STANDARDIZATION OF FERTIGATION DOSE FOR OPEN AND PROTECTED CULTIVATION OF BANANA CV. GRAND NAINE (*Musa* spp. AAA) UNDER PUNJAB CONDITIONS

A Thesis

Submitted in partial fulfillment of the requirements for the

award of the degree of

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in

HORTICULTURE

by

Lal Bahadur

(41500080)

Supervised By

(Dr. Shailesh Kumar Singh)

Co-Supervised By

(Dr. R. K. Arora)

LOVELY PROFESSIONAL UNIVERSITY
PUNJAB
2020

DECLARATION

I hereby declare that the thesis entitled **"Standardization of fertigation dose for open and protected cultivation of banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions"** submitted for **Doctor of Philosophy in Horticulture** to the School of Agriculture, Lovely Professional University is entirely original work and all ideas and references are duly acknowledged. The research work has not been formed the basis for the award of any other degree.

Place: LPU, Phagwara (Lal Bahadur)

Date: 03/May/2020 (Reg No. 41500080)

CERTIFICATE-I

This is to certify that the thesis entitled, **"Standardization of fertigation dose for open and protected cultivation of banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions"** submitted to the Faculty of Technology and Sciences**,** Lovely Professional University, Phagwara, Punjab in partial fulfilment of the requirement for the degree of **DOCTOR OF PHILOSOPHY (Ph.D.)** in the discipline of **Horticulture** embodies the results of a piece of bonafide research carried out by **Mr. Lal Bahadur** under my guidance and supervision. To the best of my knowledge, the present work is the result of original investigation and study. No part of this thesis has ever been submitted for any other degree or diploma or published in any other form. All the assistance and help received during the course of investigation and the sources of literature have been duly acknowledged by him.

Supervisor

Date: 03/May/2020

Place: LPU, Punjab

(Dr. Shailesh Kumar Singh)
Associate Professor and Head
Department of Horticulture
Lovely Professional University
Phagwara-144 411

Co-Supervisor

(Dr. R. K. Arora)
Ex-Principal Scientist
ICAR-CPRI, Shimla,
Himachal Pradesh

CERTIFICATE-II

This is to certify that the thesis entitled **"Standardization of fertigation dose for open and protected cultivation of banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions"** submitted by **Mr. Lal Bahadur (Registration No. 41500080)** to the Lovely Professional University, Phagwara in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (Ph.D.)** in the discipline of **Horticulture** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an external examiner.

Chairperson, Advisory Committee
(Dr. Shailesh Kumar Singh)
Associate Professor and Head
Department of Horticulture
Lovely Professional University
Phagwara-144 411

External Examiner

Dean
School of Agriculture
Lovely Professional University
Phagwara-144 411

SCHOOL OF AGRICULTURE

LOVELY PROFESSIONAL UNIVERSITY, PHAGWARA

Title	**:** Standardization of fertigation dose for open and protected cultivation of banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions
Name of the Student	**:** Lal Bahadur
Registration Number	**:** 41500080
Year of Admission	**:** 2015
Name of Research Guide and Designation	**:** Dr Shailesh Kumar Singh Associate Professor & Head Department of Horticulture Lovely Professional University, Punjab

ABSTRACT

Introduction: Banana is perennial fruit crop which belongs to the family *Musaceae* and order Scitamineae. There are two genera *viz*. *Ensete* and *Musa* with about 50 species in the family. The best-known banana of commerce from all over the world belongs to the pure triploid acuminata (AAA) group. Grand Naine is well adopted triploid acuminate banana and known for high yield and good quality fruits. Banana fruit is well known for its nutritive and therapeutic values and is rich source of energy (128 kcal in cooking banana and 116 kcal in desert banana per 100g). The fruits are good source of carbohydrates with low cholesterol and free from salt so are good for diabetic patients.

Background of research: Banana is moisture loving plants in nature and it requires adequate soil moisture throughout its life span, so to meet this requirement most efficient method of water application is micro irrigation especially trough drippers. The water use efficiency (WUE) is high with drip system when compared to basin system of irrigation. In Punjab, the major challenge of banana is frost injury and adverse climatic conditions during winter seasons the yield is adversely affected and most of the time whole crop remain damaged. Thus, protected cultivation is one of the important solutions for this. Keeping in view the importance of fertigation through drip irrigation and protected cultivation, the study was carried out as "Standardization of fertigation doze for open and protected cultivation banana (Musa spp. AAA) under Punjab conditions".

Methodology: The study was carried out during the time period of year 2016-2018 in poly-net house unit and open fields located at Centre of Excellence for Fruits, Village- Khanaura in distt Hoshiarpur. The experiment was designed in factorial randomized block design (FRBD) under two factors viz., fertilizer application (F) at six levels consisting 5 fertigation with one controlled treatment and two growing conditions. The observations were recorded on various plant growth parameters, yield and related attributes, fruit quality parameters, leaf nutrient status and soil nutrient status and subjected to statistical analysis.

Experimental findings: A positive correlation was reported with nutrient application through fertigation and the growth parameters where 120% RDF fertigation performed better than 100% RDF fertigation followed by 80% RDF fertigation under both poly net house and open field conditions. However, the yield and related attributes were responded differently and interestingly was in line with the average number of leaves per plant. The F_3 (Fertigation with 80 percent recommended dose of fertilizers) and F_4 (Fertigation with 100 percent recommended dose of fertilizers) treatment have reported with significantly better yield and yield contributing factors. Similar pattern was reported with fruit quality aspect of banana fruits determined on the basis of TSS, sugar, acidity and TSS/Acidity ratio. Further leaf nutrient status was reported to be influenced by increasing nutrient doses given with the fertigation treatments and a positive correlation was established with poor level under lowest dose 40 percent RDF as fertigation (F_1) and control with RDF as soil application (F_6). Except soil available nitrogen other factors were not significantly affected with any of the treatment factors.

Conclusion: The outcome of this investigation can be summarized as the F_3 (Fertigation with 80 percent recommended dose of fertilizers) and F_4 (Fertigation with 100 percent recommended dose of fertilizers) treatment can be considered as best treatments where better yield can be harvested from banana plants without any compromise with quality of fruits. Further, protected cultivation may be recommended for banana cultivation under subtropics where there is challenge of frost injury during winter.

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Place: Jalandhar, Punjab **Lal Bahadur**

Date: 03/May/2020 **(41500080)**

TABLE OF CONTENTS

Chapter	Titles	Page No.
1	INTRODUCTION	1-3
2	REVIEW OF LITERATURE	4-26
3	MATERIAL AND METHODS	27-34
4	RESULTS AND DISCUSSION	35-76
5	SUMMARY AND CONCLUSION	77-81
	BIBLIOGRAPHY	82-95
	APPENDICES	96-99

LIST OF TABLES

Table No.	Description	Page No.
4.1	Effect of fertigation and growing condition on Pseudostem height (cm) of Banana plants	36
4.2	Effect of fertigation and growing condition on Pseudostem girth (cm) of Banana plants	37
4.3	Effect of fertigation and growing conditions on average number of leaves per plant in banana	38
4.4	Effect of fertigation and growing conditions on average number of days taken for shooting	39
4.5	Effect of fertigation and growing conditions on average number of days taken from shooting to harvest	41
4.6	Effect of fertigation and growing conditions on total crop duration in banana	42
4.7	Effect of fertigation and growing conditions on average bunch weight (kg) in banana	43
4.8	Effect of fertigation and growing conditions on average number of hands per bunch in banana	45
4.9	Effect of fertigation and growing conditions on average number of fingers per hand in banana	46
4.10	Effect of fertigation and growing conditions on average finger or fruit length (cm) in banana	47
4.11	Effect of fertigation and growing conditions on average fruit circumference (cm) in banana	48
4.12	Effect of fertigation and growing conditions on average fruit or finger weight (gm) in banana	50
4.13	Effect of fertigation and growing conditions on average fruit yield (kg per plant) in banana	51
4.14	Effect of fertigation and growing conditions on TSS (°Brix) of banana fruit	53
4.15	Effect of fertigation and growing conditions on Titratable Acidity (%) of banana fruit	54
4.16	Effect of fertigation and growing conditions on TSS/ acid ratio of banana fruit	55
4.17	Effect of fertigation and growing conditions on total sugars (%) of banana fruit	56

4.18	Effect of fertigation and growing conditions on nitrogen (%) content of banana leaves	57
4.19	Effect of fertigation and growing conditions on phosphorus content (%) of banana leaves	59
4.20	Effect of fertigation and growing conditions on potassium content (%) of banana leaves	60
4.21	Effect of fertigation and growing conditions on calcium content (%) of banana leaves	61
4.22	Effect of fertigation and growing conditions on magnesium content (%) of banana leaves	62
4.23	Effect of fertigation and growing conditions on iron content (ppm) of banana leaves	63
4.24	Effect of fertigation and growing conditions on Zinc content (ppm) of banana leaves	64
4.25	Effect of fertigation and growing conditions on Manganese content (ppm) of banana leaves	65
4.26	Effect of fertigation and growing conditions on copper content (ppm) of banana leaves	66
4.27	Status of soil parameters at different depths before experiment	70
4.28	Status of soil pH at different depths after experiment	71
4.29	Status of soil electrical conductivity (dSm^{-1}) at different depths after experiment	72
4.30	Status of soil organic carbon (percent) at different depths after experiment	73
4.31	Status of soil available nitrogen (kg/ha) at different depths after experiment	74
4.32	Status of soil available phosphorus (kg/ha) at different depths after experiment	75
4.33	Status of soil available potassium (kg/ha) at different depths after experiment	76

LIST OF PLATES

Figure No.	Description	Page No.
1	Banana plantation under experiment	96
2	Fruiting in banana plants under experiment	97
3	Data collection and observation	98
4	Measurement of fruit length	99

LIST OF ABBREVIATIONS

Abbreviated Form	Full Form
ha	Hectare
ha^{-1}	Per hectare
MT	Metric tonnes
et al.	et alii (and others)
ft.	Foot
mm	Milli meter
m	Meter
%	Per cent
g	Gram
cm	Centi meter
cm2	Centi meter square
mg	Mili gram
mg/g	Milli gram per gram
cv.	Cultivar
FYM	Farm Yard Manure
N: P: K	Nitrogen: Phosphorus: Potassium
ml	Milli liter
/	Per
^{0}C	Degree celsius
^{0}B	Degree Brix
hrs	Hours
Min.	Minute
nm	Nano Meter
A	Absorbance at specific wavelength
V	Volume
W	Weight
sq. cm	Square centimeter
DAP	Diammonium phosphate
LAI	Leaf area index
TSS	Total Soluble Solids
E-W	East-West
N-S	North-South
WSF	Water Soluble Fertilizers
RDF	Recommended Doses of Fertilizers

CHAPTER I

INTRODUCTION

Banana is perennial fruit crop which belongs to the family *Musaceae* and order Scitamineae. There are two genera *viz*. *Ensete* and *Musa* with about 50 species in the family. The best-known banana of commerce from all over the world belongs to the pure acuminata (AAA) group. Banana is an important tropical fruit and is one of the oldest known fruits which was being used for various purposes. Banana is one of the dominating fruit crops in the world market and is well recognized as the “Apple of paradise”, so taxonomically called as *Musa paradisiaca***.** Banana name also mentioned in great Indian epics Ramayana and Mahabharata. This is originated in the hot, tropical regions of South East Asia including Assam, Indo-Burma and China. Its cultivation is distributed throughout the warmer countries. Geographical location of banana growing areas is confined to tropical region near equator between 20^0N and 20^0S latitudes while the subtropical belt is located between 20^0N to 30^0N and 20^0S to 30^0S latitudes.

Banana fruits are rich in vitamin A, vitamin C and Riboflavin and also contain a good amount of mineral elements like Mg, Na, K and P and significant value of Ca and Fe. The fruit contains water-70%, carbohydrates-27%, crude fiber-0.5%, fat-0.3 %, protein-1.2 %, potassium-460 mg, magnesium-36 mg, phosphorous-27 mg, calcium-7 mg, ascorbic acid-10 mg and energy-104 calories per100 gm of fruits (Bal, 1997). Banana fruits contain lectin, a protein and antioxidant which may help to prevent leukemia cells from growing. In addition, banana fruits are good for asthma, blood pressure, diabetes, heart and digestion related problems.

Banana fruit is well known for its nutritive and therapeutic properties and is rich in energy (128 kcal in cooking banana and 116 kcal in desert banana per 100g). The fruits are good source of carbohydrates with low cholesterol and free from salt so are good for diabetic patients. In South India, both the plants and the fruits are used extensively in wedding, festivals and for worship. The terminal portion of inflorescence consists of male flowers, is called as pendent, and is used to make vegetables. Banana fruits are used to make many products like chips, soft drinks, banana flour, jam etc. Every part of banana used for various purposes. Banana are ideally suited for baby foods.

In Africa, banana flour is fermented with yeast and is used to replace malt in breweries. It is also used to make beer and alcohol. The ripe banana fruits are used to make bear and alcohol. The ripe banana fruits are used to make banana powder while unripe fruits are used to make flour. In South India and Africa, the central core of the pseudostem is taken for counteracting the stones and juice or extract of pseudostem is used to by lactating women for increasing milk production and is also added in dye due to its property to develop permanent strain. The pseudostem is also used to make starch and paper, leaves are popularly used as dinner plate and to wrap goods. Banana is also used to make good quality ropes due to strong fibre quality. It is also used as animal food. In the international fruit market and trade banana is the single biggest item.

Banana is widely grown in countries like India, Mexico, Philippines, Uganda, Tanzania, Thailand, Brazil and China etc. In the world, total area under banana is 5.49 million hectares having 113.28 million metric tonnes (MT) production with 20.62 MT ha^{-1} productivity. In this, India is number one in area and production having total area 0.85 million hectares and production of 29.12 million metric tonnes with productivity of 34.43 MT ha^{-1} followed by China having 0.43 million ha area and production 13.32 million metric tonnes with productivity of 30.92 MT ha^{-1}, Philippines having area 0.46 million hectares with production 5.83 million metric tonnes with productivity of 12.77 MT ha^{-1}, Ecuador produces 38.86 million metric tonnes fruits from 0.18 million hectares coverage and having productivity of 38.86 MT ha^{-1} (Anonymous, 2018a).

In India, major banana producing states are Karnataka having area of 110550 hectares with production of 2328900 metric tonnes followed by Kerala with production of 1119160 metric tonnes from 109260 hectares area, Andhra Pradesh with area of 88960 hectares with production of 5003070 metric tonnes and Tamil Nadu having area of 82630 hectares with production of 3205040 metric tonnes (Anonymous, 2018b).

In Punjab, cultivation of Banana also started successfully from last 3-4years under subtropical conditions. In Punjab, the central zone comprising district of Ludhiana, Moga, Fatehgarh Sahib, Mohali, Sangrur, Barnala and paddy belt of arid-irrigated region having pH 8.5 are suitable for cultivation of banana. In Punjab, banana is cultivated in area of 78 hectares with production of 4398 metric tonnes having productivity of 56386 kg per hectare (Anonymous, 2018c). Grand Naine is recommended variety for Punjab conditions.

In Punjab, banana is growing from last 4-5 years but due to frost injury and adverse climatic conditions during winter seasons the yield is adversely affected and most of the time whole crop remain damaged (Srinivasarao *et al.*, 2020). So, to overcome this problem banana cultivation under net house conditions is needed and so far, there no proper work has been done on protected cultivation of banana under Punjab conditions in relation to different fertigation doses through drip system. Drip irrigation may be considered as one of the technological advancements which is related to water conservation through precise application of water directly in root zone of plants grown at wider spacing, thus avoiding the watering of uncropped places (Ahluwalia *et al.*, 1993). Gubbuk & Pekmezci, (2004) have claimed the protected cultivation of banana as better option for high production and is more suitable in comparison to open field conditions as described for papaya by Hueso *et al.* (2017) and Schmildt *et al.* (2019).

Banana is moisture loving plants in nature and it requires adequate soil moisture throughout its life span, so to meet this requirement most efficient method of water application is micro irrigation especially trough drippers (Srinivas, 1997). For judicious water management, drip irrigation system is well suited for high value crops like banana. The water use efficiency (WUE) is high with drip system when compared to basin system of irrigation (Mustaffa and Kumar, 2012). Similarly, according to Pawar and Dingre (2013) drip irrigation will reduce the quantity of water and will increase the yield and decrease the number of days for harvest as well which may be associated with proper maintenance of soil field capacity where soil may load with excess N and P as advocated by Musazura *et al.* (2019) in banana cultivation. It also saves water up to 50% in comparison to convention approaches of irrigation.

Considering the significance of fertigation through drip irrigation and protected cultivation, the research work was executed with the undermentioned objectives:

- To standardize the fertigation doze for banana cv. Grand Naine under open and protected cultivation
- To evaluate the performance of banana cultivation in protected and open field conditions
- To evaluate the nutrient status of banana plant under different fertigation treatments
- To evaluate quality parameters of banana fruit grown under Punjab conditions

CHAPTER-II

REVIEW OF LITERATURE

Banana being a moisture loving plants requires large quantity of water (Robinson, 1996) and similarly it requires different nutrients throughout its growing period (Thangeselvibei *et al*., 2009) thus it is very important to adopt proper irrigation and nutrient management practices for obtaining a good and quality yield. Banana is a surface feeder and nutrient exhausting crop so it is very important to ensure a significant level of soil fertility for obtaining sustainable yield. Keeping in view of these back ground, the literatures considering drip irrigation, fertigation and protected cultivation of banana and other fruits have been reviewed for all parameters under study and is being discussed here through the following heads and sub- heads.

2.1 Drip irrigation system and its effect

- **2.1.1** Vegetative growth
- **2.1.2** Fruit yield and related attributes
- **2.1.3** Fruit quality and related attributes
- **2.1.4** Leaf nutrient content

2.2 Fertigation and its effect

- **2.2.1** Vegetative growth
- **2.2.2** Fruit yield and related attributes
- **2.2.3** Fruit quality and related attributes
- **2.2.4** Leaf nutrient content

2.3 Protected cultivation and its effect

- **2.3.1** Vegetative growth
- **2.3.2** Fruit yield and related attributes
- **2.3.3** Fruit quality and related attributes
- **2.3.4** Diseases-pest incidence

2.1 Drip irrigation system and its effect

The concern for improvement of water use efficiency in agriculture was felt due to growing problem of ground water scarcity and challenges faced due to persistent ground water degradation, generally the worldwide and particularly in developing countries. As stated by Seckler *et al.* (1998) there is possibility of meeting out of 50% of raised demand of water by the 2025, if effectiveness of irrigation is improved. Drip irrigation may be considered as one of the technological advancements which is related to water conservation through precise application of water directly in root zone of plants grown at wider spacing, thus avoiding the watering of uncropped places (Ahluwalia *et al.*, 1993). Sivanappan (1994) reported 100 percent increase in water use efficiency through proper management and use of drip irrigation system. Narayanamoorthy (1997) also reported that drip method of irrigation reduces the over exploitation of ground water and prevents the area from waterlogging and salinity. Drip method of irrigation decreases wastage of water thus help in saving of irrigation water. This also increases the fertilizer use efficiency and increases the crop yield and decreases tillage requirement (Qureshi *et al.* 2001, Sivanappan, 2002).

Banker *et al.* (1993) reported that drip system of irrigation as an efficient precise water application system that delivers moisture very close to the root zone of plants**.** Eckstein *et al.* (1998a) reported that drip irrigation system gave high production and also save water with superior water use efficiency. Shivanappan (1985) stated that drip irrigation plays a positive role for improving the production of crops and this ultimately helps the farmers by increasing their income and this will be beneficial in water scarcity areas. Similarly, Mishra and Pyasi (1993) reported that water distribution through drip method of irrigation found to be more uniform within 10 cm radius of drip emitter. With increase in distance, non-uniformity of water increased and maximum uniformity found at zero level. Dasberg (1999) reported that efficiency of drip irrigation is as high as 90% compared with surface irrigation followed by 60 to 80% in sprinkler irrigation. Padhye (1990) reported that drip irrigation is significantly effective in saving water, power, labour and annual maintenance cost in comparison to sprinkler system.

