR = Intercepted Photosynthetically Active Radiation

PARa = PAR measured above canopy (µmol m^{-2} s^{-1})

PAR_b = PAR measured below canopy (µmol m^{-2} s^{-1})

3.5.5 Photosynthetic rate, stomatal conductance and transpiration rate:

Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}), and transpiration rate (mmol H_2O m^{-2} s^{-1}) were measured between 9:00-12:00 PM using a LI-6400XT (LI-COR) portable photosynthesis system. Reference air (CO_2) (400 µmol s^{-1}) and light intensity (1000 µmol m^{-2} s^{-1}) were set. Measurement of photosynthesis were performed on five mature leaves around the periphery of tree as described by Erf and Proctor (1987).

3.5.6 Leaf chlorophyll content

A sample of ten representative fully grown leaves from the current season's growth of each experimental tree was detached in the first week of July during morning hours, immediately placed in ice box and brought to the laboratory (Halfacre *et al*. 1968). The samples were then kept in the refrigerator below 0^oC to avoid degradation of chlorophyll pigments.

Extraction

Leaves from each sample were washed and chopped into fine pieces under subdued light and 100 mg of chopped material was placed in vial containing 7 ml of dimethyl sulphoxide. The contents of the vials were incubated at 65^oC temperature for half an hour and then extract was transferred to graduate test tube and final volume was made to 10 ml with dimethyl sulphoxide (Hiscox and Israelstam, 1979).

Estimation

The optical density (OD) of the extract was recorded on Spectronic-20 D at 645 and 663 nm wavelengths against a dimethyl sulphoxide blank solution and total chlorophyll content was calculated by using the following formula:

$$\text{Total chlorophyll (mg/g)} = \frac{20.2\ A_{645} + 8.02\ A_{663}}{a \times 1000 \times W} \times V$$

Where,

V	=	Volume of extract used
a	=	Length of light path in cell (usually 1cm)
W	=	Weight of the sample (g)
A645	=	Absorbance at 645 nm wavelength
A663	=	Absorbance at 663 nm wavelength

The results thus obtained were expressed as mg of total chlorophyll per gram of fresh weight.

3.5.7 Leaf nutrient analysis

3. 5.7.1 Collection and preparation of leaf samples

Leaves including petioles from mid terminal shoots of current season's growth (Kenworthy, 1964) were collected from the same trees, from the basin of which the soil samples were drawn in the first week of August, during each year of the study.

The leaf samples collected, were brought directly to the laboratory, thoroughly washed first under tap water, followed by 0.1 N HCl and distilled water as suggested by Chapman (1964). The washed leaf samples were spread on filter paper sheets for surface drying and were subsequently put into paper bags which were kept in hot air oven at 65 ± 5˚C for 48 hours for final drying. The dried samples were ground in a stainless steel blender and stored in butter paper bags for the estimation of various nutrient elements.

3.5.7.2 Determination of nutrient elements

Digestion of the leaf samples

The digestion of leaf sample (1g) was carried out using concentrated H_2SO_4 and digestion mixture (Potassium sulphate 400 parts, Copper sulphate 20 parts, Mercuric oxide 3 parts and Selenium powder 1 part) for nitrogen estimation as suggested by Jackson (1973).

For the estimation of P, K, Ca, Mg and micronutrients (Fe, Cu, Mn & Zn) well ground samples of known weight (1g) of leaf were digested in di-acid mixture prepared by mixing HNO_3 and $HClO_4$ in the ratio of 4:1 taking all relevant precautions as suggested by Piper (1966).

3.5.7.2.1 Nitrogen

Distillation and titration: Total nitrogen was determined by micro-Kjeldhal's method (Jackson, 1973) and results were expressed in per cent nitrogen on dry weight basis.

3. 5.7.2.2 Phosphorus

Total phosphorus was estimated by Vanado-molybdate Phosphoric Yellow Colour Method (Jackson, 1973). Five ml of aliquot (digested) was pipette out in a 25 ml volumetric flask and 5 ml of vanado molybdate reagent was added. Solution was then diluted to 25 ml with distilled water and allowed to develop colour for half an hour. After the development of colour, concentration of phosphorus in the solution was recorded on Nukes UV-VIS Spectrophotometer at 470 nm wavelength and a blank was run simultaneously to adjust zero absorbance. Leaf phosphorus was expressed in per cent on dry weight basis.

3.5.7.2.3 Potassium, Calcium, Magnesium

Total potassium content was estimated using Agilent 5110 ICP-OES as suggested by Jackson (1973) and the results were expressed in per cent. Total Ca and Mg were determined on Analyst 400 Atomic Absorption Spectrometer and the results were expressed as per cent on dry weight basis.

3.5.7.2.4 Micronutrients (Fe, Mn, Cu and Zn)

Total Fe, Mn, Cu and Zn content of leaf sample were determined by using Agilent 5110 ICP-OES at 238.20, 257.61, 327.40 and 213.86 nm wavelength, respectively and expressed in ppm on dry weight basis.

3.5.8 Soil analysis

3.5.8.1 Collection and preparation of soil samples

The soil samples from 0-30 cm depth were collected before the start of the experiment and at the end of the experiment during both the year of study. Before the start of the experiment a composite sample of the experimental site was collected, whereas at the end of experiment, samples were collected from basin of the experimental tree with the help of screw type auger. Collected soil samples were dried in shade, grounded, sieved through 2 mm plastic sieve and stored in polyethylene bags for further analysis of soil.

3.5.8.2 Soil pH

Soil pH was determined in soil: water suspension (1:2) by following the procedure as described by Jackson (1973) using pH meter.

3.5.8.3 Electrical conductivity

Soil EC was determined in soil: water suspension (1:2) by following the procedure as described by Jackson (1973) using digital conductivity meter and was expressed in dS m^{-1}.

3.5.8.4 Organic carbon

Organic carbon was estimated by wet digestion method of Walkley and Black (1934) and was expressed in gram/kg.

3.5.8.5 Available N

The available nitrogen content of soil was estimated by alkaline potassium permanganate method as given by Subbiah and Asija (1956) and expressed as kilogram per hectare (kg ha^{-1}).

3.5.8.6 Available P

The available phosphorus content of soil was estimated by stannous chloride reduced ammonium molybdate method using Olsen's extractant (Olsen *et al*. 1954) and determined using Nukes UV-VIS Spectrophotometer at 660 nm wave length. Estimated phosphorus content was expressed as kilogram per hectare (kg ha^{-1}).

3.5.8.7 Available K

The available potassium in soil was extracted with neutral ammonium acetate as per the procedure given by Merwin and Peach (1951). Potassium was estimated using Flame Photometer (MODEL TMF-45) and was expressed as kilogram per hectare (kg ha^{-1}).

3.5.8.8 Calcium and Magnesium

Calcium and Magnesium were extracted with the neutral normal ammonium acetate and determined by using Analyst 400 Atomic Absorption Spectrophotometer and expressed in mg/kg.

3.5.8.9 Micronutrients (Fe, Mn, Cu & Zn)

The available micronutrients content of soil were determined by following the procedure as outlined by Lindsay and Norvell (1978). Ten gram of soil was shaken with 20 ml of DTPA extractant of pH 7.3 for two hours and filtered. Available Fe, Mn, Cu & Zn in the extract were determined on Analyst 400 Atomic Absorption Spectrophotometer and expressed in ppm on dry weight basis.

3.5.9 Statistical Analysis

The data obtained from the investigation were appropriately computed, tabulated and analysed using Randomized Block Design (Factorial) as per method as suggested by Panse and Sukhatme (2000). The statistical analysis was carried out for each observed character using MS-Excel and OPSTAT as per the design of experiment. The critical difference was calculated at a significance level of 5 per cent.

Analysis of variance for experiment:

The data were analyzed for three factor analysis in randomized block design (RBD) according to the procedure as suggested by Panse and Sukhatme (2000).

Source of Variation	Degrees of freedom	Sum of square	Mean sum of square (M)	F_{cal}
Replications	(r-1)	S_r	Sr/(r-1)	M_r/M_e
Treatments	(t-1)	S_t	St/(t-1)	M_t/M_e
Factor (A)	(a-1)	S_a	Sa/(a-1)	M_a/M_e
Factor (B)	(b-1)	S_b	Sb/(b-1)	M_b/M_e
A×B interaction	(a-1) (b-1)	S_{ab}	Sab/(a-1) (b-1)	M_{ab}/M_e
Factor (C)	(c-1)	S_c	Sc/(c-1)	M_c/M_e
A×C interaction	(a-1) (c-1)	S_{ac}	Sac/(a-1) (c-1)	M_{ac}/M_e
B×C interaction	(b-1) (c-1)	S_{bc}	Sbc/(b-1) (c-1)	M_{bc}/M_e
A×B×C interaction	(a-1) (b-1) (c-1)	S_{abc}	Sabc/(a-1)(b-1) (c-1)	M_{abc}/M_e
Error	(t-1) (r-1)	S_e	Se /(t-1) (r-1)	M_{tr}/M_e
Total	(n-1)	$S_{(tr-1)}$		

where,

r	=	Number of replications
t	=	Number of treatments
n	=	Total number of observations (rt)
a	=	Levels of factor A
b	=	Levels of factor B
c	=	Levels of factor C
AB	=	Interactions of A and B
AC	=	Interactions of A and C
BC	=	Interactions of B and C
ABC	=	Interactions of A, B and C

The standard error of mean SE (m) and critical difference (CD) for comparing the means of factors were calculated as below:

$$SE\ (m) \pm \quad = \quad \sqrt{Me/r}$$

$$SE\ (d) \pm \quad = \quad \sqrt{2\,Me/r}$$

SE (m) = Standard error of mean

SE (d) = Standard error of differences

Critical Difference (CD) = SE(d) x t_{tab} (5%) value at error degrees of freedom.

The calculated ‘F’ values were compared with the tabulated ‘F’ values at 5 per cent level of significance. If the calculated ‘F’ value was higher than the tabulated, it was considered to be significant. All the characters which show significant differences among factors were further subjected to the calculation of critical difference.

Chapter-4

RESULTS AND DISCUSSION

The present investigation titled **"Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)"** was carried out in the experimental farm of Department of Fruit Science, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, during 2019 and 2020. The experimental results obtained during the study are presented and discussed in this chapter under the following heads:

4.1 Effect of planting densities, training systems and fertigation levels on growth, yield and quality of apple

4.2 Effect of planting densities, training systems and fertigation levels on light interception and photosynthesis efficiency

4.3 Effect of planting densities, training systems and fertigation levels on leaf nutrients content of apple

4.4 Effect of planting densities, training systems and fertigation levels on chemical properties of soil

4.1 EFFECT OF PLANTING DENSITIES, TRAINING SYSTEMS AND FERTIGATION LEVELS ON GROWTH, YIELD AND FRUIT QUALITY OF APPLE

4.1.1 Vegetative parameters

Tree growth parameters examined were tree height and spread, annual shoot growth, scion and stock diameter, tree volume, leaf area, leaf area Index and pruning wood weight. The data pertaining to tree growth parameters are presented in Tables 4.1-4.5.

4.1.1.1 Tree height

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 reveal that planting densities, training systems and fertigation levels exerted a significant effect on tree height during both the years of study, however, their interactions were found non-significant (Appendix VII).

Table 4.1: Effect of different planting densities, training systems and fertigation levels on tree height and spread of apple cv. Jeromine

D \ T, F	Increase in tree height (cm)						Increase in tree spread (cm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	21.14	15.77	**18.45**	26.75	22.12	**24.43**	13.85	11.14	**12.49**	17.79	14.52	**16.16**
D_2	24.20	18.86	**21.53**	30.45	25.28	**27.86**	16.89	13.98	**15.43**	20.99	18.01	**19.50**
D_3	27.61	22.95	**25.28**	33.98	29.01	**31.50**	19.93	16.73	**18.33**	23.95	21.06	**22.50**
Mean (T×F)	**24.31**	**19.19**		**30.39**	**25.47**		**16.89**	**13.95**		**20.91**	**17.86**	
Mean (T)	**21.75**			**27.93**			**15.42**			**19.38**		

D \ F	D × F (height)			$CD_{0.05}$		D × F (spread)			$CD_{0.05}$	
	F_1	**F_2**	**Mean (D)**	D T F D×T T×F D×F D×T×F	1.70 1.39 1.39 NS NS NS NS	**F_1**	**F_2**	**Mean (D)**	D T F D×T T×F D×F D×T×F	1.79 1.46 1.46 NS NS NS NS
D_1	23.94	18.95	**21.44**			15.82	12.83	**14.32**		
D_2	27.32	22.07	**24.69**			18.94	15.99	**17.46**		
D_3	30.79	25.98	**28.39**			21.94	18.89	**20.42**		
Mean (F)	**27.35**	**22.33**				**18.90**	**15.90**			

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The perusal of pooled data of two years given in Table 4.1 also indicated that planting densities, training systems and fertigation levels individually had a significant effect on tree height, however, their interactions were found non-significant. Considering the effect of planting densities, the highest increase in tree height (28.39 cm) was recorded in planting density of D_3 (2666 trees/ha) and was found significantly superior to planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). However, the lowest increase in tree height (21.44 cm) was found in D_1 (4000 trees/ha) planting density. Among the training systems, the significantly higher increase in tree height (27.93 cm) was observed in T_2 (Vertical Axis) training system than T_1 (Tall Spindle) training system (21.75 cm). Similarly, data of fertigation levels also showed significant effect on tree height and the significantly higher increase in tree height (27.35 cm) was attained by the trees subjected under F_1 fertigation level as compared to the trees subjected under F_2 level of fertigation (22.33 cm).

The pooled data presented in Table 4.1 reveal that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest increase in tree height (33.98 cm) was recorded in trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 level of fertigation and the lowest (15.77 cm) was noticed in trees planted at D_1 density, trained with Tall Spindle and subjected under F_2 level of fertigation.

4.1.1.2 Tree spread

Appraisal of the data recorded during 2019 and 2020 led to an inference that planting densities, training systems, fertigation levels exhibited a significant effect on tree spread during both the years of study, however, their interactions were found non-significant (Appendix VIII).

The pooled data of two years presented in Table 4.1 also reveal that different planting densities, training systems and fertigation levels exerted significant effect on tree spread. Among the planting densities, the highest increase in tree spread (20.42 cm) was observed in D_3 (2666 trees/ha) planting density, which was significantly higher to D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the lowest increase in tree spread of 14.32 cm was found in D_1 (4000 trees/ha) density. In case of training systems, the higher increase in tree spread (19.38 cm) was attained by the trees trained with T_2 (Vertical Axis) training system, which was significantly superior to T_1 (Tall Spindle) training system (15.42 cm). Considering the effect of fertigation, the trees subjected under F_1 fertigation level showed significantly more increase in tree spread (18.90 cm) as compared to the trees subjected under F_2 level of fertigation (15.90 cm).

It is apparent from the pooled data presented in Table 4.1 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found to be non-significant. However, among three factors interaction, the highest increase in tree spread (23.95 cm) was recorded in trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 level of fertigation. Whereas the lowest increase in tree spread (11.14 cm) was observed in trees planted at D_1 density, trained with Tall Spindle and subjected under F_2 level of fertigation.

4.1.1.3 Annual shoot growth

The data cited in Appendix IX recorded during 2019 and 2020 reveal that planting densities, training systems and fertigation levels exerted a significant effect on annual shoot growth during both the years of study, however, their interactions were found non-significant.

The pooled data of two years pertaining to the effect of different planting densities, training systems, fertigation levels and their interactions on annual shoot growth depicted in Table 4.2 reveal that planting densities, training systems and fertigation levels exhibited significant effect on annual shoot growth, however their interactions were found non-significant. Among the planting densities, the highest annual shoot growth (36.48 cm) was recorded in D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest annual shoot growth of 26.96 cm was found in D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the higher annual shoot growth of 33.58 cm was observed in T_2 (Vertical Axis) training system and it was found statistically significant than T_1 (Tall Spindle) training system (30.06 cm). Similarly, the trees subjected to F_1 fertigation level registered significantly higher annual shoot growth (33.28 cm) in comparison to the trees subjected under F_2 fertigation level (30.36 cm).

Table 4.2: Effect of different planting densities, training systems and fertigation levels on annual shoot growth and scion diameter of apple cv. Jeromine

D \ T, F	Annual shoot growth (cm)						Increase in scion diameter (mm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	26.92	23.84	**25.38**	30.50	26.58	**28.54**	5.01	4.94	**4.98**	5.07	5.01	**5.04**
D_2	31.46	28.67	**30.06**	35.41	32.56	**33.98**	5.54	5.37	**5.45**	5.61	5.49	**5.55**
D_3	35.88	33.58	**34.73**	39.53	36.93	**38.23**	6.08	5.97	**6.02**	6.16	6.05	**6.10**
Mean (T×F)	**31.42**	**28.69**		**35.14**	**32.02**		**5.54**	**5.43**		**5.61**	**5.52**	
Mean (T)	**30.06**			**33.58**			**5.48**			**5.56**		

Annual shoot growth (cm):

D \ F	D × F: F_1	F_2	Mean (D)	$CD_{0.05}$	
D_1	28.71	25.21	**26.96**	D	1.77
D_2	33.43	30.61	**32.02**	T	1.45
D_3	37.70	35.25	**36.48**	F	1.45
Mean (F)	**33.28**	**30.36**		D×T	NS
				T×F	NS
				D×F	NS
				D×T×F	NS

Increase in scion diameter (mm):

D \ F	D × F: F_1	F_2	Mean (D)	$CD_{0.05}$	
D_1	5.04	4.98	**5.01**	D	0.05
D_2	5.57	5.43	**5.50**	T	0.04
D_3	6.12	6.01	**6.06**	F	NS
Mean (F)	**5.58**	**5.47**		D×T	NS
				T×F	NS
				D×F	NS
				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

It is evident from the pooled data presented in Table 4.2 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest annual shoot growth (39.53 cm) was recorded in trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 level of fertigation, whereas, the lowest annual shoot growth (23.84 cm) was noted in trees planted at D_1 density, trained with Tall Spindle and subjected under F_2 level of fertigation.

4.1.1.4 Scion diameter

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix X) indicate that planting densities, training systems and fertigation levels exerted a significant effect on scion diameter during both the years of study, however, their interactions were found non-significant.

The pooled data of two years related to effect of different planting densities, training systems, fertigation levels and their interactions on scion diameter are presented in Table 4.2. The data reveal that planting densities, training systems and fertigation levels had significant influence on scion diameter, however their interactions were found non-significant. Among the planting densities, the maximum increase in scion diameter (6.06 mm) was registered in D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. The minimum increase in scion diameter of 5.01 mm was found in D_1 (4000 trees/ha) planting density. The scion diameter was also significantly influenced by different training systems. The higher increase of 5.56 mm in scion diameter was observed in T_2 (Vertical Axis) training system and it was found significantly higher than T_1 (Tall Spindle) training system (5.48 mm). The effects of fertigation levels on scion diameter were found non-significant.

It is clear from the pooled data presented in Table 4.2 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant in respect of scion diameter. However, the maximum increase in scion diameter (6.16 mm) was recorded in trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 level of fertigation and the minimum increase was noted in trees planted at D_1 density, trained with Tall Spindle and fertigated with F_2 level.

4.1.1.4 Stock diameter

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 displayed in Appendix XI indicate that planting densities, training systems and fertigation levels exerted a significant effect on stock diameter during both the years of study, however, their interactions were found non-significant.

From the perusal of the pooled data of two years presented in Table 4.3, it is clear that different planting densities, training systems and fertigation levels exhibited significant effect on stock diameter, however, their interactions were found non-significant. Among the planting densities, the maximum increase in stock diameter (7.12 mm) was observed in D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. The minimum increase of 5.49 mm in stock diameter was found in D_1 (4000 trees/ha) planting density. In case of training systems, T_2 (Vertical Axis) training system with an increase of 6.49 mm in stock diameter was found significantly superior to T_1 (Tall Spindle) training system (6.28 mm). Considering the effect of fertigation, the trees subjected under F_1 fertigation level exhibited significantly more increase in stock diameter (6.49 mm) as compared to the trees fertigated with F_2 fertigation level (6.29 mm).

It is apparent from the pooled data given in Table 4.3 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the highest increase in stock diameter (7.27 mm) was recorded in trees planted at density D_3, trained with Vertical Axis and subjected under F_1 fertigation level.

Table 4.3: Effect of different planting densities, training systems and fertigation levels on stock diameter and tree volume of apple cv. Jeromine

D \ T, F	Increase in stock diameter (mm)						Increase in tree volume (m^3)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	5.54	5.19	**5.37**	5.70	5.53	**5.61**	1.04	0.88	**0.96**	1.67	1.64	**1.65**
D_2	6.55	6.32	**6.44**	6.72	6.60	**6.66**	1.29	1.22	**1.26**	1.83	1.71	**1.77**
D_3	7.14	6.93	**7.04**	7.27	7.15	**7.21**	2.09	1.52	**1.80**	2.38	1.87	**2.12**
Mean (T×F)	**6.41**	**6.15**		**6.56**	**6.42**		**1.47**	**1.21**		**1.96**	**1.74**	
Mean (T)	**6.28**			**6.49**			**1.34**			**1.85**		

D \ F	D × F (stock diameter)			$CD_{0.05}$		D × F (tree volume)			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	5.62	5.36	**5.49**	D	0.19	1.36	1.26	**1.31**	D	0.01
				T	0.16				T	0.01
				F	0.16				F	0.01
D_2	6.64	6.46	**6.55**	D×T	NS	1.56	1.47	**1.52**	D×T	0.02
				T×F	NS				T×F	0.01
D_3	7.20	7.04	**7.12**	D×F	NS	2.24	1.70	**1.97**	D×F	0.02
Mean (F)	**6.49**	**6.29**		D×T×F	NS	**1.72**	**1.48**		D×T×F	0.02

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

4.1.1.6 Tree volume

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on tree volume recorded during 2019 and 2020 are presented in Appendix XII. It is inferred from the data that planting densities, training systems, fertigation levels and their interactions had significant effect on tree volume.

An inquisition of the pooled data of two years given in Table 4.3 clearly indicates that different planting densities, training systems, fertigation levels and their interactions showed a significant effect on tree volume. Considering the effect of planting densities, the highest increase in tree volume (1.97 m^3) was recorded in D_3 (2666 trees/ha) planting density, which was significantly higher than planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). However, the lowest increase of 1.31 m^3 in tree volume was found in D_1 (4000 trees/ha) planting density. Among the training systems, the significantly higher increase of 1.85 m^3 in tree volume was observed in T_2 (Vertical Axis) training system than T_1 (Tall Spindle) training system (1.34 m^3). Similarly, data of fertigation levels also showed significant effect on tree volume and the maximum increase in tree volume (1.72 m^3) was attained by the trees subjected under F_1 fertigation level, while minimum (1.48 m^3) was noted in F_2 level of fertigation.

The pooled data presented in Table 4.3 show that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were significant on tree volume. In case of interactions between planting densities and training systems, significantly highest increase in tree volume of 2.12 m^3 was recorded in trees planted at density D_3 and trained with Vertical Axis and the lowest increase in tree volume was observed in trees planted at density D_1 and trained with Tall Spindle (0.96 m^3). Among training systems and fertigation levels interactions, the maximum increase of 1.96 m^3 in tree volume was registered in trees trained with Vertical Axis and subjected to F_1 fertigation level, whereas, the lowest (1.21 m^3) was observed in Tall Spindle trained trees subjected to F_2 fertigation level. Considering the interaction effect of planting densities and fertigation levels, the significantly higher increase in tree volume (2.24 m^3) was recorded in the trees planted at D_3 density and subjected under F_1 fertigation level and the lowest increase (1.26 m^3) was noted in the trees planted at D_1 density and fertigated with F_2 level. Among three factors interaction, significantly highest increase in tree volume (2.38 m^3) was attained by the trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 level of fertigation and it was found statistically significant than all the treatment combinations.

4.1.1.7 Leaf area

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf area recorded during 2019 and 2020 are presented in Appendix XIII. It reveals that planting densities, training systems and fertigation levels exerted a significant effect on leaf area during both the years of study, however, their interactions were found non-significant.

The pooled data on effect of different planting densities, training systems, fertigation levels and their interactions are cited in Table 4.4. The data reveal that planting densities, training systems and fertigation levels exhibited significant effect on leaf area. Among the planting densities, the highest leaf area (36.09 cm^2) was recorded in D_3 (2666 trees/ha) planting density, which was significantly higher than other planting densities. However, the lowest leaf area of 35.00 cm^2 was noticed in D_1 (4000 trees/ha) planting density. In case of training systems, significantly higher leaf area (35.89 cm^2) was recorded in T_2 (Vertical Axis) training system in comparison to the trees trained with T_1 (Tall Spindle) training system (35.29 cm^2). Considering the effect of fertigation levels, the trees subjected under F_1 fertigation level had significantly more leaf area (36.13 cm^2) than F_2 fertigation level (35.04 cm^2).

It is evident from the pooled data assembled in Table 4.4 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the maximum leaf area (37.01 cm^3) was observed in the trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 fertigation level, while the minimum leaf area (34.04 cm^2) was noted in trees planted at D_1 density, trained with Tall Spindle and subjected under F_2 fertigation level.

Table 4.4: Effect of different planting densities, training systems and fertigation levels on leaf area and leaf area index of apple cv. Jeromine

D \ T / F	Leaf area (cm^2)						Leaf area index ($m^2 m^{-2}$)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	35.17	34.04	**34.61**	35.85	34.93	**35.39**	2.12	2.03	**2.07**	2.16	2.06	**2.11**
D_2	36.00	34.86	**35.43**	36.44	35.42	**35.93**	1.90	1.82	**1.86**	1.93	1.85	**1.89**
D_3	36.35	35.30	**35.82**	37.01	35.70	**36.35**	1.81	1.72	**1.77**	1.86	1.75	**1.80**
Mean (T×F)	**35.84**	**34.73**		**36.43**	**35.35**		**1.94**	**1.85**		**1.98**	**1.88**	
Mean (T)	**35.29**			**35.89**			**1.90**			**1.93**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.56	F_1	F_2	Mean (D)	D	0.04
D_1	35.51	34.49	**35.00**	T	0.46	2.14	2.04	**2.09**	T	0.03
				F	0.46				F	0.03
D_2	36.22	35.14	**35.68**	D×T	NS	1.92	1.83	**1.87**	D×T	NS
				T×F	NS				T×F	NS
D_3	36.68	35.50	**36.09**	D×F	NS	1.84	1.73	**1.78**	D×F	NS
Mean (F)	**36.13**	**35.04**		D×T×F	NS	**1.96**	**1.87**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

4.1.1.8 Leaf area index

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XIV) reveal that planting densities, training systems and fertigation levels exerted a significant effect on leaf area index during both the years of study, however, their interactions were found non-significant.

Examination of the pooled data of two years presented in Table 4.4 also reveals that the individual effect of different planting densities, training systems and fertigation levels was significant in respect of leaf area index, while their interactions were found to be non-significant. Among the planting densities, the maximum leaf area index (2.09) was recorded in planting density of D_1 (4000 trees/ha) and was found significantly superior to planting density of D_3 (2666 trees/ha) and D_2 (3200 trees/ha). However, the minimum leaf area index (1.78) was found in D_3 (2666 trees/ha) planting density. In case of training systems, the higher leaf area index of 1.93 was noticed in T_2 (Vertical Axis) training system, which was found statistically at par with T_1 (Tall Spindle) training system (1.90). Considering the effect of fertigation levels, the higher leaf area index was attained by the trees subjected with F_1 fertigation level (1.96), which was significantly superior to F_2 level of fertigation (1.87).

It is clear from the pooled data presented in Table 4.4 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were non-significant. However, the highest leaf area index (2.16) was recorded in trees planted at D_1 density, trained with Vertical Axis and subjected under F_1 fertigation level, while the lowest (1.72) was observed in trees planted at D_3 density trained with Tall Spindle and subjected under F_2 level of fertigation.

4.1.1.9 Pruning wood weight

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on pruning wood weight recorded during 2019 and 2020 are depicted in Appendix XV. It led to an inference that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on pruning wood weight during both the years of study.

The perusal of pooled data of two years cited in Table 4.5 also reveals that the pruning wood weight was significantly influenced by different planting densities, training systems and fertigation levels. The highest pruning wood weight of 369.20 g tree^{-1} was obtained in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). However, the lowest pruning wood weight of 227.94 g tree^{-1} was recorded in D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the trees trained with T_2 (Vertical Axis) training system registered significantly higher pruning wood weight of 323.28 g tree^{-1} than T_1 (Tall Spindle) training system (277.93 g tree^{-1}). In case of fertigation, the significantly higher pruning wood weight (367.00 g tree^{-1}) was attained by the trees subjected under F_1 fertigation level in comparison to the trees subjected under F_2 level of fertigation (234.20 g tree^{-1}).

The pooled data assembled in Table 4.5 indicate that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on pruning wood weight were significant. Among planting densities and training systems interactions, highest pruning wood weight of 381.69 g tree^{-1} was registered by the trees planted at density D_3 and trained with Vertical Axis, however, the lowest (199.22 g tree^{-1}) pruning wood weight was observed in trees planted at density D_1 and trained with Tall Spindle. Considering the interaction effect of training systems and fertigation levels, the highest pruning wood weight of 387.33 g tree^{-1} was obtained in trees trained with Vertical Axis and subjected to F_1 fertigation level whereas, the lowest (203.29 g tree^{-1}) was noted in trees trained with Tall Spindle and subjected to F_2 fertigation level. In case of interactions between planting densities and fertigation levels, the maximum pruning wood weight of 449.26 g tree^{-1} was recorded in trees planted at density D_3 and subjected to F_1 fertigation level, while the lowest (177.25 g tree^{-1}) pruning wood weight was noticed in trees planted at D_1 planting density and fertigated with F_2 level. Among three factors interaction, highest pruning wood weight (458.08 g tree^{-1}) was obtained in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation, which was found at par with

Table 4.5: Effect of different planting densities, training systems and fertigation levels on pruning wood weight of apple cv. Jeromine

D \ T / F	Pruning wood weight (g $tree^{-1}$)								
	T_1			T_2			D × F		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D)
D_1	244.62	153.83	**199.22**	312.65	200.67	**256.66**	278.64	177.25	**227.94**
D_2	354.99	200.71	**277.85**	391.25	271.73	**331.49**	373.12	236.22	**304.67**
D_3	458.08	255.33	**256.71**	440.44	322.95	**381.69**	449.26	289.14	**369.20**
Mean (T×F)	**352.56**	**203.29**		**381.44**	**265.11**		**367.00**	**234.20**	**Mean (F)**
Mean (T)	**277.93**			**323.28**					

$CD_{0.05}$	D	8.05	T	6.58	F	6.58	D×T	11.39	T×F	9.30	D×F	11.39	D×T×F	16.11

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

the trees planted at D_3 density, trained with Vertical Axis and subjected under F_1 fertigation level.

The results of present investigation revealed that vegetative growth traits such as tree height and spread, annual shoot growth, scion and stock diameter, tree volume, leaf area and pruning wood weight were significantly influenced by planting density, training system and fertigation level. The study shows that the planting density had negative effect on tree growth parameters. Tree height, spread and volume, annual shoot growth, scion and stock diameter, tree volume, leaf area and pruning wood weight were found more in lower planting densities of 2666 trees/ha compared to the higher planting densities. The larger tree size in lower densities might be due to the more availability of space for vegetative growth of the trees and lack of competition for the nutrients, water and light, while smaller tree size in higher densities might be due to the more competition for nutrients and water. These results are in conformity with the studies of Robinson (2007), Lordan *et al*. (2018) and Reig *et al.* (2019), who reported maximum TCSA and crown volume per tree at wider spacing and minimum under close spacing in apple.

The development of larger trees at lower densities than higher tree planting densities might be early cropping which resulted in to reduced partitioning of carbon into structural parts of the tree and, root competition for space and nutrients could also have contributed to reduced tree size at higher tree densities (Robinson, 2007). These results are in line with the findings of Costa *et al.* (1997) and Kiprijanovski *et al.* (2009), who had recorded maximum TCSA of apple for the lowest planting density and minimum in highest planting density. Similarly, Dhiman *et al.* (2018) reported that the tree growth parameters like tree height and spread, annual shoot growth, scion and stock girth, and tree volume were highest in low planting density of 2666 trees/ha. The results of present study are in consonance with the findings of Widmer and Krebs (2001), Szczygie *et al.* (2001), Granelli and Eccher (2006), Ozkan *et al.* (2012) and Srivastava *et al.* (2017), who reported that increase in planting densities leads to reduction of the tree height, spread and volume in apple.

In the present study, Vertical Axis training system resulted in higher growth as compared to Tall Spindle. The lesser vegetative growth in trees trained with Tall Spindle might be due to bending of branches below horizontal and no heading back of branches and leader during dormant pruning, which reduced branch growth due to more accumulation of carbohydrates resulting in to small canopy (Robinson, 2007). The present findings are similar to that observed by Robinson *et al*. (2013) and Reig *et al.* (2019), who reported that the Tall Spindle trained trees were least vigorous and TCSA was 25 per cent lower than Vertical Axis. Similarly, Sander *et al*. (2019) also reported minimum canopy volume with Tall Spindle and maximum canopy volume with Vertical Axis training system.

Tree growth and vigour, in terms of tree height and spread, annual shoot growth, scion and stock diameter, and tree volume was significantly affected by different fertigation levels. Drip fertigation provides optimal availability of soil moisture regime and the nutrient pool at root zone for mobilization and continuous supply of nutrients, meeting the requirements during the critical period of growth and the increased nutrients content might have increased the rate of various metabolic and physiological processes such as cell division, formation of more tissues and translocation of food materials, which resulted in higher vegetative growth of plant parts (Mishra *et al.* 2005). In the present study, higher growth was reported under higher levels of fertigation, which declines with decreased fertigation dose. The higher growth characteristics at higher fertigation levels may partially be assigned to the higher leaf nutrients content (NPK) in the tree foliage, which had a positive correlation with the level of fertilizer used (Treder, 2006). The present findings are in confirmatory with the studies of Raina *et al.* (2013), Kumar *et al.* (2016) and Thakur *et al.* (2020)**,** who observed maximum tree height and spread, annual shoot growth, trunk girth and tree volume with the application of 100 % of AD (NPK) fertigation dose.

The better vegetative growth of trees planted at wider spacing, trained with Vertical Axis and subjected under higher fertigation levels might be due to cumulative effect of planting density, training system and fertigation level.

4.1.2 Cropping parameters

Cropping parameters include spur density, blossom density, fruit set, fruit drop, yield and yield efficiency in the study. The data referring to cropping parameters are presented in Tables 4.6 to 4.9 and Fig. 4.1 to 4.14.

4.1.2.1 Spur density

The data depicted in Appendix XVI recorded during 2019 and 2020 reveal that planting densities, training systems and fertigation levels exerted a significant effect on spur density during both the years of study, however, their interactions were found non-significant.

An inquisition of pooled data of two years given in Table 4.6 clearly indicates that planting densities, training systems and fertigation levels individually had a significant effect on the spur density, however, their interactions were found non-significant. The highest spur density (0.23 cm^{-1}) was observed in trees planted at D_3 (2666 trees/ha) and was found significantly superior to D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities. However, the lowest spur density (0.12 cm^{-1}) was observed in trees planted at D_1 (4000 trees/ha) planting density. In case of training systems, the trees trained with T_1 (Tall Spindle) training system registered significantly higher spur density (0.20 cm^{-1}) in comparison to the trees trained with T_2 (Vertical Axis) training system (0.15 cm^{-1}). Considering the effect of fertigation levels, the F_1 fertigation level registered higher spur density (0.19 cm^{-1}), which was significantly superior to the trees fertigated with F_2 level of fertigation (0.16 cm^{-1}).

It is evident from the pooled data presented in Table 4.6 that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the highest spur density (0.27 cm^{-1}) was observed in trees planted at density D_3, trained with Tall Spindle and subjected to F_1 fertigation level.

4.1.2.2 Blossom density

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on blossom density recorded during 2019 and 2020 have been presented in Appendix XVII. It is inferred from the data that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on blossom density during both the years of study.

Table 4.6: Effect of different planting densities, training systems and fertigation levels on spur density and blossom density of apple cv. Jeromine

D \ T, F	Spur density (number cm^{-1} shoot length)						Blossom density (flower clusters cm^{-2} TCSA)					
	T_1			**T_2**			**T_1**			**T_2**		
	F_1	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**
D_1	0.15	0.13	**0.14**	0.11	0.09	**0.10**	13.61	8.21	**10.91**	9.46	7.83	**8.64**
D_2	0.23	0.19	**0.21**	0.17	0.13	**0.15**	14.60	8.41	**11.50**	9.75	8.07	**8.91**
D_3	0.27	0.24	**0.25**	0.22	0.19	**0.20**	15.11	11.38	**13.25**	11.10	8.44	**9.77**
Mean (T×F)	**0.22**	**0.18**		**0.16**	**0.13**		**14.44**	**9.33**		**10.10**	**8.11**	
Mean (T)	**0.20**			**0.15**			**11.89**			**9.10**		

D \ F	Spur density D × F			Blossom density D × F		
	F_1	**F_2**	**Mean (D)**	**F_1**	**F_2**	**Mean (D)**
D_1	0.13	0.11	**0.12**	11.53	8.02	**9.78**
D_2	0.20	0.16	**0.18**	12.17	8.24	**10.21**
D_3	0.24	0.21	**0.23**	13.10	9.91	**11.51**
Mean (F)	**0.19**	**0.16**		**12.27**	**8.72**	

$CD_{0.05}$	Spur density	Blossom density
D	0.17	0.05
T	0.14	0.04
F	0.14	0.04
D×T	NS	0.07
T×F	NS	0.06
D×F	NS	0.07
D×T×F	NS	0.10

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appraisal of the pooled data of two years depicted in Table 4.6 and Fig. 4.1 to 4.7 also led to an inference that planting densities, training systems and fertigation levels, and their interactions exhibited a significant effect on blossom density. Considering the effect of planting densities, the highest blossom density (11.51 flower clusters cm^{-2} TCSA) was recorded in trees planted at D_3 (2666 trees/ha) density, which was found significantly superior to D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities. However, the lowest blossom density (9.78 flower clusters cm^{-2} TCSA) was observed in trees planted at D_1 (4000 trees/ha) density. Among the training systems, the blossom density of 11.89 flower clusters cm^{-2} TCSA was observed in T_1 (Tall Spindle) training system, which was significantly higher than the blossom density in trees trained to T_2 (Vertical Axis) training system (9.10 flower clusters cm^{-2} TCSA). Similarly, data of fertigation levels also showed significant influence on blossom density and the trees treated with F_1 fertigation level registered significantly higher blossom density (12.27 flower clusters cm^{-2} TCSA) as compared to the trees treated with F_2 level of fertigation (8.72 flower clusters cm^{-2} TCSA).

The pooled data cited in Table 4.6 and Fig. 4.4 to 4.7 showed that interactions effect of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on blossom density were significant. Among planting densities and training systems interactions, highest blossom density of 13.25 flower clusters cm^{-2} TCSA was recorded in trees planted at 2666 trees/ha and trained with Tall Spindle (D_3T_1), which was significantly higher than all the treatment combinations. However, the lowest (8.64 flower clusters cm^{-2} TCSA) was found in trees planted at 4000 trees/ha and trained with Vertical Axis (D_1T_2). In case of training systems and fertigation levels interactions, the maximum blossom density of 14.44 flower clusters cm^{-2} TCSA was recorded in trees trained with Tall Spindle and subjected to F_1 fertigation level (T_1F_1), whereas, the minimum (8.11 flower clusters cm^{-2} TCSA) was found in Vertical Axis trained trees subjected to F_2 fertigation level (T_2F_2).

The pooled data displayed in Table 4.6 and Fig. 4.6 and 4.7 showed that blossom density was significantly influenced by planting densities and fertigation levels, and planting densities, training systems and fertigation levels interactions. The highest blossom density of 13.10 flower clusters cm^{-2} TCSA was observed in trees planted at D_3 density and subjected under F_1 level of fertigation (D_3F_1), while the lowest (8.02 flower clusters cm^{-2} TCSA) was recorded in trees planted at D_1 density and subjected under F_2 level of fertigation (D_1F_2). Among three factors interaction, highest blossom density (15.11 flower clusters cm^{-2} TCSA) was found in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation ($D_3T_1F_1$) and the lowest (7.83 flower clusters cm^{-2} TCSA) was noted in trees planted at density D_1, trained with Vertical Axis and subjected under F_2 level of fertigation ($D_1T_2F_2$).

4.1.2.2 Fruit set

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XVIII) led to an inference that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on fruit set during both the years of study.

The pooled data of two years cited in Table 4.7 and Fig. 4.1 to 4.3 also revealed that planting densities, training systems and fertigation levels individually exerted significant impact on fruit set. Among the planting densities, the highest fruit set (52.90 %) was recorded in trees planted at D_3 (2666 trees/ha) density and was found significantly superior to D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities. However, the lowest fruit set (45.68 %) was observed in D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the significantly higher fruit set (51.69 %) was obtained in trees trained to T_1 (Tall Spindle) training system in comparison to the trees trained to T_2 (Vertical Axis) training system (47.06 %). In case of fertigation, the trees subjected under F_1 fertigation level showed significantly higher fruit set (52.38 %) than the trees fertigated with F_2 level of fertigation (46.37 %).

