RESPONSE OF TOMATO (*Lycopersicon esculentum* Mill.) TO VARYING LEVELS OF FERTIGATION

By

D. RAJASEELAN KINGSLY

THESIS

Submitted in partial fulfilment of the requirement for the degree of

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Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680656
KERALA, INDIA

2002

DECLARATION

I hereby declare that this thesis entitled **"Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara
Date : [illegible]

D. Rajaseelan Kingsly

CERTIFICATE

Certified that this thesis, entitled **"Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation"** is a record of research work done independently by **Mr. D. Rajaseelan Kingsly** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Dr. U. Jaikumaran
Chairman, Advisory Committee
Associate Professor (Agronomy) and Head
Agricultural Research Station
Kerala Agricultural University
Mannuthy
Thrissur, Kerala

Vellanikkara
Date : 7/8/09

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr. D. Rajaseelan Kingsly,** a candidate for the degree of **Master of Science in Agriculture** with major in **Agronomy,** agree that this thesis entitled **"Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation"** may be submitted by **Mr. D. Rajaseelan Kingsly,** in partial fulfilment of the requirement for the degree.

Dr. U. Jaikumaran
Chairman, Advisory Committee
Associate Professor (Agronomy) and Head
Agricultural Research Station
Kerala Agricultural University
Mannuthy, Thrissur

Dr. C.T. Abraham
(Member, Advisory Committee)
Associate Professor
(Agronomy) and Head
Department of Agronomy
College of Horticulture
Vellanikkara, Thrissur

Dr. V.K.G. Unnithan
(Member, Advisory Committee)
Associate Professor
(Agrl. Statistics) and Head
Department of Agrl. Statistics
College of Horticulture
Vellanikkara, Thrissur

Dr. C. Narayanankutty
(Member, Advisory Committee)
Assistant Professor (Horticulture)
Agricultural Research Station
Kerala Agricultural University
Mannuthy, Thrissur

Dr.T.N.Balasubramanian
Professor (Agronomy) and Head
Department of Agrl. Meteorology
Tamil Nadu Agricultural University
Coimbatore
(EXTERNAL EXAMINER)

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D. Rajaseelan Kingsly

Dedicated to

my

beloved parents

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Introduction

INTRODUCTION

Water is fast becoming a scarce resource in many parts of the world (Chand, 2002). Hence utilization of available water resources in a fair and equitable manner is *sine qua non* for higher production of food crops to feed the growing population of the world. At the current rate of population growth in India, the annual per capita availability of water is likely to shrink from 1869 m^3 in 2000 to 1342 m^3 in 2025 (Hindu, 2002). Eventhough irrigated area has risen from 22.6 m ha (1950-51) to 94.73 m ha by 1999-2000, the ultimate irrigation potential of 139.89 m ha is yet to be reached.

Micro irrigation techniques are always useful to improve irrigation efficiency of crops. Drip irrigation provides water to the plants continuously to the root zone at the volumes approximate to the consumptive use of the crop. It also dispenses all the conventional water flow and evaporative losses (Michael, 1992).

Drip irrigation ensures precision in water application in the form of discrete or continuous tiny streams of moisture supply. It has immense potential in India. Already 3,00,000 hectare area is under drip in India and it has provided a water saving of as much as 84 per cent compared to conventional surface method of irrigation (Singh *et al.*, 2000).

The nutrient requirement of crops vary with varying levels of irrigation, growing conditions and phenology of the crop. Many research findings indicated that, higher nutrient supply under glass house conditions increased yield and quality of crops like tomato (Fonties *et al.*, 1997, Gualberto *et al.*, 1998 and Srivastava, 2000).

Mulching has improved the yield and quality of produce of several crops through reduction in evaporative losses, maintenance of sub-soil temperature and efficiency in weed control as well as input use (Lourduraj *et al.*, 1996 and Raina *et al.*, 1998).

Drip irrigation and fertigation have gained enormous popularity in recent years especially in case of widely spaced high value plantation crops and vegetable crops, owing to the substantial saving in water and fertilizer input as well as considerable enhancement in their production efficiency. These two technologies combined with mulching have remarkable superiority over conventional farming practices (Prabhakar *et al.*, 2001).

Tomato is the second most important vegetable crop in the world, after potato. It is produced mainly for culinary purposes and industrial processing. Food and Agricultural Organization (FAO) estimates showed that world tomato production was 85.6 million tonnes during 1999 from an area of 31 lakh hectares. The annual production of tomato in India is 5.44 million tonnes from an area of 3.5 lakh hectares during 2000 (NHB, 2000).

Total vegetable production in Kerala is 5.78 lakh tonnes annually from an area of 85,122 hectares (FIB, 1998). The corresponding requirement of vegetables for the state is 14.35 lakh tonnes (GOK, 1998). Vegetables are mainly grown in summer season. Due to paucity of water and its mismanagement, the overall vegetable productivity is low in Kerala. High-tech agriculture involving fertigation and mulching is essential in vegetable production, as the area is limited and water is scarce. There is paucity of research in Kerala for high tech production of vegetables.

Considering all the above facts the present study entitled, "Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation" was conducted with the following objectives.

1) To study the growth, development and yield of tomato as affected by irrigation and nutrient level by way of continuous nutrition through fertigation.
2) To provide information on the effect of fertigation on soil moisture and nutrient relations in tomato.
3) To bring out information on the development of plant as well as quality of fruits due to progressive addition of nutrients and water.

Review of Literature

REVIEW OF LITERATURE

Fertigation in crops is a technology that is gaining added emphasis in India and abroad. Although only a few works have been done in India, the favourable results from these investigations have indicated immense potential for practising this technology throughout the country. Tomato is one of the crops that respond to nutrient application and water supply quickly and favourably. This chapter gives an insight into the research works done elsewhere relevant to the present study and is described under following sub-heads.

2.1 Fertigation

2.2 Mulching

2.3 Economic feasibility of mulching, drip and fertigation technologies

2.1 Fertigation

Fertigation is the application of solid or liquid mineral fertilizers through irrigation water (Magen, 1995). Drip irrigation was ideally suited for controlling the placement and supply rate of water soluble fertilizers (Goldberg *et al.*, 1976). Even though combined application of irrigation and fertilizers could be practised through different irrigation systems like sprinkler, microjet etc., the one through drip irrigation system was superior (Bar-Yosef, 1999).

According to Fertilizer Association of India (FAI, 1995) fertigation has various advantages like (i) higher water and fertilizer use efficiency, (ii) minimum losses of nutrients due to prevention of leaching, (iii) optimisation of nutrient balance by supplying nutrient directly to root zone in available form, (iv) control of nutrient concentration in soil solution to effect proper supply, (iv) saving in application cost and (vi) improvement of soil physical and biological conditions due to proper maintenance of soil moisture levels.

2.1.1 Effect of fertigation on growth and yield

Karlen *et al.* (1985) observed that N-rates of 130-200 kg ha^{-1} did significantly increase fresh marketable tomato production by increasing the number of large sized fruits. This was due to reduced leaching of nutrients under trickle irrigation.

Hayness (1988) obtained increased vegetative growth in chilli when 75 kg ha^{-1} N was applied through fertigation compared to broadcast application. Similarly in Nendran banana application of 200 g N per plant through drip irrigation gave a higher bunch weight compared to 200 g N applied to soil (KAU, 1997).

Locascio *et al.* (1977) while working on straw berry observed that N and K applied through trickle irrigation with daily or weekly increments in fertilizer nutrients produced 2 to 20 per cent more fruit yield than with overhead irrigation at 0 and 50 per cent fertilizer dose.

Kataria and Michael (1990) reported that under Delhi conditions drip irrigation gave higher yield to the tune of 47.4 per cent over furrow method of irrigation in tomato.

Tomatoes grown in sandy soils under arid conditions of Egypt produced higher yield under high fertigation frequency (two day intervals), than under low (once in a week) (Ibrahim, 1992).

Kolte *et al.* (1999) observed at Rahuri that 125 per cent recommended fertilizer dose (250:250:250 kg NPK ha^{-1}) in tomato, applied half in the form of liquid fertilizer and half through vermicompost, produced maximum dry matter and fruit yield of 31.89 t ha^{-1} and 74.14 t ha^{-1} respectively.

The study conducted by Tumbare *et al.* (1999) in Okra during 1996-1997 in Rahuri revealed that the crop gave 194.90 q ha^{-1} yield when 75 per cent of recommended dose of fertilizer was applied through drip as liquid fertilizer. The same treatment also produced higher plant height, more fruits per plant and higher fruit weight than the treatment which received the recommended dose of straight fertilizer and surface irrigation.

Deolankar and Berad (1999) found that in ckickpea 75 per cent of recommended fertilizer dose (18.75: 37.5: 18.75 kg N, P_2O_5, K_2O $hectare^{-1}$) was sufficient, if applied as liquid fertilizer through drip to sustain better growth and crop yield.

The fertigation study on potato cv. Kufri Chandermukhi in Ludhiana revealed that leaf area index, per cent groundcover and dry matter accumulation were higher in trickle fertigated crop than the furrow irrigated conventionally fertilized crop. The trickle fertigated crop also gave maximum fresh tuber yield of 36.29 t ha^{-1} as compared to 21.5 t ha^{-1} produced by furrow irrigated crop (Chawla and Narda, 2000).

Application of N, P, K fertilizers in tomato at weekly intervals (31:30:69 to 133:0:198 kg ha^{-1}) through fertigation significantly increased fruit yield, its quality and water use efficiency (Segalla, 2001).

Youssef *et al.* (2001) found that application of chicken (organic) manure (25%) + mineral fertilizers (NH_4NO_3 and Kcl - 75%) through irrigation water produced early and higher total yields as well as high TSS content in tomato. Higher fruit weight and bigger fruit length, diameter and flesh thickness were produced by the treatment which received chicken (organic) manure + mineral fertilizers (25%).

Castellanos *et al.* (2001) reported higher P uptake in fertigated garlic crop (89 kg P_2O_5 ha^{-1}) compared to furrow irrigated crop (64 kg P_2O_5 ha^{-1}).

Paskar and Bhoi (2001) reported higher cane yield and commercial cane sugar (CCS) yield with increase in levels of fertilizer applied through drip irrigation. The maximum yields of 157.19 and 17.35 t ha^{-1} of cane and CCS respectively were recorded with 125 per cent fertilizer levels.

Study conducted on tomato cv. BRH-1 at IIHR, Hessarghatta revealed that mean fruit yield of 134.1 t ha^{-1}, fruit weight of 61.20 g and average fruit yield of 3.6 kg $plant^{-1}$ were obtained when 50% of NK fertigation i.e. (100:100:100 kg NPK ha^{-1}) was adopted under black LDPE sheet mulch. Under full NK fertigation i.e., 200:100:200 kg NPK ha^{-1} a fruit yield of 121.3 t ha^{-1} was obtained with an average of 60.10 g weight of fruits and 3.6 kg fruit $plant^{-1}$ under the same mulch condition (Prabhakar *et al.*, 2001).

Chandrakumar *et al.* (2001) reported that banana plant had maximum plant height of 143.11 cm on 180th day when N and K_2O were applied @200 g each per plant as compared to 50, 100 or 150 g $plant^{-1}$ each of the nutrients. The former treatment also gave the maximum bunch yield of 88.46 t ha^{-1}.

Jeyakumar *et al.* (2001) reported that growth, yield and quality characteristics of papaya cv. Co-2 was improved when 13.5 g urea and 10.5 g of muriate of potash was applied weekly through irrigation water applied @ 10 litres per day. Phosphorus was applied as superphosphate @278 g plant^{-1} through soil incorporation at bimonthly intervals.

2.1.2 Effect of fertigation on nutrient uptake

Rauchkolb *et al.* (1978) reported significantly higher P content in trickle irrigated tomato over surface irrigation method. Gamayun (1980) observed that a moisture regime of 80 per cent of the field capacity was ideal for tomato for maximum uptake of N, P and K when compared to moisture regime of 60 and 70 per cent of field capacity.

Bar-Yosef and Sagiv (1982) found that in sandy soils N uptake increased with increase in N application rate through fertigation. Csizinszky and Schuster (1982) observed that the application of fertilizers above the dosage level of 148 kg ha^{-1} N, 30 kg ha^{-1} P, 171 kg ha^{-1} K and 10 kg ha^{-1} Mg did not improve fruit size and yield of tomato, but increased residual salt content of soil.

Stark *et al.* (1983) found a linear relationship between total N uptake by tomato with fertigation of 300 kg N ha^{-1}. He opined that adequate N could be applied to tomatoes using high frequency nitrogen fertilization without high denitrification losses.

Multiple application of nitrogenous fertilizers through drip did not appear to improve the efficiency of fertilizer uptake by tomatoes over a single injection (Miller *et al.*, 1981). Lahav and Kalmar (1988) observed that weekly fertilizer application in banana had only slight but non-significant advantages over the continuous injection of fertilizer into irrigation water.

Hegde and Srinivas (1990) reported that the total N uptake and its distribution in the plant system of banana was higher with irrigation at a soil matric potential of -40 kPa and lower with less frequent irrigation at -85 kPa.

According to Melton and Dufault (1991) as N in nutrient solution increased from 25 to 225 mg $litre^{-1}$, fresh shoot weight, plant height, stem diameter, leaf number, leaf area, shoot and root dry weight and total chlorophyll increased in tomato under glass house conditions upto 45 mg l^{-1}. Phosphorus had absolute effect only in one year. Whereas potassium did not affect plant growth when concentration was varied from 25 to 225 mg l^{-1}.

Consumptive use and the ratio of evapotranspiration to the pan evaporation (Et/E_0) values of bittergourd increased progressively with increasing levels of nitrogen and irrigation (Thampatti *et al.*, 1993). Bafna *et al.* (1993) reported that a significantly higher total N uptake by different parts of tomato plant was recorded under drip irrigation over conventional irrigation.

A field study conducted by Veeraputhiran (1996) on irrigation and sub-surface moisture conservation in oriental pickling melon revealed that N, P and K content of leaves were significantly higher in plants where paddy waste was incorporated for moisture conservation. Higher levels of irrigation i.e., 0.8 and 1.2 IW/CPE ratio markedly increased the N and K content of leaves upto 40 DAS and

P content upto 75 DAS. Decomposable mulch materials were effective in increasing the N, P and K content of leaves. A soil moisture regime of 80 per cent of field capacity is ideal for maximum uptake of nutrients by plants.

Raghupathi *et al.* (2000) observed a steady decrease in nitrogen concentration and steady level of phosphorus concentration in banana fruits irrespective of fertigation treatments. They also observed that roots were the greatest repository for N, P, K concentration.

Castellanos *et al.* (2001) found that garlic crop grown under fertigation treatment removed 25 kg more phosphorus than furrow irrigated crop under Mexican conditions. They also observed that higher yield of the crop under fertigation increased phosphorus demand by the plant by almost 50 per cent.

Idate *et al.* (2001) reported that drip fertigation in pomegranate using 75 per cent recommended dose of fertilizers (100% - 500:250:250 g $N:P_2O_5:K_2O$ $plant^{-1}$) with 20 per cent wetted area gave a fruit yield of 19.35 kg $plant^{-1}$ compared to 100 per cent recommended dose of fertilizers.

Thomas *et al.* (2002) reported that drip fertigation in banana in 24 splits at weekly intervals resulted in a higher absorption of major elements and reduced absorption of native non-applied elements, when compared to conventional fertilizer application and irrigation. They observed 23 per cent improvement in production efficiency and 60 per cent improvement in economic efficiency in fertigation over conventional method of fertilizer application.

2.1.3 Effect of drip irrigation on soil moisture characteristics

Sivanappan *et al.* (1987) studied the water movement pattern in soil at a discharge rate of 8 lph through drip irrigation and observed that water moved upto 30 cm and 40 cm distance in horizontal and vertical directions respectively under Coimbatore conditions.

Carmi and Plant (1988) reported that, most of the water supplied by drip irrigation was found at 0-30 cm depth and as evaporation rate decreased the infilteration depth was increased. Randall and Locascio (1988) observed that, in trickle irrigated cucumber and tomato fields the discharge rate of 8 lph resulted in higher soil water content in top 20 cm of soil than that under the discharge rate of 2 lph.

Amir and Dag (1993) inferred that the instantaneous application rates increased the width and uniformity of wetting of soil, but it caused high lateral dispersion and reduced the depth of soil irrigated in heavy clay soils.

Isomoisture lines drawn to study the horizontal and vertical movement of water showed that higher water application rate @12 lph saturated the soil near the dripper and infiltration was slower in the beginning, whereas with lower application rate of 4 lph the water, penetration increased (Goel *et al.*, 1993).

Studies conducted at Haryana revealed that the moisture distribution under drip irrigation was more uniform within a radius of 10 cm of the emitter with maximum uniformity at zero. Uniformity shattered with increase in distance from the emitters (Mishra and Pyasi, 1993).

Dahiwalkar *et al.* (1994) observed that radial spread of water increased and vertical spread reduced when discharge rate of dripper was increased in sandy clay loam soil. Maheshvarappa *et al.* (1997) reported that in littoral sandy soil under drip irigation, the vertical moisture movement was greater than the lateral due to highly porous nature of the soil. The horizontal wetted area increased with increase in discharge rate.

Soil moisture content in the fields cultivated with grape vine cultivar Anab-e-Shahi varied from 36 mm after 24 hour of irrigation to 18 mm prior to irrigation in the upper 0 to 15 cm of soil, when basin irrigation was scheduled at 100% evaporation replenishment. On the contrary, the soil moisture content varied between 43 and 46 mm in the upper 0 to 15 cm soil depth when drip irrigation was scheduled with 50, 75 or 100 per cent evaporation replenishment (Srinivas *et al.*, 1999).