2.1.1 Vegetative growth

Srinivas (1997) reported that with application of N through irrigation there was increase in plant height, leaf number, leaf area as compare to direct application of fertilizers. Similarly, More *et al.* (1999) also compared drip irrigation with basin irrigation system and reported that the plant growth parameters were significantly affected by irrigation methods where plant height, pseudo stem girth and flowering percentage were greater under drip irrigation as compare to basin system.

Mahalakshmi *et al*. (2001a) also reported that fertigation resulted in better plant morphology like plant growth parameter and number of leaves at harvest. Similarly, Madhava Rao *et al*. (2002) had also advocated that fertigation treatments of Nitrogen and K_2O (200gm each plant) as urea and muriate of potash, respectively enhanced the plant growth and yield of Banana cultivar Robusta. Kumar and Pandey (2008) also observed that with 75% of fertilizer recommendations as N:P:K in the ratio of 3:2:1, 1:3:2 and 2:1:3 as fertigation treatments applied at vegetative growth, flowering stage and fruit development to maturity stage gave maximum pseudo stem height, stem girth in banana. Krishnasamy *et al.* (2012) observed that plant growth, yield related attributes and quality characters were higher under the fertigation treatment with the use of 100% of fertilizer recommendations in which 50 per cent of phosphorus and potassium were provided as basal dose during plantation and remaining of the fertilizers were provided as WSF (water soluble fertilizer) as fertigation with sulpho-zinc @ 25 kg ha^{-1} through soil application.

Ahmed *et al.* (2010) evaluated the growth, yield and quality response in banana cultivar Grand Naine (Musa AAA) after drip irrigation and fertigation treatments. It was reported that supply of water by using drip system can bring significant reduction in the water requirement in comparison to surface irrigation while plant growth was reported to be better with earliness in flowering and fruiting. Application of fertilizer doses with drip irrigation system improved water use efficiency to bring influence over vegetative growth parameters.

Senthilkumar *et al.* (2013) found that growth characters in banana crop including leaf count and plant girth were significantly affected by the application of fertilizers through drip system and the biofertilizers inoculum in the main and ratoon crops of banana.

2.1.2 Yield and related attributes

Bered *et al*. (1998) carried out an experiment at Rahuri (1995-97) to study the influence of fertilizer sources, irrigation system and plant spacing in Basrai banana cultivar grown in clay soil. These three factors each of two levels have been evaluated and it was found that the planting at 1.8m x 1.5 m spacing had responded best among all combinations when nutrient sources as 40 g P_2O_5 plant^{-1} and 200 g K_2O plant^{-1} were applied in solid form while nitrogen @ 100 g plant^{-1} was applied through drip irrigation and had resulted 15% higher yield with better yield contributing factors.

Chandrakumar *et al.* (2001) compared four levels of nitrogen and potassium (50, 100, 150 and 200 g plant^{-1}) applied as fertigation treatments through drip irrigation in Robusta banana. They observed that nitrogen and potassium level at 200 g/plant produced maximum hand count (7.43 bunch^{-1}), maximum finger count (96.02 bunch^{-1}), highest average finger weight (207.37 g) and highest yield (88.46 t/ha) in comparison to other fertilizer levels. A positive linearity was observed in yield and yield contributing attributes with fertilizer doses.

Similarly, Srinivas *et al.* (2001) working on growth and yield related parameters of banana cultivar Robusta after fertigation of N and K containing fertilizers at Bangalore and recommended that with treatment of 200 gm per plant N & 300 gm per plant K_2O through drip irrigation method at 0.80 PEF gave maximum fruit yield and better yield contributing traits including hand count per bunch and average weight of finger and bunches. Mahalakshmi *et al.* (2001b) observed that the fertigation treatment at 25 l/day/plant with 100 per cent N and K (200: 300 g N: K_2O /plant) in addition to a common dose of P_2O_5 @ 30 g/plant applied through fertigation resulted highest bunch weight (44.53 kg) and highest hands count (10.52 bunch^{-1}) and fingers count (203.73 bunch^{-1}).

Tumbare and Bhoite (2001) had also conducted an experiment on fertigation in banana to optimize the dose of liquid fertilizers through drip irrigation as 50, 75, 100 and 125 per cent of fertilizer recommendations and found that 125 per cent of fertilizer recommendations gave maximum fruit yield. Similarly, Madhava Rao *et al*. (2002) carried out experimental study at Kovvur, Andhra Pradesh and reported that fertigation of each level of fertilizer recommendations (N and K_2O, 200 g each/plant) as urea and muriate of potash, respectively enhanced various growth and yield parameters in banana cultivar

Robusta. Kavino *et al***.** (2002) examined the efficacy of conventional fertilizers over WSF in influencing the yield and fruit quality attributes of banana cultivar Robusta at Coimbatore and responded that the use of water soluble fertilizers was very effective in producing the maximum yield related attributes including average weight of bunch, hands count, fingers count, average weight of finger, pulp weight and fruit yield. Reddy *et al.* (2002) also reported that with increase in N & K_2O fertigation level there was increase in fruit yield in banana and K_2O per plant through fertigation gave higher fruit yield when compared with soil application of fertilizers.

Badgujar *et al***.** (2004) also confirmed an increase in hands count (8.17 bunch^{-1}), fingers count (116.24 bunch^{-1}), bunch circumference (106.62 cm), finger girth (13.46 cm), average bunch weight (14.03 kg) and average fruit yield (66.33 t ha^{-1}) in Grand Naine cultivar of banana after application of 75% recommended fertilizer doses (200: 200 N: K_2O /plant) of N and K_2O at weekly intervals through drip on basis of pan evaporation (PE) scheduled at daily basis through drip irrigation system.

Kumar *et al.* (2007) evaluated the response of banana for fertigation and had reported that among six different treatments including 100, 80 and 60% of water in combination with fertilizers as per recommendation applied through drip irrigation system or broad cast, at 60% + fertilizers through drip irrigation gave maximum fertilizer use efficiency along with higher yield and saving of 35.52% fertilizer compared to conventional cultivation. Anonymous (2008) reported that by giving drip irrigation at 0.6 PEF on alternate day and months of planting through drip system in banana var. Grand Naine resulted in maximum yield i.e. 84.0 t/ha, which was 17.0 % greater than the conventional methods of irrigation and fertilizer application.

Kumar and Pandey (2008) had also reported that with 75% of fertilizer recommendations with N:P:K in the ratio of 3:2:1, 1:3:2 and 2:1:3 applied at different stages including vegetative growth, flowering stage and fruit development to maturity stage gave maximum pseudo stem height, stem girth, weight of hands & fingers, bunch weight, yield & fruit quality of banana.

Lensheng *et al.* (2008) worked out on the growth response of banana after application of nitrogen through drip or traditional methods. The growth status of banana at variable stages was measured along with fruit yield, dry mass and nitrogen content in distinct parts of banana. N fertigation with drip system significantly increased the total mass of plant and fruit yield by 9.5 and 8.0%, respectively as compared with traditional nitrogen application and a 30% saving in N fertilizer was also noticed. Bhalerao *et al.* (2009) reported that nitrogen and potassium fertigation by 75% of recommended dose at weekly intervals increased banana yield and 25% saving in fertilizers with increased uptake of nutrients.

Ahmed *et al.* (2011) also reported low water need of crops by drip irrigation system in comparison with surface irrigation. It was reported that the growth, flowering and yield contributing attributes were substantially influenced in irrigation regimes. The maximum irrigation productivity efficiency was reported with 120% of crop evapo-transpiration (ETc) through fertigation in banana. Krishnasamy *et al.* (2012) observed that the plant growth, yield related attributes and quality characters were greater under the fertigation treatments with the use of 100% of fertilizer recommendations where 50 per cent of P and K was supplied as basal dose while rest of the NPK was as WSF through fertigation in combination with sulphozinc @25 kg/ha subjected to soil application. Kumar *et al.* (2012) noted that there was increase in all growth and quality parameters on banana cv. Monthan (Banthal-ABB) due to supply of N, P & K through fertigation. Mehandran *et al.* (2013) advocated that drip irrigation of 100 per cent of fertilizer recommendations Urea, mixture grade-13:40:13 and KNO_3 in combination with bio-fertilizers as liquid formulation gave the highest bunch yield and WUE in banana in comparison to surface irrigation in combination with soil application of fertilizer recommendations and also reported higher yield in banana can only be achieved if a desirable level of N (3.90%), P (0.38%) and K (4.50%) is being maintained in leaves during shooting.

Pawar and Dingre (2013) had studied and reported that with the use of 100 per cent of fertilizer recommendations by drip irrigation system showed 46.22 % increase in yield and maximum WUE in banana. Similarly, Zangxiaoping *et al.* (2013) through an experiment to understand the impact of drip fertigation amount on banana growth, water and fertilizer utilization efficiency in Donghe county of Hainan, China and found that N and P fertilizer with supplementation of liquid fertilizer gave significant effect on banana production.

Naveeneethakrishnan *et al.* (2013) recommended that fertigation treatment of 200 gm of N in five split doses and 60 gm of P had significantly affected yield and related attributes like hands count, fingers count, bunch weight and hand weight. Sharma &

Bhattacharya (2014) reported that 100% N & K recommendations through drip irrigation improved fruit quality. Similarly, Pramanik and Patra (2015) investigated the impact of drip irrigation and surface irrigation on fruit yield, nutrient uptake, WUE and fruit quality of banana fruits and found that drip irrigation at 60% of CPE with 80% of fertilizer recommendations as fertigation was reported as the best treatment combination for getting better yield and yield related attributes and fruit quality parameters.

2.1.3 Fruit quality and related attributes

Srinivas (1997) reported in cultivar Ney poovan with N application both under drip fertigation and soil application only upto 100 g per plant, the total soluble solids and pulp to peel ratio increased. Sepaskhah and Kashefipour (1994) reported that in frequently irrigated citrus plants there was improvement in fruit weight, size, pulp and juice content of sweet lime whereas TSS and ascorbic acid content was reduced significantly in comparison to control plants. Deolankar and Firake (2001) stated that quality parameters like pulp to peel ratio and TSS were significantly greater in 100% of fertilizer recommendations applied through fertigation followed by 60% and 40% of fertilizer recommendations.

Similarly, Kavino *et al***.** (2002) worked out the experiment to examine the efficacy of conventional fertilizers over water soluble fertilizers affecting the fruit yield and quality of banana cultivar Robusta at Coimbatore and they recommended that the use of water soluble fertilizers was very effective in producing the maximum weight of bunch, hands count, fingers count, average finger weight, pulp weight and yield. Kavino *et al*. (2002) also stated that by giving drip irrigation at 200 % of PE and 75 % of fertilizer recommendations per pit using normal fertilizer gave the highest value of TSS and sugars as compared to water soluble fertilizers.

Raskar (2003) recommended that application of WSFs with drip irrigation can significantly increase quality parameters as compared to N alone. Application of 100% of fertilizer recommendations through drip had significantly improved TSS and pulp to peel ratio. With increase in fertilizer dose acidity decreased significantly and it was maximum under 50% recommended dose of fertilizers. Guerra *et al.* (2004) observed decrease in acidity in banana cultivar Prata Ava due to fertigation treatments while quality of banana fruit was not affected even after reducing 50% doses of N and K.

Kumar and Pandey (2008) also reported that with 75% of fertilizer recommendations with N:P:K in the ratio of 3:2:1, 1:3:2 and 2:1:3 applied at vegetative growth, flowering stage and fruit development to maturity stage gave maximum pseudo stem height, stem girth, weight of hands & fingers, bunch weight, yield & fruit quality of banana. Kumar *et al.* (2012) noted that there was increase in all growth and quality parameters on cooking banana cv. Monthan (Banthal-ABB) due to application of N, P & K through fertigation. Kumar *et al.* (2012) observed that with 75% recommended dose of fertilizers through fertigation increase in TSS apart from early flowering and fruit maturity. Pulp to peel ratio was obtained maximum in 50% recommended dose of fertilizers in cultivar Monthan (ABB). Kumar *et al* (2012) observed that the fruits harvested from strawberry plants subjected to drip irrigation were reported with higher TSS, ascorbic acid, reducing sugar and anthocyanin level as compared to other irrigation treatments. Sharma & Bhattacharya (2014) had also proposed improved fruit quality in banana due to application of 100% of fertilizer recommendations through drip irrigation.

Similarly, Mustaffa and Kumar (2012) also reported that fertigation treatments improved yield and quality attributes and saved 20 to 30 percent of fertilizers in comparison to conventional method application. Pawar and Dingre (2013) also reported that there was improvement in quality parameters in banana through fertigation as compared to conventional fertilizers. Mahendran *et al.* (2013) had also recommended that by application of 100 percent of fertilizer recommendations through drip fertigation improved fruit quality attributes in Rasthali banana.

2.1.4 Leaf nutrient content

Chandel and Singh (1992) experimented over different irrigation levels and their influence over plant growth, crop and mineral content of Dashehari mango trees and concluded that irrigation of trees with 20 and 40 percent lower available soil moisture had statistically high leaf nitrogen, phosphous, potassium, calcium, magnesium, iron and manganese contents than under both irrigated at 60 percent lowering of available soil moisture and unirrigated (control).

Koszanski *et al.* (2006) studied different irrigation treatments in strawberry cultivars Elansta, Elkat, and Senga Sengana and found substantially increased leaf phosphours, potassium and vitamin c content due to drip irrigation. However, leaf nitrogen and magnesium were decreased. Bhalerao *et al.* (2009) reported that nitrogen and potassium fertigation by 75% of recommended dose at weekly intervals increased uptake of nutrients, banana yield and 25% saving in fertilizers.

2.2 Fertigation and its effect

Fertigation is a technique in which solid or liquid mineral fertilizers are applied through pressurized irrigation approach where nutrients sources are dissolved to develop nutrient containing irrigation water (Magen, 1995). Although, it was first initiated in Isreal in 1960, Golderg and Shimueli (1970) had described that fertigation is method in which water and dissolved fertilizers are forced out through emitters with a certain pressure in the form of droplets into the root zone of plants.

Robinson (1996) found that in comparison to conventional methods of soil application fertigation improves the productivity, minimizes the requirement of water and fertilizer and saves labour in respect of weeding, fertilizer application and irrigation. Similarly, Lewis (2001) in his studies found that fertigation approach reduced fertilizer usage, minimized leaching of nutrients, maximized the fertilizer use efficiency (FUE) and also allowed a flexible approach in application time. It has further reduced the requirement of labour for application of fertilizers.

When fertigation technique was compared with conventional approach of water and fertilizer application, 30-40% of extended nutrient uptake efficacy was noticed, also fertigation had prevented degradation of soil and reduced the fertilizer cost and wages of labour for its application (Badgujar *et al*., 2004). Further, it was also confirmed that fertigation ensured supply of nutrients through micro irrigation system to the root zone of plants. It was just like spoon feeding of plants (Nanda, 2010).

Teixeira *et al.* (2011) in his studies found that use efficiency of nutrient, either nitrogen or potassium increased by 36% as compared to conventional fertilization which resulted into reduction in the cost of fertilization. Mustaffa and Kumar (2012) also reported that as compared to the conventional methods of fertilizers, upto 20 to 30% of fertilizers can be saved through fertigation and it can also improve the yield and quality.

2.2.1 Vegetative growth

In various studies it has been revealed that use of nitrogen through fertigation resulted in higher shoot growth. Like Hipps (1992) in his experimental study on apple found that use of nitrogen 20 g/tree through fertigation, in comparison to conventional method, resulted in higher shoot growth in fresh plantation. Similarly, Spayd *et al*. (1993) do found that when higher doses of nitrogen were applied on grapes through fertigation it resulted in shoot growth and pruned wood weight in grapes.

Guazzelli *et al*. (1995) used 200mg nitrogen per litre through fertigation on oranges which resulted into improved average growth, trunk size and leaf dry weight. Neilson *et al*. (1995) had reported increase in plant growth due to fertigation in their comparative study of conventional fertilizer application with fertigation.

Srinivas (1997) also reported that with application of N through fertigation, there was improvement in plant height, leaf count and leaf area in comparison to direct application. Shirgure *et al*. (1999) observed that when nitrogen was used as 100 percent through fertigation treatment in acid lime there was greater plant height, plant girth and plant canopy.

Buban and Laktos, (2000) while using different nitrogen fertilizers through drip irrigation observed in apples that it increased the trunk area and shoot numbers and the best effects were when higher ammonium doses were applied in first half followed by nitrate form in second half of growing season in comparison to simultaneous application of both nitrogen forms throughout the season.

Murthy *et al*. (2001) in their studies on grapes variety Banglore Blue found that 80% drip irrigation accompanied with water soluble fertilizers was the best treatment which resulted in maximum leaf area production. However, when recommended fertilizer dose instead of 80% fertigation was used it resulted in highest shoot growth, maximum trunk circumference and he found that nitrogen fertilizer was the main cause of increase in mean shoot length attributed to the total shoot extension.

Mahalakshmi *et al.* (2001a) also reported improvement in plant growth and number of leaves at harvest due to fertigation treatments. Chandrakumar *et al.* (2001) compared four levels of nitrogen and potassium (50, 100, 150 and 200 g plant^{-1}) as fertigation in banana cultivar Robusta. They observed that nitrogen and potassium level at 200 g/plant produced maximum hands count (7.43 bunch^{-1}), fingers count (96.02 bunch^{-1}), average finger weight and yield in comparison to other fertigation levels.

Srinivas *et al.* (2001) worked out on an experimentation to find the influence of fertigation on growth and yield of Robusta cultivar of banana due to N and K fertigation at

Bangalore and recommended that with treatment of 200 gm N & K_2O per plant through drip irrigation method at 0.80 PEF gave maximum fruit yield, average bunch weight, hands count and average finger weight.

Jeyakumar *et al.* (2002) carried out an experiment by using fertigation at the rate of 10 liters water per day along with 13.5gm urea and 10.5gm muriate of potash as weekly dose in addition to soil application of 278gm super phosphate per plant at bi-monthly intervals on papaya trees crop and found that it increased highest plant height, maximum leaves count accompanying minimum flowering and bearing height in papaya.

Madhava Rao *et al*. (2002) carried out an experiment at Kovvur, Andhra Pradesh and recommended that fertigation of N and K_2O @ 200 g each/plant as urea and muriate of potash, respectively enhanced growth and yield of Robusta banana. In Robusta banana, by application of 100% of N and K recommendation through fertigation treatments increased the plant growth and all yield parameters as result of fertigation (Raghupathi *et al.*, 2002). Similarly, Raina *et al*. (2005) reported significant improvement in shoot growth, tree height and canopy volume in apricots when measured annually.

Sharma *et al.* (2005) on papaya crops of cultivar (Red Lady) did experiment and laid out constituting five fertigation levels and reported tallest plants with widest girth and maximum functional leaves under 100% fertigation level. The same treatment in addition to the above promising growth parameters also resulted in early flowering and fruiting. In another study on strawberry variety `Elsanta`, Martinsson *et al*. (2006) by applying full nutrient package through fertigation in comparison to control found improvement in leaf numbers.

Chauhan and Chandel (2008) in a study on Kiwifruit cultivar `Bruno` experimented and identified the level of fertilizer effect on plant growth, yield and fruit quality attributes and reported higher fertilizer use efficiency through fertigation treatments. Opstad and Sonsteby (2008) in an experiment on `Korona` cultivar of Strawberry practically assessed the impact of timings and methodology of fertilizer application on flowering and fruit ripening and they reported that in comparison to non-fertigated plants there was earlier flowering and more leaf area in plants under fertigation.

Santos and Chandler (2009) study the effect of fertigation using only nitrogen fertilizers in strawberry cultivars `Festival` and `Winter Down` and reported a vigorous canopy circumference with higher nitrogen applications upto the tune of 0.9 kg/ha/day.

Similarly, Singh *et al*. (2009) worked on the impact of fertigation treatment on mango cultivar `Dasheri` in terms of plant growth and revealed that the combined treatments of irrigation, mulching and 100% fertigation resulted significantly higher leaf area.

Rao and Subramanyam (2009) reported that application of 50% of nitrogen recommendation at the interval of 15 days 50% of nitrogen recommended at monthly interval through drip system in pomegranate cv. Mirdula resulted highest plant height, stem girth per tree.

