FERTIGATION FOR PRECISION FARMING IN TOMATO (*Solanum lycopersicum* L.)

by

AMALA. J

(2014-11-130)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"FERTIGATION FOR PRECISION FARMING IN TOMATO (*Solanum lycopersicum* L.)"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"FERTIGATION FOR PRECISION FARMING IN TOMATO (*Solanum lycopersicum* L.)"** is a record of research work done independently by Ms. Amala J. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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B	:	Boron
B: C ratio	:	Benefit: Cost ratio
CD (0.05)	:	Critical difference at 5 % level
C: N ratio	:	Carbon: Nitrogen ratio
cm	:	Centimeter
cm^2	:	Square centimeter
cm^3	:	Cubic centimeter
CPE	:	Cumulative pan evaporation
Cu	:	Copper
DAP	:	Days after planting
DMP	:	Dry matter production
dm^2	:	Square decimeter
dSm^{-1}	:	deci Siemens per meter
EC	:	Electrical conductivity
Ep	:	Potential evaporation
ET	:	Evapo-transpiration
et al.	:	And others
etc.	:	And other things
Fe	:	Iron
Fig.	:	Figure
g	:	Gram
g^{-1}	:	Per gram
GIS	:	Geographic information system
$g\ L^{-1}$	:	Gram per litre

g plant^{-1}	:	Gram per plant
GPS	:	Global positioning system
ha	:	Hectare
HI	:	Harvest index
hour^{-1}	:	Per hour
i.e.,	:	That is
K	:	Potassium
KAU	:	Kerala Agricultural University
kg	:	Kilogram
kg ha^{-1}	:	Kilogram per hectare
kg ha mm^{-1}	:	Kilogram per hectare millimeter
L	:	Litre
LAI	:	Leaf area index
L hour^{-1}	:	Litre per hour
Ltd.	:	Limited
m	:	Meter
MAP	:	Month after planting
Mg	:	Magnesium
mg	:	Milligram
mm	:	Millimeter
Mn	:	Manganese
Mo	:	Molybdenum
MOP	:	Muriate of Potash
N	:	Nitrogen
NHB	:	National Horticulture Board

NO_3- : Nitrate
NRC : National Research Council
NS : Non significant
Plant^{-1} : Per plant
Plant^{-1} day^{-1} : Per plant per day
pH : Potenz hydrogen
POP : Package of practices
Pvt. : Private
q : Quintals
RD : Recommended dose
RH : Relative humidity
SSCM : Site specific crop management
SEm : Standard error of mean
sp. : Species
t : Tonnes
t ha^{-1} : Tonnes per hectare
TSS : Total soluble solids
Unit^{-1} : Per unit
viz., : Namely
VRT : Variable rate technology
Vs. : Versus
Zn : Zn

LIST OF SYMBOLS

& : And

@ : At the rate of

^{0}C : Degree Celsius

^{0}E : Degree East

^{0}N : Degree North

% : Per cent

₹ : Rupees

INTRODUCTION

1. INTRODUCTION

Vegetables play an important role in the nutritional security of our nation due to their high yield, nutritional richness, economic viability and ability to generate on-farm and off-farm employment. Our country is blessed with diverse agro-climate with distinct seasons, making it possible to grow wide array of vegetables year round. Vegetables are called protective foods as their consumption can prevent several diseases. Further, vegetables play an important role in balanced diet by providing not only energy but vital protective nutrients like minerals and vitamins. Food habits of population are changing and demand for fresh vegetables is steadily increasing due to rise in income, population growth, urbanization and increased health consciousness.

Tomato (*Solanum lycopersicum* L.) is an important and widely grown solanaceous vegetable crop around the world, both for fresh market and processing. It is considered as an important source of vitamin A, C and minerals (Hari, 1997). Tomato covers an area of about 8.8 lakh ha in India with a production of 182.27 lakh tons and productivity of 20.7 t ha^{-1} (NHB, 2013).

Dayanand *et al.* (2003) reported that about 60 per cent of our cultivation suffer from indiscriminate use of irrigation water and chemical fertilizers. This type of degradation has resulted from over exploitation of our natural resources and adoption of certain faulty agricultural practices. As far as Kerala is concerned, the extent of cultivated land is limited and hence, we should exploit the full production potential of vegetables from existing area through proper agronomic practices. For realising maximum yield potential, management of water, nutrients and weeds is very important. Efficient irrigation methods like micro irrigation can save water by 50 per cent and result in yield improvement to the tune of 20- 40 per cent.

Precision farming is considered as one of recent and scientific approaches to enhance productivity. It refers to the management of each crop production unit by recognizing site specific differences within the field and soil and crop accordingly to reduce waste, increase profit and maintain the quality of the environment.

Fertilizers are chemical compounds (liquid or granular) which provides essential plant nutrients to the plants to promote growth. They are either applied through soil or irrigation water. Application of fertilizers, soil amendments and other water soluble products required by the plant during its growth stages through drip or sprinkler irrigation system known as fertigation. In this system, fertilizer solution is distributed evenly through irrigation water. Due to better availability of nutrients, the fertigation was found more efficient. In this method liquid fertilizers as well as water soluble fertilizers are used. It is the most effective and convenient means of maintaining optimum fertility level and water supply according to the specific requirement (Shirgure *et al.,* 2000).

Drip fertigation technology is beneficial to the farmers for higher and quality vegetable production. Achieving maximum fertigation efficiency requires knowledge of crop nutrient requirements, soil nutrient supply, fertilizer injection technology, irrigation scheduling and crop and soil monitoring techniques. Thus, success in using this system depends on a sound knowledge in fertilizer management based on soil testing and a drip irrigation system that is designed and operated properly. Due to rapid increase in area under micro irrigation, now fertigation is getting momentum in a number of the countries. The concept of fertigation is new to the Indian subcontinent and gaining popularity as it is easy to adopt.

Fertigation is an excellent method for optimizing the utilization of water and nutrients to improve the productivity of tomato. It allows frequent, uniform and precise application of nutrients through drip directly into the zone of maximum root activity as per the crop need which results in higher fruit yield and quality. In addition it saves the fertilizers, time and labour. The quantity of nutrients and the interval of application are of vital for adequate uptake and optimal growth of tomato.

Tomato responds positively to irrigation and fertilizer application. The impact of precision farming on yield improvement of this crop needs to be explored. Standardisation of fertigation schedule *i.e.,* quantity of fertilizers to be applied through fertigation and fertigation interval, in open field precision farming in tomato will be useful for vegetable farmers to enhance the productivity of the crop.

Present study was therefore planned with the following objectives:

i) To standardize the fertigation schedule for tomato under precision farming.

ii) To assess the impact of precision farming practices on growth and yield of tomato.

iii) To work out the economics of fertigation.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Precision farming practices are one of the major approaches for realising maximum yield potential in crops. Various precision farming practices are available for proper management of water, nutrients and weeds. Among these practices drip irrigation and fertigation has a key role for maximizing productivity in vegetable crops. Impact of different precision farming practices are reviewed here with more emphasis on levels of fertigation and fertigation interval.

2.1 PRECISION FARMING

Precision farming is based on temporal and spatial variability in the field. It is also known as Site Specific Crop Management system (SSCM). According to NRC (2007), SSCM refers to developing agricultural-management system that promotes variable management practices within a field according to site or soil conditions.

Sensor based technologies are widely used and major tools are Global Positioning System (GPS), Geographic Information System (GIS), Variable Rate Technologies (VRT) etc. (Tran and Nguyen, 2006).

General practices of precision farming include deep ploughing using chisel plough or disc plough, preparation of raised beds, polythene mulching to control weeds and drip irrigation. Based on experimental results, Tamil Nadu Agricultural University (TNAU) recommends precision farming practices like deep ploughing, planting in raised beds and fertigation for yield improvement of crops. According to Vadivel (2008), the chisel plough technology in land preparation (once in two years) ensured better aeration in the root zone and effective drainage during rainy days. Further, it helped the plants to develop root system with characteristic uniformity in pattern, architecture and in adequate mass. Moreover, it enhanced the moisture retention capacity of soils.

2.1.1 Drip Irrigation and Mulching

Among the various techniques developed for application of water, drip irrigation also referred to as tickle irrigation or micro-irrigation is gaining popularity as perhaps the most efficient method of water application (Bucks *et al.*, 1986). Drip irrigation is ideally suited for controlled placement and rate of water soluble fertilizers through fertigation.

Application of 1/3rd to 1/5th of the normal quantity of water was enough for the drip irrigated plots compared to normal quantity of water applied to plots under surface irrigation in vegetable crops (Sivanappan and Padmakumari, 1980). Drip irrigation at 0.8 cumulative pan evaporation (CPE) enhanced the growth and yield parameters of brinjal significantly over the check basin irrigation during 1989-1991 in Gujarat. It increased the number (35.5 per cent) and yield of fruits (41.6 per cent) over check basin method of irrigation due to favourable soil moisture status in root zone throughout the life span of the crop which led to better growth and distribution of roots (Jadav *et al.*, 1995).

Drip irrigation has gained wide spread popularity as an efficient method for fertigation because both time of application and rate of nutrients can be controlled to meet the requirements of a crop at each physiological growth stage (Bar-Yosef, 1997).

Mahajan and Singh (2006) opined that drip irrigation at 0.5 Ep (potential evaporation rate) treatments saved 48.1 per cent of irrigation water and resulted in 51.7 per cent higher yield as compared to recommended practice inside the green house. Tyson and Harrison (2009) of Georgia University stated that drip irrigation is gaining popularity for production of some vegetable crops. It can be used with or without plastic mulch.

Singh *et al.* (2009) found that drip irrigation at 80 per cent crop evapo-transpiration based on pan evaporation gave significantly higher fruit yield (45.57 t ha^{-1}) for tomato compared with surface irrigation. Shedeed *et al.* (2009) compared the WUE between furrow irrigation and drip irrigation. The water quantity used was not equal for all the treatments; furrow irrigation required 590 mm while the corresponding values for drip irrigation treatments was 450 mm for the entire season for tomato. Drip irrigation recorded significantly higher WUE (95 kg yield mm^{-1}) over furrow irrigation (58 kg yield mm^{-1}), which accounted to 64 per cent efficiency increase.

Sufficient fertilizer application and convenient irrigation techniques are very important factors affecting the growth and yield of tomato (Gupta *et al.*, 2010). Semiz and Yurtseven (2010) reported that among grafted and ungrafted tomato, drip irrigated grafted tomato registered the highest fruit yield as well as water use efficiency (WUE) compared to grafted furrow irrigated, ungrafted drip irrigated and ungrafted furrow irrigated treatments. Comparing drip-grafted to other treatments, WUE were six per cent, 27 per cent and 38 per cent higher than drip-ungrafted, furrow-grafted and furrow-ungrafted treatments, respectively.

Pandey *et al.* (2013) revealed that drip irrigation significantly increased yield and net income of chilli compared to flood irrigation. Butter *et al.* (2014) reported that canal water applied through drip registered a yield increment of tomato to the tune of 8.6 per cent in paired row over furrow irrigation coupled with 50 per cent saving in irrigation water applied. Biswas *et al.* (2015) pointed out that in tomato, the growth, yield and yield contributing characters like plant height, fruit length, fruit diameter, and unit fruit weight were influenced significantly by different levels of irrigation. The plant height varied significantly with different levels of irrigation and was maximum with 100 per cent ETc and minimum with 50 per cent ETc through drip irrigation.

Mulching with black polythene for vegetable production has been reported to control weed incidence, reduce nutrient losses and improve the hydro thermal characteristics of soil (Singh, 2005). Swarajyalakshmi *et al.* (2005) opined that the highest green chilli yield (21.56 t ha^{-1}) was recorded through drip method scheduled at 0.8 ET under black polythene mulch. This increase was accounted to 34 per cent over conventional method of irrigation practiced. Singh *et al.* (2009) reported that plant height, leaf area index (LAI), and dry matter production (DMP) of tomato were significantly superior for the treatment which consisted of black polythene mulch along with drip irrigation than other treatments.

Biswas *et al.* (2015) pointed out that use of mulches along with irrigation gave higher WUE over irrigation alone. A better effect of mulches on WUE was observed when it was combined with lower irrigation regime. At irrigation level of 50 per cent ETc, irrigation to tomato plot mulched with polythene produced better WUE (592 kg ha mm^{-1}) than that of paddy straw mulched (581 kg ha mm^{-1}) or unmulched treatment.

2.2 FERTIGATION

Fertigation is an important practice in precision farming that permits the farmer to apply optimum dose of fertilizers through drip irrigation which enhance production and productivity of crops. Or and Coelho (1996) opined that crop nutrient requirements can be met accurately through a drip fertigation system. Fertilizers should be applied in a form that becomes available in synchrony with crop demand for maximum utilization of nutrients from fertilizers (Boyhan *et al.*, 2001). In fertigation, nutrient use efficiency could be as high as 90 per cent compared to 40 to 60 per cent in conventional methods (Solaimalai *et al.*, 2005).

Similar to frequent application of water, optimum split application of fertilizer improves quality and quantity of crop yield than the conventional practice (Miller *et al.*, 1976). Clark *et al.* (1991) reported that fertigation resulted in reduced water and fertilizer application as compared to those associated with conventional irrigation method. Papadopoulos (1992) stated that fertigation is an attractive technology in modern irrigated agriculture to increase the yield and quality together with improved water and fertilizer use efficiency. Drip fertigation provides an efficient method of fertilizer delivery and if properly managed, reduce overall fertilizer application rate and minimize the adverse environmental impact (Hartz and Hochmuth, 1996).

Increased growth and yield of vegetable crops under fertigation have been reported by many scientists (Bhella, 1988; Bafna *et al.*, 1993; Malik *et al.*, 1994; Bresler, 1997; Akanda *et al.*, 2004).

In tomato, the yield increased linearly with the application of 50 kg phosphorus (P) ha^{-1} through broadcast. But in fertigated treatment, application of 25 kg P ha^{-1} was enough and 50 per cent of P was saved through fertigation due to increased fertilizer use efficiency (Carrijo and Hochmuth, 2000). Hebbar *et al.* (2004) observed higher tomato yield through nitrogen (N) fertigation than banded and furrow irrigation or banded and then trickle irrigated. Fertigation in tomato and brinjal gave encouraging results in terms of yield and economic return (Akanda *et al.*, 2004). Potassium (K) fertigation in tomato produced maximum marketable fruit yield and qualities and improved the fruit colour (Hartz *et al.*, 2005).

2.2.1 Fertigation Levels

2.2.1.1 Effect on Growth Attributes of Solanaceous Vegetables

A study conducted by Alcanter *et al.* (1999) revealed that higher amount of NPK fertigation in tomato showed increased DMP and growth compared to lower dose as fertigation and surface furrow irrigation treatments with fertilizer application. Hebbar *et al.* (2004) pointed out that fertigation with water soluble fertilizer gave significantly higher dry weight per plant and LAI compared to drip irrigation with conventional soil application of fertilizers in tomato.

Four levels of N (0, 100, 200 and 300 kg ha^{-1}) were applied through fertigation to evaluate the effect of N fertigation on growth attributes of tomato. Results revealed that the highest LAI (at 75 days after transplanting) and DMP were observed with the highest N rate of 300 kg ha^{-1} (Elia *et al.*, 2007).

Shedeed *et al.* (2009) revealed that a significantly higher dry weight was obtained with fertigation treatments over drip irrigation and the total dry weight at final harvest did not differ significantly among 50 per cent (4.17 t ha^{-1}) and 75 per cent (4.48 t ha^{-1}) fertigation rates while the maximum DMP was obtained with 100 per cent fertigation (4.86 t ha^{-1}) in tomato.

According to Brahma *et al.* (2010) application of recommended dose (RD) of N and K through drip significantly influenced the growth parameters of tomato and 100 per cent RD of N and K (75:60 kg ha^{-1}) fertigation recorded higher values for plant height and number of primary branches than 50 per cent RD of N and K through fertigation and drip irrigation with conventional application of fertilizers.

Gupta *et al.* (2010) reported that 60 per cent recommended NPK through fertigation recorded the maximum plant height (132.4 cm), number of primary branches plant^{-1} (8.20) and number of nods per main stem (29.2) compared to 100 per cent and 80 per cent recommended NPK through fertigation and 100 per cent RD through manual application in tomato. Growth attributes, *viz.*, plant height (96.70 cm), number of branches (18.25), stem diameter (2.06 cm) and LAI (3.49) of tomato were significantly higher owing to application of 100 per cent RD through water soluble fertilizer fertigation at 80 per cent evaporation (Imamsaheb *et al.*, 2011).

Prabhakar *et al.* (2012) found that all fertigation treatments resulted in better tomato growth as indicated by higher plant height, number of branches plant^{-1} and flower cluster plant^{-1} compared to conventional soil applied fertilizers. The pooled data analysis revealed that 50 per cent NPK fertigation of 70 per cent RD registered significantly higher plant height (62.7 cm) and higher number of branches (10.2).

Ugade *et al.* (2015) opined that plant height, number of primary branches plant^{-1}, number of leaflets plant^{-1} and leaf area plant^{-1} were significantly influenced by different fertigation levels and 100 per cent RD of NPK as fertigation registered higher values for these growth parameters whereas minimum values of these attributes of tomato were registered with fertigation of 60 per cent RD of NPK.

Fontes *et al.* (2000) studied the effect K fertigation on yield of tomato and reported that total and marketable tomato yields increased with the K rates, reaching their maxima of 86.4 and 73.4 t ha^{-1} at 198 and 194 kg ha^{-1} K, respectively.

Growth attributes, *viz.*, plant height (62.2 cm) and number of branches plant^{-1} (8.4) were higher for fertigation of 100 per cent RD of fertilizers in chilli (Tumbare and Bhoite, 2002). Fertigation of RD of fertilizer at every irrigation up to 105 days registered significantly higher growth attributes of chilli, like plant height, number of primary branches plant^{-1} and total DMP plant^{-1} (Tumbare and Nikam, 2004). Prabhakara *et al.* (2010) reported that, in chilli daily drip irrigation with sub surface fertigation at 10 cm depth recorded the highest plant height, leaf area and DMP and it was significantly superior to other treatments like surface fertigation and direct application of fertilizers.

Compared to check basin irrigation with normal fertilization, application of 125 per cent RD of solid soluble fertilizer as fertigation registered the highest plant height and plant spread in brinjal (Shinde *et al.*, 2002). Yadav *et al.* (2004) reported that 80 mm cumulative pan evaporation (CPE) irrigation treatment and fertigation of 100:50:25 kg NPK ha^{-1} in brinjal recorded the maximum plant height and number of branches per plant. In brinjal, maximum shoot length at 30, 60 and 90 days after planting (DAP) and number of branches plant^{-1} were observed in drip irrigation at 75 per cent of PE with 75 per cent of recommended N and K whereas the least shoot length (34.4, 70.0 and 99.1 cm at 30, 60 and 90 DAP, respectively) and less number of branches plant^{-1} were recorded in drip irrigation at 50 per cent of PE with 125 per cent of recommended N and K (Vijayakumar *et al.*, 2010).

2.2.1.2 Effect on Yield and Yield Attributes of Solanaceous Vegetables

Fertigation with higher dose of NPK in tomato registered 31.5 per cent yield increase compared to surface irrigation treatments with fertilizer application (Alcanter *et al.,* 1999).

Ajmalkhan (2000) found that fertigation of RD of N as urea and K_2O as muriate of potash applied in 15 equal splits at eight days interval from eight days after planting through fertigation registered higher tomato yield as compared to surface irrigation with conventional method of fertilizer application in sandy loam soil at Madhurai in Tamil Nadu. Fertigation of 250:250:250 kg NPK with water soluble fertilizer recorded the highest yield of 102 t ha^{-1} in tomato (Natrajan *et al.*, 2002).

According to Singandhupe *et al.* (2003) application of 120 kg N ha^{-1} produced the maximum tomato fruit yield of 27.4 and 35.2 t ha^{-1} in two year study compared to lower levels of N fertigation. Application of 100 per cent water soluble fertilizer (WSF) through fertigation registered the highest fruit yield and it was significantly superior over furrow irrigated and drip irrigated treatments with soil application of fertilizers, while 75 per cent rate of WSF through fertigation recorded 8 per cent yield reduction compared to 100 per cent WSF fertigation. Application of WSF recorded significantly higher number of fruits $plant^{-1}$ compared to other treatments (Hebbar *et al.*, 2004).

Singandhupe *et al.* (2005) revealed that application of 31 per cent RD of N and 69 per cent RD of N through fertigation during initial crop growth stages and flowering to reproductive stages of tomato, respectively resulted a higher marketable fruit yield of 41 t ha^{-1} over other treatments. Kadam and Karthikeyan (2006) found that 100 per cent RD of NPK through drip fertigation in tomato registered the highest yield contributing characters like number of fruits $plant^{-1}$and weight of fruits $plant^{-1}$.

Badr and El-Yazied (2007) reported that yield components and yield of tomato increased with high N rate compared to low N rate through fertigation and average fruit yields across fertigation were 48.71 t ha^{-1} and 62.63 t ha^{-1} for 200 and 300 kg N ha^{-1} respectively. Elia *et al.* (2007) also reported increased yield with high N rate in tomato.