2.1.4 Effect of drip and fertigation on water use efficiency

According to Moynihan and Haman (1992) the surface irrigation system used 3.4 times more water than drip irrigation system, produced lesser yield and required more labour for irrigation of Callaloo (*Amaranthus viridis* L.) and cucumber (*Cucumis sativus* L.).

Kadam *et al.* (1993) recorded higher WUE (374 kg ha cm^{-1}) under drip irrigation compared to furrow irrigation (214 kg ha cm^{-1}) in okra. Aziz *et al.* (1998) reported that drip irrigation was the best method of water management for higher yield, water conservation and water use efficiency in cucumber under sandy soil condition of Egypt.

According to Raina *et al.* (1998) water use efficiency of Pea under Solan condition was 1.87 q ha cm^{-1} for drip system without plastic mulch, 2.21 q ha cm^{-1} for drip plus plastic mulch and 1.06 q ha cm^{-1} when surface irrigation was given without mulch.

Tumbare *et al.* (1999) reported that Okra gave a WUE of 42.59 kg ha cm^{-1} when recommended dose of fertilizer was applied through drip irrigation by seven equal splits. But the crop which received same quantity of nutrients through straight fertilizer by band placement with surface irrigation had only 29.84 kg ha cm^{-1}.

According to Dalvi *et al.* (1999) drip irrigation scheduled at every second day frequency with irrigation level of 79 per cent ET and fertigation at 96 per cent of recommended dose in tomato saved water to the tune of 21 per cent and increased fruit yield upto 27 per cent.

According to Shelke *et al.* (1999) application of 0.4 ETC irrigation water through drip system saved 55 per cent water over surface irrigation scheduled at 0.9 IW/CPE under alternate furrow irrigation in cotton.

Deolankar and Firake (1999) opined that in chilli drip irrigation saved 58 per cent water when compared to conventional irrigation which used 1140 mm of water. Raina *et al.* (1999) at Solan found that in tomato crop WUE under drip irrigation alone, drip irrigation plus polyethylene mulch and surface irrigation were 0.34, 0.48 and 0.16 tonnes ha cm^{-1} respectively. Drip irrigation besides saved 54 per cent irrigation water, enhanced tomato fruit yield by 40 per cent when compared to the surface irrigation.

Water use efficiency (WUE) in sweet corn was higher (40.04 kg ha^{-1} mm) with drip at 0.4 PE with a saving of 187.36 mm water over weekly surface irrigation at 0.8 PE which gave WUE of only 27.19 kg ha^{-1} mm (Viswanatha *et al.*, 2000). Ragheb *et al.* (2000) opined that WUE was more under the drip irrigation system compared with sprinkler irrigation in case of faba bean and increasing the irrigation interval had increased the WUE.

A comparative study of drip and sprinkler irrigation on garlic by Sankar *et al.* (2001) indicated that drip irrigation at 100 per cent PE led to the production of 147.8 q ha^{-1} bulbs and 44 per cent water saving over conventional method. Sprinkler irrigation at 100 per cent PE gave 128.2 q ha^{-1} yield and 41 per cent water saving.

According to Veeranna *et al.* (2001) WUE in chillies was significantly higher (2.81 kg ha mm^{-1}) with drip fertigation using 80 per cent recommended level of water soluble fertilizer. This was closely followed by drip fertigation using 100 per cent water soluble fertilizer (2.77 kg ha mm^{-1}) and these two treatments were significantly superior to other treatments viz., soil application of fertilizers coupled with conventional irrigation, 60 per cent fertilizer application through fertigation.

Gebremedhin (2001) reported that drip irrigation in oriental pickling melon at sandy loam soils of Agricultural Research Station, Mannuthy @ 50 Ep led to 158.68 kg ha cm^{-1} of CWUE whereas conventional irrigation, i.e., basin irrigation once in three days produced 62.69 kg ha mm^{-1}.

2.2 Mulching

2.2.1 Effect of mulching on growth, yield and quality of vegetables

Berrocal and Vives (1978) opined that saw dust and rice husk mulching led to higher production in tomato cv. Tropic compared to black polyethylene mulch. Applying 10 cm straw mulch increased the summer moong yield on an average by 66 kg ha^{-1} over the unmulched crop in Hissar (Balyan and Malik, 1981). Wein and Minotti (1987) observed that black LDPE sheet mulch increased rate of basal branch appearance and led to early flowering in tomato. Total plant growth as measured by dry weight at final harvest was increased by mulch. It also increased total yield by 79 per cent over unmulched control.

The use of trickle irrigation increased plant height, whereas polyethylene mulch increased plant spread and dry matter production in case of tomato cv. Sunny in Indiana . Total yields were 66, 70 and 123 per cent greater for plants grown with polyethylene mulch, trickle irrigation and polyethylene mulch plus trickle irrigation respectively than the control plants grown without polyethylene mulch and trickle irrigation (Bhella,1988)

Shukla and Prabhakar (1988) observed that tomato cv. Arka Vikas yielded 36.06 t ha^{-1} when mulched with plastic sheets whereas the crop yielded 35.18 t ha^{-1} under non mulched condition. Tomato cvs. Sunny and Pine-Rite grown under trickle irrigation produced on an average 84 t ha^{-1} of fruits under black polyethylene mulching whereas the fruit yield was only 43 t ha^{-1} under non-mulching (Abdul-Baki *et al.*, 1992).

When the tomato crop cv. Pusa Ruby was mulched with sugarcane trash and irrigated at 10 days interval it produced more fruit yield and saved 44.34 per cent irrigation water over unmulched crop (Firake *et al.* (1991).

The experiment conducted by Abdul-Baki *et al.* (1996) on tomato grown in bare soil or under black polyethylene or hairy vetch (*Vicia villosa* Roth) mulches revealed that yield was higher and fruits were larger under hairy vetch mulching than in bare soil or black polyethylene mulch. Percent solids was highest with black polyethylene and lowest in hairy vetch. The hairy vetch mulch delayed fruit maturity compared to the bare soil and black polyethylene.

According to Lourduraj *et al.* (1996) tomato cv Co.3 produced 12735, 11334 and 9922 kg ha^{-1} of fruits when plastic mulching, organic mulching and unmulched control respectively were resorted to.

According to Veeraputhiran (1996) the highest fruit yield ha^{-1} in oriental pickling melon was obtained from paddy waste incorporation, but comparable with that of coir pith incorporation. It produced 27 and 17 per cent more yield respectively compared to unmulched control.

Almasoum (1998) reported that tomato plants grown on bare soil or black plastic mulch were more taller than that grown on red and clear plastic mulches. But red mulched plants gave 9.58, 86.7 and 57.8 per cent more yield compared to that under bare soil, black and clear mulches respectively.

Kumar and Singh (1999) from Ranchi reported that 120 mm CPE irrigation along with grass mulching in banana cv Dwarf Cavendish led to its highest growth, yield as well as quality of fruits. Shinde *et al* (1999) observed that sugarcane trash mulching for the chilli variety Agnirekha gave maximum plant height (91.5 cm), more number of branches (17.5) and maximum yield of green chilli (12.2 t ha^{-1}) compared to mulching using black or transparent plastic mulch.

Black polythene mulching using 50μ sheet throughout the cropping period in pineapple cv Kew led to maximum plant height (113 cm), number of leaves (67.80), number of sucker and slip (1.73 and 3.33 respectively) and fruit yield (55.87 t ha^{-1}) (Hazarika and Das, 2000).

Strawberry plants mulched with black polyethylene (50 gauge) sheets gave highest weekly yield as well as total yield, followed by transparent polyethylene and sarkanda (*Saccharum munja*) mulches (Hassan *et al.*, 2000).

2.2.2 Effect of mulching on rooting and nutrient uptake

Polyethylene mulching accelerated early root growth in tomato by enhancing root zone temperature. This stimulated above ground growth as expressed through branching, flowering, early and total fruit yields and nutrient concentration in the tops (Knavel and Mohr, 1967).

According to Papadopoulos and Tiessen (1987) most of the variation observed in the nutrient composition of tomato leaves was due to air temperature. But response to high root temperature (27°C) was greater for phosphorus than nitrogen. They found that air and root temperatures had little effect on potassium concentration in tomato leaves.

Wein and Minotti (1988) concluded that the early uptake of phosphorus by tomatoes was enhanced under polyethylene mulch. Since early phosphorus uptake was more important for increasing yields than total uptake, yield was ultimately increased.

Ham *et al.* (1993) found that mid day soil temperatures were the highest beneath the mulches with high short wave absorptance (black plastics). These microclimate changes strongly affect the soil moisture in the root zone and hence root growth increased.

Wein *et al.* (1993) reported that tomato plants grown on polyethylene mulch have more branches and increased yield as well as mineral nutrient uptake than plants that were not mulched. Clear polyethylene mulch stimulated root extension shortly after transplanting. One week after transplanting roots were significantly longer for mulched than unmulched plants in all experiments. Mulching increased branching, hastened flowering and increased concentration of major nutrients in the above ground parts.

2.2.3 Effect of mulching on soil moisture characteristics

Preliminary study conducted at Nagpur indicated that tomato crop grown under black polyethylene mulch conserved more water than the unmulched crop (Patil and Bansod, 1970). Channabasavanna *et al.* (1992) observed 10.4 and 29.6 per cent more soil moisture under straw mulch and polyethylene mulch respectively than unmulched control plot grown with tomato.

Patra *et al.* (1993) reported that straw mulched soils grown with Japanese mint contained approximately 2 to 4 per cent more moisture at ploughing depth compared to unmulched plots. According to Uthaiah *et al.* (1993) both natural and synthetic mulches helped in conserving soil moisture in the root zone of coconut and hence enhanced the growth.

According to Chakraborty and Sadhu (1994) the ability of rice straw mulch or water hyacinth mulch to conserve soil moisture was appreciably lower than that of the polyethylene mulch. Srinivas and Hegde (1994) observed that water use by banana crop was lowest under the polyethylene mulch followed by straw mulch and was highest when banana was raised with cover crops. The ET under polyethylene mulch decreased by 8 per cent and 14 per cent respectively compared with that under straw mulch and no mulch. WUE was highest under polyethylene mulch, largely due to higher yield and reduced evapotranspiration.

Investigations on the effects of drip irrigation and mulching on capsicum conducted at four locations in Korean Republic by Yoon *et al.* (1995) revealed that mulching increased soil water content as well as crop yield compared with control where no mulch was applied.

Mikhov *et al.* (1995) reported that sowing of cabbage and simultaneously covering the rows with perforated plastic strips increased soil moisture in the top soil by upto 14.5 per cent and soil temperature by 0.5 to 1.6°C.

According to Xinju *et al.* (2000) as the quantity of straw increased from 1.5 t ha^{-1} to 6.75 t ha^{-1} in silt loam soil under saline condition, evaporation of soil water decreased from 40 to 65 per cent, when compared to non mulched soil.

2.2.4 Effect of mulch on soil temperature

Among the various types of mulches, plastic mulch promoted rapid plant growth and early fruit set and thereby higher yield in tomato. Rise in temperature below the plant canopy due to more light reflection by the plastics ultimately resulted in higher photosynthetic activity (Franklin and Raymond, 1966).

According to Wein and Minotti (1987) plastic mulched tomato crop flowered and fruited earlier than unmulched crop due to increased soil temperature.

Decoteau *et al.* (1988) observed that soil temperature 2.5 cm below the black mulch surface on an average was 1°C higher than that under the white mulch surface as evidenced from a green house study on tomato at South Carolina, U.S.A.

Gutal *et al.* (1990) while experimenting with polyethylene mulches in tomato observed that coloured polyethylene films increased soil temperature by 5-7°C which facilitated faster germination and better root proliferation. Chakraborty and Sadhu (1994) reported that polyethylene mulch increased soil temperature by 2 to 3°C compared to the unmulched control. Whereas plots mulched with natural materials such as straw or water hyacinth were not different from the control.

Gupta and Acharya (1994) observed that black polyethylene mulch performed superior to transparent polyethylene. Black polyethylene raised the soil temperature by two to three °C during night and did not alter the day temperature in a field planted with strawberry.

Siwek *et al.* (1994) observed that soil under black mulch planted with sweet pepper was warmed by 0.5°C while that under white polyethylene was cooled by 0.5°C compared to the bare soil. A similar study by Cebula (1995) on sweet pepper revealed that the soil temperature on an average was higher by 2°C under both transparent and black plastic mulch at the depths of 4 cm and 12 cm respectively than with the unmulched control. The transparent film ensured higher soil temperatures during the day, while the loss of heat energy at night to a greater degree was prevented by the black mulch.

Ravinder *et al.* (1997) reported that mulching by black, blue or transparent polyethylene sheets increased soil temperature by two to three °C than mulching by paddy straw, sugarcane trash or *poplar* leaves.

2.3 Economic feasibility of mulching, drip and fertigation technologies

Djiima and Diemkouna (1986) observed through cost analysis in egg plant and tomatoes that saving in water use due to better weed control and higher productivity with the use of black polyethylene mulching justified the investment in these crops.

Liu *et al.* (1987) reported that the highest marketable yield of tomato (64.5 t ha^{-1}) and net income were obtained from plastic mulching in combination with hand weeding.

Rajagopalan *et al.* (1989) reported that irrigation at IW/CPE ratio of 0.5 had the maximum cost benefit ratio for watermelon and cucumber crops.

Jadhav *et al.* (1990) observed that the benefit cost ratio for tomato cv. Pusa Ruby was 5.15 with drip irrigation and 2.96 with furrow irrigation.

Results of the studies of Singh and Surajbhan (1993) revealed that in cotton maximum return of Rs.17,501 per hectare obtained by the use of plastic mulch, closely followed by maize stover mulch (Rs.17,188 per hectare).

Salvi *et al.* (1995) reported that when irrigation was scheduled in bell pepper (*Capsicum annuum* L. var. *grossum gendt*) at 25 mm CPE in combination with 150 kg N ha^{-1} in lateritic soil highest yield of 15.03 t ha^{-1}, net monetary return of RS.46,772 ha^{-1} and benefit:cost ratio of 2.75 were obtained.

Rani and Pushpakumary (1996) found that six equal split application of nutrients in bhindi (equal split applications at basal, 15 DAS, 25 DAS, 35 DAS, 45 DAS, 55 DAS) gave a net profit of Rs.9,322 ha^{-1} whereas two equal split doses one as basal and second at 30 DAS gave Rs. 14710 ha^{-1}.

Veeraputhiran (1996) reported that incorporation of paddy waste, coir pith and saw dust in oriental pickling melon increased net profit by Rs.27,697 (68%), Rs.13,958 (34%) and Rs.4,254 (10%) respectively over unmulched control. The tomato cv. Co.3 grown under plastic mulching recorded gross return of Rs.50,940 compared to Rs.39,688 in non-mulched control. Plastic mulching resulted in Rs.5,602 increase in net seasonal income over control (Lourduraj *et al.*, 1996).

The research conducted at Solan on pea cv. Lincoln revealed that the seasonal income under drip only and drip plus plastic mulch was 60.8 and 91.6 per cent higher respectively as compared to conventional method of irrigation. The benefit cost ratio worked out for drip alone, drip plus mulch and conventional irrigation respectively were 2.06, 2.11 and 1.98 (Raina *et al.*, 1998).

Berad *et al.* (1998) observed that nitrogen (urea) application through drip in banana crop improved all yield attributes and resulted in 15 per cent more yield (68.5 t ha^{-1}) and 7 per cent more returns (Rs.1,09130 per hectare) when compared to surface irrigation with same planting technique and fertilizer dose.

Shinde and Firake (1998) opined that the canewall drip tape was the most ecnomical for chillies. The benefit cost ratio of 2.84:1 and net extra income of Rs.42,164 per hectare were obtained for the system over border layout (control). Sunilkumar (1998) found that a maximum BC ratio of 1.58 was derived for bhindi crop when the crop was mulched and irrigated at soil moisture tension of 0.08 MPa.

Shinde *et al.* (1999) found that fertigation of sugarcane using liquid fertilizers through drip led to 25 per cent fertilizer saving and 20.74 per cent yield increase. However the high cost of liquid fertilizers significantly reduced net profit margin. Urea through drip was found to be better proposition with highest net returns (Rs.55103 per hectare) and BC ratio of 1.5.

According to Sharmasarkar *et al.* (2001) in USA, returns from sugar beet crops were $ 2080 and $ 2310 ha^{-1} for furrow and drip irrigation practices respectively. They also observed that sugar beet production under drip irrigation would be most profitable for larger area with payback periods ranging from 7 to 10 years.

Materials and Methods

MATERIALS AND METHODS

The experiment, "Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation" was carried out at Agricultural Research Station (ARS), Mannuthy of Kerala Agricultural University during December 2000 to April 2001. The materials used and methods adopted during the course of investigation are presented in this chapter.

3.1 Location

The experiment was conducted at Agricultural Research Station located at Mannuthy in Trichur district of Kerala state. This station is geographically situated at 12° 32' N latitude and 74° 20'E longitude at an altitude of 22.5 m above mean sea level. The typical warm humid tropical climate prevails in the area.

3.2 Soil

Soil of the experimental site is texturally classified as sandy clay loam. Soil has a bulk density ranging from 1.50 to 1.52 g cm^{-3}. The soil is medium in organic carbon, nitrogen as well as phosphorus, but low in available potassium and has a mean pH of 5.6. The important physical and chemical properties of the soil are presented in Table 1.