2.2.2 Yield and related attributes

Srinivas (1997) reported that with application of 100gm nitrogen through drip system both in main and ratoon crop increased yield in cultivar `Ney Poovan` of Banana. Srinivas *et al*. (2001) found that there was greater bunch weight, hands count (bunch^{-1}), fingers count (bunch^{-1}) and finger weight at higher dose which was increased with N & K fertigation upto 200gm per plant.

Similarly, Mahalakshmi *et al*. (2001a) carried out an experiment on Robusta cultivar of banana and found that 100% fertilizer through drip system increased bunch weight and quality of fruits. Raghupathi *et al*. (2002) also confirmed enhanced yield attributes and total yield per hectare in cultivar banana cultivar Robusta due to application of 100 percent of N and K recommendation through fertigation there was. Reddy *et al.* (2002) investigated the influence of various N and K fertigation levels and found that 200gm per plant application of each nitrogen and potassium gave maximum fruit yield.

Alva *et al*. (2003) found that Valencia orange trees grown on rough lemon root stock gave maximum fruit yield with 180gm nitrogen fertigation in comparison to conventional fertilizer application. Thakur and Singh (2004) reported that in mango cultivar Amarpali maximum fruit yield and fruit number was harvested due to application of 75% of fertilizer recommendation through fertigation treatments. Similarly, Gutal (2005) reported an average 15.6% increase in fruit yield with application of 75% of fertilizer recommendation through fertigation and ultimately 25% fertilizer saving was reported.

Kumar *et al*. (2009) confirmed that supply of 100% of fertilizer recommendation through drip system lead to in higher yield (95.2 tons per ha) and with only 65% of fertilizer recommendation through drip system resulted yield at par with 100% of fertilizer recommendation through conventional method.

Khound and Bhatacharya (2010) reported that there was improvement in yield, average weight of bunch, hands count, fruits hand^{-1}, fruit weight due to application of 100% of fertilizer recommendation followed by 75% of fertilizer recommendation through fertigation in cultivar `Barjahajai` (AAA). Similarly, Kumar *et al*. (2012) worked out an experiment on cultivar Mothan (ABB) and reported that fertigation treatments resulted in maximum hands count, bunch weight and fruit yield. Similarly, in cultivar Rasthali of banana higher yield was obtained through supply of 100% of fertilizers recommendation through sub surface drip irrigation and crop duration was also reduced by fertigation treatments (Mahendren *et al*., 2013).

Pawar and Dingre (2013) recommended that in banana there was 46.27% increase in yield (83.62 tonnes per ha) with application of 100% of fertilizer recommendation through fertigation followed by 80% fertigation treatment (79 tonnes per ha), while under 60% of fertigation treatment in banana produced 19% more yield (68 tonnes per ha) over conventional method of fertilizer application (57.4tonnes per ha) and by this there was 40% fertilizer saving.

Paramanik and Patra (2015) reported that fruit yield and yield related traits were significantly affected by different fertigation treatments and plants subjected to drip fertigation treatment gave better results as compare with plants subjected to conventional irrigation approach. 80% recommended dose of fertilizer with 60% CPE irrigation gave higher yield (49.2 tonnes per ha) in main crop and lower yield (44.1 tonnes per ha) in ratoon crops. In addition, it also resulted in saving of about 41.7% water in main crop and 40.4% water in ratoon crop due to high water use efficiency.

2.2.3 Fruit quality and related attributes

Bachchhav (1995) observed that in fertigated plants there was improvement in fruit thickness, weight and quality in comparison to soil fertilized plants. Similarly, Mahalakshmi *et al*. (2001b) reported that in Banana cultivar Robusta applying fertilizer through fertigation method has substantially improved the quality of fruits. Jeyakumar *et al*. (2001) in an experiment on Papaya plants compared the performance under fertigation and conventional fertilization method and found higher nutrition and chlorophyll content in fertigated plants along with improved photosynthetic activity, water use efficiency, fruit size and total soluble solids as compare to plants under conventional fertilization.

Shirgure *et al*. (2001) worked out an experimentation on Nagpur Mandarin by applying N:P:K fertilizers in the ratio of 500g: 140g:70g per tree through fertigation which resulted into maximum fruit weight, TSS and juice percent in the fruits. Similarly, Jaikumar *et al.* (2002) in an experiment on Papaya variety "CO2" found highest pulp thickness and total soluble solids content to the tune of 12.4° Brix in the fruits on fertigated plants.

Kavino *et al*. (2002) also stated that by giving fertigation at 200 per cent of PE and 75 % of fertilizer recommendation per pit using normal fertilizer gave the highest value of TSS and sugars as compared to water soluble fertilizers. Rana and Chandel (2003) when applied 100kg nitrogen per hectare through fertigation on strawberry cultivar Chandler in hilly region found significantly greater TSS and sugar in the fruits.

Raskar (2003) conducted experiment on banana cultivar Basarai and reported a significant improvement in fruit quality parameters with supply of water-soluble fertilizers as fertigation. Pulp to peel ratio and TSS were improved upto significant level with supply of 100% of fertilizer recommendation. The acidity decreased significantly with higher fertilizer dose and found highest under 50% of fertilizer recommendation.

Dahiwalkar *et al.* (2004) worked out an experimentation on banana cultivar Basrai and found the highest pulp to peel ratio and total soluble solids with drip irrigation fertigation as compare to conventional treatments. Kavino *et al*. (2004) worked out on the influence of fertigation on Banana plants and found that there was maximum average weight of bunch weight, hands count bunch^{-1}, fingers count bunch^{-1} and average weight of fingers in fertigated plants as compare to control treatments. In apple cultivar Delicious, Park *et al*. (2004) found improvement in average fruit weight, TSS and fruit firmness with fertigation treatment. Similarly, fruit colour was also improved under fertigation treatment.

Moor *et al.* (2005) worked out an experimentation on Strawberry and reported increase in fruit juice, vitamin C and anthocyanin content under fertigation treatment. Similarly, Taghavi *et al.* (2006) also reported that by applying fertigation using nitrate and ammonium forms of nitrogen in Strawberry cultivar Selva there was highest fruit juice, pH and vitamin C concentrations in the fruits, whereas TSS and titratable acidity content was reduced with increasing ammonium content in the fertigation solution.

Maldonado and Prittis (2008) found that in Strawberry plants, fertigation treatments improved starch, glucose, sucrose and total non-structural carbohydrate levels as compared to conventional fertilization. In apricot fruit, Raina *et al*. (2011) worked out an experimentation to study the influence of fertigation on fruit yield and quality and recorded highest fruit in the plants applied with 100% fertigation in comparison to application in soil.

Pandit *et al*. (2011) had recorded that medium nitrogen and higher dose of phosphorus and potash in fertilizer application enhanced the fruit pulp content with minimum fruit peel percentage while combination of 400:300:250 gm of NPK gave highest reducing sugar and lower non reducing sugar. Kumar *et al*. (2012) found greater TSS with 75% of fertilizer recommendations through fertigation. There was early flowering and fruit maturity.

Pawar and Dingre (2013) also reported that with fertigation treatment there was improvement in quality attributes as compare to conventional method of fertilization in Banana plants. Similarly, Mahendran *et al.* (2013) observed high value of fruit quality attributes in Rasthali cultivar of Banana by 100% of fertilizer recommendation through sub surface drip irrigation. In red lady cultivar of Papaya, Panigrahi *et al*. (2015) found that with 80% of fertilizer recommendations by drip irrigation improved fruit quality as compare to other fertigation levels.

The variation in acidity of fruits after fertigation treatments might be associated with K uptake and utilization by the plants as K content in fertigation dose increased from F_1 to F_3 or F_4, the activity of acid accumulation was decreased with decrease in sugar-acid concentration so it can be correlated with increase in sugar in the current study (Zhang *et al*., 2018). Further increase in fertigation to F_6 might had also resulted in simultaneous increase in N and K where the concentration was nitrogen was sufficient to interfere with K metabolism (Zhang *et al*., 2018). Adequate K nutrition greatly influences the synthesis of sucrose and starch in plants such as apple (Mosa *et al.*, 2015), muskmelon (Lester *et al.*, 2010), tomato (Almeselmani *et al.*, 2010) and strawberry (Ahmad *et al.*, 2014). However, K levels have different effects on organic acid metabolism depending on the plant species (Etienne *et al.*, 2014; Flores *et al.*, 2015; Niu *et al.*, 2016).

2.2.4 Leaf nutrient content

Klein *et al*. (1989) had reported that there was substantial rise in leaf nitrogen level with application of 150kg nitrogen per hectare. With increase in nitrogen content other nutrient concentrations were also affected, like phosphorous and potassium levels were decreased and magnesium level was enhanced with increased nitrogen levels. Hegde and Srinivas (1991) reported co linearity between nitrogen doses in fertigation and leaf nutrient status including nitrogen, potassium and magnesium content. Intrigliolo *et al*. (1992) also observed a substantial improvement in nutritional and physiological status of plant with fertigation as compare to conventional method of fertilization.

Parida *et al*. (1994) reported that high nitrogen contents in the leaf resulted in greater accumulation of phosphorus which might be responsible for greater meristematic growth, LAI and more protein biosynthesis. Similarly, in pear plants there was significant improvement of leaf phosphorus content with fertigation (Meimon *et al*. 1995). Likewise, Noe *et al*. (1995) had also recommended that due to fertigation treatment there was higher leaf elemental concentrations viz. 2.49% nitrogen, 1.81% calcium and 0.27% magnesium as compared to non-fertilized plants.

In Papaya plants, there was higher nutritional and chlorophyll contents in leaves with improved photosynthetic activity in fertigated plants as compare to non-fertigated plants (Jeyakumar *et al*., 2001). In an experiment on grapes variety Bangalore Blue, Murthy *et al*. (2001) observed that there was maximum leaf potassium and calcium content with the application of 100% of fertilizer recommendation through fertigation with 80% water soluble fertilizers. Similarly, Kavino *et al.* (2002) reported that in banana plants there was higher leaf nitrogen (3.30%) three months after rationing and at the stage of harvesting (2.65%) and greater level of potassium at five and seven months after ratooning (4.63%) and (4.48%) while phosphorus level in the leaf was not affected.

Jeyakumar *et al.* (2002) reported that in Papaya plants fertigation treatment resulted to significantly higher leaf nitrogen and potassium content but on the other side there was insignificant effect on phosphorous content. Babu *et al*. (2004) reported that with increased number of applications of nitrogen enhanced the uptake of nitrogen. Similarly, Chen and Cheng (2004) observed that with decreasing nitrogen dose in fertigation nitrogen contents in leaves also decreased. Similarly, Nielsen *et al*. (2004) worked out on an experimentation on apples and found that there was increase in leaf potassium, magnesium and boron content with application of nitrogen potassium through fertigation.

With fertigation of 80kg nitrogen per hectare per year there was significantly higher N: P: K nutrient contents in the leaves of plants i.e 2.5%:0.33%:1.14% (Wold and Opstad, 2007). Similarly, Maldonado and Prittis (2008) conducted an experiment on strawberry plants and found that there was higher leaf nitrogen content (12.7 mg/g) in fertigated plants in comparison with non-fertigated plants.

Jeyakumar *et al*. (2010) recommended that leaf nutrient contents (1.72 % nitrogen, 0.41% phosphorus and 2.91% potassium) were significantly higher in the plants under 100% of nitrogen and potassium recommendation through drip irrigation in comparison to soil placement of fertilizers. In an experiment on apricot plants there was significantly higher leaf nitrogen and phosphorus content (9.1% and 0.6%, respectively) in plants under fertigation in comparison to non-fertigated one (Weijun *et al*. 2011). The increase in leaf nitrogen content might be result of regular nutrient availability that improves the uptake of plant and its translocation within the plant under various fertigation treatments over the control as observed in 'Co7' papaya by Jeyakumar *et al.* (2010). Similarly, Valji (2011) also reported an enhancement in leaf nitrogen content in 'Madhu Bindu' papaya as a result of fertigation.

Yuvaraj and Mahendran (2015) conducted an experiment under All India Coordinated Research Project at Madurai with eleven treatment combinations of subsurface fertigation approach for nitrogen, phosphorus and potassium delivery in comparison with surface irrigation and had recorded highest N, P & K content in leaves of banana with application of fertilizer through sub-surface drip irrigation of 100% of fertilizer recommendation as water soluble fertilizers alone or in combination with liquid biofertilizers.

Kuchanwar *et al.* (2017) worked out on the influence of fertigation on nutrients level Nagpur Mandarin leaves and defined a direct correlation between the leaf nutrient content and increased levels of NPK and the maximum nitrogen (2.63%) and phosphorous (0.18%) content were found under 160% of recommended dose of fertilizer through fertigation.

2.3 Protected Cultivation and its effect

As the world population is rapidly growing towards urbanization all over, it has resulted into decrease in land holding capacity for growing different crops and due to environmental changes, this is the need of the hour to adopt new cultivation techniques to protect the crops from some biotic and abiotic factors. Protected cultivation provides favorable environment or growing conditions to the plants by providing optimum light, temperature, humidity, carbon dioxide and circulated air which are suitable for better plant growth, heavy yield and good quality fruits. It also ensures plant protection from various biotic and abiotic factors and reduced gestation period of the crops.

2.3.1 Vegetative growth

Saucov *et al.* (1992) worked specifically in Canary Island on the `Dwarf Cavendish` variety of banana and studied the influence of environment variants by using the protected structure on plant morphology and they found that in comparison to open field plants under greenhouse conditions the plants were superior in terms of all plant growth characteristics. In an experiment on custard apple, Hirokazu *et al.* (2001) carried out an experimentation to determine the impact of various shade percentage on plant growth and reported maximum shoot length and leaf number in low shade conditions allowing 64% light interception and maximum shade increased the inter-nodal and specific stem length and in light shading conditions stem diameter, leaf and stem dry weight were found higher. Thinner and larger leaves developed due to suppressed tissue dry weight under more shady conditions.

Gubbuk and Pekmezci (2004) conducted an experiment on banana (Musa AAA) cultivation in protected and open field conditions and found that there was increase in hands count, fingers count, bunch weight and average annual yield under protected conditions.

Santos *et al.* (2008) worked out on an experimentation to find the growth of papaya and passion fruit nursery seedlings under protected conditions and found that there was uniform height in all treatments upto 31 days after sowing and plant height was maximum under monofilament net and aluminizada shading after 38 days of sowing. Due to low transpiration losses under modified environment improvement in height occurred.

Medany *et al.* (2009) also observed a significant rise in count of green leaves and average maximum count of total leaves of mango Variety "Keitt" grown under white greenhouse net in comparison to open-field condition. Overall vegetative growth including plant height, leaf count and stem circumference were also better under white net and this was due to crop favorable environmental conditions like adequate relative humidity, lower maximum temperature, lower light irradiance, lower evapotranspiration, higher maximum temperature and lower wing speed usually prevailed under net house protection.

Casierra-Posada *et al.* (2011) worked out on an experimentation on the influence of various shading and light environments on the growth of strawberry plants. On these strawberry plants different light quantity regimes were maintained using polypropylene films of different colours viz. yellow, green, blue, red, and transparent along with a naked control. Significant difference among root to shoot ratio recorded in green cover conditions only and there was not any significant difference in any parameters in all others cover conditions in comparison to control. Similarly, Schettini *et al.* (2011) worked out to determine the influence of two photo selective and three photoluminescent greenhouse plastic films on the plant growth of cherry and peach trees and found that there was significant improvement in shoot growth due to modified spectral distribution of solar radiations under plastic films.

In different varieties of grapes, Kamiloglu *et al.* (2011) conducted an experiment and found enhanced shoot growth under protected cultivation in comparison to open-field conditions. Under both protected and open field conditions "Uslu" variety grew more rapidly as compared to "Yalova Incise" and "Perlette".

Kaur and Kaur (2017) studied the performance of "Red Lady" papaya under protected cultivation and open field conditions and found maximum plant height (214.05 cm) leaf number (20.46) and leaf area (876.5cm^2) in comparison to open-field condition.

2.3.2 Yield and related attributes

In peach, fruit plants grown under protected conditions 13 to 20 days advancement of fruiting occurred as compared to open field conditions. In protected conditions, earliness in anthesis promoted the earliness in fruiting. The overall mean yield was found maximum in open field conditions as compared to protected conditions despite this earliness of fruiting (Furukawa *et al*., 1990).

Saucov *et al*. (1992) worked out on an investigation to determine the influence of protected structures on banana "Dwarf Cavendish" variety in the Canary Islands and found that there was more bunch weight and finger size ultimately gave higher yield under protected conditions as compared to open field conditions. Similarly, Eckstein *et al.* (1998b) studied the performance of banana under protected cultivation and open field conditions and found that due to earliness in anthesis and shooting under protected cultivation there was shorten in harvesting period. Although there was shorter crop duration from planting to harvest but flowering to harvest duration increased under protected conditions. There was a greater number of fingers per bunch (251), highest fruit circumference (10.9 cm) and fruit length (21.0 cm) under protected cultivation as compared to 185, 8.3 cm and 16.6 cm, respectively under open field conditions. Due to these improvement in fruiting characters, 53 percent increase in yield occurred under protected conditions.

Kamiloglu *et al*. (2011) carried out an experiment under protected conditions and open fields on grape vines and reported that there was earliness in phonologic periods of grape vines grown under protected conditions by advancement of bud break stage, full bloom, veraison and fruit maturity. There was 14 days early blooming than open field grapes due to nine days early bud break of fruiting vines. Due to sixteen days advancement in veraison stage fruit maturity occurred 17 days early under protective conditions as compare to open field conditions.

Similarly, in Mango plants grown under white net and open-field orchards there was a rise in fruit yield under white net as a response of white net on irradiation. Photosynthetic capacity of leaves affected due to reduced radiation under the white net and this resulted in low light saturated photosynthesis rate as compared to the mango plants grown in open field conditions (Medany *et al*., 2009).

Reddy and Gowda (2014) worked out on an experimentation to determine the impact of protected cultivation over flowering, fruit yield and quality on Red Lady cultivar of Papaya and it was found that under protected cultivation early flower initiation and bearing resulted in higher yield of Papaya. Under protected conditions flowering started in 84.69 days and higher flowers count per plant (48.8%) and greater fruit setting (74.38%) was observed. This earliness in flowering and fruiting resulted in advance maturity. Due to favorable environmental conditions under protective cultivation there was improved hormonal metabolism and photosynthesis in plants resulting in early fruiting and enhancement in harvesting period. Under protected conditions, a significant rise in fruit size (length x breadth), fruit circumference and total yield per plant as compare to open field conditions was reported. Due to continues availability of healthy, disease or pest free growth and maximum leaf area under protected conditions resulted in promising yield attributes. Similarly, Tyagi *et al*. (2015) worked out an experimentation on five different cultivars of Papaya grown under protected conditions and found that there was early harvesting (295 days) in Red Lady cultivar.

Kaur and Kaur (2017) also studied the performance of Red Lady papaya grown under protected conditions and open field conditions. They found that under protected cultivation there was improvement in flowering (51.32), fruiting (49.52 fruits plant^{-1}) and yield (45.39 kg plant^{-1}).

2.3.3 Fruit quality and related attributes

Furukawa *et al*. (1990) worked out an experimentation to find the influence of protected conditions on peach plants as compared to open field cultivation and found a significant influence on TSS and pH under protected conditions. Hirokazu *et al*. (2001) worked out on an experimentation to study the impact of shading conditions on custard apple and reported that there was increase in leaf chlorophyll content due to low light intensity under shady conditions. In pre shade leaves higher level of chlorophyll content was found and post shade leaves the chlorophyll content was found higher at 24% sunlight perception i.e. middle shading conditions. With increased stomatal conductance under light and middle shading conditions they found that leaves performed higher carbon dioxide assimilation rate. Under light shading, this carbon dioxide assimilation rate was uniformly higher all day long except during mid-day when stomatal conductance and leaf water potential was minimum. High leaf vapor pressure deficit resulted in low gas exchange rate due to high light perception that caused higher leaf temperature. In this regard they found that under higher shady conditions fruit quality and weight of custard apple were inferior and the maturity was also delayed. Similarly, cherimoya production was also nil while with light environment created by use of 50 to 70% shading this cherimoya production was recorded optimum.