Shedeed *et al.* (2009) reported that fertigation with 100 per cent NPK water- soluble fertilizer produced significantly superior fruit yield (58.76 t ha^{-1}) over furrow irrigated control, drip irrigation, 50 per cent NPK fertigation (48.18 t ha^{-1}) and 75 per cent NPK fertigation (54.16 t ha^{-1}). Also, fertigation treatments recorded significantly higher number of fruits and mean fruit weight plant^{-1} compared to drip and furrow irrigation.

Brahma *et al.* (2010) reported that N and K fertigation significantly increased the fruit yield of tomato and pooled data of two experiments showed an increasing trend with each corresponding increase in the level of N and K fertigation. Application of 100 per cent fertigation level recorded the highest marketable fruit yield and fertigation efficiency compared to the conventional soil application of N and K. However, there was no significant difference in marketable yield between 100 per cent and 75 per cent fertigation levels.

Gupta *et al.* (2010) found that the treatment combination of 80 per cent evapotranspiration through drip along with 60 per cent recommended NPK through fertigation recorded the maximum values for yield attributes and produced the highest tomato yield of 989.3 q ha^{-1}, which was found 81.6 per cent higher than the traditional method of surface irrigation and fertilizer application. Imamsaheb *et al.* (2011) opined that 100 per cent NPK recommendation through drip registered the highest value for yield and yield attributes such as number of fruits plant^{-1} (40.71), average fruit weight (60.89 g), yield plant^{-1}, plot^{-1} and ha^{-1} (2.36 kg, 53.84 kg and 56.98 t ha^{-1} respectively).

Akanda *et al.* (2012) revealed that satisfactory yield of summer tomato can be obtained with the balanced and lower fertilizer doses of N-100 P-55 K-120 B-1 Zn-4 Mg-4 kg ha^{-1}. Prabhakar *et al.* (2012) found that all fertigation treatments (50 per cent and 100 per cent NPK fertigation) recorded higher marketable tomato yield over conventional soil application of fertilizers to the tune of 10.75 to 20.69 per cent. Singh *et al.* (2013) reported that the highest average fruit weight, fruit yield plant^{-1} and fruit yield ha^{-1} were registered with 100 per cent RD of NPK through fertigation as compared to 2/3 rd RD of NPK fertilizer in tomato.

Rajan *et al.* (2014) also reported that fertigation with conventional fertilizers + liquid fertilizers registered maximum yield in tomato.

Fertigation of NPK with different levels significantly influenced the yield attributing parameters of polyhouse tomato and higher number of fruits plant^{-1}and fruit weight plant^{-1} were registered for 100 per cent RD through fertigation than rest of the fertigation levels such as 80 per cent and 60 per cent. Application of 70 per cent of RD of NPK through fertigation recorded significantly higher marketable yield (44.9 t ha^{-1}) and was at par with application of 50 per cent N and K fertigation of the RD using commercial fertilizers. The maximum fruit yield unit^{-1} of polyhouse was recorded with fertigation of 100 per cent RD during two years (Ugade *et al.*, 2015).

Vijayakumar *et al.* (2010) reported that fertigation of 70 per cent N and K registered the highest yield (38.46 t ha^{-1} in first crop season and 34.13 t ha^{-1} in second crop season) in brinjal and it was superior over other treatments. In brinjal, 100 per cent RD of fertilizer (150:50:50 kg ha^{-1}) through water soluble fertigation recorded significantly superior yield of 36.74 t ha^{-1} over 80 per cent RD through water soluble fertigation (32.31 t ha^{-1}) (Ugade *et al.*, 2014).

Pandey *et al.* (2013) reported that, in chilli N fertigation significantly influenced the yield attributes and yield and recorded 34.46 per cent higher yield compared to top dressing method.

2.2.1.3 Effect on Quality Attributes of Solanaceous Vegetables

Alcanter *et al.* (1999) studied the quality parameters (size, firmness and soluble sugars) of tomato in response to various fertigation programmes and found that quality parameters were consistently enhanced by fertigation. Fertigation treatments increased sugar content. Fertigation at low level registered the highest sugar content and fruit firmness compared to higher levels of fertigation and conventional application of fertilizers.

Studies on NPK fertigation by field grown tomato showed that titrable acidity and ascorbic acid concentration varied with treatments. Ascorbic acid concentration was significantly higher in water soluble fertilizer fertigation (19.33 mg 100 g^{-1} fresh weight) compared to furrow irrigation and drip irrigation (Hebbar *et al.*, 2004).

Kaviani *et al.* (2004) found that the highest vitamin C content in tomato was obtained with application of moderate rates of macro nutrients and micro nutrients with K as sulphate of potash applied by fertigation. The quality parameters such as pH, TSS (Total soluble solids) and lycopene content at 100 per cent recommended NPK level from liquid fertilizer through drip irrigation were superior to solid fertilizer plus surface irrigation while the reverse trend was observed in the case of acidity (Kadam and Karthikeyan, 2006).

Aruna *et al.* (2007) reported that the quality attributes of tomato improved with fertigation along with black polythene mulching. TSS (3.60^0 brix), acidity (0.79 per cent) and ascorbic acid content (64.20 mg 100g^{-1}) were high in the treatment, mulching with black polythene along with the application of 100 per cent RD of NPK in the form of ammonium sulphate + super phosphate + potassium chloride.

According to Brahma *et al.* (2010) fruit quality parameters of tomato were significantly influenced by fertigation treatments. Application of 100 per cent RD of N and K recorded the highest fruit length, fruit girth, pericarp thickness, edible portion, juice percentage, TSS and ascorbic acid content. Akanda *et al.* (2012) revealed that fruit quality parameters like TSS, vitamin- C, and beta carotene were the highest for the treatment with N-100 P-55 K-120 B-1 Zn-4 Mg-4 kg ha^{-1} through fertigation. They opined that application of micro nutrients along with balanced dose of NPK has significant effect on quality of fruits.

Ugade *et al.* (2015) reported that tomato quality parameters, *viz.*, TSS, titrable acidity, ascorbic acid content, lycopene content, carotene content and pericarp thickness were significantly influenced by different fertigation levels. Fertigation of 100 per cent RD recorded significantly superior quality attributes, *viz.*, TSS (5.47 and 5.43° Brix), titrable acidity (0.46 and 0.47 percentage), ascorbic acid (26.65 and 25.56 mg 100 g^{-1}), lycopene content (2.86 and 2.79 mg 100 g^{-1}), carotene content (1.29 and 1.25 mg 100 g^{-1}) and pericarp thickness (6.43 and 6.37 mm) during first and second year while minimum values of these parameters were noticed with fertigation of 60 per cent RD .

2.2.1.4 Effect on Nutrient Uptake in Solanaceous Vegetables

Singandhupe *et al.* (2003) found that there was progressive increase in N uptake with increasing N levels through fertigation; optimum and maximum total estimated N uptake at 120 kg N ha^{-1} during first year of experiment were 110.70 and 111.75 kg ha^{-1} respectively in tomato. Water soluble fertigation in tomato had significantly higher NPK uptake over drip irrigation with conventional fertilizer application. Sub surface drip fertigation, N and K fertigation, half soil application and half fertigation of RD of fertilizers showed N uptake close to that of water soluble fertilizer fertigation (Hebbar *et al.*, 2004).

According to Elia *et al.* (2007) N uptake by tomato crop varied with levels of N applied through fertigation. The crop N uptake increased linearly from control (176 kg ha^{-1}) to the highest N dose (339 kg ha^{-1}).

Shedeed *et al.* (2009) reported that total uptake and recovery of NPK by tomato plants was significantly affected by method of fertilizer application and rate of fertigation. The applied NPK in soluble form in fertigation treatments may have been distributed better through root zone of tomato than soil applied treatments providing more available amounts for plant uptake. Uptake of NPK and recovery was the highest under 100 per cent fertigation rate over all other fertigation rates.

Ugade *et al.* (2014) observed that NPK uptake by leaves, stems and fruits of brinjal were significantly influenced by the levels of fertigation. Application of 100 per cent RD of fertilizers through drip irrigation showed significantly higher uptake of major nutrients N, P and K than fertigation of 80 per cent RD of fertilizers.

2.2.1.5 Effect on Water Use Efficiency of Solanaceous Vegetables

Singandhupe *et al.* (2003) observed that WUE in drip irrigation with different levels of N in tomato was 68 and 76.8 per cent higher over furrow irrigation at two years respectively. Butter *et al.* (2014) reported that highest WUE was observed in 50 per cent RD of N applied through trickle irrigation in tomato under paired row planting than 100 per cent RD of N application through trickle irrigation in tomato under semi-arid condition.

Muralidhar (1999) stated that higher WUE was recorded at an application of 100 per cent RD of water soluble fertilizer through drip irrigation in capsicum, which was at par with 75 per cent RD. Ugade *et al.* (2014) reported that, in brinjal 100 per cent RD of fertilizers through drip irrigation recorded the highest WUE of 3230.5 kg ha cm^{-1} than fertigation of 80 per cent RD of fertilizers.

2.2.1.6 Effect on Root Characteristics of Solanaceous Vegetables

Hebbar *et al.* (2004) found that root characteristics of tomato were significantly influenced by fertigaton and it was evidenced by significantly higher number of primary roots (13.8–15.3), fibrous roots arising from stem base (30.3–34.0), maximum root length (82.8–91.2 cm) and average length of primary roots (44.2–50.3 cm) in fertigation treatments compared to soil application treatment. Root dry weight was significantly higher (13.9–16.2 g $plant^{-1}$) in fertigation treatments compared to soil application treatments (10.2–10.7 g).

According to Rajan *et al.* (2014), root growth of tomato showed marked differences among three different fertilizer combinations applied through drip systems. Application of 100 per cent RD through fertigation showed the highest root growth than conventional fertilization with solid soluble fertilizers. The lowest root growth was observed under conventional fertilization.

2.2.2 Fertigation Interval

2.2.2.1 Effect on Growth Attributes of Solanaceous Vegetables

Prabhakara *et al.* (2010) reported that daily drip irrigation with daily sub surface fertigation at 10 cm depth recorded significantly higher plant height (71.8 cm), number of primary branches (18.1 plant^{-1}), leaf area (94.2 plant^{-1}), fruit dry weight (77.2 g plant^{-1}) and total DMP (176.7 g plant^{-1}) and it was on par with daily drip irrigation with weekly subsurface fertigation at 10 cm depth in chilli.

Ugade *et al.* (2015) revealed that fertigation of 12 equal splits of NPK at every nine days interval up to 120 days after transplanting registered significantly higher growth attributes *viz*., plant height (207.42 and 221.97 cm), number of primary branches plant^{-1} (14.99 and 14.36), number of leaflets plant^{-1} (81.20 and 76.81) and leaf area plant^{-1} (87.51 and 87.51 dm^{2}) while the lowest values of these parameters were noticed with fertigation of six equal splits of NPK at every 18 days interval upto 120 days after transplanting in tomato.

2.2.2.2 Effect on Yield and Yield Attributes of Solanaceous Vegetables

Cook and Sanders (1991) examined the effect of fertigation frequency (daily to monthly) on sub surface drip-irrigated tomato yields in two South Carolina soils. Daily or weekly fertigation significantly increased yield compared with monthly fertigation, but there was no advantage of daily over weekly fertigation on loamy sand. The same fertigation frequencies resulted in no differences in yield and quality on a loamy fine sand soil. Nwadukwe and Chude (1994) revealed that tomato yield was significantly different when N was fertigated at five days interval compared with nine days via a surface drip system. The findings of two-year investigation using tomato, chilli and aubergine have indicated with high statistical significance that fertigation twice a week with compound fertilizer NPK of 18-18-18 with 3 per cent Mg and chelated forms of micronutrients Fe, Cu, Zn, Mn, B and Mo at a concentration of 0.75 g L^{-1} was the most efficient rate for higher yield per applied fertilizer. Also, at this fertigation frequency the tested vegetables had maintained high productivity in line with yields gained with more frequent fertigation (Al-Ghawas and Al-Mazidi, 2004).

Badr and El-Yazied (2007) found that yield of tomato was significantly influenced by the fertigation frequencies. Singh *et al.* (2013) reported that with change in fertilizer application from conventional to weekly and daily resulted in significant increase in the fruit yield of tomato. In terms of per cent increase, daily and weekly method of fertilizer application recorded an increase of 22.6 and 13.38 per cent respectively over conventional method of fertilizer application. In the case of yield attributes of tomato, fertigation of 12 equal splits of NPK at every nine days interval upto 120 days after transplanting exhibited significantly higher number of fruits plant^{-1} (72.54 and 66.30) and fruit weight plant^{-1} (4.80 and 4.24 kg) during both the years of study while the lowest number of fruits plant^{-1} and fruit weight plant^{-1} was noticed under the fertigation of six equal splits of NPK at every 18 days interval upto 120 days after transplanting during the period of investigation (Ugade *et al.*, 2015).

In green chilli, yield attributes increased significantly with increased frequency (from fortnightly to daily interval) and optimum depth of fertigation (10 cm). The practice of daily drip irrigation with daily sub surface fertigation produced significantly higher yield attributes like fruit length (12.2 cm), fruit girth (4.7 cm), number of flowers (85.2 plant^{-1}), number of fruits(66.8 plant^{-1}) and fruit yield (426.1 g plant^{-1} and 16.09 t ha^{-1}) and compared to other treatments (Prabhakara *et al.*, 2010).

2.2.2.3 Effect on Quality Attributes of Solanaceous Vegetables

Prabhakara *et al.* (2010) found that the quality characteristics of green chilli like TSS and ascorbic acid content were reduced with reduced frequency of fertigation. Daily sub surface fertigation registered significantly superior values for TSS and ascorbic acid content (141.9 mg 100 g^{-1}) compared to all other treatments at weekly and fortnightly intervals.

Ugade *et al.* (2015) reported that fertigation of 12 equal splits of NPK at every nine days interval upto 120 days after transplanting noticed significantly superior fruit quality parameters in tomato, *viz.*, TSS (5.40 and 5.37° Brix), titrable acidity (0.45 and 0.46 per cent), ascorbic acid (26.38 and 25.02 mg 100 g^{-1}), lycopene content (2.83 and 2.76 mg 100 g^{-1}), carotene content (1.25 and 1.20 mg 100 g^{-1}) and pericarp thickness (6.21 and 6.21 mm) during two years of study, while minimum values of these parameters were noticed with fertigation of six equal splits of NPK at every 18 days interval upto120 days after transplanting.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

An investigation entitled "Fertigation for precision farming in tomato (*Solanum lycopersicum* L.)" was conducted to standardize the fertigation schedule and to assess the impact of precision farming practices on the growth and yield of tomato. The materials used and methods adopted are briefly described below.

3.1 MATERIALS

3.1.1 Experimental Site

The investigation was carried out in farmer's field at Pirappancode in Manickal Panchayath, Thiruvananthapuram, Kerala. Field is situated at 8.65^0 N latitude and 76.91^0 E longitude at an altitude 18 m above mean sea level.

3.1.2 Season

The field experiment was conducted during the summer season of 2015 (February to June 2015).

3.1.3 Weather Conditions

Warm humid tropical climatic condition prevailed in the area. The detailed weather data (rainfall, maximum temperature, minimum temperature and relative humidity) during cropping period are depicted in Fig.1 and Appendix 1. The total rainfall during the period was 759.8 mm. Rainfall during crop period in comparison with the average of previous five year data are presented in Fig. 2.

3.1.4 Soil

Soil of the experimental site was red sandy loam. Soil was slightly acidic, medium in available N, P and K. Physical and chemical properties of the soil are described in Table 1.

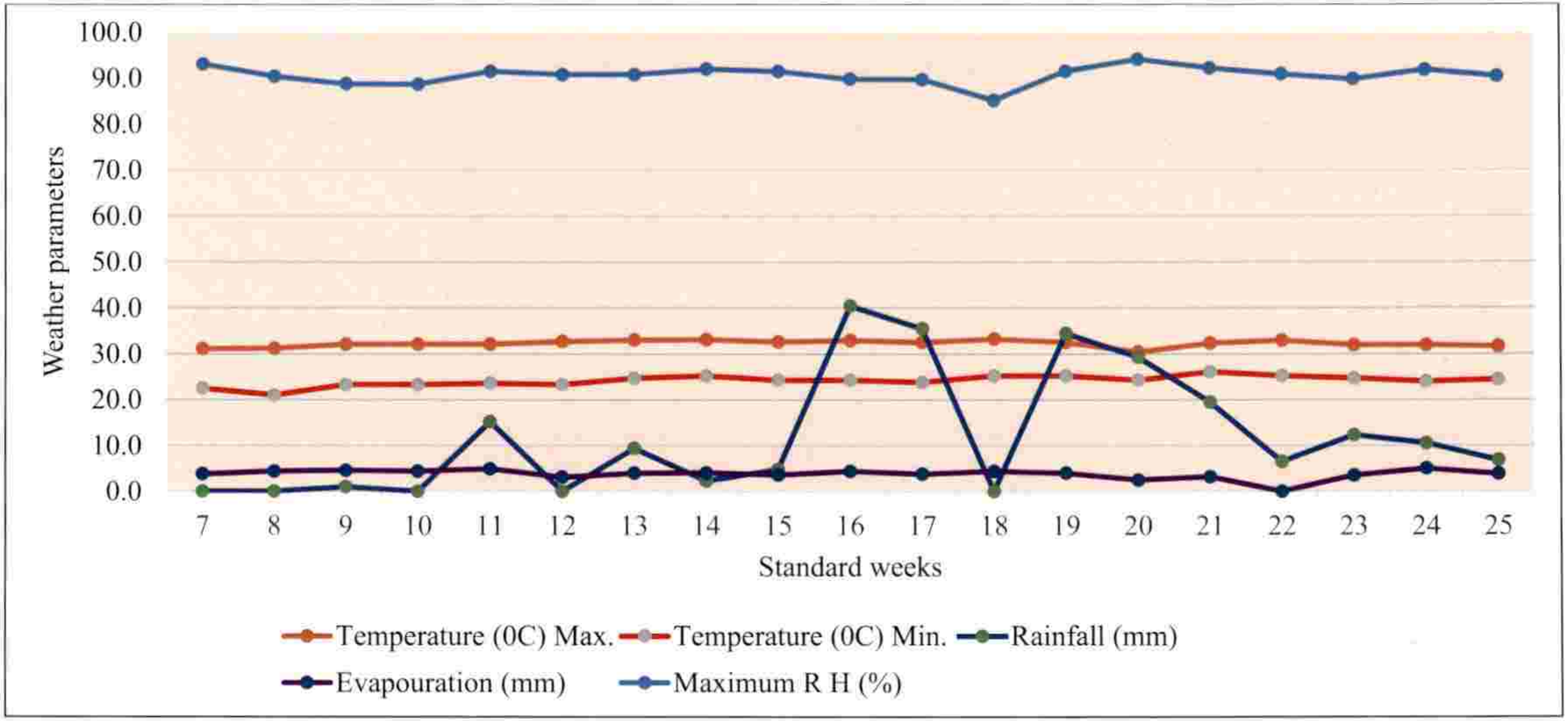

Fig. 1. Weather parameters during the cropping period (February – June 2015)

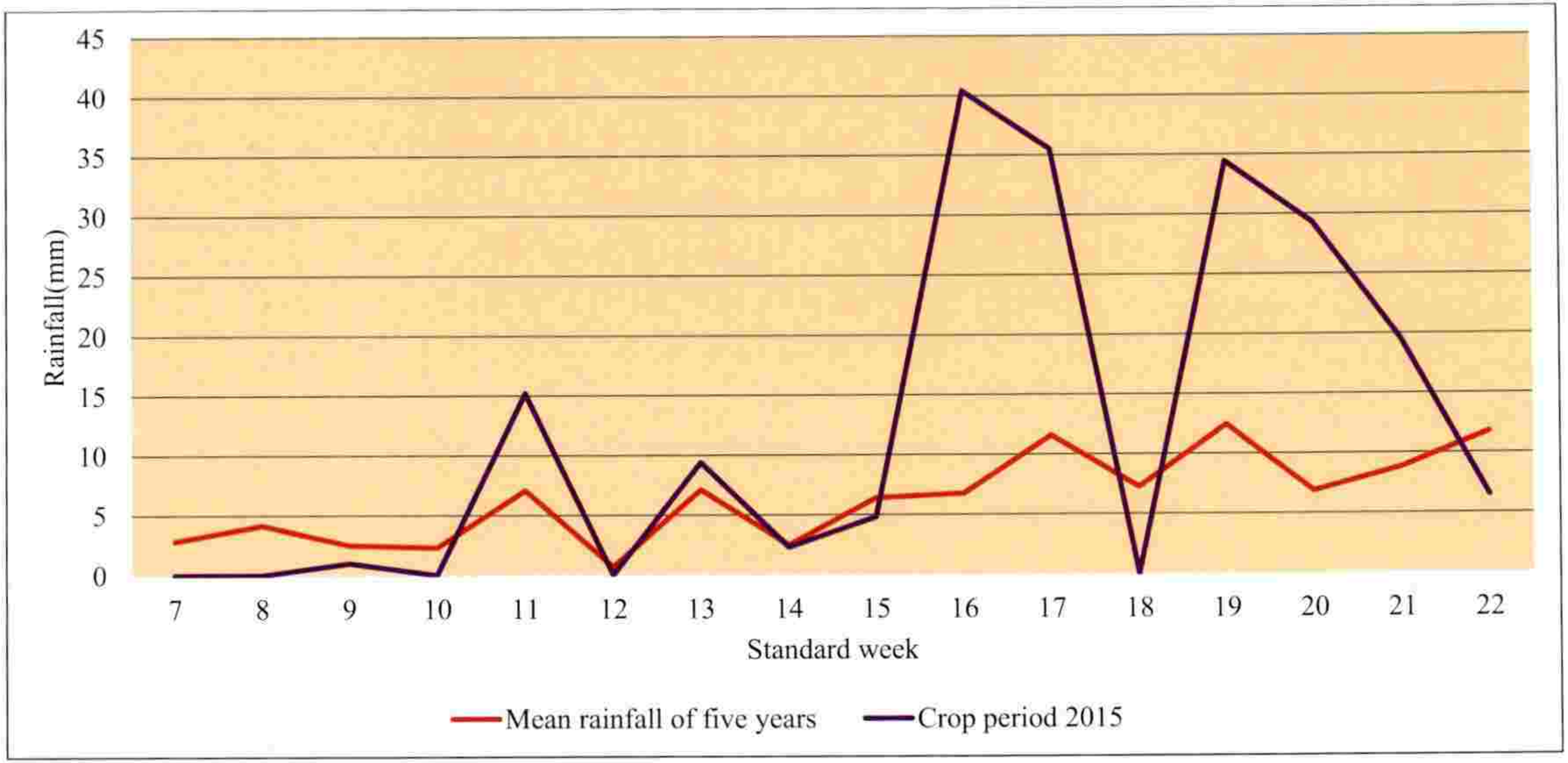

Fig. 2. Rainfall during crop period (Feb- June, 2015) in comparison with the average of previous five years

Table 1. Physical and chemical properties of soil at experiment site

Parameters	Content	Status	Methodology
A. Mechanical composition			
Coarse sand (%)	46.85		Bouyoucos Hydrometer Method (Bouyoucos, 1962)
Fine sand (%)	11.40		
Silt (%)	24.32		
Clay (%)	18.64		
Texture		Sandy loam	
B. Chemical Properties			
Soil reaction (pH)	5.94	Slightly acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
EC (dS m^{-1})	0.108	Normal	Ammonium saturation using neutral normal ammonium acetate (Jackson, 1973)
Organic carbon (%)	0.31	Low	Walkley and Black's rapid titration (Jackson, 1973)
Available N (kg ha^{-1})	294.00	Medium	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	12.99	Medium	Bray's colorimetric method (Jackson, 1973)
Available K (kg ha^{-1})	242.93	Medium	Ammonium acetate method (Jackson, 1973)

3.1.5 Cropping History of the Field

The field was left fallow during the previous year.