3.3 Climate and weather conditions

The mean weekly data on different weather elements for the crop period from December 2000 to April 2001 and corresponding normal weather data were obtained from the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

Table 1. Characteristics of the soil at the experimental field

Particulars	Value	Procedure adopted
1. Mechanical composition		
Coarse sand (%)	27.2	Robinson's international pipette method (Piper, 1966)
Fine sand (%)	23.8	
Silt (%)	22.6	
Clay (%)	26.4	
Textural class	Sandy clay loam	Soil survey staff (1992)
2. Physical constants of the soil		
Field capacity (0.3 bars)	23.69% w/w	Pressure plate apparatus (Richard, 1947)
Permanent wilting point (15 bars)	9.54% w/w	
Bulk density		
0-15 cm depth	1.50 g cm^{-3}	Core method (Blake, 1965)
15-30 cm depth	1.52 g cm^{-3}	
3. Chemical composition		
Organic carbon	0.579%	Walkley and Black rapid titration method (Jackson, 1958)
Available nitrogen	268 kg ha^{-1}	Alkaline permanganate distillation (Subbiah and Asija, 1956).
Available phosphorus	16.25 kg ha^{-1}	Bray-I extractant - Ascorbic acid reductants method (soil survey staff, 1992)
Available potassium	114.50 kg ha^{-1}	Neutral normal ammonium acetate extractant - Flame photometry (Jackson, 1958)
pH	5.6	1:2.5 soil water suspension using pH meter (Jackson, 1958)
Electrical conductivity	1.25 ds m^{-1}	Supernatant of 1:2:5 soil : water suspension using EC bridge (Jackson, 1958)

The mean monthly weather data for the last 15 years (1986 to 2000) are given in Appendix I. The mean weakly data are given in Table 2 and graphically presented in Fig.1.

Climatically a tropical monsoon climate prevails in the experimental location. The analysis of the normal weather data of the last 15 years (1986 to 2000) for the cropping period from December to April indicates that March is the hottest month while January is the coolest. Normal total rainfall for the cropping period i.e., from December to April is 101.3mm.

During the period of investigation the weekly average maximum temperature ranged between 30.7°C and 35.9°C and the minimum between 21.4°C and 25.3°C.

The crop received 25.6 mm rainfall scattered over six days during the cropping period. Thus the rainfall during the cropping period was far below the normal rainfall.

The relative humidity during the crop season ranged from 63 to 90 per cent at 7.25 AM and 34 to 62 per cent at 2.25 PM.

The wind velocity during the crop season ranged from 3.6 km hr^{-1} to 10.7 km hr^{-1}.

The mean weekly pan evaporation values varied from 4.2 to 7.9 mm. The accumulated pan evaporation value for the crop period from 26-12-2000 to 7-4-2000 is 496.1 mm.

The absolute values of daily evaporation and rainfall data for the cropping period is given in Appendix II.

Fig. 1. Meteorological data (weekly) during the crop growth period

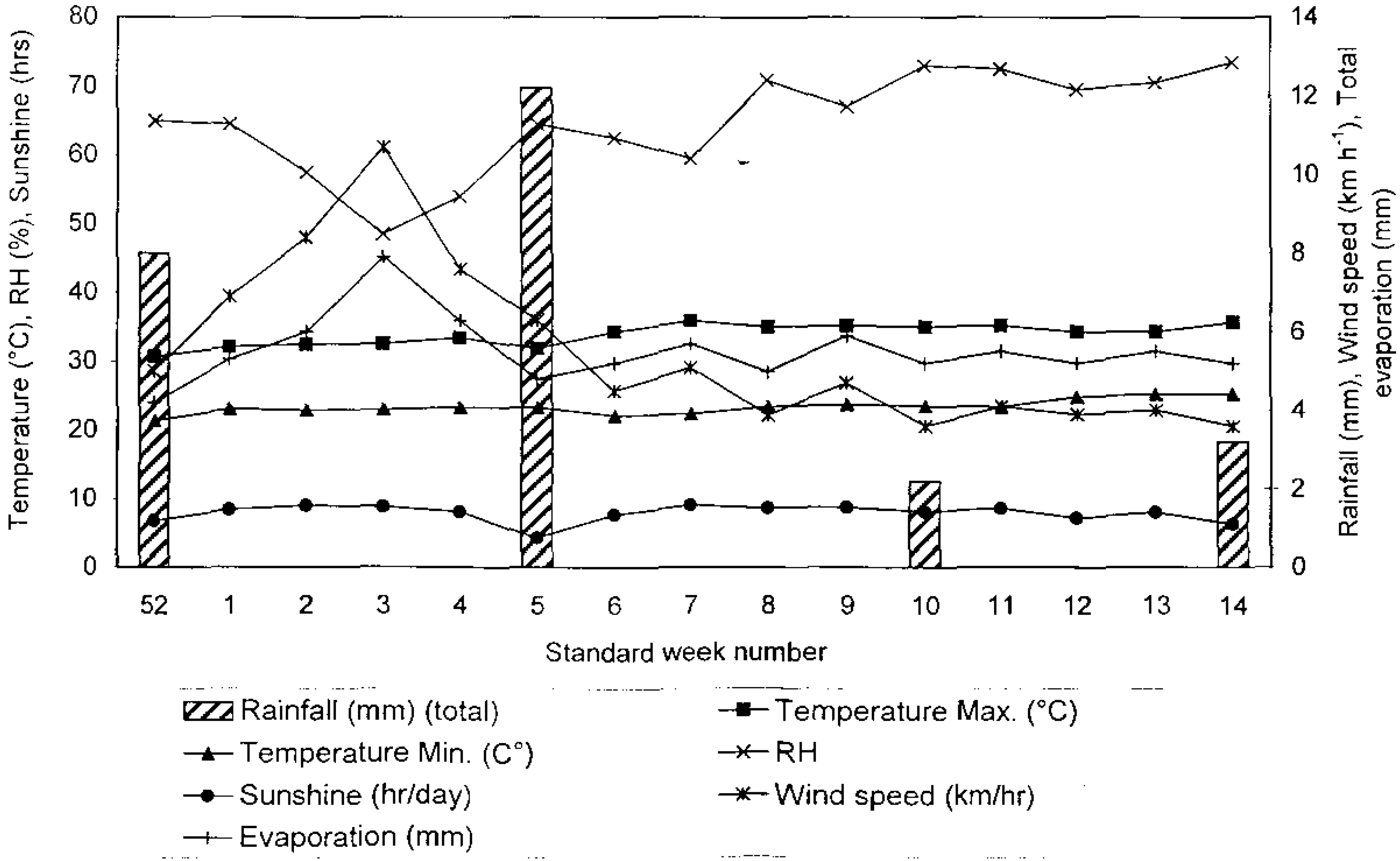


Table 2. Mean weekly weather parameters during the crop growth period (Dec. 2000 - April 2001)

Standard week No.	Month and date	Surface air temperature (°C)		Relative humidity (%)		Wind speed (km hr^{-1})	Sunshine (hr/day)	Evaporation (mm)	Total rainfall (mm)
		Max.	Min.	Morning	Evening				
52	2000 Dec. 24-31	30.7	21.4	75	55	5.0	6.8	4.2	8.0
1	2001 Jan. 1-7	32.1	23.1	80	49	6.9	8.4	5.3	0.0
2	Jan. 8-14	32.5	22.9	75	40	8.4	9.0	6.0	0.0
3	Jan. 15-21	32.6	23.0	63	34	10.7	8.8	7.9	0.0
4	Jan. 22-28	33.5	23.4	69	39	7.6	8.1	6.3	0.0
5	Jan. 29 - Feb. 4	31.9	23.3	77	52	6.3	4.3	4.8	12.2
6	Feb. 5-11	34.3	22.1	81	44	4.5	7.7	5.2	0.0
7	Feb. 12-18	35.9	22.4	82	37	5.1	9.1	5.7	0.0
8	Feb. 19-25	35.1	23.5	90	52	3.9	8.7	5.0	0.0
9	Feb. 26 - Mar. 4	35.2	23.7	85	49	4.7	8.7	5.9	0.0
10	Mar. 5-11	35.0	23.5	89	57	3.6	8.1	5.2	2.2
11	Mar.12-18	35.2	23.4	88	57	4.1	8.6	5.5	0.0
12	Mar.19-25	34.3	24.8	85	54	3.9	7.2	5.2	0.0
13	March 26- April 1	34.3	25.2	87	54	4.0	8.0	5.5	0.0
14	April 2-8	35.7	25.3	85	62	3.6	6.3	5.2	3.2

3.4 Cropping history

The experimental site is a single cropped wetland paddy area ,cultivated every year during April-September. The field is usually used for growing vegetables during early summer season.

The cultivar Shakthi (LE.79) developed by KAU was used for the study. It is having a duration of four months and its average productivity is 32 t ha^{-1}. It is resistant to bacterial wilt caused by *Raulstonia solanacearum* E.F. Smith. The variety was released by State Seed Sub Committee of Kerala in 1990.

3.5 Details of experiment

The field experiment was conducted during summer season of 2001. The layout of the experiment is given in Fig. 2. Plate 1 provides overall view of the field. The technical programme followed is as follows.

Design : Randomized Block Design

Replications	: 3
Plot size	: 6 m x 3 m
Spacing	: 0.6 m x 0.6 m
Number of plants per plot	: 50
Treatments	: 10

The treatments consisted of combinations of three levels of irrigation and three levels of nutrient application and one control treatment.

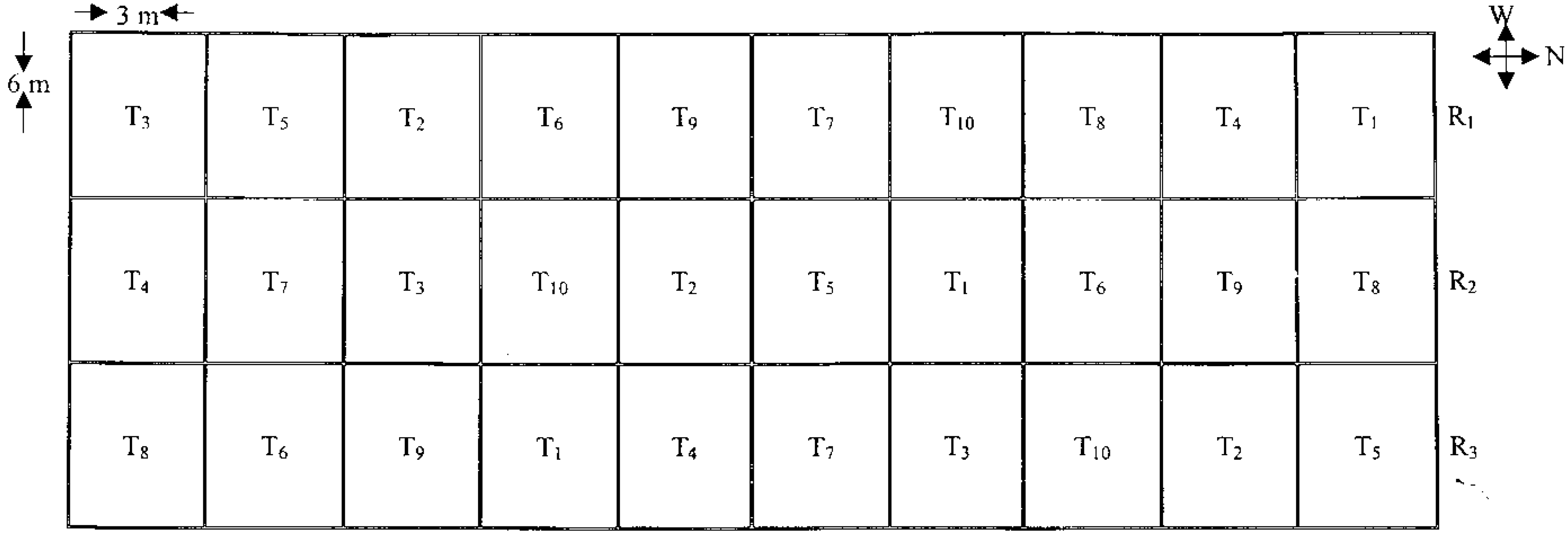
A. Levels of irrigation

I_1 : Drip irrigation @ 0.3 pan evaporation (PE)

I_2 : Drip irrigation @ 0.6 pan evaporation (PE)

I_3 : Drip irrigation @ 0.9 pan evaporation (PE)

Fig. 2. Layout of the experiment



Replication - 3
Plot size - 3 m x 6 m
Total plots - 30

T_1 - I_1F_1	T_6 - I_2F_3	I_1 - 0.3 PE irrigation	F_1 - 100 % recommended fertilizer dose
T_2 - I_1F_2	T_7 - I_3F_1	I_2 - 0.6 PE irrigation	F_2 - 50 % recommended fertilizer dose
T_3 - I_1F_3	T_8 - I_3F_2	I_3 - 0.9 PE irrigation	F_3 - 150 % recommended fertilizer dose
T_4 - I_2F_1	T_9 - I_3F_3		Control - Furrow irrigation with surface application of recommend fertilizer dose
T_5 - I_2F_2	T_1 - Control		

Plate 1. The overall view of the experimental site

The control plot (T_{10}) received furrow irrigation at 3 days interval with 20 mm water per irrigation. The crop received recommended dose of fertilizers through soil application. The plot was not mulched.

3.6 Crop husbandry

3.6.1 Nursery management

Tomato variety Shakthi (LE.79) seeds were sown on 25th November 2000, and adequate number of seedlings were raised as per Package of Practices Recommendation of KAU (1993).

3.6.2 Land preparation

The experimental field was ploughed using tractor drawn disc plough and pulverised using rotavator. The plots of size of 6 x 3 m were drawn forming ridges around plot. Each plot was levelled manually and then ridges and furrows were formed at 60 cm apart.

3.6.3 Planting in the main field

Planting was done on 26th December 2000. Before planting, black LDPE sheets were spread in all the plots except the one accommodating control treatment. In the mulched plots, holes of approximately 10 cm^2 were punched evenly at 60 cm x 60 cm grid points on the LDPE sheets. Seedlings were then planted in these holes. The seedlings planted were given initial shade protection for four days.

3.6.4 Manures and fertilizer application

Well decomposed farm yard manure at the rate of 20 t ha^{-1} was applied in each plot at the time of ploughing. There after fertilizer dose was followed as per treatments. As per Package of Practices Recommendation of KAU (1993), the fertilizer nutrient recommendation for tomato crop is N, P_2O_5 and K_2O @ 70:40:25 kg ha^{-1} respectively. In case of control treatment full dose of P_2O_5 and half the dose of N and K_2O were applied as basal dose during the final formation of furrows. The remaining 50 per cent nitrogen and 50 per cent K_2O were applied in two equal split doses on 20^{th} and 40^{th} DAP as surface incorporation. The fertilizer materials used were Urea, Rajphos and MoP.

Vardhaman Blue (20:10:10% N, P, K and 7% S) along with DAP and urea were applied daily with irrigation water as per technical programme in case of fertigation treatments (T_1 to T_9).

3.6.5 Irrigation

A pre-planting irrigation was given uniformly to all the plots. After planting, daily light irrigation with rose can was given for 14 days. Differential fertigation schedules (fertilizer + irrigation), according to the treatments were started from 15^{th} DAP i.e. from 10^{th} January 2001. Drip irrigation was given every day based on the PE value of the previous day as per treatments. The details of irrigation water applied are given in Table 3.

Each plot was provided with a 100 litre over head plastic tank kept at 1.5 m above ground level. A 30 mm PVC main line fitted with ball valve ran from the tank and connected to a take-off line of 30 mm PVC. Five take-off lateral HDPE lines of 12 mm dia ran from this main take off line through the plant rows to provide irrigation to 10 plants per lateral line through distributors. Micro tubes of 4 mm diameter acted as distributer cum emitter to the plants. According to

Table 3. Total quantity of water used for the different irrigation treatments.

Treatment	Irrigation interval	Quantity of water used			Total quantity of water applied (mm)
		Pre-treatment irrigation (mm)	Irrigation as per treatment (mm)	Effective rainfall (mm)	
0.3 PE	Daily	42	148	20	210
0.6 PE	Daily	42	296	20	358
0.9 PE	Daily	42	444	20	506
Control	Once in three days	100	580	20	700

treatment water was filled in each tank every morning and fertilizer was mixed well before opening the ball valve. The lay out of fertigation assembly is given in Fig.3.

3.6.6 After cultivation

Gap filling

Gap filling was done on 10th DAP to maintain the required plant population.

Weeding

Hand weeding was done on 20th and 40th DAP in the control plots. The weeds emerged through the holes in mulched plots were also removed.

3.6.7 Plant protection

Lime was applied at the base of the crop on 20th DAP to check bacterial wilt @ 250 kg ha^{-1}. Streptomycin @ one gram in 40 litres of water was drenched into root zone to control bacterial wilt on 28th DAP. Ekalux @ two ml $litre^{-1}$ was applied on 25th DAP to control leaf miner. Neem oil @ 2 ml mixed with garlic extract @ 20 g $litre^{-1}$ was sprayed on 30th DAP to control leaf curl virus.