The pooled data depicted in Table 4.7 and Fig. 4.4 to 4.6 indicate that interactions between planting densities and training systems, training systems and fertigation levels and planting densities and fertigation levels were found significant in respect of fruit set. Among the interactions effect of planting densities and training systems, the highest fruit set of 55.43 per cent was registered in trees planted at D_3 density and trained with Tall Spindle (D_3T_1), which was significantly higher as

Table 4.7: Effect of different planting densities, training systems and fertigation levels on fruit set and drop of apple cv. Jeromine

D \ T, F	Fruit set (%)						Fruit drop (%)					
	T_1			T_2			T_1			T_2		
	F_1	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**
D_1	49.08	45.87	**47.48**	47.30	40.48	**43.89**	70.96	74.25	**72.60**	73.80	76.29	**75.05**
D_2	54.64	49.66	**52.15**	50.56	43.31	**46.93**	68.27	71.55	**69.91**	70.57	73.16	**71.86**
D_3	57.83	53.02	**55.43**	54.86	45.88	**50.37**	65.52	68.80	**67.16**	67.22	71.05	**69.13**
Mean (T×F)	**53.85**	**49.52**		**50.90**	**43.23**		**68.25**	**71.53**		**70.53**	**73.50**	
Mean (T)	**51.69**			**47.06**			**69.89**			**72.01**		

D \ F	Fruit set (%) D × F			Fruit drop (%) D × F		
	F_1	**F_2**	**Mean (D)**	**F_1**	**F_2**	**Mean (D)**
D_1	48.19	43.18	**45.68**	72.38	75.27	**73.82**
D_2	52.60	46.49	**49.54**	69.42	72.35	**70.89**
D_3	56.34	49.45	**52.90**	66.37	69.92	**68.15**
Mean (F)	**52.38**	**46.37**		**69.39**	**72.51**	

$CD_{0.05}$	Fruit set (%)	Fruit drop (%)
D	0.66	0.45
T	0.54	0.37
F	0.54	0.37
D×T	0.93	NS
T×F	0.76	NS
D×F	0.93	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

compared to all other treatment combinations. However, the lowest fruit set (43.89 %) was noticed in trees planted at D_1 density and trained with Vertical Axis (D_1T_2). In case of interactions between training systems and fertigation levels, the maximum fruit set (53.85 %) was registered by the trees trained with Tall Spindle and subjected under F_1 fertigation level (T_1F_1), while the minimum fruit set (43.23 %) was observed in trees trained with Vertical Axis and fertigated with F_2 level (T_2F_2). Considering the interactions effect of planting densities and fertigation levels, the highest fruit set (56.34 %) was noticed in trees planted at density D_3 and subjected to F_1 fertigation level (D_3F_1), whereas the lowest (43.18 %) was recorded in trees planted at density D_1 and fertigated with F_2 level (D_1F_2).

It is evident from the pooled data presented in Table 4.7 that three factors interaction were found non-significant. However, among the three factors interaction the highest fruit set (57.83 %) was registered in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 fertigation level.

4.1.2.4 Fruit drop

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on fruit drop recorded during 2019 and 2020 are given in Appendix XIX. It reveals that planting densities, training systems and fertigation levels exerted a significant effect on fruit drop during both the years of study, however, their interactions were found non-significant.

The pooled data of two years related to fruit drop as influenced by different planting densities, training systems and fertigation level are presented in Table 4.7. The data reveal that planting densities, training systems and fertigation levels individually exhibited significant effect on fruit drop, however their interactions were found non-significant. Among the planting densities, the lowest fruit drop (68.15 %) was recorded in trees planted at D_3 (2666 trees/ha) density, which was significantly lower than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the highest fruit drop of 73.82 per cent was found in D_1 (4000 trees/ha) planting density. In case of training systems, the trees trained to T_1 (Tall Spindle) training system registered significantly lower fruit drop (69.89 %) as compared to T_2 (Vertical Axis) training system (72.01 %). Similarly, the trees subjected to F_1 fertigation level

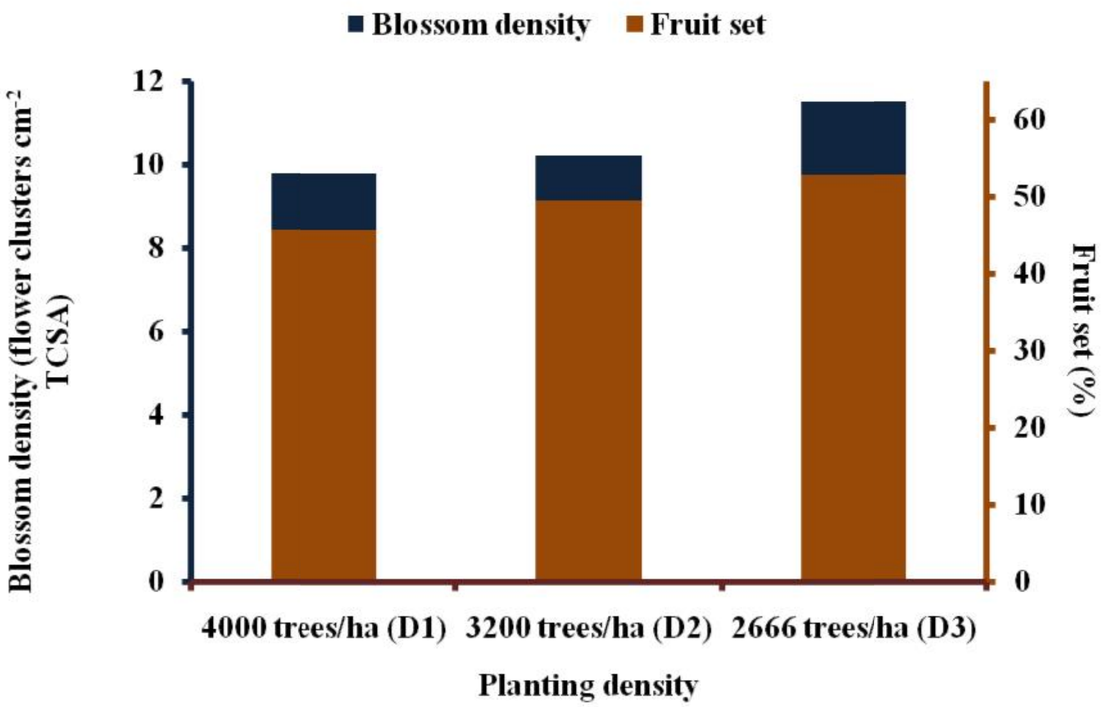

Fig. 4.1: Effect of different planting densities on blossom density and fruit set of apple cv. Jeromine

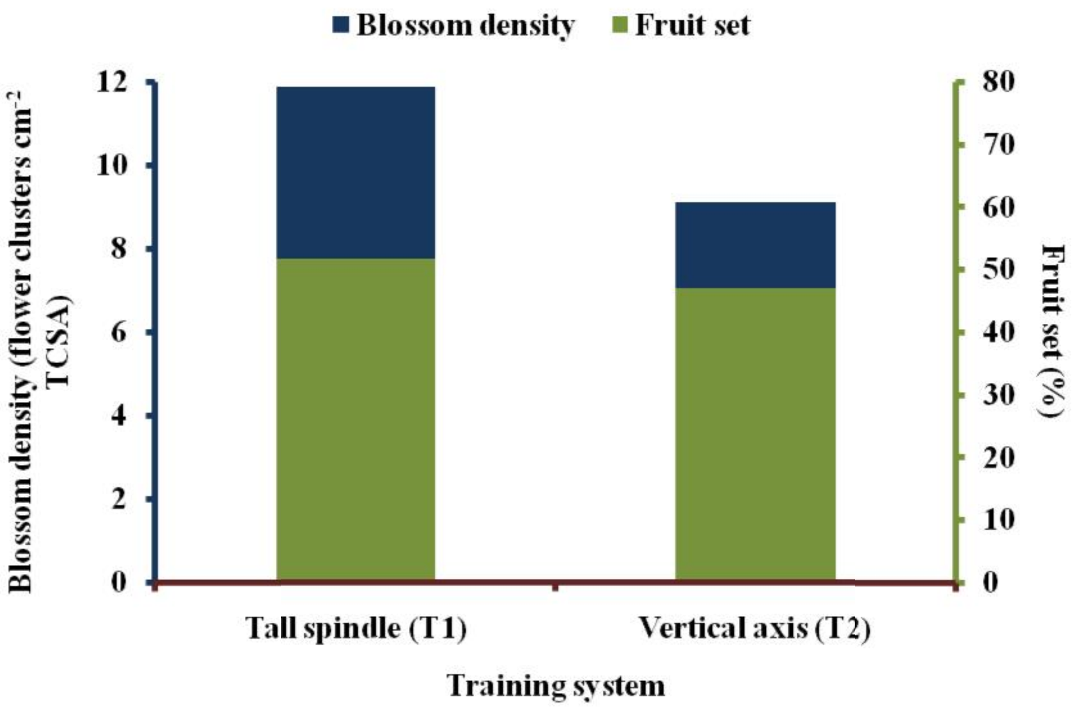

Fig. 4.2: Effect of different training systems on blossom density and fruit set of apple cv. Jeromine

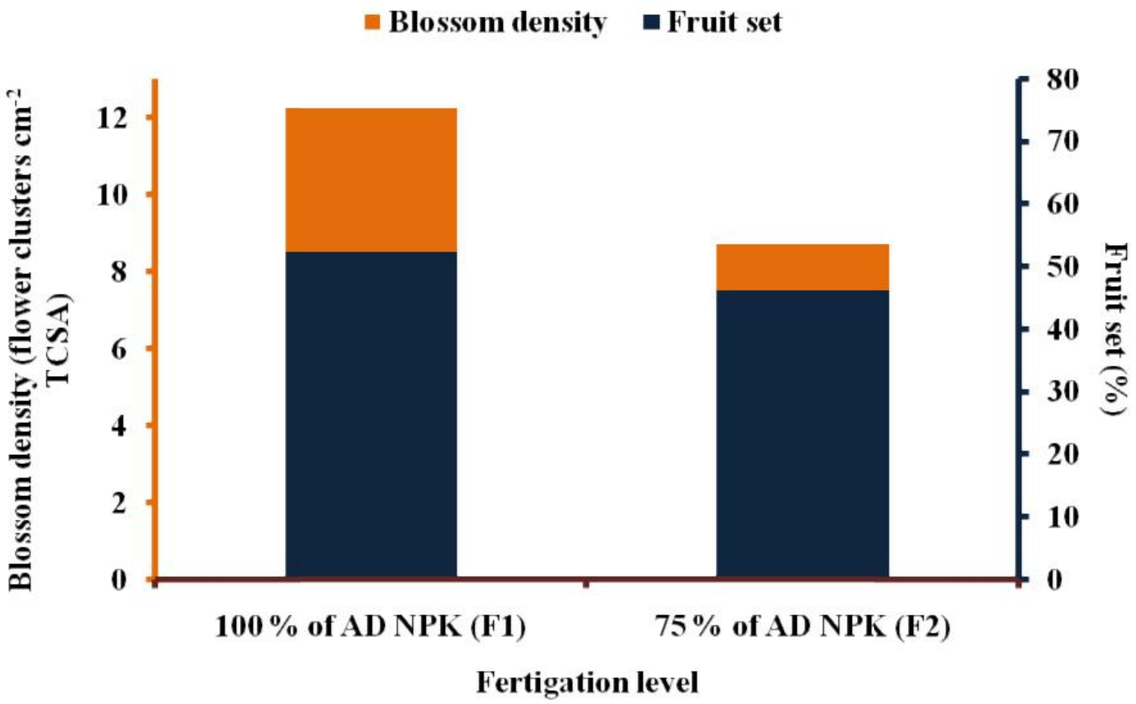

Fig. 4.3: Effect of different fertigation levels on blossom density and fruit set of apple cv. Jeromine

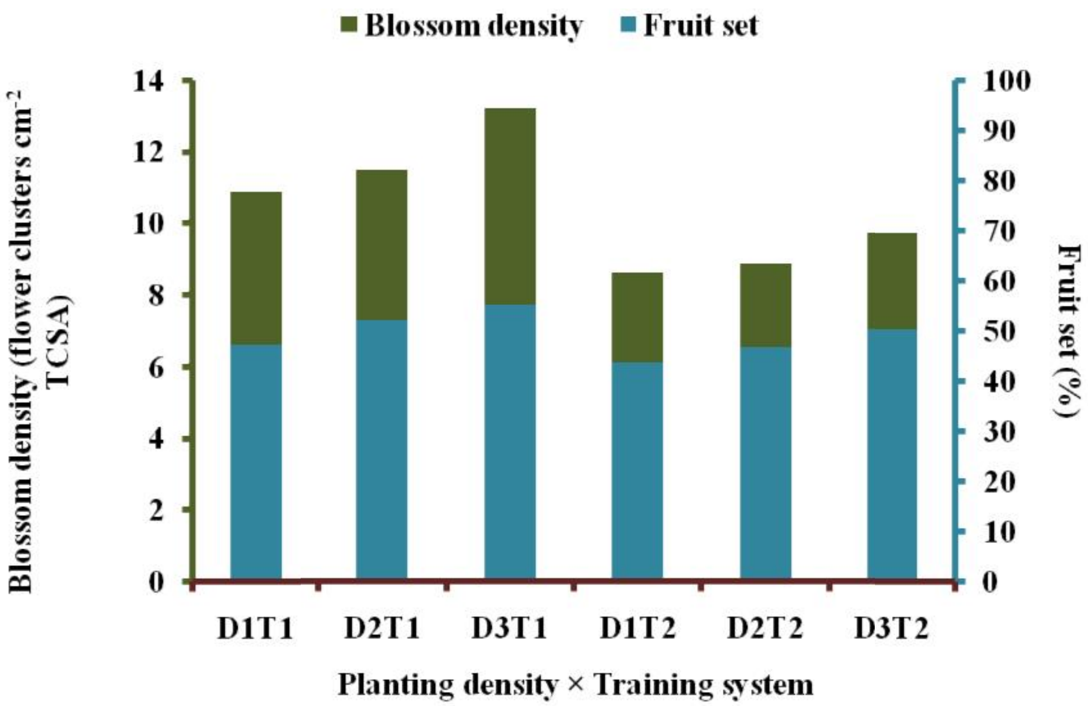

Fig. 4.4: Effect of different planting densities and training systems on blossom density and fruit set of apple cv. Jeromine

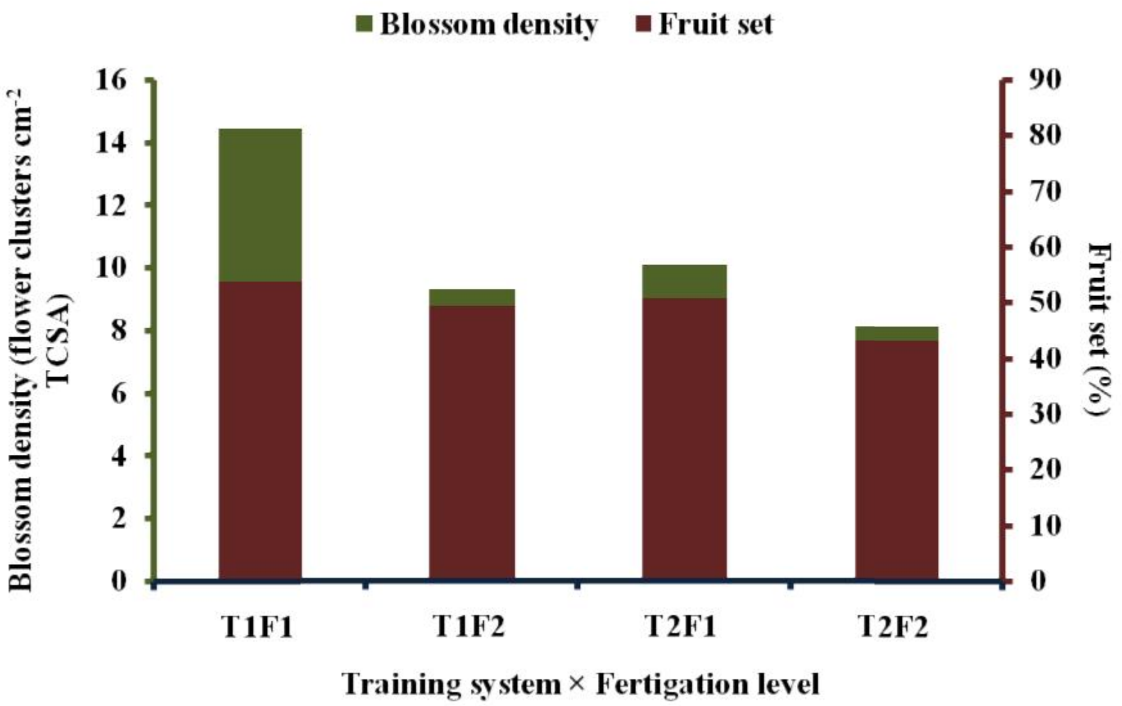

Fig. 4.5: Effect of different training systems and fertigation levels on blossom density and fruit set of apple cv. Jeromine

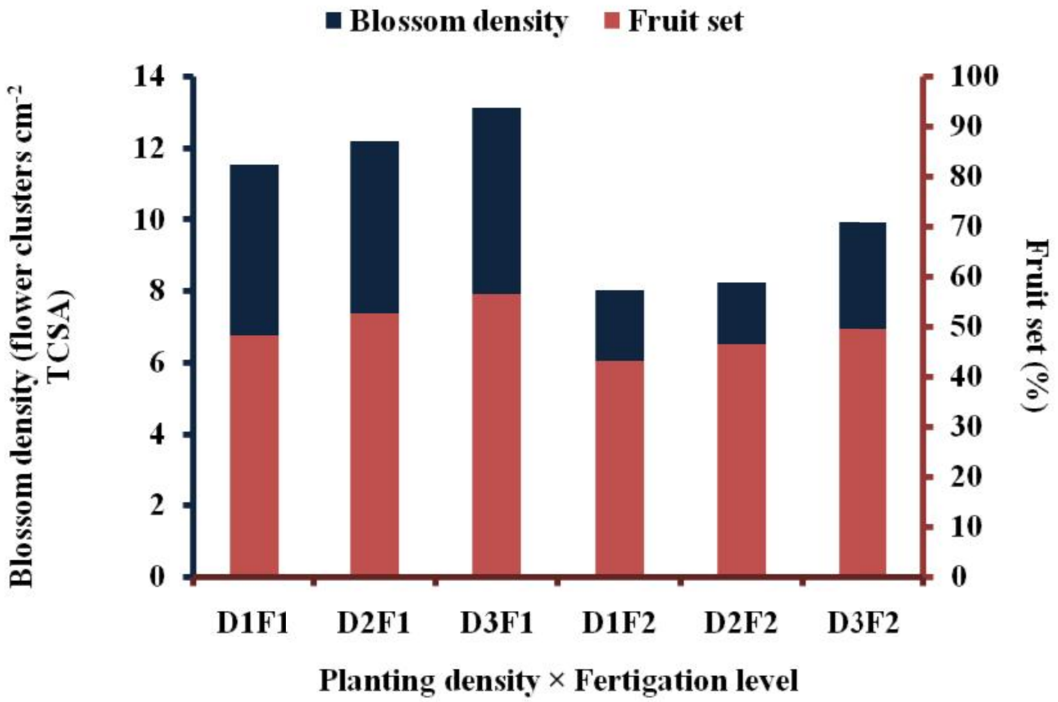

Fig. 4.6: Effect of different planting densities and fertigation levels on blossom density and fruit set of apple cv. Jeromine

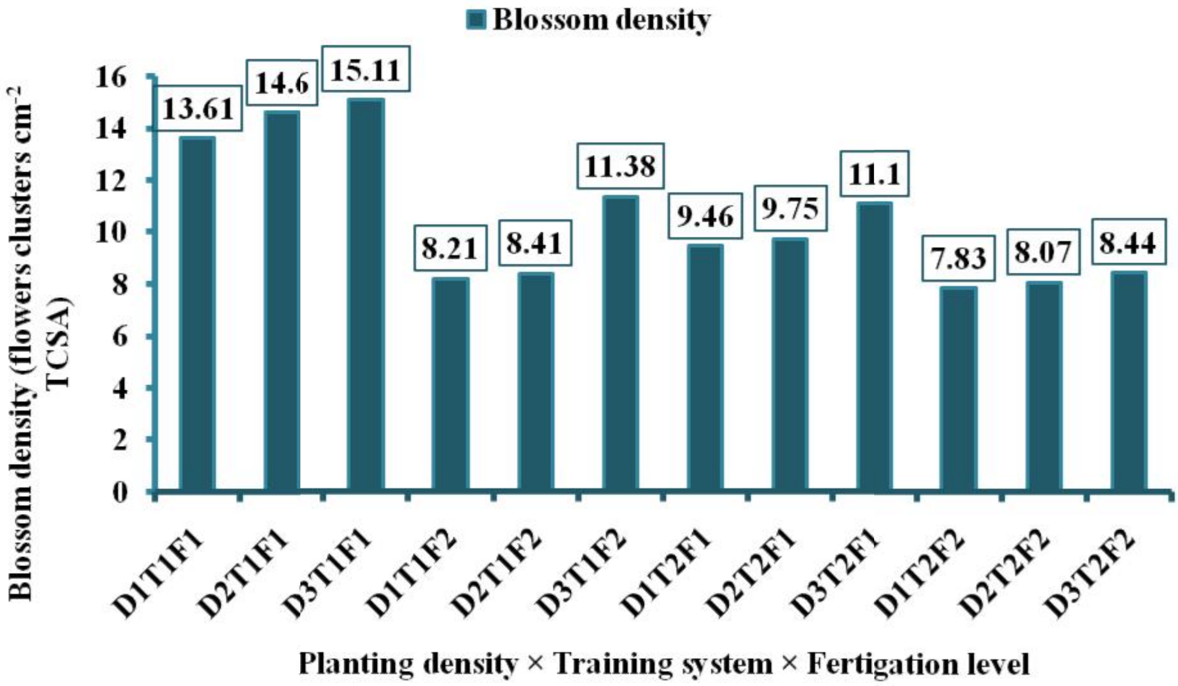

Fig. 4.7: Effect of different planting densities, training systems and fertigation levels on blossom density of apple cv. Jeromine

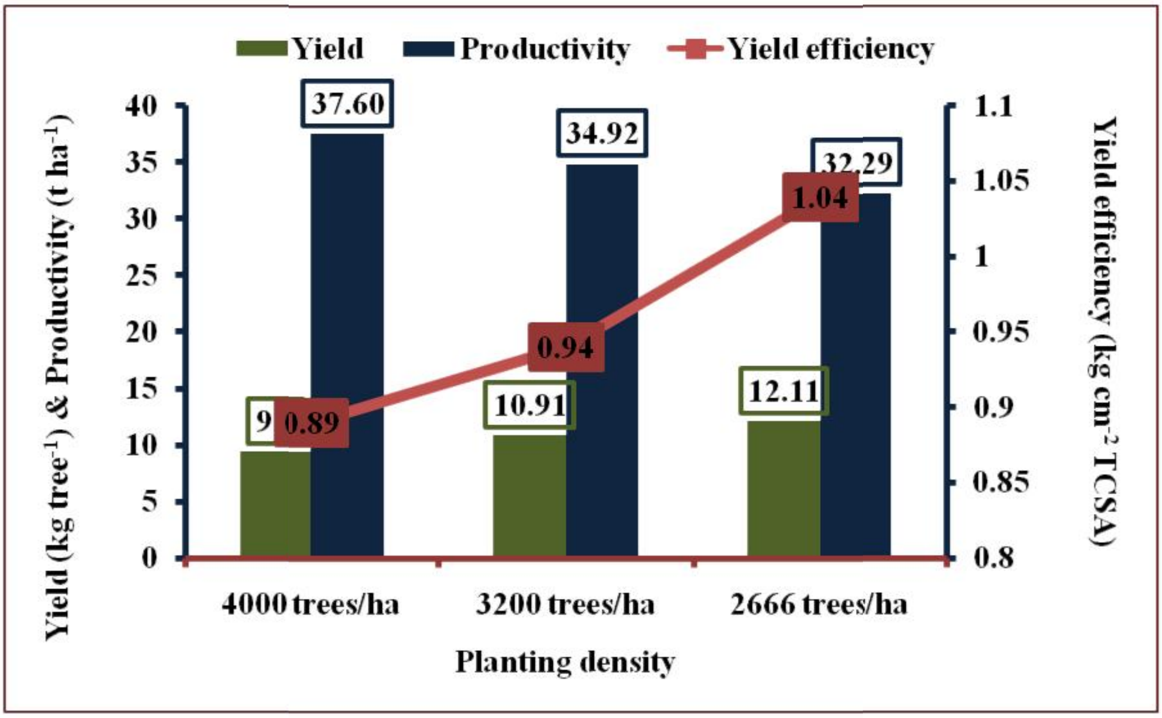

Fig. 4.8: Effect of different planting densities on yield, yield efficiency and productivity of apple cv. Jeromine

registered significantly less fruit drop of 69.39 per cent in comparison to the trees subjected under F_2 level of fertigation (72.51 %).

It is evident from the pooled data presented in Table 4.7 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the lowest fruit drop (65.52 %) was recorded in trees planted at density D_3, trained with Tall Spindle and subjected to F_1 fertigation level and the highest fruit drop (76.29 %) was observed in trees planted at density D_1, trained with Vertical Axis and fertigated with F_2 level.

4.1.2.5 Yield

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on yield recorded during 2019 and 2020 is presented in Appendix XX. It is inferred from the data that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on yield during both the years of study.

The pooled data of two years presented in Table 4.8 and Fig. 4.8 to 4.14 revealed that fruit yield per tree was significantly influenced by different planting densities, training systems, fertigation levels and their interactions. Among the planting densities, the highest fruit yield of 12.11 kg $tree^{-1}$ was obtained in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the lowest yield (9.40 kg $tree^{-1}$) was recorded in trees planted at D_1 (4000 trees/ha) density. In case of training systems, the trees trained with T_1 (Tall Spindle) registered significantly higher yield (11.47 kg $tree^{-1}$) than the trees trained with T_2 (Vertical Axis) training system (10.14 kg $tree^{-1}$). Considering the effect of fertigation levels, the maximum fruit yield of 11.36 kg $tree^{-1}$ was recorded in trees subjected under F_1 level of fertigation, which was significantly more as compared to the trees fertigated with F_2 level of fertigation (10.25 kg $tree^{-1}$).

Table 4.8: Effect of different planting densities, training systems and fertigation levels on yield and yield efficiency of apple cv. Jeromine

D \ T / F	Yield (kg tree^{-1})						Yield efficiency (kg cm^{-2} TCSA)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	10.53	9.49	**10.01**	9.22	8.36	**8.79**	1.12	0.88	**1.00**	0.83	0.75	**0.79**
D_2	12.16	10.98	**11.57**	10.77	9.74	**10.26**	1.21	0.93	**1.07**	0.84	0.79	**0.81**
D_3	13.56	12.10	**12.83**	11.93	10.84	**11.39**	1.27	1.13	**1.20**	0.92	0.84	**0.88**
Mean (T×F)	**12.08**	**10.86**		**10.64**	**9.65**		**1.20**	**0.98**		**0.86**	**0.79**	
Mean (T)	**11.47**			**10.14**			**1.09**			**0.83**		

D \ F	Yield: D × F			Yield efficiency: D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	9.88	8.92	**9.40**	0.97	0.81	**0.89**
D_2	11.47	10.36	**10.91**	1.02	0.86	**0.94**
D_3	12.75	11.47	**12.11**	1.09	0.98	**1.04**
Mean (F)	**11.36**	**10.25**		**1.03**	**0.89**	

$CD_{0.05}$	Yield	Yield efficiency
D	0.04	0.01
T	0.03	0.01
F	0.03	0.01
D×T	0.05	0.01
T×F	0.04	0.01
D×F	0.05	0.01
D×T×F	0.07	0.02

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The pooled data depicted in Table 4.8 and Fig. 4.11 & 4.12 showed that interaction effects of planting densities and training systems, and training systems and fertigation levels were significant on fruit yield per tree. Among planting densities and training systems interaction, the highest yield of 12.83 kg $tree^{-1}$ was achieved in trees planted at D_3 (2666 trees/ha) density and trained with Tall Spindle (D_3T_1), however, it was lowest (8.79 kg $tree^{-1}$) in trees planted at D_1 density and trained with Vertical Axis (D_1T_2). Similarly, in case of interaction between training systems and fertigation levels, the maximum yield (12.08 kg $tree^{-1}$) was recorded in trees trained with Tall Spindle and subjected under F_1 fertigation level (T_1F_1), whereas, the minimum yield (9.65 kg $tree^{-1}$) was observed in trees trained with Vertical Axis and subjected under F_2 level of fertigation (T_2F_2).

Pooled data of two years pertaining to the interactions between planting densities and fertigation levels, and planting densities, training systems and fertigation levels depicted in Table 4.8 and Fig. 4.13 & 4.14 showed significant influence on yield. Considering the interactions effect of planting densities and fertigation levels, the highest yield of 12.75 kg $tree^{-1}$ was recorded in trees planted at density D_3 (2666 trees/ha) and subjected under F_1 fertigation level (D_3F_1), while the lowest (8.92 kg $tree^{-1}$) was found in trees planted at density D_1 (4000 trees/ha) and fertigated with F_2 level (D_1F_2). Among three factors interaction, the highest yield of 13.56 kg $tree^{-1}$ was registered by the trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 fertigation level ($D_3T_1F_1$), however, the lowest (8.36 kg $tree^{-1}$) was recorded in trees planted at density D_1, trained with Vertical Axis and fertigated with F_2 level ($D_1T_2F_2$).

4.1.2.7 Yield efficiency

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXI) indicate that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on yield efficiency during both the years of study.

The pooled data on the effect of different planting densities, training systems and fertigation levels on yield efficiency are presented in Table 4.8 and Fig. 4.8 to

4.14. It is inferred from the data that individual effect of planting densities, training systems and fertigation levels and their interactions had significant effect on the yield efficiency. Among the planting densities, the highest yield efficiency (1.04 kg cm^{-2} TCSA) was observed in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities and the lowest (0.89 kg cm^{-2} TCSA) was recorded in trees planted at D_1 (4000 trees/ha) density. Considering the effect of training systems, the significantly higher yield efficiency of 1.09 kg cm^{-2} TCSA was observed in trees trained to T_1 (Tall Spindle) training system, which was significantly superior to T_2 (Vertical Axis) training system. In case of fertigation levels, significantly higher yield efficiency of 1.03 kg cm^{-2} TCSA was attained by the trees subjected under F_1 fertigation level as compared to the trees subjected under F_2 level of fertigation (0.89 kg cm^{-2} TCSA).

The pooled data depicted in Table 4.8 and Fig. 4.11 to 4.14 reveal that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on yield efficiency were significant. Among the planting densities and training systems interactions, the highest yield efficiency of 1.20 kg cm^{-2} TCSA was registered by the trees planted at D_3 (2666 trees/ha) density and trained with Tall Spindle (D_3T_1), which was significantly higher than all other treatment combinations. However, the lowest (0.79 kg cm^{-2} TCSA) was observed in trees planted at D_1 (4000 trees/ha) density and trained with Vertical Axis (D_1T_2). In case of interactions between training systems and fertigation levels, the highest yield efficiency (1.20 kg cm^{-2} TCSA) was recorded in trees trained with Tall Spindle and subjected under F_1 fertigation level (T_1F_1). However, the lowest (0.79 kg cm^{-2} TCSA) yield efficiency was observed in trees trained with Vertical Axis and subjected under F_2 level of fertigation (T_2F_2). Considering the interactions effect of planting densities and fertigation levels, the significantly highest yield efficiency (1.09 kg cm^{-2} TCSA) was recorded in trees planted at D_3 (2666 trees/ha) planting density and subjected under F_1 level of fertigation (D_3F_1), whereas, the lowest (0.81 kg cm^{-2} TCSA) was observed in trees planted at density D_1 (4000 trees/ha) and subjected to F_2 level of fertigation (D_1F_2). Among the three factors interaction, the highest yield efficiency of 1.27 kg cm^{-2} TCSA was obtained in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation ($D_3T_1F_1$), which was significantly

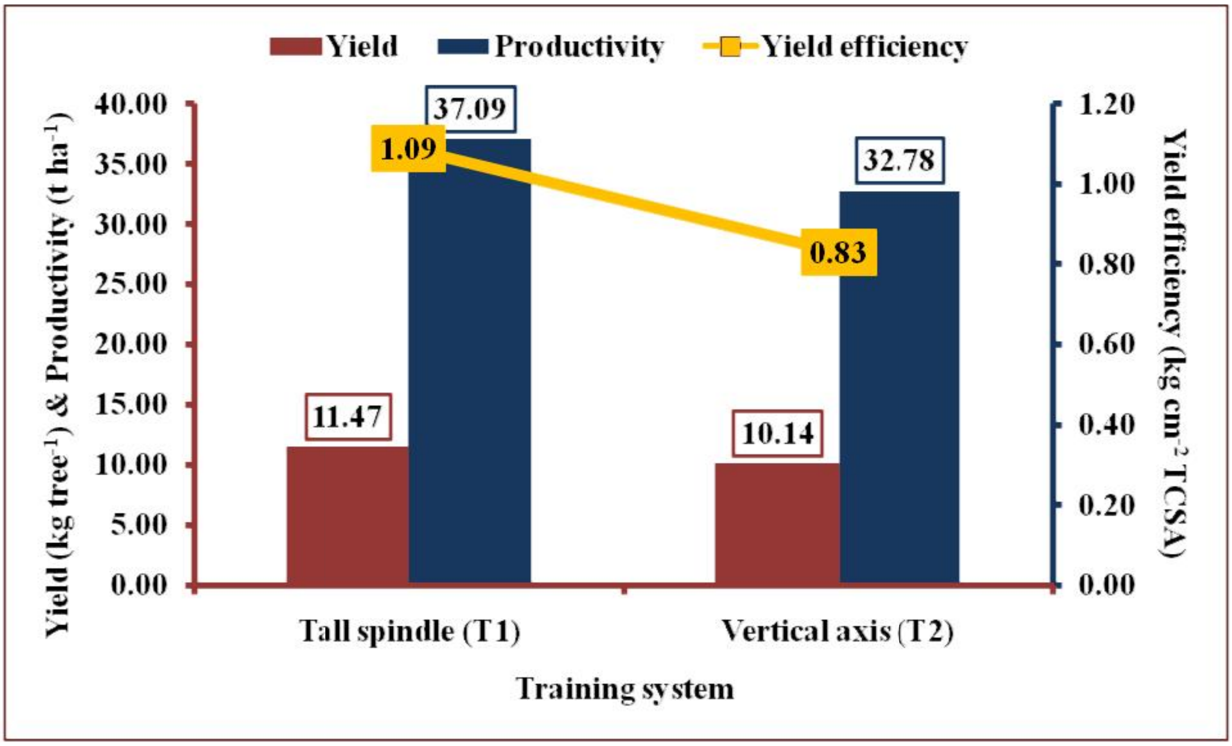

Fig. 4.9: Effect of different training systems on yield, yield efficiency and productivity of apple cv. Jeromine

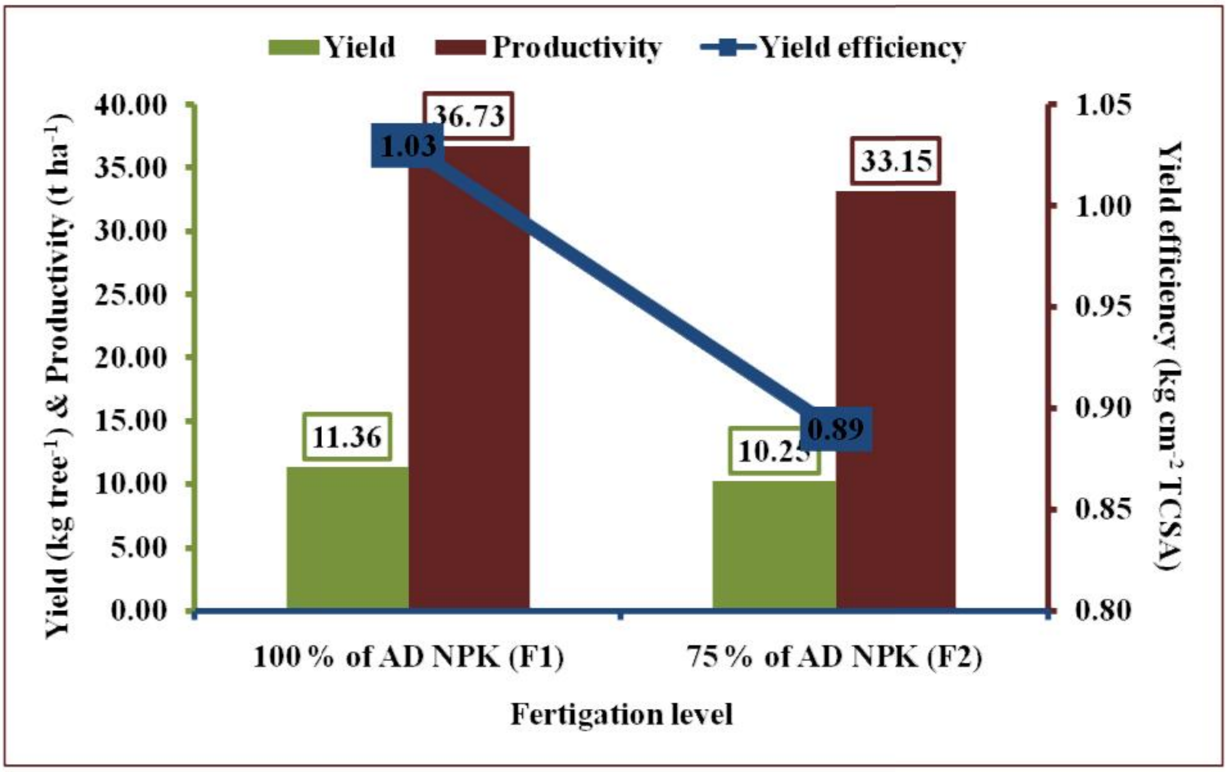

Fig. 4.10: Effect of different fertigation levels on yield, yield efficiency and productivity of apple cv. Jeromine

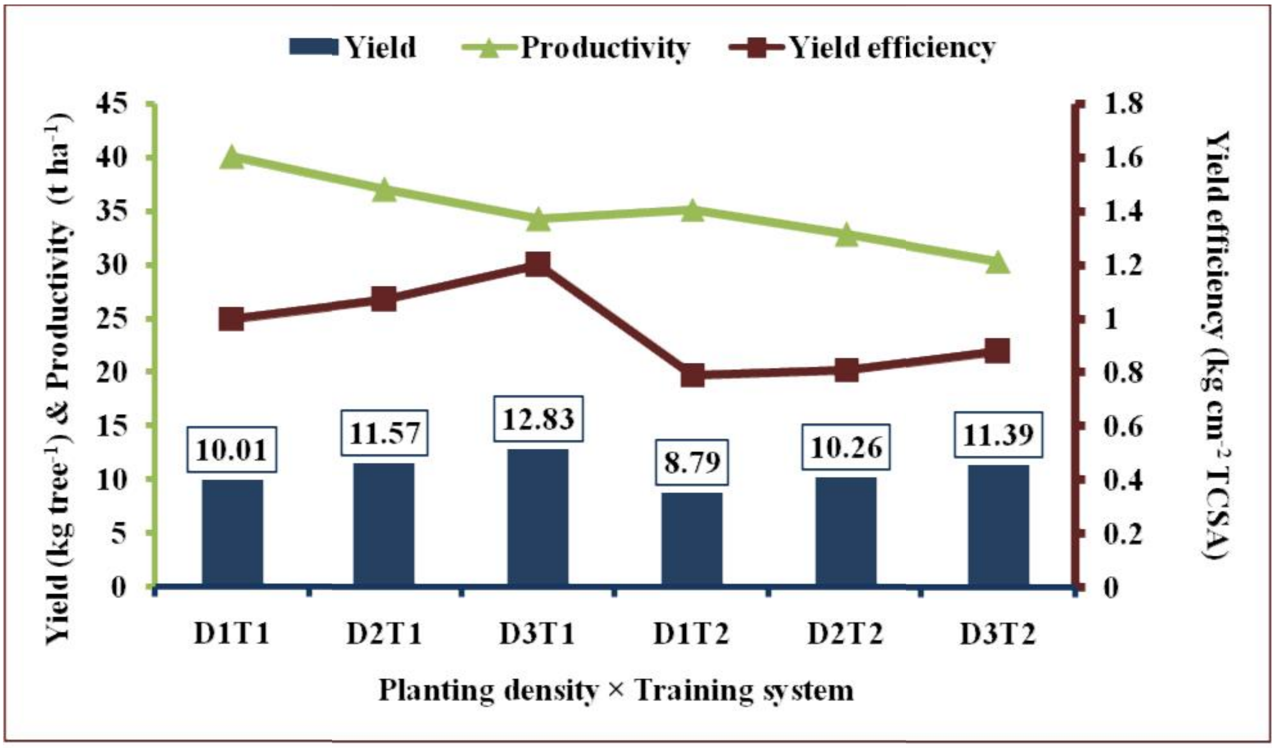

Fig. 4.11: Effect of different planting densities and training systems on yield, yield efficiency and productivity of apple cv. Jeromine