3.1.6 Crop and Variety

Indeterminate tomato hybrid Lakshmi from Nunhems India Pvt. Ltd. Bengaluru was grafted on wild brinjal (*Solanum torvum*) and these grafts were used for the study. Wild brinjal is resistant to bacterial wilt disease and which is a serious problem in tomato cultivation.

3.2 METHODS

3.2.1 Design and Layout

Design : Split plot
Replication : 4
Treatment : 4 main plot treatments, 2 sub plot treatments and 2 controls
Treatment combinations: 8+2 = 10
Sub plot size : 3 m × 3.6 m (net plot size : 2.4 m x 3.0 m)
Spacing : 60 cm × 60 cm

3.2.2 Treatment Details

Treatments consisted of four main plot treatments, *viz.*, levels of nutrients and two subplot treatments, *viz.*, fertigation intervals and two controls.

Main plot treatments: Levels of nutrients (L)

l_1 – 75 per cent RD of N and K

l_2 – 100 per cent RD of N and K

l_3 – 125 per cent RD of N and K

l_4 – 150 per cent RD of N and K

[The RD for tomato is 75:40:25 kg N, P_2O_5 and K_2O ha^{-1} (KAU, 2011)]

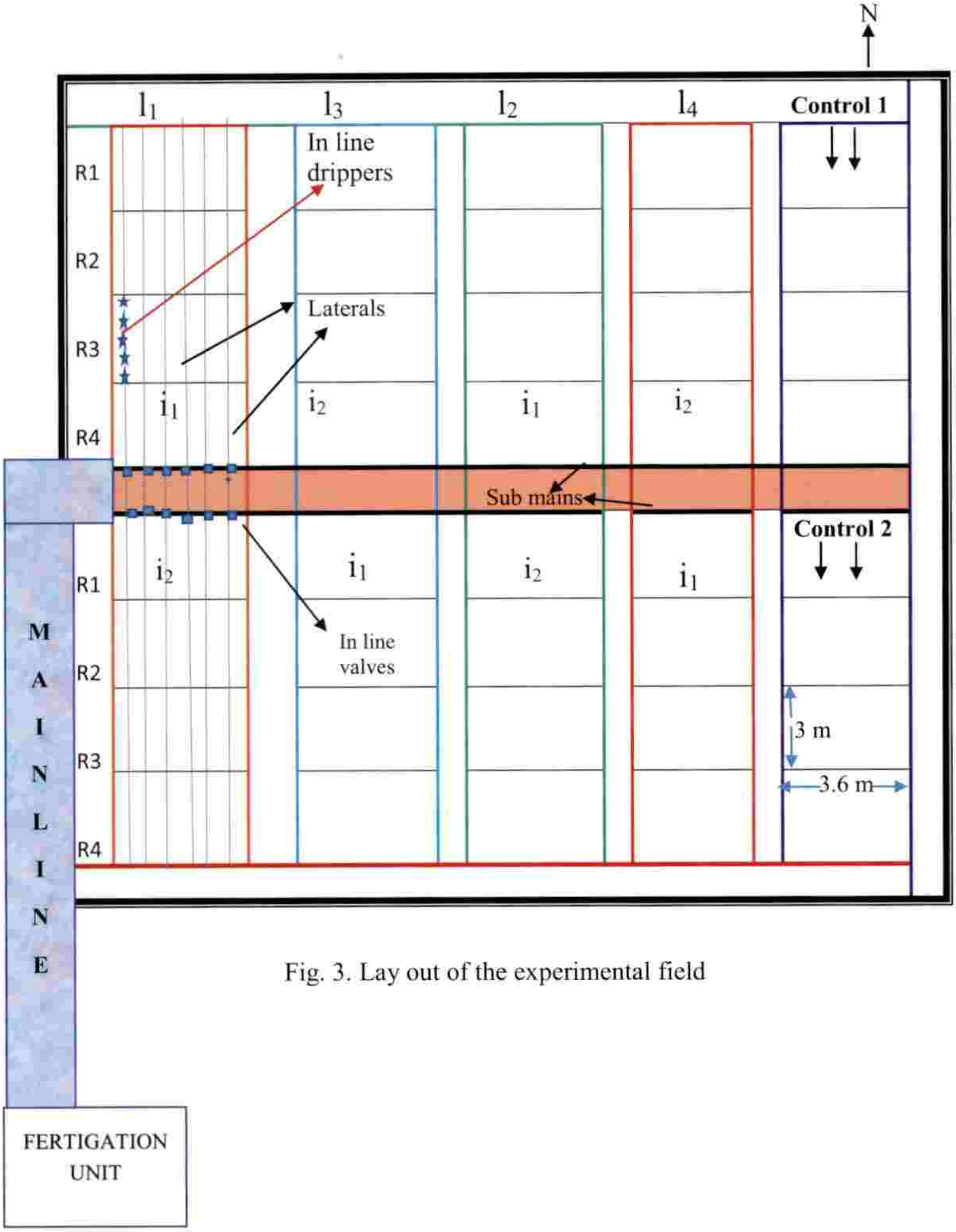

Fig. 3. Lay out of the experimental field

Sub plot treatments: Fertigation interval (I)

i_1 – Fertigation once in 4 days

i_2 – Fertigation once in 8 days

Control 1 - KAU *ad hoc* POP for precision farming for tomato (KAU, 2013)

Control 2 - KAU POP for conventional farming (Normal planting with basin irrigation and soil application of fertilizers without mulching) (KAU, 2011)

Treatment combinations: 8+2= 10

l_1i_1, l_1i_2, l_2i_1, l_2i_2

l_3i_1, l_3i_2, l_4i_1, l_4i_2 + 2 controls

3.2.3 Field Preparation and Planting

Field was cleaned and deep ploughing was done with a cultivator. Since soil pH was in acidic range, lime was applied @ rate of 500 kg ha^{-1}. Farm yard manure was applied @ 25 t ha^{-1}. Raised beds of 20 cm height were taken and field layout was carried out. Each subplot had a size of 3 m x 3.6 m. Tomato grafts were planted at 60 cm x 60 cm spacing. Shading was given to the seedlings for better establishment.

3.2.4 Polythene Mulching

Black polythene mulch was provided to all treatments except control 2 (KAU POP for conventional farming). Ordinary black polythene of 30 micron size was used for mulching.

3.2.5 Layout of Drip Fertigation System

Irrigation water was pumped from a well and an injector assembly was attached for fertigation purpose. Two sub main lines were laid out in the field to supply water and nutrients to the plant. Five laterals were laid out in each plot and inline drippers with a discharge rate of 4 L $hour^{-1}$at 60 cm spacing was provided to

Plate 1. Drip installation

Plate 2. Polythene mulching

supply water and nutrients to the root zone of the plant. Irrigation was given on all days except rainy days at 2 L plant^{-1} day^{-1}.

Fertigation for i_1 started four days after planting and the entire dose was given in 30 splits and for i_2, fertigation started eight days after planting and completed in 15 splits. For KAU ad hoc recommendation for precision farming (control 1), fertigation started three days after planting and completed with 40 splits.

3.2.6 Manures and Fertilizers

Farm Yard Manure (containing 0.55 per cent N, 0.23 per cent P and 0.46 per cent K) @ 25 t ha^{-1} and P_2O_5 @ 40 kg ha^{-1} were applied uniformly to all treatments as basal. For fertigation except control 1 (KAU *ad hoc* POP for precision farming), N and K were supplied as urea (46 per cent N) and muriate of potash (60 per cent K) respectively. In control 1, 19:19:19, 12:61:0, 13:0:45, urea and rock phosphate were given as N, P and K source (Table 2 and Table 3).

3.2.7 After Cultivation

The new sprouts and leaves of root stock (*Solanum torvum*) were removed for enhanced growth of tomato. Staking was provided to each plant one month after planting (MAP) and bamboo poles were used for staking.

3.2.8 Plant Protection

Psudomonas flourescens @ 20 g litre^{-1} was given as a prophylactic spray against fungal diseases. Dimethoate @ 0.5 per cent was sprayed twice against sucking pests and mite, at 20 DAP and 45 DAP.

3.2.9 Harvesting

Harvesting was done from 60 DAP. Number of harvests varied with treatments. Fruits were harvested at red ripe stage.

Plate 3. General view of the field experiment

Plate 4. Crop at fruiting stage

Table 2. Schedule of nutrient application in treatments

Levels of nutrients	N:P:K doses (kg ha^{-1})	Quantity of fertilizers		Fertigation intervals
		Urea (kg ha^{-1})	MOP (kg ha^{-1})	
l_1	56.25:40:18.75	122	31.25	i_1- Four days (30 splits) i_2- Eight days (15 splits)
l_2	75:40:25	163	42	
l_3	93.75: 40: 31.25	204	52	
l_4	112.5: 40: 37.5	245	63	
P @ 40 kg ha^{-1} as basal for all treatments supplied as rock phosphate - 200 kg ha^{-1}				

Table 3. Schedule of nutrient application in controls

Controls	N:P:K recommendation (kg ha^{-1})	Quantity of fertilizers (kg ha^{-1})	Application interval / schedule
Control 1 (KAU *ad hoc* POP for precision farming)	264: 130: 281	19:19:19 = 198 12:61:0 = 44 13:0:45 = 540 Urea = 327 Rock phosphate = 325 (basal soil application)	3 days
Control 2 (KAU POP for conventional farming)	75:40:25	Urea - 163 Rock phosphate - 200 MOP - 42	½ N and full P and ½ K -basal ¼ N and ½ K – 1 MAP Remaining N – 2 MAP

MAP- Month after planting

3.3 OBSERVATIONS TAKEN

Five plants from each plot were selected and tagged as observational plants.

3.3.1 Biometric Observations

3.3.1.1 Plant Height

Height of observational plants was taken from base to the top most leaf and expressed in cm. Plant height was recorded at 30, 60 and 90 DAP.

3.3.1.2 Primary Branches Plant $^{-1}$

Number of primary branches were counted from five observational plants at 30, 60 and 90 DAP and the mean was worked out.

3.3.1.3 Leaf Area Index at Flowering

The leaf area was calculated using a general relationship, A= b x l x w where b is a coefficient. Leaf area index at flowering was calculated using the equation developed by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area plant}^{-1}\ (\text{cm}^2)}{\text{Land area occupied by the plant}\ (\text{cm}^2)}$$

3.3.1.4 Dry Matter Production at Harvest

Total DMP was determined after final harvest from the observational plants in each treatment. Dry weight of fruits as well as vegetative parts were taken. The samples were dried to a constant weight in hot air oven at 65 ± 5^0 C and the dry weights were recorded.

3.3.1.5 Crop Duration

Crop duration was recorded in days and it was taken from the day of planting to the end of cropping period.

3.3.2 Yield and Yield Attributes

3.3.2.1 Days to 50 Per cent Flowering

Days taken for the 50 per cent flowering of the net population in each treatment was recorded.

3.3.2.2 Fruit Set (%)

Number of fruits produced per selected tagged inflorescence was recorded and expressed as percentage.

$$\text{Fruit set (\%)} = \frac{\text{Number of fruits per inflorescence}}{\text{Number of flowers per inflorescence}} \times 100$$

3.3.2.3 Fruits Plant^{-1}

Number of fruits harvested in observational plants in each treatment was recorded upto the last harvest and average was calculated.

3.3.2.4 Fruit Length

Using Vernier Calipers, fruit length was measured from the apex of the fruits to the base and expressed in cm.

3.3.2.5 Fruit Girth

Fruit girth was measured using a thread. Thread was kept around middle portion of the fruits and the length of the thread was measured using meter scale and expressed as cm. Five fruits from each observational plant were taken for measuring girth.

3.3.2.6 Fruit Weight

Fruits harvested from observational plants were weighed using an electronic balance and individual fruit weight expressed in g and mean weight calculated.

3.3.2.7 Fruit Yield Plant $^{-1}$

Total fruit yield from each tagged plant was found out and mean yield was calculated in kg.

3.3.2.8 Fruit Yield ha $^{-1}$

Fruit yield in the net plot were converted to yield in t ha $^{-1}$.

3.3.2.9 Number of Pickings

Total number of harvests from each observational plant during the entire crop period was counted and mean worked out.

3.3.2.10 Harvest Index

Harvest index was found out by the standard equation given by Donald (1962)

$$\text{HI} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}$$

3.3.3 Root Studies at Final Harvest

3.3.3.1 Root Length

Root length of the observational plants was measured after final harvest using a meter scale and expressed in cm.

3.3.3.2 Root Volume

Water displacement method using a graduated cylinder was used to measure the root volume of the observational plants in each treatment and the volume expressed as cm^3. Root volume was taken after the final harvest.

3.3.3.3 Root weight

Root weight was taken using an electronic balance after final harvest and expressed in grams.

3.3.4 Moisture Studies

3.3.4.1 Water Use Efficiency

$$\text{Field Water Use Efficiency} = \frac{\text{Economic yield of the crop (kg ha}^{-1}\text{)}}{\text{Total water requirement (mm)}}$$

Water requirement was measured by adding irrigation water required, effective rainfall and soil moisture contribution. Since moisture contribution was negligible,

WR = irrigation requirement + effective rainfall [70% of total rainfall (Dastane, 1974)]. WUE is expressed as kg ha mm^{-1}

3.3.4.2 Water Productivity

Water productivity was calculated using the following formula (Kijne *et al.*, 2003) and expressed as kg ha mm^{-1}

$$\text{Water Productivity} = \frac{\text{Total biomass produced (kg ha}^{-1}\text{)}}{\text{Total water utilized (mm)}}$$

3.3.5 Pest and Disease Incidence

The incidence of major pest and disease was noticed during crop growth period. Major pests include mite (*Tetranichus* sp.) and serpentine leaf miner (*Liriomyza trifolii*).

3.3.6 Chemical Analysis

3.3.6.1 Uptake of N, P and K by Crop at Harvest

Nutrients N, P and K were measured by plant analysis using standard procedures (Table 4) and uptake was calculated by multiplying the nutrient content with dry matter yield of respective treatment and expressed as kg ha $^{-1}$.

Table 4. Estimation of plant nutrient status

Particulars	Method used
N (%)	Microkjeldahl method (Jackson, 1973)
P (%)	Single acid digestion & colorimetry (Piper, 1967)
K (%)	Single acid digestion & flame photometry (Piper, 1967)

3.3.6.2 Soil Nutrient Status

Before the experiment soil samples were collected and a composite soil sample was analysed for N, P and K. After the experiment, samples were taken from different treatment plots. Soil samples were sieved through 2 mm sieve and analysed for N, P and K using standard procedures as outlined in Table 1.

3.3.6.3 Organic Carbon

Organic carbon content of the soil samples was assessed using Walkey and Black's rapid titration method (Jackson, 1973) before and after the field experiment.

3.3.6.4 Soil pH

Soil reaction was estimated before and after the experiment using pH meter with glass electrode (Jackson, 1973).

3.3.7 Quality Attributes

3.3.7.1 Lycopene

Lycopene content of fresh ripe fruits was measured by colorimetric method using petroleum ether procedure as suggested by Srivastava and Kumar (1994). Fresh ripe fruit from tagged plants of each treatment was taken and lycopene content was determined and expressed as mg 100 g^{-1} fruit.

3.3.7.2 Total Soluble Solids (TSS)

TSS of tomato fruits were determined using hand refractometer (Ranganna, 1977) and is measured as ^{0} Brix. Tomato juice was dropped on refractometer and value noted.

3.3.7.3 Ascorbic Acid

Ascorbic acid content of fresh ripen tomato was determined using 2, 6 - dichlorophenol indophenole dye method (Sadasivam and Manickam, 1996) and was expressed as mg 100 g $^{-1}$.

3.3.8 Economic Analysis

3.3.8.1 Net Income

Net income = Gross income – Cost of cultivation

Net income is expressed as ₹ ha^{-1}

3.3.8.2 Benefit Cost Ratio

Ratio of gross income and cost of cultivation (Benefit Cost ratio) was calculated

$$\text{B: C ratio} = \frac{\text{Gross income} \quad (₹\ \text{ha}^{-1})}{\text{Cost of cultivation } (₹\ \text{ha}^{-1})}$$

3.3.9 Statistical Analysis

Data recorded from field experiment were subjected to statistical analysis by Analysis of Varience technique for split plot design (Panse and Sukhatme, 1985). Whenever the F test values were significant, critical difference (CD) was also determined for treatment comparison.

RESULTS

4. RESULTS

Field experiment was conducted in farmer's field at Pirappancode, Thiruvananthapuram, during February to June 2015 to standardize the fertigation schedule for tomato and to assess the effect of precision farming on the growth, yield and quality of tomato. The data on growth attributes, yield attributes and yield, fruit quality, moisture studies and root studies as well as chemical analysis of plant and soil were statistically analyzed and the results are presented in this chapter.

4.1 BIOMETRIC OBSERVATIONS

4.1.1 Plant Height

The plant height recorded at 30, 60 and 90 DAP for various treatments is presented in Table 5. A perusal of the data revealed that both the levels of nutrients and fertigation intervals tested did not have any significant influence on plant height. Even interaction effect was also not significant.

Comparison of controls and treatment mean indicated that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean at all growth stages. However, no significant difference in plant height was observed between control 2 and treatment mean.

4.1.2 Primary Branches Plant^{-1}

The data on primary branches plant^{-1} are furnished in Table 6. Different levels of nutrients did not have any significant effect on primary branches plant^{-1} at all crop growth stages.

Fertigation intervals too did not have any significant influence on number of primary branches plant^{-1} at different growth stages.

Interaction effect of levels of nutrients and fertigation intervals was found non significant with respect to on number of primary branches plant^{-1}.

Comparison of controls and treatment mean indicated that control 1 (KAU *ad hoc* POP for precision farming) was superior to control 2 (KAU POP for conventional farming) at all growth stages. Further the primary branches recorded with control 1 was significantly superior over treatment mean at 30 and 60 DAP, whereas at 90 DAP it was on par. Control 2 and treatment mean did not show any significant effect at 30 and 60 DAP. However at 90 DAP, treatment mean exerted significant effect on this growth attribute compared to control 2.

4.1.3 Leaf Area Index at Flowering

The data on LAI revealed that different levels of nutrients and its interaction with fertigation interval did not have any significant effect on LAI (Table 7).

However, LAI at flowering was significantly influenced by fertigation intervals. The fertigation interval once in four days (i_1) registered significantly higher LAI (1.87) compared to eight days interval (1.58).

Comparison of controls and treatment mean showed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean. Treatment mean and control 2 are non significant.

4.1.4 Dry Matter Production at Harvest

The DMP as influenced by different nutrient levels and fertigation intervals varied significantly (Table 7).

Application of 125 per cent RD of N and K (l_3) recorded the highest DMP (219.42 g plant $^{-1}$) closely followed by 150 per cent RD of N and K (208.00 g plant^{-1}) which was on par. This treatment was significantly superior to l_2 (100 per cent RD of N and K) and l_1 (75 per cent RD of N and K).