3.6.8 Harvesting

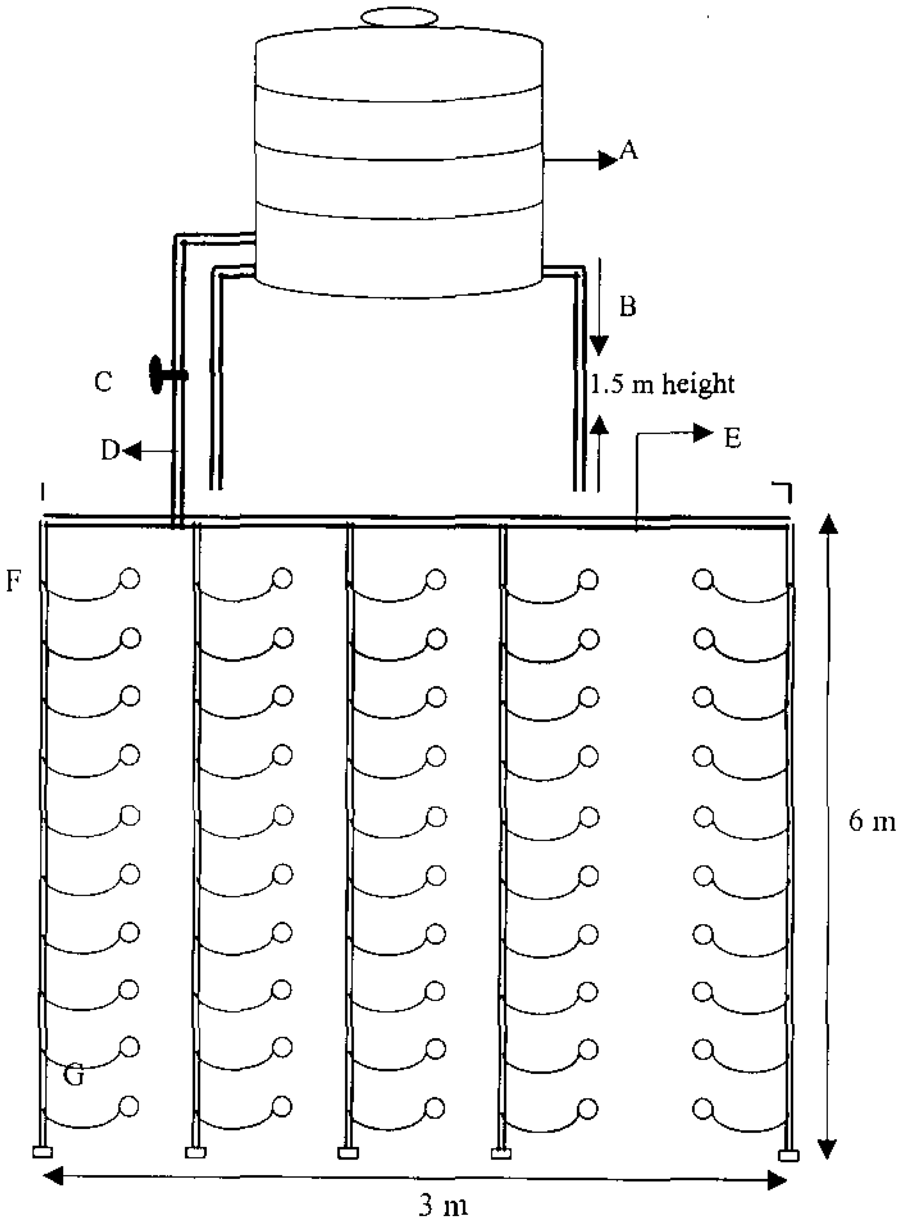
Fruits were harvested at red ripe stage as indicated by the colour change from green to red.

3.7 Observations

3.7.1 Biometrical observations

Growth and yield parameters were recorded from four plants per plot after random selection and tagging. All biotmetric observations were taken from the same plants during the course of investigation and observations recorded were

Fig. 3. Layout of the fertigation assembly



A - 100 litre overhead plastic tank
B - Supporting structure
C - Ball valve
D - Main line (30 mm PVC)
E - Take off line (30 mm PVC)
F - Take off lateral line (12 mm HDPE)
G - Microtubes (4 mm) distributor cum emitter
○- Tomato plants
▭- End cap

1) Height of the plant
2) Leaf area index (LAI)
3) Leaf area duration (LAD)
4) Number of fruiting branches plant^{-1}
5) Percentage of fruit set
6) Number of fruits plant^{-1}
7) Weight of fruits plant^{-1}
8) Yield hectare^{-1} (computed value)
9) Rooting pattern

3.7.1.1 Height of the plant

The height of the four sample plants were recorded at 15 days interval. Height from soil surface to the tip of the top most leaf was recorded. The mean height of four sample plants was reported.

3.7.1.2 Leaf area index (LAI)

The graph paper method was employed to calculate leaf area. The number of leaves in a sample plant was counted. The different sized leaves were grouped and number of leaves in each group was counted. The average leaf area of representative leaf of each group was traced on a graph sheet and area was calculated. Using this leaf area of the representative leaf the total leaf area of the plant was worked out.

LAI was found out by dividing the total leaf area by the land area occupied by the plant (Watson, 1947). It was worked out at 20 days interval by the formula given below.

$$LAI = \frac{\text{Leaf area plant}^{-1}}{\text{Land area plant}^{-1}}$$

3.7.1.3 Leaf area duration (LAD)

LAD expressed the magnitude and persistence of leaf or leafiness during the period of crop growth (Ondok and Kvet, 1971). This was calculated employing the formula

$$LAD = \frac{(L_1 + L_2)}{2} \times (T_2 - T_1) \text{ days}$$

where L_1 and L_2 are LAI at time of T_1 and T_2.

3.7.1.4 Number of fruiting branches plant^{-1}

The total number of fruiting branches on the four sample plants were recorded and the mean reported.

3.7.1.5 Percentage of fruit set

The fruit set percentage was determined in four sample plants as per the following formula suggested by Leopold and Scott (1952).

$$\text{Fruit set (\%)} = \frac{\text{Fruits plant}^{-1}}{\text{Flowers plant}^{-1}} \times 100$$

3.7.1.6 Number of fruits per plant

The total number of fruits of the four sample plants were recorded and the mean reported.

3.7.1.7 Weight of fruits per plant

The weight of fruits collected from the sample plants was recorded and the mean reported.

3.7.1.8 Yield per hectare

Total weight of fruits of the sample plants recorded were used to compute and report per ha fruit yield.

3.7.1.9 Rooting pattern

After the harvest of the entire fruits from the sample plants the entire root system was excavated by digging soil carefully. The roots were washed and the maximum vertical length, lateral distance and dry weight of roots were recorded by using cm scale.

3.7.2 Quality of fruits

1) Acidity

2) Total soluble solids (TSS)

3) Cracking of fruits

3.7.2.1 Acidity

Acidity was estimated as per the AOAC. (1975) method and expressed as percentage of anhydrous citric acid (mg $100g^{-1}$ juice).

3.7.2.2 Total soluble solids (TSS)

TSS was determined with the help of Erma hand refractometer (range 0-32° brix) and expressed in degree brix.

3.7.2.3 Cracking of fruits

The concentric cracks formed on the fruits of sample plants were recorded and percentage of cracked fruits over total number of fruits reported.

3.8 Nutrient content

Plant samples were collected at 30 days interval that is 30, 60 and 90 DAP and dried and powdered. The content of N, P, K, Ca, Mg, S, Fe, Mn, Zn and

Si were estimated employing the following methods and concentration of nutrients in the plants at 3 different stages are reported.

Methods used for plant nutrient analysis

Nutrient	Method	Reference
Nitrogen	Microkjeldhal method	Jackson, 1958
Phosphorus	Diacid extract estimated calorimetrically in a spectronic-20 spectrophotometer by vanadomolybdo-phosphoric yellow colour method	Jackson, 1958
Potassium	Diacid extract method using flame photometer	Jackson, 1958
Calcium	Volumetric method	Jackson, 1958
Magnesium	Volumetric method	Jackson, 1958
Sulphur	Turbidimetric method using spectronic-20 spectrophotometer	Hart, 1961
Iron	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
Zinc	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
Mangenese	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
Silicon	Rapid micro-determination of silicon	Nayar *et al.*, 1975

3.9 N, P, K content of the soil after cropping

Available N (Alkaline permanganate distillation), available P (Bray-I extractant - Ascorbic acid reductants method) and available K (Neutral normal ammonium acetate extractant - Flame photometry) of the soil after cropping was estimated by adopting the procedures provided by Subbiah and Asija (1956), Soil Survey Staff (1992) and Jackson (1958) respectively.

3.10 Incidence of pests and diseases

The number of plants infected with either bacterial wilt or leaf curl diseases were recorded and percentage of disease incidence was worked out separately for the above two diseases as per the following formula.

$$\text{Percent disease incidence} = \frac{\text{Number of plants infected}}{\text{Total number of plants observed}} \times 100$$

3.11 Soil moisture studies

1) Bulk density
2) Field capacity
3) Permanent wilting point
4) Gravimetric estimation of soil moisture after cropping
5) Soil temperature

3.11.1 Bulk density of soil

The bulk density of soil at 0-15 and 15-30 cm depth from surface was found out by using core sampler.

3.11.2 Field capacity

The field capacity of the soil was found out by using pressure plate apparatus. The moisture content of the soil at 0.3 bar was found out gravimetrically and taken as the field capacity.

3.11.3 Permanent wilting point

The permanent wilting point was found out by using pressure-plate apparatus. The moisture content of the soil at 15 bar was found out gravimetrically and taken as the permanent wilting point.

3.11.4 Gravimetric estimation of soil moisture content

Soil moisture content of the soil at 15 and 30 cm layer depth was found out gravimetrically 24 hours after final irrigation.

3.11.5 Soil temperature

Glass mercury soil thermometers were installed at 5, 10, 15 and 20 cm depth. The thermometers were placed at 45° angle with the help of supporter provided with it. Observations were taken at 7.25 AM and 2.25 PM IST for 15 days in case of fertigation treatments (T_1 to T_9) and 45 days in case of control plant. The mean soil temperature for each depth was calculated and reported.

3.12 Estimated parameters

1) Soil moisture distribution pattern

2) Water use efficiency

3) Economic analysis

3.12.1 Soil moisture distribution pattern

The soil moisture available at 15 and 30 cm depth immediately after the harvest of the crop was determined by gravimetric method. Point estimates was done at 15 and 30 cm radially away from the plant at 15 and 30 cm perpendicular to 15 and 30 cm radial distance. The soil moisture content in per cent (w/w) is reported.

3.12.2 Water use efficiency

Field WUE were computed by using the following formula and expressed as kg fruit m^{-3} of water.

$$FWUE = \frac{\text{Fruit yield (kg)}}{\text{Total water applied (mm)}}$$

3.12.3 Economic analysis

The economics of production was worked out based on the input costs, labour charges and the local sale price of tomato fruits. Input costs were taken as the actual cost of the materials incurred at the time of conduct of the experiment. Labour charges considered were the prevailing labour wages of the area. Cost of drip irrigation system and LDPE sheets used for the experiment were calculated as one fifth of the total cost, since they can be used for atleast five consecutive crop growing seasons. Based on this the total cost and returns were worked out. From this the net income and the net profit per rupee invested was calculated.

3.13 Statistical analysis

Analysis of variance was done for all the characters at different stages as per the statistical design of RBD with ten treatments and also with two factor combinations. The variance was tested by 'F' test and significance by 'T' test (Snedecor and Cochran, 1967).

The estimated parameters such as soil moisture distribution pattern, irrigation requirement and field water use efficiency were explained only based on comparative performance.

RESULTS

The field investigation "Response of tomato (*Lycopersicon esculentum* Mill.)" to varying levels of fertigation" was carried out as per the details described in the previous chapter and the observations recorded were compiled, analysed and tabulated. This chapter deals with the results obtained from the observations recorded during the course of investigation.

4.1 Studies on growth and yield of tomato as influenced by different levels of fertigation.

4.1.1 Height of the plants

The data on mean height of tomato plants observed at different stages of growth at 15 days interval at different levels of fertigation are given in Table 4.

The varying fertilizer levels remarkably altered height of the plants as the growth progressed. The treatment T_6 incorporating irrigation at 0.6 PE and fertilizer level at 150% of recommended dose consistently produced taller plants throughout the growth period. At the last stage of observation i.e., 60 DAP, T_6 produced significantly taller plants than the rest of the treatments. Throughout this observation period, the control crop i.e., normal fertilizer application with furrow irrigation (T_{10}) produced shorter plants.

At 15 DAP treatment T_9 (0.9 PE irrigation with 150% recommended dose of fertilizer) and T_7 (0.9 PE irrigation with 100% recommended dose of fertilizer) produced plants with similar stature to that of crop receiving fertigation levels at T_6. At 30 DAP, all the treatments except T_1 and T_2 produced plants with

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Table 4. Mean height (cm) of tomato plants at 15 days interval as influenced by different levels of fertigation

		Irrigation levels															
		15 DAP				30 DAP				45 DAP				60 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	10.26	11.21	11.12	10.86	15.64	19.23	17.58	17.48	38.76	38.90	38.17	38.61	48.45	48.28	50.66	49.13
	100% RD	9.65	10.36	11.44	10.48	16.39	18.47	17.83	17.56	40.34	39.07	39.11	39.50	49.33	50.16	51.46	50.32
	150% RD	10.92	12.49	11.56	11.65	18.25	18.64	19.07	18.65	39.25	40.43	39.81	39.83	51.51	53.07	51.37	51.98
	Mean	10.27	11.35	11.37	11.00	16.76	18.78	18.16	17.90	39.45	39.26	39.03	39.32	49.76	50.50	51.16	50.48
	Control	10.18				17.32				38.55				48.52			
Critical Difference (0.05)	For comparing between treatments	1.25				1.98				1.50				0.989			
	For comparing between irrigation levels	0.72				1.14				NS				0.571			
	For comparing between fertilizer levels	0.72				NS				0.86				0.571			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

similar heights as that of T_6. But when crop entered to the growth stage i.e., 45 DAP, the treatments T_1, T_9, T_3, T_7 and T_4 behaved similar to T_6. At peak vegetative phase i.e., 60 DAP fertigation level T_6 produced significantly taller plants than rest of the treatments and the average height of the plant at this stage was 53.07 cm.

Throughout the growth period, irrigation at 0.3 PE resulted in shorter plants than the rest two irrigation levels i.e., I_3 (0.9 PE) and I_2 (0.6 PE). At initial growth phase i.e., 15 and 30 DAP, irrigation levels I_3 and I_2 had similar effect on growth in terms of plant height. However at 60 DAP, irrigation at 0.9 PE produced significantly taller plants with the average height of 51.16 cm.

Among the fertilizer levels, application @ 150 per cent of recommended dose of fertilizer consistently produced taller plants than the rest of the fertilizer levels i.e., 50 per cent (F_2) and 100 per cent (F_1) of recommended dose. This result was significant at last stage of observation i.e., 60 DAP.

At early stages of growth i.e., 15 or 30 or 45 DAP the interaction of irrigation and fertilizer levels did not affect the height of the plants. But at 60 DAP, the application of fertilizer at 150 per cent level along with irrigation level of 0.6 PE produced taller plants with the mean height of 53.07 cm.

4.1.2 Leaf area index (LAI)

The data on mean LAI of tomato plants computed for different growth stages are given in Table 5.

The fertigation treatments variably influenced LAI of the crop as growth progressed. However, throughout the stages of growth, the treatment T_6, T_7 and T_9

Table 5. Mean leaf area index (LAI) of tomato plants at 20 days interval as influenced by different levels of fertigation

		Irrigation levels															
		20 DAP				40 DAP				60 DAP				80 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	1.74	1.51	1.58	1.61	3.04	3.16	3.09	3.10	5.47	5.55	5.83	5.48	5.40	5.40	5.34	5.38
	100% RD	1.79	1.83	1.80	1.80	3.14	3.16	3.27	3.19	5.78	5.74	5.94	5.78	5.70	5.63	5.64	5.65
	150% RD	1.80	1.88	1.90	1.86	3.14	3.38	3.25	3.26	5.86	5.94	5.42	5.91	5.76	5.80	5.79	5.78
	Mean	1.77	1.74	1.76	1.76	3.11	3.23	3.20	3.18	5.70	5.74	5.72	5.72	5.62	5.61	5.59	5.60
	Control	1.77				3.04				5.62				5.46			
Critical Difference (0.05)	For comparing between treatments	0.13				0.17				0.38				0.40			
	For comparing between irrigation levels	NS				0.09				NS				NS			
	For comparing between fertilizer levels	0.07				0.09				0.22				0.23			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

had higher values of LAI. Similarly throughout the four stages of observation, the treatments T_5, T_2 and T_8, received 50 per cent of fertilizer doses, produced lesser leaf area. At 80 DAP, treatment T_6 and T_9, produced maximum LAI of 5.80 and 5.79 respectively and lowest was produced by the treatment T_8 (5.34).

Maximum leaf area was produced by the fertilizer level F_3 i.e., 150 per cent of recommended dose of fertilizers. This was significantly superior to F_2 level (50% recommended dose) but on par with 100 per cent fertilizer dose during 20, 60 and 80 DAP. The LAI recorded at 20, 40, 60 and 80 DAP at different growth stages at F_3 levels were 1.86, 3.26, 5.91 and 5.78 respectively. The three levels of irrigation did not profoundly influence leaf area at all growth stages except at 40 DAP where 0.6 and 0.9 PE irrigation levels remarkably increased leaf area over 0.3 PE irrigation.

4.1.3 Leaf area duration (LAD)

The data on mean LAD of tomato plants recorded at different growth stages are given in Table 6.