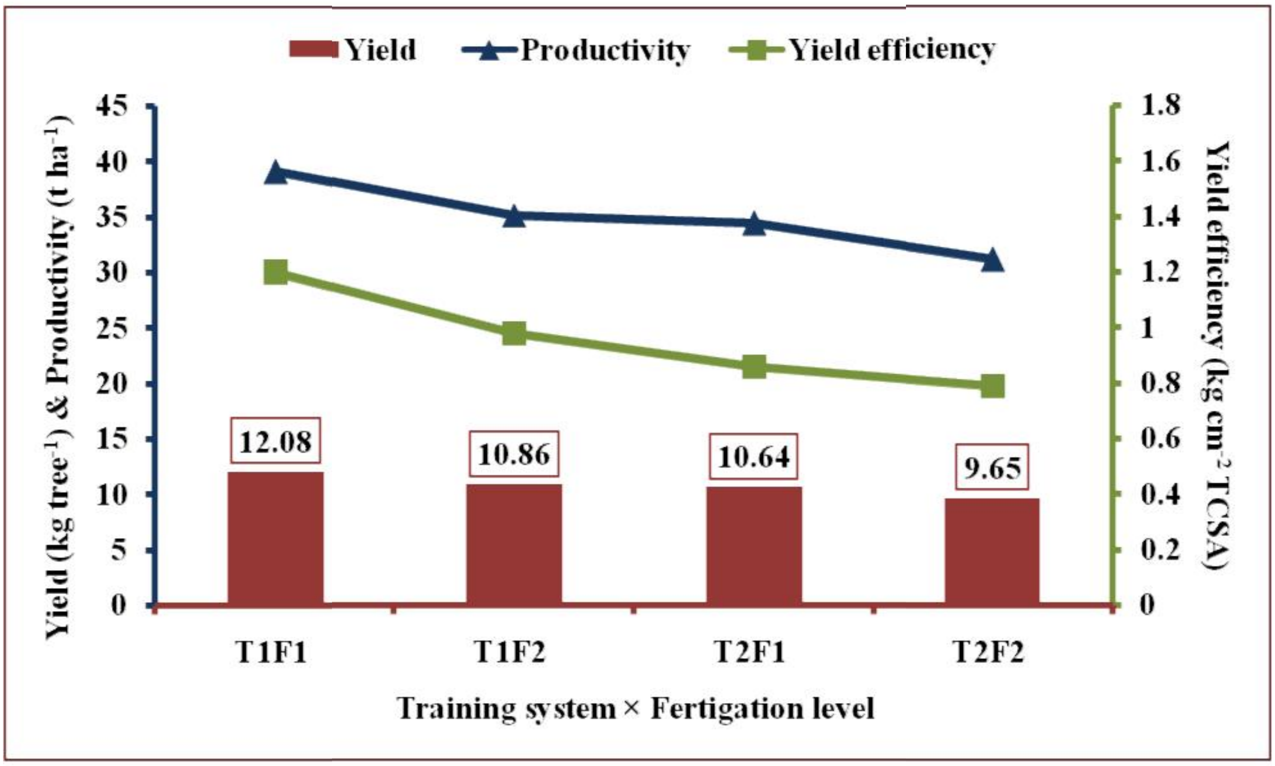

Fig. 4.12: Effect of different training systems and fertigation levels on yield and yield efficiency of apple cv. Jeromine

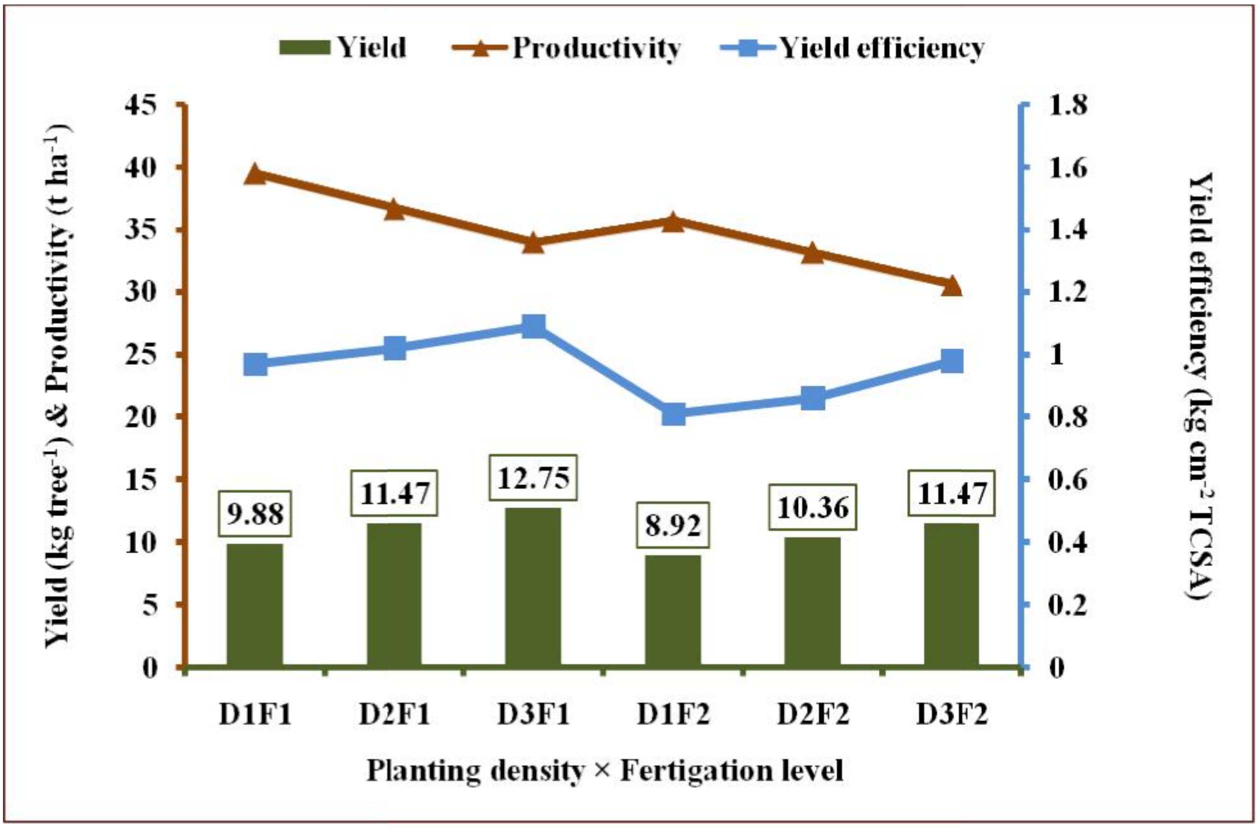

Fig. 4.13: Effect of different planting densities and fertigation levels on yield and yield efficiency of apple cv. Jeromine

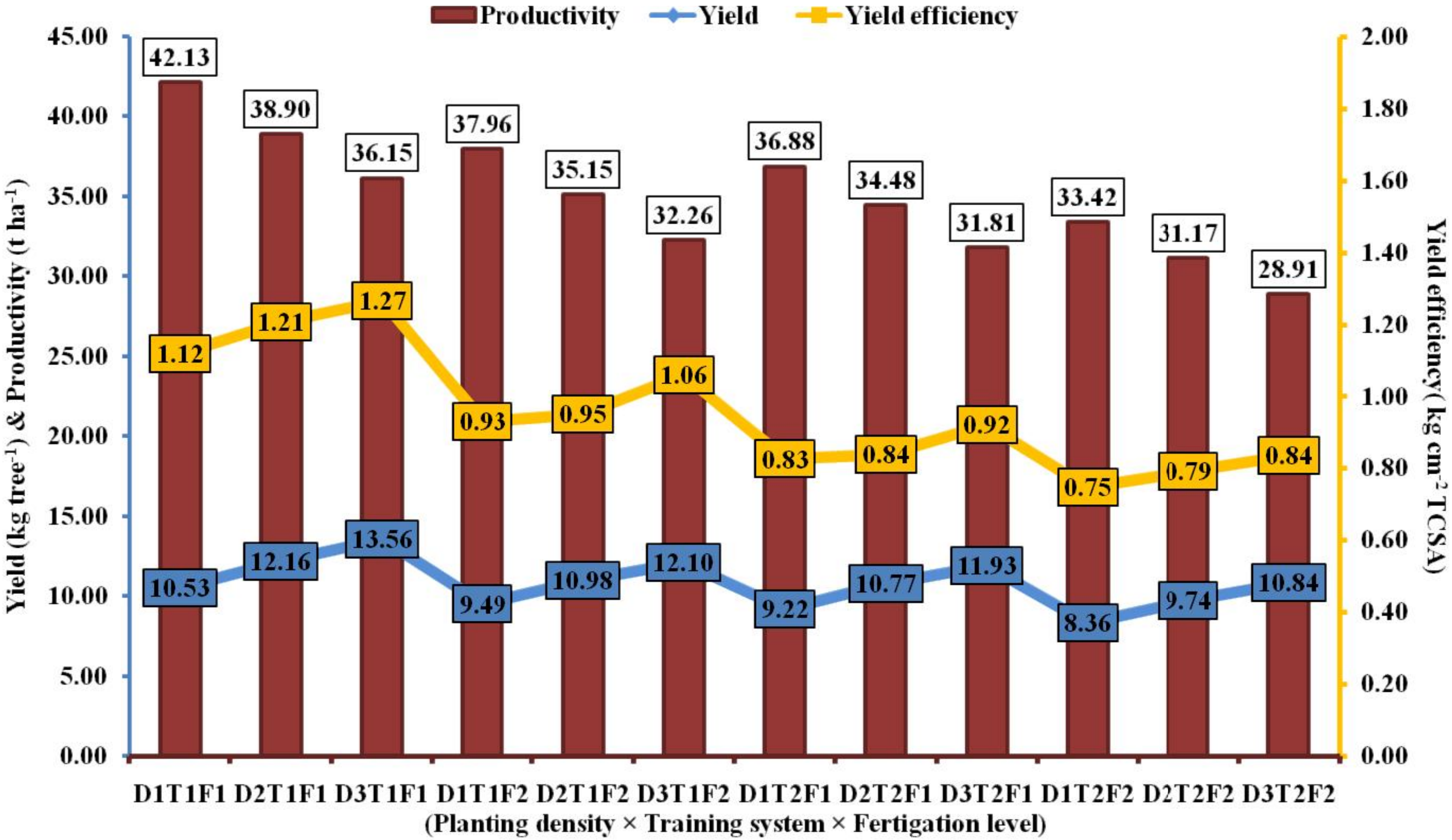

Fig. 4.14: Effect of different planting densities, training systems and fertigation levels on yield, yield efficiency and productivity of apple cv. Jeromine

Plate 7: Fruiting in 2666 trees ha^{-1} planting density (2.5 × 1.50 m), trained with Tall Spindle and subjected under F_1 level of fertigation

Plate 8: Fruiting in 4000 trees ha^{-1} planting density (2.5 × 1.00 m), trained with Tall Spindle and subjected under F_1 level of fertigation

higher than all treatment combinations and the lowest (0.75 cm^{-2} TCSA) was noted in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation ($D_1T_2F_2$).

4.1.2.6 Productivity

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on productivity recorded during 2019 and 2020 have been presented in Appendix XXII. It indicates that planting densities, training systems, fertigation levels and their interactions exerted a significant effect on productivity during both the years of study.

A critical appraisal of pooled data of two years presented in Table 4.9 and Fig. 4.8 to 4.14 indicates that different planting densities, training systems and fertigation levels and their interactions had significant effect on productivity. Considering the effect of planting densities, the highest productivity (37.60 t ha^{-1}) was recorded in D_1 (4000 trees/ha) planting density, which was significantly higher than planting density of D_2 (3200 trees/ha) and D_3 (2666 trees/ha). However, the lowest productivity of 32.29 t ha^{-1} was found in D_3 (2666 trees/ha) planting density. Among the training systems, the trees trained to T_1 (Tall Spindle) training system registered significantly higher productivity (37.09 t ha^{-1}) as compared to the trees trained with T_2 (Vertical Axis) training system (32.78 t ha^{-1}). Considering the effect of fertigation levels, the significantly higher productivity (36.73 t ha^{-1}) was obtained from the trees subjected under F_1 fertigation level than the trees subjected with F_2 level of fertigation (33.15 t ha^{-1}).

The pooled data depicted in Table 4.9 and Fig. 4.11 to 4.14 showed that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on productivity were found significant. Among the planting densities and training systems interaction, the highest productivity of 40.05 t ha^{-1} was recorded in trees planted at density of D_1 (4000 trees/ha) and trained with Tall Spindle (D_1T_1), which was significantly superior to other interactions. However, the lowest productivity (30.36 t ha^{-1}) was observed in trees planted at D_3 density (2666 trees/ha) and trained with Vertical Axis (D_3T_2). In case of training

Table 4.9: Effect of different planting densities, training systems and fertigation levels on productivity of apple cv. Jeromine

D \ T / F	Productivity (t ha^{-1})								
	T_1			T_2			D × F		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D)**
D_1	42.13	37.96	**40.05**	36.88	33.42	**35.15**	39.51	35.69	**37.60**
D_2	38.90	35.15	**37.02**	34.48	31.17	**32.82**	36.69	33.16	**34.92**
D_3	36.15	32.26	**34.21**	31.81	28.91	**30.36**	33.98	30.59	**32.29**
Mean (T×F)	**39.06**	**35.12**		**34.39**	**31.17**		**36.73**	**33.15**	**Mean (F)**
Mean (T)	**37.09**			**32.78**					

$CD_{0.05}$	D	0.11	T	0.09	F	0.09	D×T	0.15	T×F	0.12	D×F	0.15	D×T×F	0.21

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

systems and fertigation levels interaction, the maximum productivity of 39.06 t ha^{-1} was recorded under trees trained with Tall Spindle and subjected to F_1 fertigation level (T_1F_1), however, the lowest productivity (31.17 t ha^{-1}) was observed under Vertical Axis trained trees subjected to F_2 fertigation level (T_2F_2). Considering the interactions effect of planting densities and fertigation levels, highest productivity (39.51 t ha^{-1}) was registered by the trees planted at D_1 density and subjected under F_1 fertigation level (D_1F_1), while the lowest (30.59 t ha^{-1}) was noted in trees planted at D_3 density and fertigated with F_2 level (D_3F_2). Among three factors interaction, the significantly highest productivity of 42.13 t ha^{-1} was obtained in trees planted at density of D_1, trained with Tall Spindle and subjected under F_1 fertigation level ($D_1T_1F_1$), however, the lowest (28.91 t ha^{-1}) was noticed in trees planted at density of D_3, trained with Vertical Axis and subjected under F_2 level of fertigation ($D_3T_2F_2$).

In the present investigation, fruiting parameters such as spur density, blossom density, fruit set, yield and yield efficiency were significantly affected by the planting densities, training systems and fertigation levels. The maximum spur and blossom density, fruit set and yield was obtained in planting density of 2666 trees/ha, which decreased with the increase in planting density. This might be due to poor penetration of light in the canopy under more dense planting, resulting in to reduced spur formation as proper distribution of sunlight is essential or beneficial for flower bud initiation and flowering (Westwood, 1993). The more spur formation, flowering, fruit set and yield under low density could be attributed due to proper light interception, higher photosynthesis rate, resulting in to higher accumulation of carbohydrates and minerals reserves in the trees, which is further used in flower bud initiation, flowering and fruit set (Jackson and Palmer, 1977). The results of present study are in accordance with the findings of Dhiman *et al.* (2018), who recorded highest spur density, flowering intensity, fruit set and yield in low density of apple as compared to higher density, however productivity increased with higher tree density. These results are in agreement with the findings of Saoir *et al.* (2014), who reported that fruit yield per tree was higher in low density but yield per hectare increased with the increase in planting densities.

In the present study, trees trained with Tall Spindle had higher spur density, blossom density, fruit set and yield as compared to Vertical Axis. In Tall Spindle training system, bending of shoots below horizontal reduce the vigour and increases the proportion of the buds that become floral resulting in to more flower bud formation. The spur formation is positively correlated with total light interception and photosynthesis, higher light interception influences the better fruit bud differentiation in branches (Buler and Mika, 2009). The better light interception and photosynthesis in Tall Spindle system of training may accounted for higher flower bud formation, fruit set, yield and productivity.

These results are in conformity with the studies of Lordan *et al*. (2018) and Reig *et al.* (2019), who reported highest cumulative yield in trees under highest planting density trained with Tall Spindle. Similarly, Robinson and Dominguez (2014) also reported that the yield, fruit set and yield efficiency were best in Tall Spindle training system in comparison to Modified Spanish Bush system. Several studies on the same line were reported by Hampson *et al*. (2002), Robinson *et al*. (1991), Robinson (2003; 2007) and Lordan *et al*. (2018), where yield/ha increased with the high density planting in apple.

The findings of the present study is in consonance with the work of Raina *et al.* (2013), Kumar *et al.* (2016) and Thakur *et al.* (2020), who reported highest flowering intensity, fruit set, yield and lowest fruit drop with the application of higher rate of NPK fertigation [100 % of AD (NPK)] in apple. This might be attributed to the reason that frequent application of nutrients through fertigation near the root zone of trees resulted in to increased uptake of nutrients particularly during the flowering, fruit set and fruit development stages, which significantly improved fruit set and retention. Fertigation near the root zone always maintains optimum soil moisture.

Nitrogen application might have increased the supply of auxin, which inhibits the formation of abscission zone in fruits and hence increased the fruit retention (Addicot, 1970). Higher fruit set and yield with higher dose of fertigation treatment might be due to higher fertilizer use efficiency and higher uptake of nutrients (N, P and K). Under optimum nutrient conditions, growth hormones like auxin, gibberellins and cytokinins are produced, which further increases the nutrient uptake and translocation of assimilates aiding towards increased yield. The present findings are in line with those of Raina *et al.* (2013) and Zhong *et al.* (2019) in apple.

4.1.3 Fruit quality parameters

4.1.3.1 Fruit length

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXIII) indicate that different treatments had a significant effect on fruit length during both the years of study, however, their interactions were found non-significant.

The pooled data of two years presented in Table 4.10 also revealed that planting densities, training systems and fertigation levels exhibited significant effect on fruit length, however, their interactions were found to be non-significant. Considering the effect of planting densities, the highest fruit length (63.63 mm) was recorded in trees planted at D_3 (2666 trees/ha), which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. The lowest fruit length (54.87 mm) was observed in planting density of D_1 (4000 trees/ha). Among the training systems, the trees trained with T_1 (Tall Spindle) training system registered significantly higher fruit length of 61.07 mm in comparison to the trees trained with T_2 (Vertical Axis) training system (57.49 mm). In case of fertigation, the trees subjected under F_1 fertigation level exhibited significantly more fruit length (61.36 mm) than the trees subjected under F_2 level of fertigation (57.21 mm).

It is evident from the pooled data presented in Table 4.10 that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the highest fruit length (68.12 mm) was recorded in trees planted at density D_3, trained with Tall Spindle and subjected under F_1 fertigation level and the lowest (51.81 mm) was noted in trees planted at density D_1, trained with Vertical axis and fertigated with F_2 level.

4.1.3.2 Fruit diameter

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on fruit diameter recorded during 2019 and 2020 are depicted in Appendix XXIV. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on fruit diameter during both the years of study, however, their interactions were found non-significant.

Table 4.10: Effect of different planting densities, training systems and fertigation levels on fruit length and diameter of apple cv. Jeromine

D \ T / F	Fruit length (mm)						Fruit diameter (mm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	58.71	54.26	**56.48**	54.73	51.81	**53.27**	62.78	59.16	**60.97**	60.30	57.54	**58.97**
D_2	63.88	58.81	**61.34**	58.97	55.72	**57.34**	68.85	66.25	**67.55**	66.73	62.76	**64.75**
D_3	68.12	62.68	**65.40**	63.74	59.98	**61.86**	75.50	71.64	**73.57**	72.67	68.87	**70.77**
Mean (T×F)	**63.57**	**58.58**		**59.14**	**55.83**		**69.04**	**65.68**		**66.60**	**63.06**	
Mean (T)	**61.07**			**57.49**			**67.36**			**64.83**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	1.69	F_1	F_2	Mean (D)	D	1.87
D_1	56.72	53.03	**54.87**	T F	1.38 1.38	61.59	58.35	**59.97**	T F	1.53 1.53
D_2	61.42	57.26	**59.34**	D×T	NS	67.79	64.51	**66.15**	D×T	NS
D_3	62.93	61.33	**63.63**	T×F D×F	NS NS	74.09	70.25	**72.17**	T×F D×F	NS NS
Mean (F)	**61.36**	**57.21**		D×T×F	NS	**67.82**	**64.37**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

From the perusal of the pooled data of two years presented in Table 4.10, it is clear that the different planting densities, training systems and fertigation levels exhibited significant effect on fruit diameter, however, their interactions were found non-significant. Among the planting densities, the maximum fruit diameter (72.17 mm) was observed in trees planted at D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the minimum fruit diameter (59.97 mm) was observed in D_1 (4000 trees/ha) planting density. In case of training systems, the significantly higher fruit diameter (67.36 mm) was observed in T_1 (Tall Spindle) training system as compared to the trees trained with T_2 (Vertical Axis) training system (64.83 mm). Similarly, the trees subjected to F_1 fertigation level recorded significantly higher fruit diameter of 67.82 mm in comparison to the trees subjected under F_2 level of fertigation (64.37 mm).

It is apparent from the pooled data presented in Table 4.10 that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest fruit diameter (75.50 mm) was registered by the trees planted at density D_3, trained with Tall Spindle and subjected under F_1 fertigation level and the lowest (57.54 mm) was observed in trees planted at density D_1, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.1.3.3 Fruit weight

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXV) reveal that planting densities, training systems and fertigation levels exerted a significant effect on fruit weight during both the years of study, however, their interactions were found non-significant.

The perusal of the pooled data of two years given in Table 4.11 reveals that different planting densities, training systems and fertigation levels exhibited significant effect on fruit weight. Among the planting densities, the highest fruit weight (151.97 g) was observed in trees planted at D_3 (2666 trees/ha) density, which was significantly superior to D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest (133.19 g) fruit weight was observed in trees planted at D_1 (4000 trees/ha) planting density. In case of training systems, the significantly higher fruit weight (145.27 g) was attained by the trees trained with T_1 (Tall Spindle) training system as compared to the trees trained with T_2 (Vertical Axis) training system (140.39 g). Considering the effect of fertigation, the trees subjected under F_1 fertigation level registered significantly higher fruit weight (144.90 g) than the trees fertigated with F_2 level of fertigation (140.76 g).

It is apparent from the pooled data presented in Table 4.11 that interaction between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels in respect of fruit weight were found to be non-significant. However, among three factors interaction, the highest fruit weight (156.32 g) was recorded in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 fertigation level and the lowest (128.99 g) was found in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.1.3.4 Fruit volume

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on fruit volume recorded during 2019 and 2020 are given in Appendix XXVI. It reveals that planting densities, training systems and fertigation levels exerted a significant effect on fruit volume during both the years of study.

The perusal of pooled data of two years given in Table 4.11 reveals that the different planting densities, training systems and fertigation levels individually exerted significant effect on fruit volume, while their interactions were found non-significant. The maximum fruit volume of 186.15 cm^3 was obtained in trees planted at D_3 (2666 trees/ha) density and the minimum (156.89 cm^3) was recorded in D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the significantly higher fruit volume of 174.36 cm^3 was registered by the trees trained with T_1 (Tall Spindle) training system in comparison to the trees trained with T_2 (Vertical Axis) training system (168.93 cm^3). Similarly, in case of fertigation, the trees subjected under F_1 fertigation level recorded higher fruit volume (176.08 cm^3), which was significantly superior to the trees subjected under F_2 level of fertigation (167.21 cm^3).

Table 4.11: Effect of different planting densities, training systems and fertigation levels on fruit weight and volume of apple cv. Jeromine

D \ T / F	Fruit weight (g)						Fruit volume (cm^3)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	137.10	134.13	**135.61**	132.57	128.99	**130.78**	162.45	155.91	**159.18**	158.30	150.91	**154.60**
D_2	148.23	144.05	**146.14**	142.91	138.15	**140.53**	178.97	170.99	**174.98**	174.12	163.51	**168.81**
D_3	156.32	151.81	**154.06**	152.32	147.43	**149.88**	194.31	183.56	**188.93**	188.34	178.39	**183.36**
Mean (T×F)	**147.21**	**143.33**		**142.60**	**138.19**		**178.57**	**170.15**		**173.59**	**164.27**	
Mean (T)	**145.27**			**140.39**			**174.36**			**168.93**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	**Mean (D)**	D	1.08	F_1	F_2	**Mean (D)**	D	4.38
D_1	134.80	131.56	**133.19**	T	0.88	160.38	153.41	**156.89**	T	3.58
D_2	145.57	141.10	**143.33**	F	0.88	176.54	167.25	**171.90**	F	3.58
D_3	154.32	149.62	**151.97**	D×T	NS	191.32	180.97	**186.15**	D×T	NS
Mean (F)	**144.90**	**140.76**		T×F	NS	**176.08**	**167.21**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

It is clear from the pooled data presented in Table 4.11 that the interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest fruit volume (194.31 cm^3) was recorded in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation and the lowest (150.91 cm^3) was observed in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

The data reveals that different planting densities, training systems and fertigation levels significantly influenced the fruit size, weight and volume during both the years of study. The highest fruit length, diameter, weight and volume were recorded in trees planted at D_3 density, trained with Tall Spindle and subjected to 100 % of AD (NPK) fertigation dose. The results revealed that the fruit size, weight and volume increased significantly with the increase in tree spacing. The trees planted at a density of D_3 (2666 trees/ha) produced the fruits of bigger size, weight and volume than the high density planting of D_1 (4000 trees/ha). These results are in accordance with the findings of Dhiman *et al.* (2018), Lordan *et al.* (2018) and Reig *et al.* (2019), who recorded bigger size and weight of fruits harvested from low density planting in comparison to high density planting. Similarly, Costa *et al.* (1997), Szczygie *et al.* (2001), Pramanick *et al.* (2012), Srivastava *et al.* (2017) also reported that under highest density planting of apple, the fruits were of smaller in size and weight.

The higher fruit size, weight and volume were recorded in trees trained with Tall Spindle training system. These results are in conformity with those of Lordan *et al.* (2018) and Reig *et al.* (2019), who also found increased fruit size and weight in trees trained with Tall Spindle training system. The fruits of bigger size and weight in Tall Spindle could be due to better light interception within the tree canopy and higher rate of photosynthesis and synthesis of more carbohydrates. However, the results are in contrary with the findings of Hampson *et al.* (2002), who reported that the fruit size and weight were not significantly influenced by different training systems.

The fruit size, weight and volume were increased with the increased doses of fertilizer and the highest fruit size, weight and volume were obtained under application of 100 % of AD (NPK) through fertigation. Nitrogen is an essential constituent of chlorophyll and increase in chlorophyll content would enhanced the

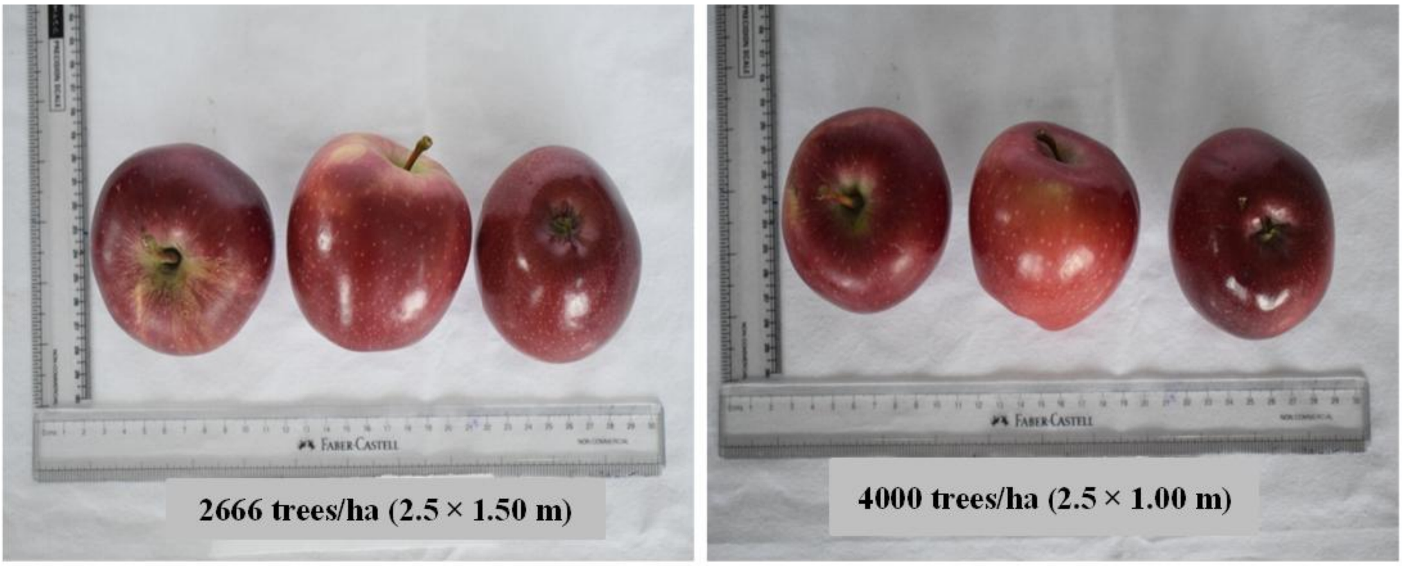

Plate 9: Fruit size under different planting densities

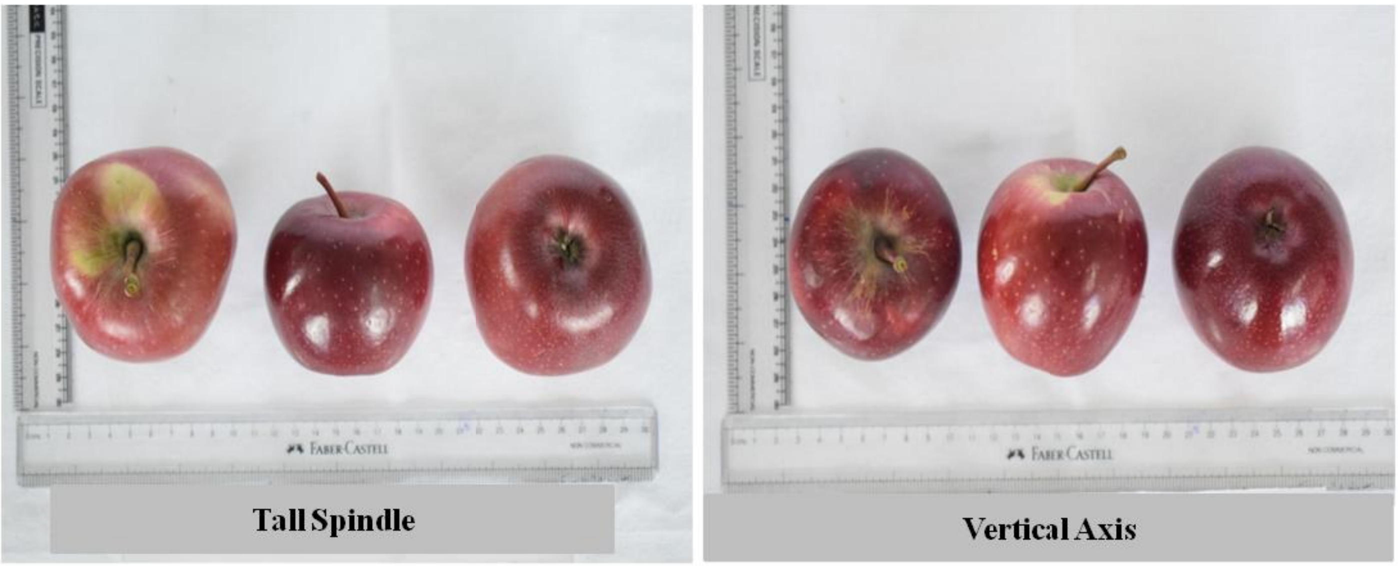

Plate 10: Fruit size under different training systems

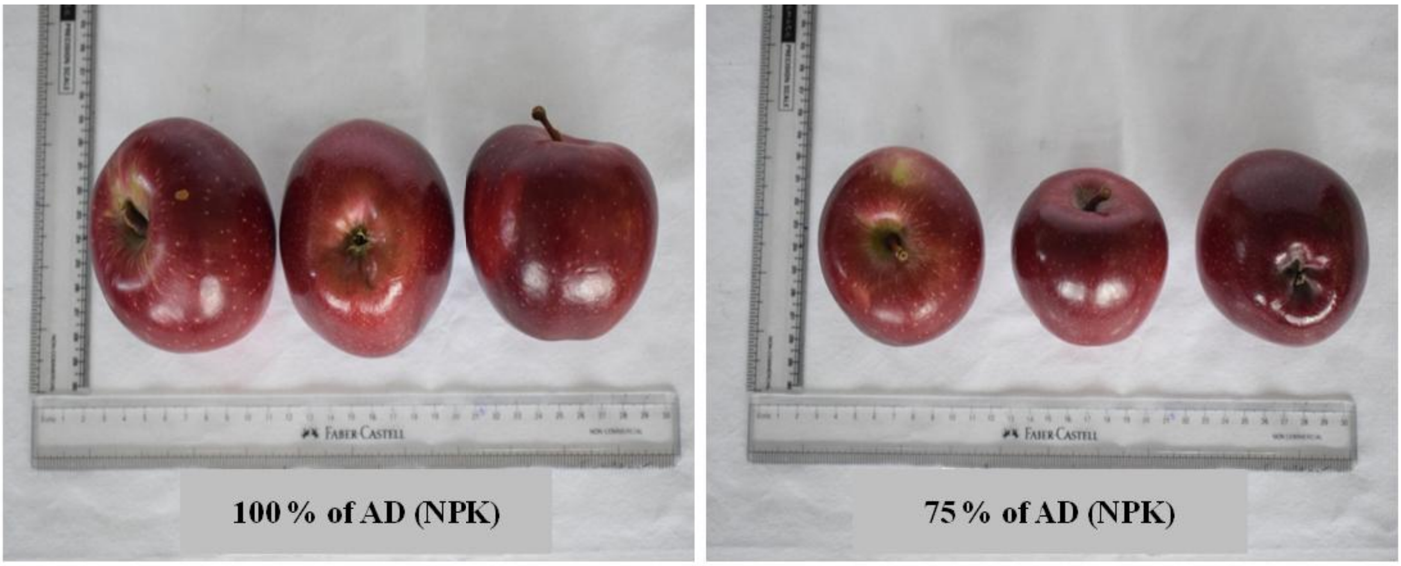

Plate 11: Fruit size under different fertigation levels

Plate 12: Fruit size under different treatment combinations

rate of photosynthesis, which could have further led to the better partitioning of assimilates and further resulting in to increased size, weight and volume of apple fruits. The results of Banyal and Sharma (2012), Banyal *et al.* (2015), Kumar *et al.* (2016), Fallahi *et al.* (2018) and Thakur *et al.* (2020) are in accordance with the present findings.

4.1.3.5 Fruit firmness

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXVII) reveal that planting densities and fertigation levels exerted a significant effect on fruit firmness during both the years of study, however, effect of training systems and their interactions were found non-significant.

The perusal of the pooled data of two years given in Table 4.12 also reveals that different planting densities and fertigation levels individually had significant influence on fruit firmness, however, training systems and their interactions were non-significant. Among the planting densities, the highest fruit firmness (5.41 kg cm^{-2}) was observed in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the lowest fruit firmness of 4.67 kg cm^{-2} was found in the trees planted at density of D_1 (4000 trees/ha). In case of training systems, the trees trained with T_2 (Vertical Axis) training system recorded higher fruit firmness (5.14 kg cm^{-2}), which did not differ significantly from T_2 (Tall Spindle) training system (4.98 kg cm^{-2}). Considering the effect of fertigation levels, the trees subjected to F_2 fertigation level showed significantly higher fruit firmness (5.26 kg cm^{-2}) as compared to the trees fertigated with F_1 level of fertigation (4.85 kg cm^{-2}).

It is apparent from the pooled data depicted in Table 4.12 that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest fruit firmness (5.70 kg cm^{-2}) was recorded in trees planted at D_3 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

Table 4.12: Effect of different planting densities, training systems and fertigation levels on fruit firmness and total soluble solids of apple cv. Jeromine

D \ T / F	Fruit firmness (kg cm^{-2})						Total soluble solids (^{o}Brix)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	4.32	4.85	**4.58**	4.49	5.03	**4.76**	10.84	9.85	**10.34**	10.27	9.59	**9.93**
D_2	4.83	5.22	**5.03**	5.03	5.29	**5.16**	11.46	10.84	**11.15**	11.06	10.29	**10.67**
D_3	5.15	5.50	**5.33**	5.29	5.70	**5.49**	11.91	11.46	**11.70**	11.84	11.16	**11.48**
Mean (T×F)	**4.77**	**5.19**		**4.94**	**5.34**		**11.41**	**10.72**		**11.04**	**10.35**	
Mean (T)	**4.98**			**5.14**			**11.06**			**10.69**		

D \ F	Fruit firmness: D × F			Total soluble solids: D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	4.41	4.94	**4.67**	10.55	9.72	**10.14**
D_2	4.93	5.25	**5.09**	11.26	10.57	**10.91**
D_3	5.22	5.60	**5.41**	11.88	11.31	**11.59**
Mean (F)	**4.85**	**5.26**		**11.23**	**10.53**	

$CD_{0.05}$	Fruit firmness	Total soluble solids
D	0.29	0.11
T	NS	0.09
F	0.24	0.09
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

4.1.3.6 Total soluble solids

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on TSS recorded during 2019 and 2020 are presented in Appendix XXVIII. It indicates that planting densities, training systems and fertigation levels exerted a significant effect on total soluble solids during both the years of study, however, their interactions were found non-significant.

From the perusal of the pooled data of two years presented in Table 4.12, it is clear that different planting densities, training systems and fertigation levels exhibited significant effect on total soluble solids, however, their interactions were found non-significant. Among the planting densities, the maximum total soluble solids (11.59 ^{o}B) was observed in the fruits obtained from trees planted at D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the minimum total soluble solids of 10.14 ^{o}B was found in the fruits from trees planted at D_1 (4000 trees/ha) planting density. In case of training systems, the fruits harvested from trees trained with T_1 (Tall Spindle) training system registered the higher total soluble solids (11.06 ^{o}B) as compared to the the fruits from trees trained with T_2 (Vertical Axis) training system (10.69 ^{o}B). Considering the effect of fertigation levels, the significantly higher total soluble solids (11.23 ^{o}B) was attained by the fruits harvested from the trees subjected under F_1 fertigation level.

The pooled data presented in Table 4.12 also reveals that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest total soluble solids (11.91 ^{o}B) was recorded in the fruits obtained from trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation and the lowest (9.59 ^{o}B) was noted in the fruits from trees at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.1.3.7 Titratable acidity

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXIX) indicate that planting densities, training systems and fertigation levels exerted a significant effect on titratable acidity during both the years of study, however, their interactions were found non-significant.

An inquisition of pooled data of two years presented in Table 4.13 clearly indicates that planting densities, training systems and fertigation levels individually had a significant effect on titratable acidity, however, their interactions were found non-significant. In case of planting densities, the lowest titratable acidity of fruit juice (0.32 %) was observed in trees planted at density D_3 (2666 trees/ha), which was significantly lower than the D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the highest titratable acidity (0.59 %) was observed in fruit juice of trees planted at D_1 (4000 trees/ha) planting density. Among the training systems, T_1 (Tall Spindle) training system registered significantly lower titratable acidity of fruit juice (0.41 %) and it was higher in fruits harvested from the trees trained with T_2 (Vertical Axis) training system (0.49 %). Considering the effect of fertigation levels, fruits from the trees subjected under F_1 level of fertigation showed significantly lower titratable acidity (0.41 %) as compared to the trees subjected under F_2 level of fertigation (0.49 %).

The pooled data presented in Table 4.13 indicate that interaction effects of planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the lowest titratable acidity (0.25 %) in the fruit juice was registered by the trees planted at density D_3, trained with Tall Spindle and subjected under F_1 fertigation level and the highest (0.69 %) was noted in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.1.3.8 Total sugars

The data cited in Appendix XXX recorded during 2019 and 2020 reveal that planting densities, training systems and fertigation levels exerted a significant effect on total sugars content during both the years of study, however, their interactions were found non-significant.