Gubbuk and Pekmezci (2004) investigated the impact of protected cultivation on banana production and reported that there was rise in bunch stalk circumference and total hands count ($bunch^{-1}$) in comparison to open field production. Kamiloglu *et al*. (2011) conducted an experiment on five grapes varieties grown under open fields and protective conditions. He found that overall performance of grapes was better under protective conditions in comparison to open conditions. Different parameters like grape cluster weight, cluster length, cluster width, total soluble solid contents, titrable acidity, pH and maturity index were significantly different among these two growing conditions.

Vool *et al*. (2013) also investigated the impact of protective structures and open fields on grapes cultivation. To evaluate the performance of grapes in these two growing conditions different parameters were evaluated like total soluble solids, acidity, phenolics and anthocyanins in grape berries, they reported that total soluble solid contents phenolic and anthocyanin contents were promising in the grape berries cultivated under protected conditions and maximum value of this is 25.4°brix, 540mg per 100gm and 480mg per 100gm, respectively. Acid content was lowest in the protected cultivation berries as compared to open cultivation i.e. 1.2gm per 100gm and 1.6gm per 100gm respectively.

Jiang *et al*. (2013) investigated the impact of protected cultivation as rain shelter on fruit quality of grape vines and found that there were overall decreases in anthocyanin content of grape berries skin. Lower sunlight availability and risen temperature influenced the accumulation of anthocyanins resulted in reduced pigment contents. The higher levels of air moisture were also found non-favorable for this pigment accumulation.

Reddy and Gowda (2014) carried out a study to determine the influence of protected cultivation on papaya cultivar “Red lady” and found a significant influence on different fruit quality parameters. Under protected conditions, the highest pulp mass, least peel mass, more pulp to peel proportion, highest total soluble solids content, sugars content, sugar:acid proportion, carotene concentration, titratable acid content and vitamin C content were recorded. In addition to this, other biochemical characteristics like fruit firmness, shelf-life and organoleptic score were also reported promising under protected cultivation conditions. Under protected cultivation conditions, due to prevailing favorable climatic factors viz. temperature, light intensity and humidity, chlorophyll content was promoted and this ultimately affected the photosynthesis in leaves and due to this there might be more translocation of carbohydrates for cell division which ultimately affected the growth of plant and fruits. Development of sweeter and quality fruits with low acidity at maturity might be due to adequate and timely translocation of carbohydrates accompanied with a greater number of leaves and leaf area.

2.3.4 Disease and pest incidence

Jiang *et al.* (2013) investigated the impact of protected cultivation as rain shelter on fruit quality of grape vines and found that there was very less fruit diseases incidence under protected cultivation conditions as compared to open field conditions where downy mildew, anthracnose and white berries diseases of grape vines occurred. In open field conditions, these infections were upto the extent of 75% and causing adverse effect on fruit quality and yield.

Reddy and Gowda (2014) also conducted experiment on papaya cultivar “Red Lady” to determine the influence of protected cultivation on the prevalence of PRSV and found that there was no virus incidence in protected conditions whereas in open field conditions, virus occurred with 100% infected plants after 163.23 days. Under protected structure due to presence of insect-net on outer walls of the growing structure there was no any presence of virus vector i.e. aphids.

Hueso *et al.* (2017) had also confirmed the protected cultivation of papaya under subtropical part of Spain where lowering of temperature below 10^0C is the major challenge during winter season. It was reported that the papaya ring spot virus (PRSV) incidence was completely excluded and fruits were ripened properly with good quality and sweet taste.

CHAPTER III

MATERIALS AND METHODS

The current research entitled **"Standardization of fertigation dose for open and protected cultivation of banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions"** was worked out during the year 2016-2018 in poly-net house unit and open fields located at Centre of Excellence for Fruits, Village- Khanaura in distt Hoshiarpur. The materials and methods employed during the experimentation are elaborated as under:

3.1 Planting material

The study was conducted on Grand Naine cultivar of banana planted in poly-net house unit as well as in open fields during the month of September. All the plants were planted at a spacing of 1.8×1.8 m. The description of Grand Naine variety is as under:

3.1.1 Grand Naine

It is selection from "Gaint Cavendish" cultivar of banana having average bearing potential as 40 kg of bunch. Plant attributes resembles "Cavendish" for all attributes with exception of robust growth, well-spaced hands and large sized straight fingers. The planting material was taken from GVS Tissue culture Lab, Pojewal, SBS Nagar, Punjab.

3.2 Experimental details

The experiment was designed in factorial randomized block design (FRBD) under two factors as described below:

Factor-1: Fertilizer application (F) at six levels consisting 5 fertigation and one controlled treatment.

F_1: Fertigation with 40 percent recommended dose of fertilizers.

F_2: Fertigation with 60 percent recommended dose of fertilizers.

F_3: Fertigation with 80 percent recommended dose of fertilizers.

F_4: Fertigation with 100 percent recommended dose of fertilizers.

F_5: Fertigation with 120 percent recommended dose of fertilizers.

F_6: Fertilizer application through conventional method using 100 percent recommended dose of fertilizer.

Factor 2: Growing conditions (C) at two levels

C_1: Poly-net house

C_2: open fields

Each treatment was replicated four times with five plants in each replication. Total 12 treatment combinations were formulated by using both factors that have been given below:

F_1C_1: Fertigation with 40 percent recommended dose of fertilizers under poly net house

F_2C_1: Fertigation with 60 percent recommended dose of fertilizers under poly net house

F_3C_1: Fertigation with 80 percent recommended dose of fertilizers under poly net house

F_4C_1: Fertigation with 100 percent recommended dose of fertilizers under poly net house

F_5C_1: Fertigation with 120 percent recommended dose of fertilizers under poly net house

F_6C_1: Fertilizers through conventional method with 100 percent recommended dose of fertilizers under poly-net house.

F_1C_2: Fertigation with 40 percent recommended dose of fertilizers in open fields

F_2C_2: Fertigation with 60 percent recommended dose of fertilizers in open fields

F_3C_2: Fertigation with 80 percent recommended dose of fertilizers in open fields

F_4C_2: Fertigation with 100 percent recommended dose of fertilizers in open fields

F_5C_2: Fertigation with 120 percent recommended dose of fertilizers in open fields

F_6C_2: Fertilizers through conventional method with 100 percent recommended dose of fertilizers in open fields

The experimental layout of study has been listed as under:

Number of growing conditions	: 2 (Protected cultivation and open fields)
Number of treatments	: 6 (5 fertigation + 1 controlled treatment)
Number of plants per application	: 5
Number of replications per treatment	: 4
Total number of plants under study:	240

3.3 Methodology

The healthy plants of Grand Naine variety were procured from registered tissue culture laboratory. These plants were planted in Poly-net house unit and open field and were given fertigation treatment of N:P:K fertilizer with drip system of irrigation. The control was applied in the form of conventional fertilization system (through direct soil application) using 360g urea, 180g Diammonium Phosphate (DAP) and 350g muriate of potash (Anonymous, 2018c). The experimental plants were further periodically used to record various vegetative, fruiting, physico-chemical characteristics and leaf nutrients status. The amount of nutrients calculated as per RDF for various treatments was as under:

Nutrient dose	40 percent	60 percent	80 percent	100 percent	120 percent
N (gram)	80.00	120.00	160.00	200.00	240.00
P_2O_5 (gram)	35.00	52.00	70.00	87.00	105.00
K_2O (gram)	84.00	126.00	168.00	210.00	252.00

3.4 Fertigation scheduling:

The drip line consisted of drippers having individual discharge capacity of 2 to 2.4 liters per hour. The drip irrigation was scheduled every third day whereas fertigation was done at seven days interval starting from 60 days after planting. However, in control plants the fertilizers were applied at the time of planting and then in five equal doses, first dose after 60 days, then after every 30 days.

3.5 List of recorded observations:

A. Plant growth parameters

3.5.1 Pseudostem height (cm)

3.5.2 Pseudostem girth (cm)

3.5.3 Average number of leaves per plant

B. Production parameters

3.5.4 Days taken for shoot emergence

3.5.5 Days taken from shoot emergence to harvest

3.5.6 Total crop duration

3.5.7 Average bunch weight (kg)

3.5.8 Average number of hands per bunch

3.5.9 Average number of fingers per bunch

3.5.10 Average fruit length (cm)

3.5.11 Average fruit circumference (cm)

3.5.12 Average fruit weight (gm)

3.5.13 Average fruit yield (kg/ tree)

C. Fruit quality parameters

3.5.14 TSS (^{0}Brix)

3.5.15 Titratable acidity (%)

3.5.16 TSS/Acid ratio

3.5.17 Total sugar (%)

D. Leaf nutrient content

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

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

E. Soil Parameters (at 0-15,15-30, 30-60 & 60-90 cm depth) before and after experiment

3.5.20 Soil pH

3.5.21 Electrical conductivity (dS m^{-1})

3.5.22 Organic carbon (%)

3.5.23 Available nitrogen (%)

3.5.24 Available phosphorus (%)

3.5.25 Available potassium (%)

3.6 Description of recorded observations:

A. Plant growth parameters

3.6.1 Pseudostem height (cm)

Pseudostem height was taken from the base of the trunk to the axis of the youngest leaf using the measuring tape and average was expressed in centimeters.

3.6.2 Pseudostem girth (cm)

Pseudostem girth was taken at a height of 30 cm from the ground and average was expressed in centimeters.

3.6.3 Average number of leaves per plant

The matured and fully developed leaves were counted on all the five plants from each replication and the mean value was expressed in terms of average number of leaves per plant.

B. Production parameters

3.6.4 Days taken for shoot emergence

The experimental plants were regularly observed and number of days taken for shoot emergence was counted in all the experiments.

3.6.5 Days taken from shoot emergence to harvest

The days from shoot emergence to harvest was counted in all the experimental plants and average was expressed in number of days.

3.6.6 Total crop duration

The number of days counted from planting to harvesting of crop was taken as the total crop duration.

3.6.7 Average bunch weight (kg)

Bunch weight was recorded in all the experimental plants after harvesting and average was calculated and average was expressed in kilogram.

3.6.8 Average number of hands per bunch

In all the experimental plants, hands were counted and average was expressed as hands count per bunch.

3.6.9 Average number of fingers per bunch

Fingers borne on each bunch was counted at maturity and the average finger number from all replication was worked out for each treatment under observation and average was expressed as finger count per bunch.

3.6.10 Average fruit length (cm)

Three ripened fruits were identified through random selection from each replication and their length was taken by using ordinary scale (marked in cm). Thereafter average fruit length for each treatment was worked out.

3.6.11 Average fruit circumference (cm)

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

3.6.12 Average fruit weight (gm)

The ripened fruits randomly selected for observing fruit size were further weighed with the help of electronic balance and the average was worked out to be expressed in gram.

3.6.13 Average fruit yield (kg/ tree)

The estimation of fruit yield was done by adding the weight of hands from each bunch under observation and the average was expressed in terms of kilogram per tree of kilogram per bunch.

C. Fruit quality parameters

The fruits were harvested at full maturity when angularity was lost and ripening was induced through application of ethephon @ 500ppm by dipping for 2 minutes. After one week of harvesting the following quality parameters were estimated from fully ripened banana fruits.

3.6.14 TSS (Total Soluble Solids in ^{0}Brix)

For determining TSS content, the juice of three randomly selected fruits per plant were taken and filtered through muslin cloth. The filtered juice was stirred properly. A drop of this juice was placed on the prism of Erma Hand Refractometer and value of TSS was taken from direct reading (AOAC, 1990). The Refractometer was washed and cleaned with distilled water before taking each reading.

3.6.15 Titratable acidity (%)

3.6.16 To determine acidity, 10ml of juice was extracted and diluted to 100ml in a volumetric flask then it was titrated against N/10 NaOH alkali solution using phenolphthalein as an external indicator. The moment when colourless juice extract turned to light pink the beurate reading of NaOH solution was taken as end point. The percentage of acid content was determined and estimated in terms of citric acid using the following formula (AOAC, 1990).

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

3.6.17 TSS/ Acid ratio

TSS/ Acid ratio was calculated by dividing TSS with respective titratable acidity values for a given treatment and replication.

3.6.18 Total sugars (%)

The sugar content of banana fruits was estimated by using following steps as described by AOAC (1990):

i. Twenty-five gram of fruit flesh was macerated by using distilled water and the volume was made up to 100ml.

ii. To this solution, 1gm lead acetate was added and mixed thoroughly and the solution was allowed to stand for 10 minutes to induce precipitation of extraneous material.

iii. Then 1gm potassium oxalate was mixed to it, for removing excess led.

iv. The obtained solution was passed through a filter paper and the filtrate was further diluted with distilled water upto 250ml.

v. The aliquot so formed was used for sugar estimation.

vi. In 25 ml of aliquot, 5ml of 60 percent concentrated HCl was added and the solution was allowed to stand for 24 hours at room temperature to complete acid hydrolysis of sugar.

vii. Thereafter the excess of HCl was neutralized with 10 percent NaOH in initial stages and the with 0.1% NaOH near the point of neutralization.

viii. The neutralized solution so produced was titrated against standard Fehling solution (mixture of Fehling-A & Fehling-B in equal volume) in presence of methylene blue as an external indicator.

ix. The end point came when solution turned to brick red in colour.

x. The percentage of total sugars was calculated by using the given formula:

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

D. Leaf nutrient content

For determining of leaf nutrient content, third leaf from top, six months after transplantation was collected from each experimental plant. The lamina portion of 3rd leaf was taken as sample by removing a strip of tissue 10 cm wide, on both sides of the central vein which includes the tissues which ranges from central vein to center of lamina as stated by Lopez and Espinosa (2000). These collected leaves were thoroughly washed first with tap water, then with distilled water and afterwards with a mixture of 0.01 N HCl and then teepol solutions. Leaf samples were firstly dried in the shade and finally in an oven at 60°C at least for 48 hours. The grinding of dried samples was carried out in the Willy Mill having all components made of stainless steel and the ground samples were passed through 40 mesh sieves. These sieved samples were packed in butter paper bags and were used for leaf nutrients analysis by the procedure as described below:

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

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

Leaf element (ppm) = dilution factor × ICP leaf elements value (ppm)

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

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

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

3.7 Statistical analysis

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

CHAPTER IV

RESULTS AND DISCUSSSION

The research study in titled "Standardization of fertigation dose for open and protected cultivation of Banana cv. Grand Naine (*Musa* spp. AAA) under Punjab conditions" was carried out on Grand Naine variety of Banana. The results obtained on different parameters of the crop are illustrated and discussed as under:

4.1. Plant growth parameters:

4.1.1 Pseudostem height (cm)

The observations recorded to determine the impact of fertigation and growing conditions on pseudostem height has been presented in Table 4.1 which confirmed that pseudostem height was significantly improved in all the fertigation treatments and growing conditions (poly-net house and open field). The maximum mean pseudostem height was recorded in poly net house conditions. The pseudostem height was maximum (232.23 cm) where 120% RDF (recommended dose of fertilizers) was given through fertigation technique. Further, height was significantly better under poly-net house (C_1-237.81 cm) in comparison to open field banana plants (C_2-208.35 cm). The interactions between growing conditions and fertigation treatments were also statistically significant analyzing the 120% RDF fertigation under poly net house (F_5C_1) to be the highest value (250.27 cm) followed by 242.42 cm average height in F_4C_1 (100% RDF fertigation under poly net house) and minimum average pseudostem height was in F_1C_2.

An increase in height was obviously expected in treatments where plants were grown under poly net house conditions with fertigation due to availability of favourable growing environment under green house and due to constant nutrient availability in soil regime very near to root zone comparing to open field and conventionally fertilized plants. The results were supported with the findings of Mahalakshmi *et al*. (2001a), Ahmed *et al.* (2011) and Kumar *et al.* (2012) who reported that fertigation exhibited improvement in plant morphology in terms of plant growth. Similarly, Gubbuk and Pekmezci, (2004) have also reported an improvement in plant vegetative growth in banana under protected structures. Kaur and Kaur (2017) also reported the performance of "Red Lady" papaya under protected cultivation and open field conditions and observed maximum plant height (214.05 cm), leaf number (20.46) and leaf area (876.5cm²) as compared to open field.

Table 4.1: Effect of fertigation and growing condition on Pseudostem height (cm) of Banana plants

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	230.30	205.30	**217.80[e]**
F_2	233.20	200.40	**216.80[f]**
F_3	238.35	211.23	**224.79[c]**
F_4	242.42	213.12	**227.77[b]**
F_5	250.27	214.20	**232.23[a]**
F_6	232.35	205.87	**219.11[d]**
Mean (C)	**237.81[a]**	**208.35[b]**	
CD ($p \leq 0.05$)			
F	**0.974**		
C	**0.563**		
F x C	**1.378**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.1.2 Pseudostem girth (cm)

The plant pseudostem girth was significantly affected by various fertigation treatments as shown in Table 4.2. The maximum stem girth (65.19 cm) was recorded in 80 percent RDF fertigation (F_3) under poly net house conditions followed by (62.31 cm) in 100 percent RDF fertigation (F_4) and minimum 56.15 stem girth was recorded in 40 percent RDF fertigation (F_1). In open field conditions also, maximum stem girth (58.45 cm) was recorded in 80 percent RDF fertigation (F_3) followed by (56.21 cm) in 100 percent RDF fertigation (F_4) and minimum 50.51cm stem girth was recorded in 40 percent RDF fertigation (F_1). Further, girth was significantly better under poly-net house (C_1-60.83 cm) in comparison to open field banana plants (C_2-54.63 cm). However, interaction effect was not significant for pseudostem girth and among various interactions maximum stem girth was recorded in 80 percent RDF fertigation (F_3C_1) followed by 100 percent RDF fertigation (F_4C_1) and 60 percent RDF fertigation (F_2C_1) under poly-net house in comparison to open-field condition. The improvement in pseudostem girth might be function of efficient nutrient utilization in all fertigation treatments in comparison to conventional approach (Mahendran *et al.*, 2013; and Tyagi *et al.*, 2015).

Table 4.2: Effect of fertigation and growing condition on Pseudostem girth (cm) of Banana plants

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	56.15	50.51	**53.33^e**
F_2	60.83	54.15	**57.49^c**
F_3	65.20	58.45	**61.82^a**
F_4	62.31	56.21	**59.26^b**
F_5	63.18	56.02	**59.60^b**
F_6	57.31	52.47	**54.89^d**
Mean (C)	**60.83^a**	**54.63^b**	
CD ($p \leq 0.05$)			
F	**0.813**		
C	**0.469**		
F x C	**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.1.3 Average number of leaves per plant

The total number of leaves on a banana plant was significantly affected by different fertigation and cultivation treatments (Table 4.3). The maximum number of leaves (16.27) were recorded in 80 percent RDF treatment (F_3) which was significantly better than and followed by 15.17 in 100 percent RDF treatment (F_4) and 15.00 average leaves in 60 percent RDF treatment (F_2) but the variation among F_2 and F_4 was not significant. There was significantly a greater number of leaves in all the treatments under poly-net house with mean (C_1-16.04) in comparison to mean value (C_2-13.30) under open-field condition. The interaction effect of both the factors had also significantly influenced the attributes. The maximum number of leaves (17.32) were recorded under protected conditions (F_3C_1) and minimum number of leaves found under open field conditions (F_6C_2).