The results obtained for LAD followed the same trend as that of LAI. LAD was significant for the period 20-40 days wherein treatment T_6 had more duration than any other treatment except T_9. Treatment T_7 also produced similar duration as that of T_9 but lesser than T_6. Treatments receiving 50 per cent of recommended fertilizer dose i.e., T_2, T_8 and T_5 had a lesser duration than others and behaved as that of control crop (T_{10}). During the last stage of observation (60-80 DAP) all treatments except T_2, T_5 and T_8 were on par with T_6 treatment.

Table 6. Mean leaf area duration (LAD) of tomato plants as influenced by different levels of fertigation

		Irrigation levels											
		20-40 DAP				40-60 DAP				60-80 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	47.83	46.76	46.80	47.13	85.13	87.10	85.23	85.82	108.8	109.5	107.7	108.6
	100% RD	49.30	49.96	50.76	50.01	89.26	89.03	91.03	89.77	114.9	113.7	114.7	114.4
	150% RD	49.46	52.73	51.63	51.27	90.13	93.33	91.86	91.77	116.3	117.5	117.2	117.0
	Mean	48.86	49.82	49.73	49.47	88.17	89.82	89.37	89.12	113.3	113.6	113.2	113.4
	Control	48.20				86.66				110.90			
Critical Difference (0.05)	For comparing between treatments	1.73				NS				7.80			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	1.0				2.50				4.5			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Three different irrigation levels did not affect LAD remarkably and the average LAD for the irrigation levels 0.3, 0.6 and 0.9 PE were 113.3, 113.6 and 113.2 at 60-80 days interval respectively. But the fertilizer levels affected LAD remarkably. Lowest LAD was reported at all stages by F_2 level i.e., 50 per cent fertilizer application and highest by 150 per cent fertilizer level. LAD of crops receiving 100 per cent fertilizer dose had similar duration as that of 150 per cent level.

4.1.4 Number of fruiting branches plant^{-1}

The data on mean number of fruiting branches plant^{-1} recorded are given in Table 7.

The varying levels of fertigation did not affect the number of fruiting branches plant^{-1} significantly.

4.1.5 Percentage of fruitset

The mean data on percentage of fruitset are given in Table 7.

The varying fertigation levels remarkably altered the fruitset in the crop. Maximum fruitset of 61.74 per cent was recorded when the crop was irrigated at 0.9 PE with 100 per cent fertilizer application. This fruit setting percentage was statistically on par to treatments receiving 50 per cent fertilizer through irrigation water either at 0.3 PE or 0.6 PE levels. The lowest fruit setting percentage of 42.58 was recorded in the control plot, irrigated once in three days without mulch cover.

The different irrigation levels did not significantly affect fruit setting percentage. However the different fertilizer levels or its interaction with irrigation water affected the fruit setting percentage. Fertilizer application at 50 per cent or 100 per cent recommended dose through irrigation water remarkably increased fruit setting and as the fertilizer level increased to 150 per cent there was significant reduction in fruit setting percentage. The application of 100 per cent fertilizer level with 0.9 PE and 50 per cent fertilizer level at 0.3 or 0.6 PE level irrigation resulted in maximum fruit setting.

4.1.6 Number of fruits plant^{-1}

The data on mean number of fruits plant^{-1} recorded are given in Table 7.

The data on number of fruits plant^{-1} indicated that the control crop produced the lowest number of fruits plant^{-1} i.e., 22. This was lower than all other treatments except the treatment receiving 50 per cent fertilizer level with 0.3 PE or 50 per cent fertilizer with 0.6 PE irrigation. Maximum number of fruits plant^{-1} (41.16) was recorded in T_6, where the crop was fertilized with 150 per cent of fertilizer and irrigation at 0.6 PE. This was significant over control crop as well as the one received 50 per cent fertilizer with irrigation at 0.3 PE.

Irrigation level or fertilizer level did not significantly affect the production of number of fruits plant^{-1}. However, control crop produced significantly lower number of fruits plant^{-1}.

4.1.7 Fruit weight plant^{-1}

The data on mean fruit weight plant^{-1} recorded are given in Table 7.

The data on fruit weight per plant indicated that the crop receiving 150 per cent fertilizer dose along with irrigation at 0.6 PE (T_6) level or irrigation at 0.9 PE (T_9) with 100 per cent fertilizer (T_7) level produced significantly higher fruit weight per plant. The respective fruit weight per plant were 1343, 1250 and 1307 g respectively. The yield of the crop receiving fertilizer level of 100 per cent recommended dose and irrigation at 0.3 or 0.6 PE and the crop receiving 150 per cent recommended dose fertilizer with 0.3 PE irrigation

Table 7. Fruiting branches plant^{-1}, fruit set (%), number of fruits plant^{-1}, fruit weight plant^{-1} and yield hectare^{-1} as influenced by different levels of fertigation

		Irrigation levels											
		Fruiting branches plant^{-1}				Fruit set (%)				No. of fruits plant^{-1}			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	14.55	15.55	13.88	14.66	58.86	58.83	55.43	57.71	31.70	32.16	33.40	32.42
	100% RD	16.33	15.10	13.66	15.03	52.28	57.30	61.74	57.11	33.83	36.50	40.33	36.88
	150% RD	15.22	17.44	13.55	16.07	55.62	55.48	52.61	54.57	35.10	41.16	38.46	38.24
	Mean	15.36	16.03	14.36	15.25	55.59	57.20	56.59	56.46	33.54	36.61	37.40	35.85
	Control	15.32				42.58				22.00			
Critical Difference (0.05)	For comparing between treatments	NS				4.30				10.36			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				2.48				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Contd.

Table 7. Continued.

		Irrigation levels							
		Fruit weight plant^{-1} (gram)				Yield hectare^{-1} (tonnes)			
Fertilizer levels		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
	50% RD	986.8	1021.0	1015.0	1008.0	27.40	28.36	28.19	27.98
	100% RD	1106.0	1102.0	1307.0	1172.0	30.71	30.60	36.30	32.54
	150% RD	1082.0	1343.0	1250.0	1225.0	30.06	37.30	34.73	34.03
	Mean	1058.0	1155.0	1191.0	1135.0	29.39	32.08	33.07	31.51
	Control	695.42				19.31			
Critical Difference (0.05)	For comparing between treatments	175.4				4.87			
	For comparing between irrigation levels	101.3				2.81			
	For comparing between fertilizer levels	101.3				2.81			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

were similar as that of the crop receiving 150 per cent fertilizer along with 0.9 PE. The lowest yield per plant (695 g) was recorded in the control plot.

The results indicated that higher levels of irrigation led to maximum fruit weight and lower levels to a lower fruit weight (Table 7). Irrigation at 0.9 and 0.6 PE produced on an average of 1191, 1155 gram per plant respectively and the yield levels of former treatment was significantly superior to irrigation at 0.3 PE. The fertilizer dose of 150 per cent and 100 per cent produced on an average yield of 1225 and 1172 g per plant respectively and this was superior to the mean yield of 1008 g per plant produced by the crop receiving 50 per cent fertilizer dose.

4.1.8 Yield per hectare

The data on yield per hectare are given in Table 7.

The mean data on yield per hectare (Table 7) is the extrapolation of yield per plant and the population per hectare (27778 plants). Hence the result gives same trend as that of values observed in case of yield per plant. The treatment T_6, produced maximum yield per hectare (37.3 t ha^{-1}) of fruits which is 93.16 per cent more than control crop. The treatment T_7 and T_9 which were statistically on par with T_6 produced 87.98 per cent and 79.85 per cent more yield than the control crop. Application of 150 per cent fertilizer on an average produced 34.03 tonnes of fruit per hectare that was 76.22 per cent more than control crop. Cent per cent fertilizer dose applied crop produced 68.51 per cent more fruit yield than the control crop. The corresponding increase in the 50 per cent recommended dose fertilizer was only 44.89 per cent. Irrigation at 0.9 PE produced 13.76 tonnes more fruit than the control crop. Corresponding increase in case of 0.6 and 0.3 PE irrigation levels were 12.77 and 10.08 tonnes.

4.1.9 Rooting pattern

The data on vertical and horizontal root growth and root dry weight observed per plant are given in Table 8.

The data indicated that the control crop had significantly larger root growth both vertical and lateral as well as higher root weight per plant than the rest of the treatments. Roots of the crop under this treatment extended 26.8 cm deep and 15 cm laterally, weighing 8.19 g per plant. The corresponding overall mean for the different combination of irrigation and fertilizer levels under mulched situation were 18.65 cm, 11.01 cm and 3.94 g respectively. The varying levels of fertilizer or irrigation or its interaction could not enhance root growth in terms of vertical and radial root growth or root weight even to the level of the control crop.

4.2 Studies on quality of tomato fruits as influenced by different levels of fertigation

4.2.1 Acidity of fruits

The mean data on acidity computed are given in Table 9.

The fruits produced in the control plot had the highest acidity of 0.44 per cent. The treatments T_2 and T_1 also produced fruits with higher acidity on par with control crop and these values are higher than that for the rest of the treatments.

Irrigation significantly affected acidity level in fruits. Least irrigated crop i.e., irrigation at 0.3 PE produced maximum acidity of 0.366 per cent followed by the crop irrigated most profusely (0.9 PE - irrigation) with an acidity value of 0.309 per cent. Least acidic fruits were produced at the irrigation level 0.6 PE. Among the fertigation levels 100 or 50 per cent recommended dose of fertilizer resulted in maximum acidity . The crop fertilized with 150 per cent recommended dose of fertilizer produced fruits with lowest level of acidity i.e., 0.281 per cent.

Table 8. Rooting pattern of tomato plants as influenced by different levels of fertigation

		Irrigation levels											
		Vertical length (cm)				Lateral length (cm)				Root dry weight (g)			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	18.13	18.20	17.73	18.02	11.26	10.10	10.90	10.75	3.29	5.01	4.14	4.15
	100% RD	19.97	20.26	19.20	19.81	12.06	11.56	11.17	11.60	3.30	4.11	3.95	3.79
	150% RD	19.30	17.34	17.70	18.11	11.13	10.46	10.50	10.70	4.53	2.86	4.32	3.90
	Mean	19.13	18.60	18.21	18.65	11.48	10.71	10.85	11.01	3.70	3.99	4.13	3.94
	Control	26.80				15.00				8.19			
Critical Difference (0.05)	For comparing between treatments	3.33				1.79				2.01			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Table 9. The quality of tomato fruits (acidity, TSS and fruit cracking) as influenced by different levels of fertigation.

		Irrigation levels											
		Acidity (%)				TSS (°Brix)				Fruit cracking (%)			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	0.427	0.240	0.297	0.321	4.783	4.833	5.067	4.894	0.289 (8.21)	0.274 (8.23)	0.276 (7.72)	0.280 (8.05)
	100% RD	0.403	0.270	0.317	0.330	4.733	5.083	5.117	4.978	0.275 (7.40)	0.286 (8.13)	0.313 (9.80)	0.291 (8.44)
	150% RD	0.267	0.263	0.313	0.281	4.600	5.133	5.133	4.956	0.284 (8.07)	0.253 (6.35)	0.306 (9.06)	0.281 (7.83)
	Mean	0.366	0.258	0.309	0.311	4.706	5.017	5.106	4.94	0.283 (7.89)	0.271 (7.57)	0.298 (8.86)	0.284 (8.11)
	Control	0.440				4.717				0.353 (12.00)			
Critical Difference (0.05)	For comparing between treatments	0.054				NS				0.076			
	For comparing between irrigation levels	0.031				NS				NS			
	For comparing between fertilizer levels	0.031				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose
Values in the parenthesis indicate original values

4.2.2 Total soluble solids (TSS)

The mean data on TSS computed are presented in Table 9.

The fruits produced under control treatment had TSS content of 4.72° brix and fruits produced under varying levels of fertigation had a mean TSS content of 4.94° brix. The different treatments did not impart any significant variation in the TSS content of fruits.

4.2.3 Fruit cracking

The percentage of fruit cracking is a measure of fruit quality. The data in Table 9 revealed that while 12 per cent of total fruit harvest was affected by cracking in case of control plots, on an average only 8.11 per cent of fruits in various fertigation treatments was affected by cracking. However the irrigation levels or fertilizer levels or its interaction did not significantly affect fruit cracking.

4.3 Studies on nutrient content of the tomato plants as influenced by different levels of fertigation

4.3.1 Nitrogen content in the plants

The mean content of nitrogen in the plants observed at 30, 60 and 90 DAP are given in Table 10.

The plant raised in control treatment contained on an average 4.02 per cent nitrogen compared to 4.32 per cent nitrogen in case of rest of the treatments, at 30 DAP. At this stage, the different fertigation levels could not alter the nitrogen content in the plant. However, the control plant recorded lowest mean nitrogen content and the plant receiving T_6 treatment produced maximum nitrogen content which was significantly superior to that in control plant.

Table 10. Mean nitrogen content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	4.07	4.10	4.10	4.09	4.95	4.63	4.40	4.66	4.04	3.60	3.05	3.56
	100% RD	4.57	4.21	4.44	4.41	4.62	4.94	5.08	4.88	3.32	3.24	3.38	3.31
	150% RD	4.47	4.60	4.26	4.44	5.17	5.33	4.99	5.16	3.80	3.82	3.04	3.56
	Mean	4.37	4.30	4.27	4.32	4.91	4.97	4.82	4.90	3.72	3.55	3.16	3.48
	Control	4.02				4.00				3.34			
Critical Difference (0.05)	For comparing between treatments	0.41				NS				0.70			
	For comparing between irrigation levels	NS				NS				0.40			
	For comparing between fertilizer levels	0.23				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

As the growth progressed to 60 DAP, the nitrogen content in the plant was not altered due to variation in fertilization levels or irrigation levels or its combination, in comparison to the control plot. While the mean content of nitrogen of the crop receiving different fertigation level was 4.90 per cent compared to 4 per cent in the control plot. But at the harvest stage (90 DAP) the different treatments had varying effects on the mean nitrogen content of the plants. Application of fertilizer at 50 per cent recommended dose either at 0.3 or 0.6 PE irrigation level or application of 150 per cent recommended dose either at 0.3 or 0.6 PE irrigation level or application of 100 per cent recommended dose at 0.9 PE irrigation level produced higher mean nitrogen content, but the values were on par with each other. The highest nitrogen content was recorded in the least fertilized (50% recommended dose of fertilizer) and least irrigated (0.3 PE) crop, i.e., 4.04 per cent nitrogen. The lowest nitrogen content was recorded in the crop receiving highest level of fertilizer and highest level of irrigation i.e., 3.04 per cent.

The mean nitrogen content was not variably affected by different levels of fertilizer doses but by various irrigation levels. Irrigation at 0.3 PE level produced more nitrogen in the plant than irrigation at 0.9 PE. Irrigation at 0.6 PE level produced similar nitrogen content in plants as that of 0.3 or 0.9 PE levels.

4.3.2 Phosphorus content in the plants

The mean content of phosphorus estimated in plants is given in Table 11.

In general the different levels of fertilizer and irrigation could not impart any significant variation in plants especially at 60 or 90 DAP. Initially, i.e., 30

Table 11. Mean phosphorus content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	0.418	0.458	0.476	0.451	0.277	0.281	0.315	0.291	0.246	0.226	0.220	0.231
	100% RD	0.482	0.391	0.467	0.446	0.282	0.267	0.261	0.270	0.231	0.194	0.234	0.220
	150% RD	0.403	0.499	0.468	0.457	0.304	0.269	0.306	0.293	0.247	0.261	0.178	0.228
	Mean	0.434	0.449	0.470	0.451	0.287	0.272	0.294	0.285	0.241	0.227	0.211	0.226
	Control	0.302				0.245				0.241			
Critical Difference (0.05)	For comparing between treatments	0.12				NS				NS			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

DAP, the crop receiving different irrigation levels and fertilizer levels had high content of phosphorus compared to the control crop.

As the growth progressed, this difference reduced and all the treatments remained same at 60 and 90 DAP. As the growth progressed in general there was a lowering in the content of phosphorus in plants.

4.3.3 Potassium content in plants

The mean data on potassium content (Table 12) indicated that the absorption of potassium by the crop at different growth phases was remarkably affected by the level of irrigation as well as fertilizer. Initially the treatments T_3, T_4 and T_9 had significantly higher potassium content than the control plot. At this stage, the crop receiving 150 per cent recommended dose of fertilizer had maximum potassium content (2.67%) in plants than the other levels of fertilizer. At 60 DAP all the treatments had more or less similar potassium content. But the potassium content was significantly low in the crop receiving irrigation at 0.3 PE level and fertilizer at 150 per cent recommended dose when compared to T_4 and T_7 treatments. At harvest stage, the treatment receiving 50 per cent recommended dose of fertilizer accompanied by 0.6 PE irrigation had significantly higher potassium than the rest of the treatments except the treatment receiving 150 per cent fertilizer dose along with 0.9 PE irrigation. The control crop produced lower potassium than all other treatments.

Though different doses of fertilizer did not significantly alter potassium content at 60 and 90 DAP, the different levels of irrigation significantly affected

Table 12. Mean potassium content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	2.15	2.55	2.50	2.39	3.07	3.76	3.16	3.13	2.10	2.43	2.10	2.20
	100% RD	2.44	2.64	2.30	2.47	3.12	3.14	3.22	3.16	2.10	2.21	2.20	2.17
	150% RD	2.65	2.58	2.8	2.67	2.99	3.16	3.15	3.10	2.11	2.17	2.32	2.20
	Mean	2.42	2.60	2.52	2.51	3.06	3.15	3.18	3.13	2.09	2.27	2.20	2.20
	Control	2.34				3.07				2.08			
Critical Difference (0.05)	For comparing between treatments	0.29				0.17				0.19			
	For comparing between irrigation levels	NS				NS				0.11			
	For comparing between fertilizer levels	0.17				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

potassium content at harvest and irrigation at 0.6 or 0.9 PE produced maximum potassium content than irrigation at 0.3 PE.