The perusal of pooled data of two years displayed in Table 4.13 indicates that planting densities, training systems and fertigation levels individually had a significant effect on total sugars content, however, their interactions were found non-

Table 4.13: Effect of different planting densities, training systems and fertigation levels on titratable acidity and total sugars of apple cv. Jeromine

D \ T / F	Titratable acidity (%)						Total sugars (%)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.51	0.57	**0.54**	0.61	0.69	**0.65**	8.99	8.42	**8.70**	8.72	7.90	**8.31**
D_2	0.38	0.44	**0.41**	0.41	0.52	**0.46**	9.43	9.01	**9.22**	9.18	8.66	**8.92**
D_3	0.25	0.30	**0.27**	0.33	0.42	**0.37**	10.15	9.74	**9.94**	9.84	9.18	**9.51**
Mean (T×F)	**0.38**	**0.43**		**0.45**	**0.54**		**9.52**	**9.06**		**9.25**	**8.58**	
Mean (T)	**0.41**			**0.49**			**9.29**			**8.91**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.04	F_1	F_2	Mean (D)	D	0.21
D_1	0.56	0.63	**0.59**	T F	0.04 0.04	8.85	8.16	**8.51**	T F	0.17 0.17
D_2	0.39	0.48	**0.44**	D×T T×F	NS NS	9.31	8.83	**9.07**	D×T T×F	NS NS
D_3	0.29	0.36	**0.32**	D×F	NS	9.99	9.46	**9.72**	D×F	NS
Mean (F)	**0.41**	**0.49**		D×T×F	NS	**9.38**	**8.82**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

significant. Considering the effect of planting densities, the highest total sugars content (9.72 %) was recorded in fruits obtained from the trees planted at a density of D_3 (2666 trees/ha), which was significantly higher than D_2 (3200 trees/ha) and D_3 (4000 trees/ha) planting densities. However, the lowest total sugars content (8.51 %) was found in fruits obtained from trees planted at D_1 (4000 trees/ha) planting density. Among the training systems, the fruits harvested from trees trained with T_1 (Tall Spindle) training system registered significantly higher total sugars content (9.29 %) than the fruits from trees trained with T_2 (Vertical Axis) training system (8.91 %). Similarly, data of fertigation levels also showed significant effect on total sugars content and the significantly higher total sugars content (9.38 %) was attained by the fruits in trees subjected under F_1 fertigation level than the trees subjected under F_2 level of fertigation (8.82 %).

The pooled data presented in Table 4.13 reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest total sugars content (10.15 %) was recorded in fruits harvested from trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 fertigation level and the lowest (7.90 %) was noticed in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.1.3.9 Reducing sugars

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on reducing sugars content recorded during 2019 and 2020 are depicted in Appendix XXXI. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on reducing sugars content during both the years of study, however, their interactions were found non-significant.

The pooled data of two years pertaining to the effect of different planting densities, training systems, fertigation levels and their interactions on reducing sugars content presented in Table 4.14 also reveal that planting densities, training systems and fertigation levels exhibited significant effect on reducing sugars content, however, their interactions were found non-significant. Among the planting densities, the highest reducing sugars content (6.70 %) was recorded in fruits harvested from the

Table 4.14: Effect of different planting densities, training systems and fertigation levels on reducing and non-reducing sugars of apple cv. Jeromine

D \ T / F	Reducing sugars (%)						Non-reducing sugars (%)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	6.26	5.85	**6.05**	6.07	5.50	**5.78**	2.59	2.45	**2.52**	2.52	2.28	**2.40**
D_2	6.59	6.25	**6.42**	6.37	6.01	**6.19**	2.70	2.62	**2.66**	2.67	2.52	**2.59**
D_3	6.94	6.70	**6.82**	6.84	6.33	**6.58**	3.05	2.88	**2.97**	2.85	2.70	**2.78**
Mean (T×F)	**6.60**	**6.27**		**6.42**	**5.95**		**2.78**	**2.65**		**2.68**	**2.50**	
Mean (T)	**6.43**			**6.18**								

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	6.16	5.67	**5.92**	D	0.20	2.56	2.36	**2.46**	D	0.12
D_2	6.48	6.13	**6.30**	T	0.13	2.68	2.57	**2.63**	T	0.09
D_3	6.89	6.52	**6.70**	F	0.13	2.95	2.79	**2.87**	F	0.09
Mean (F)	**6.51**	**6.11**		D×T	NS	**2.73**	**2.57**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

trees planted at D_3 (2666 trees/ha) planting density and the lowest reducing sugars content of 5.92 per cent was found in fruits from trees planted at D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the trees trained with T_1 (Tall Spindle) training system registered significantly higher reducing sugars content (6.43 %) in the fruits as compared to the fruits from trees trained with T_2 (Vertical Axis) training system. Similarly, the significantly higher reducing sugars content (6.51 %) was recorded in fruits obtained from trees subjected under F_1 fertigation level than the fruits from trees subjected under F_2 level of fertigation (6.11 %).

It is evident from the pooled data presented in Table 4.14 that interaction effects of planting densities, training systems and fertigation levels on reducing sugar content were found non-significant. However, among the three factors interaction, the highest reducing sugars content (6.94 %) was recorded in fruits from trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation.

4.1.3.10 Non-reducing sugars

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 cited in Appendix XXXII led to the conclusion that planting densities, training systems and fertigation levels exerted a significant effect on non-reducing sugars content during both the years of study.

The pooled data of two years related to non-reducing sugars content as influenced by different planting densities, training systems and fertigation level are presented in Table 4.14. The data reveal that planting densities, training systems and fertigation levels individually exhibited significant effect on non-reducing sugars content, however, their interactions were found non-significant. Among the planting densities, the highest non-reducing sugars content (2.87 %) was recorded in fruits harvested from trees at D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest non-reducing sugars content of 2.46 per cent was found in fruits from trees at D_1 (4000 trees/ha) planting density. In case of training systems, fruits obtained from the trees trained with T_1 (Tall Spindle) training system recorded significantly higher non-reducing sugars content (2.71 %) as compared to the fruits from trees trained to T_2 (Vertical Axis) training system. Similarly, the trees subjected to F_1 fertigation level registered significantly higher non-reducing sugars content (2.73 %) in their fruits than the trees subjected to F_2 level of fertigation (2.57 %).

It is evident from the pooled data presented in Table 4.14 that interaction between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction, the highest non-reducing sugars content (3.05 %) was recorded in fruits obtained from the trees planted at density D_3, trained with Tall Spindle and subjected to F_1 fertigation level.

4.1.3.11 Ascorbic acid

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on ascorbic acid content recorded during 2019 and 2020 are displayed in Appendix XXXIII. It revealed that planting densities, training systems and fertigation levels exerted a significant effect on ascorbic acid content during both the years of study.

An examination of pooled data of two years depicted in Table 4.15 clearly shows that planting densities, training systems and fertigation levels individually had a significant effect on ascorbic acid content, however, their interactions were found non-significant. Among the planting densities, the highest ascorbic acid content (5.65 mg $100g^{-1}$) was observed in fruits obtained from the trees planted at density of D_1 (4000 trees/ha), which was significantly higher than D_2 (3200 trees/ha) and D_3 (2666 trees/ha) planting densities. However, the lowest ascorbic acid content (4.39 mg $100g^{-1}$) was observed in fruits from trees planted at D_3 (2666 trees/ha) density. Considering the effect of training systems, the fruits harvested from trees trained with T_2 (Vertical Axis) training system registered significantly higher ascorbic acid content (5.02 mg $100g^{-1}$) and it was markedly lower in fruits from trees trained with T_2 (Tall Spindle) training system (4.82 mg $100g^{-1}$). Considering the effect of fertigation, the fruits obtained from the trees treated with F_2 fertigation level registered significantly higher ascorbic acid content (5.43 mg $100g^{-1}$) in comparison to the fruits from trees subjected under F_1 level of fertigation (4.41 mg $100g^{-1}$).

Table 4.15: Effect of different planting densities, training systems and fertigation levels on ascorbic acid and anthocyanin content of apple cv. Jeromine

D \ T / F	Ascorbic acid (mg $100g^{-1}$)						Anthocyanin content (A_{530})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	5.10	5.77	**5.43**	5.43	6.32	**5.87**	1.04	0.87	**0.95**	0.95	0.81	**0.88**
D_2	4.28	5.26	**4.77**	4.00	5.36	**4.68**	1.34	1.12	**1.23**	1.20	0.96	**1.08**
D_3	3.76	4.79	**4.28**	3.91	5.10	**4.50**	1.55	1.36	**1.46**	1.43	1.13	**1.28**
Mean (T×F)	**4.38**	**5.27**		**4.44**	**5.59**		**1.31**	**1.11**		**1.19**	**0.97**	
Mean (T)	**4.82**			**5.02**			**1.21**			**1.08**		

D \ F	Ascorbic acid: D × F			$CD_{0.05}$		Anthocyanin: D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	5.26	6.04	**5.65**	D	0.15	0.99	0.84	**0.91**	D	0.13
D_2	4.14	5.31	**4.72**	T	0.12	1.27	1.04	**1.15**	T	0.11
D_3	3.83	4.95	**4.39**	F	0.12	1.49	1.25	**1.37**	F	0.11
Mean (F)	**4.41**	**5.43**		D×T	NS	**1.25**	**1.04**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The pooled data presented in Table 4.15 reveal that interaction effects of planting densities, training systems and fertigation levels on ascorbic acid content were non-significant. However, among three factors interaction, the highest ascorbic acid content (6.32 mg $100g^{-1}$) was registered by the trees planted at density D_1, trained with Vertical Axis and subjected under F_2 fertigation level and the lowest (3.76 mg $100g^{-1}$) was noted in fruits from trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation.

4.1.3.12 Anthocyanin content

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 are cited in Appendix XXXIV. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on anthocyanin content during both the years of study, however, their interactions were found non-significant.

The perusal of the pooled data of two years presented in Table 4.15 indicates that different planting densities, training systems, fertigation levels had significant influence on anthocyanin content. Among the planting densities, the highest anthocyanin content (1.37 OD) was observed in fruits harvested from trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest (0.91 OD) was observed in fruits from trees planted at D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the higher anthocyanin content (1.21 OD) was recorded in fruits obtained from the trees trained with T_1 (Tall Spindle) training system, which was significantly more than fruits from trees trained with T_2 (Vertical Axis) training system (1.08 OD). Similarly, data on the effect of fertigation levels also revealed significant influence on anthocyanin content and the higher anthocyanin content (1.25 OD) was registered in fruits obtained from trees subjected under F_1 fertigation level as compared to the fruits from trees subjected under F_2 level of fertigation (1.04 OD).

It is clear from the pooled data given in Table 4.15 that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on anthocyanin content were non-significant. However, among three factors interaction, the highest anthocyanin content (1.55 OD) was recorded in fruits of trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation.

The results clearly indicate that the biochemical properties of fruit (fruit firmness, TSS, titratable acidity, reducing, non-reducing and total sugars, ascorbic acid and anthocyanin contents) were significantly influenced by different planting densities, training systems and fertigation levels. The results showed that the highest values of all biochemical traits except acidity were recorded in the fruits of trees planted at D_3 density, trained with Tall Spindle and subjected to 100 per cent of AD (NPK).

The trees under high density planting had more efficient photosynthetic activity due to better light interception resulting in to higher net photosynthesis, which might be translated by the tree to produce good quality fruits. The findings of the present study is in consonance with the work of Hudina *et al*. (2001), who obtained best quality fruits with high total soluble solids and sugars from low density planting in apple. Similarly, Dhiman *et al.* (2018) found maximum TSS, sugars and anthocyanin contents in low density planting and minimum in high density planting in apple.

According to Heinicke (1966), Tall Spindle system of training has been reported to improve the light interception and photo-synthetically active radiation in the tree canopy, which might have indirectly helped in accumulation of more assimilates, carbohydrates and sugars in the fruits. These results are in conformity with the findings of Lordan *et al.* (2018) and Reig *et al*. (2019), who reported that fruits obtained from Tall Spindle trained trees had higher soluble solids and sugars contents. However, little effect of training systems on fruit quality in apple was reported by Meland and Hovland (1997).

The data indicated that biochemical traits of apple fruit significantly improved with higher dose of NPK through fertigation. The increase in sugars content of fruits harvested from trees receiving 100 per cent of AD (NPK) through fertigation might be due to more availability of nutrients, which may have further exerted the regulatory role in affecting the fruit quality positively. These results are in confirmatory with the findings of Kumar *et al.* (2016) and Thakur *et al.* (2020), who reported higher total sugars, reducing sugars and non-reducing sugars content in apple tree receiving 100 % of AD (NPK) through fertigation. Similarly, Chauhan and Chandel (2008), also recorded higher total sugars and reducing sugars content in kiwifruit vines receiving recommended dose and $3/4^{th}$ of recommended dose of NPK through drip fertigation. Jeyakumar *et al*. (2001) reported higher total sugars content in papaya fruits harvested from plants receiving 100 per cent recommended dose of N and K_2O through drip fertigation.

Higher ascorbic acid content with the higher level of nitrogen could be attributed to increase in synthesis and catalytic activity for several enzymes and co-enzymes, which are implemental in ascorbic acid synthesis (Boora and Singh, 2000). The present findings are in accordance with the results of Moor *et al.* (2005) and Wold and Opstad (2007), who recorded increased anthocyanin content in strawberry with increased fertigation.

4.2 EFFECT OF PLANTING DENSITIES, TRAINING SYSTEMS AND FERTIGATION LEVELS ON LIGHT INTERCEPTION AND PHOTOSYNTHESIS EFFICIENCY

The data pertaining to the light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content are presented in Tables 4.16 to 4.18.

4.2.1 Light interception

The data recorded during 2019 and 2020, and cited in Appendix XXXV reveal that planting densities, training systems and fertigation levels exerted a significant effect on light interception during both the years of study, however, their interactions were found non-significant.

The pooled data of two years cited in Table 4.16 revealed that individually planting densities, training systems and fertigation levels exerted significant influence on total light interception. Among the planting densities, the highest light interception (62.17 %) was recorded in trees planted at D_1 (4000 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_3 (2666 trees/ha) planting densities. However, the lowest light interception of 54.34 per cent was observed in D_3 (2666 trees/ha) planting density.

Table 4.16: Effect of different planting densities, training systems and fertigation levels on light interception and photosynthesis rate of apple cv. Jeromine

D \ T / F	Light interception (%)						Photosynthesis rate (μmol CO_2 m^{-2} s^{-1})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	66.44	64.02	**65.23**	59.85	58.38	**59.11**	15.53	15.02	**15.27**	15.37	13.60	**14.48**
D_2	62.57	60.14	**61.35**	55.97	54.48	**55.22**	12.80	11.05	**11.93**	12.08	10.33	**11.21**
D_3	58.60	56.19	**57.39**	52.01	50.55	**51.28**	9.96	8.32	**9.14**	9.40	7.56	**8.48**
Mean (T×F)	**62.54**	**60.12**		**55.94**	**54.47**		**12.76**	**11.46**		**12.28**	**10.50**	
Mean (T)	**61.33**			**55.20**			**12.11**			**11.39**		

D \ F	D × F (Light interception)			$CD_{0.05}$		D × F (Photosynthesis rate)			$CD_{0.05}$	
	F_1	F_2	**Mean (D)**	D	1.43	F_1	F_2	**Mean (D)**	D	0.43
D_1	63.14	61.20	**62.17**	T F	1.17 1.17	15.45	14.31	**14.88**	T F	0.35 0.35
D_2	59.27	57.31	**58.29**	D×T T×F	NS NS	12.44	10.69	**11.57**	D×T T×F	NS NS
D_3	55.30	53.37	**54.34**	D×F	NS	9.68	7.94	**8.81**	D×F	NS
Mean (F)	**59.24**	**57.29**		D×T×F	NS	**12.52**	**10.98**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The data also showed significant variation in light interception of trees subjected to different training systems and fertigation levels (Table 4.16). In case of training systems, the trees trained with T_1 (Tall Spindle) training system registered higher light interception (61.33 %), which was significantly superior to T_2 (Vertical Axis) training system (55.20 %). Considering the effect of fertigation levels, the higher light interception of 59.24 per cent was recorded in trees subjected under F_1 fertigation level than in F_2 level of fertigation.

It is apparent from the data presented in Table 4.16 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest light interception (66.44 %) was recorded in trees planted at D_1 density, trained with Tall Spindle and subjected under F_1 level of fertigation, whereas, the lowest light interception (50.55 %) was noted in trees planted at D_3 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.2.2 Photosynthesis efficiency

4.2.2.1 Photosynthesis rate

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXXVI) reveal that planting densities, training systems and fertigation levels exerted a significant effect on photosynthesis rate during both the years of study, however, their interactions were found non-significant.

It is clearly evident from the pooled data of two years presented in Table 4.16 that different planting densities, training systems and fertigation levels significantly affected the photosynthesis rate. Among the planting densities, the highest photosynthesis rate (14.88 µmol CO_2 $m^{-2}s^{-1}$) was recorded in trees planted at D_1 (4000 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_3 (2666 trees/ha) planting densities. However, the lowest photosynthesis rate of 8.81 µmol CO_2 $m^{-2}s^{-1}$ was noted in trees planted at D_3 (2666 trees/ha) planting density. In case of training systems, the trees trained to T_1 (Tall Spindle) training system registered significantly higher photosynthesis rate (12.11 µmol CO_2 $m^{-2}s^{-1}$) as compared to the trees trained to T_2 (Vertical Axis) training system (11.39 µmol CO_2

$m^{-2}s^{-1}$). Considering the effect of fertigation levels, the higher photosynthesis rate of 12.52 µmol CO_2 $m^{-2}s^{-1}$ was recorded in trees subjected under F_1 fertigation level than the trees subjected under F_2 level of fertigation (10.98 µmol CO_2 $m^{-2}s^{-1}$).

It is apparent from the data presented in Table 4.16 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest photosynthesis rate (15.53 µmol CO_2 $m^{-2}s^{-1}$) was registered in trees planted at density D_1, trained as Tall Spindle and subjected under F_1 fertigation level, while the lowest (7.56 µmol CO_2 $m^{-2}s^{-1}$) was found in trees planted at density D_3, trained as Vertical Axis and fertigated with F_2 level of fertigation.

4.2.2.2 Stomatal conductance

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on stomatal conductance recorded during 2019 and 2020 are displayed in Appendix XXXVII. It revealed that planting densities, training systems and fertigation levels exerted a significant effect during both the years of study.

Examination of the pooled data of two years presented in Table 4.17 revealed that the individual effect of different planting densities, training systems and fertigation levels significantly influenced the stomatal conductance, while their interactions were found non-significant. Among the planting densities, the highest stomatal conductance (0.270 mol H_2O $m^{-2}s^{-1}$) was recorded in trees planted at D_1 (4000 trees/ha) planting density. However, the lowest stomatal conductance of 0.140 mol H_2O $m^{-2}s^{-1}$ was observed in trees planted at D_3 (2666 trees/ha) planting density. In case of training systems, the significantly higher stomatal conductance of 0.206 mol H_2O $m^{-2}s^{-1}$ was registered by the trees trained with T_1 (Tall Spindle) training system and the lower stomatal conductance (0.196 mol H_2O $m^{-2}s^{-1}$) was found in trees trained with T_2 (Vertical Axis) training system. Considering the effect of fertigation, the trees subjected under F_1 fertigation level exhibited significantly higher stomatal conductance (0.216 mol H_2O $m^{-2}s^{-1}$) than the trees subjected under F_2 level of fertigation (0.185 mol H_2O $m^{-2}s^{-1}$).

Table 4.17: Effect of different planting densities, training systems and fertigation levels on stomatal conductance and transpiration rate of apple cv. Jeromine

D \ T, F	Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)						Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.289	0.263	**0.276**	0.281	0.249	**0.265**	4.31	3.88	**4.09**	4.11	3.75	**3.93**
D_2	0.216	0.180	**0.198**	0.203	0.167	**0.185**	3.59	3.37	**3.48**	3.46	3.13	**3.29**
D_3	0.160	0.128	**0.144**	0.151	0.123	**0.137**	3.05	2.77	**2.91**	2.91	2.59	**2.75**
Mean (T×F)	**0.221**	**0.190**		**0.221**	**0.180**		**3.65**	**3.34**		**3.49**	**3.16**	
Mean (T)	**0.206**			**0.196**			**3.49**			**3.32**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.008	F_1	F_2	Mean (D)	D	0.11
D_1	0.285	0.256	**0.270**	T F	0.007 0.007	4.21	3.81	**4.01**	T F	0.09 0.09
D_2	0.209	0.174	**0.191**	D×T	NS	3.52	3.25	**3.39**	D×T	NS
D_3	0.155	0.125	**0.140**	T×F D×F	NS NS	2.98	2.68	**2.83**	T×F D×F	NS NS
Mean (F)	**0.216**	**0.185**		D×T×F	NS	**3.57**	**3.25**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

It is clear from the data assembled in Table 4.17 that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on stomatal conductance were found non-significant. However, among the three factors interaction, the highest stomatal conductance (0.289 mol H_2O $m^{-2}s^{-1}$) was observed in trees planted at D_1 density trained as Tall Spindle and subjected to F_1 fertigation level whereas, the lowest (0.123 mol H_2O $m^{-2}s^{-1}$) was noted in trees planted at D_3 density trained with Vertical Axis and subjected to F_2 level of fertigation.

4.2.2.3 Transpiration rate

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XXXVIII) reveal that planting densities, training systems and fertigation levels exerted a significant effect on transpiration rate.

The pooled data of two years pertaining to transpiration rate in Table 4.17 indicate that the individual effects of different planting densities, training systems and fertigation levels on transpiration rate were significant, however their interactions were non-significant. Among the planting densities, the highest transpiration rate (4.01 mmol H_2O $m^{-2}s^{-1}$) was recorded in trees planted at D_1 (4000 trees/ha) density, which was significantly more than D_2 (3200 trees/ha) and D_3 (2666 trees/ha) planting densities. However, the lowest transpiration rate of 2.83 mmol H_2O $m^{-2}s^{-1}$ was noted in D_3 (2666 trees/ha) planting density. Considering the effect of training systems, the trees trained with T_1 (Tall Spindle) training system recorded significantly higher transpiration rate (3.49 mmol H_2O $m^{-2}s^{-1}$) in comparison to the trees trained with T_2 (Vertical Axis) training system (3.32 mmol H_2O $m^{-2}s^{-1}$). Similarly, the trees subjected under F_1 fertigation level registered significantly higher transpiration rate (3.57 mmol H_2O $m^{-2}s^{-1}$) than the trees subjected under F_2 level of fertigation (3.25 mmol H_2O $m^{-2}s^{-1}$).

It is apparent from the data presented in Table 4.17 that interactions between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found to be non-significant. However, among three factors interaction, the highest transpiration rate (4.31 mmol H_2O $m^{-2}s^{-1}$) was recorded in trees planted at density D_1, trained as Tall Spindle and subjected under F_1 fertigation level and the lowest (2.59 mmol H_2O $m^{-2}s^{-1}$) was found in trees planted at density D_3, trained as Vertical Axis and subjected under F_2 fertigation level.

4.2.2.4 Chlorophyll content

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf chlorophyll content recorded during 2019 and 2020 are cited in Appendix XXXIX. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on leaf chlorophyll content during both the years of study.

The perusal of pooled data of two years presented in Table 4.18 reveal that the leaf chlorophyll contents was significantly influenced by the individual effect of different planting densities, training systems and fertigation levels, however, their interactions were found non-significant. Among the planting densities, the trees planted at planting density of D_1 (4000 trees/ha) registered highest leaf chlorophyll content (2.70 mg g^{-1}), which was significantly higher than D_2 (3200 trees/ha) and D_3 (4000 trees/ha) planting densities. However, the lowest chlorophyll content (1.92 mg g^{-1}) was recorded in D_3 (2666 trees/ha) planting density. Considering the effect of training systems, significantly higher chlorophyll content of 2.43 mg g^{-1} was registered in trees trained to T_1 (Tall Spindle) training system and the lower (2.21 mg g^{-1}) was found in trees trained to T_2 (Vertical Axis) system. In case of fertigation, the trees subjected under F_1 fertigation level recorded significantly higher leaf chlorophyll content (2.49 mg g^{-1}) than the trees subjected under F_2 level of fertigation (2.15 mg g^{-1}).

The data acquainted in Table 4.18 reveal that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on leaf chlorophyll content were found non-significant. However, among the three factors interaction, the highest leaf chlorophyll content (3.30 mg g^{-1}) was recorded in trees planted at D_1 density, trained as Tall Spindle and subjected under F_1 fertigation level, while the lowest (1.64 mg g^{-1}) was observed in trees planted at D_3 density, trained as Vertical Axis and subjected under F_2 fertigation level.

Table 4.18: Effect of different planting densities, training systems and fertigation levels on total leaf chlorophyll content of apple cv. Jeromine

D \ T / F	Chlorophyll content (mg g^{-1} fresh weight)								
	T_1			T_2			D × F		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D)
D_1	3.30	2.63	**2.81**	2.76	2.41	**2.59**	2.88	2.52	**2.70**
D_2	2.63	2.28	**2.45**	2.39	2.09	**2.24**	2.51	2.18	**2.34**
D_3	2.18	1.87	**2.03**	1.97	1.64	**1.81**	2.08	1.76	**1.92**
Mean (T×F)	**2.60**	**2.26**		**2.37**	**2.05**		**2.49**	**2.15**	**Mean (F)**
Mean (T)	**2.43**			**2.21**					

$CD_{0.05}$	D	0.15	T	0.12	F	0.12	D×T	NS	T×F	NS	D×F	NS	D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content were significantly affected by different planting densities, training systems and fertigation levels in the present study. The highest light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content were recorded in trees under high density planting of 4000 trees/ha (D_1), trained as Tall Spindle and subjected to 100 per cent of AD (NPK) fertilizer dose. The results of present study are in accordance with the findings of Robinson *et al.* (1991), Palmer *et al.* (1992), Tustin *et al.* (1998), Wunsche and Lakso (2000), Corelli and Lakso (2007) and Robinson *et al.* (2013), who reported higher light interception by increasing planting density, reducing tractor alley spacing, orienting rows north-south, increasing the height of trees and smaller tree size. The small size trees planted at closer spacing and trained as Tall Spindle intercept more solar radiation as small size with open canopy provides better distribution of light in the canopy.

The better light interception in Tall Spindle trained trees might be due to the bending of branches leading to openness of the canopy of the center, which allows the light to penetrate within the tree canopy. The present findings are in line with the findings of Mallikarjuna (2020), who observed that Tall Spindle trained trees had better light interception than Vertical Axis and Slender Spindle training system.

The findings of the present study are in consonance with the work of Fallahi *et al* (2001), who reported that increasing the supply of nitrogen fertilizer increases chlorophyll content and photosynthesis rate of apple leaves.

4.3 EFFECT OF PLANTING DENSITIES, TRAINING SYSTEMS AND FERTIGATION LEVELS ON LEAF NUTRIENTS CONTENT OF APPLE

The data on leaf nutrients content (N, P, K, Ca, Mg, Fe, Mn, Cu and Zn) have been shown in Tables 4.19 to 4.23 and Fig. 4.15.

4.3.1 Leaf N

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf N recorded during 2019 and 2020 are depicted in Appendix XL. It indicates that training systems and fertigation levels exerted a significant effect on leaf N content during both the years of study.

Table 4.19: Effect of different planting densities, training systems and fertigation levels on leaf N and P contents of apple cv. Jeromine

D \ T, F	N (%)						P (%)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	2.69	2.12	**2.40**	2.53	1.93	**2.23**	0.24	0.19	**0.21**	0.22	0.16	**0.19**
D_2	2.79	2.20	**2.49**	2.56	1.98	**2.27**	0.30	0.25	**0.28**	0.27	0.20	**0.24**
D_3	2.83	2.43	**2.63**	2.65	2.29	**2.47**	0.37	0.30	**0.34**	0.33	0.26	**0.30**
Mean (T×F)	2.77	2.25		2.58	2.06		**0.30**	**0.25**		**0.27**	**0.21**	
Mean (T)	**2.51**			**2.32**			**0.28**			**0.24**		

D \ F	N (%) D × F			P (%) D × F		
	F_1	F_2	**Mean (D)**	F_1	F_2	**Mean (D)**
D_1	2.61	2.02	**2.31**	0.23	0.17	**0.20**
D_2	2.67	2.09	**2.38**	0.29	0.23	**0.26**
D_3	2.74	2.36	**2.55**	0.35	0.28	**0.32**
Mean (F)	**2.67**	**2.16**		**0.29**	**0.23**	

	N (%) $CD_{0.05}$	P (%) $CD_{0.05}$
D	NS	0.02
T	0.16	0.01
F	0.16	0.01
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appraisal of pooled data of two years given in Table 4.19 and Fig. 4.15 led to an inference that the leaf N content was significantly influenced by the individual effect of different training systems and fertigation levels, however, planting densities failed to exert any significant effect on leaf N content. Among the training systems, the trees trained with T_1 (Tall Spindle) training system recorded significantly higher leaf N content (2.51 %) than T_2 (Vertical Axis) training system (2.32 %). Considering the effect of fertigation levels, the significantly higher leaf N content (2.67 %) was observed in trees subjected under F_1 fertigation level in comparison to F_2 level of fertigation (2.16 %).

The data depicted in Table 4.19 revealed that individual effect of planting densities and interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest leaf N content (2.83 %) was recorded in trees planted at D_3 density, trained as Tall Spindle and subjected under F_1 fertigation level, while the lowest (1.93 %) was observed in trees planted at D_1 density, trained as Vertical Axis and subjected under F_2 fertigation level.

4.3.2 Leaf P

The data recorded during 2019 and 2020, and cited in Appendix XLI led to an inference that planting densities, training systems and fertigation levels exerted a significant effect on leaf P content during both the years of study.

The perusal of pooled data of two years given in Table 4.19 and Fig. 4.15 indicates that planting densities, training systems and fertigation levels individually had a significant effect on leaf P content, however, their interactions were found non-significant. Considering the effect of planting densities, the highest leaf P content (0.32 %) was recorded in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities. However, the lowest leaf P content (0.20 %) was found in trees planted at D_1 (4000 trees/ha) density. Among the training systems, the trees trained as Tall Spindle (T_1) registered significantly higher leaf P content of 0.28 per cent than the trees trained as Vertical Axis (0.24 %). Considering the effect of fertigation levels, the significantly higher leaf P content (0.29 %) was registered in trees subjected under F_1 fertigation level as compared to the trees subjected under F_2 level of fertigation (0.23 %).

The data presented in Table 4.19 revealed that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on leaf P content were found non-significant. However, the maximum leaf P content (0.37 %) was recorded in trees planted at D_3 density, trained as Tall Spindle and subjected to F_1 level of fertigation and the minimum (0.16 %) was noticed in trees planted at D_1 density, trained as Vertical Axis and subjected to F_2 level of fertigation.

4.3.3 Leaf K

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf K recorded during 2019 and 2020 are cited in Appendix XLII. It revealed that planting densities, training systems and fertigation levels exerted a significant effect on leaf K content, however, their interactions were found non-significant during both the years of study.

Examination of the pooled data of two years presented in Table 4.20 and Fig. 4.15 indicates that planting densities, training systems and fertigation levels individually had a significant effect on leaf K content. Considering the effect of planting densities, the highest leaf K content (1.82 %) was recorded in trees planted at D_3 (2666 trees/ha) density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the lowest leaf K content (1.66 %) was observed in trees planted at D_1 (4000 trees/ha) density. Among the training systems, the significantly higher leaf K content of 1.78 per cent was recorded in trees trained with T_1 (Tall Spindle) training system in comparison to the trees trained with T_2 (Vertical Axis) training system (1.70 %). The data on fertigation levels also showed significant variation in leaf K content of trees subjected to different fertigation levels. The significantly higher leaf K content (1.81 %) was registered by the trees subjected under F_1 fertigation level compared with F_2 level of fertigation (1.67 %).

Table 4.20: Effect of different planting densities, training systems and fertigation levels on leaf K and Ca contents of apple cv. Jeromine

D \ T / F	K (%)						Ca (%)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	1.78	1.63	**1.70**	1.70	1.53	**1.61**	2.14	2.37	**2.25**	2.18	2.44	**2.31**
D_2	1.85	1.72	**1.78**	1.77	1.66	**1.71**	1.95	2.18	**2.06**	2.03	2.28	**2.15**
D_3	1.93	1.79	**1.86**	1.84	1.71	**1.78**	1.80	1.95	**1.87**	1.88	2.08	**1.98**
Mean (T×F)	**1.85**	**1.71**		**1.77**	**1.63**		**1.96**	**2.16**		**2.03**	**2.26**	
Mean (T)	**1.78**			**1.70**			**2.06**			**2.15**		

D \ F	K: D × F			K: $CD_{0.05}$		Ca: D × F			Ca: $CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	1.74	1.58	**1.66**	D	0.08	2.16	2.40	**2.28**	D	0.16
				T	0.07				T	NS
				F	0.07				F	0.13
D_2	1.81	1.69	**1.75**	D×T	NS	1.99	2.23	**2.11**	D×T	NS
				T×F	NS				T×F	NS
D_3	1.89	1.75	**1.82**	D×F	NS	1.84	2.01	**1.92**	D×F	NS
Mean (F)	**1.81**	**1.67**		D×T×F	NS	**1.99**	**2.21**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

It is clear from the data presented in Table 4.20 that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on leaf K content were found non-significant. However, among three factors interaction, the highest leaf K content (1.93 %) was registered in trees planted at density D_3, trained as Tall Spindle and subjected to F_1 fertigation level and the lowest (1.53 %) was observed in trees planted at density D_1, trained to Vertical Axis and subjected to F_2 fertigation level.

4.3.4 Leaf Ca

The data recorded during 2019 and 2020 (Appendix XLIII) indicate that planting densities and fertigation levels exerted a significant effect on leaf Ca content.

The pooled data of two years cited in Table 4.20 revealed that planting densities and fertigation levels individually exerted significant influence on leaf Ca content, however, individual effect of training systems and interaction effects of planting densities, training systems and fertigation were non-significant on leaf Ca content. Among the planting densities, significantly highest leaf Ca content (2.28 %) was recorded in trees planted at D_1 (4000 trees/ha) density and was found significantly superior to D_2 (3200 trees/ha) and D_3 (2666 trees/ha) planting densities. However, the lowest leaf Ca content was observed in trees planted at D_3 (2666 trees/ha) planting density (1.92 %). In case of fertigation levels, the trees subjected under F_2 fertigation level registered significantly higher leaf Ca content (2.21 %) as compared to the trees subjected under F_1 level of fertigation (1.99 %).

The data presented in Table 4.20 revealed that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on leaf Ca content were found non-significant. However, among three factors interaction, the highest leaf Ca content (2.44 %) was registered in trees planted at density D_1, trained as Vertical Axis and subjected to F_2 fertigation level and the lowest (1.80 %) was observed in trees planted at density D_3, trained as Tall Spindle and subjected to F_2 fertigation level.

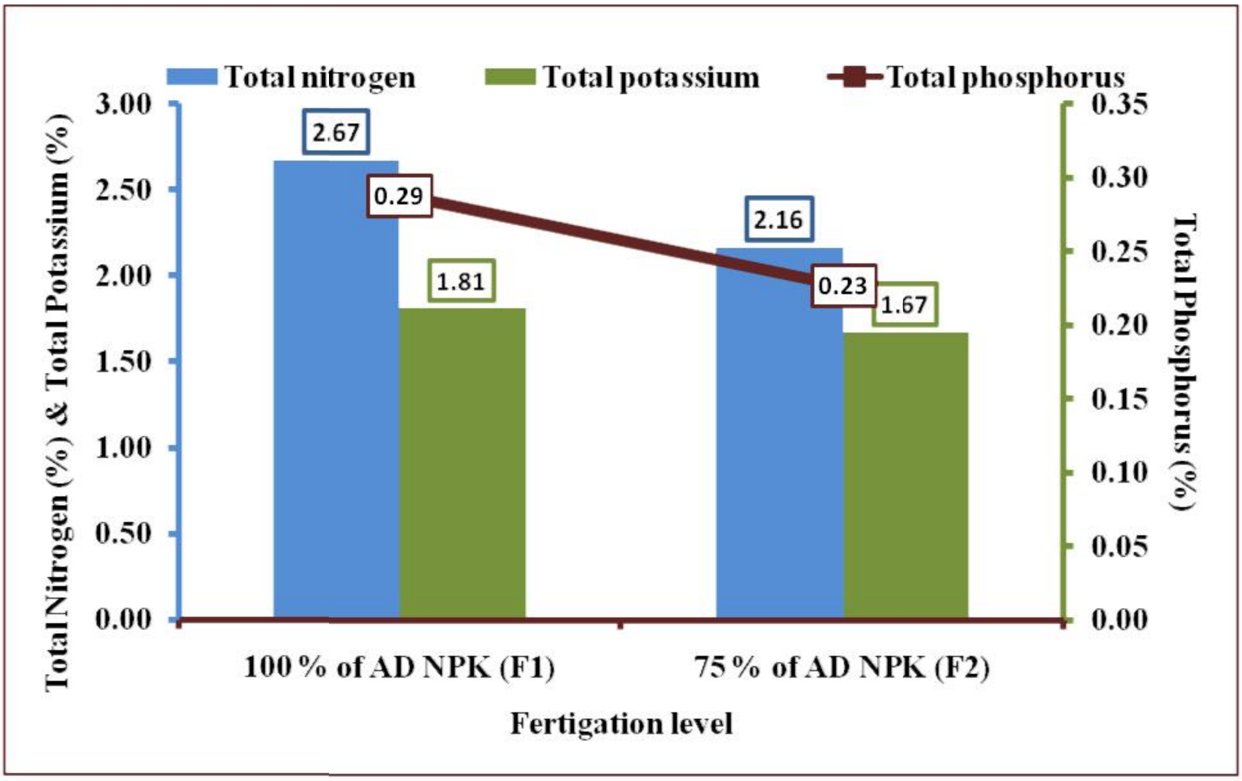

Fig. 4.15: Effect of different fertigation levels on leaf N, P and K content of apple cv. Jeromine

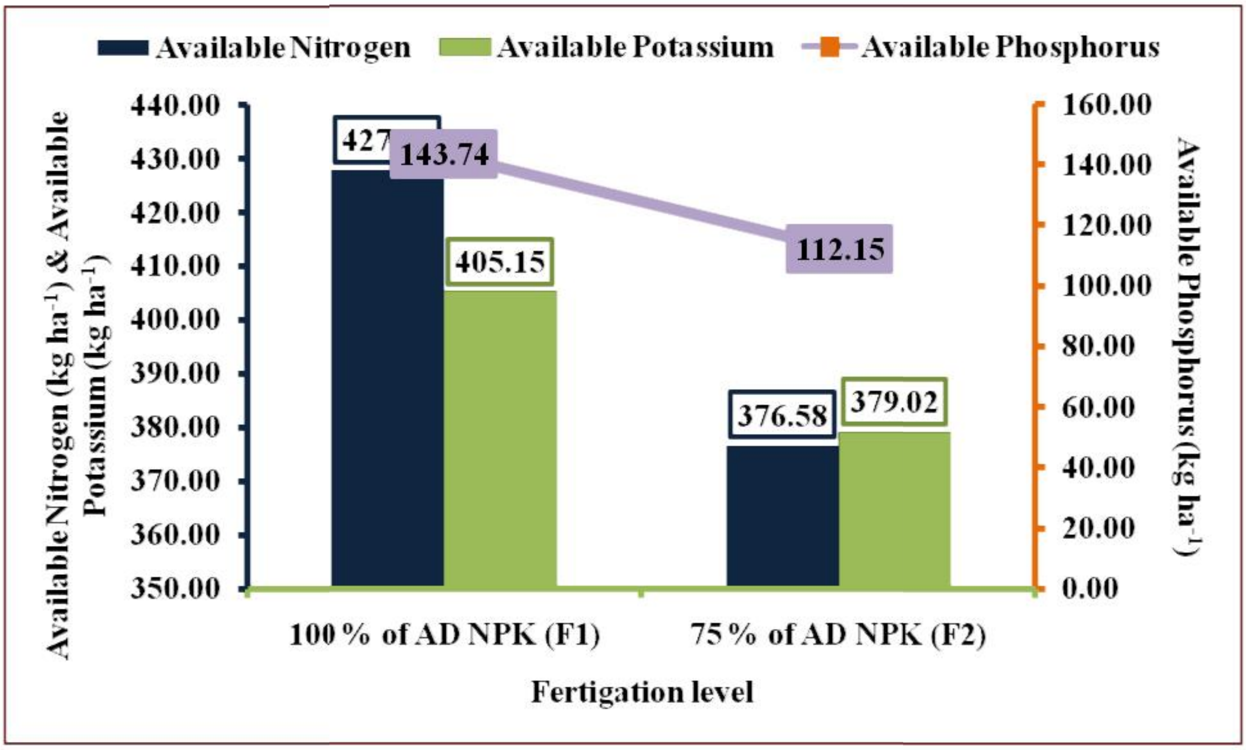

Fig. 4.16: Effect of different fertigation levels on soil available N , P and K contents of apple cv. Jeromine

4.3.5 Leaf Mg

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf Mg content recorded during 2019 and 2020 are depicted in Appendix XLIV. It revealed that fertigation levels exerted a significant effect on leaf Mg content, however, the effect of planting densities and training systems were found non-significant.