Among different fertigation intervals fertigation at four days interval, (i_1) registered a DMP of 224.21 g plant^{-1} and it was significantly superior to fertigation at eight days interval (i_2) which recorded a DMP of 184.97 g plant^{-1}.

Table 5. Plant height as influenced by levels of nutrients and fertigation intervals

Treatments	Plant height (cm)		
	30 DAP	60 DAP	90 DAP
Levels of nutrients (L)			
l_1 - 75% RD of N & K	55.98	80.92	132.04
l_2 - 100% RD of N &K	54.84	82.51	133.10
l_3 - 125% RD of N &K	55.49	81.64	132.99
l_4 - 150% RD of N &K	55.78	83.49	133.21
SEm (±)	1.618	1.222	2.395
CD (0.05)	NS	NS	NS
Fertigation intervals (I)			
i_1 - four days	56.54	83.06	133.85
i_2 - eight days	54.50	81.22	131.82
SEm (±)	1.023	1.204	1.826
CD (0.05)	NS	NS	NS
Interaction (L x I)			
l_1i_1	57.43	81.09	132.58
l_1i_2	54.53	80.75	131.50
l_2i_1	56.17	82.84	135.66
l_2i_2	53.52	82.20	130.55
l_3i_1	56.67	83.20	134.30
l_3i_2	54.31	80.09	131.69
l_4i_1	55.92	85.12	132.86
l_4i_2	55.64	81.87	133.56
SEm (±)	2.046	2.409	3.649
CD (0.05)	NS	NS	NS
Treatment mean	55.51	82.14	132.84
Control 1 (C_1)	62.24	88.17	142.92
Control 2 (C_2)	51.47	78.09	126.09
C_1 *Vs.* C_2	S	S	S
C_1 *Vs.* Treatments	S	S	S
C_2 *Vs.* Treatments	NS	NS	NS

S - Significant at 5% level, NS - Non significant at 5% level

DAP – Days after planting

Table 6. Number of primary branches plant^{-1} as influenced by levels of nutrients and fertigation intervals

Treatments	Number of primary branches plant^{-1}		
	30 DAP	60 DAP	90 DAP
Levels of nutrients (L)			
l_1 - 75% RD of N & K	7.83	11.89	13.13
l_2 - 100% RD of N &K	8.23	12.32	13.09
l_3 - 125% RD of N &K	8.40	12.96	13.56
l_4 - 150% RD of N &K	8.40	12.94	13.40
SEm (±)	0.306	0.531	0.223
CD (0.05)	NS	NS	NS
Fertigation intervals (I)			
i_1 - four days	8.41	12.89	13.30
i_2 - eight days	8.02	12.17	13.29
SEm (±)	0.239	0.254	0.184
CD (0.05)	NS	NS	NS
Interaction (L x I)			
l_1i_1	8.09	12.45	13.47
l_1i_2	7.58	11.33	12.79
l_2i_1	8.32	12.77	12.89
l_2i_2	8.14	11.88	13.30
l_3i_1	8.61	13.15	13.76
l_3i_2	8.21	12.78	13.38
l_4i_1	8.65	13.18	13.09
l_4i_2	8.16	12.72	13.72
SEm (±)	0.479	0.511	13.47
CD (0.05)	NS	NS	NS
Treatment mean	8.21	12.52	17.52
Control 1 (C_1)	10.85	15.41	18.12
Control 2 (C_2)	7.83	10.77	16.25
C_1 *Vs*. C_2	S	S	S
C_1 *Vs*. Treatments	S	S	NS
C_2 *Vs*. Treatments	NS	NS	S

S - Significant at 5% level, NS - Non significant at 5% level

DAP – Days after planting

Interaction of nutrient levels and fertigation intervals also significantly influenced this growth attribute. The highest DMP (245.28g plant^{-1}) was recorded by l_3i_1 (125 per cent RD of N and K given as fertigation at four days interval) and it was significantly superior to all other interactions. This treatment was followed by l_4i_1 (150 per cent RD of N and K given as fertigation at four days interval) and it was statistically on par with l_2i_1, *i.e.*, 100 per cent RD of N and K at four days fertigation interval.

Comparison of controls and treatment mean revealed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to both control 2 (KAU POP for conventional farming) and treatment mean and control 2 was inferior to treatment mean and it recorded the lowest DMP (171.27 g plant^{-1}).

4.1.5 Crop Duration

The total crop duration was uniform for all the treatments and controls, *i.e.*, 120 days.

4.2 YIELD AND YIELD ATTRIBUTES

4.2.1 Days to 50 Per cent Flowering

Data on days to 50 per cent flowering are furnished in Table 8. Neither the nutrient levels nor fertigation intervals had significant effect on days to 50 per cent flowering. Interaction effect was also found non significant. This is true for variation among treatment mean and controls too.

4.2.2 Fruit Set Per cent

Data on fruit set per cent are given in Table 8. The results revealed that levels of nutrients exerted significant influence on this yield attribute. The per cent fruit set was highest at 125 per cent RD of N and K (62.77) and it was statistically on par with 100 per cent RD of N and K (58.87).

Table 7. Leaf area index and dry matter production as influenced by levels of nutrients and fertigation intervals

Treatments	LAI at flowering	Dry matter production (g plant^{-1})
Levels of nutrients (L)		
l_1 - 75% RD of N & K	1.57	190.44
l_2 - 100% RD of N &K	1.67	200.49
l_3 - 125% RD of N &K	1.83	219.42
l_4 - 150% RD of N &K	1.83	208.00
SEm (±)	0.089	4.328
CD (0.05)	NS	13.848
Fertigation intervals (I)		
i_1 - four days	1.87	224.21
i_2 - eight days	1.58	184.97
SEm (±)	0.073	2.458
CD (0.05)	0.228	7.575
Interaction (L x I)		
l_1i_1	1.61	206.25
l_1i_2	1.54	174.64
l_2i_1	1.85	215.84
l_2i_2	1.49	185.14
l_3i_1	2.09	245.28
l_3i_2	1.57	193.57
l_4i_1	1.94	229.46
l_4i_2	1.73	186.54
SEm (±)	0.148	4.916
CD (0.05)	NS	15.150
Treatment mean	1.72	204.59
Control 1 (C_1)	2.10	241.24
Control 2 (C_2)	1.29	171.27
C_1 *Vs*. C_2	S	S
C_1 *Vs*. Treatments	S	S
C_2 *Vs*. Treatments	NS	S

S - Significant at 5% level, NS - Non significant at 5% level

Among fertigation intervals, fertigation at four days interval (i_1) was significantly superior to i_2 (fertigation at eight days interval). None of the interactions had a significant effect on percentage fruit set. Further, there was no significant difference in fruit set per cent between two controls and treatment mean.

4.2.3 Fruits Plant^{-1}

The data on number of fruits plant^{-1} are furnished in Table 8. A critical analysis of data indicated that number of fruits plant^{-1} varied significantly due to different levels of nutrients and fertigation intervals. Among the different levels of nutrients, 125 per cent RD of N and K (l_3) registered the highest number of fruits (33.67) and it was significantly superior over others. The remaining nutrient levels are on par with each other.

A perusal of the data indicated that fertigation at four days interval (i_1) was significantly superior to fertigation at eight days interval (i_2). Interaction effect did not have any significant influence on number of fruits plant^{-1}.

Comparing controls and treatment mean, it was observed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean, whereas control 2 was significantly inferior to treatment mean.

4.2.4 Fruit Length

The length of fruit did not show significant variations either due to nutrient levels or fertigation intervals. The interaction effect was also not significant. The treatment mean and controls are too comparable (Table 8).

4.2.5 Fruit Girth

Data on fruit girth are presented in Table 8. The data revealed that none of the nutrient levels and fertigation intervals influence significantly the fruit girth. Interaction effect of nutrient levels and fertigation interval also failed to influence fruit girth. Controls and treatment mean were also not significant with regard to fruit girth.

4.2.6 Fruit Weight

The data on fruit weight are furnished in Table 9. Perusal of the data indicated that different levels of nutrients had no significant effect on this yield attribute. However, fertigation interval significantly influenced this yield attribute. Fertigation at four days interval has recorded higher fruit weight (44.41 g) than eight days interval (40.93 g).

There was no significant variation in fruit weight due to interaction effect of nutrient levels and fertigation interval.

Appraisal of data showed that control 1 (KAU *ad hoc* POP for precision farming) significantly increased this yield attribute and it recorded higher fruit weight than control 2 (KAU POP for conventional farming). But there was no significant variation between control 1 and treatment mean. Treatment mean (42.67 g) was found significantly superior to control 2 with respect to fruit weight (37.88 g).

4.2.7 Fruit Yield Plant^{-1}

A perusal of the data presented in Table 9 revealed that levels of nutrients, fertigation intervals as well as their interaction influenced fruit yield plant^{-1}. Significant variation in fruit yield plant^{-1} was observed at different levels of nutrients. Among these levels, 125 per cent RD of N and K (l_3) recorded the highest fruit yield (1.54 kg plant^{-1}) and it was significantly superior to other three levels. The next best treatment was 150 per cent RD of N and K (l_4) and it was statistically on par with l_2 (100 per cent RD of N and K) and l_1 (75 per cent RD of N and K).

Among the two fertigation intervals tested, fertigation at four days interval (i_1) recorded significantly higher fruit yield (1.61 kg) than fertigation at eight days interval (i_2) (1.09 kg).

Comparing different nutrient level-fertigation interval interactions, l_3i_1 (125 per cent RD of N and K given as fertigation at four days interval) recorded the highest fruit yield of 1.92 kg plant^{-1} which was significantly higher than other interactions. It was followed by l_4i_1 (150 per cent RD of N and K given as fertigation at four days interval) and it was statistically on par with l_1i_1 (75 per cent RD of N and K given as fertigation at four days interval) and l_2i_1 (100 per cent RD of N and K given as fertigation at four days interval) and the lowest yield was registered in l_1i_2 (75 per cent RD of N and K given as fertigation at eight days interval).

Among controls and treatment mean, control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to treatment mean and control 2 (KAU POP for conventional farming). However, treatment mean was significantly superior to control 2.

4.2.8 Fruit Yield ha^{-1}

The data pertaining to fruit yield ha^{-1} furnished in Table 9 revealed that levels of nutrients, fertigation intervals as well as their interaction exerted significant influence on fruit yield. Comparing different levels of nutrients, l_3 (125 per cent RD of N and K) recorded the highest yield of 42.36 t ha^{-1} which was significantly superior to other levels of nutrients.

With regard to fertigation interval, i_1 (fertigation at four days interval) recorded significantly higher yield of 44.25 t ha^{-1} over i_2 (fertigation at eight days interval) which registered a fruit yield of 30.11 t ha^{-1}.

Nutrient level- fertigation interval interaction also significantly influenced fruit yield ha^{-1}. Among different interactions, l_3i_1 (125 per cent RD of N and K given as fertigation at four days interval) was significantly superior and registered a yield of 52.7 t ha^{-1}. This was followed by l_4i_1 (150 per cent RD of N and K given as fertigation at four days interval) with a fruit yield of 43.75 t ha^{-1} and it was on par with l_1i_1 (75 per cent RD of N and K given as fertigation at four days interval) and l_2i_1 (100 per cent RD of N and K given as fertigation at four days interval).

Comparing controls and treatment mean, it was observed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to treatment mean and control 2 (KAU POP for conventional farming) whereas treatment mean was significantly superior to control 2.

4.2.9 Number of Pickings

Data on number of pickings are presented in Table 9. Perusal of the data revealed that different levels of nutrients did not have any significant effect on this yield attribute.

Comparing fertigation intervals, fertigation at four days interval (i_1) recorded significantly higher number of pickings than i_2 (fertigation at eight days interval).

Nutrient level-fertigation interval interaction also significantly influenced this yield attribute. Among the interactions, l_3i_1 (125 per cent RD of N and K given as fertigation at four days interval) registered the highest number of pickings (7.33) and was significantly superior to other interactions. Number of pickings registered for l_2i_1 (100 per cent RD of N and K given as fertigation at four days interval) and l_4i_1 (150 per cent RD of N and K given as fertigation at four days interval) were statistically on a par.

Significant difference was observed between controls and treatment mean also. Control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean. There was no significant variation between control 2 and treatment mean.

4.2.10 Harvest Index

The data on harvest index indicated that different levels of nutrients did not have any significant effect (Table 9). However, harvest index was significantly influenced by fertigation intervals with fertigation at four days interval (i_1) recording significantly higher harvest index (0.43) than fertigation at eight days interval (0.36). Effect of nutrient level-fertigation interval interactions was not significant.

Table 8. Yield attributes of tomato as influenced by levels of nutrients and fertigation intervals

Treatments	Yield attributes					
	Days to 50 per cent flowering	Fruit set (%)	Fruits plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)
Levels of nutrients (L)						
l_1 – 75% RD of N&K	47.01	54.74	30.33	3.98	4.65	41.92
l_2 – 100% RD of N&K	43.88	58.87	29.86	4.16	4.43	43.03
l_3 – 125% RD of N&K	42.61	62.77	33.67	4.18	4.73	43.58
l_4 – 150% RD of N&K	44.10	58.14	29.03	4.03	4.46	42.16
SEm (±)	1.613	1.217	0.999	0.104	0.122	1.146
CD (0.05)	NS	3.896	3.198	NS	NS	NS
Fertigation intervals (I)						
i_1 – four days	43.32	60.74	35.53	4.18	4.67	44.41
i_2 – eight days	45.48	56.52	25.91	3.99	4.47	40.93
SEm (±)	0.905	0.959	0.617	0.101	0.088	0.771
CD (0.05)	NS	2.957	1.904	NS	NS	2.378
Interactions (L x I)						
l_1i_1	47.05	57.20	35.33	4.05	4.67	42.47
l_1i_2	46.97	52.29	25.33	3.90	4.65	41.37
l_2i_1	42.60	60.10	33.25	4.10	4.54	44.08
l_2i_2	45.16	57.65	26.47	4.23	4.33	41.98
l_3i_1	40.19	66.20	40.04	4.38	4.83	46.53
l_3i_2	45.04	59.36	27.31	3.98	4.64	40.64
l_4i_1	43.44	59.47	33.50	4.18	4.66	44.57
l_4i_2	44.77	56.81	24.56	3.88	4.27	39.75
SEm (±)	1.810	1.915	1.236	0.202	0.177	1.540
CD (0.05)	NS	NS	NS	NS	NS	NS
Treatment mean	44.40	58.63	30.72	4.05	4.56	42.67
Control 1 (C_1)	41.83	60.84	38.22	4.48	4.47	45.15
Control 2 (C_2)	45.71	56.48	25.83	3.93	4.24	37.88
C_1 *Vs.* C_2	NS	NS	S	NS	NS	S
C_1 *Vs.* Treatments	NS	NS	S	NS	NS	NS
C_2 *Vs.* Treatments	NS	NS	S	NS	NS	S

S - Significant at 5% level, NS - Non significant at 5% level

Table 9. Number of pickings, yield and harvest index of tomato as influenced by levels of nutrients and fertigation intervals

Treatments	Fruit yield plant^{-1}(kg)	Fruit yield ha^{-1} (t)	No. of pickings	Harvest index
Levels of nutrients (L)				
l_1 - 75% RD of N & K	1.26	34.60	5.62	0.39
l_2 - 100% RD of N &K	1.29	35.29	5.54	0.39
l_3 - 125% RD of N &K	1.54	42.36	6.21	0.41
l_4 - 150% RD of N &K	1.32	36.46	5.50	0.39
SEm (±)	0.036	0.952	0.276	0.006
CD (0.05)	0.118	3.047	NS	NS
Fertigation intervals (I)				
i_1 - four days	1.61	44.25	6.43	0.43
i_2 - eight days	1.09	30.11	5.00	0.36
SEm (±)	0.022	0.605	0.118	0.009
CD (0.05)	0.068	1.865	0.365	0.028
Interactions (L x I)				
l_1i_1	1.48	40.44	6.00	0.42
l_1i_2	1.05	28.76	5.25	0.37
l_2i_1	1.46	40.12	6.33	0.42
l_2i_2	1.11	30.47	4.75	0.36
l_3i_1	1.92	52.70	7.33	0.47
l_3i_2	1.17	32.03	5.08	0.36
l_4i_1	1.59	43.75	6.08	0.44
l_4i_2	1.06	29.17	4.92	0.35
SEm (±)	0.044	1.207	0.234	0.014
CD (0.05)	0.136	3.720	0.721	NS
Treatment mean	1.36	37.17	5.71	0.40
Control 1 (C_1)	1.82	50.12	6.33	0.46
Control 2 (C_2)	1.03	28.26	5.33	0.36
C_1 *Vs.* C_2	S	S	S	NS
C_1 *Vs.* Treatments	S	S	S	NS
C_2 *Vs.* Treatments	S	S	NS	NS

S - Significant at 5% level, NS - Non significant at 5% level

Comparison of controls and treatment mean indicated that harvest index did not vary significantly between the two controls and also between controls and treatment mean.

4.3 ROOT STUDIES

4.3.1 Root Length

Root length of the plant was measured after the harvest and data are furnished in Table 10. The data revealed that root length was not significantly influenced by different levels of nutrients.

Fertigation interval had a significant effect on root length and i_1 (fertigation at four days interval) recorded significantly higher root length compared to i_2 (fertigation at eight days interval). Interaction effect was not significant.

Comparing controls, control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming). There was no significant variation between control 1 and treatment mean whereas treatment mean was significantly superior to control 2.

4.3.2 Root Weight

Data on fruit weight presented in Table 10 indicated that both levels of nutrients and fertigation intervals had significant influence on root weight. A critical analysis of the data revealed that l_3 (125 per cent RD of N and K) registered the highest root weight (10.27 g) and it was on par with l_4 (150 per cent RD of N and K) and l_2 (100 per cent RD of N and K).

Observed data on root weight revealed that fertigation at four days interval recorded significanty higher root weight (10.06) and it was superior to fertigation at eight days interval (i_2) (9.31 g). No interaction effect was noticed. Comparison of controls and treatment mean indicated no significant difference among them.

Table 10. Root characteristics of tomato as influenced by levels of nutrients and fertigation intervals

Treatments	Root characteristics		
	Root length (cm)	Root weight (g)	Root volume (cm^3)
Levels of nutrients (L)			
l_1 - 75% RD of N & K	64.95	8.95	23.83
l_2 - 100% RD of N &K	67.99	9.53	25.03
l_3 - 125% RD of N &K	70.08	10.27	26.58
l_4 - 150% RD of N &K	70.64	9.99	26.34
SEm (±)	1.326	0.294	0.599
CD (0.05)	NS	0.939	1.916
Fertigation intervals (I)			
i_1 - four days	70.51	10.06	26.73
i_2 - eight days	66.32	9.31	24.16
SEm (±)	0.836	0.232	0.413
CD (0.05)	2.576	0.715	1.273
Interactions (L x I)			
l_1i_1	67.63	9.46	24.61
l_1i_2	62.28	8.45	23.05
l_2i_1	69.75	9.79	26.66
l_2i_2	66.23	9.28	23.41
l_3i_1	72.84	10.81	28.25
l_3i_2	67.34	9.74	24.92
l_4i_1	71.83	10.21	27.43
l_4i_2	69.45	9.77	25.26
SEm (±)	1.669	0.464	0.829
CD (0.05)	NS	NS	NS
Treatment mean	68.41	9.68	25.45
Control 1 (C_1)	71.77	10.27	27.79
Control 2 (C_2)	63.07	8.99	24.28
C_1 *Vs.* C_2	S	NS	S
C_1 *Vs.* Treatments	NS	NS	S
C_2 *Vs.* Treatments	S	NS	NS

S - Significant at 5% level, NS - Non significant at 5% level

4.3.3 Root Volume

Data on root volume presented in Table 10 indicated that different levels of nutrients and fertigation intervals had significant influence on root volume. Comparing different levels of nutrients, l_3 (125 per cent RD of N and K) recorded the highest root volume (26.58 cm^3) and it was statistically on par with l_2 (100 per cent RD of N and K) and l_4 (150 per cent RD of N and K).

Fertigation interval i_1 (four days) was significantly superior to i_2 (fertigation at eight days interval). Interaction effect was not significant.

Among controls and treatment mean, control 1 (KAU *ad hoc* POP for precision farming) registered significantly higher root volume than control 2 (KAU POP for conventional farming) and treatment mean, but no significant variation was observed between control 2 and treatment mean.

4.4 MOISTURE STUDIES

4.4.1 Water Use Efficiency (WUE)

A critical analysis of data presented in Table 11 revealed that different levels of nutrients, fertigation intervals and their interaction had significant effect on this parameter.

Comparing different levels of nutrients, l_3 (125 per cent RD of N and K) registered the highest WUE of 40.62 kg ha $mm^{-1}$and it was significantly higher than all other levels of nutrients. The next best treatment was l_4 (150 per cent RD of N and K) and it was statistically on par with l_2 (100 per cent RD of N and K) and l_1 (75 per cent RD of N and K).

Among fertigation intervals, fertigation at four days interval (i_1) had a significantly higher WUE (42.42 kg ha mm^{-1}) than fertigation at eight days interval (i_2) (28.87 kg ha mm^{-1}).