Table 4.3: Effect of fertigation and growing conditions on average number of leaves per plant in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	15.45	12.25	**13.85^d**
F_2	16.31	13.70	**15.00^b**
F_3	17.32	15.23	**16.27^a**
F_4	16.47	13.87	**15.17^b**
F_5	16.12	13.15	**14.63^c**
F_6	14.55	11.63	**13.09^e**
Mean (C)	**16.04^a**	**13.30^b**	
CD ($p \leq 0.05$)			
F	**0.297**		
C	**0.171**		
F x C	**0.420**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

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

4.2 Production parameters

4.2.1 Days taken for shoot emergence

Table 4.4: Effect of fertigation and growing conditions on average number of days taken for shooting

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	219.50	235.25	**227.25^d**
F_2	217.00	231.00	**224.00^e**
F_3	210.00	226.00	**218.00^f**
F_4	221.00	238.00	**229.50^c**
F_5	224.00	240.75	**232.37^b**
F_6	230.00	248.00	**239.00^a**
Mean (C)	**220.20^b**	**236.50^a**	
CD ($p \leq 0.05$)			
F	**0.831**		
C	**0.480**		
F x C	**1.176**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

It is apparent from data reflected in Table 4.4 that application of fertigation levels from 40 to 120 percent under protected and open field conditions significantly reduced the days taken for shooting in banana. The analysis also confirms significant individual and interaction effect of both factors over number of days taken for shoot emergence. The least number of days taken for shooting (210) was recorded under 80 percent RDF fertigation (F_3) followed by 216.75 days in 60 percent RDF fertigation (F_2) of plants as compared to control plants (F_4-100 percent conventional fertilization) which took maximum days for shooting i.e. 230 days. Among two growing conditions, poly-net house (C_1) conditions taken average 220.20 days for shooting as compared to open field condition (C_2-236.50 days). Overall, F×C interactions was also significantly advanced the days for shoot emergence (210 days) in 80 percent RDF fertigation under poly net house (F_3C_1) followed by 216.75 days in 60 % RDF fertigation plants grown under same field condition (F_2C_1).

It is pertinent to mention here that the banana plants grown under poly-net house conditions applied with fertigation tend to show precocity in bearing i.e. earlier shifting from vegetative to reproductive phase with the increased hormonal metabolism and photosynthesis due to presence of most favourable climatic conditions inside poly-net house which ensured earlier flowering in banana crop grown under poly-net house with fertigation treatments as advocated by Ahmed *et al.* (2010) while it is also in line with the findings of Reddy and Gowda (2014) in the papaya plants.

4.2.2 Days taken from shoot emergence to harvest

It is clear from data given in Table 4.5 that varying fertigation levels from 40 to 120 percent under protected and open field conditions significantly reduced the days taken from shoot emergence to harvest in banana. The analysis also confirms significant individual and interaction effect of both factors over number of days taken from shoot emergence to harvest. The least number of days taken from shoot emergence to harvest (143.75 days) was recorded under 80 percent RDF fertigation (F_3) followed by 147.12 days in 60 percent RDF fertigation (F_2) plants as compared to control plants (F_4) which took maximum days for shooting to harvest i.e. 161.37 days. Among to two growing conditions, poly-net house conditions taken an average 147.91 days from shoot emergence to harvest as compared to open field condition (156.58 days). Overall, F×C interactions had also significantly advanced the days from shoot emergence to harvest (138.25 days) in 80 percent RDF fertigation under poly-net house (F_3C_1) followed by 143.25 days in 60 percent RDF fertigation under poly-net house (F_2C_1).

It is pertinent to mention here that the poly-net house plants applied with fertigation tend to show precocity in bearing i.e. earlier shifting from vegetative to reproductive phase. Further, the advancement of flowering had also reduced the days taken for harvest of crop. The active growth in early phase followed by senescence in plant growth is responsible for creating a new sink as fruits resulting translocation of photosynthates towards the fruit growth and development and making the plants available for harvest at earliest as confirmed by the findings of Ahmed *et al.* (2010). Reddy and Gowda (2014) related this earliness in fruiting with the increased hormonal metabolism and photosynthesis in the papaya plant due to presence of most favourable climatic conditions inside poly-net house.

Table 4.5: Effect of fertigation and growing conditions on average number of days taken from shooting to harvest

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	146.00	155.00	**150.50^d**
F_2	143.25	151.00	**147.12^e**
F_3	138.25	149.25	**143.75^f**
F_4	149.00	158.00	**153.50^c**
F_5	153.25	161.25	**157.25^b**
F_6	157.75	165.00	**161.37^a**
Mean (C)	**147.91^b**	**156.58^a**	
CD ($p \leq 0.05$)			
F	**0.904**		
C	**0.522**		
F x C	**1.278**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.2.3 Total crop duration

The data regarding effect of fertigation treatments *viz.* F_1 (40 percent fertigation), F_2 (60 percent fertigation), F_3 (80 percent fertigation), F_4 (100 percent fertigation) F_5 (120 percent fertigation) and F_6 (100 percent conventional fertilization) and growing conditions *i.e.* C_1 (poly-net house) and C_2 (open fields) and their interactions on fruit maturity in banana had shown statistically significant results as given in Table 4.6. The most advanced harvesting (361.75 days) was caused by 80 percent RDF fertigation *i.e.* F_3 followed by 371.00 days in 60 percent RDF fertigation *i.e.* F_2 and maximum (400.37 days) was taken for fruit harvesting in control fertilization treatment *i.e.* F_6. As compared to protected conditions, open field conditions significantly taken more days from planting to harvesting of crop with an average value of 393.08 days.

The interactions between growing conditions and fertigation treatments were also statistically significant analyzing the 80% RDF fertigation under poly net house (F_3C_1) to be the lowest value (348.25) followed by 360.00 in F_2C_1 (60% RDF fertigation under poly net house), 365.25 in F_1C_1 (40% RDF fertigation under poly net house) and 370.00 in F4C1 (100% RDF fertigation under poly net house) while it was maximum (413 days) in F_6C_2 (fertilizer application through conventional method using 100 percent recommended dose of fertilizers under open field conditions). The total crop duration can be considered as the sum of days taken for shooting and number of days from shooting to harvest. Thus, the current result can be justified by the findings of 4.2.2 and 4.2.3. This study is in line with the findings of Kumar *et al*. (2012) that 75% recommended dose of fertilizers through fertigation, there was early flowering and fruit maturity in banana.

Table 4.6: Effect of fertigation and growing conditions on total crop duration in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	365.25	390.25	**377.75^d**
F_2	360.00	382.00	**371.00^e**
F_3	348.25	375.25	**361.75^f**
F_4	370.00	396.00	**383.00^c**
F_5	377.25	402.00	**389.62^b**
F_6	387.75	413.00	**400.37^a**
Mean (C)	**368.08^b**	**393.08^a**	
CD ($p \leq 0.05$)			
F	**1.067**		
C	**0.616**		
F x C	**1.509**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.2.4 Average bunch weight (kg)

The data shown in Table 4.7 confirms that bunch weight was significantly influenced by fertigation treatments and growing conditions. The maximum mean bunch weight (24.85 kg) was recorded in 80% RDF fertigation (F_3) followed by 100% RDF fertigation (22.28 kg) and minimum was recorded in 40% RDF fertigation (16.18 kg) and F_6 (16.23 kg). The maximum bunch weight was recorded in all treatments under poly house as compare to open field and followed same trend as the mean value. The average bunch weight under protected condition was 21.78 kg and in open field condition, the average bunch weight was 17.66 kg.

Table 4.7: Effect of fertigation and growing conditions on average bunch weight (kg) in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	18.37	13.99	**16.18^e**
F_2	22.20	17.83	**20.01^c**
F_3	27.09	22.62	**24.85^a**
F_4	24.25	20.31	**22.28^b**
F_5	20.74	16.83	**18.78^d**
F_6	18.05	14.42	**16.23^e**
Mean (C)	**21.78^a**	**17.66^b**	
CD ($p \leq 0.05$)			
F	**0.092**		
C	**0.053**		
F x C	**0.130**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Similarly, the interaction between growing conditions and fertigation treatment had significantly affected the bunch weight of banana and the highest bunch weight (27.09 kg) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 24.25 kg in F_4C_1 (100% RDF fertigation under poly net house) and 22.62 kg in F_3C_2 (80% RDF fertigation under open field) while it was minimum (13.99 kg) in F_1C_2 (40% RDF fertigation under open field conditions). The greater bunch weight under protected cultivation might be associated to better finger filling and increased number of hands in the bunch due to better accumulation and assimilation of photosynthates in the banana fingers. Further, fertilizer application through drip irrigation had also amplified the utilization of nutrients for synthesis of biomolecules contributing to formation of fingers and bunch (Mahendran *et al.*, 2013). This result is related with findings of Kavino *et al*. (2004) who had reported that fertigation treatment in banana plants increased bunch weight. In apple cultivar Delicious, Park *et al*. (2004) also reported that there was an increase in average fruit weight with fertigation treatment.

4.2.5 Average number of hands per bunch

The data given in Table 4.8 shows that number of hands per bunch was significantly affected by fertigation treatments. The maximum number of hands per bunch (10.38) was recorded in 80% RDF fertigation (F_3) followed by 100% RDF fertigation (F_4) i.e. 9.85 and minimum was recorded in 100% RDF through conventional method (F_6) (8.60). The average number of hands per bunch i.e. 9.72 was found to be highest under protected conditions and under open field conditions average number of hands per bunch was 8.82.

Although, the interaction effect of growing conditions and fertigation treatments was not significant the highest number of hands per bunch (10.82) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 10.10 in F_4C_1 (100% RDF fertigation under poly net house) and 9.70 in F_2C_1 (60% RDF fertigation under poly net house) while it was minimum (8.10) in F_6C_2 (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers under open field conditions). The greater number of hands might be associated with the increased hormonal metabolism and photosynthesis due to presence of most favourable climatic conditions inside poly house which ensured earlier flowering and greater fruit set under poly-net house with fertigation treatments as advocated by Ahmed *et al.* (2010). Further, fertilizer application through drip irrigation had also amplified the utilization of nutrients for synthesis of biomolecules contributing to formation of fingers and bunch (Mahendran *et al.*, 2013).This result is corelated with the findings of Kavino *et al.* (2004) who recommended that fertigation increases the number of hands per bunch and Mahalakshmi *et al*. (2001b) reported that on Robusta cultivar of banana, 100% fertilizer through drip system increased bunch weight and quality of fruits.

Table 4.8: Effect of fertigation and growing conditions on average number of hands per bunch in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	9.20	8.20	**8.70^{de}**
F_2	9.70	8.70	**9.20^{c}**
F_3	10.82	9.95	**10.38^{a}**
F_4	10.10	9.60	**9.85^{b}**
F_5	9.40	8.40	**8.90^{d}**
F_6	9.10	8.10	**8.60^{e}**
Mean (C)	**9.72^{a}**	**8.82^{b}**	
CD ($p \leq 0.05$)			
F	**0.343**		
C	**0.198**		
F x C	**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.2.6 Average number of fingers per hand

The data accessible in Table 4.9 shows that number of fingers per hand was significantly affected by fertigation treatments and growing conditions. The highest number of fingers per hand (18.63) was observed in 80% RDF fertigation (F_3) followed by 100% RDF fertigation (F_4) i.e. 18.00 and minimum was observed in 100% RDF through conventional method (F_6) (15.60). The maximum average number of fingers per hand (17.76) was found under protected conditions and under open field conditions average number of fingers per hand was 16.52.

Table 4.9: Effect of fertigation and growing conditions on average number of fingers per hand in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	16.50	14.70	**15.60^{d}**
F_2	18.10	17.02	**17.56^{c}**
F_3	19.14	18.12	**18.63^{a}**
F_4	18.70	17.30	**18.00^{b}**
F_5	17.90	16.85	**17.37^{c}**
F_6	16.25	15.13	**15.69^{d}**
Mean (C)	**17.76^{a}**	**16.52^{b}**	
CD ($p \leq 0.05$)			
F	**0.243**		
C	**0.140**		
F x C	**0.340**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The interaction effect of growing conditions and fertigation treatments was significantly influenced the number of fingers per hand and highest (19.14) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 18.70 in F_4C_1 (100% RDF fertigation under poly net house) and 18.10 in F_2C_1 (60% RDF fertigation under poly net house) while it was minimum (14.70) in F_1C_2 (40% RDF fertigation under open field conditions). The greater number of fingers might be associated with the increased hormonal metabolism and photosynthesis due to presence of most favourable climatic conditions inside poly house which ensured earlier flowering and greater fruit set under poly-net house with fertigation treatments as advocated by Ahmed *et al.* (2010). Further, fertilizer application through drip irrigation had also amplified the utilization of nutrients for synthesis of biomolecules contributing to formation of fingers and bunch (Mahendran *et al.,* 2013). This study is correlated with the findings of Srinivas *et al*. (2001) with N&K fertigation in banana.

4.2.7 Average finger or fruit length (cm)

The data given in Table 4.10 shows that the finger length was significantly influenced by fertigation treatments and growing conditions. The maximum number of finger length (20.74) was recorded in 80% RDF fertigation (F_3) followed by 100% RDF fertigation (F_4) i.e. 19.27 and minimum was recorded in 100% RDF through conventional method (F_6) (16.97). The maximum average finger length 19.09 cm was found under protected conditions and under open field conditions average finger length was 18.12 cm.

Table 4.10: Effect of fertigation and growing conditions on average finger or fruit length (cm) in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	17.99	17.07	**17.53^{e}**
F_2	19.40	18.50	**18.95^{c}**
F_3	20.70	19.78	**20.74^{a}**
F_4	19.95	18.60	**19.27^{b}**
F_5	18.65	17.70	**18.17^{d}**
F_6	16.85	17.10	**16.97^{f}**
Mean (C)	**19.09^{a}**	**18.12^{b}**	
CD ($p \leq 0.05$)			
F	**0.182**		
C	**0.105**		
F x C	**0.258**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The interaction effect of growing conditions and fertigation treatments was significantly influenced the average finger length and the highest (20.70) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 19.95 in F_4C_1 (100% RDF fertigation under poly net house) and 19.40 in F_2C_1 (60% RDF fertigation under poly net house) while it was minimum (17.07) in F_1C_2 (40% RDF fertigation under open field conditions). The cultivation of banana under protected condition in combination with fertigation treatments ensured high degree of water and nutrient utilization which might be instrumental in better finger growth as stated by Srinivas *et al.* (2001) who had documented that there were higher fingers per bunch, weight and length with N and K fertigation.

4.2.8 Average fruit circumference (cm)

Table 4.11: Effect of fertigation and growing conditions on average fruit circumference (cm) in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	12.62	11.90	**12.26^{e}**
F_2	12.85	12.10	**12.47^{d}**
F_3	13.64	12.87	**13.25^{a}**
F_4	13.10	12.40	**12.75^{b}**
F_5	12.99	12.30	**12.64^{c}**
F_6	12.50	11.80	**12.15^{f}**
Mean (C)	**12.95^{a}**	**12.22^{b}**	
CD ($p \leq 0.05$)			
F	**0.103**		
C	**0.060**		
F x C	**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The perusal of data given in Table 4.11 complies that various environmental modifications accompanied with different levels of fertigation had a significant impact over fruit circumference. However, the interaction effect was not significant. The mean value worked out for different fertigation levels in Banana elaborates that F_3 (80 percent fertigation) to be the best in terms of maximum fruit circumference (13.25 cm). The minimum fruit circumference (12.15 cm) was recorded under control treatment where 100 percent RDF was given through conventional fertilization (F_6). Overall mean fruit circumference was maximum (12.95 cm) in plants growing under protected conditions as compared to fruits borne on plants in the open field where circumference was 12.22 cm.

Although, the interaction effect of growing conditions and fertigation treatments was not significant the highest average fruit circumference (13.64 cm) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 13.10 cm in F_4C_1 (100% RDF fertigation under poly net house) and 12.99 cm in F_5C_1 (120% RDF fertigation under poly net house) while it was minimum (11.80 cm) in F_6C_2 (Fertilizer application through conventional method using 100 percent recommended dose of fertilizers under open field conditions). The fruit circumference might have improved due to more photosynthesis that resulted in higher accumulation and utilization of reserves for fruit development. These findings are supported with the findings of Khound and Bhatacharya (2010) that there was increase in yield, fruit size and fruit weight in 100% recommended dose of fertilizer.

4.2.9 Average fruit or finger weight (gm)

The data presented in Table 4.12 illustrates that the average fruit or finger weight had followed similar trend as of fruit size and was significantly affected by fertilizer treatments and growing conditions. The mean average fruit or finger weight was maximum (128.27 gm) in 80 percent fertigation (F_3) as compared to other treatments and minimum fruit/ finger weight (118.58 gm) was recorded in 40% RDF treatment (F_1). By comparing both growing conditions there was significantly more average finger weight (125.54 g) was recorded under protected conditions then open field condition (120.20 g). The interaction effect of growing conditions and fertigation treatments was significantly influenced the average finger length and the highest (130.85 gm) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 128.40 gm in F_4C_1 (100% RDF fertigation under poly net house) and 126.50 gm in F_2C_1 (60% RDF fertigation under poly net house) while it was minimum (116.10) in F_1C_2 (40% RDF fertigation under open field conditions).

The increased fruit weight has a direct relationship with the enhanced fruit size. These superior fruit weight observations as compared to control may be a result of efficient fertilizer usage in combination with effective photosynthesis which might be responsible for accumulation of more carbohydrates and ultimately translocating higher carbohydrates to the sink, promoting cell division and thus enhancing fruit size and weight.

These results are in accordance with the reporting of Srinivas *et al*. (2001) that there was higher bunch weight, higher fingers per bunch, higher finger weight with N&K fertigation. Similarly, Panigrahi *et al.* (2015) for papaya fruit have evidenced the heavy weight of papaya fruits under fertigation treatments as compared to control. Similarly, Bachchhav (1995) had also confirmed better fruit weight in fertigated plants. Protected cultivation had also improved papaya fruit weight as compared to open field environment as reported by Reddy and Gowda (2014) and Kaur and Kaur (2017).

Table 4.12: Effect of fertigation and growing conditions on average fruit or finger weight (gm) in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	121.07	116.10	**118.58^f**
F_2	126.50	120.45	**123.47^c**
F_3	130.85	125.70	**128.27^a**
F_4	128.40	122.30	**125.35^b**
F_5	124.32	118.95	**121.63^d**
F_6	122.10	117.72	**119.91^e**
Mean (C)	**125.54^a**	**120.20^b**	
CD ($p \leq 0.05$)			
F	**0.259**		
C	**0.149**		
F x C	**0.366**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.2.10 Average fruit yield (kg/plant)

The data given in Table 4.13 illustrates that the average fruit yield in banana had followed similar trend as of bunch weight and was significantly affected by fertilizer treatments and growing conditions. The mean average fruit yield was maximum (22.35 kg) in 80 percent fertigation (F_3) as compared to other treatments and minimum average fruit yield (13.93 kg) was recorded in 40% RDF treatment (F_1). Under both, poly-net house and open field conditions similar trend of average yield was reported reflecting the influence of fertigation doses over average fruit yield of banana. By comparing both growing conditions there was significantly more average fruit yield (19.34 kg) was recorded under protected conditions then open field condition (16.67 kg).

Table 4.13: Effect of fertigation and growing conditions on average fruit yield (kg per plant) in banana

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	16.12	11.74	**13.93^e**
F_2	19.85	15.53	**17.69^c**
F_3	24.59	20.12	**22.35^a**
F_4	21.85	17.95	**19.90^b**
F_5	17.84	16.53	**17.18^d**
F_6	15.80	12.17	**13.98^e**
Mean (C)	**19.34^a**	**16.67^b**	
CD ($p \leq 0.05$)			
F	**0.109**		
C	**0.063**		
F x C	**0.154**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The interaction effect of growing conditions and fertigation treatments was significantly influenced the average fruit yield and the highest (24.59 kg) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 21.85 kg in F_4C_1 (100% RDF fertigation under poly net house) and 20.12 kg in F_3C_2 (80% RDF fertigation under open field condition) while it was minimum (11.74 kg) in F_1C_2 (40% RDF fertigation under open field condition).

The increased average fruit yield has a direct relationship with the enhanced fruit weight and bunch weight. The better average fruit yield under different fertigation treatments viz., F_3, F_4 and F_2 as compared to F_5, F_1 and control may be a result of greater plant spread and efficient fertilizer usage in combination with effective photosynthesis under balanced fertigation. These factors in combination might have accumulated more carbohydrates for the fruits development and ultimately translocating higher carbohydrates to the sink, promoting cell division and thus enhancing fruit size and weight hence the average fruit yield. These results are in line with the reporting of Srinivas *et al*. (2001) that there was higher average fruit yield with N & K fertigation. Similarly, and Panigrahi *et al.* (2015) for papaya fruit have evidenced the heavy weight of papaya fruits under fertigation treatments as compared to control. Similarly, Bachchhav (1995) had also confirmed better fruit weight and average fruit yield in fertigated plants. Protected cultivation had also improved papaya fruit yield as compared to open field environment as reported by Reddy and Gowda (2014) and Kaur and Kaur (2017).