An inquisition of the pooled data of two years given in Table 4.21 clearly indicates that individual effects of fertigation levels exerted a significant effect on leaf Mg content. However, individual effect of planting densities and training systems were found to be non-significant. Among the fertigation levels, the trees subjected under F_2 fertigation level registered significantly higher leaf Mg content (0.44 %) than those under F_1 level of fertigation (0.32 %).

The data (Table 4.21) also showed that interactions between planting densities, training systems and fertigation levels did not exert significant effect on leaf Mg content. However, among three factors interaction, the maximum leaf Mg content (0.52 %) was recorded in trees planted at D_1 density, trained as Vertical Axis and subjected to F_2 level of fertigation and the minimum (0.23 %) was found in Tall Spindle (T_1) trees planted at D_3 density and subjected to F_1 fertigation level.

4.3.6 Leaf Fe

The data recorded during 2019 and 2020, and cited in Appendix XLV revealed that planting densities, training systems and fertigation levels exerted a significant effect on leaf Fe content.

Examination of the pooled data of two years presented in Table 4.21 reveals that the individual effect of different planting densities, training systems and fertigation levels significantly influenced the leaf Fe content, while their interactions were found to be non-significant. Considering the effect of planting densities, the highest leaf Fe content (187.33 ppm) was reported in trees planted at D_3 (2666 trees/ha) planting density and was found significantly superior to planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). However, the lowest leaf Fe content (176.18 ppm) was found in trees planted at D_1 (4000 trees/ha) planting density.

Table 4.21: Effect of different planting densities, training systems and fertigation levels on leaf Mg and Fe contents of apple cv. Jeromine

D \ T, F	Mg (%)						Fe (ppm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.38	0.49	**0.43**	0.39	0.52	**0.46**	183.01	173.05	**178.03**	178.64	170.01	**174.33**
D_2	0.30	0.42	**0.36**	0.34	0.45	**0.39**	189.62	181.17	**185.39**	185.22	175.74	**180.48**
D_3	0.23	0.36	**0.30**	0.28	0.40	**0.34**	194.00	185.20	**189.60**	189.70	180.42	**185.06**
Mean (T×F)	**0.30**	**0.42**		**0.34**	**0.46**		**188.88**	**179.81**		**184.52**	**175.39**	
Mean (T)	**0.36**			**0.40**			**184.34**			**179.95**		

D \ F	Mg D × F			$CD_{0.05}$		Fe D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	NS	F_1	F_2	Mean (D)	D	1.65
D_1	0.38	0.50	**0.44**	T	NS	180.83	171.53	**176.18**	T	1.35
				F	0.04				F	1.35
D_2	0.32	0.44	**0.38**	D×T	NS	187.42	178.45	**182.93**	D×T	NS
				T×F	NS				T×F	NS
D_3	0.26	0.38	**0.32**	D×F	NS	191.85	182.81	**187.33**	D×F	NS
Mean (F)	**0.32**	**0.44**		D×T×F	NS	**186.70**	**177.60**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Among the training systems, the trees trained with T_1 (Tall Spindle) training system registered significantly higher leaf Fe content (184.34 ppm) in comparison to the trees trained with T_2 (Vertical Axis) training system (179.95 ppm). Similarly, data of fertigation levels also showed significant effect on leaf Fe content and the higher leaf Fe content (186.70 ppm) was recorded by trees subjected under F_1 fertigation level and the lower leaf Fe content (177.60 ppm) was found in trees subjected under F_2 level of fertigation.

The data also reveal that interaction between planting densities, training systems and fertigation levels were found non-significant (Table 4.21). However, among three factors interaction, the highest leaf Fe content (194.00 ppm) was recorded in trees planted at D_3 density, trained to Tall Spindle and subjected under F_1 level of fertigation and the lowest (170.01 ppm) was noted in trees planted at D_1 density, trained to Vertical Axis and subjected under F_2 level of fertigation.

4.3.7 Leaf Mn

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 displayed in Appendix XLVI led to the inference that planting densities, training systems and fertigation levels exerted a significant effect on leaf Mn content.

As per the pooled data of two years presented in Table 4.22, the leaf Mn content was significantly influenced by the individual effects of different planting densities, training systems and fertigation level whereas, their interaction effects were found to be non-significant. Among the planting densities, the highest leaf Mn content (39.14 ppm) was registered by the trees planted at a density of 2666 trees/ha (D_3), which was significantly higher than D_2 (3200 trees/ha) and D_3 (4000 trees/ha) planting densities. However, the lowest (35.14 ppm) was found in trees planted at D_1 (4000 trees/ha) density. Considering the effect of training systems, the significantly higher leaf Mn content of 38.01 ppm was observed in trees trained with T_1 (Tall Spindle) training system as compared to the trees trained with T_2 (Vertical Axis) training system (36.43 ppm). In case of fertigation levels, the trees subjected under F_1 level of fertigation registered significantly higher leaf Mn content of 39.56 ppm than the trees under F_2 level of fertigation (34.88 ppm).

Table 4.22: Effect of different planting densities, training systems and fertigation levels on leaf Mn and Cu contents of apple cv. Jeromine

D \ T, F	Mn (ppm)						Cu (ppm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	38.10	33.81	**35.95**	36.46	32.20	**34.33**	11.41	9.85	**10.63**	10.93	8.75	**9.84**
D_2	40.53	35.55	**38.04**	38.89	34.52	**36.70**	11.87	10.42	**11.14**	11.50	9.79	**10.64**
D_3	42.54	37.54	**40.04**	40.83	35.66	**38.25**	12.67	11.41	**12.04**	11.98	10.37	**11.18**
Mean (T×F)	**40.39**	**35.63**		**38.72**	**34.13**		**11.98**	**10.56**		**11.47**	**9.63**	
Mean (T)	**38.01**			**36.43**			**11.27**			**10.55**		

D \ F	Mn D × F			$CD_{0.05}$		Cu D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	37.28	33.00	**35.14**	D	1.11	11.17	9.30	**10.23**	D	0.25
				T	0.91				T	0.21
				F	0.91				F	0.21
D_2	39.71	35.03	**37.37**	D×T	NS	11.69	10.10	**10.89**	D×T	NS
				T×F	NS				T×F	NS
D_3	41.69	36.60	**39.14**	D×F	NS	12.33	10.89	**11.61**	D×F	NS
Mean (F)	**39.56**	**34.88**		D×T×F	NS	**11.73**	**10.10**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The data also reveal that interaction between planting density, training system and fertigation level were found non-significant (Table 4.22). However, among three factors interaction, the highest leaf Mn content (42.54 ppm) was recorded in trees planted at D_3 density, trained with Tall Spindle and fertigated under F_1 level of fertigation and the lowest (32.20 ppm) was observed in trees planted at D_1 density, trained with Vertical Axis and fertigated under F_2 level of fertigation.

4.3.8 Leaf Cu

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix XLVII) indicate that planting densities, training systems and fertigation levels exerted a significant effect on leaf Cu content.

Pooled data of two years given in Table 4.22 showed that the individual effect of different planting densities, training systems and fertigation levels on leaf Cu content were significant, however their interactions were non-significant. Among the planting densities, the highest leaf Cu content (11.61 ppm) was registered in the trees planted at D_3 (2666 trees/ha) planting density and the lowest (10.23 ppm) in trees planted at D_1 (4000 trees/ha) planting density. In case of training systems, the significantly higher leaf Cu content of 11.27 ppm was recorded in trees trained with T_1 (Tall Spindle) training system than Vertical Axis system (10.55 ppm). Considering the effect of fertigation levels, the trees subjected under F_1 fertigation level registered significantly higher leaf Cu content of 11.73 ppm as compared to the trees subjected under F_2 level of fertigation (10.10 ppm).

The data also indicate that interaction effects of planting densities, training systems and fertigation levels on leaf Cu content were found non-significant. However, among three factors interactions, the highest leaf Cu content (12.67 ppm) was recorded in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation and the lowest (8.75 ppm) was observed in trees planted at D_1 density, trained with Vertical Axis and subjected under F_2 level of fertigation.

4.3.9 Leaf Zn

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on leaf Zn recorded during 2019 and 2020 have been presented in Appendix XLVIII. The data indicate that planting densities, training systems and fertigation levels exerted a significant effect on leaf Zn content during both the years.

The perusal of pooled data of two years given in Table 4.23 indicates that the individual effect of different planting densities, training systems and fertigation levels exhibited significant effect on leaf Zn content, however, their interactions were found non-significant. Considering the effect of planting densities, the highest leaf Zn content (27.59 ppm) was registered by the trees planted at density D_3 (2666 trees/ha), which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest (25.36 ppm) leaf Zn content was noted in trees planted at D_1 (4000 trees/ha) planting density. Similarly, in case of training systems, significantly higher leaf Zn content of 26.99 ppm was recorded in trees trained with T_1 (Tall Spindle) training system in comparison to the trees trained with T_2 (Vertical Axis) training system (25.82 ppm). Considering the effect of fertigation levels, the trees subjected under F_1 fertigation level registered significantly higher leaf Zn content of 27.96 ppm than the trees subjected under F_2 fertigation level (24.84 ppm).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest leaf Zn content (29.92 ppm) was observed in trees planted at D_3 density, trained with Tall Spindle and subjected under F_1 level of fertigation and the lowest (23.25 ppm) was found in trees planted at density D_1, trained with Vertical Axis and subjected under F_2 fertigation level.

Foliage nutrients content were significantly influenced by different planting densities, training systems and fertigation levels. The highest leaf nutrients content (except Ca and Mg) was recorded in trees planted at low density (D_3), trained with Tall Spindle and subjected to 100 % of AD (NPK) fertilizer dose. These results are in accordance with the findings of Pramanick *et al.* (2012), who reported that lower planting density had significantly higher leaf nutrient levels as compared to high density plating in apple. Similarly, Kumar *et al.* (2013) also obtained higher leaf nitrogen, phosphorus and potassium content in trees planted at wider spacing than

Table 4.23: Effect of different planting densities, training systems and fertigation levels on leaf Zn content of apple cv. Jeromine

D \ T / F	Zn (ppm)								
	T_1			T_2			D × F		
	F_1	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D)**
D_1	27.22	24.59	**25.91**	26.40	23.25	**24.82**	26.81	23.92	**25.36**
D_2	28.04	25.43	**26.73**	27.53	24.02	**25.77**	27.78	24.72	**26.25**
D_3	29.92	26.71	**28.32**	28.67	25.07	**26.87**	29.29	25.89	**27.59**
Mean (T×F)	**28.39**	**25.58**		**27.53**	**24.11**		**27.96**	**24.84**	**Mean (F)**
Mean (T)	**26.99**			**25.82**					
$CD_{0.05}$	D 0.70	T 0.57	F 0.57	D×T NS	T×F NS	D×F NS	D×T×F NS		

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

closer spacing. The possible reason for higher leaf nutrients content in low density planting (2666 trees/ha), might be due to less number of plants in wider spacing, which leads to less competition between the trees for uptake of nutrients from the soil and their further utilization for growth and development of the trees.

The trees trained with Tall Spindle training system had less vegetative growth as compared to Vertical Axis training system, which might have accounted for lesser utilization of nutrients for vegetative growth and development and thus resulting in more accumulation of these nutrients in the leaves. The findings of the present study are in consonance with the work of Sharma and Chauhan (1991) who observed significantly higher leaf nutrients content in Spindle-Bush system in comparison to trees trained to Modified Central Leader in apple. Mallikaarjuna (2020) also reported higher leaf nutrients content in apple trees trained with Tall Spindle training system as compared to Vertical Axis.

The results of the present study indicate that the increase in dose of N, P, K increased the N, P, K, Fe, Mn, Cu and Zn and decreased Ca and Mg content of apple leaves. In the present study, slow and frequent application of nutrients through fertigation might have increased nutrients availability in soil solution near plants root. The increased availability of these nutrients in soil under fertigation with higher doses of N, P, K fertilizers might have accounted for higher uptake of these nutrients. Similar increase in leaf nutrient content by application of higher doses of fertilizer (NPK) was also reported by Kumar *et al.* (2016) and Thakur *et al.* (2020), who showed higher leaf N, P and K and lower leaf Ca and Mg in trees subjected under higher dose of N, P, K. These results are in accordance with those of Neilsen *et al.* (1995), Neilsen *et al.* (2004), Neilsen *et al.* (2009), Chauhan *et al.* (2005), Singh *et al.* (2007), Raina *et al.* (2013), Meland *et al.* (2016), Sharma *et al.* (2018) and Kuzin *et al.* (2018), who reported increased leaf N content due to fertigation with higher dose of NPK fertilizer in apple crop.

Similar increase in leaf P content by application of high level of P through fertigation have been reported by Porro *et al.* (2013), Kuzin *et al.* (2018) and Thakur *et al.* (2020) in apple crop. Moreover, application of P might have helped in the root proliferation leading to the formation of more number of feeder roots and thus aiding in the uptake of available nutrients and their accumulation in leaves. Similarly, higher leaf K content with the application of higher dose of K through fertigation was recorded by Neilsen *et al.* (2004), Kuzin *et al.* (2018) and Thakur *et al.* (2020).

In the present study, higher dose of K application resulted in reduction in Ca and Mg contents of leaves. This might be attributed to the fact that Ca and K, and Mg and K shows antagonism effect. Application of higher dose of K through fertigation decreased the Ca and Mg content of leaves mainly due to increased K uptake, which reduced Ca and Mg uptake (Neilsen and Neilsen, 2011). The inverse relationship between availability of K in soil and leaf Ca content was reported by Porro *et al.* (2013). These results are in confirmatory with those of Neilsen *et al.* (1995), and Neilsen *et al.* (1998), who noted decreased Mg content with higher level of K content in the soil.

The present findings are in conformity with findings of Chauhan and Chandel (2008), who obtained significantly higher leaf nutrients content in kiwifruit vines fertigated with recommended dose and $3/4^{th}$ of recommended dose of N, P and K.

4.4 EFFECT OF PLANTING DENSITIES, TRAINING SYSTEMS AND FERTIGATION LEVELS ON CHEMICAL PROPERTIES OF SOIL

Data pertaining to soil chemical properties like soil pH, EC, organic carbon and nutrient contents (N, P, K, Ca, Mg, Fe, Mn, Cu and Zn) are presented in Tables 4.24 to 4.29 and Fig. 4.16.

4.4.1 Soil pH

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 cited in Appendix XLIX indicate that planting densities, training systems, fertigation levels, however, their interactions did not exerted a significant effect on soil pH.

The pooled data also showed that planting densities, training systems and fertigation levels and their interactions did not exhibit any significant effect on soil pH (Table 4.24). However, among three factors interaction, the highest pH of 7.20 was recorded in soil under D_3 planting density with Tall Spindle and F_2 level of fertigation and the lowest pH (6.65) was observed under D_1 planting density with Vertical Axis and F_1 level of fertigation.

Table 4.24: Effect of different planting densities, training systems and fertigation levels on soil pH and EC in apple cv. Jeromine plantation

D \ T / F	pH						EC (dS m^{-1})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	6.81	6.97	**6.89**	6.65	6.90	**6.77**	0.31	0.28	**0.29**	0.28	0.24	**0.26**
D_2	6.89	7.03	**6.96**	6.86	7.00	**6.93**	0.33	0.30	**0.32**	0.31	0.28	**0.29**
D_3	6.96	7.20	**7.08**	6.90	7.07	**6.98**	0.40	0.32	**0.36**	0.35	0.31	**0.33**
Mean (T×F)	**6.89**	**7.06**		**6.80**	**6.99**		**0.35**	**0.30**		**0.31**	**0.28**	
Mean (T)	**6.98**			**6.90**			**0.32**			**0.29**		

D \ F	pH: D × F			pH: $CD_{0.05}$		EC: D × F			EC: $CD_{0.05}$	
	F_1	F_2	Mean (D)	D	NS	F_1	F_2	Mean (D)	D	NS
D_1	6.73	6.93	**6.83**	T	NS	0.29	0.26	**0.27**	T	NS
				F	NS				F	NS
D_2	6.87	7.01	**6.94**	D×T	NS	0.32	0.29	**0.31**	D×T	NS
				T×F	NS				T×F	NS
D_3	6.93	7.13	**7.03**	D×F	NS	0.37	0.31	**0.34**	D×F	NS
Mean (F)	**6.84**	**7.03**		D×T×F	NS	**0.33**	**0.29**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

4.4.2 Electrical conductivity (EC)

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix L) reveal that planting densities, training systems, fertigation levels and their interactions did not exerted a significant effect on soil EC.

The pooled data (Table 4.24) showed that planting densities, training systems and fertigation levels and their interactions did not show significant effect on soil EC. However, among three factors interaction, the highest EC (0.40 dS m^{-1}) was recorded in soil under D_3 planting density with Tall Spindle training system and F_1 level of fertigation and the lowest EC (0.24 dS m^{-1}) was observed under D_1 planting density with Vertical axis training system and F_2 level of fertigation.

4.4.3 Organic carbon

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on soil organic carbon recorded during 2019 and 2020 are given in Appendix LI. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on soil organic carbon.

Pooled data of two years given in Table 4.25 indicate that planting densities, training systems and fertigation levels individually exhibited significant effect on soil organic carbon, while their interactions were found non-significant. Among the planting densities, the highest soil organic carbon of 26.37 g kg^{-1} was recorded at planting density of D_3 (2666 trees/ha), which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest (22.80 g kg^{-1}) was found in soil of D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the higher soil organic carbon (23.63 g kg^{-1}) was observed in T_1 (Tall Spindle) training system, which was significantly more than T_2 (Vertical Axis) training system (22. 87 g kg^{-1}). In case of fertigation, F_1 level of fertigation recorded significantly higher organic carbon (23.95 g kg^{-1}) as compared to F_2 level of fertigation (22.55 g kg^{-1}).

Table 4.25: Effect of different planting densities, training systems and fertigation levels on soil organic carbon and soil available N in apple cv. Jeromine plantation

D \ T / F	Organic carbon (g kg^{-1})						Available N (kg ha^{-1})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	22.33	20.90	**21.61**	21.81	20.38	**21.09**	421.79	365.34	**393.57**	410.82	355.94	**383.38**
D_2	24.39	23.22	**23.81**	24.06	21.90	**22.98**	431.20	381.02	**406.11**	421.79	373.18	**397.49**
D_3	26.01	24.96	**25.48**	25.14	23.97	**24.55**	446.88	396.70	**421.79**	434.34	387.30	**410.82**
Mean (T×F)	**24.24**	**23.02**		**23.6**	**22.1**		**433.29**	**381.02**		**422.31**	**372.14**	
Mean (T)	**23.63**			**22.87**			**407.16**			**397.23**		

D \ F	Organic carbon D × F			$CD_{0.05}$		Available N D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	22.07	20.64	**22.80**	D	0.78	416.30	360.64	**388.47**	D	8.27
D_2	24.23	22.56	**24.57**	T	0.64	426.50	377.10	**401.80**	T	6.75
D_3	25.57	24.46	**26.37**	F	0.64	440.61	392.00	**416.30**	F	6.75
Mean (F)	**23.95**	**22.55**		D×T	NS	**427.80**	**376.58**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest soil organic carbon (26.01 g kg^{-1}) was recorded under density D_3 with Tall Spindle training system and F_1 level of fertigation and the lowest (20.38 g kg^{-1}) was observed under D_1 planting density with Vertical Axis training system and F_2 level of fertigation.

4.4.4 Available N

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 cited in Appendix LII reveal that planting densities, training systems and fertigation levels exerted a significant effect on available soil N.

The pooled data depicted in Table 4.25 and Fig. 4.16 also indicate that the different planting densities, training systems and fertigation levels individually exhibited significant effect on available N content of soil, however their interactions were non-significant. Among the planting densities, the highest available soil N (416.30 kg ha^{-1}) was found at planting density of D_3 (2666 trees/ha), which was significantly higher than D_1 (4000 trees/ha) and D_2 (3200 trees/ha) planting densities. However, the lowest (388.47 kg ha^{-1}) was noted at D_1 (4000 trees/ha) planting density. Under different training systems, the higher available soil N of 407.16 kg ha^{-1} was registered with T_1 (Tall Spindle) training system than T_2 (Vertical Axis) training system (397.23 kg ha^{-1}). Among the fertigation levels, F_1 fertigation level registered significantly higher available soil N of 427.80 kg ha^{-1} as compared to F_2 level of fertigation (376.58 kg ha^{-1}).

The data also indicate that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest available soil N (446.88 kg ha^{-1}) was recorded under density D_3 with Tall Spindle training system and F_1 fertigation level and the lowest (355.94 kg ha^{-1}) was found under D_1 density with Vertical Axis training system and F_2 level of fertigation.

4.4.5 Available P

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 presented in Appendix LIII led to the inference that planting densities, training systems and fertigation levels exerted a significant effect on available soil P, however, their interactions were found non-significant.

Examination of the pooled data of two years led to the conclusion that available P in the soil varied significantly in different planting densities, training systems and fertigation levels (Table 4.26 and Fig. 4.16). Among the planting densities, the highest available soil P (149.37 kg ha^{-1}) was observed at planting density of D_3 (2666 trees/ha) and was found significantly superior to planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). Whereas, the lowest available soil P (105.60 kg ha^{-1}) was noted at D_1 (4000 trees/ha) planting density. In case of training systems, T_1 (Tall Spindle) training system registered significantly higher available soil P of 133.62 kg ha^{-1} as compared to T_2 (Vertical Axis) training system (122.27 kg ha^{-1}). Considering the effect of fertigation levels, the soil fertigated with F_1 level of fertigation recorded significantly higher available soil P of 143.74 kg ha^{-1} than the soil fertigated with F_2 level of fertigation (112.15 kg ha^{-1}).

The data also show that interactions between planting densities, training systems and fertigation levels were found non-significant. However, the maximum available soil P (168.52 kg ha^{-1}) was recorded under planting density D_3 with Tall Spindle training system and F_1 level of fertigation and the minimum (82.05 kg ha^{-1}) was noted under density D_1 with Vertical Axis training system and F_2 level of fertigation.

4.4.6 Available K

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix LIV) reveal that planting densities, training systems and fertigation levels exerted a significant effect on available soil K, however, their interactions were found non-significant.

Table 4.26: Effect of different planting densities, training systems and fertigation levels on soil available P and K in apple cv. Jeromine plantation

D \ T / F	Available P (kg ha^{-1})						Available K (kg ha^{-1})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	133.00	89.53	**111.27**	117.82	82.05	**99.93**	388.68	361.08	**374.88**	382.16	355.03	**368.59**
D_2	149.80	118.64	**134.22**	139.67	107.36	**123.52**	408.85	385.97	**397.41**	399.96	373.30	**386.63**
D_3	168.52	142.23	**155.37**	153.65	133.08	**143.36**	433.70	402.44	**418.07**	417.56	396.31	**406.93**
Mean (T×F)	**150.44**	**116.80**		**137.05**	**107.49**		**410.41**	**383.16**		**399.89**	**374.88**	
Mean (T)	**133.62**			**122.27**			**396.78**			**387.38**		

D \ F	P: D × F			P: $CD_{0.05}$		K: D × F			K: $CD_{0.05}$	
	F_1	F_2	**Mean (D)**			F_1	F_2	**Mean (D)**		
				D	12.15				D	10.17
D_1	125.41	85.79	**105.60**	T	9.92	385.42	358.05	**371.73**	T	8.30
				F	9.92				F	8.30
D_2	144.73	113.00	**128.87**	D×T	NS	404.40	379.63	**392.02**	D×T	NS
				T×F	NS				T×F	NS
D_3	161.09	137.65	**149.37**	D×F	NS	425.63	399.37	**412.50**	D×F	NS
Mean (F)	**143.74**	**112.15**		D×T×F	NS	**405.15**	**379.02**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

As per the pooled data of two years, planting densities, training systems and fertigation levels individually showed significant effect on available K content of soil, however their interactions were non-significant (Table 4.26 and Fig. 4.16). In case of planting densities, the highest available soil K (412.50 kg ha^{-1}) was recorded at D_3 (2666 trees/ha) planting density, which was significantly higher than D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. Whereas, the lowest available soil K (371.73 kg ha^{-1}) was observed at D_1 (4000 trees/ha) planting density. Among training systems, T_1 (Tall Spindle) training system had significantly higher available soil K of 396.78 kg ha^{-1} as compared to T_2 (Vertical Axis) training system (387.38 kg ha^{-1}). Considering the effect of fertigation levels, the orchard soil subjected under F_1 fertigation level registered significantly higher available K (405.15 kg ha^{-1}) than the soil fertigated with F_2 level of fertigation (379.02 kg ha^{-1}).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, the highest available soil K (433.70 kg ha^{-1}) was recorded under density D_3 (2666 trees/ha) with Tall Spindle training system and F_1 fertigation level, however, the lowest available soil K (355.03 kg ha^{-1}) was under D_1 density with Vertical axis training system and F_2 level of fertigation.

4.4.7 Available Ca

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on available soil Ca recorded during 2019 and 2020 are presented in Appendix LV. It revealed that planting densities and fertigation levels exerted a significant effect on available soil Ca during both the years.

Pooled data of two years given in Table 4.27 also indicate that the individual effect of planting densities and fertigation levels exhibited significant effect on available Ca content in soil, while the individual effect of training systems were found non-significant. The highest available soil Ca of 1678.94 mg kg^{-1} was recorded at D_3 (2666 trees/ha) planting density, which was significantly higher than other planting densities. Whereas, the lowest available soil Ca (1665.57 mg kg^{-1}) was found in D_1

(4000 trees/ha) planting density. Considering the effect of fertigation levels, the orchard soil subjected under F_1 fertigation level recorded significantly higher available soil Ca (1677.64 mg kg^{-1}) as compared to F_2 level of fertigation (1666.77 mg kg^{-1}).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. Among three factors interaction, the highest available soil Ca (1686.06 mg kg^{-1}) was recorded under density D_3 with Tall Spindle training system and F_1 fertigation level and the lowest available soil Ca (1657.14 mg kg^{-1}) was observed under density D_1 with Vertical Axis training system and F_2 fertigation level.

4.4.8 Available Mg

The data on available soil Mg recorded during 2019 and 2020 cited in Appendix LVI reveals that fertigation levels exerted a significant effect on available soil Mg, however, planting densities, training systems and interaction effects of planting densities, training systems and fertigation levels were found non-significant.

An inquisition of the pooled data of both the years presented in Table 4.27 reveals that individual effect of fertigation levels exhibited a significant influence on available soil Mg, however, interaction effect of planting densities and training systems were found non-significant. The significantly higher (584.25 mg kg^{-1}) available soil Mg was registered in orchard soil fertigated with F_1 fertigation level as compared to the orchard soil fertigated with F_2 level of fertigation (573.93 mg kg^{-1}).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among the three factors interaction the highest available soil Mg (590.10 mg kg^{-1}) was registered under density D_3 with Tall Spindle training system and F_1 fertigation level and the lowest (569.97 mg kg^{-1}) was under D_1 density with Vertical Axis training system and F_2 level of fertigation.

Table 4.27: Effect of different planting densities, training systems and fertigation levels on soil available Ca and Mg in apple cv. Jeromine plantation

D \ T / F	Available Ca (mg kg^{-1})						Available Mg (mg kg^{-1})					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	1673.93	1660.62	**1667.27**	1670.58	1657.14	**1663.86**	583.39	573.12	**578.25**	579.01	569.97	**574.49**
D_2	1679.37	1669.23	**1674.30**	1674.96	1664.92	**1669.94**	585.62	574.93	**580.27**	582.82	571.79	**577.30**
D_3	1686.06	1676.24	**1681.15**	1680.98	1672.48	**1676.73**	590.10	578.95	**584.52**	584.58	574.84	**579.71**
Mean (T×F)	**1679.78**	**1668.69**		**1675.51**	**1664.84**		**586.37**	**575.66**		**582.13**	**572.20**	
Mean (T)	**1674.24**			**1670.18**			**581.01**			**577.17**		

D \ F	Ca D × F: F_1	Ca D × F: F_2	**Mean (D)**	Mg D × F: F_1	Mg D × F: F_2	**Mean (D)**
D_1	1672.25	1658.88	**1665.57**	581.20	571.54	**576.37**
D_2	1677.16	1667.07	**1672.12**	584.22	573.36	**578.79**
D_3	1683.52	1674.36	**1678.94**	587.34	576.89	**582.11**
Mean (F)	**1677.64**	**1666.77**		**584.25**	**573.93**	

$CD_{0.05}$	Ca	Mg
D	6.49	NS
T	NS	NS
F	5.30	8.15
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

4.4.9 DTPA extractable Fe

The data on the effect of different planting densities, training systems, fertigation levels and their interactions recorded during 2019 and 2020 (Appendix LVII) indicate that planting densities, training systems and fertigation levels exerted a significant effect on DTPA extractable Fe content, however, their interactions were found non-significant.

As per the pooled data of two years presented in Table 4.28, it is clear that planting densities, training systems and fertigation levels individually exhibited significant effect on soil Fe content, while their interactions were found non-significant. Among the planting densities, the highest soil Fe content of 28.68 ppm was recorded in planting density of D_3 (2666 trees/ha), which was found statistically at par with D_2 (3200 trees/ha) planting density. Both the treatments had significantly higher Fe content as compared to D_1 (4000 trees/ha) planting density, where minimum Fe content (26.63 ppm) was observed. In case of training systems, the significantly higher soil Fe content (29.12 ppm) was observed in T_1 (Tall Spindle) training system than T_2 (Vertical Axis) training system (26.48 ppm). Considering the effect of fertigation levels, the orchard soil fertigated with F_1 fertigation level registered significantly higher Fe content of 29.90 ppm as compared to F_2 level of fertigation (25.70 ppm).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant, however, among three factors interaction, the highest soil Fe content (32.68 ppm) was recorded under density D_3 with Tall Spindle training system and F_1 level of fertigation and the lowest (23.89 ppm) was noted under density D_1 with Vertical Axis training system and F_2 level of fertigation.

4.4.10 DTPA extractable Mn

The data on the effect of different planting densities, training systems, fertigation levels and their interactions on soil Mn content recorded during 2019 and 2020 are given in Appendix LVIII. It is inferred from the data that planting densities, training systems and fertigation levels exerted a significant effect on DTPA extractable Mn content, however, their interactions were found non-significant.

Table 4.28: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Fe and Mn in soil of apple cv. Jeromine plantation

D \ T / F	Fe (ppm)						Mn (ppm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	29.89	25.44	**27.66**	27.32	23.89	**25.60**	20.36	19.19	**19.77**	19.63	19.00	**19.31**
D_2	32.02	26.91	**29.46**	28.53	24.91	**26.72**	21.76	20.22	**20.99**	20.98	19.68	**20.33**
D_3	32.68	27.78	**30.23**	28.98	25.29	**27.13**	22.71	21.14	**21.93**	22.08	20.67	**21.38**
Mean (T×F)	**31.53**	**26.71**		**28.27**	**24.69**		**21.61**	**20.18**		**20.89**	**19.78**	
Mean (T)	**29.12**			**26.48**			**20.90**			**20.34**		

D \ F	Fe: D × F			Fe: $CD_{0.05}$		Mn: D × F			Mn: $CD_{0.05}$	
	F_1	F_2	Mean (D)	D	1.24	F_1	F_2	Mean (D)	D	0.59
D_1	28.60	24.66	**26.63**	T	1.01	19.99	19.09	**19.54**	T	0.48
				F	1.01				F	0.48
D_2	30.27	25.91	**28.09**	D×T	NS	21.37	19.95	**20.66**	D×T	NS
				T×F	NS				T×F	NS
D_3	30.83	26.53	**28.68**	D×F	NS	22.40	20.91	**21.65**	D×F	NS
Mean (F)	**29.90**	**25.70**		D×T×F	NS	**21.25**	**19.98**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The perusal of pooled data given in Table 4.28 indicates that planting densities, training systems and fertigation levels individually exerted significant effect on DTPA extractable Mn content of soil, while their interactions were non-significant. Among the planting densities, the highest soil Mn content (21.65 ppm) was observed in planting density of D_3 (2666 trees/ha) and was found significantly superior to planting density of D_1 (4000 trees/ha) and D_2 (3200 trees/ha). However, the lowest soil Mn content (19.54 ppm) was noted in D_1 (4000 trees/ha) planting density. Considering the effect of training systems, the higher soil Mn content of 20.90 ppm was recorded in T_1 (Tall Spindle) training system than T_2 (Vertical Axis) training system (20.34 ppm). In case of fertigation levels, the orchard soil fertigated with F_1 fertigation level registered significantly higher soil Mn content (21.25 ppm) as compared to the orchard soil fertigated with F_2 level of fertigation (19.98 ppm).

The data also reveal that interactions between planting densities, training systems and fertigation levels were found non-significant. However, among three factors interaction, the highest soil Mn content (22.71 ppm) was observed in D_3 density with Tall Spindle training system and F_1 fertigation level and the minimum soil Mn content (19.00 ppm) in D_1 density with Vertical Axis training system and F_2 level of fertigation.

4.4.11 DTPA extractable Cu

The data on available soil Cu recorded during 2019 and 2020 displayed in Appendix LIX led to the inference that fertigation levels exerted a significant effect on DTPA extractable Cu content, however, planting densities, training systems and the interactions between planting density, training system and fertigation level were found non-significant.

The cursory glance of the pooled data presented in Table 4.29 represents that fertigation levels individually exerted significant effect on available Cu content of the soil, however, interaction effects of training systems and planting densities did not significantly affect the Cu content of the soil. Among the fertigation levels, the significantly higher Cu content (12.73 ppm) was recorded in orchard soil fertigated with F_1 level of fertigation in comparison to the orchard soil treated with F_2 level of fertigation (11.10 ppm).

Table 4.29: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Cu and Zn in soil of apple cv. Jeromine plantation

D \ T / F	Cu (ppm)						Zn (ppm)					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	12.41	10.85	**11.63**	11.93	9.75	**10.84**	6.15	5.36	**5.75**	5.61	5.19	**5.40**
D_2	12.87	11.42	**12.14**	12.50	10.79	**11.64**	6.41	5.75	**6.08**	6.34	5.57	**5.96**
D_3	13.67	12.41	**13.04**	12.98	11.37	**12.18**	7.47	6.78	**7.12**	6.85	6.28	**6.56**
Mean (T×F)	**12.98**	**11.56**		**12.47**	**10.63**		**6.67**	**5.96**		**6.26**	**5.68**	
Mean (T)	**12.27**			**11.55**			**6.32**			**5.97**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	NS	F_1	F_2	Mean (D)	D	0.42
D_1	12.17	10.30	**11.23**	T F	NS 0.76	5.88	5.27	**5.57**	T F	0.34 0.34
D_2	12.69	11.10	**11.89**	D×T	NS	6.37	5.66	**6.02**	D×T	NS
D_3	13.33	11.89	**12.61**	T×F D×F	NS NS	7.16	6.53	**6.84**	T×F D×F	NS NS
Mean (F)	**12.73**	**11.10**		D×T×F	NS	**6.47**	**5.82**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

The data also reveal that interaction between planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels were found non-significant. In case of three factors interaction, the maximum soil Cu content (13.67 ppm) was recorded in planting density of D_3 with Tall Spindle training system and F_1 level of fertigation and the minimum (9.75 ppm) was observed in planting density of D_1 with Vertical Axis training system and F_2 fertigation level.

4.4.12 DTPA extractable Zn

The data recorded during 2019 and 2020, and cited in Appendix LX reveal that planting densities, training systems and fertigation levels exerted a significant effect on DTPA extractable Zn content.

From the pooled data of two years enumerated in Table 4.29, it is clear that the planting densities, training systems and fertigation levels individually had a significant effect on DTPA extractable Zn content of soil, however, their interactions were found non-significant. Among the planting densities, the highest soil Zn content of 6.84 ppm was observed in D_3 (2666 trees/ha) planting density, which was found significantly superior to D_2 (3200 trees/ha) and D_1 (4000 trees/ha) planting densities. However, the lowest soil Zn content (5.57 ppm) was observed in D_1 (4000 trees/ha) planting density. In case of training systems, the significantly higher soil Zn content (6.32 ppm) was observed in T_1 (Tall Spindle) training system and the lower soil Zn content (5.97 ppm) was noted in T_2 (Vertical Axis) training system. The data on fertigation levels also showed significant variation in soil Zn content and the significantly higher Zn content (6.47 ppm) was recorded in orchard soil subjected under F_1 fertigation level in comparison to the orchard soil subjected under F_2 level of fertigation (5.82 ppm).

The pooled data presented in Table 4.29 reveal that interaction effects of planting densities and training systems, training systems and fertigation levels, planting densities and fertigation levels, and planting densities, training systems and fertigation levels on soil Zn content were found non-significant. In case of three factors interaction, the highest soil Zn content (7.47 ppm) was registered under D_3 density with Tall Spindle training system and F_1 fertigation level, while the lowest soil Zn content (5.19 ppm) was observed under D_1 density with Vertical Axis training system and F_2 level of fertigation.

The results pertaining to soil nutrient content indicate that the fertigation with higher doses of NPK (100 % of AD) significantly improved the soil N, P, K, Ca, Mg, Fe, Mn, Cu and Zn status of the soil. The results of present study are in accordance with Raina *et al.* (2013) and Thakur (2020), who reported highest available soil N, P and K with the application of 100 % of RD (NPK) and 100 % of AD (NPK), respectively through fertigation. The increase in available soil N, P and K status might be due to periodical application of nutrients in solution form resulting in to reduced nutrient losses due to leaching and mineralization besides providing a continuous supply of nutrients in readily available form. The findings of the present study is in consonance with the work of Nijjar (1985), who reported increase in the availability of Fe, Mn, Cu and Zn with the highest rate of N application.

Chapter-5

SUMMARY AND CONCLUSION

The results obtained from the present investigation titled **"Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)"** are summarized as under:

5.1 Effect of planting densities, training systems and fertigation levels on growth parameters

- The highest increase in tree height (28.39 cm), spread (20.42 cm), volume (1.97 m^3), scion diameter (6.06 mm) and stock diameter (7.12 mm) were recorded in planting density of D_3 (2666 trees/ha). However, the lowest were observed in high density of D_1 (4000 trees/ha).
- Among the training systems, Vertical Axis recorded the significantly higher increase in tree height (27.93 cm), spread (19.38 cm), volume (1.85 m^3), scion (5.56 mm) and stock diameter (6.49 mm).
- In case of fertigation, significantly higher increase in tree height (27.35 cm), spread (18.90 cm), volume (1.72 m^3), scion (5.58 m^3) and stock diameter (6.49 m^3) were observed in F_1 fertigation level as compared to F_2 fertigation level.
- Among the three factors interaction, the highest tree height, spread, volume, scion and stock diameter were recorded in treatment combination of $D_3T_2F_1$ (2666 trees/ha, Vertical Axis and F_1 fertigation level).
- The maximum annual shoot growth (36.48 cm), leaf area (36.09 cm^2) and pruning wood weight (369.20 g $tree^{-1}$) were observed in planting density of D_3 (2666 trees/ha) and the minimum in D_1 planting density (4000 trees/ha).
- In case of training systems, significantly higher annual shoot growth (33.58 cm), leaf area (35.89 cm^2) and pruning wood weight (323.28 g $tree^{-1}$) were attained by the trees trained to Vertical Axis as compared to Tall Spindle.
- Considering the effect of fertigation levels, F_1 fertigation level registered higher annual shoot growth (33.28 cm), leaf area (36.13 cm^2) and pruning wood weight (367.00 g $tree^{-1}$) than F_2 fertigation level.

- Among the three factors interaction, the maximum annual shoot growth, leaf area and pruning wood weight were recorded in treatment combination of $D_3T_2F_1$ (2666 trees/ha, Vertical Axis and F_1 fertigation level).
- The highest leaf area index (2.09) was recorded in planting density of D_1 (4000 trees/ha) and the lowest (1.78) was noted in D_3 (2666 trees/ha) planting density, whereas training systems did not exert significant effect on leaf area index.
- Among the fertigation levels, higher leaf area index (1.96) was recorded in F_1 fertigation level.
- In case of three factors interaction, $D_1T_2F_1$ treatment combination (4000 trees/ha, Vertical Axis and F_1 fertigation level) recorded the maximum leaf area index.

5.2 Effect of planting densities, training systems and fertigation levels on cropping parameters

- The maximum spur (0.23 number cm^{-1} shoot length) and blossom density (11.51 flower clusters cm^{-2} TCSA) were recorded in planting density of D_3 (2666 trees/ha), while minimum were noted in planting density of D_1 (4000 trees/ha).
- Among the training systems, higher spur density (0.20 number cm^{-1} shoot length) and blossom density (11.89 flower clusters cm^{-2} TCSA) were registered by trees trained to Tall Spindle.
- In case of fertigation, F_1 fertigation level recorded significantly higher spur density (0.19 number cm^{-1} shoot length) and blossom density (12.27 flower clusters cm^{-2} TCSA) than F_2 fertigation level.
- Among three factors interaction, the highest spur and blossom density were recorded in treatment combination of $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level).
- The highest fruit set (52.90 %) and lowest fruit drop (68.15 %) were recorded in planting density of D_3 (2666 trees/ha) and the lowest fruit set and highest fruit drop were observed in planting density of D_1 (4000 trees/ha).
- In case of training systems, the higher fruit set (51.69 %) and the lower fruit drop (69.89 %) were registered by Tall Spindle as compared to Vertical Axis.