Table 11. Water use efficiency and water productivity as influenced by levels of nutrients and fertigation intervals

Treatments	Water use efficiency (kg ha mm^{-1})	Water productivity (kg ha mm^{-1})
Levels of nutrients (L)		
l_1 - 75% RD of N & K	33.17	4.57
l_2 - 100% RD of N &K	33.84	4.81
l_3 - 125% RD of N &K	40.62	5.26
l_4 - 150% RD of N &K	34.96	4.99
SEm (±)	0.912	0.103
CD (0.05)	2.919	0.331
Fertigation intervals (I)		
i_1 - four days	42.42	5.38
i_2 - eight days	28.87	4.43
SEm (±)	0.579	0.060
CD (0.05)	1.786	0.186
Interactions (L x I)		
l_1i_1	38.77	4.95
l_1i_2	27.58	4.19
l_2i_1	38.47	5.18
l_2i_2	29.21	4.44
l_3i_1	50.53	5.89
l_3i_2	30.72	4.64
l_4i_1	41.94	5.50
l_4i_2	27.97	4.47
SEm (±)	1.159	0.117
CD (0.05)	3.572	NS
Treatment mean	35.65	4.91
Control 1 (C_1)	48.05	5.78
Control 2 (C_2)	22.40	4.11
C_1 *Vs.* C_2	S	S
C_1 *Vs.* Treatments	S	S
C_2 *Vs.* Treatments	S	S

S - Significant at 5% level, NS - Non significant at 5% level

Among different interaction effects, l_3i_1, *i.e.*, 125 per cent RD of N and K given as fertigation at four days interval was significantly superior to all other interactions with a WUE of 50.5 kg ha mm^{-1}.

Comparing controls and treatment mean, it is found that both control 1 (KAU *ad hoc* POP for precision farming) and treatment mean were significantly superior to control 2 (KAU POP for conventional farming) whereas control 1 was significantly superior to treatment mean.

4.4.2 Water Productivity

Water productivity was influenced by both nutrient levels and fertigation intervals (Table 11). Application of 125 per cent RD of N and K (l_3) recorded the highest water productivity over other levels of nutrients.

Fertigation intervals also influenced this parameter and i_1 (fertigation at four days interval) had higher water productivity compared to i_2 (fertigation at eight days interval). Interaction effect did not have any significant influence on water productivity.

Control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to treatment mean and control 2 (KAU POP for conventional farming) whereas control 2 was significantly inferior to treatment mean.

4.5 PEST AND DISEASE INCIDENCE

Only mite (*Tetranichus* sp.) and serpentine leaf miner (*Liriomyza trifolii*) were noticed in the initial stage of the crop.

4.6 CHEMICAL ANALYSIS

4.6.1 Uptake of N, P and K by Crop

4.6.1.1 Nitrogen Uptake

Data furnished in Table 12 showed that different levels of nutrients had significant influence on total N uptake. The nutrient level l_3, *i.e.*, 125 per cent RD of N and K registered significantly higher (151.17 kg ha^{-1}) N uptake and it was statistically on par with 150 per cent RD of N and K (l_4).

Regarding fertigation intervals, fertigation at four days interval (i_1) recorded N uptake of 150.54 kg ha^{-1} and it was significantly higher than fertigation at eight days interval (i_2) (124.55 kg ha^{-1}). Interaction effect was found non significant.

Critical study of controls showed that control 1 (KAU *ad hoc* POP for precision farming) registered significantly higher N uptake than control 2 (KAU POP for conventional farming) and treatment mean. Treatment mean also had a significantly higher N uptake compared to control 2.

4.6.1.2 Phosphorus Uptake

Data furnished in Table 12 revealed that uptake of P was influenced by different levels of nutrients and fertigation intervals. Nutrient level l_3 (125 per cent RD of N and K) registered the highest P uptake of 16.98 kg ha^{-1} and it was statistically on par with l_4 (150 per cent RD of N and K).

Fertigation intervals also influenced P uptake. A perusal of data pointed out that fertigation at four days interval (i_1) had a higher uptake of P and it was found significantly superior with respect to 'P' uptake (16.81 kg ha^{-1}) to fertigation at eight days interval (13.25 kg ha^{-1}) . None of the interactions had significant effect.

Comparison of controls and treatment mean indicated significant variation in P uptake. Control 1 (KAU *ad hoc* POP for precision farming) had a higher uptake of P than control 2 (KAU POP for conventional farming) and treatment mean and it was significantly superior. Comparing control 2 and treatment mean, treatment mean showed a higher uptake of P than control 2.

4.6.1.3 Potassium Uptake

Perusal of the data (Table 12) showed that K uptake was influenced by different levels of nutrients and fertigation intervals. Among different levels of nutrients, l_3 (125 per cent RD of N and K) recorded the highest K uptake (218.56 kg ha^{-1}) and it was statistically on par with l_4, *i.e.*, 150 per cent RD of N and K

Among, fertigation intervals, fertigation at four days interval (i_1) showed significantly higher K uptake of 221.98 kg ha^{-1} than that of fertigation at eight days interval (i_2). There was no significant effect for interaction.

Comparison of controls and treatment mean revealed that control 1 (KAU *ad hoc* POP for precision farming) recorded significantly higher K uptake than treatment mean and control 2 (KAU POP for conventional farming). However, treatment mean showed significantly higher value than control 2.

4.6.2 Soil Nutrient Status

Initial soil sample analysis indicated that soil of the experimental site was medium in available N (294 kg ha^{-1}) P (12.99 kg ha^{-1}) and K (242.93 kg ha^{-1}). (Table 1).

4.6.2.1 Soil Nutrient Status after the Experiment

Soil nutrient status after the experiment is presented in Table 13. Data showed that soil N status was not influenced by both levels of nutrients and fertigation intervals. Interaction effect was also not significant. Analysis of controls and treatment mean revealed that control 1 (KAU *ad hoc* POP for precision farming) recorded significantly higher available N content than treatment mean and control 2 (KAU POP for conventional farming) but no significant variation was observed between control 2 and treatment mean.

Available P status of soil was influenced by fertigation interval and fertigation at four days interval (i_1) registered significantly higher available soil P status compared to i_2 (fertigation at eight days interval). Levels of nutrients and interaction had and no significant influence on soil P status.

Comparison of controls and treatment mean showed significant variation in available P status. Control 1 (KAU *ad hoc* POP for precision farming) recorded significantly higher available P content than treatment mean and control 2 (KAU POP for conventional farming) but no significant variation was observed between control 2 and treatment mean.

Table 12. Uptake of nitrogen, phosphorus and potassium by the crop as influenced by levels of nutrients and fertigation intervals

Treatments	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Levels of nutrients (L)			
l_1 - 75% RD of N & K	120.04	12.87	178.36
l_2 - 100% RD of N &K	132.21	14.23	193.94
l_3 - 125% RD of N &K	151.57	16.98	218.56
l_4 - 150% RD of N &K	146.37	16.05	206.33
SEm (±)	4.622	0.692	6.287
CD (0.05)	14.787	2.215	20.113
Fertigation intervals (I)			
i_1 - four days	150.54	16.81	221.98
i_2 - eight days	124.55	13.25	176.61
SEm (±)	3.763	0.258	4.259
CD (0.05)	11.595	0.798	13.127
Interactions (L x I)			
l_1i_1	122.08	14.56	199.55
l_1i_2	118.01	11.18	157.18
l_2i_1	144.07	15.61	211.83
l_2i_2	120.35	12.85	176.05
l_3i_1	175.32	19.27	247.79
l_3i_2	127.83	14.69	189.34
l_4i_1	160.71	17.79	228.78
l_4i_2	132.03	14.32	183.88
SEm (±)	7.525	0.514	8.516
CD (0.05)	NS	NS	NS
Treatment mean	137.55	15.03	199.29
Control 1 (C_1)	175.00	18.62	246.32
Control 2 (C_2)	109.97	12.36	166.82
C_1 *Vs*. C_2	S	S	S
C_1 *Vs*. Treatments	S	S	S
C_2 *Vs*. Treatments	S	S	S

S - Significant at 5% level, NS - Non significant at 5% level

Soil K status was not influenced by different levels of nutrients and fertigation intervals. Interaction effect was also not significant. Analysis of controls and treatment mean revealed that control 1 (KAU *ad hoc* POP for precision farming) recorded significantly higher available K status than treatment mean and control 2 (KAU POP for conventional farming) but no significant variation was observed between control 2 and treatment mean.

4.6.3 Organic Carbon

Data on soil organic carbon revealed that organic carbon did not vary significantly due to different nutrient levels and fertigation intervals. Interaction effect was also found non significant (Table 14).

The soil organic carbon content recorded with controls and treatment mean was comparable.

4.6.4 Soil pH

Data on soil pH presented in Table 14 indicated that levels of nutrients, fertigation intervals and their interactions did not have any significant influence on soil pH. There was no significant variation in soil reaction between controls and treatment mean.

4.7 QUALITY ATTRIBUTES

4.7.1 Lycopene

Data on lycopene content of ripe fruits are presented in Table 15. Levels of nutrients, fertigation intervals and interactions did not have any significant influence on lycopene content of fruits.

Controls and treatment means also did not exert any significant effect on lycopene content.

Table 13. Available nitrogen, phosphorus and potassium status of soil after the experiment as influenced by levels of nutrients and fertigation intervals

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Levels of nutrients (L)			
l_1 - 75% RD of N & K	307.69	10.27	268.54
l_2 - 100% RD of N &K	319.57	10.04	268.22
l_3 - 125% RD of N &K	324.85	10.56	266.89
l_4 - 150% RD of N &K	312.33	11.89	260.16
SEm (±)	6.104	0.799	4.744
CD (0.05)	NS	NS	NS
Fertigation intervals (I)			
i_1 - four days	318.04	11.78	266.77
i_2 - eight days	314.18	9.60	265.13
SEm (±)	3.944	0.622	3.048
CD (0.05)	NS	1.918	NS
Interactions (L x I)			
l_1i_1	310.17	10.68	268.69
l_1i_2	305.23	9.855	268.40
l_2i_1	321.00	11.14	267.41
l_2i_2	318.14	8.94	269.04
l_3i_1	326.45	11.505	266.10
l_3i_2	323.26	9.615	267.68
l_4i_1	314.56	13.805	264.91
l_4i_2	310.11	9.975	255.43
SEm (±)	7.886	1.241	6.094
CD (0.05)	NS	NS	NS
Treatment mean	316.11	10.69	265.95
Control 1 (C_1)	361.91	15.10	300.09
Control 2 (C_2)	305.31	10.89	255.86
C_1 *Vs.* C_2	S	S	S
C_1 *Vs.* Treatments	S	S	S
C_2 *Vs.* Treatments	NS	NS	NS

S- Significant at 5% level, NS- Non significant at 5% level

Table 14. Soil organic carbon content and soil pH as influenced by levels of nutrients and fertigation intervals

Treatments	Organic carbon (%)	Soil pH
Levels of nutrients (L)		
l_1 - 75% RD of N & K	0.65	6.01
l_2 - 100% RD of N &K	0.67	6.14
l_3 - 125% RD of N &K	0.67	6.19
l_4 - 150% RD of N &K	0.69	6.09
SEm (±)	0.025	0.085
CD (0.05)	NS	NS
Fertigation intervals (I)		
i_1 - four days	0.68	6.09
i_2 - eight days	0.66	6.12
SEm (±)	0.110	0.066
CD (0.05)	NS	NS
Interactions (L x I)		
l_1i_1	0.65	6.05
l_1i_2	0.64	5.98
l_2i_1	0.68	6.17
l_2i_2	0.67	6.12
l_3i_1	0.70	6.16
l_3i_2	0.65	6.23
l_4i_1	0.70	6.01
l_4i_2	0.68	6.19
SEm (±)	0.022	0.130
CD (0.05)	NS	NS
Treatment mean	0.66	6.10
Control 1 (C_1)	0.65	5.94
Control 2 (C_2)	0.68	6.20
C_1 *Vs.* C_2	NS	NS
C_1 *Vs.* Treatments	NS	NS
C_2 *Vs.* Treatments	NS	NS

S- Significant at 5% level, NS- Non significant at 5% level

4.7.2 Total Soluble Solids (TSS)

The data on TSS of ripen fruits are furnished in Table 15. Critical analysis of data revealed that there was no significant difference in TSS content due to different levels of nutrients and fertigation intervals. Interaction effect was also not significant. Further, there was no significant variation between controls and treatment mean.

4.7.3 Ascorbic Acid

Ascorbic acid content of fruits (Table 15) did not vary significantly either due to different nutrient levels and fertigation intervals. Even interaction effect was also found non significant.

Observed data on controls and treatment mean showed no significant difference between controls and treatment mean.

4.8 ECONOMIC ANALYSIS

4.8.1 Net Income

Data on net income are presented in Table 16. A perusal of data on net income indicated that l_3 (125 per cent RD of N and K) recorded the highest net income (₹ 4,55,466 ha^{-1}) and it was significantly superior to other levels of nutrients tested.

Among fertigation intervals, i_1 (fertigation at four days interval) recorded significantly higher net income (₹ 4,93,051 ha^{-1}) compared to fertigation at eight days interval (i_2) (₹ 2,11,411 ha^{-1}).

Nutrient level – fertigation interval interaction revealed that l_3i_1, *i.e.*, fertigation of 125 per cent RD of N and K at four days interval recorded the highest net income (₹ 6,61,515 ha^{-1}) and it was significantly superior to all other interactions studied. The lowest net income was registered by l_1i_2, *i.e.*, 75 per cent RD of N and K at eight days fertigation interval.

Table 15. Quality attributes of tomato as influenced by levels of nutrients and fertigation intervals

Treatments	Quality attributes		
	TSS (^{0} Brix)	Ascorbic acid (mg 100 g fruit^{-1})	Lycopene (mg 100 g fruit^{-1})
Levels of nutrients (L)			
l_1 - 75% RD of N & K	4.18	14.03	10.90
l_2 - 100% RD of N &K	4.12	14.14	11.41
l_3 - 125% RD of N &K	4.33	14.02	10.96
l_4 - 150% RD of N &K	4.11	14.32	10.69
SE (±)	0.157	0.274	0.349
CD (0.05)	NS	NS	NS
Fertigation intervals (I)			
i_1 - four days	4.15	14.22	11.14
i_2 - eight days	4.22	14.04	10.84
SE (±)	0.110	0.174	0.364
CD (0.05)	NS	NS	NS
Interactions (L x I)			
l_1i_1	4.17	14.05	11.20
l_1i_2	4.19	14.02	10.61
l_2i_1	4.02	13.98	11.50
l_2i_2	4.22	14.30	11.32
l_3i_1	4.31	14.45	11.19
l_3i_2	4.34	13.59	10.73
l_4i_1	4.09	14.41	10.68
l_4i_2	4.14	14.23	10.70
SE (±)	0.224	0.345	0.732
CD (0.05)	NS	NS	NS
Treatment mean	4.18	14.13	10.99
Control 1 (C_1)	4.03	14.39	11.25
Control 2 (C_2)	4.37	13.60	10.95
C_1 *Vs.* C_2	NS	NS	NS
C_1 *Vs.* Treatments	NS	NS	NS
C_2 *Vs.* Treatments	NS	NS	NS

NS- Non significant at 5% level

Comparison of controls and treatment mean revealed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean. However, treatment mean was significantly higher than control 2.

4.8.2 B: C Ratio

The data on B: C ratio as influenced by varied nutrient levels and fertigation interval are presented in Table 16.

Among different levels of nutrients, l_3 *i.e.*, 125 per cent RD of N and K registered the highest B: C ratio of 2.16 and it was significantly superior to other levels of nutrients. This was followed by l_4 (150 per cent RD of N and K) and it was on par with l_2 (100 per cent RD of N and K) and l_1 (75per cent RD of N and K).

Different fertigation intervals had significant influence on B: C ratio. Fertigation interval of four days (i_1) recorded significantly higher B: C ratio of 2.26 compared to i_2 (fertigaton at eight days interval) (1.54).

Among different nutrient level- fertigation interval interactions, l_3i_1 (125 per cent RD of N and K given as fertigation at four days interval) recorded the highest B: C ratio of 2.69 and it was significantly superior to all other interactions. It was followed by l_4i_1 (150 per cent RD of N and K given as fertigation at four days interval) with a B: C ratio of 2.23.

Control 1 (KAU *ad hoc* POP for precision farming) registered a comparatively low B: C ratio of 1.87. However it was higher than control 2 (KAU POP for conventional farming) and there was no significant difference between control 1 and treatment mean. Data indicated that treatment mean was significantly superior to control 2.

Table 16. Net income and B: C ratio as influenced by levels of nutrients and fertigation intervals

Treatments	Net income (₹ ha^{-1})	B: C ratio
Levels of nutrients (L)		
l_1 - 75% RD of N & K	3,01,871	1.77
l_2 - 100% RD of N &K	3,15,334	1.81
l_3 - 125% RD of N &K	4,55,466	2.16
l_4 - 150% RD of N &K	3,36,256	1.86
SEm (±)	19029.6	0.049
CD (0.05)	60875. 3	0.158
Fertigation intervals (I)		
i_1 - four days	4,93,051	2.26
i_2 - eight days	2,11,411	1.54
SEm (±)	12095.4	0.029
CD (0.05)	37273.2	0.090
Interactions (L x I)		
l_1i_1	4,18,025	2.07
l_1i_2	1,85,720	1.48
l_2i_1	4,11,285	2.05
l_2i_2	2,19,380	1.56
l_3i_1	6,61,515	2.69
l_3i_2	2,49,415	1.64
l_4i_1	4,81,380	2.23
l_4i_2	1,91,135	1.49
SEm (±)	24191.2	0.062
CD (0.05)	74547.3	0.191
Treatment mean	3,52,232	1.90
Control 1 (C_1)	4,67,272	1.87
Control 2 (C_2)	2,21,634	1.65
C_1 *Vs.* C_2	S	S
C_1 *Vs.* Treatments	S	NS
C_2 *Vs.* Treatments	S	S

S –Significant at 5% level, NS - Non significant at 5% level

DISCUSSION

5. DISCUSSION

An investigation entitled "Fertigation for precision farming in tomato (*Solanum lycopersicum* L.)" was conducted during summer 2015 to standardize the fertigation schedule for tomato under precision farming. Combination of four levels of nutrients and two fertigation intervals in comparison with two controls (control 1- KAU *ad hoc* POP for precision farming and control 2 - KAU POP for conventional farming) were tested in split plot design. Salient results of the study are briefly discussed in this chapter.

5.1 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND THEIR INTERACTION ON GROWTH ATTRIBUTES

5.1.1 Plant Height and Primary Branches Plant^{-1}

A perusal of the data (Table 5 and Table 6) revealed that levels of nutrients, fertigation intervals and interaction did not have any significant influence on these growth attributes. However, control 1 (KAU *ad hoc* POP for precision farming *i.e.,* fertigation of high analysis water soluble fertilizers) registered a significantly higher plant height and number of primary branches plant^{-1} compared to control 2 (KAU POP for conventional farming *i.e.*, soil application of straight fertilizers) at all growth stages. Similar results were reported by Brahma *et al.* (2010), who found that application of RD of N and K through fertigation significantly increased plant height and number of primary branches plant^{-1} in tomato over conventional soil application of fertilizers. Corroborative results were obtained by Shedeed *et al.* (2009) and Prabhakar *et al.* (2012). Increased plant height in fertigation treatments in tomato was reported by Singandhupe *et al.* (2003) and Gupta *et al.* (2010) and maximum number of primary branches reported by Kavitha *et al.* (2009) and Parvej *et al.* (2010) in fertigation treatments.

5.1.2 Leaf Area Index and Dry Matter Production

Critical analysis of results (Table 7) showed that fertigation interval had significant influence on LAI. Fertigation at four days interval (i_1) registered significantly higher LAI compared to i_2 (fertigation at eight days interval). Higher

LAI in i_1 might be due to the increased photosynthetic capacity of plants in this treatment due to the continuous availability of N and K through drip irrigation.

Ugade *et al.* (2015) reported the influence of fertigation schedule on leaf area production and they found that fertigation of NPK at 9 days interval upto 120 days after transplanting registered significantly higher leaf area while the lowest value of this parameter was noticed with fertigation at 18 days interval. They also opined that increased leaf area production might be due to frequent supply of fertilizers through drip irrigation in the vicinity of root zone to meet the nutritional requirement of crop leading to maximum absorption and translocation of nutrients resulting in increased cell multiplication. Prabhakara *et al.* (2010) reported that daily subsurface fertigation registered the highest leaf area production compared to other treatments and it was on par with weekly sub surface fertigation.

Results of present study revealed that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean. LAI is the measure of source size and significantly higher LAI was recorded in fertigation treatment with water soluble fertilizers compared to furrow irrigated control as reported by Hebbar *et al.* (2004). This is in conformity with the findings of Chawla and Narda (2000) and Shedeed *et al.* (2009).