4.3.4 Calcium content in plants

The mean content of calcium (Table 13) in the plant observed at three different growth stages indicated that the different irrigation levels or fertilizer levels did not affect calcium content in the crop independently. However, the result indicated that lower levels of fertilizer and lower level of irrigation are sufficient to produce plants with higher calcium content. But when the fertilizer dosage was increased a higher moisture level is required to produce plants with high calcium content.

At 30 DAP with 50 per cent fertilizer dose, irrigation either at 0.3 PE or 0.9 PE level was sufficient to produce higher calcium content. But a similar level of calcium content was produced with 0.6 or 0.9 PE irrigation when fertilizer dosage was increased to 100 or 150 per cent. The same trend continued at 60 DAP. At the harvest stage all the treatment combinations 0.3, 0.6 and 0.9 PE along with 50, 100 or 150 per cent fertilizer dose produced higher calcium in plants i.e., on average of 2.22 per cent than the plants receiving control treatment i.e., 1.59 per cent.

4.3.5 Magnesium content in plants

The mean data on magnesium content (Table 14) indicated that the various fertigation levels did not significantly affect magnesium content of the plant at all the three stages of observation when compared to that in control plant.

Table 13. Mean calcium content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	2.29	1.82	2.17	2.09	2.83	2.45	1.97	2.42	2.22	2.20	2.13	2.18
	100% RD	1.98	1.83	2.04	1.95	2.57	2.32	2.32	2.40	2.03	2.25	2.28	2.19
	150% RD	1.68	2.08	2.03	1.93	2.00	1.93	2.42	2.12	2.17	2.52	2.18	2.29
	Mean	1.98	1.91	2.08	2.00	2.47	2.23	2.23	2.31	2.14	2.32	2.20	2.22
	Control	1.82				2.72				1.59			
Critical Difference (0.05)	For comparing between treatments	0.28				0.66				0.68			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Table 14. Mean magnesium content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	0.533	0.600	0.680	0.604	0.847	0.607	0.553	0.669	0.440	0.507	0.647	0.531
	100% RD	0.553	0.540	0.640	0.578	0.600	0.820	0.607	0.676	0.700	0.600	0.487	0.596
	150% RD	0.613	0.560	0.567	0.580	0.500	0.587	0.680	0.589	0.620	0.533	0.560	0.571
	Mean	0.567	0.567	0.629	0.587	0.649	0.671	0.613	0.644	0.587	0.547	0.564	0.566
	Control	0.673				0.667				0.513			
Critical Difference (0.05)	For comparing between treatments	NS				0.292				NS			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

The average magnesium content in plants of the crop receiving different fertigation levels where 0.59, 0.64 and 0.57 per cent respectively at 30, 60 and 90 DAP. The corresponding values for the control crop where 0.67, 0.67 and 0.51 per cent.

4.3.6 Sulphur content in plants

The mean data on sulphur content given in Table 15 indicated that the fertigation had no significant influence on sulphur content. All the three stages, the average of mean content of sulphur over different fertigation levels was not significant.

4.3.7 Iron content in plants

The data on mean content of iron in plant samples observed at three stages of growth are given in Table 16.

As the growth progressed, the mean content of iron in the control crop as well as in the treatments increased. The average content of iron in the control crop at 30 DAP was 87 ppm and there was 21 and 66 per cent increase over this at 60 and 90 DAP. A similar trend was observed in fertigation treatments also.

At early stages of growth (30 DAP) irrigation levels did not alter significantly the iron content in the plants. But as growth proceeded to 60 or 90 DAP, the irrigation levels remarkably affected iron content and in both stages, irrigation scheduled at 0.9 PE resulted in significantly higher iron content than irrigation scheduled at 0.6 PE level or 0.3 PE level. The iron content of the plants at 60 or 90 DAP were not altered due to various fertilizer levels. Though

Table 15. Mean sulphur content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	0.470 (0.234)	0.340 (0.120)	0.483 (0.233)	0.431 (0.196)	0.302 (0.137)	0.451 (0.237)	0.566 (0.377)	0.440 (0.250)	0.651 (0.575)	0.274 (0.081)	0.596 (0.406)	0.507 (0.354)
	100% RD	0.521 (0.273)	0.484 (0.238)	0.499 (0.249)	0.501 (0.253)	0.552 (0.365)	0.543 (0.379)	0.530 (0.300)	0.542 (0.348)	0.458 (0.218)	0.530 (0.385)	0.422 (0.206)	0.470 (0.270)
	150% RD	0.554 (0.313)	0.403 (0.166)	0.396 (0.184)	0.451 (0.221)	0.742 (0.640)	0.638 (0.455)	0.393 (0.202)	0.591 (0.438)	0.614 (0.390)	0.610 (0.488)	0.637 (0.413)	0.621 (0.430)
	Mean	0.515 (0.273)	0.409 (0.175)	0.459 (0.222)	0.461 (0.223)	0.532 (0.381)	0.544 (0.357)	0.496 (0.293)	0.524 (0.343)	0.574 (0.394)	0.471 (0.318)	0.552 (0.342)	0.532 (0.351)
	Control	0.342 (0.123)				0.195 (0.046)				0.437 (0.194)			
Critical Difference (0.05)	For comparing between treatments	NS				NS				NS			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Values in the parenthesis indicate original values

Table 16. Mean Fe content (ppm) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	72.33	85.33	84.00	80.55	112.3	111.7	115.7	115.2	153.0	124.0	166.7	147.9
	100% RD	93.00	82.00	86.00	87.00	108.0	117.0	104.7	109.9	133.3	151.7	164.7	149.9
	150% RD	75.33	86.66	75.66	79.22	103.3	110.7	119.7	111.2	129.3	150.0	153.3	144.2
	Mean	80.22	84.66	81.88	82.25	107.9	113.1	113.3	111.4	138.6	141.9	161.6	147.3
	Control	87.0				105.3				143.7			
Critical Difference (0.05)	For comparing between treatments	8.49				8.01				26.66			
	For comparing between irrigation levels	NS				4.62				15.39			
	For comparing between fertilizer levels	4.90				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

fertigation levels (irrigation and fertilizer) affected iron content at 30 and 60 DAP this effect was not observed at 90 DAP.

4.3.8 Manganese content in plants

The data on mean content of manganese in plant samples observed at three stages of growth are given in Table 17.

Like Fe the Mn content also increased as the growth progressed and the highest mean content in plants was observed at the last stage of growth i.e., 90 DAP. The overall mean content of Mn in fertigated plots was 27.92, 35.40 and 42.72 at 30, 60 and 90 DAP. The respective values for the control plot were 28.3, 36 and 41.7 ppm Mn.

The different irrigation levels or fertilizer doses in general did not significantly affect Mn contents in plants at all growth stages. However, at 90 DAP irrigation and fertilizer application levels could alter the Mn content in plants significantly. The highest Mn content was recorded at 150 per cent fertilizer with 0.3 PE irrigation level but it was on par with all other treatments including control except the treatments which received 0.9 PE irrigation with 50 per cent fertilizer dose and 0.9 PE irrigation with 150 per cent fertilizer dose.

4.3.9 Zinc content in plants

The data on mean content of zinc in plant samples observed at different growth stages are given in Table 18.

Table 17. Mean Mn content (ppm) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	28.66	31.00	27.66	29.11	35.66	35.00	36.00	35.55	43.66	45.00	39.33	42.66
	100% RD	27.66	28.00	31.00	28.88	36.66	32.66	34.33	34.55	42.33	41.33	44.66	42.77
	150% RD	25.66	24.66	27.00	25.77	38.00	36.00	34.33	36.11	45.33	43.00	40.33	42.88
	Mean	27.33	27.88	28.55	27.92	36.77	34.55	34.88	35.40	43.77	43.11	41.44	42.72
	Control	28.33				36.00				41.66			
Critical Difference (0.05)	For comparing between treatments	3.6				3.97				3.92			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	1.82				NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Table 18. Mean Zn content (ppm) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels											
		30 DAP				60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	14.60	13.85	18.77	15.74	26.66	26.33	29.66	27.55	38.00	33.66	35.00	35.55
	100% RD	13.11	13.68	17.19	14.66	21.00	28.00	28.66	25.88	31.00	27.00	29.33	29.11
	150% RD	17.05	17.38	16.43	16.95	24.00	28.00	31.00	27.66	34.33	32.00	34.00	33.44
	Mean	14.92	14.97	17.46	15.78	23.88	27.44	29.77	27.03	34.44	30.88	32.77	32.70
	Control	13.83				31.33				26.00			
Critical Difference (0.05)	For comparing between treatments	2.66				3.40				4.81			
	For comparing between irrigation levels	1.53				1.96				2.77			
	For comparing between fertilizer levels	1.53				NS				2.77			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

The Zn content almost doubled both in control as well as fertigated plants when the growth progressed from 30 DAP to 60 DAP. Thereafter the Zn content did not increase remarkably in plants.

The irrigation levels significantly affected Zn content at all growth stages and the irrigation level at 0.9 PE remained superior to other two levels at 30 and 60 DAP. However, irrigation scheduled at 0.3 or 0.9 PE was superior to the one scheduled at 0.6 PE when observed at 90 DAP.

The fertilizer levels influenced the Zn content of the plants significantly at 30 and 90 DAP. At both these stages, zinc content was maximum in plants fertigated at 150 per cent or 50 per cent recommended dose.

4.3.10 Silica content in plants

The mean content of silica at 60 and 90 DAP are given in Table 19.

The crop contained, on an average 1.38 per cent silica at 60 DAP and 1.85 per cent at 90 DAP. The various irrigation level affected silica content of the plants only at 90 DAP and the crop irrigated at 0.9 PE enabled it to contain more silica than the crop irrigated at 0.3 or 0.6 PE. The various fertilizer levels altered silica content at 60 DAP but the effect was not carried over to the final stage. The interactive effect of fertilizer and irrigation was visible only at 90 DAP. The combination of 0.9 PE irrigation with 50 per cent fertilizer and 0.9 PE irrigation with 100 per cent fertilizer or the crop irrigated at 0.6 PE level with 50 per cent fertilizer dose had higher silica content in its biomass over the other fertigated crops or control crop except the crop irrigated at 0.3 PE level with 100 per cent fertilizer.

Table 19. Mean Si content (%) of tomato plants at 30 days interval as influenced by different levels of fertigation

		Irrigation levels							
		60 DAP				90 DAP			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	1.55	1.63	1.40	1.52	1.74	1.93	1.92	1.86
	100% RD	1.43	1.32	1.58	1.44	1.89	1.72	1.94	1.85
	150% RD	1.19	1.26	1.30	1.25	1.82	1.79	1.84	1.81
	Mean	1.39	1.40	1.43	1.40	1.81	1.81	1.90	1.84
	Control	1.36				1.86			
Critical Difference (0.05)	For comparing between treatments	0.35				0.07			
	For comparing between irrigation levels	NS				0.04			
	For comparing between fertilizer levels	0.20				NS			

4.4 NPK content of the soil after cropping

The data on nitrogen, phosphorus and potassium content of soil estimated after cropping under various treatments are given in Table 20.

On an average 315 kg of nitrogen per hectare was available after harvesting. Obviously the lowest nitrogen content was observed at 50 per cent fertilizer level plot and highest in 150 per cent fertilizer level plot both under 0.3 PE irrigation level and significantly differing each other. The remaining all treatments including control were on par with these treatments.

The mean available phosphorus content of the soil was 27.7 kg ha^{-1} in the control plot and 25.2 kg ha^{-1} in the treatment plots at different fertigation levels. The varying levels of fertilizer or irrigation did not affect phosphorus significantly in the soil after cropping. Highest phosphorus content was recorded in plots receiving 50 per cent of recommended fertilizer dose under 0.6 PE irrigation.

The mean content of available potassium under different treatments are given in Table 20. The treatments did not affect potassium level in the soil after cropping. On an average 112 kg of potassium was available in the soil after the crop was harvested.

4.5 Incidence of leaf curl and bacterial wilt diseases

The percentage of leaf curl and bacterial wilt affected plants were observed as an ancillary observation in the present investigation. The data (Table 21) indicated that percentage of leaf curl incidence was severe in general. Nearly 40 per cent of the fertigated plants and 72 per cent of the control plants were

Table 20. Mean N, P and K content (kg ha^{-1}) of the soil after cropping

		Irrigation levels											
		Nitrogen				Phosphorus				Potassium			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	300.60	312.38	303.63	305.53	23.27	32.70	27.67	27.88	110.96	111.92	116.00	112.96
	100% RD	329.20	327.10	303.30	319.85	21.59	24.09	21.95	22.54	114.70	109.06	114.94	112.90
	150% RD	339.02	316.08	305.57	320.22	24.91	23.16	27.35	25.14	111.19	112.61	114.43	112.42
	Mean	322.924	318.52	304.16	315.20	23.25	26.65	25.67	25.18	112.28	110.87	115.12	112.76
	Control	314.51				27.68				111.83			
Critical Difference (0.05)	For comparing between treatments	38.34				7.62				NS			
	For comparing between irrigation levels	NS				NS				NS			
	For comparing between fertilizer levels	NS				NS				NS			

DAP = Days after planting; PE = Pan evaporation: RD = Recommended dose

Table 21. Percentage of leaf curl and bacterial wilt infected tomato plants

		Irrigation levels							
		Leaf curl (%)				Bacterial wilt (%)			
		0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
Fertilizer levels	50% RD	0.706 (42.22)	0.574 (30.49)	0.723 (43.85)	6.668 (38.85)	0.434 (18.19)	0.423 (16.95)	0.405 (15.94)	0.421 (17.02)
	100% RD	0.734 (45.21)	0.843 (54.72)	0.611 (33.06)	0.730 (44.33)	0.403 (15.50)	0.459 (19.81)	0.387 (14.30)	0.416 (16.53)
	150% RD	0.620 (34.87)	0.704 (42.03)	0.633 (35.67)	0.652 (37.52)	0.362 (13.40)	0.424 (17.12)	0.396 (15.43)	0.394 (15.32)
	Mean	0.687 (40.77)	0.707 (42.41)	0.656 (37.52)	0.683 (40.23)	0.400 (15.70)	0.435 (17.96)	0.396 (15.22)	0.410 (16.29)
	Control	1.023 (71.93)				0.377 (13.57)			
Critical Difference (0.05)	For comparing between treatments	0.281				NS			
	For comparing between irrigation levels	NS				NS			
	For comparing between fertilizer levels	NS				NS			

DAP = Days after planting; PE = Pan evaporation; RD = Recommended dose

Values in the parenthesis indicate original values

affected by this virus disease. Application of fertilizers through irrigation water could significantly reduce the incidence of this disease and the varying levels of fertigation did not cause significant variation among those treatments.

Varying fertilizer or irrigation level did not impart any significant variation in the incidence of bacterial wilt. Nearly 14 per cent of control plants and 16 per cent of fertigated plants were affected by the disease.

4.6 Soil temperature

The data on the soil temperature recorded at four depths (5, 10, 15 and 20 cm) at morning 7-30 IST and evening 2-30 IST of different treatments are given in Table 22.

The relative change in soil temperature with respect to the control plot is given in Table 23. The data indicated that in general all the fertigated plots had a higher soil temperature; 3.3°C and 2.6°C more than control plots in the morning and evening hours respectively. At all depths soil temperature was lowest at 0.9 PE irrigation level and highest at 0.3 PE irrigation level. When observed in the morning, soil temperature gradually increased with increasing depth in all levels of irrigation. During evening the soil temperature gradually reduced with depth. In general as the irrigation level decreased the soil temperature increased. This increase in soil temperature was relatively lower at 0.9 PE, followed by 0.6 and 0.3 PE.

The soil temperature increased gradually from the depth of 10 cm in all irrigation levels and increase was observed upto 20 cm depth. Maximum temperature was recorded at 0.3 PE followed by 0.6 and 0.9 PE levels both in morning and evening.

Table 22. Soil temperature (°C) as influenced by mulch and irrigation levels at 5, 10, 15 and 20 cm depths

Treatments	Morning				Evening			
	5 cm	10 cm	15 cm	20 cm	5 cm	10 cm	15 cm	20 cm
0.3 PE	29.5	29.6	30.5	30.5	34.8	31.6	31.3	30.8
0.6 PE	28.8	29.1	30.2	30.3	34.8	31.2	30.8	30.3
0.9 PE	28.5	28.6	28.8	29.1	34.6	30.9	30.1	29.7
Control	25.5	25.9	26.3	26.8	31.2	29.6	28.5	27.3

Table 23. Relative change in soil temperature (°C) at four different depths due to different irrigation levels and mulching over the control.

Depth of soil (cm)	Irrigation levels							
	Morning				Evening			
	0.3 PE	0.6 PE	0.9 PE	Mean	0.3 PE	0.6 PE	0.9 PE	Mean
5 cm	+4.00	+3.30	+3.00	+3.43	+3.60	+3.60	+3.40	+3.53
10 cm	+3.70	+3.20	+2.70	+3.20	+2.00	+1.60	+1.30	+1.63
15 cm	+4.20	+3.90	+2.50	+3.53	+2.80	+2.30	+1.60	+2.23
20 cm	+3.70	+3.50	+2.30	+3.16	+3.50	+3.00	+2.40	+2.96
Mean	+3.90	+3.48	2.63	3.33	+2.97	+2.63	+2.17	+2.58

4.7 Water use efficiency (WUE)

The details of irrigation applied in different treatments are given in Table 3. The crop was maintained by life saving irrigation upto 09-01-01 and various irrigation treatments were imposed from 10-01-01 to 07-04-01. The control crop received irrigation @ 20 mm water at three days interval through ridges and furrow system without any mulch cover and was applied with 700 mm irrigation water. Irrigation scheduled at 0.3, 0.6 and 0.9 PE utilized 210, 358 and 506 mm of water respectively. The crop under irrigation levels 0.3, 0.6 and 0.9 PE were provided with 42 mm water as pre-treatment irrigation, whereas control crop received 100 mm water for the initial establishment of the crop.