- Under fertigation, F_1 fertigation level exhibited significantly higher fruit set (52.38 %) and lower fruit drop (69.39 %) than F_2 fertigation level.
- Among three factors interaction, the highest fruit set and lowest fruit drop were recorded in treatment combination of $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level).
- The maximum yield (12.11 kg $tree^{-1}$) and yield efficiency (1.04 kg cm^{-2} TCSA) were recorded in planting density of D_3 (2666 trees/ha) and the minimum were noted in D_1 (4000 trees/ha) planting density. On the contrary, the highest productivity (32.29 t ha^{-1}) was recorded in planting density of D_1 (4000 trees/ha) and the lowest was observed in D_3 (2666 trees/ha) planting density.
- In case of training systems, significantly higher yield (11.47 kg $tree^{-1}$), yield efficiency (1.09 kg cm^{-2} TCSA) and productivity (37.09 t ha^{-1}) were obtained in Tall Spindle as compared to Vertical Axis.
- Under fertigation, F_1 fertigation level recorded higher yield (11.36 kg $tree^{-1}$), yield efficiency (1.03 kg cm^{-2} TCSA) and productivity (36.73 t ha^{-1}) in comparison to F_2 fertigation level.
- In case of three factors interaction, the highest yield and yield efficiency were recorded in $D_3T_1F_1$ treatment combination (2666 trees/ha, Tall Spindle and F_1 fertigation level), however highest productivity were obtained in treatment combination of $D_1T_1F_1$ (4000 trees/ha, Tall Spindle and F_1 fertigation level).

5.2 Effect of planting densities, training systems and fertigation levels on fruit quality parameters

- The highest fruit length (63.63 mm), diameter (72.17 mm), weight (151.97 g) and volume (186.15 cm^3) were recorded in planting density of D_3 (2666 trees/ha) and the lowest were found in D_1 (4000 trees/ha) planting density.
- In case of training systems, Tall Spindle registered significantly higher fruit length (61.07 mm), diameter (67.36 mm), weight (145.27 g) and volume (174.36 cm^3) as compared to Vertical Axis.
- Among fertigation levels, the higher fruit length (61.36 mm), diameter (67.82 mm), weight (144.90 g) and volume (176.08 cm^3) were recorded in F_1 fertigation level than F_2 fertigation level.

- Among three factors interaction, the maximum fruit length, diameter, weight and volume were observed in $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) treatment combination.
- The maximum fruit firmness (5.41 kg cm^{-2}) was recorded in planting density of D_3 (2666 trees/ha) and the minimum were found in planting density of D_1 (4000 trees/ha), whereas, training systems failed to exert any significant effect on fruit firmness.
- Among fertigation levels, significantly higher fruit firmness of 5.26 kg cm^{-2} was observed in F_2 fertigation level as compared to F_1 fertigation level.
- In case of three factors interaction, the highest fruit firmness was observed in treatment combination of $D_3T_2F_2$ (2666 trees/ha, Vertical Axis and F_2 fertigation level).
- The highest TSS (11.59 ^oB), total sugars (9.72 %), reducing sugars (6.70 %), non-reducing sugars (2.87 %) and anthocyanin content (1.37 OD) were observed in planting density of D_3 (2666 trees/ha) and the minimum were noted in planting density of D_1 (4000 trees/ha).
- Among the training systems, Tall Spindle exhibited higher TSS (11.06 ^oB), total sugars (9.29 %), reducing sugars (6.43 %), non-reducing sugars (2.71 %) and anthocyanin content (1.21 OD) than Vertical Axis.
- In case of fertigation, the higher TSS (11.23 ^oB), total sugars (9.38 %), reducing sugars (6.51 %), non-reducing sugars (2.73 %) and anthocyanin content (1.25 OD) were observed in F_1 fertigation level as compared to F_2 fertigation level.
- Among three factors interaction, the highest TSS, total sugars, reducing sugars, non-reducing sugars and anthocyanin content were recorded in treatment combination of $D_3T_1F_1$(2666 trees/ha, Tall Spindle and F_1 fertigation level).
- The lowest titratable acidity (0.32 %) was observed in planting density of D_3 (2666 tress/ha) and highest in D_1 (4000 trees/ha) planting density.
- In case of training systems, lower titratable acidity (0.41 %) was registered by Tall Spindle as compared to Vertical Axis.
- Among fertigation levels, F_1 fertigation level recorded lower titratable acidity (0.41 %) than F_2 fertigation level.

- Among three factors interaction, treatment combination of $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) registered the lowest titratable acidity.

5.3.6 Ascorbic acid content

- The maximum ascorbic acid content (5.65 mg $100g^{-1}$) was observed in planting density of D_1 (4000 trees/ha) and minimum was in D_3 (2666 trees/ha) planting density.
- In case of training systems, Vertical Axis recorded higher ascorbic acid content (5.02 mg $100g^{-1}$) than Tall Spindle.
- Among fertigation levels, the higher ascorbic acid content (5.43 mg $100g^{-1}$) was found in F_2 fertigation level as compared to F_1 fertigation level.
- Among the three factors interaction, the highest ascorbic acid content was found in $D_1T_2F_2$ (4000 trees/ha, Vertical Axis and F_2 fertigation level) treatment combination.

5.4 Effect of planting densities, training systems and fertigation levels on light interception and plant physiological parameters

- The highest light interception (62.17 %), photosynthesis rate (14.88 µmol CO_2 m^{-2} s^{-1}), stomatal conductance (0.270 mol H_2O $m^{-2}s^{-1}$), transpiration rate (4.01 mmol H_2O $m^{-2}s^{-1}$) and leaf chlorophyll content (2.70 mg g^{-1} fresh weight) were recorded in planting density of D_1 (4000 trees/ha).
- Among the training systems, Tall Spindle registered significantly higher light interception (61.33 %), photosynthesis rate (12.11 µmol CO_2 m^{-2} s^{-1}), stomatal conductance (0.206 mol H_2O $m^{-2}s^{-1}$), transpiration rate (3.49 mmol H_2O $m^{-2}s^{-1}$) and leaf chlorophyll content (2.43 mg g^{-1} fresh weight) as compared to Vertical Axis.
- In case of fertigation, the higher light interception (59.24 %), photosynthesis rate (12.52 µmol CO_2 m^{-2} s^{-1}), stomatal conductance (0.216 mol H_2O $m^{-2}s^{-1}$), transpiration rate (3.57 mmol H_2O $m^{-2}s^{-1}$) and leaf chlorophyll content (2.49 mg g^{-1} fresh weight) were recorded in F_1 fertigation level than F_2 fertigation level.
- Among three factors interaction, the maximum light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf

chlorophyll content were noted in treatment combination of $D_1T_1F_1$ (4000 trees/ha, Tall Spindle and F_1 fertigation level).

5.5 Effect of planting densities, training systems and fertigation levels on leaf nutrients content

- Planting densities failed to exert significant effect on leaf N content, however, highest leaf P (0.32 %) and K (1.82 %) contents were recorded in lowest planting density of D_3 (2666 trees/ha).
- In case of training systems, Tall Spindle registered higher leaf N (2.51 %), P (0.28 %) and K (1.78 %) as compared to Vertical Axis.
- Among fertigation levels, significantly higher leaf N (2.67 %), P (0.29 %) and K (1.81 %) were recorded in F_1 fertigation level than F_2 fertigation level.
- In case of three factors interaction, the highest leaf N, P and K contents were recorded in $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) treatment combination.
- Effect of planting densities and training systems on leaf Ca and Mg content were found non-significant.
- In case of fertigation, F_2 fertigation level recorded higher leaf Ca (2.21 %) and Mg (0.44 %) contents as compared to F_1 fertigation level.
- Among three factors interaction, the maximum leaf Ca and Mg contents were recorded in $D_1T_2F_2$ (4000 trees/ha, Vertical Axis and F_2 fertigation level) treatment combination.
- The highest leaf Fe (187.33 ppm), Mn (39.14 ppm), Cu (11.61 ppm) and Zn (27.59 ppm) contents were registered by lowest planting density of 2666 trees/ha (D_3).
- In case of training system, Tall Spindle registered higher leaf Fe (184.34 ppm), Mn (38.01 ppm), Cu (11.27 ppm) and Zn (26.99 ppm) contents as compared to Vertical Axis.
- Among fertigation levels, significantly higher leaf Fe (186.70 ppm), Mn (39.56 ppm), Cu (11.73 ppm) and Zn (27.96 ppm) contents were recorded in F_1 fertigation level than F_2 fertigation level.
- In case of three factors interaction, the highest leaf Fe, Mn, Cu and Zn contents were recorded in $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) treatment combination.

5.5 Effect of planting densities, training systems and fertigation levels on soil chemical properties

- An examination of data revealed that planting densities, training systems, fertigation levels and their interactions had no significant effect on soil pH and EC.
- The maximum soil organic carbon (26.37 g kg^{-1}) was recorded in planting density of D_3 (2666 trees/ha) and the minimum in D_1 (4000 trees/ha) planting density.
- Among training systems, Tall Spindle exhibited higher organic carbon (23.63 g kg^{-1}) as compared to Vertical Axis.
- In case of fertigation levels, significantly higher organic carbon (23.95 g kg^{-1}) was recorded in F_1 fertigation level than F_2 fertigation level.
- Among three factors interaction, the maximum soil organic carbon was recorded in treatment combination of $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level).
- The highest available soil N (416.30 kg ha^{-1}), P (149.37 kg ha^{-1}), K (412.50 kg ha^{-1}), Ca (1678.94 mg kg^{-1}) and Mg (582.11 mg kg^{-1}) contents were recorded in D_3 (2666 trees/ha) planting density. However, the lowest macro nutrient contents were found in D_1 (4000 trees/ha) planting density.
- In case of training systems, Tall Spindle registered higher available soil N (407.16 kg ha^{-1}), P (133.62 kg ha^{-1}) and K (396.78 kg ha^{-1}) as compared to Vertical Axis, whereas, training systems failed to exert significant effect on soil available Ca and Mg.
- Among fertigation levels, F_1fertigation level registered significantly higher available soil N (427.80 kg ha^{-1}), P (143.74 kg ha^{-1}), K (405.15 kg ha^{-1}), Ca (1677.64 mg kg^{-1}) and Mg (584.25 mg kg^{-1}) contents than F_2 fertigation level.
- In case of three factors interaction, the highest available soil N, P, K, Ca and Mg were recorded in $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) treatment combination.
- The highest available soil Fe (28.68 ppm), Mn (21.65 ppm) and Zn (6.84 ppm) contents were recorded in D_3 (2666 trees/ha) planting density while, lowest were found in D_1 (4000 trees/ha) planting density. However, planting densities failed to exert any significant effect on available Cu content of the soil.

- In case of training systems, Tall Spindle registered higher available soil Fe (29.12 ppm), Mn (20.90 ppm) and Zn (6.32 ppm) as compared to Vertical Axis. However, training systems did not show any significant effect on available Cu content of the soil
- Among fertigation levels, F_1fertigation level exhibited significantly higher soil Fe (29.90 ppm), Mn (21.25 ppm), Cu (12.73 ppm) and Zn (6.47 ppm) contents than F_2 fertigation level.
- In case of three factors interaction, the highest available soil Fe, Mn, Cu and Zn contents were recorded in $D_3T_1F_1$ (2666 trees/ha, Tall Spindle and F_1 fertigation level) treatment combination.

Conclusion

On the basis of results obtained in the present investigation, it can be concluded that treatment combination of high density planting of 4000 trees/ha with Tall Spindle training system and subjected under 100 % of AD (NPK) may be considered best treatment as it resulted in significantly higher productivity (42.13 t/ha), leaf area index, light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content without any significant adverse effect on physico-chemical fruit quality characteristics, leaf nutrients content and soil chemical properties. This treatment resulted in 8.30 to 45.72 per cent increase in productivity in comparison to different treatment combinations under study.

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Appendix-I

Agro-meteorological data during the cropping season (January, 2019-August, 2020)

Month	Rainfall (mm)	Temperature (°C)			Relative Humidity (%)
		Maximum	Minimum	Mean	
January, 2019	73.00	15.70	2.00	8.80	59.00
February, 2019	103.10	16.30	4.40	10.30	63.00
March, 2019	54.60	20.30	6.40	13.40	54.00
April, 2019	36.80	27.30	12.70	20.00	49.00
May, 2019	21.3	30.50	14.70	22.60	44.00
June, 2019	98.5	33.70	17.80	25.75	57.39
July, 2019	218.10	27.70	19.90	23.80	79.00
August, 2019	225.80	28.80	20.10	24.45	79.00
September, 2019	151.40	28.30	18.60	23.45	78.00
October, 2019	5.60	25.60	11.30	18.45	66.00
November, 2019	32.20	22.80	8.10	15.45	61.00
December,2019	33.20	19.10	1.90	10.50	58.00
January, 2020	168.30	15.70	2.50	9.10	68.00
February, 2020	38.50	20.20	4.10	12.15	57.00
March, 2020	171.80	21.20	7.20	14.20	62.00
April, 2020	47.70	27.60	10.70	19.15	51.00
May, 2020	74.80	29.70	14.40	22.05	53.00
June, 2020	58.70	30.80	17.40	24.10	64.00
July, 2020	278.10	30.20	19.90	25.05	76.00
August, 2020	148.60	29.20	20.70	24.95	81.00

Source: Meteorological Observatory, Department of Environmental Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) 173230

Appendix II: Effect of different planting densities, training systems and fertigation levels on tree height (cm) of apple cv. Jeromine

Treatment	2019	2020	2021
$D_1T_1F_1$	174.76	195.58	217.03
$D_2T_1F_1$	210.61	234.24	259.00
$D_3T_1F_1$	210.24	236.72	265.45
$D_1T_1F_2$	197.83	213.36	229.37
$D_2T_1F_2$	240.20	258.58	277.91
$D_3T_1F_2$	244.84	266.70	290.73
$D_1T_2F_1$	255.66	281.94	309.15
$D_2T_2F_1$	213.61	243.33	274.51
$D_3T_2F_1$	235.30	267.97	303.26
$D_1T_2F_2$	260.84	282.57	305.08
$D_2T_2F_2$	237.04	261.62	287.59
$D_3T_2F_2$	221.59	249.42	279.61

Appendix III: Effect of different planting densities, training systems and fertigation levels on tree spread (cm) of apple cv. Jeromine

Treatment	2019		2020		2021	
	EW	NS	EW	NS	EW	NS
$D_1T_1F_1$	151.53	96.84	162.81	112.32	179.19	124.56
$D_2T_1F_1$	124.61	110.23	142.75	124.41	158.53	143.87
$D_3T_1F_1$	149.59	244.76	165.64	265.97	184.22	289.85
$D_1T_1F_2$	178.6	236.22	190.83	245.41	203.71	255.65
$D_2T_1F_2$	140.79	116.21	152.72	130.84	165.64	147.26
$D_3T_1F_2$	117.85	123.03	131.27	140.65	147.44	160.36
$D_1T_2F_1$	106.82	99.66	125.46	115.92	146.18	131.46
$D_2T_2F_1$	111.48	104.01	130.84	125.49	153.68	145.75
$D_3T_2F_1$	114.57	140.96	135.35	165.82	158.61	192.7
$D_1T_2F_2$	204.2	138.02	220.52	150.26	237.38	162.92
$D_2T_2F_2$	138.94	109.22	157.38	125.84	177.56	142.62
$D_3T_2F_2$	118.95	144.86	136.21	167.52	155.33	192.7

Appendix IV: Effect of different planting densities, training systems and fertigation levels on scion diameter (mm) of apple cv. Jeromine

Treatment	2019	2020	2021
$D_1T_1F_1$	26.86	32.59	36.95
$D_2T_1F_1$	27.49	33.52	38.35
$D_3T_1F_1$	27.76	34.62	39.83
$D_1T_1F_2$	26.18	31.84	35.99
$D_2T_1F_2$	34.16	40.40	45.11
$D_3T_1F_2$	36.45	43.39	48.46
$D_1T_2F_1$	29.82	35.60	40.02
$D_2T_2F_1$	31.99	38.10	43.02
$D_3T_2F_1$	31.13	38.05	43.38
$D_1T_2F_2$	29.93	35.65	39.89
$D_2T_2F_2$	30.89	37.18	42.02
$D_3T_2F_2$	31.13	38.11	43.29

Appendix V: Effect of different planting densities, training systems and fertigation levels on stock diameter (mm) of apple cv. Jeromine

Treatment	2019	2020	2021
$D_1T_1F_1$	33.07	39.41	44.15
$D_2T_1F_1$	29.42	36.67	42.52
$D_3T_1F_1$	34.03	41.74	48.31
$D_1T_1F_2$	35.6	41.51	45.98
$D_2T_1F_2$	41.67	48.6	54.31
$D_3T_1F_2$	43.23	50.87	57.09
$D_1T_2F_1$	36.16	42.75	47.56
$D_2T_2F_1$	37.94	45.42	51.38
$D_3T_2F_1$	32.6	40.45	47.13
$D_1T_2F_2$	37.78	44.19	48.83
$D_2T_2F_2$	34.15	41.47	47.34
$D_3T_2F_2$	38.41	46.18	52.71

Appendix VI: Effect of different planting densities, training systems and fertigation levels on tree volume (m^3) of apple cv. Jeromine

Treatment	2019	2020	2021
$D_1T_1F_1$	1.99	2.75	3.75
$D_2T_1F_1$	2.73	3.84	5.31
$D_3T_1F_1$	4.56	6.33	8.74
$D_1T_1F_2$	4.25	5.20	6.33
$D_2T_1F_2$	3.88	4.96	6.33
$D_3T_1F_2$	3.78	5.06	6.81
$D_1T_2F_1$	3.53	5.02	6.95
$D_2T_2F_1$	2.57	3.97	5.91
$D_3T_2F_1$	3.70	5.66	8.46
$D_1T_2F_2$	6.09	7.75	9.75
$D_2T_2F_2$	3.65	5.07	6.93
$D_3T_2F_2$	3.39	4.95	7.12

Appendix VII: Effect of different planting densities, training systems and fertigation levels on tree height of apple cv. Jeromine

D \ T \ F	Increase in tree height (cm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	20.82	15.53	**18.18**	26.28	21.73	**24.01**	21.45	16.01	**18.73**	27.21	22.51	**24.86**
D_2	23.63	18.38	**21.01**	29.72	24.58	**27.15**	24.76	19.33	**22.05**	31.18	25.97	**28.58**
D_3	26.48	21.86	**24.17**	32.67	27.83	**30.25**	28.73	24.03	**26.38**	35.29	30.19	**32.74**
Mean (T×F)	**23.64**	**18.59**		**29.56**	**24.71**		**24.98**	**19.79**		**31.23**	**26.22**	
Mean (T)	**21.12**			**27.14**			**22.39**			**28.73**		

D \ F	2019 D × F			2020 D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	23.55	18.63	**21.09**	24.33	19.26	**21.80**
D_2	26.68	21.48	**24.08**	27.97	22.65	**25.31**
D_3	29.58	24.85	**27.21**	32.01	27.11	**29.56**
Mean (F)	**26.60**	**21.65**		**28.10**	**23.01**	

$CD_{0.05}$	2019	2020
D	2.47	2.56
T	2.02	2.09
F	2.02	2.09
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix VIII: Effect of different planting densities, training systems and fertigation levels on tree spread of apple cv. Jeromine

D \ T \ F	Increase in tree spread (cm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	13.38	10.71	**12.05**	17.45	14.28	**15.87**	14.31	11.56	**12.94**	18.13	14.76	**16.45**
D_2	16.16	13.28	**14.72**	20.42	17.53	**18.98**	17.62	14.67	**16.15**	21.55	18.48	**20.02**
D_3	18.63	15.52	**17.08**	22.82	19.96	**21.39**	21.23	17.94	**19.59**	25.07	22.15	**23.61**
Mean (T×F)	**16.06**	**13.17**		**20.23**	**17.26**		**17.72**	**14.72**		**21.58**	**18.46**	
Mean (T)	**14.61**			**18.74**			**16.22**			**20.02**		

D \ F	2019 D × F			2020 D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	15.42	12.50	**13.96**	16.22	13.16	**14.69**
D_2	18.29	15.41	**16.85**	19.59	16.58	**18.08**
D_3	20.73	17.74	**19.23**	23.15	20.05	**21.60**
Mean (F)	**18.14**	**15.21**		**19.65**	**16.59**	

$CD_{0.05}$	2019	2020
D	2.57	2.61
T	2.10	2.13
F	2.10	2.13
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix IX: Effect of different planting densities, training systems and fertigation levels on annual shoot growth of apple cv. Jeromine

D \ T / F	Annual shoot growth (cm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	25.63	22.87	**24.25**	28.74	25.67	**27.21**	28.21	24.80	**26.51**	32.25	27.49	**29.87**
D_2	29.82	27.43	**28.63**	33.37	31.26	**32.32**	33.09	29.91	**31.50**	37.45	33.85	**35.65**
D_3	34.28	32.29	**33.29**	37.34	35.34	**36.34**	37.47	34.86	**36.17**	41.71	38.52	**40.12**
Mean (T×F)	**29.91**	**27.53**		**33.15**	**30.76**		**32.92**	**29.86**		**37.14**	**33.29**	
Mean (T)	**28.72**			**31.95**			**31.39**			**35.21**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	2.61	F_1	F_2	Mean (D)	D	2.72
D_1	27.19	24.27	**25.73**	T	2.14	30.23	26.15	**28.19**	T	2.22
D_2	31.60	29.35	**30.47**	F	2.14	35.27	31.88	**33.58**	F	2.22
D_3	35.81	33.82	**34.81**	D×T	NS	39.59	36.69	**38.14**	D×T	NS
Mean (F)	**31.53**	**29.14**		T×F	NS	**35.03**	**31.57**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix X: Effect of different planting densities, training systems and fertigation levels on scion diameter of apple cv. Jeromine

D \ T / F	Increase in scion diameter (mm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	5.66	5.73	**5.70**	5.72	5.78	**5.75**	4.36	4.15	**4.26**	4.42	4.24	**4.33**
D_2	6.24	6.03	**6.14**	6.29	6.11	**6.20**	4.83	4.71	**4.77**	4.92	4.87	**4.90**
D_3	6.94	6.86	**6.90**	6.98	6.92	**6.95**	5.21	5.07	**5.14**	5.33	5.18	**5.26**
Mean (T×F)	**6.28**	**6.21**		**6.33**	**6.27**		**4.80**	**4.64**		**4.89**	**4.76**	
Mean (T)	**6.24**			**6.30**			**4.72**			**4.83**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.06	F_1	F_2	Mean (D)	D	0.11
D_1	5.69	5.76	**5.72**	T	0.05	4.39	4.20	**4.29**	T	0.09
D_2	6.27	6.07	**6.17**	F	0.05	4.88	4.79	**4.83**	F	0.09
D_3	6.96	6.89	**6.93**	D×T	NS	5.27	5.13	**5.20**	D×T	NS
Mean (F)	**6.31**	**6.24**		T×F	NS	**4.85**	**4.70**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XI: Effect of different planting densities, training systems and fertigation levels on stock diameter of apple cv. Jeromine

Increase in stock diameter (mm)

D \ T, F	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	6.34	5.91	**6.13**	6.59	6.41	**6.50**	4.74	4.47	**4.61**	4.81	4.64	**4.73**
D_2	7.25	6.93	**7.09**	7.48	7.32	**7.40**	5.85	5.71	**5.78**	5.96	5.87	**5.92**
D_3	7.71	7.64	**7.68**	7.85	7.77	**7.81**	6.57	6.22	**6.40**	6.68	6.53	**6.61**
Mean (T×F)	**7.10**	**6.83**		**7.31**	**7.17**		**5.72**	**5.47**		**5.82**	**5.68**	
Mean (T)	**6.96**			**7.24**			**5.59**			**5.75**		

2019

D \ F	F_1	F_2	**Mean (D)**	$CD_{0.05}$	
D_1	6.47	6.16	**6.31**	D	0.25
D_2	7.37	7.13	**7.25**	T	0.21
D_3	7.78	7.71	**7.74**	F	0.21
Mean (F)	**7.20**	**7.00**		D×T	NS
				T×F	NS
				D×F	NS
				D×T×F	NS

2020

D \ F	F_1	F_2	**Mean (D)**	$CD_{0.05}$	
D_1	4.78	4.56	**4.67**	D	0.18
D_2	5.91	5.79	**5.85**	T	0.15
D_3	6.63	6.38	**6.50**	F	0.15
Mean (F)	**5.77**	**5.57**		D×T	NS
				T×F	NS
				D×F	NS
				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XII: Effect of different planting densities, training systems and fertigation levels on tree volume of apple cv. Jeromine

Increase in tree volume (m^3)

D \ T, F	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	0.95	0.77	**0.86**	1.65	1.49	**1.57**	1.13	0.99	**1.06**	2.00	1.92	**1.96**
D_2	1.11	1.08	**1.10**	1.42	1.40	**1.41**	1.47	1.36	**1.42**	1.93	1.86	**1.90**
D_3	1.77	1.28	**1.53**	1.96	1.56	**1.76**	2.41	1.75	**2.08**	2.80	2.18	**2.49**
Mean (T×F)	**1.28**	**1.04**		**1.68**	**1.48**		**1.67**	**1.37**		**2.24**	**1.99**	
Mean (T)	**1.16**			**1.58**			**1.52**			**2.12**		

2019

D \ F	F_1	F_2	**Mean (D)**	$CD_{0.05}$	
D_1	1.30	1.13	**1.22**	D	0.02
D_2	1.25	1.25	**1.25**	T	0.01
D_3	1.86	1.42	**1.64**	F	0.01
Mean (F)	**1.47**	**1.27**		D×T	0.02
				T×F	0.02
				D×F	0.02
				D×T×F	0.03

2020

D \ F	F_1	F_2	**Mean (D)**	$CD_{0.05}$	
D_1	1.57	1.46	**1.51**	D	0.02
D_2	1.70	1.61	**1.66**	T	0.01
D_3	2.60	1.96	**2.28**	F	0.01
Mean (F)	**1.96**	**1.68**		D×T	NS
				T×F	0.02
				D×F	0.02
				D×T×F	0.03

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XIII: Effect of different planting densities, training systems and fertigation levels on leaf area of apple cv. Jeromine

D \ T / F	Leaf area (cm^2) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	34.96	33.85	**34.41**	35.63	34.75	**35.19**	35.37	34.23	**34.80**	36.06	35.11	**35.59**
D$_2$	35.77	34.65	**35.21**	36.21	35.22	**35.72**	36.22	35.07	**35.65**	36.67	35.62	**36.15**
D$_3$	36.09	35.05	**35.57**	36.73	35.47	**36.10**	36.61	35.54	**36.08**	37.28	35.94	**36.61**
Mean (T×F)	**35.61**	**34.52**		**36.19**	**35.15**		**36.07**	**34.95**		**36.67**	**35.56**	
Mean (T)	**35.06**			**35.66**			**35.51**			**36.11**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$	
D$_1$	35.30	34.30	**34.80**	D T F D×T T×F D×F D×T×F	0.73 0.60 0.60 NS NS NS NS	35.72	34.67	**35.20**	D T F D×T T×F D×F D×T×F	0.70 0.57 0.57 NS NS NS NS
D$_2$	35.99	34.94	**35.46**			36.44	35.35	**35.90**		
D$_3$	36.41	35.26	**35.83**			36.94	35.74	**36.34**		
Mean (F)	**35.90**	**34.83**				**36.37**	**35.25**			

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix XIV: Effect of different planting densities, training systems and fertigation levels on leaf area index of apple cv. Jeromine

D \ T / F	Leaf area index (m^{2}m^{-2}) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	2.04	1.92	**1.98**	2.11	1.96	**2.04**	2.19	2.13	**2.16**	2.21	2.15	**2.18**
D$_2$	1.86	1.76	**1.81**	1.91	1.78	**1.84**	1.94	1.88	**1.91**	1.96	1.91	**1.94**
D$_3$	1.75	1.68	**1.72**	1.82	1.72	**1.77**	1.87	1.76	**1.82**	1.90	1.78	**1.84**
Mean (T×F)	**1.88**	**1.79**		**1.95**	**1.82**		**2.00**	**1.92**		**2.02**	**1.95**	
Mean (T)	**1.83**			**1.88**			**1.96**			**1.99**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$	
D$_1$	2.08	1.94	**2.01**	D T F D×T T×F D×F D×T×F	0.06 0.05 0.05 NS NS NS NS	2.36	2.28	**2.32**	D T F D×T T×F D×F D×T×F	0.03 0.02 0.02 NS NS NS NS
D$_2$	1.88	1.77	**1.83**			2.23	2.16	**2.20**		
D$_3$	1.79	1.70	**1.74**			2.15	2.08	**2.11**		
Mean (F)	**1.91**	**1.80**				**2.24**	**2.17**			

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix XV: Effect of different planting densities, training systems and fertigation levels on pruning wood weight of apple cv. Jeromine

D \ T / F	Pruning wood weight (g tree^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	173.62	125.32	**149.47**	241.82	170.68	**206.25**	315.62	182.33	**248.98**	383.48	230.66	**307.07**
D_2	282.73	158.13	**220.43**	320.82	235.63	**278.23**	427.25	243.29	**335.27**	461.67	307.82	**384.75**
D_3	431.68	238.41	**335.05**	354.76	281.46	**318.11**	484.48	272.25	**378.37**	526.11	364.43	**445.27**
Mean (T×F)	**296.01**	**173.95**		**305.80**	**229.26**		**409.12**	**232.62**		**457.09**	**300.97**	
Mean (T)	**234.98**			**267.53**			**320.87**			**379.03**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	207.72	148.00	**177.86**	D T	17.88 14.60	349.55	206.50	**278.02**	D T	6.52 5.33
D_2	301.78	196.88	**249.33**	F D×T	14.60 25.29	444.46	275.56	**360.01**	F D×T	5.33 9.23
D_3	393.22	259.94	**326.58**	T×F D×F	20.65 25.29	505.30	318.34	**411.82**	T×F D×F	7.53 9.23
Mean (F)	**300.91**	**201.61**		D×T×F	35.77	**433.10**	**266.80**		D×T×F	13.05

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XVI: Effect of different planting densities, training systems and fertigation levels on spur density of apple cv. Jeromine

D \ T / F	Spur density (number cm^{-1} shoot length)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.14	0.11	**0.13**	0.09	0.08	**0.09**	0.16	0.14	**0.15**	0.12	0.10	**0.11**
D_2	0.22	0.18	**0.20**	0.15	0.11	**0.13**	0.24	0.20	**0.22**	0.18	0.14	**0.16**
D_3	0.26	0.23	**0.25**	0.21	0.18	**0.20**	0.27	0.24	**0.26**	0.23	0.19	**0.21**
Mean (T×F)	**0.21**	**0.17**		**0.15**	**0.12**		**0.22**	**0.19**		**0.18**	**0.14**	
Mean (T)	**0.19**			**0.14**			**0.21**			**0.16**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	0.12	0.10	**0.11**	D T	0.29 0.24	0.14	0.12	**0.13**	D T	0.35 0.28
D_2	0.19	0.15	**0.17**	F D×T	0.24 NS	0.21	0.17	**0.19**	F D×T	0.28 NS
D_3	0.24	0.21	**0.22**	T×F D×F	NS NS	0.25	0.22	**0.23**	T×F D×F	NS NS
Mean (F)	**0.18**	**0.15**		D×T×F	NS	**0.20**	**0.17**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XVII: Effect of different planting densities, training systems and fertigation levels on blossom density of apple cv. Jeromine

D \ T / F	Blossom density (flower clusters cm^{-2} TCSA)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	12.59	7.96	**10.28**	9.21	7.81	**8.51**	14.64	8.46	**11.55**	9.70	7.84	**8.77**
D_2	14.05	8.18	**11.12**	9.24	7.92	**8.58**	15.15	8.63	**11.89**	10.25	8.22	**9.23**
D_3	14.66	10.67	**12.67**	10.82	8.24	**9.53**	15.57	12.09	**13.83**	11.37	8.63	**10.00**
Mean (T×F)	**13.77**	**8.94**		**9.76**	**7.99**		**15.12**	**9.73**		**10.44**	**8.23**	
Mean (T)	**11.35**			**8.87**			**12.42**			**9.33**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.41 0.34 0.34 0.59 0.48 NS 0.83	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.45 0.37 0.37 0.64 0.52 0.64 0.91
D_1	10.90	7.89	**9.39**			12.17	8.15	**10.16**		
D_2	11.64	8.05	**9.84**			12.70	8.43	**10.56**		
D_3	12.74	9.45	**11.09**			13.47	10.36	**11.91**		
Mean (F)	**11.76**	**8.46**				**12.78**	**8.98**			

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XVIII: Effect of different planting densities, training systems and fertigation levels on fruit set of apple cv. Jeromine

D \ T / F	Fruit set (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	47.68	44.57	**46.13**	45.95	39.18	**42.57**	50.48	47.17	**48.83**	48.65	41.78	**45.22**
D_2	52.94	48.06	**50.50**	48.91	41.71	**45.31**	56.34	51.26	**53.80**	52.21	44.91	**48.56**
D_3	55.88	51.17	**53.53**	52.96	44.03	**48.49**	59.78	54.87	**57.33**	56.76	47.73	**52.24**
Mean (T×F)	**52.17**	**47.94**		**49.27**	**41.64**		**55.53**	**51.10**		**52.54**	**44.81**	
Mean (T)	**50.05**			**45.46**			**53.32**			**48.67**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	1.38 1.13 1.13 NS 1.60 NS NS	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	1.50 1.23 1.23 NS 1.73 NS NS
D_1	46.82	41.88	**44.35**			49.57	44.48	**47.02**		
D_2	50.92	44.89	**47.91**			54.27	48.09	**51.18**		
D_3	54.42	47.60	**51.01**			58.27	51.30	**54.78**		
Mean (F)	**50.72**	**44.79**				**54.04**	**47.96**			

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XIX: Effect of different planting densities, training systems and fertigation levels on fruit drop of apple cv. Jeromine

T / D / F	Fruit drop (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	71.44	75.45	**73.45**	74.73	77.39	**76.06**	70.48	73.04	**71.76**	72.87	75.19	**74.03**
D_2	69.12	72.87	**71.00**	71.42	74.15	**72.79**	67.41	70.23	**68.82**	69.72	72.16	**70.94**
D_3	66.20	70.26	**68.23**	68.31	72.67	**70.49**	64.84	67.33	**66.09**	66.12	69.43	**67.78**
Mean (T×F)	68.92	72.86		71.49	74.74		**67.58**	**70.20**		**69.57**	**72.26**	
Mean (T)	**70.89**			**73.11**			**68.89**			**70.92**		

F / D	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T	2.71 2.21	F_1	F_2	Mean (D)	D T	2.46 2.01
D_1	73.09	76.42	**74.75**	F	2.21	71.68	74.12	**72.90**	F	2.01
D_2	70.27	73.51	**71.89**	D×T	NS	68.57	71.20	**69.88**	D×T	NS
D_3	67.26	71.47	**69.36**	T×F D×F	NS NS	65.48	68.38	**66.93**	T×F D×F	NS NS
Mean (F)	**70.20**	**73.80**		D×T×F	NS	**68.57**	**71.23**		D×T×F	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XX: Effect of different planting densities, training systems and fertigation levels on yield of apple cv. Jeromine

T / D / F	Yield (kg tree^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	10.23	9.06	**9.64**	8.82	7.70	**8.26**	10.83	9.92	**10.38**	9.62	9.01	**9.32**
D_2	11.58	10.65	**11.11**	10.26	8.95	**9.61**	12.73	11.32	**12.02**	11.29	10.53	**10.91**
D_3	12.88	11.57	**12.22**	11.26	10.03	**10.64**	14.24	12.63	**13.44**	12.61	11.66	**12.13**
Mean (T×F)	**11.56**	**10.43**		**10.11**	**8.90**		**12.60**	**11.29**		**11.17**	**10.40**	
Mean (T)	**10.99**			**9.50**			**11.95**			**10.79**		

F / D	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T	0.05 0.04	F_1	F_2	Mean (D)	D T	0.07 0.06
D_1	9.52	8.38	**8.95**	F	0.04	10.23	9.47	**9.85**	F	0.06
D_2	10.92	9.80	**10.36**	D×T	0.07	12.01	10.92	**11.47**	D×T	0.10
D_3	12.07	10.80	**11.43**	T×F D×F	0.06 0.07	13.43	12.15	**12.79**	T×F D×F	0.08 0.10
Mean (F)	**10.84**	**9.66**		D×T×F	0.10	**11.89**	**10.84**		D×T×F	0.14

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXI: Effect of different planting densities, training systems and fertigation levels on yield efficiency of apple cv. Jeromine

Yield efficiency (kg cm^{-2} TCSA)

D \ T / F	2019 T_1 F_1	2019 T_1 F_2	2019 T_1 Mean (D×T)	2019 T_2 F_1	2019 T_2 F_2	2019 T_2 Mean (D×T)	2020 T_1 F_1	2020 T_1 F_2	2020 T_1 Mean (D×T)	2020 T_2 F_1	2020 T_2 F_2	2020 T_2 Mean (D×T)
D_1	1.23	0.78	**1.01**	0.89	0.77	**0.83**	1.01	0.98	**0.99**	0.76	0.72	**0.74**
D_2	1.31	0.83	**1.07**	0.90	0.82	**0.86**	1.10	1.03	**1.07**	0.78	0.76	**0.77**
D_3	1.39	1.14	**1.26**	0.99	0.88	**0.93**	1.14	1.11	**1.13**	0.85	0.79	**0.82**
Mean (T×F)	**1.31**	**0.92**		**0.93**	**0.83**		**1.09**	**1.04**		**0.80**	**0.76**	
Mean (T)	**1.11**			**0.88**			**1.06**			**0.78**		

D \ F	2019 D × F F_1	2019 D × F F_2	2019 Mean (D)	2020 D × F F_1	2020 D × F F_2	2020 Mean (D)
D_1	1.06	0.78	**0.92**	0.89	0.85	**0.87**
D_2	1.11	0.83	**0.97**	0.94	0.90	**0.92**
D_3	1.19	1.01	**1.10**	1.00	0.95	**0.98**
Mean (F)	**1.12**	**0.87**		**0.94**	**0.90**	

$CD_{0.05}$	2019	2020
D	0.03	0.01
T	0.02	0.01
F	0.02	0.01
D×T	0.04	0.02
T×F	0.03	NS
D×F	0.04	NS
D×T×F	0.06	0.03

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXII: Effect of different planting densities, training systems and fertigation levels on productivity of apple cv. Jeromine

Productivity (t ha^{-1})

D \ T / F	2019 T_1 F_1	2019 T_1 F_2	2019 T_1 Mean (D×T)	2019 T_2 F_1	2019 T_2 F_2	2019 T_2 Mean (D×T)	2020 T_1 F_1	2020 T_1 F_2	2020 T_1 Mean (D×T)	2020 T_2 F_1	2020 T_2 F_2	2020 T_2 Mean (D×T)
D_1	40.92	36.23	**38.58**	35.27	30.81	**33.04**	43.34	39.69	**41.52**	38.49	36.03	**37.26**
D_2	37.04	34.08	**35.56**	32.84	28.65	**30.75**	40.75	36.21	**38.48**	36.12	33.69	**34.90**
D_3	34.33	30.85	**32.59**	30.02	26.74	**28.38**	37.97	33.68	**35.83**	33.61	31.08	**32.35**
Mean (T×F)	**37.43**	**33.72**		**32.71**	**28.73**		**40.69**	**36.53**		**36.53**	**33.60**	
Mean (T)	**35.58**			**30.72**			**38.61**			**34.84**		

D \ F	2019 D × F F_1	2019 D × F F_2	2019 Mean (D)	2020 D × F F_1	2020 D × F F_2	2020 Mean (D)
D_1	38.10	33.52	**35.81**	40.91	37.86	**39.39**
D_2	34.94	31.37	**33.15**	38.43	34.95	**36.69**
D_3	32.18	28.80	**30.49**	35.79	32.38	**34.09**
Mean (F)	**35.07**	**31.23**		**38.38**	**35.06**	

$CD_{0.05}$	2019	2020
D	0.17	0.18
T	0.14	0.15
F	0.14	0.15
D×T	0.24	0.26
T×F	0.19	0.21
D×F	0.24	0.26
D×T×F	0.33	0.27

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXIII: Effect of different planting densities, training systems and fertigation levels on fruit length of apple cv. Jeromine