Among different levels of nutrients tested, application of 125 per cent RD of N and K (l_3) registered the highest DMP plant^{-1} and it was statistically on par with 150 per cent RD of N and K. Among nutrient level - fertigation interval interactions, l_3i_1 (125 per cent RD of N and K at four days interval) registered the highest DMP of 245.28 g plant^{-1} and it was significantly superior to all other interactions. The amount of dry matter produced by a crop depends up on its photosynthetic efficiency (Arnon, 1975). Effectiveness of photosynthesis, to a great extent is a function of LAI. The differences in dry matter yield among treatments in the present study could be ascribed to difference in leaf area. LAI was higher for 125 per cent RD of N and K and it was on par with 150 per cent RD of N and K. Higher LAI contributed to greater carbohydrate synthesis and better yield (Le Bot *et al.*, 1998; Tei *et al.*, 2002; Hebbar *et al.*, 2004). Similar findings on the favourable effect of higher level of nutrition through fertigation on DMP was reported by Alcanter *et al.* (1999) and Elia *et al.* (2007).

Among different fertigation intervals, i_1 (fertigation at four days interval) registered the highest DMP of 224.21 g plant^{-1} and it was significantly superior to i_2 (fertigation at eight days interval) (184.97 g plant^{-1}). It could be attributed to supply of small quantity of fertilizers throughout the crop growth stages *via* fertigation at four days interval and supply of fertilizers exactly to the active root zone reducing the leaching and evaporation loss of both nutrients and water, promoting higher nutrient uptake and physiological activity. Similar increase in dry matter yield with increased frequency of fertigation in solanaceous crops were reported earlier. (Goo *et al.*, 2003; Al-Ghawas and Al-Mazidi, 2004; Prabhakara *et al.*, 2010).

Comparison of controls and treatment mean revealed that both control 1 (KAU *ad hoc* POP for precision farming) and treatment mean were significantly superior to control 2 (KAU POP for conventional farming). Soil application might have enhanced losses by leaching and reduced nutrient availability. Battilani and Solimando (2006) reported that fertigation had a great influence on DMP. Shedeed *et al.* (2009) reported that the total DMP at final harvest was significantly higher in drip irrigation (3.60 t ha^{-1}) over furrow irrigated control (2.86 t ha^{-1}).

5.2 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND THEIR INTERACTION ON YIELD ATTRIBUTES AND YIELD

5.2.1 Yield Attributes

Among the yield attributes, only extent of fruit set and number of fruits plant^{-1} varied significantly with different levels of nutrients. The per cent fruit set was highest in l_3 *i.e.*, 125 per cent RD of N and K (62.77) and it was statistically on par with l_2 (100 per cent RD of N and K) with a percentage fruit set of 58.87 (Table 8). Further, the treatment l_3 registered significantly higher number of fruits plant^{-1} compared to other levels of nutrients.

This might be due to the enhanced supply of nitrogen and potassium in the root rhizosphere resulting in increased uptake (Table 12) of these nutrients contributing to better expression of growth and yield attributes. Thus, higher rate of photosynthesis, as evidenced by higher dry matter accumulation, might have caused efficient translocation of photosynthates towards reproductive parts. The substantial increase in per cent fruit set observed at higher levels of N is attributed to enhanced metabolic activity as a result of translocation of sugar and narrowing down of C:N ratio (Singh *et al.*,1982). Ugade *et al.* (2015) reported that fertigation of NPK with different levels significantly influenced the yield attributes of tomato. They found that fertigation of 100 per cent RD of fertilizers recorded significantly higher number of fruits plant^{-1} and fruit weight plant^{-1}. Similar results were reported by Kadam and Sahane (2001) and Brahma *et al.* (2010) in tomato. Significant improvement in yield attributes of chilli by fertigation at 100 and 125 per cent RD of N and K was also reported by Muralikrishnaswamy *et al.* (2006). Badr and El- Yazied. (2007) found that yield components of tomato registered higher values at higher N rate compared to lower N rates.

Yield attributes, *viz.*, per cent fruit set, number of fruits plant^{-1}, fruit weight and number of pickings were significantly higher for fertigation at four days interval (i_1) compared to fertigation at eight days interval (i_2) (Table 8 and Table 9). Uninterrupted availability of N and K might have favoured rapid absorption of these nutrients resulting in higher rate of photosynthesis contributing to better expression of yield attributes. According to Ugade *et al.* (2015), fertigation at every nine days interval exhibited significantly higher number of fruits plant^{-1} and fruit weight plant^{-1} compared to fertigation at 18 days interval in tomato. Corroborative findings were reported by Bahadur *et al.* (2006) in tomato and Tumbare and Nikam (2004) and Prabhakara *et al.* (2010) in chilli.

In the present study, harvest index increased significantly due to frequent fertigation (four days interval). The more frequent application of nutrients throughout the crop growth period might have enabled maximum absorption of nutrients as well as translocation of photosynthates towards reproductive parts resulting in substantially higher harvest index.

Among yield attributes, number of pickings varied significantly with nutrient level- fertigation interval interactions and l_3i_1 *i.e.*, 125 per cent RD of N and K through fertigation at four days interval recorded the highest number of pickings. It was significantly superior to all other interactions studied.

Control 1 (KAU *ad hoc* POP for precision farming) registered significantly higher number of pickings and number of fruits plant^{-1} compared to control 2 (KAU POP for conventional farming). The number of fruits plant^{-1} in treatment mean was significantly higher compared to control 2. Application of fertilizers in soil generally tends to cause uneven distribution of fertilizers in the root zone. Alternatively, entire NPK fertilizers can be applied *via* fertigation through drip system to obtain proper distribution in soil. This will result in longer activity of nutrients applied through split doses to match the nutrient uptake by the crop. This enhanced uptake of nutrients might have caused uninterrupted supply of photosynthates to the developing fruits resulting more number of marketable fruits plant^{-1} in fertigation treatments compared to soil application treatments. Increased number of fruits plant^{-1} and fruit weight due to fertigation over soil application have been reported by Lara *et al.* (1996), Locascio *et al.* (1997) and Pan *et al.* (1999).

5.2.2 Yield

Among different levels of nutrients, l_3 (125 per cent RD of N and K) registered the highest fruit yield (1.54 kg plant^{-1} and 42.36 t ha^{-1}) and it was significantly superior over other levels of nutrients (Table 9 and Fig. 4). Increase in fruit yield could be related to significantly higher number of fruits plant^{-1} and per cent fruit set in 125 per cent RD of N and K. Better expression of growth parameters, *viz.*, DMP and comparatively higher photosynthetic surface area as indicated by higher LAI coupled with better yield parameters like per cent fruit set and number of fruits plant^{-1} might be the reason for realising significantly higher fruit yield in l_3 . Brahma *et al.* (2010) obtained the highest productivity of tomato by providing higher level of nutrients (100 per cent N and K fertilizers) and they also reported that the marketable yield of tomato showed an increasing trend with each corresponding increase in the level of N and K fertigation. Hebbar *et al.* (2004) also reported significant increase in marketable fruit yield of tomato with cent per cent fertigation of RD (water soluble fertilizers) over control.

In the present study, 75 per cent RD of N and K registered the lowest yield. The reduction in yield with 25 per cent reduction in the RD of N and K fertigation is in agreement with the findings of Aramini *et al.* (1995) and Hebbar *et al.* (2004).

The response of crops to nutrient application depends directly on the status of available plant nutrient in the soil and a low rating in the available status indicates that crops on such soils respond very readily to nutrient application (Bains and Bharadwaj, 1976). In the present study, the initial soil N and K status (Table 1) was medium (294 and 242.93 kg ha^{-1} respectively) which explains the better response to higher doses of applied nutrients.

Result of present study also revealed that fertigation at four days interval (i_1) registered significantly higher fruit yield (44.25 t ha^{-1}) compared to fertigation at eight days interval (i_2). Per cent increase in fruit yield in i_1 compared to i_2 was 32. This might be due to the frequent supply of nutrients directly in the vicinity of the root zone throughout the crop growth period resulting in better nutrient uptake (Table 12) and use efficiency leading to enhanced yield attributes. These result is in general agreement with the results reported by several other authors. Cook and Sanders (1991) found that marketable yield and fruit size of sub surface drip irrigated tomato were significantly higher with daily compared with biweekly or monthly fertigation on a loamy sand soil. Nwadukwe and Chude (1994) reported that tomato yield was significantly higher when N was fertigated at five days interval compared with nine days *via* surface drip system. Significant improvement in yield attributes and yield with frequent fertigation was also reported by Al-Ghawas and Al-Mazidi (2004), Badr and El- Yazied (2007) and Ugade *et al.* (2015) in tomato and Prabhakara *et al.* (2010) in chilli.

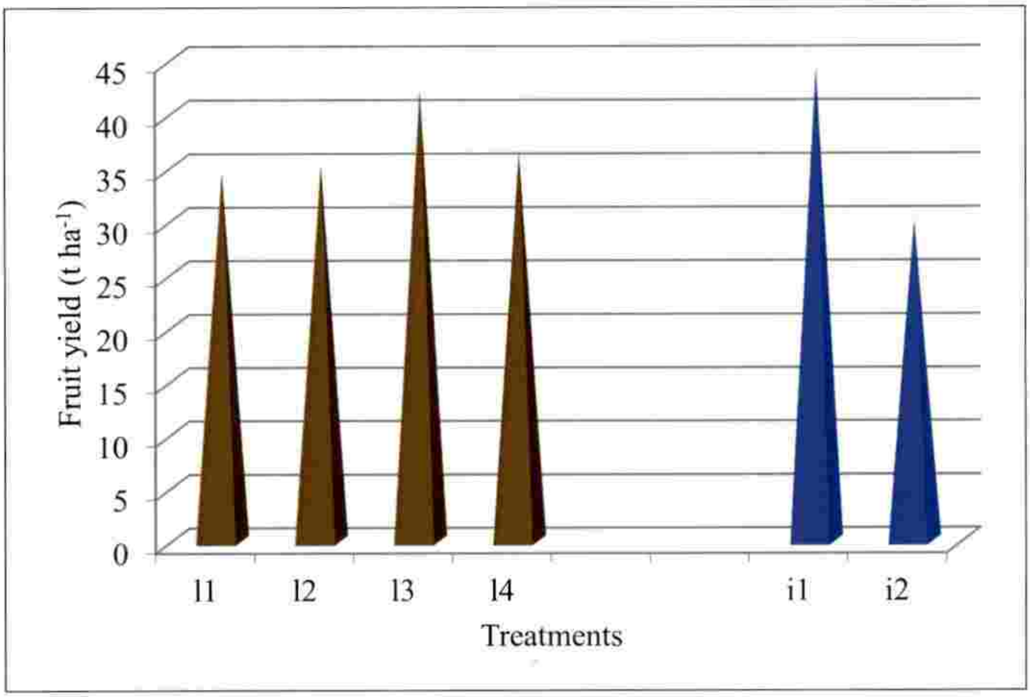

Fig. 4. Fruit yield as influenced by levels of nutrients (L) and fertigation intervals (I)

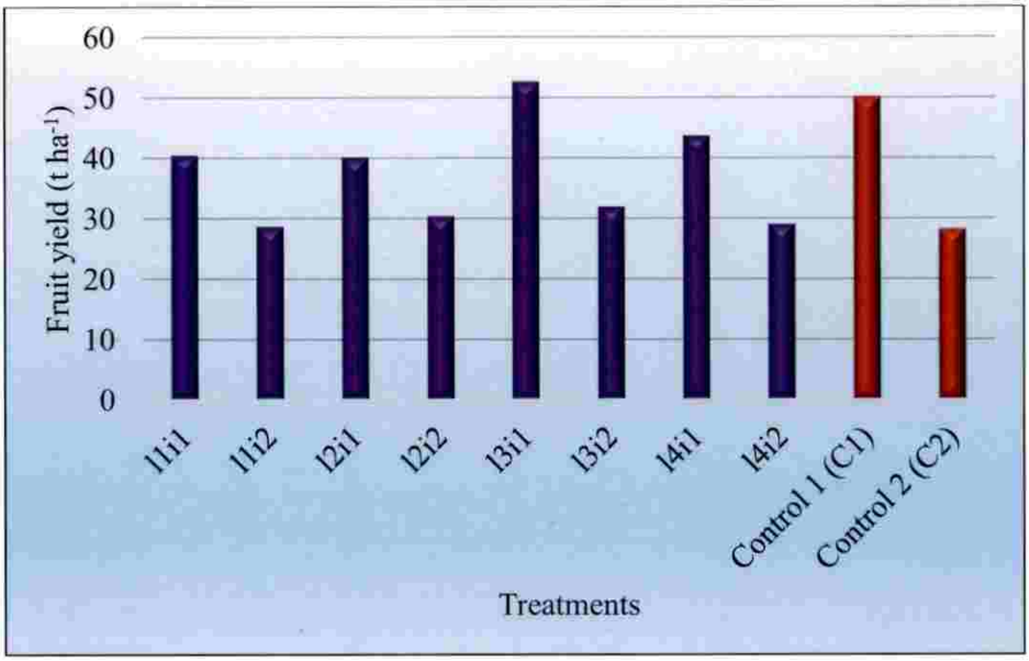

Fig. 5. Fruit yield as influenced by nutrient level - fertigation interval interaction

Crops grown in coarse-textured soil or crops grown during summer growing season, when higher amounts of water and nutrients are applied, may benefit most from frequent as opposed to infrequent fertigation (Badr and El- Yazied, 2007). Better response to frequent fertigation (i_1) in the present study which was carried out during summer season could be ascribed to this fact.

The treatment combination l_3i_1 (125 per cent RD of N and K through fertigation at four days interval) recorded the highest yield of 1.92 kg plant^{-1} and 52.7 t ha^{-1} which was significantly higher than that obtained from other interactions (Fig. 5). This might be due to frequent supply of higher levels of nutrients in the root zone of the plants leading to better uptake of nutrients resulting in more number of pickings and higher fruit yield. Corroborative findings were reported by Akanda *et al.* (2004) who obtained the highest tomato fruit yield was obtained with higher levels of nutrients (N-100 P-55 K-120) under fertigaton at two days interval.

Control 1 (KAU *ad hoc* POP for precision farming) and treatment mean were significantly superior to control 2 (KAU POP for conventional farming). Even though control 1 *i.e.,* KAU *ad hoc* POP for precision farming wherein 264 kg N, 130 kg P_2O_5 and 281 kg K_2O were applied through fertigation at three days interval registered a high DMP of 241.24 g plant^{-1}, it was not manifested in fruit yield. Brahma *et al.* (2010) reported that fertigation with N and K exerted a consistent and significant influence on yield of tomato over conventional soil application of N and K. The better performance under drip was attributed to maintenance of favourable soil water conditions in the root zone which in turn helped the plants to utilize water and nutrients more efficiently from the wetted area (Ibrahim, 1992; Lara *et al.*, 1996; Singh *et al.*, 2002).

Compared to control 1, *i.e.,* KAU *ad hoc* POP for precision farming, the best treatment combination l_3i_1 registered an yield increase of 4.89 per cent, probably due to the fact that the requirement of tomato crop for N and K is very high as reported by Hebbar *et al.* (2004). But further increase in N and K as in control 1 might have only resulted in improvement in vegetative growth (plant height, primary branches plant^{-1}, LAI) as evident from Tables (5,6 and 7).

5.3 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND THEIR INTERACTION ON ROOT CHARACTRISTICS

Present study revealed that both root weight and root volume significantly varied with levels of nutrients. The treatment l_3 (125 per cent RD of N and K) registered the highest root weight (10.27 g) and root volume (26.58 cm^3) and it was on par with l_4 (150 per cent RD of N and K) and l_2 (100 per cent RD of N and K) (Table 10).

Fertigation interval significantly influenced all root characteristics (root length, root volume and root weight) and fertigation at four days interval (i_1) was found superior to fertigation at eight days interval (i_2). Frequent supplementation of nutrients through irrigation water increased the availability of N and K in the crop root zone which in turn might have influenced the root growth. Jenny and Raychaudhuri (1960) opined that fertilization with artificial N compounds with additional nutrients would enhance the yield and stimulate the root system. Here, control 1 (KAU *ad hoc* POP for precision farming) recorded the highest root length and root volume compared to control 2 (KAU POP for conventional farming). These results are in line with Hebbar *et al.* (2004) and Rajan *et al.* (2014) in tomato.

5.4 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND INTERACTION ON WATER USE EFFICIENCY AND WATER PRODUCTIVITY

WUE and water productivity were significantly influenced by levels of nutrients and fertigation intervals. Application of 125 per cent RD of N and K (l_3) recorded the highest WUE and water productivity over other levels of nutrients. Among fertigation intervals, fertigation at four days interval registered the highest value for these parameters (Table 11 and Fig. 6).

WUE, being the ratio of fruit yield to the total quantity of water used during the growing season, improved significantly in the present study in l_3 as well as in i_1 (Fig. 7) treatments due to the favourable effect of higher levels of nutrients and frequent fertigation on fruit yield.

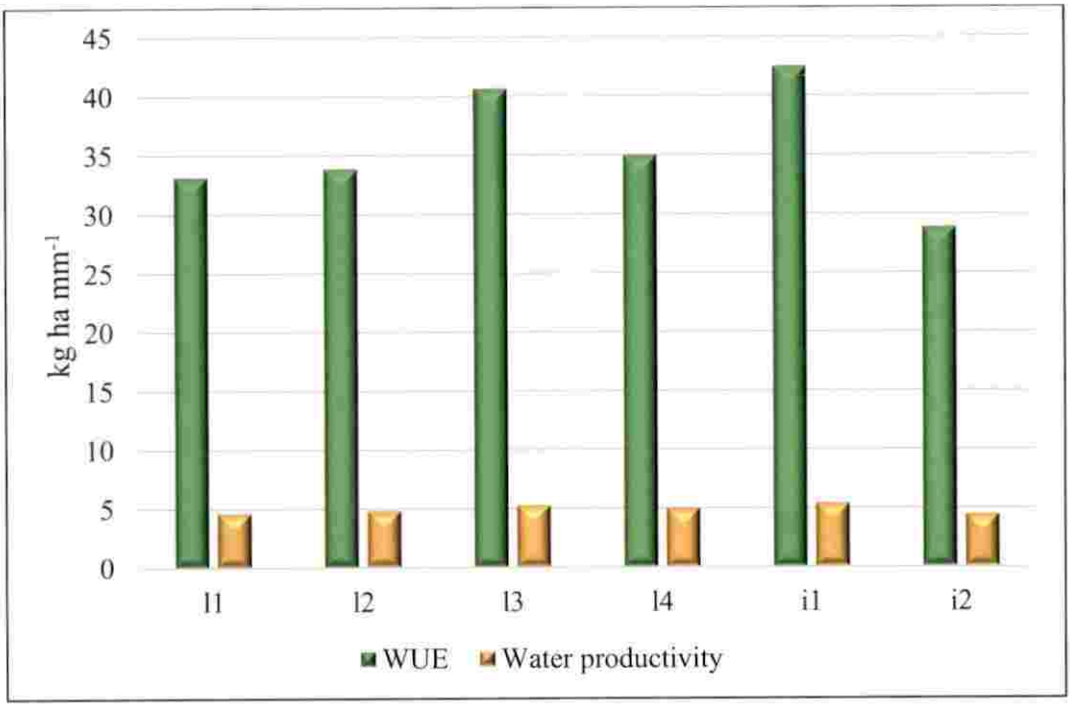

Fig. 6. Water use efficiency and water productivity as influenced by levels of nutrients (L) and fertigation intervals (I)

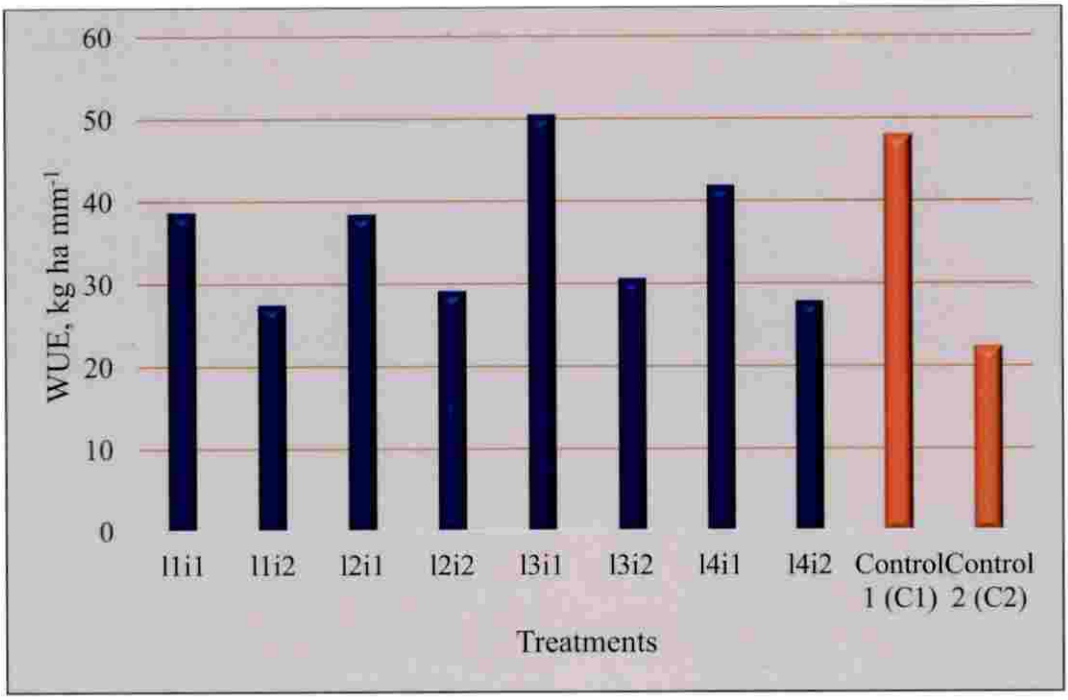

Fig. 7. Water use efficiency as influenced by nutrient level - fertigation interval interaction

In the present study, water productivity was the highest for l_3 (125 per cent RD of N and K) (Fig. 6). This could be attributed to enhanced DMP as a result of enhanced nutrient uptake. These results are in line with the results of Babu (2015).