4.3 Fruit quality parameters

4.3.1 TSS (°Brix)

The data reflected in Table 4.14 shows that TSS (°Brix) was significantly affected by fertigation treatments and growing conditions. The mean maximum TSS (21.10 °Brix) was recorded in 80% RDF fertigation (F_3) followed by 100% RDF fertigation (F_4) i.e. 19.67 °Brix and minimum was recorded in 100% RDF through conventional method (F_6) (16.65 °Brix). The maximum TSS was recorded in all treatments under poly house with an average of 19.34 °Brix while in open field condition the average TSS was 18.28 °Brix. The interaction effect of growing conditions and fertigation treatments was significantly affected the TSS content and the highest TSS (21.85 °Brix) was reported with 80% RDF fertigation under poly net house (F_3C_1) followed by 20.25 °Brix in F_4C_1 (100% RDF fertigation under poly net house) and 19.68 °Brix in F_2C_1 (60% RDF fertigation under poly net house) while it was minimum (16.18 °Brix) in F_1C_2.

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

Kaur (2017) have reported papaya fruit production with superior TSS under protected conditions in comparison to the open fields.

Table 4.14: Effect of fertigation and growing conditions on TSS (°Brix) of banana fruit

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	18.00	16.92	**17.46^{e}**
F_2	19.68	18.40	**19.04^{c}**
F_3	21.85	20.35	**21.10^{a}**
F_4	20.25	19.10	**19.67^{b}**
F_5	19.15	18.75	**18.95^{d}**
F_6	17.12	16.18	**16.65^{f}**
Mean (C)	**19.34^{a}**	**18.28^{b}**	
CD ($p \leq 0.05$)			
F	**0.083**		
C	**0.048**		
F x C	**0.117**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.3.2 Titratable acidity (%)

The statistical analysis of data pertaining to acid content in banana fruit (Table 4.15) makes it pertinent to mention that acidity of fruits was significantly influenced by different treatments. The mean lowest acidity (0.23%) was estimated in 80% RDF fertigation (F_3) and maximum was recorded in 40% RDF treatment (F_1) (0.28%). Under protected condition (C_1) the minimum titratable acidity was 0.25% which was closely followed by the open-field condition (C_2-0.26) as maximum mean TSS for all fertigation treatments. Although, the interaction effect of growing conditions and fertigation treatments was not significant for titratable acidity of banana fruits, the highest value (0.29%) was reported F_1C_2 followed by F_1C_1 (0.28%) and F_6C_2 (0.28%). The interaction among growing conditions and fertigation treatments was not significant and can be confirmed with the results concluded by the findings of Neilesen *et al.* (2004) where they have found that with the use of fertigation there was decrease in fruit acidity. The variation in acidity of fruits after fertigation treatments might be associated with K uptake and utilization by the plants as K content in fertigation dose increased from F_1 to F_3 or F_4, the activity of acid accumulation was decreased with decrease in sugar-acid concentration so it can be correlated with increase in sugar in the current study (Zhang *et al*., 2018). Further increase in fertigation to F_6 might had also resulted in simultaneous increase in N and K where the concentration was nitrogen was sufficient to interfere with K metabolism (Zhang *et al*., 2018). Adequate K nutrition greatly influences the synthesis of sucrose and starch in plants such as apple (Mosa *et al*., 2015), muskmelon (Lester *et al*., 2010), tomato (Almeselmani *et al*., 2010) and strawberry (Ahmad *et al*., 2014). However, K levels have different effects on organic acid metabolism depending on the plant species (Etienne *et al*., 2014; Flores *et al*., 2015; Niu *et al*., 2016).

Table 4.15: Effect of fertigation and growing conditions on Titratable Acidity (%) of banana fruit

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	0.28	0.29	**0.28^a**
F_2	0.25	0.26	**0.25^d**
F_3	0.22	0.24	**0.23^f**
F_4	0.23	0.25	**0.24^e**
F_5	0.25	0.27	**0.26^c**
F_6	0.27	0.28	**0.27^b**
Mean (C)	**0.25^b**	**0.26^a**	
CD ($p \leq 0.05$)			
F	**0.007**		
C	**0.004**		
F x C	**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.3.3 TSS/ Acid ratio

The TSS/ Acid ratio presented in Table 4.16 makes it pertinent to mention that various fertigation treatments had significantly affected the TSS/Acid ratio in comparison to control. The highest TSS/acid ratio (92.13) in banana fruit was recorded in F_3 (80 percent fertigation) among all fertigation treatments with least (60.34) in F_6 (100 percent RDF conventional method). Same way, among two growing conditions, numerically maximum ratio of 78.7 was observed in fruits that developed under poly-net house. Among various interactions of treatments, F_3C_1 was recorded with maximum TSS/acid ratio (99.43) followed by 88.13 in F_4C_1. However, F_6C_2 recorded the minimum ratio (57.82) among all interactions. Reddy and Gowda (2014) had reported that sugar - acid conversion might be associated with current result. Further, the variation in TSS/acid ratio due to fertigation treatments might be associated with sugar acid metabolism as described by Zhang *et al.* (2018) and has been described in titratable acidity section.

Table 4.16: Effect of fertigation and growing conditions on TSS/ acid ratio of banana fruit

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	64.32	58.31	**61.31^d**
F_2	78.80	70.80	**74.80^c**
F_3	99.43	84.84	**92.13^a**
F_4	88.13	76.45	**82.29^b**
F_5	76.67	69.49	**73.08^c**
F_6	62.87	57.82	**60.34^d**
Mean (C)	**78.37^a**	**69.62^b**	
CD ($p \leq 0.05$)			
F	**2.325**		
C	**1.343**		
F x C	**3.289**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.3.4 Total sugars (%)

The fruit sugar level data for banana under experimentation is tabulated in Table 4.17 which reveals a significant influence of various fertigation and growing conditions. The higher mean sugar content had been found significantly (17.31 and 16.39 percent, respectively in F_3 and F_2) better as compared to F_1 (13.23 percent) and control (1402). Likewise, the C_1 treatment with modified environment recorded highest fruit sugars (15.35 percent) than in fruits harvested from open fields. Similarly, among interactions significantly high value (17.91 percent) was obtained in F_3C_1 treatment and minimum in F_1C_2 (12.97 percent).

Table 4.17: Effect of fertigation and growing conditions on total sugars (%) of banana fruit

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	13.50	12.97	**13.23[e]**
F_2	16.80	15.99	**16.39[b]**
F_3	17.91	16.72	**17.31[a]**
F_4	15.12	14.83	**14.97[c]**
F_5	14.63	13.12	**13.87[d]**
F_6	14.17	13.88	**14.02[d]**
Mean (C)	**15.35[a]**	**14.58[b]**	
CD ($p \leq 0.05$)			
F	**0.325**		
C	**0.187**		
F x C	**0.459**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The improvement in fruit total sugar content with fertigation and modified growing environment might be due to more assimilates translocation to the developing fruits causing better physico-chemical activities during maturity of fruits and improving more starch to sugars conversion. The greenhouse environment might also have provided congenial light and temperature conditions for good quality fruit development during physiological maturity. These results are in accordance with the outcomes explained by Reddy and Gowda (2014) in papaya fruit showing maximum sugar level in protected cultivation fruits. Similarly, Rana and Chandel (2003) and Kumar *et al.* (2012) have also evidenced increased sugar content in strawberry fruits with fertigation treatments. Further, the variation in sugar content due to fertigation treatments might be associated with sugar acid metabolism as described by Zhang *et al.* (2018) and has been described in titratable acidity section.

4.4 Leaf nutrient content

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

4.4.1.1 Leaf nitrogen content (percent)

Table 4.18: Effect of fertigation and growing conditions on nitrogen (%) content of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	3.23	2.87	**3.05^e**
F_2	3.42	3.15	**3.28^d**
F_3	3.48	3.26	**3.37^c**
F_4	3.61	3.37	**3.49^b**
F_5	3.72	3.53	**3.62^a**
F_6	2.96	2.53	**2.74^f**
Mean (C)	**3.40^a**	**3.11^b**	
CD ($p \leq 0.05$)			
F	**0.025**		
C	**0.015**		
F x C	**0.036**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The status of leaf nitrogen content as affected by various treatments has been given in Table 4.18 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum nitrogen concentration 3.62 percent in 120 percent fertigation treatment (F_5) followed by 3.49 in 100 percent fertigation (F_4) treatment. The control (F_6) treatment recorded minimum level (2.74 percent) of mean nitrogen content in banana leaves among two growing conditions. The plants grown under poly-net house unit recorded significantly higher (3.40 percent) nitrogen level as compare to 3.13 percent in open field plants.

However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf nitrogen concentration to the level of 3.72 percent and minimum 2.53 percent was recorded under conventional fertilization in open fields (F_6C_2). This increase in leaf nitrogen content might be due to regular availability of nutrients that improves the uptake of plant and its translocation within the plant under various fertigation treatments as compare to control. The present finding is in line with findings of Kavino *et al.* (2002) in banana, Chandel and Singh (1992) in mango and Bhalerao *et al.* (2009) in Strawberry.

4.4.1.2 Leaf phosphorus content (percent)

The status of leaf phosphors contents as affected by various treatments has been given in Table 4.19 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum phosphorus concentration of 0.694 percent in 120 percent fertigation treatment (F_5) followed by 0.590 in 100 percent fertigation (F_4) treatment. The control (F_6) treatment recorded minimum level (0.305 percent) of mean phosphorus content in banana leaves among two growing conditions. The plants grown under poly-net house unit recorded significantly higher (0.538 percent) phosphorus level as compare to 0.431 percent in open field plants.

However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf phosphorus concentration to the level of 0.760 percent and minimum 0.260 percent was recorded under conventional fertilization in open fields (F_6C_2). The trend of phosphorus content in leaves is directly related to the nutrient concentration in fertigation treatments which confirms that nutrient status of plant is directly related to fertigation which ensures better uptake of nutrients when it is applied to rhizosphere through drip system. These results obtained in the present study are similar to the observations of Jeyakumar *et al.* (2010) who reported a slight increase in leaf P content due to fertigation in papaya plants but this increase was statistically non-significant. However, Koszanski et al. (2006) had reported substantial increase in phosphorus content in strawberry leaves.

Table 4.19: Effect of fertigation and growing conditions on phosphorus content (%) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	0.40	0.30	**0.35^e**
F_2	0.50	0.39	**0.44^d**
F_3	0.57	0.48	**0.52^c**
F_4	0.65	0.53	**0.59^b**
F_5	0.76	0.62	**0.69^a**
F_6	0.35	0.26	**0.30^f**
Mean (C)	**0.53^a**	**0.43^b**	
CD ($p \leq 0.05$)			
F	**0.011**		
C	**0.007**		
F x C	**0.016**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.4.1.3 Leaf potassium content (percent)

The status of leaf potassium contents as affected by various treatments has been given in Table 4.20 which confirmed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum potassium concentration of 2.42 percent in 80 percent fertigation treatment (F_3) followed by 2.27 in 60 percent fertigation (F_2) treatment. The control (F_6) treatment recorded minimum level (1.98 percent) of mean potassium content in banana leaves among two growing conditions. The plant grown under poly-net house unit recorded significantly higher (2.32 percent) phosphorus level as compare to 2.02 percent in open field plants.

However, among F × C interactions, F_3C_1 (80 percent fertigation under poly-net house conditions) was seen to have highest leaf potassium concentration to the level of 2.56 percent and minimum 1.82 percent was recorded under conventional fertilization in open fields (F_6C_2). The pattern of K content in leave is remains similar to N and P content; however, K uptake is largely dependent on balanced N and P fertilization which confirms that excess of N and P may be detrimental over the K uptake and utilization. These results obtained in the present study are similar to the observations of Jeyakumar *et al.* (2010) who reported a slight increase in leaf K content due to fertigation in papaya plants but this increase was statistically non-significant. They had further added the high level of K was in similarity with increasing pattern of N and P content of leaves.

Table 4.20: Effect of fertigation and growing conditions on potassium content (%) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	2.21	1.89	**2.05^e**
F_2	2.42	2.13	**2.27^b**
F_3	2.56	2.28	**2.42^a**
F_4	2.33	2.02	**2.17^c**
F_5	2.25	1.99	**2.12^d**
F_6	2.14	1.82	**1.98^f**
Mean (C)	**2.32^a**	**2.02^b**	
CD ($p \leq 0.05$)			
F	**0.009**		
C	**0.005**		
F x C	**0.013**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

4.4.1.4 Leaf calcium content (percent)

The status of leaf calcium contents as influenced by various treatments has been presented in Table 4.21 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum calcium concentration of 3.41 percent in 120 percent fertigation treatment (F_5) followed by 3.07 in 80 percent fertigation (F_3) treatment and 2.98 in 100 percent fertigation (F_4) treatment. The control (F_6) treatment recorded minimum level (2.23 percent) of mean calcium content in banana leaves among two growing conditions. The plant grown under poly-net house unit recorded significantly higher (2.94 percent) calcium level as compared to 2.71 percent in open field plants.

Table 4.21: Effect of fertigation and growing conditions on calcium content (%) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	2.52	2.31	**2.41^{e}**
F_2	2.98	2.75	**2.86^{d}**
F_3	3.17	2.98	**3.07^{b}**
F_4	3.06	2.90	**2.98^{c}**
F_5	3.56	3.27	**3.41^{a}**
F_6	2.38	2.09	**2.23^{f}**
Mean (C)	**2.94^{a}**	**2.71^{b}**	
CD ($p \leq 0.05$)			
F	**0.009**		
C	**0.005**		
F x C	**0.013**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf calcium concentration to the level of 3.56 percent followed by F_3C_1 (80 percent fertigation under poly-net house conditions) as 3.17 percent and F_4C_1 (100 percent fertigation under poly-net house conditions) as 3.06 percent while minimum 2.09 percent was recorded under conventional fertilization in open fields (F_6C_2). These results obtained in the present study are similar to the observations of

Jeyakumar *et al.* (2010) who reported a relatively high nutrient content in 100 percent fertigation in papaya plants.

4.4.1.5 Leaf magnesium content (percent)

The status of leaf magnesium contents as affected by various treatments has been given in Table 4.22 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum magnesium concentration of 5.73 percent in 120 percent fertigation treatment (F_5) followed by 5.57 in 80 percent fertigation (F_3) treatment. The control (F_6) treatment recorded minimum level (4.99 percent) of mean magnesium content in banana leaves among two growing conditions. The plant grown under poly-net house unit recorded significantly higher (5.46 percent) magnesium level as compare to 4.89 percent in open field plants.

Table 4.22: Effect of fertigation and growing conditions on magnesium content (%) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	5.21	5.10	**5.15^d**
F_2	5.35	5.10	**5.22^c**
F_3	5.74	5.40	**5.57^b**
F_4	5.50	3.28	**4.39^f**
F_5	5.89	5.58	**5.73^a**
F_6	5.10	4.88	**4.99^e**
Mean (C)	**5.46^a**	**4.89^b**	
	CD ($p \leq 0.05$)		
F	**0.009**		
C	**0.005**		
F x C	**0.012**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf magnesium concentration to the level of

5.89 percent followed by F_3C_1 (80 percent fertigation under poly-net house conditions) as 5.74 percent and F_4C_1 (100 percent fertigation under poly-net house conditions) as 5.50 percent while minimum 4.88 percent was recorded under conventional fertilization in open fields (F_6C_2). These results obtained in the present study are having no any defining pattern which confirms the variation was not due to mode of application it may be due to variation in nutrient doses applied in each treatment. Chandel and Singh (1992) had reported high level of magnesium content in mango leaves under both irrigated and unirrigated conditions while Koszanski *et al.* (2006) had reported decrease in leaf magnesium content of strawberry plants under fertigation.

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

4.4.2.1 Leaf iron content (ppm)

Table 4.23: Effect of fertigation and growing conditions on iron content (ppm) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	288.49	275.22	**281.85^f**
F_2	315.19	300.14	**307.66^d**
F_3	329.24	315.18	**322.21^c**
F_4	341.21	324.89	**333.05^b**
F_5	362.36	339.18	**350.77^a**
F_6	299.21	272.16	**285.68^e**
Mean (C)	**322.61^a**	**304.46^b**	
CD ($p \leq 0.05$)			
F	**0.997**		
C	**0.576**		
F x C	**1.410**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The status of leaf Fe contents as affected by various treatments has been reflected in Table 4.23 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum Fe concentration of 350.77 ppm in 120 percent fertigation treatment (F_5) followed by 333.05 ppm in 100 percent fertigation (F_4) treatment while F_1 treatment recorded minimum level (281.85 percent) of mean Fe content. The plant grown under poly-net house recorded significantly higher (322.61 ppm) Fe level as compare to 304.46 ppm in open field plants. However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf Fe concentration (362.36 ppm) followed by F_4C_1 (100 percent fertigation under poly-net house conditions) as 341.21 ppm while minimum 272.16 ppm was recorded under conventional fertilization in open fields (F_6C_2).

4.4.2.2 Leaf zinc content (ppm)

Table 4.24: Effect of fertigation and growing conditions on Zinc content (ppm) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	40.23	35.34	**37.79^{e}**
F_2	45.29	42.16	**43.72^{d}**
F_3	49.43	46.32	**47.87^{c}**
F_4	55.20	49.31	**52.25^{b}**
F_5	60.22	55.23	**57.72^{a}**
F_6	35.26	29.18	**32.22^{f}**
Mean (C)	**47.60^{a}**	**42.92^{b}**	
CD ($p \leq 0.05$)			
F	**0.776**		
C	**0.448**		
F x C	**1.098**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The status of leaf Fe contents as affected by various treatments has been given in Table 4.24 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum Zn concentration of 57.72 ppm in 120 percent fertigation treatment (F_5) followed by 52.25 ppm in 100 percent fertigation (F_4) treatment while F_6 (control) treatment recorded minimum level (37.79 ppm) of mean Zn content. The plant grown under poly-net house recorded significantly higher (47.60 percent) Zn level as compare to 42.92 ppm in open field plants. However, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) was seen to have highest leaf Zn concentration (60.22 ppm) followed by F_5C_2 (120 percent fertigation under open field conditions) as 55.23 ppm and F_4C_1 (100 percent fertigation under poly-net house conditions) as 55.20 ppm while minimum 29.18 ppm was recorded under conventional fertilization in open fields (F_6C_2).

4.4.2.3 Leaf manganese content (ppm)

Table 4.25: Effect of fertigation and growing conditions on Manganese content (ppm) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	46.40	44.43	**45.41^{f}**
F_2	52.21	49.32	**50.77^{d}**
F_3	58.43	55.39	**56.91^{c}**
F_4	64.27	61.41	**62.84^{a}**
F_5	60.41	57.59	**59.00^{b}**
F_6	48.63	46.37	**47.50^{e}**
Mean (C)	**55.06^{a}**	**52.42^{b}**	
CD ($p \leq 0.05$)			
F	**0.874**		
C	**0.505**		
F x C	**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The status of leaf Mn contents as affected by various treatments (Table 4.25) revealed a significant effect of both factors while their interaction was not significant. The leaves of banana showed presence of maximum Mn concentration of 62.84 ppm in 100 percent fertigation treatment (F_4) followed by 59.00 ppm in 120 percent fertigation (F_5) treatment while F_1 recorded minimum level (45.41 ppm) of mean Mn content. The plant grown under poly-net house recorded significantly higher (55.06 ppm) Mn level as compare to 52.42 ppm in open field plants. However, among F × C interactions, F_4C_1 (100 percent fertigation under poly-net house conditions) was seen to have highest leaf Mn concentration (64.27 ppm) followed by F_4C_2 (100 percent fertigation under open field conditions) as 61.41 ppm and F_5C_1 (120 percent fertigation under poly-net house conditions) as 60.41 ppm while minimum 44.43 percent was recorded in F_1C_2.