D \ T, F	Fruit length (mm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	60.58	56.23	**58.41**	56.72	54.27	**55.50**	56.83	52.28	**54.56**	52.73	49.34	**51.04**
D_2	65.89	61.38	**63.64**	60.79	57.76	**59.28**	61.87	56.23	**59.05**	57.14	53.67	**55.41**
D_3	71.19	65.24	**68.22**	65.62	62.28	**63.95**	65.05	60.12	**62.59**	61.85	57.68	**59.77**
Mean (T×F)	**65.89**	**60.95**		**61.04**	**58.10**		**61.25**	**56.21**		**57.24**	**53.56**	
Mean (T)	**63.42**			**59.57**			**58.73**			**55.40**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	2.56	F_1	F_2	Mean (D)	D	2.37
D_1	58.65	55.25	**56.95**	T F	2.09 2.09	54.78	50.81	**52.80**	T F	1.94 1.94
D_2	63.34	59.57	**61.46**	D×T T×F	NS NS	59.51	54.95	**57.23**	D×T T×F	NS NS
D_3	68.41	63.76	**66.08**	D×F	NS	63.45	58.90	**61.18**	D×F	NS
Mean (F)	**63.47**	**59.53**		D×T×F	NS	**59.25**	**54.89**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXIV: Effect of different planting densities, training systems and fertigation levels on fruit diameter of apple cv. Jeromine

D \ T, F	Fruit diameter (mm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	66.63	63.54	**65.09**	65.86	63.89	**64.88**	58.93	54.78	**56.86**	54.92	51.19	**53.06**
D_2	71.32	68.93	**70.13**	70.72	67.27	**69.00**	66.38	63.57	**64.98**	62.74	58.25	**60.50**
D_3	77.28	73.39	**75.34**	75.81	71.08	**73.45**	73.72	69.89	**71.81**	69.53	66.65	**68.09**
Mean (T×F)	**71.74**	**68.62**		**70.80**	**67.41**		**66.34**	**62.75**		**62.40**	**58.70**	
Mean (T)	**70.18**			**69.11**			**64.55**			**60.55**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	2.41	F_1	F_2	Mean (D)	D	1.98
D_1	66.25	63.72	**64.98**	T F	NS 1.97	56.93	52.99	**54.96**	T F	1.62 1.62
D_2	71.02	68.10	**69.56**	D×T T×F	NS NS	64.56	60.91	**62.74**	D×T T×F	NS NS
D_3	76.55	72.24	**74.39**	D×F	NS	71.63	68.27	**69.95**	D×F	NS
Mean (F)	**71.27**	**68.02**		D×T×F	NS	**64.37**	**60.72**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXV: Effect of different planting densities, training systems and fertigation levels on fruit weight of apple cv. Jeromine

D \ T \ F	Fruit weight (g)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	139.77	135.58	**137.68**	136.48	131.45	**133.97**	134.42	132.67	**133.55**	128.65	126.52	**127.59**
D_2	152.72	148.75	**150.74**	149.17	143.03	**146.10**	143.73	139.35	**141.54**	136.64	133.26	**134.95**
D_3	164.26	158.08	**161.17**	160.38	153.37	**156.88**	148.37	145.54	**146.96**	144.26	141.49	**142.88**
Mean (T×F)	**152.25**	**147.47**		**148.68**	**142.62**		**142.17**	**139.19**		**136.52**	**133.76**	
Mean (T)	**149.86**			**145.65**			**140.68**			**135.14**		

D \ F	2019 D × F			2020 D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	138.13	133.52	**135.82**	131.54	129.60	**130.57**
D_2	150.95	145.89	**148.42**	140.19	136.31	**138.25**
D_3	162.32	155.73	**159.02**	146.32	143.52	**144.92**
Mean (F)	**150.46**	**145.04**		**139.35**	**136.47**	

$CD_{0.05}$	2019	2020
D	1.71	1.67
T	1.39	1.36
F	1.39	1.36
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXVI: Effect of different planting densities, training systems and fertigation levels on fruit volume of apple cv. Jeromine

D \ T \ F	Fruit volume (cm^3)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	165.52	158.33	**161.93**	162.41	153.37	**157.89**	159.38	153.49	**156.44**	154.19	148.44	**151.32**
D_2	183.48	175.06	**179.27**	178.53	167.89	**173.21**	174.45	166.92	**170.69**	169.71	159.12	**164.42**
D_3	198.75	186.47	**192.61**	191.85	181.41	**186.63**	189.86	180.65	**185.26**	184.82	175.31	**180.07**
Mean (T×F)	**182.58**	**173.29**		**177.60**	**167.56**		**174.56**	**167.02**		**169.57**	**160.96**	
Mean (T)	**177.94**			**172.58**			**170.79**			**165.27**		

D \ F	2019 D × F			2020 D × F		
	F_1	F_2	Mean (D)	F_1	F_2	Mean (D)
D_1	163.97	155.85	**159.91**	156.79	150.97	**153.88**
D_2	181.01	171.48	**176.24**	172.08	163.02	**167.55**
D_3	**195.30**	**183.94**	**189.62**	187.34	177.98	**182.66**
Mean (F)	**180.09**	**170.42**		**172.07**	**163.99**	

$CD_{0.05}$	2019	2020
D	6.12	6.23
T	5.00	5.09
F	5.00	5.09
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXVII: Effect of different planting densities, training systems and fertigation levels on fruit firmness of apple cv. Jeromine

T / D / F	Fruit firmness (kg cm^{-2})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	4.46	5.04	**4.75**	4.62	5.12	**4.87**	4.18	4.65	**4.42**	4.36	4.93	**4.65**
D_2	4.94	5.29	**5.12**	5.08	5.36	**5.22**	4.72	5.15	**4.94**	4.98	5.21	**5.10**
D_3	5.16	5.58	**5.37**	5.31	5.75	**5.53**	5.14	5.42	**5.28**	5.27	5.64	**5.46**
Mean (T×F)	**4.85**	**5.30**		**8.23**	**6.91**		**4.68**	**5.07**		**4.87**	**5.26**	
Mean (T)	**5.08**			**7.57**			**4.88**			**5.07**		

F / D	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.36	F_1	F_2	Mean (D)	D	0.38
D_1	4.54	5.08	**4.81**	T	NS	4.27	4.79	**4.53**	T	NS
D_2	5.01	5.33	**5.17**	F	0.30	4.85	5.18	**5.02**	F	0.31
D_3	5.24	5.67	**5.45**	D×T	NS	5.21	5.53	**5.37**	D×T	NS
Mean (F)	**4.93**	**5.36**		T×F	NS	**4.78**	**5.17**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXVIII: Effect of different planting densities, training systems and fertigation levels on TSS of apple cv. Jeromine

T / D / F	Total soluble solids (°Brix)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	10.62	9.83	**10.23**	10.25	9.56	**9.91**	11.05	9.87	**10.46**	10.28	9.62	**9.95**
D_2	11.43	10.92	**11.18**	11.23	10.74	**10.99**	11.48	10.76	**11.12**	10.88	9.84	**10.36**
D_3	11.92	11.64	**11.78**	11.85	11.38	**11.62**	11.97	11.28	**11.63**	11.76	10.93	**11.35**
Mean (T×F)	**11.32**	**10.80**		**11.11**	**10.56**		**11.50**	**10.64**		**10.97**	**10.13**	
Mean (T)	**11.06**			**10.84**			**11.07**			**10.55**		

F / D	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.17	F_1	F_2	Mean (D)	D	0.22
D_1	10.44	9.70	**10.07**	T	0.14	10.67	9.75	**10.21**	T	0.18
D_2	11.33	10.83	**11.08**	F	0.14	11.18	10.30	**10.74**	F	0.18
D_3	11.89	11.51	**11.70**	D×T	NS	11.87	11.11	**11.49**	D×T	NS
Mean (F)	**11.22**	**10.68**		T×F	NS	**11.24**	**10.38**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXIX: Effect of different planting densities, training systems and fertigation levels on titratable acidity of apple cv. Jeromine

D \ T / F	Titratable acidity (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.57	0.65	**0.61**	0.69	0.72	**0.71**	0.44	0.48	**0.46**	0.52	0.65	**0.59**
D_2	0.44	0.52	**0.48**	0.48	0.47	**0.48**	0.31	0.36	**0.34**	0.34	0.56	**0.45**
D_3	0.31	0.35	**0.33**	0.39	0.43	**0.41**	0.19	0.24	**0.22**	0.26	0.41	**0.34**
Mean (T×F)	**0.44**	**0.51**		**0.52**	**0.54**		**0.31**	**0.36**		**0.37**	**0.54**	
Mean (T)	**0.47**			**0.53**			**0.34**			**0.46**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	0.63	0.69	**0.66**	D T	0.07 0.05	0.48	0.57	**0.52**	D T	0.10 0.08
D_2	0.46	0.50	**0.48**	F D×T	NS NS	0.33	0.46	**0.39**	F D×T	0.08 NS
D_3	0.35	0.39	**0.37**	T×F D×F	NS NS	0.23	0.33	**0.28**	T×F D×F	NS NS
Mean (F)	**0.48**	**0.52**		D×T×F	NS	**0.34**	**0.45**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXX: Effect of different planting densities, training systems and fertigation levels on total sugars contents of apple cv. Jeromine

D \ T / F	Total sugars (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	8.59	8.16	**8.38**	8.21	7.57	**7.89**	9.38	8.68	**9.03**	9.23	8.22	**8.73**
D_2	9.11	8.73	**8.92**	8.64	8.12	**8.38**	9.75	9.29	**9.52**	9.72	9.19	**9.46**
D_3	9.87	9.51	**9.69**	9.32	8.63	**8.98**	10.43	9.96	**10.20**	10.35	9.72	**10.04**
Mean (T×F)	**9.19**	**8.80**		**8.72**	**8.11**		**9.85**	**9.31**		**9.77**	**9.04**	
Mean (T)	**9.00**			**8.42**			**9.58**			**9.41**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	8.40	7.87	**8.13**	D T	0.36 0.30	9.31	8.45	**8.88**	D T	0.22 0.18
D_2	8.88	8.43	**8.65**	F D×T	0.30 NS	9.74	9.24	**9.49**	F D×T	0.18 NS
D_3	9.60	9.07	**9.33**	T×F D×F	NS NS	10.39	9.84	**10.12**	T×F D×F	NS NS
Mean (F)	**8.96**	**8.45**		D×T×F	NS	**9.81**	**9.18**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXI: Effect of different planting densities, training systems and fertigation levels on reducing sugar content of apple cv. Jeromine

D \ T / F	Reducing sugars (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	5.93	5.53	**5.73**	5.62	5.27	**5.45**	6.59	6.16	**6.38**	6.51	5.73	**6.12**
D_2	6.32	5.97	**6.15**	5.93	5.53	**5.73**	6.86	6.53	**6.70**	6.81	6.48	**6.65**
D_3	6.74	6.42	**6.58**	6.31	5.87	**6.09**	7.14	6.98	**7.06**	7.36	6.79	**7.08**
Mean (T×F)	**6.33**	**5.97**		**5.95**	**5.56**		**6.86**	**6.56**		**6.89**	**6.33**	
Mean (T)	**6.15**			**5.76**			**6.71**			**6.61**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	5.78	5.40	**5.59**	D	0.25	6.55	5.95	**6.25**	D	0.20
D_2	6.13	5.75	**5.94**	T	0.21	6.84	6.51	**6.67**	T	NS
D_3	6.53	6.15	**6.34**	F	0.21	7.25	6.89	**7.07**	F	0.16
Mean (F)	**6.14**	**5.77**		D×T	NS	**6.88**	**6.45**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXII: Effect of different planting densities, training systems and fertigation levels on non-reducing sugars content of apple cv. Jeromine

D \ T / F	Non-reducing sugars (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	2.53	2.50	**2.51**	2.46	2.19	**2.32**	2.65	2.39	**2.52**	2.58	2.37	**2.47**
D_2	2.65	2.62	**2.64**	2.57	2.46	**2.52**	2.75	2.62	**2.68**	2.76	2.57	**2.67**
D_3	2.97	2.94	**2.95**	2.86	2.62	**2.74**	3.13	2.83	**2.98**	2.84	2.78	**2.81**
Mean (T×F)	**2.72**	**2.69**		**2.63**	**2.42**		**2.84**	**2.62**		**2.73**	**2.57**	
Mean (T)	**2.70**			**2.53**			**2.73**			**2.65**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	2.49	2.34	**2.42**	D	0.14	2.62	2.38	**2.50**	D	0.09
D_2	2.61	2.54	**2.58**	T	0.12	2.76	2.60	**2.68**	T	0.07
D_3	2.92	2.78	**2.85**	F	0.12	2.98	2.81	**2.90**	F	0.07
Mean (F)	**2.67**	**2.55**		D×T	NS	**2.79**	**2.60**		D×T	NS
				T×F	NS				T×F	NS
				D×T×F	NS				D×F	NS
					NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXIII: Effect of different planting densities, training systems and fertigation levels on ascorbic acid content of apple cv. Jeromine

D \ T, F	Ascorbic acid (mg 100g^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	4.74	5.38	**5.06**	5.03	5.95	**5.49**	5.46	6.15	**5.81**	5.82	6.68	**6.25**
D_2	3.83	4.82	**4.33**	3.56	4.76	**4.16**	4.72	5.69	**5.21**	4.43	5.95	**5.19**
D_3	3.26	4.32	**3.79**	3.42	4.59	**4.01**	4.26	5.26	**4.76**	4.39	5.61	**5.00**
Mean (T×F)	**3.94**	**4.84**		**4.00**	**5.10**		**4.81**	**5.70**		**4.88**	**6.08**	
Mean (T)	**4.39**			**4.55**			**5.26**			**5.48**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	**Mean (D)**	D	0.19	F_1	F_2	**Mean (D)**	D	0.27
D_1	4.89	5.67	**5.28**	T	0.16	5.64	6.42	**6.03**	T	0.22
D_2	3.70	4.79	**4.24**	F	0.16	4.58	5.82	**5.20**	F	0.22
D_3	3.34	4.46	**3.90**	D×T	NS	4.33	5.44	**4.88**	D×T	NS
Mean (F)	**3.97**	**4.97**		T×F	NS	**4.85**	**5.89**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXIV: Effect of different planting densities, training systems and fertigation levels on anthocyanin content of apple cv. Jeromine

D \ T, F	Anthocyanin content (A_{530})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**	F_1	F_2	**Mean (D×T)**
D_1	1.02	0.91	**0.97**	0.98	0.86	**0.92**	1.05	0.82	**0.94**	0.91	0.76	**0.84**
D_2	1.39	1.12	**1.26**	1.17	0.94	**1.06**	1.28	1.11	**1.20**	1.22	0.98	**1.10**
D_3	1.56	1.34	**1.45**	1.39	1.12	**1.26**	1.54	1.38	**1.46**	1.46	1.14	**1.30**
Mean (T×F)	**1.32**	**1.12**		**1.18**	**0.97**		**1.29**	**1.10**		**1.20**	**0.96**	
Mean (T)	**1.22**			**1.08**			**1.20**			**1.08**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	**Mean (D)**	D	0.16	F_1	F_2	**Mean (D)**	D	0.14
D_1	1.00	0.89	**0.94**	T	0.13	0.98	0.79	**0.89**	T	0.12
D_2	1.28	1.03	**1.16**	F	0.13	1.25	1.05	**1.15**	F	0.12
D_3	1.48	1.23	**1.35**	D×T	NS	1.50	1.26	**1.38**	D×T	NS
Mean (F)	**1.25**	**1.05**		T×F	NS	**1.24**	**1.03**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXV: Effect of different planting densities, training systems and fertigation levels on light interception of apple cv. Jeromine

D \ T, F	Light interception (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	63.61	61.25	**62.43**	57.11	55.67	**56.39**	69.28	66.79	**68.03**	62.58	61.09	**61.84**
D_2	59.43	58.06	**58.74**	53.93	52.43	**53.18**	66.71	64.22	**65.46**	59.01	58.52	**58.77**
D_3	57.91	55.56	**56.73**	50.41	49.99	**50.20**	63.30	60.81	**62.05**	57.68	56.11	**56.90**
Mean (T×F)	**60.31**	**58.29**		**53.82**	**52.70**		**66.43**	**63.94**		**59.76**	**58.57**	
Mean (T)	**59.30**			**53.26**			**65.18**			**59.17**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T	1.86 1.52	F_1	F_2	Mean (D)	D T	1.94 1.58
D_1	60.36	58.46	**59.41**	F	1.52	65.93	63.94	**64.93**	F	1.58
D_2	56.68	54.25	**55.96**	D×T T×F	NS NS	62.86	61.37	**62.11**	D×T T×F	NS NS
D_3	54.16	52.78	**53.47**	D×F	NS	60.49	58.46	**59.47**	D×F	NS
Mean (F)	**57.06**	**55.49**		D×T×F	NS	**63.09**	**61.26**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXVI: Effect of different planting densities, training systems and fertigation levels on photosynthesis rate of apple cv. Jeromine

D \ T, F	Photosynthesis rate (µmol CO_2 m^{-2} s^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	15.19	14.73	**14.96**	15.01	13.38	**14.20**	15.86	15.31	**15.59**	15.72	13.82	**14.77**
D_2	12.39	10.67	**11.53**	11.69	10.01	**10.85**	13.21	11.43	**12.32**	12.47	10.65	**11.56**
D_3	9.49	7.87	**8.68**	8.94	7.17	**8.06**	10.43	8.77	**9.60**	9.85	7.95	**8.90**
Mean (T×F)	**12.36**	**11.09**		**11.88**	**10.19**		**13.17**	**11.84**		**12.68**	**10.81**	
Mean (T)	**11.72**			**11.03**			**12.50**			**11.74**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T	0.83 0.68	F_1	F_2	Mean (D)	D T	0.89 0.73
D_1	15.10	14.06	**14.58**	F	0.68	15.79	14.57	**15.18**	F	0.73
D_2	12.04	10.34	**11.19**	D×T T×F	NS NS	12.84	11.04	**11.94**	D×T T×F	NS NS
D_3	9.22	7.52	**8.37**	D×F	NS	10.14	8.36	**9.25**	D×F	NS
Mean (F)	**12.12**	**10.64**		D×T×F	NS	**12.92**	**11.32**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXVII: Effect of different planting densities, training systems and fertigation levels on stomatal conductance of apple cv. Jeromine

D \ T \ F	Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)											
	2019						**2020**					
	T_1			**T_2**			**T_1**			**T_2**		
	F_1	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**
D_1	0.285	0.258	**0.272**	0.275	0.246	**0.261**	0.292	0.267	**0.280**	0.286	0.252	**0.269**
D_2	0.210	0.177	**0.194**	0.196	0.163	**0.180**	0.221	0.183	**0.202**	0.209	0.171	**0.190**
D_3	0.155	0.124	**0.140**	0.145	0.118	**0.132**	0.164	0.131	**0.148**	0.157	0.128	**0.143**
Mean (T×F)	**0.217**	**0.186**		**0.205**	**0.176**		**0.226**	**0.194**		**0.217**	**0.184**	
Mean (T)	**0.202**			**0.191**			**0.210**			**0.201**		

D \ F	**D × F** (2019)			**$CD_{0.05}$**		**D × F** (2020)			**$CD_{0.05}$**	
	F_1	**F_2**	**Mean (D)**	D	0.010	**F_1**	**F_2**	**Mean (D)**	D	0.011
D_1	0.280	0.252	**0.266**	T	0.008	0.289	0.260	**0.274**	T	0.009
D_2	0.203	0.170	**0.187**	F	0.008	0.215	0.177	**0.196**	F	0.009
D_3	0.150	0.121	**0.136**	D×T	NS	0.161	0.130	**0.145**	D×T	NS
Mean (F)	**0.211**	**0.181**		T×F	NS	**0.222**	**0.189**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXVIII: Effect of different planting densities, training systems and fertigation levels on transpiration rate of apple cv. Jeromine

D \ T \ F	Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)											
	2019						**2020**					
	T_1			**T_2**			**T_1**			**T_2**		
	F_1	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**	**F_1**	**F_2**	**Mean (D×T)**
D_1	4.25	3.82	**4.04**	4.07	3.68	**3.88**	4.36	3.94	**4.15**	4.15	3.81	**3.98**
D_2	3.54	3.33	**3.44**	3.38	3.04	**3.21**	3.63	3.41	**3.52**	3.53	3.22	**3.38**
D_3	2.97	2.74	**2.86**	2.84	2.53	**2.69**	3.12	2.79	**2.96**	2.97	2.65	**2.81**
Mean (T×F)	**3.59**	**3.30**		**3.43**	**3.08**		**3.70**	**3.38**		**3.55**	**3.23**	
Mean (T)	**3.44**			**3.26**			**3.54**			**3.39**		

D \ F	**D × F** (2019)			**$CD_{0.05}$**		**D × F** (2020)			**$CD_{0.05}$**	
	F_1	**F_2**	**Mean (D)**	D	0.17	**F_1**	**F_2**	**Mean (D)**	D	0.16
D_1	4.16	3.75	**3.96**	T	0.14	4.26	3.88	**4.07**	T	0.13
D_2	3.46	3.19	**3.32**	F	0.14	3.58	3.32	**3.45**	F	0.13
D_3	2.91	2.64	**2.77**	D×T	NS	3.05	2.72	**2.88**	D×T	NS
Mean (F)	**3.51**	**3.19**		T×F	NS	**3.63**	**3.30**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XXXIX: Effect of different planting densities, training systems and fertigation levels on leaf chlorophyll content of apple cv. Jeromine

D \ T / F	Chlorophyll content (mg g^{-1} fresh weight)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	2.87	2.49	**2.68**	2.61	2.28	**2.45**	3.12	2.77	**2.95**	2.91	2.54	**2.73**
D_2	2.52	2.12	**2.32**	2.24	1.91	**2.08**	2.73	2.44	**2.59**	2.53	2.26	**2.40**
D_3	2.08	1.75	**1.92**	1.81	1.43	**1.62**	2.28	1.99	**2.14**	2.13	1.85	**1.99**
Mean (T×F)	**2.49**	**2.12**		**2.22**	**1.87**		**2.71**	**2.40**		**2.52**	**2.22**	
Mean (T)	**2.31**			**2.05**			**2.56**			**2.37**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.16 0.13 0.13 NS NS NS NS	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.22 0.18 0.18 NS NS NS NS
D_1	2.74	2.39	**2.56**			3.02	2.66	**2.84**		
D_2	2.38	2.02	**2.20**			2.63	2.35	**2.49**		
D_3	1.95	1.59	**1.77**			2.21	1.92	**2.06**		
Mean (F)	**2.36**	**2.00**				**2.62**	**2.31**			

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XL: Effect of different planting densities, training systems and fertigation levels on leaf N content of apple cv. Jeromine

D \ T / F	N (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	2.62	1.91	**2.27**	2.45	1.72	**2.09**	2.75	2.32	**2.54**	2.60	2.13	**2.37**
D_2	2.74	1.94	**2.34**	2.47	1.78	**2.13**	2.83	2.46	**2.65**	2.65	2.17	**2.41**
D_3	2.78	2.33	**2.56**	2.58	2.29	**2.44**	2.87	2.53	**2.70**	2.72	2.29	**2.51**
Mean (T×F)	**2.71**	**2.06**		**2.50**	**1.93**		**2.82**	**2.44**		**2.66**	**2.20**	
Mean (T)	**2.39**			**2.22**			**2.63**			**2.43**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	NS NS 0.29 NS NS NS NS	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	NS 0.13 0.13 NS NS NS NS
D_1	2.54	1.82	**2.18**			2.68	2.23	**2.45**		
D_2	2.61	1.86	**2.23**			2.74	2.32	**2.53**		
D_3	2.68	2.31	**2.50**			2.80	2.41	**2.60**		
Mean (F)	**2.61**	**2.00**				**2.74**	**2.32**			

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLI: Effect of different planting densities, training systems and fertigation levels on leaf P content of apple cv. Jeromine

D \ T / F	P (%) 2019 T$_1$ F$_1$	F$_2$	Mean (D×T)	T$_2$ F$_1$	F$_2$	Mean (D×T)	2020 T$_1$ F$_1$	F$_2$	Mean (D×T)	T$_2$ F$_1$	F$_2$	Mean (D×T)
D$_1$	0.23	0.18	**0.21**	0.21	0.15	**0.18**	0.25	0.20	**0.22**	0.23	0.17	**0.20**
D$_2$	0.29	0.24	**0.27**	0.26	0.19	**0.23**	0.32	0.27	**0.29**	0.29	0.22	**0.25**
D$_3$	0.36	0.29	**0.33**	0.32	0.25	**0.29**	0.38	0.31	**0.35**	0.34	0.27	**0.31**
Mean (T×F)	**0.29**	**0.24**		**0.26**	**0.20**		**0.31**	**0.26**		**0.28**	**0.22**	
Mean (T)	**0.27**			**0.23**			**0.29**			**0.25**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$	
D$_1$	0.22	0.17	**0.19**	D	0.03	0.24	0.18	**0.21**	D	0.04
D$_2$	0.28	0.22	**0.25**	T	0.02	0.30	0.24	**0.27**	T	0.03
D$_3$	0.34	0.27	**0.31**	F	0.02	0.36	0.29	**0.33**	F	0.03
Mean (F)	**0.28**	**0.22**		D×T	NS	**0.30**	**0.24**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLII: Effect of different planting densities, training systems and fertigation levels on leaf K content of apple cv. Jeromine

D \ T / F	K (%) 2019 T$_1$ F$_1$	F$_2$	Mean (D×T)	T$_2$ F$_1$	F$_2$	Mean (D×T)	2020 T$_1$ F$_1$	F$_2$	Mean (D×T)	T$_2$ F$_1$	F$_2$	Mean (D×T)
D$_1$	1.74	1.61	**1.68**	1.67	1.48	**1.58**	1.81	1.65	**1.73**	1.72	1.57	**1.65**
D$_2$	1.82	1.69	**1.76**	1.75	1.63	**1.69**	1.88	1.74	**1.81**	1.79	1.68	**1.74**
D$_3$	1.91	1.76	**1.83**	1.81	1.68	**1.75**	1.96	1.82	**1.89**	1.87	1.74	**1.81**
Mean (T×F)	**1.82**	**1.69**		**1.74**	**1.60**		**1.88**	**1.74**		**1.79**	**1.66**	
Mean (T)	**1.75**			**1.67**			**1.81**			**1.73**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	CD$_{0.05}$	
D$_1$	1.71	1.55	**1.63**	D	0.10	1.77	1.61	**1.69**	D	0.09
D$_2$	1.79	1.66	**1.72**	T	0.08	1.84	1.71	**1.77**	T	0.07
D$_3$	1.86	1.72	**1.79**	F	0.08	1.91	1.78	**1.85**	F	0.07
Mean (F)	**1.78**	**1.64**		D×T	NS	**1.84**	**1.70**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLIII: Effect of different planting densities, training systems and fertigation levels on leaf Ca content of apple cv. Jeromine

D \ T \ F	Ca (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	2.07	2.26	**2.17**	2.11	2.32	**2.22**	2.21	2.47	**2.34**	2.24	2.56	**2.40**
D_2	1.88	2.09	**1.99**	1.94	2.17	**2.06**	2.01	2.26	**2.14**	2.12	2.38	**2.25**
D_3	1.74	1.91	**1.83**	1.83	1.98	**1.91**	1.85	1.98	**1.92**	1.92	2.17	**2.05**
Mean (T×F)	**1.90**	**2.09**		**1.96**	**2.16**		**2.02**	**2.24**		**2.09**	**2.37**	
Mean (T)	**1.99**			**2.06**			**2.13**			**2.23**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.16 NS 0.13 NS NS NS NS	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	0.17 NS 0.14 NS NS NS NS
D_1	2.09	2.29	**2.19**			2.23	2.52	**2.37**		
D_2	1.91	2.13	**2.02**			2.07	2.32	**2.19**		
D_3	1.79	1.95	**1.87**			1.89	2.08	**1.98**		
Mean (F)	**1.93**	**2.12**				**2.06**	**2.30**			

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLIV: Effect of different planting densities, training systems and fertigation levels on leaf Mg content of apple cv. Jeromine

D \ T \ F	Mg (%)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	0.33	0.42	**0.38**	0.35	0.46	**0.41**	0.42	0.55	**0.49**	0.43	0.58	**0.51**
D_2	0.25	0.38	**0.32**	0.29	0.41	**0.35**	0.35	0.46	**0.41**	0.38	0.49	**0.44**
D_3	0.19	0.31	**0.25**	0.22	0.34	**0.28**	0.27	0.41	**0.34**	0.34	0.45	**0.40**
Mean (T×F)	**0.26**	**0.37**		**0.29**	**0.40**		**0.35**	**0.47**		**0.38**	**0.51**	
Mean (T)	**0.31**			**0.35**			**0.41**			**0.45**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	NS NS 0.04 NS NS NS NS	F_1	F_2	Mean (D)	D T F D×T T×F D×F D×T×F	NS NS 0.05 NS NS NS NS
D_1	0.34	0.44	**0.39**			0.43	0.57	**0.50**		
D_2	0.27	0.40	**0.33**			0.37	0.48	**0.42**		
D_3	0.21	0.33	**0.27**			0.31	0.43	**0.37**		
Mean (F)	**0.27**	**0.39**				**0.37**	**0.49**			

Training system:-T_1: Tall Spindle **Fertigation level:-F_1: 100 % of AD (NPK)** **Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)**
T_2: Vertical Axis **F_2: 75 % of AD (NPK)** **D_2: 3200 trees/ha (2.5 × 1.25 m)**
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLV: Effect of different planting densities, training systems and fertigation levels on leaf Fe content of apple cv. Jeromine

D \ T / F	Fe (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	172.45	165.71	**169.08**	169.76	164.69	**167.22**	193.58	180.39	**186.99**	187.52	175.34	**181.43**
D_2	179.81	174.07	**176.94**	176.81	171.18	**174.00**	199.42	188.27	**193.85**	193.62	180.29	**186.96**
D_3	184.75	178.58	**181.67**	181.77	176.23	**179.00**	203.25	191.81	**197.53**	197.63	184.61	**191.12**
Mean (T×F)	**179.00**	**172.79**		**176.11**	**170.70**		**198.75**	**186.82**		**192.92**	**180.08**	
Mean (T)	**175.90**			**173.41**			**192.79**			**186.50**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	171.10	165.20	**168.15**	D T F D×T T×F D×F D×T×F	3.01 2.46 2.46 NS NS NS NS	190.55	177.87	**184.21**	D T F D×T T×F D×F D×T×F	1.46 1.19 1.19 NS NS NS NS
D_2	178.31	172.63	**175.47**			196.52	184.28	**190.40**		
D_3	183.26	177.41	**180.33**			200.44	188.21	**194.33**		
Mean (F)	**177.56**	**171.74**				**195.84**	**183.45**			

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLVI: Effect of different planting densities, training systems and fertigation levels on leaf Mn content of apple cv. Jeromine

D \ T / F	Mn (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	37.06	32.88	**34.97**	35.44	31.25	**33.35**	39.13	34.73	**36.93**	37.47	33.16	**35.31**
D_2	39.52	34.64	**37.08**	37.85	33.54	**35.70**	41.54	36.45	**39.00**	39.92	35.49	**37.71**
D_3	41.81	36.12	**38.97**	39.77	34.68	**37.23**	43.27	38.95	**41.11**	41.89	36.65	**39.27**
Mean (T×F)	**39.46**	**34.55**		**37.69**	**33.16**		**41.31**	**36.71**		**39.76**	**35.10**	
Mean (T)	**37.01**			**35.42**			**39.01**			**37.43**		

D \ F	D × F (2019)			$CD_{0.05}$ (2019)		D × F (2020)			$CD_{0.05}$ (2020)	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	36.25	32.07	**34.16**	D T F D×T T×F D×F D×T×F	1.67 1.36 1.36 NS NS NS NS	38.30	33.94	**36.12**	D T F D×T T×F D×F D×T×F	1.44 1.18 1.18 NS NS NS NS
D_2	38.69	34.09	**36.39**			40.73	35.97	**38.35**		
D_3	40.79	35.40	**38.10**			42.58	37.80	**40.19**		
Mean (F)	**38.58**	**33.85**				**40.54**	**35.90**			

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLVII: Effect of different planting densities, training systems and fertigation levels on leaf Cu content of apple cv. Jeromine

D \ T / F	Cu (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	11.14	9.68	**10.41**	10.23	8.23	**9.23**	11.67	10.02	**10.85**	11.63	9.26	**10.45**
D_2	11.45	10.37	**10.91**	10.85	9.72	**10.29**	12.29	10.46	**11.38**	12.15	9.85	**11.00**
D_3	12.52	10.94	**11.73**	11.29	9.96	**10.63**	12.82	11.87	**12.35**	12.67	10.78	**11.73**
Mean (T×F)	**11.70**	**10.33**		**10.79**	**9.30**		**12.26**	**10.78**		**12.15**	**9.96**	
Mean (T)	**11.02**			**10.05**			**11.52**			**11.06**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	10.69	8.96	**9.82**	D	0.43	11.65	9.64	**10.65**	D	0.26
D_2	11.15	10.05	**10.60**	T	0.35	12.22	10.16	**11.19**	T	0.21
D_3	11.91	10.45	**11.18**	F	0.35	12.75	11.33	**12.04**	F	0.21
Mean (F)	**11.25**	**9.82**		D×T	NS	**12.21**	**10.37**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLVIII: Effect of different planting densities, training systems and fertigation levels on leaf Zn content of apple cv. Jeromine

D \ T / F	Zn (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	26.14	23.94	**25.04**	25.61	22.37	**23.99**	28.31	25.24	**26.78**	27.18	24.12	**25.65**
D_2	26.92	24.72	**25.82**	26.95	23.10	**25.03**	29.15	26.13	**27.64**	28.11	24.93	**26.52**
D_3	29.55	25.46	**27.51**	27.57	24.66	**26.11**	30.29	27.97	**29.13**	29.76	25.48	**27.62**
Mean (T×F)	**27.54**	**24.71**		**26.71**	**23.38**		**29.25**	**26.45**		**28.35**	**24.84**	
Mean (T)	**26.12**			**25.04**			**27.85**			**26.60**		

D \ F	D × F			$CD_{0.05}$		D × F			$CD_{0.05}$	
	F_1	F_2	Mean (D)			F_1	F_2	Mean (D)		
D_1	25.88	23.15	**24.51**	D	0.53	27.75	24.68	**26.21**	D	1.29
D_2	26.94	23.91	**25.43**	T	0.43	28.63	25.53	**27.08**	T	1.05
D_3	28.56	25.06	**26.81**	F	0.43	30.03	26.73	**28.38**	F	1.05
Mean (F)	**27.13**	**24.04**		D×T	NS	**28.80**	**25.65**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix XLIX: Effect of different planting densities, training systems and fertigation levels on soil pH in apple cv. Jeromine plantation

D \ T \ F	pH 2019 T_1 F_1	F_2	Mean (D×T)	T_2 F_1	F_2	Mean (D×T)	pH 2020 T_1 F_1	F_2	Mean (D×T)	T_2 F_1	F_2	Mean (D×T)
D_1	6.90	7.11	**7.01**	6.74	7.04	**6.89**	6.72	6.82	**6.77**	6.55	6.76	**6.66**
D_2	6.96	7.12	**7.04**	6.92	7.11	**7.02**	6.81	6.93	**6.87**	6.79	6.88	**6.84**
D_3	7.09	7.34	**7.22**	6.99	7.17	**7.08**	6.84	7.05	**6.95**	6.81	6.96	**6.89**
Mean (T×F)	**6.98**	**7.19**		**6.88**	**7.11**		**6.79**	**6.94**		**6.72**	**6.87**	
Mean (T)	**7.09**			**7.00**			**6.86**			**6.79**		

D \ F	2019 D × F F_1	F_2	Mean (D)	$CD_{0.05}$		2020 D × F F_1	F_2	Mean (D)	$CD_{0.05}$	
D_1	6.82	7.08	**6.95**	D	NS	6.64	6.79	**6.71**	D	NS
D_2	6.94	7.12	**7.03**	T	NS	6.80	6.91	**6.86**	T	NS
D_3	7.04	7.26	**7.15**	F	NS	6.83	7.01	**6.92**	F	NS
Mean (F)	**6.93**	**7.15**		D×T	NS	**6.76**	**6.90**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix L: Effect of different planting densities, training systems and fertigation levels on soil EC in apple cv. Jeromine plantation

D \ T \ F	EC ($dS\ m^{-1}$) 2019 T_1 F_1	F_2	Mean (D×T)	T_2 F_1	F_2	Mean (D×T)	2020 T_1 F_1	F_2	Mean (D×T)	T_2 F_1	F_2	Mean (D×T)
D_1	0.32	0.29	**0.30**	0.28	0.27	**0.28**	0.29	0.26	**0.28**	0.28	0.20	**0.24**
D_2	0.34	0.31	**0.33**	0.31	0.28	**0.29**	0.32	0.30	**0.31**	0.30	0.29	**0.30**
D_3	0.44	0.32	**0.38**	0.35	0.32	**0.34**	0.36	0.31	**0.34**	0.35	0.30	**0.32**
Mean (T×F)	**0.37**	**0.30**		**0.31**	**0.29**		**0.32**	**0.29**		**0.31**	**0.26**	
Mean (T)	**0.34**			**0.30**			**0.31**			**0.29**		

D \ F	2019 D × F F_1	F_2	Mean (D)	$CD_{0.05}$		2020 D × F F_1	F_2	Mean (D)	$CD_{0.05}$	
D_1	0.30	0.28	**0.29**	D	NS	0.29	0.23	**0.26**	D	NS
D_2	0.33	0.29	**0.31**	T	NS	0.31	0.29	**0.30**	T	NS
D_3	0.39	0.32	**0.36**	F	NS	0.36	0.30	**0.33**	F	NS
Mean (F)	**0.34**	**0.30**		D×T	NS	**0.32**	**0.28**		D×T	NS
				T×F	NS				T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix LI: Effect of different planting densities, training systems and fertigation levels on soil organic carbon in apple cv. Jeromine plantation

D \ T / F	Organic Carbon (g kg^{-1}) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	20.73	19.63	**20.18**	20.32	18.91	**19.62**	23.92	22.16	**23.04**	23.29	21.84	**22.57**
D$_2$	23.15	22.17	**22.66**	23.29	20.36	**21.78**	25.63	24.27	**24.95**	24.83	23.54	**24.19**
D$_3$	24.28	23.78	**24.03**	23.96	22.64	**23.30**	27.74	26.13	**26.94**	26.31	25.29	**25.80**
Mean (T×F)	**22.72**	**21.86**		**22.52**	**20.60**		**25.76**	**24.19**		**24.81**	**23.56**	
Mean (T)	**22.29**			**21.56**			**24.98**			**24.18**		

D \ F	2019 D × F F$_1$	2019 D × F F$_2$	2019 Mean (D)	2020 D × F F$_1$	2020 D × F F$_2$	2020 Mean (D)
D$_1$	20.53	19.27	**19.90**	23.61	22.00	**22.80**
D$_2$	23.22	21.22	**22.22**	25.23	23.91	**24.57**
D$_3$	24.12	23.21	**23.67**	27.03	25.71	**26.37**
Mean (F)	**22.62**	**21.23**		**25.29**	**23.87**	

CD$_{0.05}$	2019	2020
D	0.97	0.94
T	0.79	0.77
F	0.79	0.77
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LII: Effect of different planting densities, training systems and fertigation levels on soil available N in apple cv. Jeromine plantation

D \ T / F	Available N (kg ha^{-1}) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	370.05	316.74	**343.39**	357.50	310.46	**333.98**	473.54	413.95	**443.74**	464.13	401.41	**432.77**
D$_2$	373.18	326.14	**349.66**	363.78	319.87	**341.82**	489.22	435.90	**462.56**	479.81	426.50	**453.15**
D$_3$	385.73	338.69	**362.21**	370.05	326.14	**348.10**	508.03	454.72	**481.38**	498.62	448.45	**473.54**
Mean (T×F)	**376.32**	**327.19**		**363.78**	**318.83**		**490.26**	**434.86**		**480.85**	**425.45**	
Mean (T)	**351.75**			**341.30**			**462.56**			**453.15**		

D \ F	2019 D × F F$_1$	2019 D × F F$_2$	2019 Mean (D)	2020 D × F F$_1$	2020 D × F F$_2$	2020 Mean (D)
D$_1$	363.78	313.60	**338.69**	468.83	407.68	**438.26**
D$_2$	368.48	323.01	**345.74**	484.51	431.20	**457.86**
D$_3$	377.89	332.42	**355.15**	503.33	451.58	**477.46**
Mean (F)	**370.05**	**323.01**		**485.56**	**430.15**	

CD$_{0.05}$	2019	2020
D	11.94	11.28
T	9.75	9.21
F	9.75	9.21
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T$_1$: Tall Spindle
T$_2$: Vertical Axis

Fertigation level:-F$_1$: 100 % of AD (NPK)
F$_2$: 75 % of AD (NPK)

Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m)
D$_2$: 3200 trees/ha (2.5 × 1.25 m)
D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LIII: Effect of different planting densities, training systems and fertigation levels on soil available P in apple cv. Jeromine plantation