The mean data on FWUE are given in Table 24. As the crop was irrigated either through drip irrigation system daily in case of fertigation treatments or through surface irrigation once in three days in case of control crop, the consumptive use could not be worked out based on water balance method. The lowest WUE of 2.75 kg fruit m^{-3} of water was computed in case of control crop. Highest WUE (14.62 kg fruit m^{-3} of water) was recorded when the crop was irrigated at 0.3 PE and fertilized at 100 per cent of recommended dose. Among the combination of irrigation and fertilizer levels, the lowest WUE was seen when the crop was irrigated at 0.9 PE and applied with 50 per cent recommended dose of fertilizer. The data further indicated that at 0.6 PE irrigation level, high WUE was achieved with increasing fertilizer level. For getting maximum WUE at 0.3 or 0.9 PE level of irrigation, the fertilizer dose shall be 100 per cent of recommended dose and not beyond that. The overall improvement in the FWUE due to combination of fertilizer and irrigation levels over the control was 257 per cent. The relative increase in WUE over the control at 0.3, 0.6 and 0.9 PE irrigation

Table 24. Field water use efficiency (kg fruit m^{-3} of water) as influenced by different levels of fertigation

Fertilizer levels	Irrigation levels				
		0.3 PE	0.6 PE	0.9 PE	Mean
	100% RD	14.62	8.54	7.17	10.11
	50% RD	13.05	7.92	5.57	8.84
	150% RD	14.31	10.41	6.86	10.52
	Mean	13.99	8.95	6.53	9.82
	Control				2.75

levels respectively were 408, 225 and 137 per cent over control. The relative increase in WUE at fertilizer dosage of 50, 100 and 150 per cent of recommended dose were 221, 267 and 282 per cent.

4.8 Soil moisture distribution pattern

The mean data on soil moisture content after harvest are given in Tables 25, 26 and 27.

The soil moisture content from surface to 15 cm depth was more or less uniformly distributed within the radial distance 15-30 cm from the plant i.e., from the delivery point of dripper. But at 30 cm depth, there was a considerable reduction in the available soil moisture as the radial distance increased from 15-30 cm. The mean moisture content at 0.3 PE irrigation was 19.40 and 13.96 per cent at 0-15 cm depth at the radial distance of 15 and 30 cm from the plant. The corresponding value for 0.6 PE irrigation was 12.96 and 12.74 per cent and respective values for 0.9 PE irrigation was 16.48 and 11.07 per cent.

At 30 cm depth, the soil moisture reduced from 14.76 per cent at 15 cm lateral distance to 10.15 per cent at 30 cm lateral distance in case of 0.3 PE irrigation. The respective values for 0.6 PE irrigation was 10.28 and 8.55 per cent and in case of 0.9 PE was 12.72 and 8.92 per cent.

The data recorded at the grid points of 15 cm and 30 cm away perpendicular to the radial distance of 15 cm and 30 cm from the plant indicated that, as the distance increased from the plants there was reduction in the moisture content. At the point of intersection of two moisture curves of the adjacent drippers, the moisture content was comparatively higher than the moisture available at mid points.

Table 25. Moisture content of the soil (% w/w) in the fertigation treatments at 15 and 30 cm depths at the perpendicular and radial distances of 15 and 30 cm away from the plant and 15 and 30 cm perpendicular to it (24 hours after final irrigation)

0.3 PE irrigation

	Depth	RL30 cm	RL15 cm	RR15 cm	RR30 cm
P_0	15 cm	14.70	23.60	15.20	13.22
	30 cm	9.80	16.25	13.38	10.50
P_{15}	15 cm	15.90	13.60	13.40	17.38
	30 cm	9.88	8.55	9.80	8.50
P_{30}	15 cm	11.20	14.11	16.35	10.44
	30 cm	7.20	10.00	11.25	9.20

P_0 = Perpendicular plane; P_{15} = Perpendicular 15 cm; P_{30} = Perpendicular 30 cm

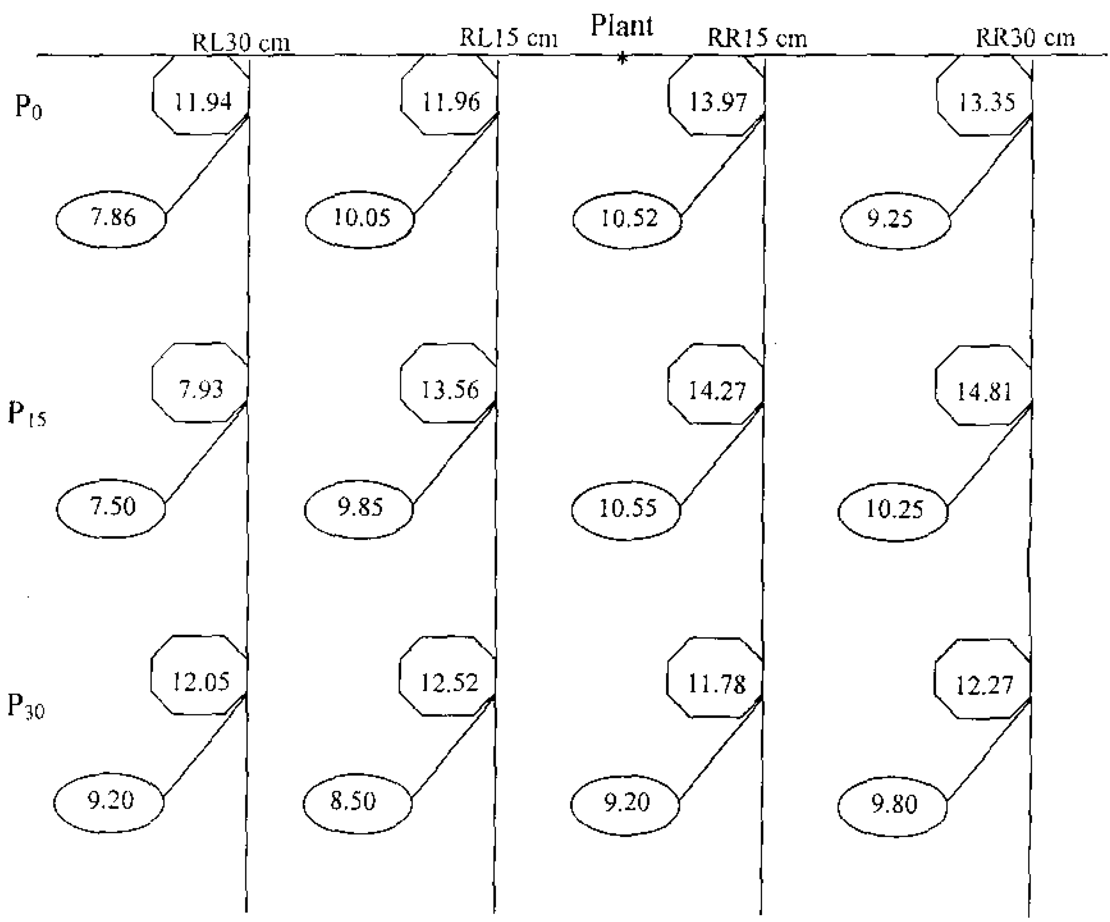
Octagon = 15 cm depth RR - Radial right

Oval = 30 cm depth RL - Radial left

Contd.

Table 25 continued.

0.6 PE irrigation



P_0 = Perpendicular plane; P_{15} = Perpendicular 15 cm; P_{30} = Perpendicular 30 cm

= 15 cm depth RR - Radial right

= 30 cm depth RL - Radial left

Contd.

Table 25 continued.

0.9 PE irrigation

Plane	Depth	RL30 cm	RL15 cm	RR15 cm	RR30 cm
P_0	15 cm	8.10	16.30	16.66	14.05
P_0	30 cm	7.80	13.20	12.25	10.05
P_{15}	15 cm	14.42	13.97	15.00	14.88
P_{15}	30 cm	9.80	10.08	9.85	10.28
P_{30}	15 cm	15.20	14.69	13.50	12.80
P_{30}	30 cm	10.22	11.20	9.25	9.35

P_0 = Perpendicular plane; P_{15} = Perpendicular 15 cm; P_{30} = Perpendicular 30 cm

(octagon) = 15 cm depth — RR - Radial right

(oval) = 30 cm depth — RL - Radial left

Table 26. Mean soil moisture content (%) at 15 and 30 cm depths at the radial distance of 15 and 30 cm away from the plant and 15 and 30 cm perpendicular grid points along the radial distance of 15 and 30 cm.

	0.3 PE				0.6 PE				0.9 PE			
	R-15 cm		R-30 cm		R-15 cm		R-30 cm		R-15 cm		R-30 cm	
	15 cm depth	30 cm depth	15 cm depth	30 cm depth	15 cm depth	30 cm depth	15 cm depth	30 cm depth	15 cm depth	30 cm depth	15 cm depth	30 cm depth
P-0 (cm)	19.40	14.76	13.96	10.15	12.96	10.28	12.74	8.55	16.48	12.72	11.07	8.92
P-15 (cm)	13.50	9.17	16.64	9.19	13.91	10.20	11.37	8.87	14.48	9.96	14.65	10.04
P-30 (cm)	15.23	10.62	10.82	8.20	12.15	8.85	12.16	9.50	14.09	10.22	14.00	9.78

PE = Pan evaporation; P = Perpendicular; R = Radial distance

Table 27. Mean soil moisture content (%) at radial distance of 15 cm and 30 cm away from the plant at 15 cm and 30 cm depths.

	0.3 PE		0.6 PE		0.9 PE	
	R-30	R-15	R-30	R-15	R-30	R-15
15 cm depth	13.80	16.04	12.05	13.01	13.24	15.02
30 cm depth	9.18	11.52	8.97	9.77	9.58	10.97

PE = Pan evaporation; R = Radial distance

4.9 Economics of production

The production economics has been worked out based on the standard procedure. The working cost and fixed cost, depreciation of the drip system, interests on both working and fixed capital etc. have been included while preparing the economics of production. The details of cost of production worked out are given in Appendices IV to VII. As highest comparative yields are produced by the treatments T_6 (150% recommended fertilizer dose with 0.6 PE irrigation) and T_7 (recommended fertilizer dose with 0.9 PE irrigation), the production costs of these two treatments along with that of control are worked out and compared at the yield produced by these treatments (Table 7).

As seen from Table 28, the control crop worked out a BC ratio of 1.56 with seasonal cost of production of Rs.61807 and gross income of Rs.96,500. The crop produced through treatments T_6 and T_7 worked out a BC ratio of 1.91 and 1.92 respectively. The corresponding net seasonal income were Rs.89,102 and Rs.87,121.

When these treatments were compared with the control based on water applied in the control plot (700 mm), the result indicated that through the fertigation system adopted in T_6 and subsequent water saving, an area of 0.95 hectare can be additionally brought under irrigated tomato with the same quantity of water used in control crop. The similar figure worked out for crop for the treatment T_7 is 0.38 hectare.

Table 28. Economics of production of tomato - A comparative analysis

Sl. No.	Particulars	Furrow irrigation (Rs.)	T6 (Rs.)	T7 (Rs.)
1.	Cost of seeds	800.00	800.00	800.00
2.	Cost of manures & fertilizers	9403.00	16653.00	13769.00
3.	Cost of plant protection chemicals	1400.00	1400.00	1400.00
4.	Cost of labour	45980.00	36140.00	35980.00
5.	Operating cost of machinery	2000.00	3466.00	3466.00
6.	Irrigation charges (electricity)	961.00	150.00	225.00
7.	Land revenue	250.00	250.00	250.00
8.	Depreciation of farm machinery & equipments	-	21338.00	21338.00
9.	Working capital	60794.00	80197.00	77228.00
10.	Interest on working capital @5% per annum for the duration of the crop	1013.00	1337.00	1287.00
11.	Cost A1 (9+10)	61807.00	81533.00	78515.00
12.	Interest on owned fixed capital @10% (10% of purchase price - annual depreciation)	-	15864.00	15864.00
13.	Cost B1 (11+12) = Cost C3	61807.00	97398.80	94379.00
14.	Gross income	96500.00	186500.00	181500.00
15.	Net seasonal income	34693.00	89102.00	87121.00
16	BC ratio	1.56	1.91	1.92
17.	Water saved over furrow irrigation	-	342 mm	194 mm
18.	Additional net area that can be irrigated due to saving of water (ha)	-	0.95	0.38
19.	Additional cost B1	-	92528.00	35864.00
20.	Additional gross income due to saving of water by fertigation	-	177175.00	68970.00
21.	Additional net income due to saving of water by fertigation	-	84647.00	33106.00
22.	Total cost B1 on water equivalent (700 mm water basis)	61807.00	189928.00	130243.00
23.	Total gross income on water equivalent basis	96500.00	363675.00	250470.00
24.	Net income	34693.00	173749.00	120227.00
25.	Net profit per mm water	49.56	248.21	171.75

Discussion

DISCUSSION

The present investigation "Response of tomato (*Lycopersicon esculentum* Mill.) to varying levels of fertigation" was made with an objective to study growth, development and yield of tomato as affected by irrigation and nutrient levels by way of continuous nutrition through fertigation. Tomato being a vegetable crop showing high sensitivity to moisture as well as nutrient stress, requires regular supply of moisture to a level which does not interfere with the basic physiological function of the plant. Similarly for the continuous generation of sink, adequate and regular supply of nutrients are also needed.

According to Raina *et al.* (1999) a crop of tomato yielding 23.25 tonnes of fruits requires 422 mm of water under drip irrigation. A crop producing 76.19 t ha^{-1} of tomato fruits through fertigation requires 312.5:312.5:312.5 NPK ha^{-1} (Kolte *et al.*, 1999). Continuous supply of moisture through a system like drip can very well offset the effect of moisture stress. Similarly continuous supply of nutrients based on demand dictated by growth stages of crop can be ensured only if nutrients can be supplied through irrigation. Hence fertigation becomes a practical method to provide moisture and nutrients to the plants based on need.

The growth of the crop like tomato, wherein the reproductive and vegetative growth go with simultaneously needs careful attention in nutritional management. As the growth advances and more and more fruits develop, the nutritional requirements increase with time (Stark *et al.*, 1983). If the entire nutritional requirement of the crop can be applied daily based on the need of the crop to the root zone in solution form, the crop is provided with adequate moisture and sufficient nutrients. Continuous supply of nutrients by splitting the entire requirement over the days of growth after proper establishment till the final sink formation by incremental dosage can be practically achieved through fertigation. This principle is being investigated in the current study.

5.1 Growth, yield and yield attributes of tomato crop as influenced by varying levels of fertigation

Growth is an overall expression of biomass accumulation in plants measured over a unit time, through biometrics. Under the present investigation, the growth of the plant in terms of increasing height (Table 4), (Fig.4), LAI (Table 5), LAD (Table 6) and number of fruiting branches plant^{-1} (Table 7) as a result of varying levels of fertigation have been observed. Irrigation levels significantly influenced the elongation of the plants measured as plant height as the moisture level increased. However, the increase in the quantity of irrigation could not contribute to more LAI as well as LAD. This indicated that the available water has been utilized for the linear growth of the plants than to increase the photosynthetic area of the plants. According to Kirkham *et al.* (1971) if the water is available in plenty over the stress limit then it will be used for elongation of the cell than to improve the photosynthetic apparatus of the plants. Cell elongation is more sensitive to changes of water potential than the cell division.

Generally, with increase in the fertilizer level, plant height and leaf area production increase proportionately (Kolte *et al.*, 1999; Tumbare *et al.*, 1999; Chawla and Narda, 2000). Application of NPK nutrients through irrigation water at

150 per cent level significantly improved height of the plants in the present study (Fig. 4) fertilizer level at 100 or 150 per cent significantly increased LAI and LAD more than the 50 per cent level. This indicated that when the moisture supply is continuous at 0.3, 0.6 or 0.9 PE irrigation level, Plants need 150 per cent recommended dose of N, P, K nutrients to have more height and 100 or 150 per cent NPK to produce more photosynthetic area.

It is interesting to note that the varying fertilizer levels could not influence the fruiting branches production in plants. The interactive effects indicated that when the nutrients applied through irrigation water upto 45 DAP, the growth of the plants in terms of height is not affected by the combined effect of 0.3, 0.6 or 0.9 PE irrigation and 50, 100 or 150 per cent recommended dose of fertilizer. But when plants reached the peak vegetative stage, a combination of 150 per cent recommended dose fertilizer applied through 0.6 PE irrigation level through drip system produced significantly taller plants than the rest of the treatments.

The interactive effect of irrigation and fertilizer levels was not visible in case of LAI and LAD and between the fertigation treatments. Number of fruiting branches $plant^{-1}$ was not altered by fertigation. The overall result indicated that when a moisture supply is resorted through drip system and nutrient supply resorted through irrigation water, the metabolic activity of the plant is not constrained due to the moisture or nutrient stress to affect plant growth.