4.4.2.4 Leaf copper content (ppm)

Table 4.26: Effect of fertigation and growing conditions on copper content (ppm) of banana leaves

Treatments	C_1 (Poly-net house)	C_2 (Open fields)	Mean (F)
F_1	7.01	6.96	**6.98^f**
F_2	7.43	7.21	**7.32^d**
F_3	8.55	8.35	**8.45^b**
F_4	7.88	7.41	**7.64^c**
F_5	8.96	8.62	**8.79^a**
F_6	7.20	7.13	**7.17^e**
Mean (C)	**7.84^a**	**7.69^b**	
CD ($p \leq 0.05$)			
F	**0.046**		
C	**0.027**		
F x C	**0.065**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

The status of leaf Cu contents as affected by various treatments has been reflected in Table 4.26 which revealed a significant effect of both factors and their interactions. The leaves of banana showed presence of maximum Cu concentration of 8.79 ppm in 120 percent fertigation treatment (F_5) followed by 8.45 ppm in 80 percent fertigation (F_3) treatment while F_1 treatment recorded minimum level (6.98 percent) of mean Cu content. The plant grown under poly-net house recorded significantly higher (7.84 ppm) Cu level as compare to 7.69 ppm in open field plants; however, among F × C interactions, F_5C_1 (120 percent fertigation under poly-net house conditions) had highest leaf Cu concentration (8.96 ppm) followed by F_5C_2 (120 percent fertigation under open field conditions) as 8.62 ppm while minimum 6.96 ppm was recorded under F_1C_2.

Although lesser work has been done over leaf nutrient status of banana and any other fruit plants after fertigation treatments but high nutrient status in leaves might be result of efficient nutrient uptake by plants, better mobilization and translocation in plant body and efficient nutrient use efficiency under fertigation treatments (Intrigliolo *et al.*, 1992). Further, the micronutrients are primarily cation so their interaction with soil chelating agents may also be responsible for these variations. Kuchanwar *et al.* (2017) had also reported high leaf nutrient status in Nagpur Mandarin under fertigation treatments.

4.5 Soil parameters (at various depth) before and after experiment

4.5.1 Soil parameters before experiment

The soil parameters presented in Table-4.27 reflects the health status of soil before planting and was reported to vary as per the depth of soil profile. The soil pH and EC (dSm-1) was reported to be increased while the organic carbon (OC), available N (kg/ha), available P (kg/ha) and available K (kg/ha) was substantially decreased with depth under both the growing conditions.

4.5.2 Soil parameters after experiment

4.5.2.1 Soil pH

The data illustrated in Table 4.28 shows that various fertigation and growing conditions did not significantly influence the soil pH. The highest pH was observed in the lowest soil layer (60-90 cm) and minimum in the uppermost layer upto 15 cm soil depth. Although the data analysis results were not significant, the highest pH range was recorded in maximum fertigation levels i.e. 120 percent RDF fertigation in almost all the soil depths. A very minute and non-significant enhancement of soil pH was reported with fertigation treatments.

4.5.2.2 Electrical conductivity (dSm^{-1})

It is clear from the conductivity values tabulated in Table 4.29 that treatments of two factors under study were not significantly affected the soil electrical conductivity in banana under discussion. The initial and final soil status regarding conductivity levels of soil were at par at all soil depths. The electrical conductivity level numerically showed a decreasing trend from upper soil layer (0-15 cm) to second layer (15-30 cm), but moving further downwards, the conductivity levels were seen to rise up to a depth of 60 cm and again a diminishing trend from 60 to 90 cm soil depth. The overall range of soil electrical conductivity was 0.21 to 0.31 dSm^{-1}.

4.5.2.3 Organic carbon (percent)

The data illustrated in Table 4.30 reveals that soil organic carbon content was neither improved nor depleted with any of the treatments given to banana plants. The overall trend of organic carbon percentage seems to be decreasing as we move to the deep layers of soil. The range of observed soil carbon content varied from approximately 0.56 percent in upper soil layers to 0.46 percent in deep layers of soil. The non-significant impact of various fertigation treatments on soil organic carbon content is line with the findings of Singh (2018) in strawberry who also reported the same soil organic carbon status in fertigation treatments.

4.5.2.4 Available N (kg/ha)

The data related to available nitrogen content in soil is presented in Table 4.31. The analysis of data revealed that the nitrogen content in upper layers of soil was significantly influenced by various fertigation and growing conditions. However, the deep layer of 30 to 60 cm and 60 to 90 cm had not shown significant variation. The general trend followed by the nitrogen content in soil was an increasing concentration when we follow lowest to highest level of fertigation. These increased levels of N content with more fertigation are corroborated with the findings of Valji (2011) who had also observed the same trend of enhanced soil nitrogen content by various fertigation treatments in papaya.

4.5.2.5 Available P (kg/ha)

The available phosphorus concentration elaborated in the Table 4.32 revealed various treatments to be non-effective in changing its soil levels. The available phosphorus content showed a diminishing trend from topmost soil layer to the deep soil layer (i.e. moving from soil surface to 90 cm deep). However, the overall highest estimates of P were recorded in F_6C_1 (48.92 kg/ha) followed by F_6C_2 (48.54 kg/ha). The lowest value was recorded in ($F_5C_{1,}$) 60 to 90 cm soil depth. Further, the soil beneath open cultivated plants had more available phosphorus levels as compared to poly net-house plants. These results are in accordance with the in-significant effect of fertigation on soil mineral composition as documented by Valji (2011).

4.5.2.6 Available K (kg/ha)

The data given in Table 4.33 illustrated that all the fertigation treatment levels reflected a significant impact on available soil K (kg/ha) in 0 to 15 cm depth and 15 to 30 cm depth. The deepest soil layers had least K elemental content as compared to the richest concentrations in top soil. The highest K content found in F_4C_2 (357.81 kg/ha) in 0-15 cm soil depth and minimum 290.44 kg/ha found in F_3C_1 in 60 to 90 cm soil depth. In general, these findings are in line with the results reported by Valji (2011) in papaya crop listing a significant enhancement of soil K concentrations in available form under the influence of various fertigation levels.

Table 4.27: Status of soil parameters at different depths before experiment

Treatments	C_1 (Poly-net house)	C_2 (Open field)	Mean		C_1 (Poly-net house)	C_2 (Open field)	Mean
	0-15 cm soil depth				**15-30 cm soil depth**		
Soil pH	7.60	8.18	**7.89**		7.50	8.22	**7.86**
EC (dSm^{-1})	0.20	0.22	**0.21**		0.21	0.22	**0.21**
OC (percent)	0.52	0.53	**0.52**		0.49	0.50	**0.45**
Available N (kg/ha)	270.48	273.87	**272.17**		234.21	235.17	**234.69**
Available P (kg/ha)	41.66	42.85	**42.25**		36.56	37.27	**36.91**
Available K (kg/ha)	330.32	331.44	**330.88**		281.21	282.34	**281.77**
	30-60 cm soil depth				**60-90 cm soil depth**		
Soil pH	7.80	8.39	**8.09**		8.20	8.40	**8.30**
EC (dSm^{-1})	0.31	0.30	**0.30**		0.25	0.26	**0.25**
OC (percent)	0.49	0.49	**0.49**		0.48	0.47	**0.47**
Available N (kg/ha)	228.48	230.42	**229.45**		224.29	225.62	**224.95**
Available P (kg/ha)	29.82	29.52	**29.67**		25.18	25.32	**25.25**
Available K (kg/ha)	283.65	284.45	**284.05**		285.32	286.29	**285.80**

Table 4.28: Status of soil pH at different depths after experiment

	After experiment						
	0-15 cm soil depth				15-30 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	8.15	8.10	**8.13**		8.14	8.16	**8.15**
F_2	8.22	8.14	**8.18**		8.16	8.25	**8.21**
F_3	8.13	8.25	**8.19**		8.25	8.28	**8.27**
F_4	8.23	8.15	**8.19**		8.27	8.25	**8.26**
F_5	8.27	8.15	**8.21**		8.30	8.23	**8.27**
F_6	8.20	8.15	**8.18**		8.25	8.30	**8.28**
Mean (C)	**8.20**	**8.16**			**8.23**	**8.25**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		
	30-60 cm soil depth				60-90 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	8.30	8.40	**8.35**		8.30	8.47	**8.39**
F_2	8.32	8.43	**8.38**		8.43	8.42	**8.43**
F_3	8.37	8.42	**8.40**		8.52	8.33	**8.43**
F_4	8.40	8.42	**8.41**		8.47	8.44	**8.46**
F_5	8.45	8.38	**8.42**		8.47	8.45	**8.46**
F_6	8.42	8.37	**8.40**		8.39	8.43	**8.41**
Mean (C)	**8.38**	**8.40**			**8.43**	**8.42**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Table 4.29: Status of soil electrical conductivity (dSm^{-1}) at different depths after experiment.

	After experiment						
	0-15 cm soil depth				15-30 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	0.22	0.23	**0.23**		0.21	0.22	**0.22**
F_2	0.23	0.24	**0.24**		0.23	0.21	**0.22**
F_3	0.24	0.22	**0.23**		0.22	0.22	**0.22**
F_4	0.24	0.23	**0.24**		0.20	0.21	**0.21**
F_5	0.23	0.22	**0.23**		0.21	0.23	**0.22**
F_6	0.26	0.25	**0.26**		0.23	0.21	**0.22**
Mean (C)	**0.24**	**0.23**			**0.22**	**0.22**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		
	30-60 cm soil depth				60-90 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	0.30	0.31	**0.31**		0.25	0.27	**0.26**
F_2	0.30	0.28	**0.29**		0.27	0.26	**0.27**
F_3	0.31	0.29	**0.30**		0.24	0.26	**0.25**
F_4	0.30	0.29	**0.30**		0.25	0.25	**0.25**
F_5	0.31	0.30	**0.31**		0.24	0.26	**0.25**
F_6	0.30	0.30	**0.30**		0.27	0.25	**0.26**
Mean (C)	**0.30**	**0.30**			**0.25**	**0.26**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Table 4.30: Status of soil organic carbon (percent) at different depths after experiment.

	After experiment						
	0-15 cm soil depth				15-30 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	0.55	0.54	**0.55**		0.49	0.52	**0.51**
F_2	0.53	0.55	**0.54**		0.52	0.51	**0.52**
F_3	0.54	0.56	**0.55**		0.51	0.51	**0.51**
F_4	0.56	0.55	**0.56**		0.50	0.51	**0.51**
F_5	0.55	0.53	**0.54**		0.52	0.50	**0.51**
F_6	0.55	0.52	**0.54**		0.52	0.50	**0.51**
Mean (C)	**0.55**	**0.54**			**0.51**	**0.51**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		
	30-60 cm soil depth				60-90 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	0.48	0.49	**0.49**		0.46	0.47	**0.47**
F_2	0.46	0.51	**0.49**		0.47	0.48	**0.48**
F_3	0.49	0.50	**0.50**		0.48	0.46	**0.47**
F_4	0.50	0.50	**0.50**		0.48	0.47	**0.48**
F_5	0.47	0.49	**0.48**		0.47	0.46	**0.47**
F_6	0.48	0.50	**0.49**		0.48	0.48	**0.48**
Mean (C)	**0.48**	**0.50**			**0.47**	**0.47**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Table 4.31: Status of soil available nitrogen (kg/ha) at different depths after experiment.

	After experiment						
	0-15 cm soil depth				15-30 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	299.56	302.17	**300.87^{f}**		263.45	264.45	**263.95^{e}**
F_2	315.68	322.46	**319.07^{d}**		275.67	276.91	**276.29^{c}**
F_3	328.28	332.58	**330.43^{b}**		287.79	289.57	**288.68^{a}**
F_4	318.72	325.46	**322.09^{c}**		261.66	262.54	**262.10^{f}**
F_5	330.45	334.92	**332.69^{a}**		273.46	274.17	**273.82^{d}**
F_6	300.56	304.37	**302.47^{e}**		285.45	287.83	**286.64^{b}**
Mean (C)	**315.54^{b}**	**320.33^{a}**			**274.58^{b}**	**275.91^{a}**	
CD ($p \leq 0.05$)							
F	**1.01**				**0.92**		
C	**0.56**				**0.54**		
F x C	**0.87**				**0.67**		
	30-60 cm soil depth				60-90 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	243.82	244.57	**244.20**		235.94	236.57	**236.26**
F_2	248.64	249.42	**249.03**		237.87	239.43	**238.65**
F_3	250.93	250.72	**250.83**		239.17	240.15	**239.66**
F_4	241.97	243.53	**242.75**		237.61	238.97	**238.29**
F_5	244.16	245.87	**245.02**		238.74	238.79	**238.77**
F_6	248.59	250.74	**249.67**		232.49	232.57	**232.53**
Mean (C)	**246.35**	**247.48**			**236.97**	**237.75**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Table 4.32: Status of soil available phosphorus (kg/ha) at different depths after experiment.

	After experiment						
	0-15 cm soil depth				15-30 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	45.43	45.67	**45.55**		39.05	38.64	**38.85**
F_2	45.72	46.36	**46.04**		39.47	39.23	**39.35**
F_3	46.15	47.53	**46.84**		40.25	41.32	**40.79**
F_4	45.43	46.02	**45.73**		39.13	39.57	**39.35**
F_5	46.33	46.87	**46.60**		39.84	39.77	**39.81**
F_6	48.92	48.54	**48.73**		40.37	40.65	**40.51**
Mean (C)	**46.33**	**46.83**			**39.69**	**39.86**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		
	30-60 cm soil depth				60-90 cm soil depth		
	C_1 (Poly-net house)	C_2 (Open field)	Mean (F)		C_1 (Poly-net house)	C_2 (Open field)	Mean (F)
F_1	31.74	31.54	**31.64**		27.38	28.29	**27.84**
F_2	31.92	32.37	**32.15**		28.56	29.11	**28.84**
F_3	33.44	33.68	**33.56**		29.13	30.24	**29.69**
F_4	34.26	34.46	**34.36**		26.94	27.25	**27.10**
F_5	33.27	33.62	**33.45**		26.78	26.89	**26.84**
F_6	33.86	34.14	**34.00**		27.32	27.57	**27.45**
Mean (C)	**33.08**	**33.30**			**27.69**	**28.23**	
CD ($p \leq 0.05$)							
F	**NS**				**NS**		
C	**NS**				**NS**		
F x C	**NS**				**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

Table 4.33: Status of soil available potassium (kg/ha) at different depths after experiment.

	After experiment					
	0-15 cm soil depth			**15-30 cm soil depth**		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
F_1	351.12	351.34	**351.23^{cd}**	310.46	312.61	**311.54^{b}**
F_2	349.85	350.64	**350.25^{d}**	315.84	317.75	**316.80^{a}**
F_3	351.38	352.19	**351.79^{c}**	304.28	305.63	**304.96^{d}**
F_4	355.79	357.81	**356.80^{a}**	308.37	310.72	**309.55^{c}**
F_5	353.26	353.79	**353.53^{b}**	311.45	313.86	**312.66^{b}**
F_6	348.47	347.52	**348.00^{e}**	315.61	318.95	**317.28^{a}**
Mean (C)	**351.65**	**352.22**		**311.00**	**313.25**	
CD ($p \leq 0.05$)						
F	**1.17**			**1.35**		
C	**NS**			**NS**		
F x C	**NS**			**NS**		
	30-60 cm soil depth			**60-90 cm soil depth**		
	C_1 (Poly-net house)	**C_2 (Open field)**	**Mean (F)**	**C_1 (Poly-net house)**	**C_2 (Open field)**	**Mean (F)**
F_1	295.86	296.37	**296.12**	290.57	291.32	**290.95**
F_2	295.89	296.16	**296.03**	291.79	292.57	**292.18**
F_3	297.23	297.92	**297.58**	290.44	290.88	**290.66**
F_4	298.75	299.57	**299.16**	291.35	291.76	**291.56**
F_5	297.24	297.83	**297.54**	291.87	292.48	**292.18**
F_6	293.36	294.13	**293.75**	292.62	293.74	**293.18**
Mean (C)	**296.39**	**297.00**		**291.44**	**292.13**	
CD ($p \leq 0.05$)						
F	**NS**			**NS**		
C	**NS**			**NS**		
F x C	**NS**			**NS**		

[F_1-Fertigation with 40 percent recommended dose of fertilizers); F_2-Fertigation with 60 percent recommended dose of fertilizers; F_3-Fertigation with 80 percent recommended dose of fertilizers; F_4-Fertigation with 100 percent recommended dose of fertilizers; F_5-Fertigation with 120 percent recommended dose of fertilizers; and F_6-Fertilizer application through conventional method using 100 percent recommended dose of fertilizers]

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Plant growth parameters

The result shows that plant growth parameters were significantly improved in all the fertigation treatments and were significantly different in both growing conditions. The plants grown under poly net house conditions have better growth in comparison to open field condition.

The pseudostem height was maximum (232.23 cm) where 120% RDF (recommended dose of fertilizers) was given through fertigation technique. Comparing both the growing conditions pseudostem height found maximum under poly net house conditions. The interactions were also statistically significant analyzing the 120% RDF fertigation under poly-net house (F_5C_1) to be the highest value (250.27) followed by 242.42cm average height in F_4C_1 (100% RDF fertigation under poly net house) and minimum average pseudostem height was in F_1 C_2.

An increase in height was obviously expected in treatments where plants were grown under poly net house conditions with fertigation due to availability of favourable growing environment under green house and due to constant nutrient availability in soil regime very near to root zone comparing to open field and conventionally fertilized plants. The maximum stem girth (65.19 cm) was recorded in 80 percent RDF fertigation (F_3) under polyhouse conditions followed by (62.31 cm) in 100 percent RDF fertigation (F_4) and minimum 56.15 stem girth was recorded in 40 percent RDF fertigation (F_1). Similarly, in open field conditions also maximum stem girth (58.45 cm) was recorded in 80 percent RDF fertigation (F_3) followed by (56.21 cm) in 100 percent RDF fertigation (F_4) and minimum 50.51cm stem girth was recorded in 40 percent RDF fertigation (F_1).

However, among various interactions maximum stem girth was recorded in 80 percent RDF fertigation (F_3C_1) followed by 100 percent RDF fertigation (F_4C_1) and 60 percent RDF fertigation (F_2C_1) under poly-net house in comparison with open-field conditions. Likewise, total number of leaves on a banana plant is significantly influenced by different fertigation and cultivation treatments. The interaction effect of both the factors was also significantly influenced the attributes.

The maximum number of leaves (17.32) was recorded in 80 percent RDF treatment (F_3) followed by 16.47 average number of leaves in 100 percent RDF treatment (F_4) and 16.31 average leaves in 60 percent RDF treatment (F_2) under poly net house conditions.

There was significantly a greater number of leaves in all the treatments under poly-net house in comparison with open-field conditions. The maximum number of leaves (17.32) was recorded under protected conditions (F_3C_1) and minimum number of leaves found under open field conditions (F_6C_2). Average number of leaves per plant was more in most of the fertigation doses that may be attributed to higher nutrients uptake and reserving them in leaf tissues for greater photosynthesis. However, excess of fertigation had not been effective to increase number of leaves which confirms the maximum FUE (fertilizer use efficiency) at RDF.

5.2 Yield and related attributes

The analysis of data pertaining to production parameters of banana under experiment revealed that varying fertigation levels from 40 to 120 percent under protected and open field conditions significantly reduced the days taken for shooting and shooting to harvest in banana. The analysis also confirms significant individual and interaction effect of both factors over number of days taken for shooting.

The least number of days taken for shooting (210) and shooting to harvest (138.25 days) recorded under 80 percent RDF fertigation followed by 216.75 days for shooting and 143.25 days for shooting to harvest in 60 percent RDF fertigation plants as compared to control plants (100 percent conventional fertilization) which took maximum days for shooting i.e. 230 days and 157.75 days taken for shooting to harvest. In comparison to two field conditions, poly net house conditions taken average 220.20 days for shooting as compared to open field condition (236.50 days). Overall F×C interactions also significantly advanced the days for shooting (210 days) in 80 percent RDF fertigation under poly net house (F_3C_1) followed by 216.75 days in 60 percent RDF fertigation plants grown under same field condition (F_2C_1). Similarly, poly net house conditions taken average 147.91 days from shooting to harvest as compared to open field condition (156.58 days). Overall F×C interactions also significantly advanced the days from shooting to harvest (138.25 days) in 80 percent RDF fertigation under poly net house (F_3C_1) followed by 143.25 days in 60 percent RDF fertigation plants grown under same field condition (F_2C_1). It is pertinent to mention here that the green house plants applied with fertigation tend to show precocity in bearing i.e. earlier shifting from vegetative to reproductive phase.