Irrigation imposes a greater demand for plant nutrients. Nutrient availability is the highest for most crops when water tension is low. All available evidence indicate that under adequate irrigation suitable fertilization generally increases yield considerably with a relatively small increase in evapotranspiration and therefore markedly improves WUE. Mecs (1986) suggested that increased nutrient supply decreased evapotranspiration co-efficient and water consumption co-efficient resulting in higher WUE. This results confirms the findings of Thomas (1984); Rao (1989); Thampatti *et al.* (1993); Lakshmi (1997) and Syriac (1998) in cucurbits and Hedge (1988); Palled *et al.* (1988), Prabhakar and Naik (1993) and Sherly (1996) in chillies.

Control 1 (KAU *ad hoc* POP for precision farming- drip irrigation) registered significantly superior WUE and water productivity than control 2 (KAU POP for conventional farming- conventional pot irrigation). In the case of drip irrigation, the depletion of available soil moisture from same soil depth was quite low and very frequent application of irrigation water created a favourable environment in soil-plant-atmosphere system which helped proper growth and yield of the tomato crop which in turn increased the WUE. Similar findings on significantly higher WUE and water saving in tomato under drip irrigation compared to surface irrigation were also reported by Bafna *et al.* (1993), Raina *et al.* (1999), Singandhupe *et al.* (2003) and Bahadur *et al.* (2006). These results are in line with Muralidhar (1999) in chilli and Ugade *et al.* (2014) in brinjal.

5.5 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND THEIR INTERACTION ON UPTAKE OF MAJOR NUTRIENTS

Present study revealed that uptake of major nutrients, N, P and K varied with levels of nutrients and fertigation intervals. Nutrient level l_3 (125 per cent RD of N and K) registered the highest uptake of major nutrients and it was statistically

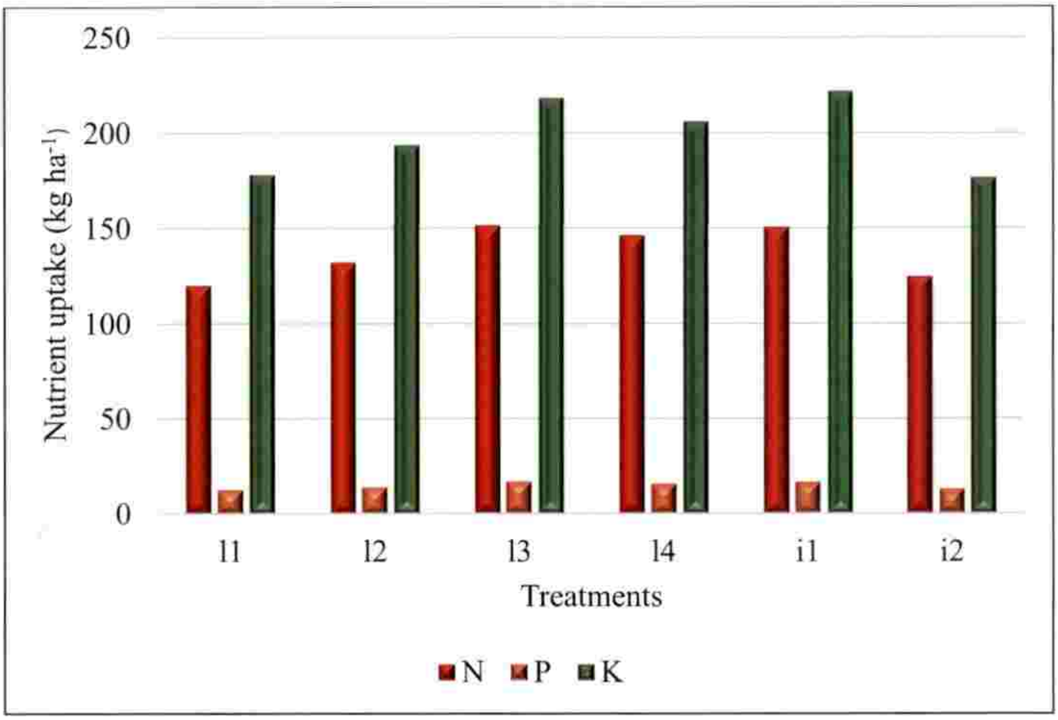

Fig. 8. Nutrient uptake as influenced by levels of nutrients (L) and fertigation intervals (I)

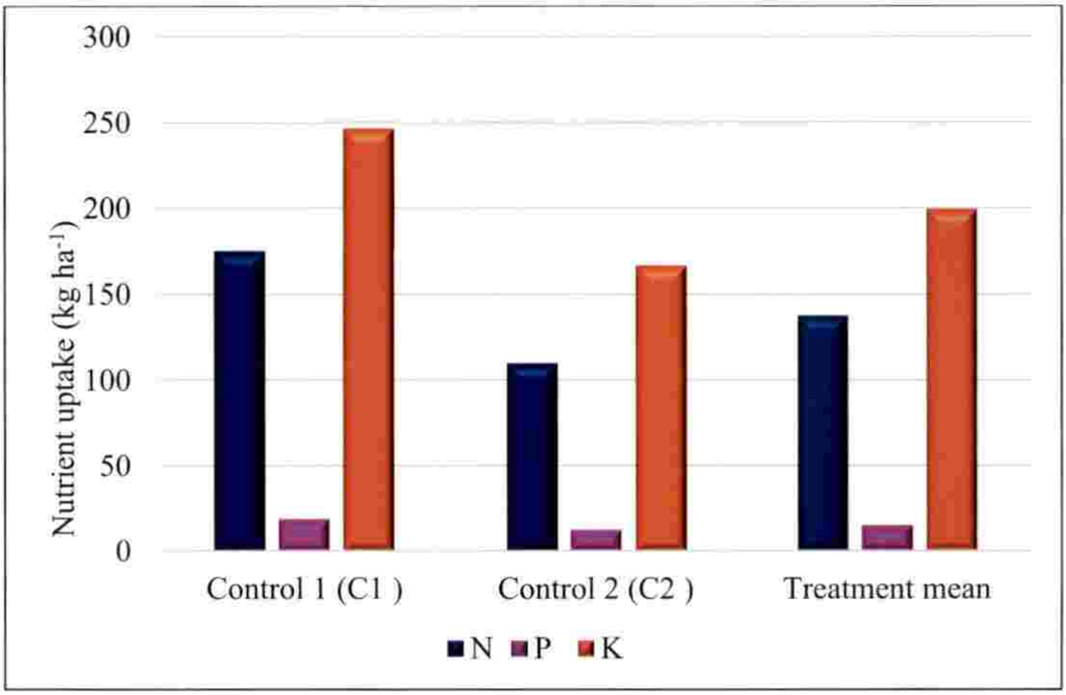

Fig. 9. Nutrient uptake as influenced by controls and treatment mean

on par with l_4 (150 per cent RD of N and K). Fertigation at four days interval (i_1) recorded the highest N, P and K uptake and it was significantly superior to fertigation at eight days interval (i_2) (Table 12 and Fig. 7).

The higher uptake of nutrients at 125 and 150 per cent RD of N and K might be due to the higher DMP and better availability of nutrients in root zone as a result of frequent application (four days interval) coupled with better root activity. Better root activity in this treatment is ascribed for more forage areas as evidenced from root length and root volume (Table 10). The increase in N uptake at higher N level was in agreement with the reports of Jyothi (1995) and Geetha (1999). According to Tanaka *et al.* (1964), the nutrient uptake is controlled by factors like nutrient availability in soil, the nutrient absorption power of roots and rate of increase in dry matter. Syriac (1998) reported that higher levels of nitrogen enhanced the total DMP and dry weight of roots which resulted in better nutrient uptake in cucurbits. Similar results were reported by Singandhupe *et al.* (2003), Elia *et al.* (2007) and Shedeed *et al.* (2009) in tomato.

Control 1 (KAU *ad hoc* POP for precision farming wherein, 264 kg N, 130 kg P_2O_5 and 281 kg K_2O were applied through fertigation at three days interval) registered significantly higher nutrient uptake (N, P and K) than control 2 (KAU POP for conventional farming- conventional soil application of fertilizers) (Fig. 8). Hebbar *et al.* (2004) reported that water soluble fertigation in tomato had significantly higher NPK uptake over drip irrigation with conventional fertilizer application. The applied NPK in soluble form in fertigation treatments may have been distributed better through root zone of tomato than soil applied treatments thus providing more available amounts for plant uptake.

5.6 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND INTERACTION ON AVAILABLE NUTRIENTS STATUS OF SOIL AFTER THE EXPERIMENT

The study revealed that available N and K status of soil were not influenced by different levels of nutrients and fertigation intervals. However, available soil P status varied significantly due to fertigation interval and fertigation at four days interval (i_1) registered a higher soil P status compared to i_2 (fertigation at eight days interval) (Table 13).

Control 1 (KAU *ad hoc* POP for precision farming) recorded significantly higher available N, P and K status than treatment mean and control 2 (KAU POP for conventional farming). Higher amount of nutrients (264 kg N, 130 kg P_2O_5 and 281 kg K_2O) applied in control 1 compared to treatments and control 2 could be the probable reason for the higher available soil nutrient status in this treatment.

5.7 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND INTERACTION ON QUALITY ATTRIBUTES

In the present study levels of nutrients, fertigation intervals and their interaction did not have any significant influence on quality attributes of tomato (Table 15). This is in conformity with the findings of Hebbar *et al.* (2004). Contrary to these results, Brahma *et al.* (2010) reported that fruit quality parameters, *viz.*, TSS and ascorbic acid content improved significantly by N fertigation.

5.8 EFFECT OF LEVELS OF NUTRIENTS, FERTIGATION INTERVALS AND INTERACTION ON ECONOMICS OF CULTIVATION

In tomato, fresh fruit is the economic plant part and hence fruit yield decides the economics of production. Therefore, any management practice that increase yield will definitely have a role in increasing the net income and B: C ratio.

Among different levels of nutrients tested, 125 per cent RD of N and K (l_3) registered the highest net income (₹ 4,55,466 ha^{-1}) and B: C ratio (2.16) and it was significantly superior to other levels of nutrients, the lowest B: C ratio being registered for 75 per cent RD of N and K (l_1) (Table 16 and Fig. 9). According to Brahma *et al.* (2010) the highest B: C ratio in tomato was recorded in the cent per cent fertigation of RD of nutrients and the lowest B: C ratio was recorded by 50 per cent fertigation level. Corroborative findings were also reported by Tumbare and Bhoite (2002) in chilli.

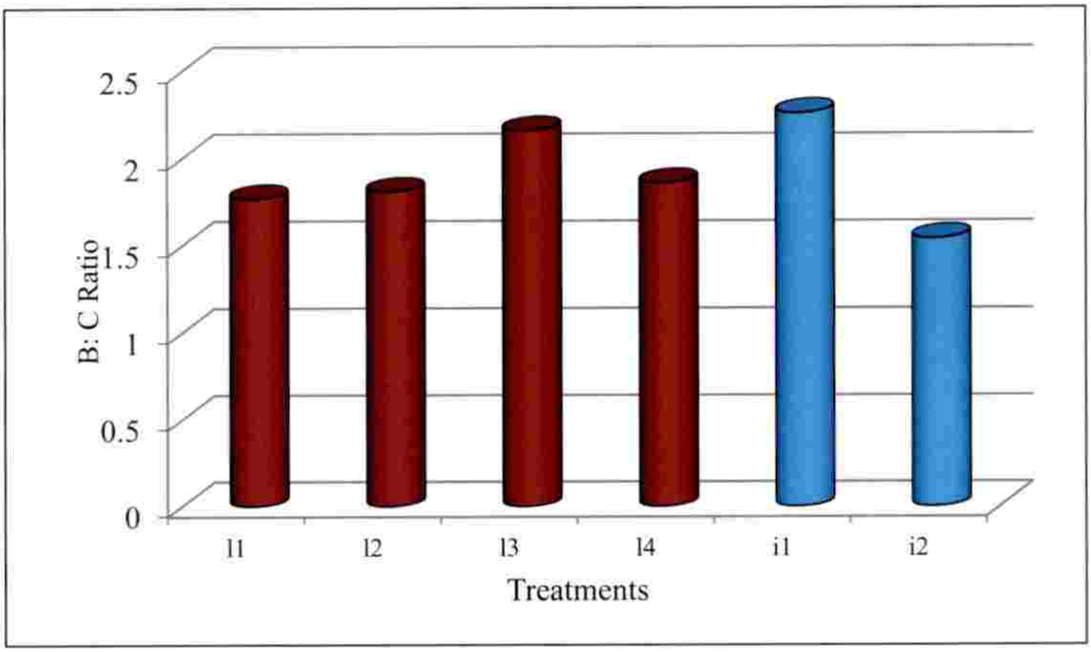

Fig. 10. B: C ratio as influenced by levels of nutrients (L) and fertigation intervals (I)

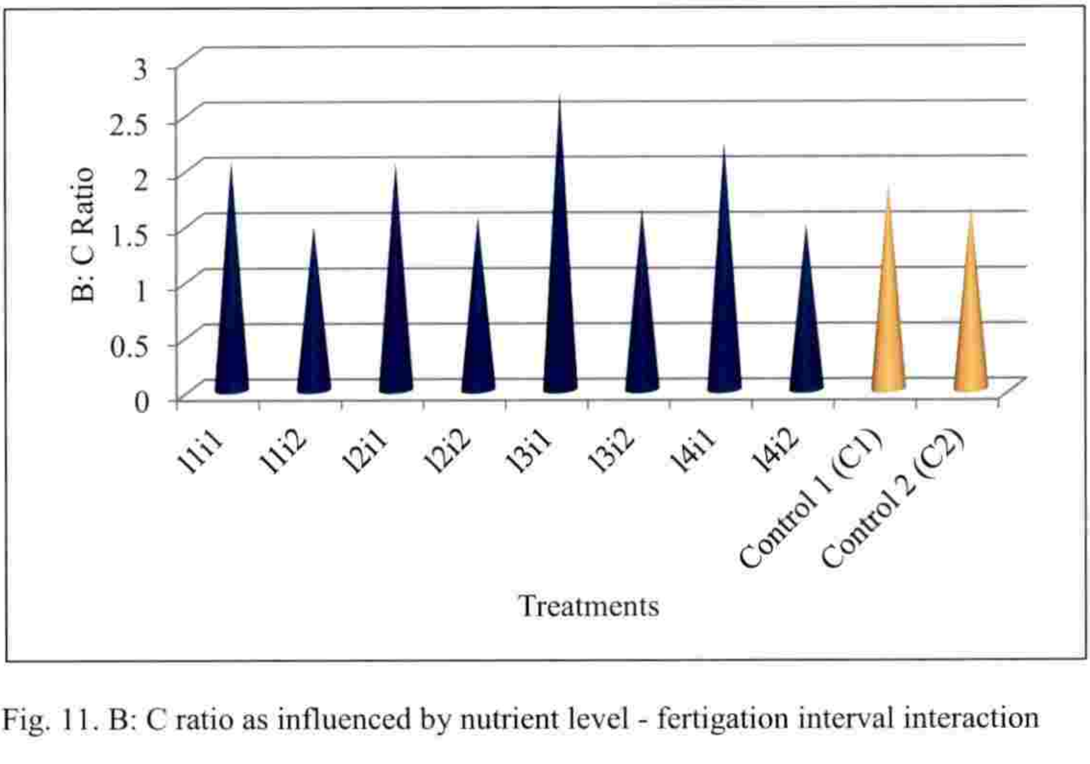

Fig. 11. B: C ratio as influenced by nutrient level - fertigation interval interaction

Fertigation interval of four days showed significantly higher net income (₹ 4,93,051 ha^{-1}) and B: C ratio (2.26) and it was superior to i_2 (fertigaton at eight days interval). The substantial yield increase due to frequent fertigation (four days interval) resulted in significantly higher net income and B: C ratio in this treatment, even though the expenditure on fertigation was comparatively more than that in i_2 (fertigation at eight days interval).

Nutrient level – fertigation interval interaction revealed that l_3i_1, *i.e.*, application of 125 per cent RD of N and K at four days fertigation interval recorded the highest net income (₹ 6,61,515 ha^{-1}) and B: C ratio (2.69).

Control 1 (KAU *ad hoc* POP for precision farming) and treatment mean registered significantly higher B: C ratio compared to control 2 (KAU POP for conventional farming) (Fig. 10). This is because of the higher yield obtained in fertigation treatments (both control 1 and treatment mean) compared to conventional soil application of fertilizers (control 2).

Even though the yield of control 1 (KAU *ad hoc* POP for precision farming wherein 264 kg N, 130 kg P_2O_5 and 281 kg K_2O were applied through fertigation at three days interval) was comparable with 125 per cent RD of N and K given through fertigation at four days interval (l_3i_1), it was not reflected in net income and B: C ratio. This is because of the high cost of cultivation in control 1. In control 1, costly high analysis fertilizers, *viz.*, 19:19:19, 12:61:0 and13:0:45 were used which costs around ₹ 200 kg^{-1}, leading to high cost of cultivation and low B: C ratio of 1.87.

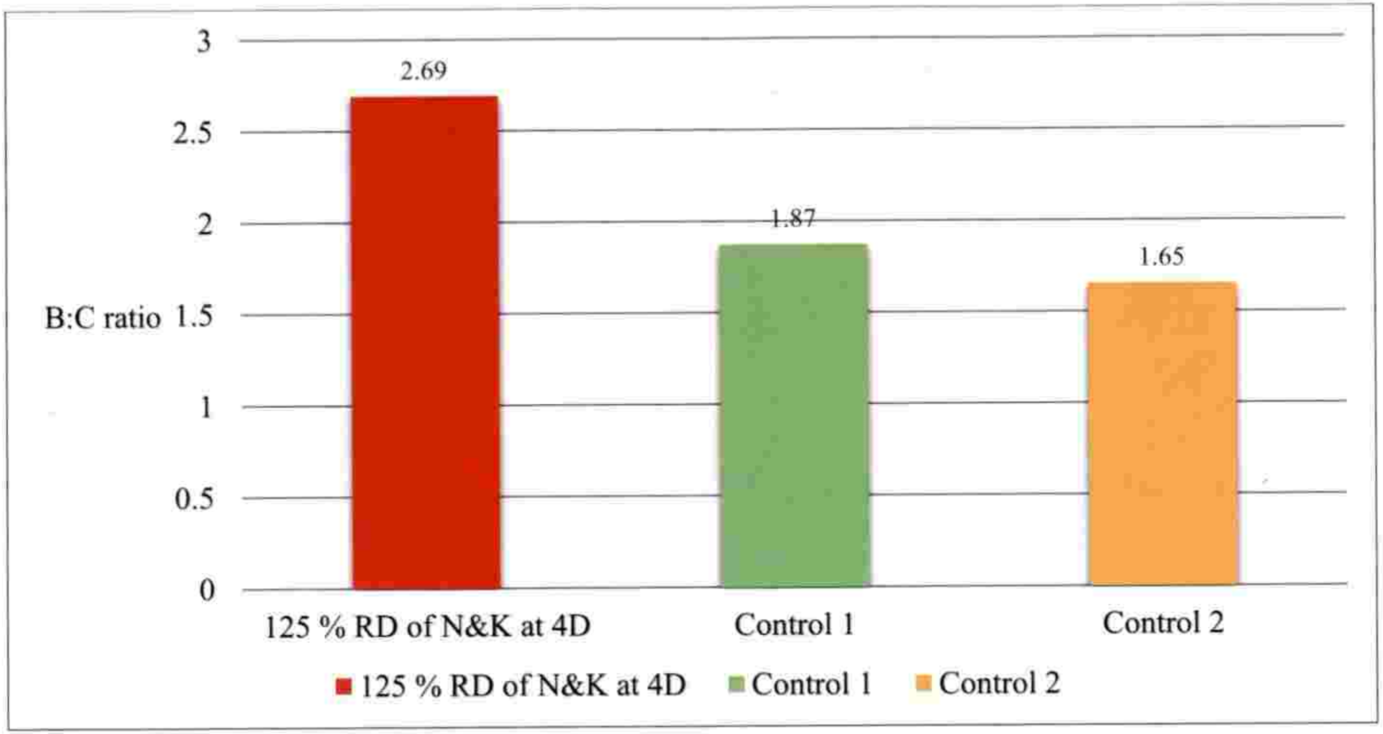

Fig. 12. Comparison of B: C ratio between controls and best treatment (125 % RD of N and K given through fertigation at four days interval)

SUMMARY

6. SUMMARY

An experiment entitled "Fertigation for precision farming in tomato (*Solanum lycopersicum* L.)" was conducted in farmers's field at Pirappancode, Thiruvananthapuram during February to June, 2015 to standardize the fertigation schedule for tomato under precision farming.