D \ T, F	Available P (kg ha^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	117.13	74.82	**95.98**	104.47	68.96	**86.72**	148.87	104.24	**126.56**	131.16	95.13	**113.15**
D_2	136.07	98.46	**117.27**	129.68	87.05	**108.37**	163.52	138.81	**151.17**	149.66	127.67	**138.67**
D_3	158.55	126.73	**142.64**	142.78	119.79	**131.29**	178.49	157.72	**168.11**	164.52	146.36	**155.44**
Mean (T×F)	**137.25**	**100.00**		**125.64**	**91.93**		**163.63**	**133.59**		**148.45**	**123.05**	
Mean (T)	**118.63**			**108.79**			**148.61**			**135.75**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	11.62	F_1	F_2	Mean (D)	D	12.96
D_1	110.80	71.89	**91.35**	T F	9.49 9.49	140.02	99.69	**119.85**	T F	10.58 10.58
D_2	132.88	92.76	**112.82**	D×T	NS	156.59	133.24	**144.92**	D×T	NS
D_3	150.67	123.26	**136.96**	T×F D×F	NS NS	171.51	152.04	**161.77**	T×F D×F	NS NS
Mean (F)	**131.45**	**95.97**		D×T×F	NS	**156.04**	**128.32**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix LIV: Effect of different planting densities, training systems and fertigation levels on soil available K in apple cv. Jeromine plantation

D \ T, F	Available K (kg ha^{-1})											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	382.24	354.52	**368.38**	377.84	349.44	**36364**	395.11	367.63	**381.37**	386.48	360.61	**373.55**
D_2	406.68	375.44	**391.06**	394.76	362.71	**378.74**	411.02	396.49	**403.76**	405.15	383.89	**394.52**
D_3	429.12	392.17	**410.65**	409.28	388.69	**398.99**	438.28	412.71	**425.50**	425.84	403.92	**414.88**
Mean (T×F)	**406.01**	**374.04**		**393.96**	**366.95**		**414.80**	**392.28**		**405.82**	**382.81**	
Mean (T)	**390.03**			**380.45**			**403.54**			**394.32**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	11.11	F_1	F_2	Mean (D)	D	9.33
D_1	380.04	351.98	**366.01**	T F	9.07 9.07	390.80	364.12	**377.46**	T F	7.62 7.62
D_2	400.72	369.08	**384.90**	D×T	NS	408.09	390.19	**399.14**	D×T	NS
D_3	419.20	390.43	**404.82**	T×F D×F	NS NS	432.06	408.32	**420.19**	T×F D×F	NS NS
Mean (F)	**399.99**	**370.50**		D×T×F	NS	**410.31**	**387.54**		D×T×F	NS

Training system:-T_1: Tall Spindle
T_2: Vertical Axis

Fertigation level:-F_1: 100 % of AD (NPK)
F_2: 75 % of AD (NPK)

Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m)
D_2: 3200 trees/ha (2.5 × 1.25 m)
D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix LV: Effect of different planting densities, training systems and fertigation levels on soil available Ca in apple cv. Jeromine plantation

D \ T, F	Available Ca (mg kg^{-1}) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	1664.49	1655.91	**1660.20**	1661.54	1652.52	**1657.03**	1683.36	1665.33	**1674.35**	1679.62	1661.76	**1670.69**
D$_2$	1670.91	1663.58	**1667.25**	1665.43	1661.24	**1663.34**	1687.82	1674.87	**1681.35**	1684.49	1668.59	**1676.54**
D$_3$	1676.36	1669.86	**1673.11**	1671.68	1666.27	**1668.98**	1695.75	1682.61	**1689.18**	1690.28	1678.68	**1684.48**
Mean (T×F)	**1670.59**	**1663.12**		**1666.22**	**1660.01**		**1688.98**	**1674.27**		**1684.80**	**1669.68**	
Mean (T)	**1666.85**			**1663.11**			**1681.62**			**1677.24**		

D \ F	2019 D × F F$_1$	2019 D × F F$_2$	2019 Mean (D)	2020 D × F F$_1$	2020 D × F F$_2$	2020 Mean (D)
D$_1$	1663.02	1654.22	**1658.62**	1681.49	1663.55	**1672.52**
D$_2$	1668.17	1662.41	**1665.29**	1686.16	1671.73	**1678.94**
D$_3$	1674.02	1668.07	**1671.04**	1693.02	1680.65	**1686.83**
Mean (F)	**1668.40**	**1661.56**		**1686.89**	**1671.97**	

CD$_{0.05}$	2019	2020
D	7.80	5.52
T	NS	NS
F	6.37	4.51
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T$_1$: Tall Spindle; T$_2$: Vertical Axis
Fertigation level:-F$_1$: 100 % of AD (NPK); F$_2$: 75 % of AD (NPK)
Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m); D$_2$: 3200 trees/ha (2.5 × 1.25 m); D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LVI: Effect of different planting densities, training systems and fertigation levels on soil available Mg in apple cv. Jeromine plantation

D \ T, F	Available Mg (mg kg^{-1}) 2019 T$_1$ F$_1$	2019 T$_1$ F$_2$	2019 T$_1$ Mean (D×T)	2019 T$_2$ F$_1$	2019 T$_2$ F$_2$	2019 T$_2$ Mean (D×T)	2020 T$_1$ F$_1$	2020 T$_1$ F$_2$	2020 T$_1$ Mean (D×T)	2020 T$_2$ F$_1$	2020 T$_2$ F$_2$	2020 T$_2$ Mean (D×T)
D$_1$	580.92	571.59	**576.26**	576.72	568.79	**572.76**	585.85	574.64	**580.25**	581.29	571.14	**576.22**
D$_2$	583.47	574.31	**578.89**	579.95	570.15	**575.05**	587.76	575.55	**581.66**	585.68	573.43	**579.56**
D$_3$	588.65	577.42	**583.04**	581.84	573.28	**577.56**	591.54	580.47	**586.01**	587.32	576.39	**581.86**
Mean (T×F)	**584.35**	**574.44**		**579.50**	**570.74**		**588.38**	**576.89**		**584.76**	**573.65**	
Mean (T)	**579.39**			**575.12**			**582.64**			**579.21**		

D \ F	2019 D × F F$_1$	2019 D × F F$_2$	2019 Mean (D)	2020 D × F F$_1$	2020 D × F F$_2$	2020 Mean (D)
D$_1$	578.82	570.19	**574.51**	583.57	572.89	**578.23**
D$_2$	581.71	572.23	**576.97**	586.72	574.49	**580.61**
D$_3$	585.25	575.35	**580.30**	589.43	578.43	**583.93**
Mean (F)	**581.93**	**572.59**		**586.57**	**575.27**	

CD$_{0.05}$	2019	2020
D	NS	NS
T	NS	NS
F	8.17	9.17
D×T	NS	NS
T×F	NS	NS
D×F	NS	NS
D×T×F	NS	NS

Training system:-T$_1$: Tall Spindle; T$_2$: Vertical Axis
Fertigation level:-F$_1$: 100 % of AD (NPK); F$_2$: 75 % of AD (NPK)
Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m); D$_2$: 3200 trees/ha (2.5 × 1.25 m); D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LVII: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Fe in soil of apple cv. Jeromine plantation

D \ T, F	Fe (ppm) 2019 T$_1$ F$_1$	F$_2$	Mean (D×T)	2019 T$_2$ F$_1$	F$_2$	Mean (D×T)	2020 T$_1$ F$_1$	F$_2$	Mean (D×T)	2020 T$_2$ F$_1$	F$_2$	Mean (D×T)
D$_1$	29.04	25.19	**27.12**	26.31	23.52	**24.92**	30.73	25.68	**28.21**	28.32	24.25	**26.29**
D$_2$	31.92	25.92	**28.92**	27.16	23.95	**25.56**	32.12	27.89	**30.01**	29.89	25.87	**27.88**
D$_3$	32.38	26.38	**29.38**	27.72	24.29	**26.01**	32.98	29.17	**31.08**	30.24	26.28	**28.26**
Mean (T×F)	**31.11**	**25.83**		**27.06**	**23.92**		**31.94**	**27.58**		**29.48**	**25.47**	
Mean (T)	**28.47**			**25.49**			**29.76**			**27.48**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	2019 CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	2020 CD$_{0.05}$	
				D	1.26				D	1.57
D$_1$	27.68	24.36	**26.02**	T F	1.03 1.03	29.53	24.97	**27.25**	T F	1.28 1.28
D$_2$	29.54	24.94	**27.24**	D×T	NS	31.01	26.88	**28.94**	D×T	NS
D$_3$	30.05	25.34	**27.69**	T×F D×F	NS NS	31.61	27.73	**29.67**	T×F D×F	NS NS
Mean (F)	**29.09**	**24.88**		D×T×F	NS	**30.71**	**26.52**		D×T×F	NS

Training system:-T$_1$: Tall Spindle; T$_2$: Vertical Axis
Fertigation level:-F$_1$: 100 % of AD (NPK); F$_2$: 75 % of AD (NPK)
Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m); D$_2$: 3200 trees/ha (2.5 × 1.25 m); D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LVIII: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Mn in soil of apple cv. Jeromine plantation

D \ T, F	Mn (ppm) 2019 T$_1$ F$_1$	F$_2$	Mean (D×T)	2019 T$_2$ F$_1$	F$_2$	Mean (D×T)	2020 T$_1$ F$_1$	F$_2$	Mean (D×T)	2020 T$_2$ F$_1$	F$_2$	Mean (D×T)
D$_1$	19.25	18.12	**18.69**	18.61	17.86	**18.24**	21.46	20.25	**20.86**	20.64	20.13	**20.39**
D$_2$	20.64	18.98	**19.81**	19.82	18.29	**19.06**	22.88	21.46	**22.17**	22.13	21.07	**21.60**
D$_3$	21.63	20.32	**20.98**	20.92	19.72	**20.32**	23.79	21.96	**22.88**	23.24	21.62	**22.43**
Mean (T×F)	**20.51**	**19.14**		**19.78**	**18.62**		**22.71**	**21.22**		**22.00**	**20.94**	
Mean (T)	**19.82**			**19.20**			**21.97**			**21.47**		

D \ F	2019 D × F F$_1$	F$_2$	Mean (D)	2019 CD$_{0.05}$		2020 D × F F$_1$	F$_2$	Mean (D)	2020 CD$_{0.05}$	
				D	0.59				D	0.78
D$_1$	18.93	17.99	**18.46**	T F	0.49 0.49	21.05	20.19	**20.62**	T F	0.64 0.64
D$_2$	20.23	18.64	**19.43**	D×T	NS	22.51	21.27	**21.89**	D×T	NS
D$_3$	21.28	20.02	**20.65**	T×F D×F	NS NS	23.52	21.79	**22.65**	T×F D×F	NS NS
Mean (F)	**20.15**	**18.88**		D×T×F	NS	**22.36**	**21.08**		D×T×F	NS

Training system:-T$_1$: Tall Spindle; T$_2$: Vertical Axis
Fertigation level:-F$_1$: 100 % of AD (NPK); F$_2$: 75 % of AD (NPK)
Planting density:-D$_1$: 4000 trees/ha (2.5 × 1.00 m); D$_2$: 3200 trees/ha (2.5 × 1.25 m); D$_3$: 2666 trees/ha (2.5 × 1.50 m)

Appendix LIX: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Cu in soil of apple cv. Jeromine plantation

D \ T \ F	Cu (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	12.14	10.68	**11.41**	11.23	9.23	**10.23**	12.67	11.02	**11.85**	12.63	10.26	**11.45**
D_2	12.45	11.37	**11.91**	11.85	10.72	**11.29**	13.29	11.46	**12.38**	13.15	10.85	**12.00**
D_3	13.52	11.94	**12.73**	12.29	10.96	**11.63**	13.82	12.87	**13.35**	13.67	11.78	**12.73**
Mean (T×F)	**12.70**	**11.33**		**11.79**	**10.30**		**13.26**	**11.78**		**13.15**	**10.96**	
Mean (T)	**12.02**			**11.05**			**12.52**			**12.06**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	NS	F_1	F_2	Mean (D)	D	NS
D_1	11.69	9.96	**10.82**	T	NS	12.65	10.64	**11.65**	T	NS
D_2	12.15	11.05	**11.60**	F	1.05	13.22	11.16	**12.19**	F	1.09
D_3	12.91	11.45	**12.18**	D×T	NS	13.75	12.33	**13.04**	D×T	NS
Mean (F)	**12.25**	**10.82**		T×F	NS	**13.21**	**11.37**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix LX: Effect of different planting densities, training systems and fertigation levels on DTPA extractable Zn in soil of apple cv. Jeromine plantation

D \ T \ F	Zn (ppm)											
	2019						2020					
	T_1			T_2			T_1			T_2		
	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)	F_1	F_2	Mean (D×T)
D_1	5.98	5.08	**5.53**	5.24	4.98	**5.11**	6.31	5.63	**5.97**	5.97	5.39	**5.68**
D_2	6.32	5.52	**5.92**	6.16	5.39	**5.78**	6.49	5.98	**6.24**	6.52	5.75	**6.14**
D_3	7.19	6.39	**6.79**	6.42	5.93	**6.18**	7.75	7.16	**7.46**	7.27	6.62	**6.95**
Mean (T×F)	**6.50**	**5.66**		**5.94**	**5.43**		**6.85**	**6.26**		**6.59**	**5.92**	
Mean (T)	**6.08**			**5.69**			**6.55**			**6.25**		

D \ F	D × F (2019)			$CD_{0.05}$		D × F (2020)			$CD_{0.05}$	
	F_1	F_2	Mean (D)	D	0.34	F_1	F_2	Mean (D)	D	0.60
D_1	5.61	5.03	**5.32**	T	0.27	6.14	5.51	**5.83**	T	0.49
D_2	6.24	5.46	**5.85**	F	0.27	6.51	5.87	**6.19**	F	0.49
D_3	6.81	6.16	**6.48**	D×T	NS	7.51	6.89	**7.20**	D×T	NS
Mean (F)	**6.22**	**5.55**		T×F	NS	**6.72**	**6.09**		T×F	NS
				D×F	NS				D×F	NS
				D×T×F	NS				D×T×F	NS

Training system:-T_1: Tall Spindle; T_2: Vertical Axis
Fertigation level:-F_1: 100 % of AD (NPK); F_2: 75 % of AD (NPK)
Planting density:-D_1: 4000 trees/ha (2.5 × 1.00 m); D_2: 3200 trees/ha (2.5 × 1.25 m); D_3: 2666 trees/ha (2.5 × 1.50 m)

Appendix LXI

Experiment: Effect of planting densities, training systems and fertigation levels on growth, yield and fruit quality of apple.

1. Analysis of variance for tree height, spread and annual shoot growth during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Tree height		Tree spread		Annual shoot growth	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	112.3842	181.4259	83.81357	143.1569	247.7717	297.8333
Training system (T)	1	325.983	361.7604	153.5121	130.074	94.09	131.4462
Fertigation level (F)	1	220.374	233.7841	77.2641	84.18063	51.2656	107.6406
D×T	2	0.082975	0.1209	0.218925	0.209425	0.476725	0.499225
T×F	1	0.099225	0.0784	0.0169	0.034225	0.0004	1.380625
D×F	2	0.163975	0.1339	0.007725	0.006775	0.676825	1.063675
D×T×F	2	0.178425	0.2443	0.108775	0.183775	0.065275	0.185425
Error	22	8.528106	9.111742	9.192424	9.518788	9.56447	10.32879

2. Analysis of variance for stock diameter, scion diameter and tree volume during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Stock diameter		Scion diameter		Tree volume	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	6.323925	6.323925	4.435675	2.4877	0.664903	2.020196
Training system (T)	1	0.6724	0.6724	0.0289	0.099225	1.587301	3.197132
Fertigation level (F)	1	0.3844	0.3844	0.04	0.180625	0.074714	0.393324
D×T	2	0.046225	0.046225	0.000175	0.0021	0.199049	0.217533
T×F	1	0.04	0.04	0.0004	0.002025	0.003759	0.000124
D×F	2	0.042175	0.042175	0.050725	0.0091	0.302537	0.453821
D×T×F	2	0.013075	0.013075	0.000325	0.0012	0.001879	0.002423
Error	22	0.087572	0.088379	0.005542	0.017833	0.00033	0.000391

3. **Analysis of variance for leaf area, leaf area index and pruning wood weight during 2019 and 2020**

Source of variation	Degree of freedom	Mean sum of squares					
		Leaf area		Leaf area Index		Pruning wood weight	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	3.287433	4.002558	0.221508	0.375175	66384.12	54613.84
Training system (T)	1	3.306336	3.306336	0.020544	0.0049	9533.57	30441.53
Fertigation level (F)	1	10.20802	11.18902	0.113344	0.0529	88744.41	248916.2
D×T	2	0.072411	0.072836	0.000369	2.5E-05	5509.752	227.8627
T×F	1	0.004669	6.94E-05	0.001878	-5.7E-14	4660.793	934.2192
D×F	2	0.018033	0.019558	0.001769	0.003325	4129.291	1460.618
D×T×F	2	0.044344	0.047169	1.94E-05	7.5E-05	3844.959	974.1412
Error	22	0.745682	0.680606	0.036564	0.060136	446.2045	59.36364

4. **Analysis of variance for spur density, blossom density and fruit set during 2019 and 2020**

Source of variation	Degree of freedom	Mean sum of squares					
		Spur density		Blossom density		Fruit set	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	0.0397	0.031825	1.437489	1.966753	133.4084	181.1177
Training system (T)	1	0.0256	0.021025	55.27076	85.85145	190.0704	194.2289
Fertigation level (F)	1	0.0081	0.009025	97.7755	130.0617	316.5639	332.7794
D×T	2	0.0007	0.000325	1.103123	4.028245	2.438516	2.438516
T×F	1	0.0001	2.5E-05	21.13773	22.80698	25.94288	24.43735
D×F	2	0.0003	0.000325	6.468344	4.559559	2.674047	2.674047
D×T×F	2	1E-04	2.5E-05	3.903495	5.304063	0.72067	0.72067
Error	22	0.00117	0.001673	0.240239	0.153715	2.691136	3.149318

5. **Analysis of variance for yield, productivity and yield efficiency during 2019 and 2020**

Source of variation	Degree of freedom	Mean sum of squares					
		Yield		Productivity		Yield efficiency	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	18.60456	25.99479	84.996	84.345	0.006671	0.034921
Training system (T)	1	19.97553	12.15119	212.156	127.888	0.507478	0.735706
Fertigation level (F)	1	12.45299	9.808516	132.960	98.973	0.543999	0.016105
D×T	2	0.029341	0.04804	1.318	0.534	0.032749	0.002859
T×F	1	0.014946	0.653813	0.150	6.397	0.191408	1.91E-05
D×F	2	0.019207	0.205386	1.236	0.163	0.051579	1.92E-05
D×T×F	2	0.051373	0.033302	0.528	0.165	0.057875	0.001406
Error	22	0.732945	0.502499	2.457	2.569	0.001016	0.000242

6. **Analysis of variance for fruit drop, fruit length and fruit diameter during 2019 and 2020**

Source of variation	Degree of freedom	Mean sum of squares					
		Fruit drop		Fruit length		Fruit diameter	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	87.34773	106.7479	250.2227	210.9084	265.7068	674.6472
Training system (T)	1	44.42223	36.9664	133.0562	99.70023	10.4329	143.88
Fertigation level (F)	1	116.3162	63.5209	139.5942	170.9556	95.2576	119.793
D×T	2	0.513775	0.2719	1.973775	0.593125	2.1232	0.527425
T×F	1	1.071225	0.01	8.970025	4.182025	0.1521	0.024025
D×F	2	0.857775	0.1603	1.226275	0.339325	2.6263	0.256675
D×T×F	2	0.571725	0.3229	0.244675	0.396025	1.0803	1.450975
Error	22	10.23659	8.415379	9.12282	7.856736	2.355479	5.47179

7. Analysis of variance for fruit volume, fruit weight and TSS during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Fruit volume		Fruit weight		Fruit TSS	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	2657.215	2489.983	1619.038	618.7876	8.153175	4.9593
Training system (T)	1	258.4056	274.068	159.7696	276.5569	0.366025	2.4025
Fertigation level (F)	1	841.29	586.3662	264.3876	74.3044	2.608225	6.5536
D×T	2	3.945025	1.272775	0.656725	5.1157	0.038275	0.1729
T×F	1	1.243225	2.512225	3.6864	0.1156	0.011025	0.0009
D×F	2	7.940575	11.46423	3.254925	2.8348	0.103225	0.0208
D×T×F	2	3.779575	2.286025	0.445575	0.3727	0.039225	0.1467
Error	22	52.26515	54.20265	4.059015	3.891515	0.039733	0.070317

8. Analysis of variance for fruit firmness, total sugars and reducing sugars during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Fruit firmness		Total sugars		Reducing sugars	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	1.890925	9.764575	4.347225	4.594525	1.678525	2.017825
Training system (T)	1	11.7649	0.8464	3.0276	0.2809	1.4161	0.0841
Fertigation level (F)	1	27.8784	5.8564	2.2801	3.61	1.2769	1.69
D×T	2	0.363475	0.258475	0.043275	0.043825	0.032275	0.059575
T×F	1	1.7161	0.5041	0.1156	0.0729	0.0036	0.1444
D×F	2	0.512175	0.009325	0.006475	0.112825	2.5E-05	0.067225
D×T×F	2	0.502825	0.043225	0.006925	0.011025	0.005475	0.036775
Error	22	0.030063	0.127952	0.182533	0.064517	0.092406	0.055733

9. Analysis of variance for non-reducing sugars, titratable acidity and ascorbic acid during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Non-reducing sugars		Titratable acidity		Ascorbic acid	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	0.566838	0.473564	0.253225	0.183925	6.165175	4.212925
Training system (T)	1	0.273006	0.051984	0.0289	0.1296	0.6561	0.9216
Fertigation level (F)	1	0.130321	0.3249	0.0169	0.1024	8.9401	9.7969
D×T	2	0.007333	0.019156	0.008725	7.5E-05	0.059475	0.036075
T×F	1	0.070756	0.01092	0.0049	0.0324	0.0081	0.0324
D×F	2	0.005573	0.005347	0.000325	0.001975	0.105925	0.175675
D×T×F	2	0.005167	0.017892	0.001525	0.001425	0.046425	0.013125
Error	22	0.028392	0.010688	0.005997	0.0143	0.052006	0.102397

10. Analysis of variance for anthocyanin content, light interception and photosynthetic rate during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Anthocyanin content		Light interception		Photosynthetic rate	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	0.504525	0.735975	106.8381	89.45916	116.0115	105.7055
Training system (T)	1	0.1936	0.126025	328.8606	325.9655	4.2849	5.175625
Fertigation level (F)	1	0.3721	0.403225	22.22664	30.29968	19.7136	23.08803
D×T	2	0.023275	0.003925	0.705785	1.851338	0.014925	0.009925
T×F	1	1E-04	0.005625	1.834709	3.820126	0.4096	0.664225
D×F	2	0.017575	0.001975	0.241499	0.271377	0.425775	0.319525
D×T×F	2	0.001525	0.011025	0.795766	0.271824	0.317575	0.373525
Error	22	0.036564	0.027906	4.820227	5.232727	0.962045	1.090606

11. Analysis of variance for transpiration rate, stomatal conductance and leaf chlorophyll content during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Transpiration rate		Stomatal conductance		Leaf chlorophyll content	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	4.219075	4.219075	0.051903	0.050859	1.900	1.797075
Training system (T)	1	0.308025	0.308025	0.001089	0.000756	0.601	0.308025
Fertigation level (F)	1	0.912025	0.912025	0.0081	0.009702	1.156	0.855625
D×T	2	0.003675	0.003675	2.7E-05	4.07E-05	0.003	0.004275
T×F	1	0.007225	0.007225	1E-06	6.25E-06	0.001	2.5E-05
D×F	2	0.018925	0.018925	2.1E-05	6.17E-05	0.000	0.006025
D×T×F	2	0.005725	0.005725	7E-06	3.33E-05	0.003	0.000325
Error	22	0.039733	0.039733	0.00014	0.000165	0.034	0.068027

12. Analysis of variance for leaf nitrogen, phosphorus and potassium during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Nitrogen		Phosphorus		Potassium	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	2.193175	0.9283	0.038603	0.042053	0.081419	0.075731
Training system (T)	1	0.013225	0.007225	0.011378	0.011378	0.063756	0.058806
Fertigation level (F)	1	0.235225	0.198025	0.033611	0.033611	0.178506	0.170156
D×T	2	0.000175	0.0028	0.000253	0.000253	0.000944	8.13E-05
T×F	1	0.000625	2.5E-05	0.000278	0.000278	0.000306	0.000506
D×F	2	0.000475	0.0028	0.000136	0.000136	0.000944	0.000731
D×T×F	2	0.000175	0.0025	5.28E-05	5.28E-05	0.001319	0.000131
Error	22	0.04222	0.038057	0.00117	0.001673	0.014709	0.010742

13. Analysis of variance for leaf calcium, magnesium and iron during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Calcium		Magnesium		Iron	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	0.005425	0.0061	0.004825	0.007075	451.1329	312.233
Training system (T)	1	0.0036	0.0036	0.005625	0.0049	55.776	355.511
Fertigation level (F)	1	0.0121	0.0144	0.013225	0.0256	304.2117	1380.494
D×T	2	7.5E-05	-7.1E-15	0.000525	2.5E-05	0.960419	1.371825
T×F	1	0.0004	0.0004	2.5E-05	0.0001	1.436003	1.890625
D×F	2	2.5E-05	7.11E-15	2.5E-05	0.000175	0.040103	0.202575
D×T×F	2	0.000175	1E-04	2.5E-05	2.5E-05	0.468453	2.155525
Error	22	0.002054	0.004572	0.001506	0.003915	12.62811	2.961515

14. Analysis of variance for leaf manganese, copper and zinc during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Manganese		Copper		Zinc	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	46.78472	49.78512	0.117025	0.061425	16.02512	14.21055
Training system (T)	1	22.5625	22.54667	0.0361	0.042025	10.45444	14.11254
Fertigation level (F)	1	200.7889	193.1637	14.0625	11.45823	85.62418	89.55468
D×T	2	0.098425	0.230836	0.000775	0.000925	0.267936	0.149519
T×F	1	0.3364	0.007803	0.0004	0.000625	0.572544	1.116544
D×F	2	1.126075	0.171886	0.008325	2.5E-05	0.467719	0.048503
D×T×F	2	0.088675	0.481969	0.000475	0.000625	1.672103	0.892369
Error	22	3.892481	2.914924	0.095075	0.028033	0.395455	2.32447

15. Analysis of variance for pH, EC and organic carbon during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		pH		EC		Organic Carbon	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	0.119608	0.128678	0.013769	0.015633	0.423925	0.383425
Training system (T)	1	0.0729	0.044803	0.010336	0.004444	0.0441	0.0576
Fertigation level (F)	1	0.413878	0.195069	0.014003	0.016044	0.1681	0.1849
D×T	2	0.011325	0.005544	0.000369	0.000711	0.000675	0.003225
T×F	1	0.0009	2.5E-05	0.004225	0.000711	0.0225	0.0025
D×F	2	0.005003	0.004544	0.003019	0.001478	0.008575	0.000625
D×T×F	2	0.005308	0.0067	0.001508	0.000711	0.005025	0.000325
Error	22	0.31697	0.442424	0.007372	0.007997	0.005445	0.012091

16. Analysis of variance for available nitrogen, phosphorus and potassium during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Available Nitrogen		Available Phosphorus		Available Potassium	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	818.7218	4609.92	6250.038	5339.851	4518.545	5477.956
Training system (T)	1	983.4496	796.5942	871.1352	1488.031	825.1256	765.9056
Fertigation level (F)	1	19914.85	27625.1	11328.41	6913.091	7827.826	4666.939
D×T	2	31.96211	7.375872	5.272825	0.705175	52.93042	5.8383
T×F	1	39.33798	4.66E-09	28.14303	48.51123	55.27922	0.540225
D×F	2	22.12762	76.21734	147.7502	369.3809	10.81097	59.9479
D×T×F	2	2.458624	7.375872	41.95697	8.808325	73.14843	22.6827
Error	22	198.8505	177.6061	188.4242	234.3636	172.2045	121.4773

17. Analysis of variance for available calcium, magnesium and iron during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Calcium		Magnesium		Iron	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	464.1793	616.6819	101.4031	98.3725	9.031075	18.55127
Training system (T)	1	125.7762	173.1856	164.2242	105.6784	79.9236	47.0596
Fertigation level (F)	1	420.8652	2001.668	784.28	1149.888	159.7696	158.0049
D×T	2	0.764725	1.212775	3.344725	3.9709	1.368975	0.659575
T×F	1	3.591025	0.3844	2.941225	0.3364	10.3041	0.2704
D×F	2	8.686825	23.84703	1.247475	2.0089	1.804675	0.351225
D×T×F	2	2.419975	3.971425	2.091325	0.2611	0.665175	0.249925
Error	22	84.87879	42.56818	139.8182	176.0833	2.204079	3.435724

18. Analysis of variance for soil zinc, copper and manganese during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Zinc		Copper		Manganese	
		2019	2020	2019	2020	2019	2020
Planting density (D)	2	4.065775	6.1009	5.567425	5.889325	14.41427	12.64067
Training system (T)	1	1.3924	0.81	8.4681	1.946025	3.4596	2.205225
Fertigation level (F)	1	4.0401	3.5721	18.4041	30.19503	14.3641	14.63062
D×T	2	0.167275	0.1263	0.272025	0.054525	0.072525	0.013125
T×F	1	0.2401	0.0121	0.0289	1.134225	0.0961	0.403225
D×F	2	0.032925	0.0003	0.294375	0.383575	0.321925	0.563925
D×T×F	2	0.069925	0.0244	0.119275	0.041475	0.016975	0.047275
Error	22	0.158209	0.507824	2.296572	2.46947	0.493354	0.850079

19. Pooled analysis of variance for tree height, tree spread, annual shoot growth, scion diameter, stock diameter and tree volume during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Tree height	Tree spread	Annual shoot growth	Scion diameter	Stock diameter	Tree volume
Planting density (D)	2	144.7885	111.3918	272.1934	3.335894	8.227975	1.248037
Training system (T)	1	343.6389	141.5505	111.9893	0.058806	0.412806	2.322475
Fertigation level (F)	1	227.0296	80.68531	76.86906	0.012656	0.363006	0.202722
D×T	2	0.099606	0.212294	0.434606	0.000681	0.004375	0.208134
T×F	1	0.088506	0.024806	0.357006	0.000156	0.035156	0.001312
D×F	2	0.148556	0.007169	0.854456	0.025669	0.008725	0.374337
D×T×F	2	0.207344	0.142819	0.114306	0.000306	0.001425	0.002124
Error	22	4.061136	4.454773	4.391117	0.003402	0.052142	0.000165

20. Pooled analysis of variance for leaf area, leaf area index, pruning wood weight, spur density, blossom density and fruit set during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Leaf area	Leaf area Index	Pruning wood weight	Spur density	Blossom density	Fruit set
Planting density (D)	2	3.635152	0.293177	60008.73	0.035606	1.40001	156.3531
Training system (T)	1	3.306336	0.011378	18511.64	0.023256	69.7228	192.144
Fertigation level (F)	1	10.6929	0.080278	158728.5	0.008556	113.3438	324.621
D×T	2	0.072605	7.15E-05	944.2231	0.000494	2.334788	2.438516
T×F	1	0.001469	0.000469	2442.089	6.25E-06	21.96442	25.18449
D×F	2	0.018777	0.000209	2624.906	0.000306	5.459535	2.674047
D×T×F	2	0.045738	4.24E-05	2126.329	4.37E-05	4.570591	0.72067
Error	22	0.438845	0.03697	90.50568	0.000383	0.004302	0.608182

21. Pooled analysis of variance for fruit drop, yield, productivity, yield efficiency, fruit length and fruit diameter during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Fruit drop	Yield	Productivity	Yield efficiency	Fruit length	Fruit diameter
Planting density (D)	2	96.78411	22.14352	84.667	0.011451	230.0486	446.6367
Training system (T)	1	40.60876	15.82152	167.370	0.61631	115.7776	57.95016
Fertigation level (F)	1	87.93751	11.09134	115.341	0.186827	154.878	107.1743
D×T	2	0.228306	0.036324	0.856	0.004154	0.469506	0.638006
T×F	1	0.218556	0.117763	1.146	0.048812	6.3504	0.074256
D×F	2	0.416106	0.077099	0.136	0.013396	0.624944	0.329631
D×T×F	2	0.429081	0.011465	0.055	0.015223	0.016331	0.890181
Error	22	0.285833	0.224393	2.339	0.000143	3.982279	4.881419

22. Pooled analysis of variance for fruit volume, fruit weight, fruit firmness, TSS, and titratable acidity during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		Fruit volume	Fruit weight	Fruit firmness	Fruit TSS	Titratable acidity
Planting density (D)	2	2568.131	1059.896	4.848025	4.848025	0.216475
Training system (T)	1	266.1792	214.1832	4.730625	4.730625	0.070225
Fertigation level (F)	1	708.0921	154.7536	14.8225	14.8225	0.050625
D×T	2	1.930619	1.527194	0.0084	0.0084	0.002575
T×F	1	1.8225	0.6241	1.0201	1.0201	0.003025
D×F	2	8.974706	1.749231	0.134425	0.134425	0.000225
D×T×F	2	2.213494	0.011406	0.0628	0.0628	0.000175
Error	22	26.82339	1.624602	0.044214	0.044214	0.002729

23. Pooled analysis of variance for reducing sugars, non reducing sugars, total sugars, ascorbic acid and anthocyanin content during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		Reducing sugars	Non reducing sugars	Total sugars	Ascorbic acid	Anthocyanin content
Planting density (D)	2	1.842919	0.518103	4.464381	5.141719	0.614775
Training system (T)	1	0.5476	0.140813	1.288225	0.783225	0.158006
Fertigation level (F)	1	1.476225	0.21669	2.907025	9.3636	0.387506
D×T	2	0.001244	0.011529	0.014294	0.045731	0.008775
T×F	1	0.0484	0.006521	0.093025	0.018225	0.001806
D×F	2	0.016556	0.004896	0.039269	0.134794	0.006975
D×T×F	2	0.010806	0.003136	0.005481	0.025481	0.003775
Error	22	0.033386	0.018545	0.062593	0.031507	0.024536

24. Pooled analysis of variance for light interception, photosynthetic rate, transpiration rate, stomatal conductance and leaf chlorophyll content during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		Total light interception	Photosynthetic rate	Transpiration rate	Stomatal conductance	Leaf chlorophyll content
Planting density (D)	2	184.2138	110.7986	4.208181	0.05138	1.8482313
Training system (T)	1	337.2554	4.719756	0.257556	0.000915	0.442225
Fertigation level (F)	1	34.09993	21.36751	0.926406	0.008883	0.564322
D×T	2	0.000199	0.012231	0.000606	3.27E-05	8.125E-05
T×F	1	2.029241	0.529256	0.001806	5.62E-07	0.0004
D×F	2	0.000499	0.370694	0.012944	3.87E-05	0.0013187
D×T×F	2	0.000189	0.344981	0.005444	1.71E-05	0.0007938
Error	22	2.843239	0.301117	0.015416	9.04E-05	0.0308992

25. Pooled analysis of variance for leaf nitrogen, phosphorus, potassium, calcium and magnesium during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Planting density (D)	2	1.489956	0.040253	0.078456	0.005756	0.005781
Training system (T)	1	0.01	0.011378	0.061256	0.0036	0.005256
Fertigation level (F)	1	0.216225	0.033611	0.174306	0.013225	0.018906
D×T	2	0.000794	0.000253	0.000394	1.88E-05	0.000119
T×F	1	0.000225	0.000278	6.25E-06	0.0004	6.25E-06
D×F	2	0.001069	0.000136	0.000831	6.25E-06	4.38E-05
D×T×F	2	0.000356	5.28E-05	0.000419	0.000119	6.25E-06
Error	22	0.020509	0.000383	0.009117	0.002314	0.002104

26. Pooled analysis of variance for leaf iron, manganese, copper, zinc and soil pH during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		Iron	Manganese	Copper	Zinc	pH
Planting density (D)	2	378.4814	48.2678	0.0868	15.1041	0.120434
Training system (T)	1	173.2295	22.55458	0.039006	12.21503	0.058001
Fertigation level (F)	1	745.199	196.9578	12.72706	87.5784	0.294306
D×T	2	1.15343	0.157344	0.000325	0.195702	0.006567
T×F	1	0.007803	0.060434	6.25E-06	0.822044	0.000306
D×F	2	0.090213	0.498169	0.0019	0.201734	0.00394
D×T×F	2	1.152047	0.121969	2.5E-05	0.055034	0.00569
Error	22	3.785966	1.73456	0.030411	0.692027	0.356818

27. Pooled analysis of variance for soil EC, organic carbon, available nitrogen, phosphorus and potassium during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares				
		EC	Organic Carbon	Available Nitrogen	Available Phosphorus	Available Potassium
Planting density (D)	2	0.013847	0.401481	2325.244	5755.084	4986.007
Training system (T)	1	0.007084	0.050625	887.5633	1159.062	795.24
Fertigation level (F)	1	0.015006	0.1764	23612.62	8985.144	6145.776
D×T	2	0.000326	0.001256	4.302592	1.287475	21.96317
T×F	1	0.000367	0.0025	9.834496	37.63823	11.2225
D×F	2	0.000981	0.002081	44.86989	196.5087	5.095881
D×T×F	2	0.000922	0.001881	0.614656	16.17997	37.33718
Error	22	0.006746	0.006102	95.45645	205.9697	144.1591

28. Pooled analysis of variance for soil available calcium, magnesium, iron, manganese, copper and zinc during 2019 and 2020

Source of variation	Degree of freedom	Mean sum of squares					
		Calcium	Magnesium	Iron	Manganese	Copper	Zinc
Planting density (D)	2	536.3436	99.87946	13.3644	13.37256	5.664456	4.974531
Training system (T)	1	148.5352	133.3448	62.41	2.797256	4.633256	1.0816
Fertigation level (F)	1	1064.554	958.3668	158.886	14.49706	23.93656	3.8025
D×T	2	0.953325	2.562044	0.831475	0.030881	0.110381	0.145356
T×F	1	0.406406	1.316756	3.478225	0.223256	0.381306	0.0361
D×F	2	14.6737	1.117056	0.157225	0.310581	0.145019	0.009356
D×T×F	2	0.455475	0.692569	0.043825	0.029831	0.028169	0.044106
Error	22	58.70265	139.1345	2.133349	0.488043	1.22562	0.242936

Department of Fruit Science
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Title of the Thesis	**:**	**Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)**
Name of the student	**:**	Tanzin Ladon
Admission Number	**:**	H-2017-18-D
Major Discipline	**:**	Fruit Science
Minor Discipline (s)	**:**	Soil Science and Water Management
Date of Thesis Submission	**:**	10-08-2021
Total Pages of the thesis	**:**	152+xliv
Major Advisor	**:**	Dr J S Chandel

ABSTRACT

The present investigation entitled "Studies on the effect of planting densities, canopy management and fertigation on growth, yield and fruit quality of apple (*Malus* × *domestica* Borkh.)" was carried out on 4-year-old trees of apple cv. Jeromine on M9 rootstock during the year 2019 and 2020 at Fruit Research Farm of Department of Fruit Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) India. The experiment was laid out in a Randomized Block Design (Factorial) with treatment combinations of three planting densities (4000, 3200 and 2666 trees/ha), two training systems (Tall Spindle and Vertical Axis) and two levels of fertigation (100 and 75 % of AD NPK). Each treatment was replicated three times with two trees per replication. The results revealed that trees planted at a density of 2666 trees/ha, trained with Vertical Axis and subjected to 100 % of AD (NPK) registered highest increase in tree height, spread and volume, scion and stock diameter, annual shoot growth and leaf area. Fruiting parameters viz. spur density, blossom density, fruit set, yield and yield efficiency were also significantly higher in trees at planting density of 2666 trees/ha, trained with Tall Spindle and fertigated with 100 % of AD (NPK) as compared to other treatment combinations. Fruits harvested from the trees at planting density of 2666 trees/ha, trained with Tall Spindle and subjected under 100 % of AD (NPK) were significantly superior in physico-chemical fruit quality characteristics viz. fruit size, weight, volume, TSS, sugars, ascorbic acid and anthocyanin content. The results indicate that with the increase in planting density yield per tree decreased, while the yield per hectare increased and the highest productivity was recorded in trees planted at high density planting of 4000 trees/ha, trained with Tall Spindle and subjected under 100 % of AD (NPK) as compared to other treatment combinations. The trees planted at planting density of 4000 trees/ha, trained to Tall Spindle and fertigated with 100 % of AD (NPK) recorded highest light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content as compared to other treatment combinations. Leaf nutrients content (N, P, K, Fe, Mn, Cu and Zn) and soil available nutrients (N, P, K, Ca, Mg, Fe, Mn, Cu and Zn) were also recorded significantly higher under lower density of 2666 trees/ha with Tall Spindle and 100 % of AD (NPK) treatment combination. On the basis of results obtained in the present investigation, it can be concluded that treatment combination of high density planting of 4000 trees/ha with Tall Spindle and subjected under 100 % of AD (NPK) may be considered best treatment as it resulted in significantly higher productivity (42.13 t/ha), leaf area index, light interception, photosynthesis rate, stomatal conductance, transpiration rate and leaf chlorophyll content without any significant adverse effect on physico-chemical fruit quality characteristics, leaf nutrients contents and soil chemical properties.

Signature of the Student	**Signature of the Major Advisor**
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Date:	**Date:**

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