The data also shows that bunch weight, finger weight, hands per bunch, fingers per hand, finger length, finger circumference and yield per plant was significantly affected by fertigation treatments and growing conditions. These parameters recorded maximum in 80% RDF fertigation followed by 100% RDF fertigation and minimum was recorded in 40% RDF fertigation under protected conditions. Similarly, in open field conditions also these parameters were maximum in 80% RDF treatment followed by 100% recommended dose of RDF and minimum was found in 40% RDF treatment.

Similarly, the interaction among field condition significantly affected al the production parameters like bunch weight, finger weight, hands per bunch, fingers per hand, fruit circumference, finger length and yield per plant recorded maximum in all treatments under poly house as compare to open field.

5.3 Fruit quality parameters

The data shows that TSS °brix was significantly affected by fertigation treatments and growing conditions. Maximum TSS (21.85 °brix) recorded in 80% RDF fertigation followed by 100% RDF fertigation i.e. 20.258 °brix and minimum was recorded in 100% RDF conventional method i.e. 17.12° brix. under protected conditions. Similarly, in open field conditions maximum TSS (20.35 °brix) was recorded in 80% RDF treatment followed by 100% recommended dose of RDF (19.10 °brix) and minimum (16.18 °brix) was found in 100% RDF conventional method.

Similarly, the interaction among field condition significantly affected the TSS of banana. Maximum TSS recorded in all treatments under poly house as compare to open field. The average TSS under protected condition is 19.34 °brix and in open field condition average TSS was 18.28 °brix this clearly shows the significant effect of protected conditions on TSS. This improvement in fruit total soluble solids content among fertigated and protected cultivation of fruits might be a result of high photosynthetic efficiency allocating more soluble sugars towards the sink.

Data pertaining to acid content in banana fruit shows that acidity of fruits significantly affected by different treatments. Minimum acidity (0.22%) recorded in 80% RDF fertigation and maximum was recorded in 40% RDF treatment i.e. 0.28% under protected conditions. Similarly, in open field conditions minimum acidity (0.24%) was recorded in 80% RDF treatment and maximum was recorded in 40% RDF treatment (0.29%). Similarly, various fertigation treatments have also significantly affected the TSS/ acid ratio in comparison to control. Highest TSS/acid ratio in banana fruit was recorded (99.43) in F_3 (80 percent fertigation) among all fertigation treatments with least (62.87) in F_6 (100 percent RDF conventional method). Same way, among two growing conditions, numerically maximum ratio of 78.7 was observed in fruits that developed under poly-net house. Among various interactions of treatments, F_3C_1 recorded maximum TSS/acid ratio (99.43) followed by 88.13 in F_4C_1. However, F_6C_2 recorded the minimum ratio (57.82) among all interactions. The TSS/ acid ratio signifies organoleptic rating of the fruit. Hence more TSS and lesser comparative acidity improve this ratio.

The various fertigation and growing conditions also significantly influence the sugars contents banana fruits. Higher sugar content has been found significantly (17.91 and 16.80 percent, respectively in F_3 and F_2) as compared to control (14.17 percent). Likewise, the C_1 treatment with modified environment recorded highest fruit sugars (15.35 percent) than in fruits harvested from open fields. Similarly, among interactions significantly high value (17.91 percent) was obtained in F_3C_1 treatment and minimum in F_1C_2 (12.97 percent).

The improvement in fruit total sugar content with fertigation and modified growing environment might be due to more assimilates translocation to the developing fruits causing better physico-chemical activities during maturity of fruits and improving more starch to sugars conversion. The greenhouse environment might also have provided congenial light and temperature conditions for good quality fruit development during physiological maturity.

5.4 Leaf nutrient content

The banana leaf nutrient analysis revealed a significant effect of various experimental treatments on macro (Nitrogen, Potassium, Calcium and Magnesium) and micro nutrients (Iron, Zinc, Manganese and Copper). The leaf nitrogen, phosphorus and magnesium content (3.72,0.76 and 5.89 percent) found maximum in F_5 (120% fertigation) treatment in comparison to all other treatments. However, the leaf potassium and calcium contents were observed maximum in plants that were 80% RDF fertigation. Among two growing conditions the mean leaf nitrogen, phosphorus and magnesium content was higher in green house conditions as compare to open field conditions. The leaf micro nutrients were also observed to show significant influence of different experimental treatments. Maximum iron, zinc and copper concentration were found under 120% RDF fertigation treatment in banana leaves. Manganese concentration was found maximum in F_4 treatment (100% RDF fertigation).

5.5 Soil parameters

The data analysis shows that various fertigation growing treatments did not significantly influenced the soil pH, electrical conductivity and organic carbon in different soil depth. Available nitrogen, phosphorus and potassium content in soil revealed that different fertigation treatments did not significantly affect these nutrient contents. Maximum nitrogen, phosphorus and potassium were found in 0 to 15 cm soil depth and value decreases with decrease in depth.

Conclusion

From the present investigation it can be concluded that banana plants grown under poly net-house under sub-tropical conditions of Punjab with application of 80% of fertilizer recommendation through fertigation system was the best treatment and this resulted in short crop duration, higher yield, higher bunch weight and bigger size of hands and fingers with superior quality fruit production, with higher TSS and sugar contents. The outcome of this investigation can be summarized as:

- The F_3 (Fertigation with 80 percent of fertilizer recommendation) and F_4 (Fertigation with 100 percent of fertilizer recommendation) treatment can be considered as best treatments where better yield can be harvested from banana plants without any compromise with quality of fruits.
- The protected cultivation may be recommended for banana cultivation under subtropics where there is challenge of frost injury during winter.

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APPENDICES

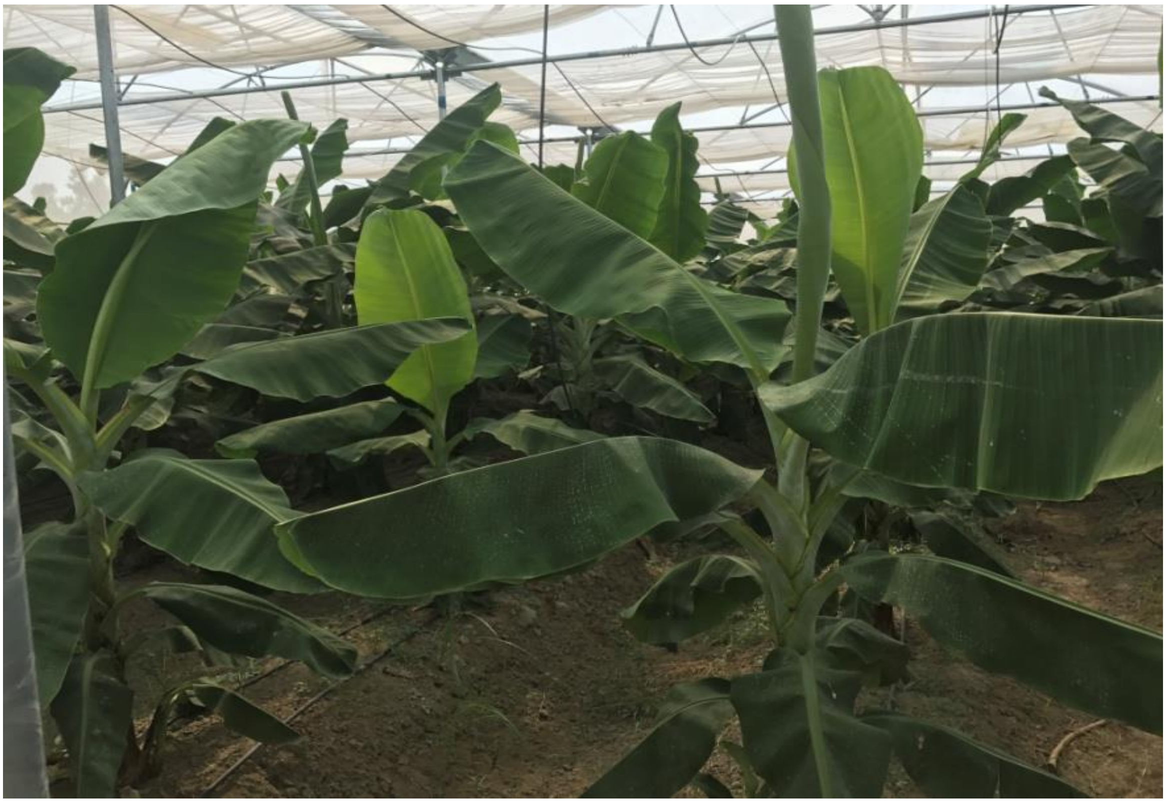


Plate 1: Banana plantation under experiment

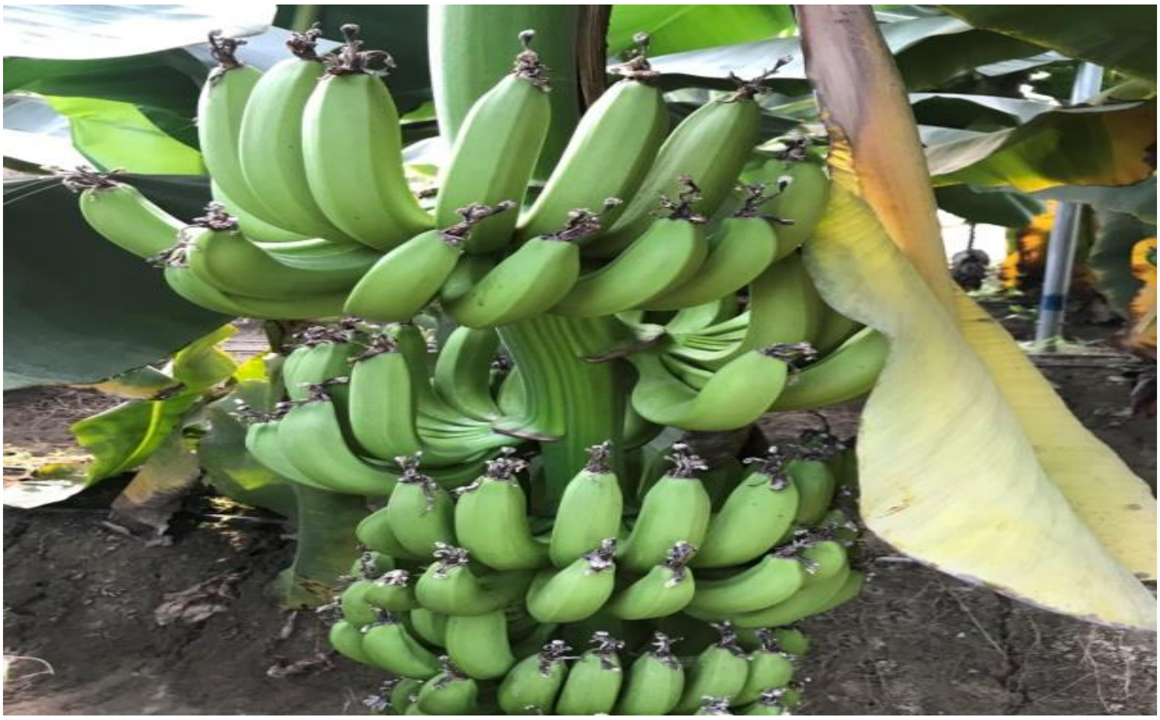
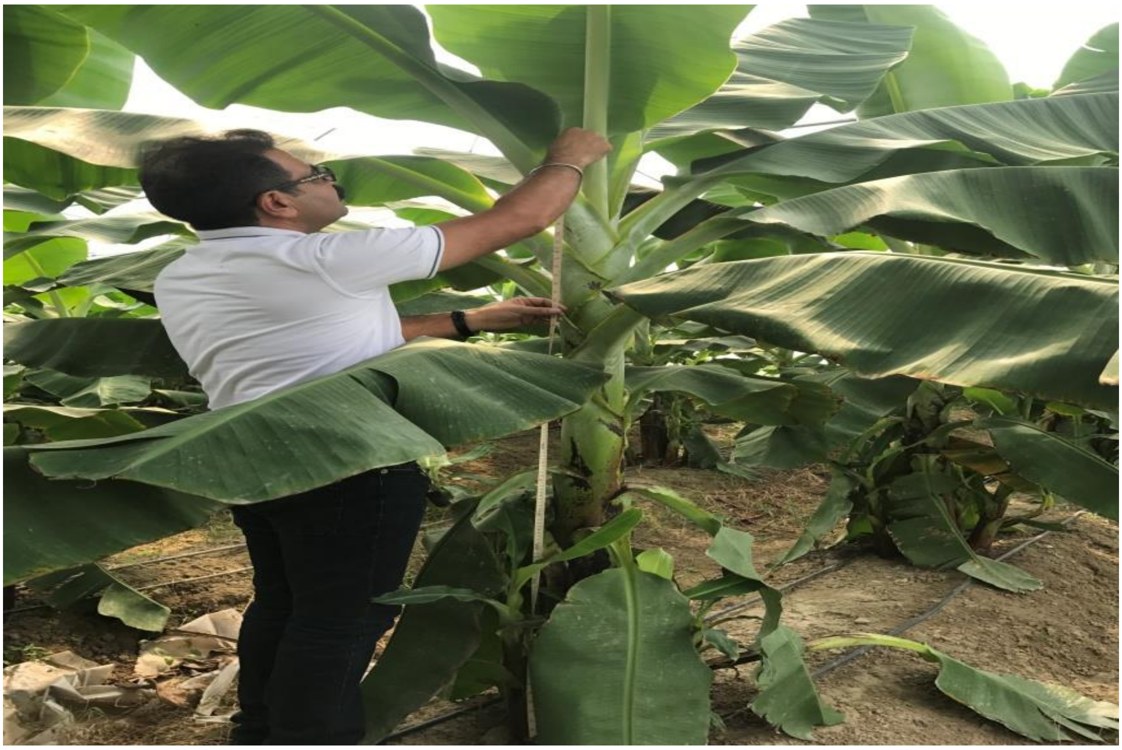


Plate 2: Fruiting in banana plants under experiment



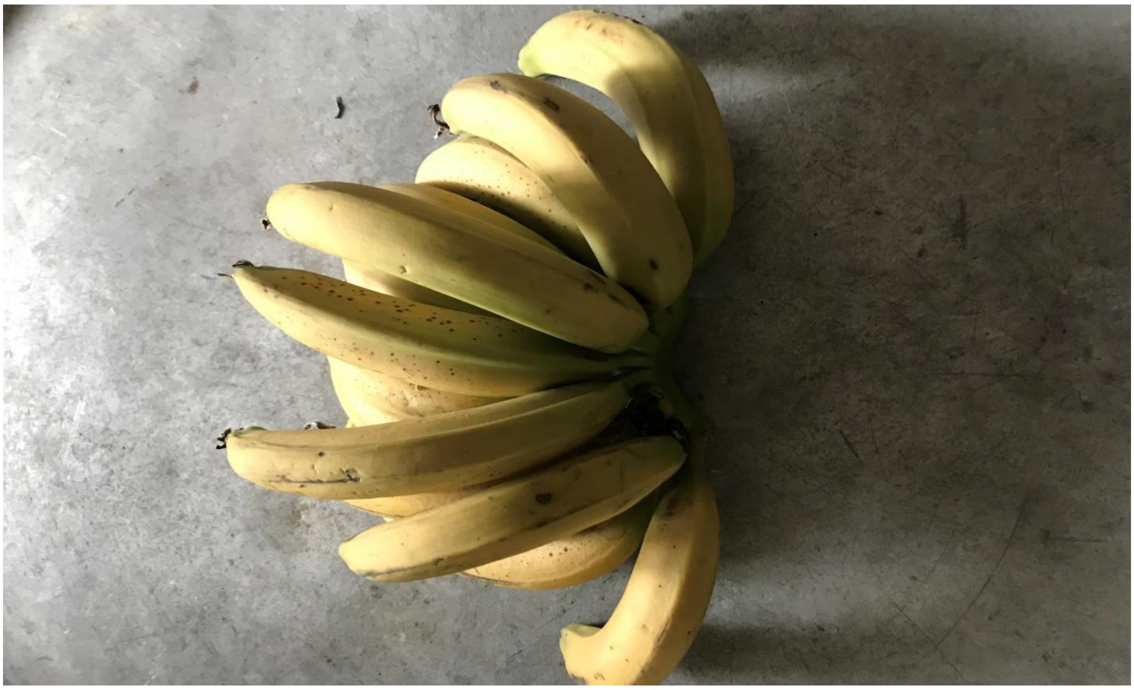


Plate 3: Data collection and observation

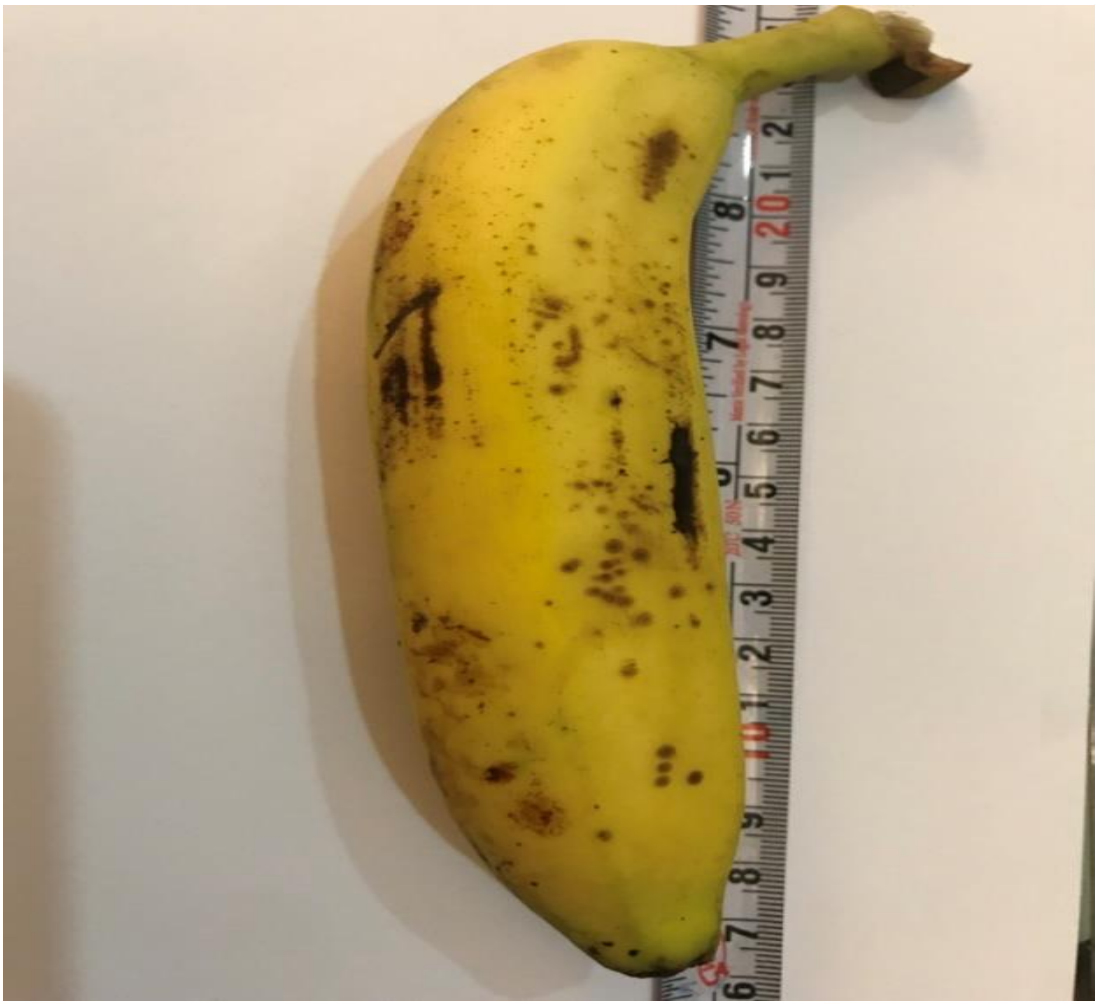


Plate 4: Measurement of fruit length