The experiment was laid out in split plot design with four main plot treatments (levels of nutrients - L) and two sub plot treatments (fertigation intervals- I)along with two controls (C_1- KAU *ad hoc* POP for precision farming, C_2- KAU POP for conventional farming). Data on growth attributes, yield attributes and yield, fruit quality parameters etc. collected were subjected to statistical analysis and the results are furnished in chapter 4. The salient findings of the study are summarised below…

Among different growth parameters, plant height, primary branches plant^{-1} and LAI did not vary significantly due to different levels of nutrients. Analysis of data on DMP revealed that, it was significantly influenced by levels of nutrients. Among four levels of nutrients tested, 125 per cent RD of N and K (l_3) recorded the highest DMP (219.42 g plant^{-1}) and it was on par with 150 per cent RD of N and K (l_4).

A critical analysis of data on yield and yield attributes pointed out that parameters like days to 50 per cent flowering, fruit length, fruit girth, number of pickings and harvest index were not influenced significantly by different levels of nutrients. Yield attributes such as per cent fruit set and number of fruit plant^{-1} varied significantly with different levels of nutrients and the highest per cent fruit set was obtained with l_3, *i.e.*, 125 per cent RD of N and K and it was significantly superior to other levels. In the case of number of fruits plant^{-1} also, 125 per cent RD of N and K registered significantly higher values followed by 150 per cent RD of N and K (l_4). Both fruit yield plant^{-1} and fruit yield ha^{-1} were also significantly influenced by different levels of nutrients. The nutrient level l_3, *i.e.,* 125 per cent RD of N and K recorded significantly higher fruit yield plant^{-1} and ha^{-1} (1.54 kg and 42.36 t respectively).

The treatment l_3 (125 per cent RD of N and K) recorded the highest root weight of 10.27 g and root volume of 26.58 cm^3 and it was statistically on par with 150 per cent RD of N and K (l_4) and 100 per cent RD of N and K (l_2).

The highest WUE (40.62 kg ha mm^{-1}) and water productivity (5.26 kg ha mm^{-1}) was registered for l_3, *i.e.*, 125 per cent RD of N and K.

Numerically higher N, P and K uptake were found higher for 125 per cent RD of N and K (l_3).

Data on soil nutrient status after the experiment pointed out that available soil N, P and K status did not vary significantly due to different levels of nutrients. So also the organic carbon content and soil pH.

Quality attributes like TSS, ascorbic acid content and lycopene content of fruit did not exhibit any significant variation due to different levels of nutrients.

Application of 125 per cent RD of N and K registered a significantly higher B: C ratio (2.16) and net income (₹ 4,55,466 ha^{-1}).

Fertigation interval was the sub plot treatment and it substantially influenced various growth and yield parameters. Among growth attributes, plant height and primary branches $plant^{-1}$ did not show any significant variation with fertigation intervals. LAI at flowering and DMP at harvest varied with fertigation interval. LAI was significantly higher and DMP recorded the highest value of 224.21 g $plant^{-1}$ for fertigation at four days interval (i_1) over i_2, *i.e.*, fertigation at eight days interval.

Among different yield attributes, fruit set per cent, number of fruits $plant^{-1}$, fruit weight, fruit yield $plant^{-1}$, fruit yield ha^{-1}, number of pickings and harvest index were significantly influenced by fertigation interval; however, attributes like days to 50 per cent flowering, fruit length and fruit girth were not significantly influenced by fertigation interval. Fertigation at four days interval (i_1) recorded higher fruit weight (44.41 g), fruit yield (1.61 kg $plant^{-1}$ and 44.25 t ha^{-1}). The treatment i_1

registered higher number of pickings and harvest index than i_2 (fertigation at eight days interval).

Fertigation at four days interval (i_1) had higher root length (70.51 cm), root weight (10.06 g) and root volume (26.73 cm^3) over fertigation at eight days interval (i_2).

Moisture studies revealed that fertigation at four days interval recorded higher WUE and water productivity over i_2 (fertigation at eight days interval).

A critical appraisal of data on plant analysis revealed that N, P and K uptake by the crop was found significantly higher for fertigation at four days interval (i_1) compared to that at eight days interval (i_2). Data on soil nutrient status showed that available soil N and K did not vary significantly with fertigation interval. However, available soil P significantly varied with fertigation interval with i_1 registering a higher amount of available soil P (11.78 kg ha^{-1}) over i_2. Soil pH and soil organic carbon content did not exhibit any variation with fertigation interval.

Fertigation interval did not have any significant influence on quality attributes of fruits such as TSS, ascorbic acid and lycopene content.

Economic analysis pointed out that fertigation at four days interval resulted in higher net income (₹ 4,93,051 ha^{-1}) and B: C ratio (2.26) over fertigation at eight days interval, *i.e.*, i_2.

Interaction effect did not exert any significant influence on growth parameters except dry matter production. Application of 125 per cent RD of N and K given as fertigation at four days interval registered the highest dry matter yield and it was significantly superior to others

The treatment combination 125 per cent RD of N and K given as fertigation at four days interval recorded significantly higher yield (1.92 kg $plant^{-1}$and 52.7 t ha^{-1}) which was significantly higher than other interactions. The treatment combination l_3i_1 (125 per cent RD of N and K at four days interval) registered the highest number of pickings (7.33) and it was significantly superior to other interactions.

None of the interaction effect was significant on root studies, nutrient uptake by the crop, soil nutrient status after the experiment, organic carbon content of soil, soil reaction and quality attributes of fruits.

The study revealed that l_3i_1, *i.e.*, 125 per cent RD of N and K given as fertigation at four days interval was significantly superior to all other interactions with a WUE of 50.53 kg ha mm^{-1}

Economic analysis revealed that application of 125 per cent RD of N and K given as fertigation at four days interval (l_3i_1) had the highest net income (₹ 6,61,515 ha^{-1}) and B: C ratio (2.69) followed by 150 per cent RD of N and K given as fertigation at four days interval (l_4i_1).

Comparison of controls and treatment mean indicated that control 1 (KAU *ad hoc* POP for precision farming) was significantly superior to control 2 (KAU POP for conventional farming) and treatment mean for growth attributes, *viz.*, plant height, LAI and DMP. For number of primary branches plant^{-1}, control 1 was significantly superior to control 2 at all growth stages. Comparing treatment mean and control 2, no significant difference was noticed in plant height at all growth stages, LAI and number of primary branches at 30 and 60 DAP, while treatment mean was significantly superior to control 2 in the case of DMP and number of primary branches plant^{-1} at 90 DAP.

A critical appraisal of data showed that control 1 significantly increased the fruit weight over control. Comparing control 2 and treatment mean, treatment mean was superior to control 2.

Data on yield attributes revealed that there was no significant difference in days to 50 per cent flowering, fruit set per cent, fruit length, fruit girth and harvest index between two controls and treatment mean. It was observed that control 1 was significantly superior to control 2 and treatment mean whereas control 2 was significantly inferior to treatment mean in the case of fruits plant^{-1}, fruit yield plant^{-1} and fruit yield ha^{-1}.

Data on number of pickings revealed that control 1 was significantly superior to control 2 and treatment mean. There was no significant variation between control 2 and treatment mean.

A perusal of data on root length revealed that control 1 and treatment mean were significantly superior to control 2. Control 1 registered significantly higher root volume than control 2 and treatment mean, but no significant variation was observed between control 2 and treatment mean.

Data on moisture studies indicated that control 1 (KAU *ad hoc* POP for precision farming) and treatment mean registered significantly higher WUE and water productivity than control 2 (KAU POP for conventional farming) whereas control 1 was significantly superior to treatment mean.

Critical analysis of data on the uptake of major nutrients revealed that, control 1 registered significantly higher N, P and K uptake than control 2 and treatment mean. Treatment mean also had a significantly higher uptake of these major nutrients compared to control 2.

Soil analysis after the experiment indicated that control 1 recorded significantly higher available N, P and K status than treatment mean and control 2, but no significant variation was observed between control 2 and treatment mean.

Economic analysis showed that control 1 had significantly higher B: C ratio and net income than control 2 and there was no significant difference between control 1 and treatment mean in B: C ratio. However, Control 1 registered significantly superior net income compared to treatment mean. Data showed that treatment mean was significantly superior to control 2 in B: C ratio and net income.

Based on the results of the present field investigation, it can be concluded that application of 125 per cent RD of N and K (93.75 kg N and 31.25 kg K ha^{-1}) as urea and muriate of potash respectively, in 30 splits through fertigation at four days interval is the best schedule for hybrid tomato under open precision farming along with basal application of farm yard manure @ 25 t ha^{-1} and P @ 40 kg ha^{-1} as rock phosphate.

Future line of work

- To assess the possibility of fertigation of N and K at six days interval thereby reducing the cost of nutrient application.
- To study the effectiveness of high analysis water soluble fertilizers instead of urea and MOP, at 125 per cent RD.

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FERTIGATION FOR PRECISION FARMING IN TOMATO
(*Solanum lycopersicum* L.)

by

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ABSTRACT

The investigation entitled "Fertigation for precision farming in tomato (*Solanum lycopersicum* L.)" was carried out at College of Agriculture, Vellayani during the period 2015-2016 to standardize a fertigation schedule for precision farming in tomato and to assess the impact of precision farming practices on growth and yield and also to work out the economics.

The field experiment was conducted during the summer season of 2015 (February to June) in farmer's field at Pirappancode, Thiruvananthapuram district. The experiment was laid out in split plot design with eight treatment combinations and two controls, with four replications. Four levels of nutrients (l_1- 75 per cent RD of N and K, l_2- 100 per cent RD of N and K, l_3- 125 per cent RD of N and K, l_4- 150 per cent RD of N and K) constituted the main plot treatments and two fertigation intervals (i_1- fertigation once in four days, i_2- fertigation once in eight days) constituted the sub plot treatments. The two control treatments were, control 1 (KAU *ad hoc* POP for precision farming) and Control 2 (KAU POP for conventional farming). The hybrid tomato Lakshmi grafted on wild brinjal was used for the study.

Among different nutrient levels, l_3 (125 per cent RD of N and K) recorded the highest DMP (219.42 g plant^{-1}), number of fruits plant^{-1}(33.67), fruit set percentage (62.77) , fruit yield (1.54 kg plant^{-1} and 42.36 t ha^{-1}) and was significantly superior to other nutrient levels tested. Fertigation at four days interval (i_1) recorded the highest LAI, DMP (224.21 g plant^{-1}), number of fruits plant^{-1} (35.53), fruit set percentage (60.74) and fruit yield (1.61 kg plant^{-1} and 44.25 t ha^{-1}) and was significantly superior to i_2 (fertigation at eight days interval).

Moisture studies indicated that both WUE and water productivity significantly varied with nutrient levels and fertigation intervals. The highest WUE (40.62 kg ha mm^{-1}) and water productivity (5.26 kg ha mm^{-1}) were

observed at 125 per cent RD of N and K. Fertigation at four days interval (i_1) registered significantly higher WUE and water productivity than i_2.

Application of 125 per cent RD of N and K (l_3) recorded the highest root weight of 10.27 g and the highest root volume of 26.58 cm^3 and was statistically on par with 150 and 100 per cent RD of N and K. The treatment i_1 was significantly superior to i_2 for all root characteristics.

Uptake of N, P and K varied significantly with nutrient levels and fertigation intervals. The treatment l_3 recorded the highest N, P and K uptake and it was statistically on par with l_4. Fertigation at four days interval (i_1) was significantly superior to i_2, in nutrient uptake.

Among different interactions, 125 per cent RD of N and K at 4 days interval (l_3i_1) registered the highest DMP (245.28 g $plant^{-1}$) and was statistically on par with 150 per cent RD of N and K at four days interval (l_4i_1). Also, l_3i_1 recorded the highest fruit yield (1.92 kg $plant^{-1}$ and 52.70 t ha^{-1}) and number of pickings (7.33) and was significantly superior to other interactions studied.

Economics of the study showed that l_3i_1 (125 per cent RD of N and K at four days interval) registered the highest net income of ₹ 6,61,515 ha^{-1} and B:C ratio of 2.69 and it was significantly superior to all other interactions.

KAU a*d hoc* POP for precision farming (Control 1) was significantly superior to KAU POP for conventional farming (Control 2), for all growth attributes, yield attributes and yield. The treatment combination 125 per cent RD of N and K given as fertigation at four days interval (l_3i_1) was superior to control 1 and control 2 with respect to yield attributes, yield and economics.

Based on the results of the present field investigation, it can be concluded that application of 125 per cent RD of N and K (93.75 kg N and 31.25 kg K ha^{-1}) as urea and muriate of potash respectively, in 30 splits through fertigation at four days interval along with basal application of FYM @ 25 t ha^{-1} and P @ 40 kg ha^{-1} as rock phosphate is the best schedule for hybrid tomato under precision farming.

സംഗ്രഹം

ഒരു പ്രധാന പച്ചക്കറി വിളയായ തക്കാളിയുടെ കൃത്യതാകൃഷിക്കുവേണ്ടി ഫെർട്ടിഗേഷൻ ഷെഡ്യൂൾ ക്രമീകരിക്കുന്നതിനും ഇതുമൂലം തക്കാളിയുടെ വളർച്ചയിലും വിളവിലും ഗുണമേന്മയിലുമുണ്ടാകുന്ന വ്യത്യാസങ്ങൾ മനസിലാക്കുന്നതിനുമായി 2015 ഫെബ്രുവരി മുതൽ ജൂൺ വരെയുള്ള കാലയളവിൽ തിരുവനന്തപുരം ജില്ലയിലെ പിരപ്പൻകോട് ഒരു കർഷകന്റെ കൃഷിയിടത്തിൽ ഒരു പരീക്ഷണം നടത്തുകയുണ്ടായി. ചുണ്ടയിൽ ഗ്രാഫ്റ്റ് ചെയ്ത ലക്ഷ്മി എന്ന ഹൈബ്രിഡ് തക്കാളിയിനമാണ് പരീക്ഷണത്തിനുപയോഗിച്ചത്.

സ്പ്ലിറ്റ് പ്ലോട്ട് ഡിസൈൻ എന്ന പരീക്ഷണ രീതിയാണ് അവലംബിച്ചത്. പരീക്ഷണത്തിൽ 4 പ്രധാനപ്ലോട്ട് പരിചരണമുറകളും (വ്യത്യസ്ത തോതിൽ പാക്യജനകവും ക്ഷാരവും കാർഷിക സർവ്വകലാശാല ശുപാർശ ചെയ്യുന്നതിന്റെ 75 %, 100 %, 125 %, 150 % എന്ന തോതിൽ നല്കുക) 2 സബ്പ്ലോട്ട് പരിചരണമുറകളും (ഫെർട്ടിഗേഷൻ ഇടവേളകൾ (നാലു ദിവസവും എട്ട് ദിവസവും) രണ്ട് കൺട്രോളുകളുമാണ് (കൺട്രോൾ 1- കാർഷിക സർവ്വകലാശാല തക്കാളിയുടെ കൃത്യതാ കൃഷിക്കുവേണ്ടി നല്കുന്ന ശുപാർശ, കൺട്രോൾ 2 കേരളകാർഷികസർവ്വകലാശാല തക്കാളിയുടെ സാധാരണ കൃഷിരീതിയ്ക്ക് നല്കുന്ന ശുപാർശ) ഉണ്ടായിരുന്നത്.

വ്യത്യസ്തതോതിൽ പാക്യജനകവും ക്ഷാരവും നല്കുന്ന പരിചരണമുറകളുടെ താരതമ്യപഠനത്തിൽ നിന്നും, പാക്യജനകവും ക്ഷാരവും ശുപാർശ ചെയ്യുന്ന തോതിന്റെ 125 % നല്കുന്ന പരിചരണമുറയ്ക്ക് (l_3) മികച്ച വളർച്ചാ മാനദണ്ഡങ്ങളും വിളവും ലഭിക്കുമെന്ന് ബോധ്യപ്പെട്ടു.

നാലു ദിവസത്തിലൊരിക്കൽ ഫെർട്ടിഗേഷൻ നല്കുന്ന പരിചരണമുറയ്ക്ക് (i_1) വളർച്ചാമാനദണ്ഡങ്ങളായ ഇല വിസ്തൃതി സൂചികയും, ഉണക്കിസൂക്ഷിക്കു

മ്പോഴുള്ള തൂക്കവും വിളവിന്റെ മാനദണ്ഡങ്ങളും വിളവും എട്ട് ദിവസത്തിലൊരിക്കൽ ഫെർട്ടിഗേഷൻ നല്കുന്ന പരിചരണ മുറയേക്കാൾ (i_2) മെച്ചപ്പെട്ടതാണെന്ന് കണ്ടെത്തി.

പ്രധാനപ്ലോട്ട് x സബ്പ്ലോട്ട് സംയുക്ത സ്വാധീനം വിശകലനം ചെയ്തതിൽ നിന്നും പാക്യജനകവും ക്ഷാരവും ശുപാർശ പ്രകാരമുള്ള തോതിന്റെ 125% ഫെർട്ടിഗേഷൻ മുഖേന നാലുദിവസത്തിലൊരിക്കൽ (l_3 i_1) നല്കുന്ന പരിചരണ മുറയ്ക്ക് മെച്ചപ്പെട്ട വളർച്ചാ വിളവ് മാനദണ്ഡങ്ങളും വിളവും ലഭിക്കുന്നതായി ബോദ്ധ്യപ്പെട്ടു. ഈ പരിചരണ മുറയ്ക്കു തന്നെ മികച്ച അറ്റാദായവും വരവ്-ചിലവ് അനുപാതവും ലഭിച്ചു.

കൺട്രോളുകൾ തമ്മിലുള്ള താരതമ്യപഠനത്തിൽ നിന്നും കൺട്രോൾ 1, കൺട്രോൾ 2 നേക്കാൾ വളർച്ചാമാനദണ്ഡങ്ങളിലും വിളവിലും മെച്ചപ്പെട്ടതാണെന്ന് കണ്ടെത്തി.

ഈ പരീക്ഷണത്തിന്റെ അടിസ്ഥാനത്തിൽ പാക്യജനകവും ക്ഷാരവും ശുപാർശപ്രകാരമുള്ള തോതിന്റെ 125 % (യൂറിയായും മ്യൂറിയേറ്റ് ഓഫ് പൊട്ടാഷായും) നാലു ദിവസത്തിലൊരിക്കൽ ഫെർട്ടിഗേഷൻ മുഖേന 30 തുല്യ തവണകളായി നല്കുന്നത് (93.75 കി .ഗ്രാം പാക്യജനകവും 31.25 കി.ഗ്രാം ക്ഷാരവും) തക്കാളിയുടെ കൃത്യതാ കൃഷിക്കുവേണ്ടിയുള്ള ഫെർട്ടിഗേഷൻ രീതിയായി ശുപാർശചെയ്യാമെന്ന് കണ്ടെത്തി.

APPENDICES

APPENDIX- I

Weather parameters during the crop period (February – June 2015)

Standard weeks	Temperature (^{0}C)		Relative humidity (%)	Rainfall (mm)	Evaporation (mm)
	Maximum temperature	Minimum temperature			
7	31.1	22.5	93.0	0.0	3.8
8	31.2	21.0	90.3	0.0	4.4
9	32.1	23.3	88.7	1.0	4.6
10	32.1	23.3	88.6	0.0	4.4
11	32.1	23.6	91.4	15.2	4.9
12	32.7	23.3	90.7	0.0	3.1
13	33.0	24.7	90.7	9.4	4.0
14	33.1	25.2	91.9	2.3	4.1
15	32.6	24.3	91.4	4.8	3.6
16	32.9	24.3	89.7	40.4	4.4
17	32.5	23.8	89.6	35.5	3.8
18	33.2	25.2	85.1	0.0	4.4
19	32.5	25.2	91.4	34.4	4.0
20	30.4	24.3	94.0	29.3	2.5
21	32.3	26.1	92.1	19.5	3.2
22	32.9	25.2	90.8	6.5	0.0
23	31.9	24.7	89.7	12.3	3.5
24	31.9	24.0	91.7	10.5	5.0
25	31.6	24.4	90.3	6.8	3.8

APPENDIX-II

Price of fertilizers

Fertilizers	Price (₹ kg^{-1})
Urea	8
MOP	17
Raj phos	7
13:0:45	200
19:19:19	140
12:61:0	140

APPENDIX- III

Cost of cultivation of tomato

Treatments	Total cost excluding treatments (₹ ha^{-1})	Treatment cost (₹ ha^{-1})	Total cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})
l_1i_1	2,87,450	1,03,206	3,90,656	8,08,600	4,17,944
l_1i_2	2,87,450	1,02,030	3,89,480	5,75,200	1,85,720
l_2i_1	2,87,450	1,03,560	3,91,010	8,02,200	4,11,190
l_2i_2	2,87,450	1,02,384	3,89,834	6,09,200	2,19,366
l_3i_1	2,87,450	1,04,864	3,92,314	10,53,800	6,61,486
l_3i_2	2,87,450	1,03,688	3,91,138	6,40,600	2,49,462
l_4i_1	2,87,450	1,05,970	3,93,420	8,74,800	4,81,380
l_4i_2	2,87,450	1,04,793	3,92,243	5,83,400	1,91,157
Control 1	2,87,450	2,47,584	5,35,034	10,02,400	4,67,366
Control 2	3,08,900	34,672	3,43,572	5,65,200	2,21,628

Note: Market price of tomato = ₹ 20 kg^{-1}