Even if nutrient supply is at higher level (150%) a moisture supply of 0.6 or 0.3 PE level was sufficient to produce taller plants. When moisture and

Fig. 4. Height of the plants as influenced by varying levels of irrigation and fertilizer at 60 DAP

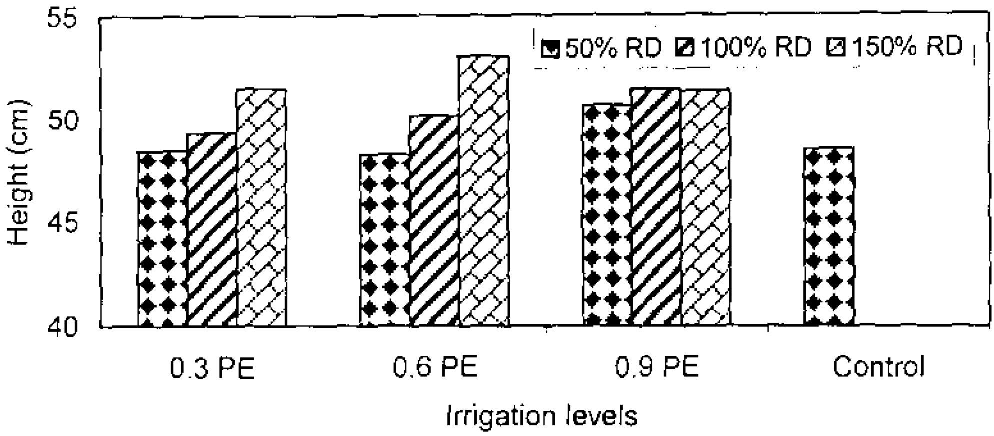
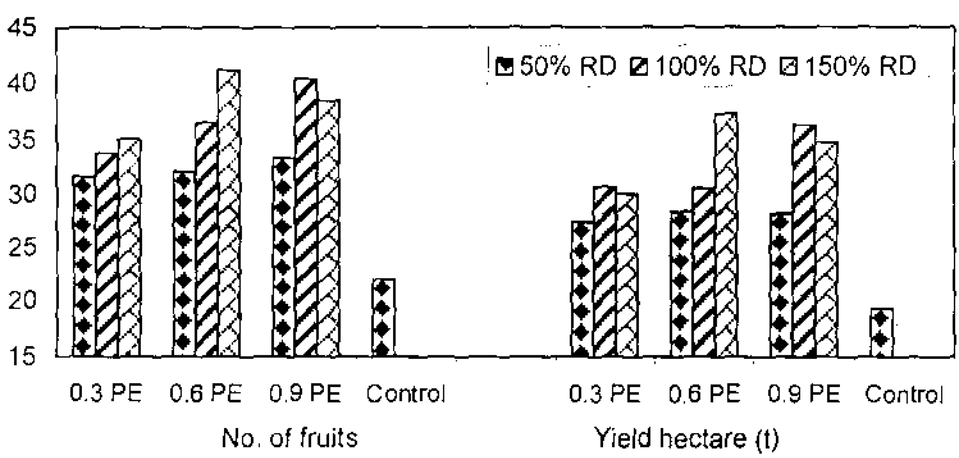


Fig. 5. Fruit numbers and yield as influenced by varying levels of irrigation and fertilizer



nutrient supply is continuous and when nutrient supply is at an incremental rate as the growth proceeds, the photosynthetic area as well as its retention in plants was not affected by irrigation or nutrient levels applied under the present investigation. As the nutrient is received to the plant daily in an incremental order and moisture is received by the plant in accordance with the climatic evaporative demand, the lowest level of moisture supply i.e. 0.3 PE along with lowest level of fertilizer i.e. 50 per cent recommended dose was sufficient to produce LAI, LAD and number of fruiting branches plant^{-1} as that produced by highest level of irrigation (0.9 PE) and fertilizer (150% R.D.). When there is restricted supply of irrigation water as well as nutrients without causing any natural losses, the plant is able to utilize this moisture and nutrients most effectively. So in the present investigation when there was a moisture supply through drip, sealing all the losses and daily supply of nutrients through irrigation water, the plant was able to utilize them very efficiently based on its biological need at its different phenological growth stages. It is to be remembered that the treatments receiving different fertigation levels are mulched and hence the evaporation losses of moisture is checked in these treatments. The control plot which received surface irrigation at three days interval using 20 mm water and fertilizer through three splits applied through soil incorporation did not produce taller plants than the fertigated crops.

The data on percentage of fruit set are given in Table 7. The observation on the physical growth of the plant has indicated that due to continuous supply of moisture and nutrients (NPK) through the fertigation system, the plant was not affected by any abiotic stresses. The percentage of fruit set indicated that the moisture supply through drip system at three levels (0.3, 0.6 or 0.9 PE) did not cause any variation in the fruit set between them, but was significantly better than the conventional irrigation system. When the nutrition alone was considered, the incremental addition of fertilizer with the advancement of growth over and above the recommended dose created a negative impact on the plant resulting in lower fruit setting. The plant was able to produce more flowers at higher nutritional level but might have adopted a self thinning mechanism as per Eatons theory to reduce its sink load for the further development of the fruits. This is evident from the data on number of fruits plant^{-1} (Table 7), where at different fertilizer levels the plant has produced same number of fruits. This is in consonance with the results obtained by Deolankar and Berad (1999) in case of chickpea.

The fruit set data further indicated that for the optimization of fruit set, at 100 per cent fertilizer level more moisture was needed by the plant for the effective assimilation of nutrient supplied. Hence, irrigation scheduled at 0.9 PE was found better to produce maximum fruit set. When the fertilizer dosage was reduced to 50 per cent a similar level of fruit set was achieved but at a lower level of moisture supply i.e., 0.3 or 0.6 PE. When 150 per cent fertilizer dose is applied through incremental addition, even moisture supply at 0.9 PE was not sufficient to enable more flowers to be converted into fruits.

Fruit setting is a very sensitive physiological process in tomato plants. For retention of more flowers and to develop into fruits, adequate moisture supply is needed and if the flower production is increased due to more nutrient supply, its retention may be balanced by ensuring adequate moisture supply.

The data on number of fruits plant^{-1} established that fertigation was significantly better than conventional method of irrigation and fertilizer application. The number of fruits produced by the control crop was as low as 22 per plant. Plate 2 depicts promising fertigation treatments and control crop in terms of growth and fruit production. In the fertigation treatments, only the lowest level of fertilizer i.e., 50 per cent dose, applied through irrigation water at 0.3 or 0.6 PE irrigation bear fruits statistically on par with control. All other fertigation levels i.e., 100 or 150 per cent recommended dose applied through irrigation water irrespective of irrigation levels significantly increased the number of fruits per plant. However there was no significant variation in fruit production between irrigation levels or fertilizer levels, when mean data were considered.

The total quantity of sink sustainable in a plant is dependent on the nutritional status of the plant and the micro-environment provided to it. A higher level of fruit set has been recorded in the treatment receiving 50 per cent recommended dose of fertilizer combined with 0.3 and 0.6 PE irrigation. However the relatively lower number of fruits recorded in these treatments indicated that with in the available nutrient supply the plant has to restrict the number of its sink considering the source capacity of the plant. Ultimately whatever sink a plant system generated is fully considering its source capacity. This contention is further established on pursuing the data that maximum fruit set has been recorded when 100 per cent recommended dose of fertilizer was applied through irrigation scheduled at 0.9 PE. The same treatment has recorded higher number of fruits per plant (40.33) indicating that the sink capacity is fully generated and there was no stress on plant system.

T_6 - 0.6 PE irrigation with 150 per cent recommended dose of fertilizer

T_7 - 0.9 PE irrigation with 100 per cent recommended dose of fertilizer

Plate 2. The view of crop under promising fertigation levels and control crop

Plate 2. Contd.

T_9 - 0.9 PE irrigation with 150 per cent recommended dose of fertilizer

T_{10} - Control - Furrow irrigation with 100 per cent recommended dose of fertilizer

Within the fertigation treatments, between irrigation levels studied or between fertilizer levels studied, no significant statistical difference was observed. As the crop was mulched and drip system of irrigation was used there was constant moisture supply to the plants restricting the evaporation, surface runoff and seepage losses. As the major nutrients were supplied through irrigation water throughout the growth period, the crop was not experiencing any nutritional deficiency with regard to the major nutrients NPK. Consequently the mean effect of fertilizer or mean effect of irrigation was not distinguishable between the levels provided. Reports indicated that when the crop was provided with adequate moisture and nutrition, the sink capacity of the plant was not altered (Deolankar and Berad, 1999; Paskar and Bhoi, 2001; Prabhakar *et al.*, 2001 and Idate *et al.*, 2001).

In tomato the yield per plant in terms of weight, is governed by per cent fruit set, number of fruits per plant and fruit weight (Fig.5). It is already seen that fruit set was more with 0.3 or 0.6 PE irrigation at 50 per cent recommended dose or at 0.9 PE irrigation if the fertilizer level was 150 per cent. The plant has applied its self thinning mechanism to maintain an equal number of fruits per plant irrespective of irrigation levels. However this level of production was remarkably higher than that was seen in the control crop. But when the yield of plant in terms of fruit weight per plant was considered (Table 7), the highest yield of 1343 g per plant was recorded when irrigation was scheduled at 0.6 PE at a fertilizer level of 150 per cent. The other combinations of irrigation and nutrient level in the fertigation treatments were inferior to this treatment except the fertigation level wherein irrigation was scheduled at 0.9 PE and fertilizer level applied either at 100 per cent (1307 g) or 150 per cent (1250 g) of recommended dose. This data clearly indicated that in a crop like tomato, whenever there was adequacy of nutrition and moisture for sustaining fruit set and number of fruits per plant the additional continuous supply of nutrients along with sufficient moisture, has been utilized by the plant for the enlargement and development of fruits. Hence at the higher moisture and nutritional level more photosynthates were metabolised and transferred to the fruits enabling more fruit weight per plant in these treatments. It is already seen that height of the plant increased with increasing levels of fertigation without affecting leaf area. This meant that more photosynthates were created inside the plants helping its elongation and later enabling the plant to transfer it for the enlargement and development of fruits.

When it is examined the individual effect of irrigation or fertilizer the above statements become very clear. The increasing levels of irrigation has contributed towards increasing stature of the plant significantly corresponding to the quantity of water applied. But this effect was not perceptible in case of LAI, LAD, fruit setting per cent and number of fruits per plant. This indicated that all the growth and yield attributes are not constrained by the irrigation levels employed in the fertigation treatments. But when fruit weight was considered (Table 7) irrigation at 0.9 and 0.6 PE have significantly contributed more fruit weight per plant than 0.3 PE irrigation. There were 12.51 and 9.16 per cent increase in fruit weight per plant at 0.9 and 0.6 PE irrigation over the 0.3 PE irrigation. This meant that the moisture given over and above 0.3 PE irrigation has been judiciously used by the crop for the development of fruits.

In case of fertilizer application, the trend was some what different. The higher level of nutrition has contributed favourably towards increasing growth of the plants measured in terms of height, LAI or LAD. At higher level of nutrition, fruit set per cent has been restricted towards maintaining a good number of fruits per plant and ultimately more fruit weight per plant at the highest nutritional level of 150 per cent. This has differentiated the plant under different nutritional levels even though number of fruits per plant was more or less equal at various nutritional levels. Thus overall results indicate that in tomato, higher the nutritional and moisture level there were fruits with more weight, even though number of fruits may not be altered, provided the nutritional level was within the reasonable level of nutritional requirement of the crop.

Yield per hectare is simple extrapolation of yield per plant in terms of weight and plant population. Consequently the yield per hectare is a reflection of yield per plant. The control crop which received surface irrigation at 3 days interval @ 20 mm per irrigation without mulching has produced only 19.31 tonnes of fruits per hectare. But the overall mean yield of fertigation treatment was 31.51 tonnes which indicated the supremacy of the fertigation treatment. When the irrigation was scheduled at 0.3 to 0.6 or 0.9 PE level, under mulch condition and fertilizer applied through irrigation water in incremental addition 10.00, 12.77 and

13.76 tonnes fruits per hectare were additionally produced by the respective crop than the control. Similarly 76.22, 68.51 and 44.89 per cent additional yield was produced when the crop was fertigated with 150, 100 and 50 per cent recommended dose. These findings strongly established that fruit production in could be significantly increased through fertigation in tomato crop. Earlier workers have recommended application of required nutrients through irrigation water in case of tomato (Kolte *et al.*, 1999; Prabhakar *et al.*, 2001).

Apart from its genetic architecture, root growth of any crop is influenced by external factors. In the present investigation (Table 8) the vertical and lateral elongation of the root was significantly lower in fertigated crop than the control crop. The moisture and nutrients were provided as point source in fertigated treatments. The crop was also mulched. Hence roots were provided with adequate nutrients and moisture within the reasonable reach of the root zone. Hence, in fertigation treatments root has not grown on an average beyond 18.65 cm vertically or 11.01 cm laterally. In case of control crop, the respective values were 26.80 and 15 cm. The control crop was not mulched. Nutrients were applied into the soil as 3 splits. This crop did not receive enough moisture and nutrients within the reasonable reach of the root. Hence the root of control crop had to grow more deeper and wider in search of moisture and nutrients.

The data on root dry weight further supported this view indicating that the average root dry weight of crop receiving fertigation was 3.94 g while that of control crop was 8.19 g. The control condition necessitated more root proliferation to support the plant with adequate moisture and nutrition. According to Thorup (1969) plants search for moisture and nutrients when they are subjected to nutrients and moisture stresses. If plant was provided with adequate nutrients and moisture within the immediate vicinity, then root spread would be restricted and more energy would be utilized for the growth and expansion of the shoot portion. The data indicated that the crop was not subjected to any sort of stress under fertigation treatments.

5.2 Quality of tomato fruits as influenced by different levels of fertigation

5.2.1 Acidity

In tomato higher acidity is preferred because of its better canning and keeping qualities. Acidity was enhanced due to application of potash as per the earlier reports by Breadley (1962) and Davies (1964). In the present investigation relatively high acidic fruits were produced in the control crop than fertigated treatments (Table 9). The potassium content in the plants of all treatments was almost identical without any significant difference between the fertigated and control crop (Table 12). According to Winsor *et al.* (1958) more than half (60-66%) of absorbed K was found in the tomato fruits. The control plot produced only 695 g fruits per plant (Table 7), but contained same level K as that of fertigated crop which produced significantly more number of fruits. Hence the control plants has more effectively translocated the available potassium to the fruits. This may be the reason for increased acid content in the fruits produced by the control plants.

The total soluble solids was least affected by fertigation. The soluble solids accumulation and synthesis in the fruits was similar in all the treatments. This is in conformity with the results obtained by Raina *et al.* (1999). It is to be remembered that, the plants have restricted the fruit production, depending upon the nutrient and water availability, and latter factors have been better utilized for the development of fruits. Hence the TSS remained unaltered.

5.2.2 Fruit cracking

According to Tiwari and Choudhury (1986) cracking can be either due to calcium deficiency, boron deficiency and also due to irrigation after a prolonged dry period. In the present investigation, significant fruit cracking was seen only in case of control crop. In case of fertigation treatments, at three irrigation levels the moisture was supplied continuously through drip system and there was no dry spell for the plant. In the control plot irrigation was given once in three days depending upon the evaporative demand and there could be variations in the soil moisture content inducing a stress to the crop. The control crop is not mulched also. The variation in moisture supply to the root zone has affected fruit development causing cracking of fruits in control plot. Similar observations have been reported by other workers also (Considine and Brown (1981), Kalloo (1985).

5.3 Nutrient content of tomato plants as influenced by varying levels of fertigation

5.3.1 Nitrogen

The application of major nutrients viz., N, P and K has been quantitatively different for the different treatments under study. Under same dose of nutrients application, the moisture content was different. Results of the nitrogen content of the plant (leaf and stem together) observed at 30, 60 and 90 DAP (Tables 10, 11 and 12) indicated that the control crop contained a lower level of nitrogen than fertigated crops. The effect of irrigation was not visible in making alterations in nitrogen content of the plant. But at final stage, the highest level of irrigation led to dilution of the nitrogen content in plants and lowest level of irrigation caused concentration of it.

The different levels of fertilizer application have increased the nitrogen content in plants in proportion to quantity of nitrogen applied in the fertigation treatments at early stages. But this effect was not statistically significant, eventhough the trend was same at later stages. A regular supply of nutrient nitrogen in liquid form throughout the growth period has ensured adequate growth of the plants and resulted in the biomass production depending upon the nutrient availability. This ensured a uniform content of nitrogen in plant without causing much variation between the fertilizer levels in fertigation treatments. Whereas, in control plot nitrogen was applied in three splits to the soil and irrigation was scheduled once in three days. Here the availability of nitrogen to the plant for absorption through mass flow was not regular. Hence a lower content of nitrogen was seen in control crop. Several workers found that when there was adequate nutrient supply in liquid form, based on the demand of the crop naturally the content of the nitrogen distributed in plant parts would not vary much eventhough fertilizer levels were quantitatively different (Locascio *et al.*, 1977 and Stark *et al.*, 1983).

5.3.2 Phosphorus

The phosphorus content of the plant (Table 11) was in general not affected by the irrigation or fertilizer levels. At any crop growth stage phosphorus is absorbed through diffusion process. Diffusion is essentially controlled by soil temperature and moisture content of the soil apart from its concentration. In the present investigation, mulching of the soil along with daily supply of nutrients and moisture have facilitated diffusion of phosphorus into tomato plants in fertigated treatments. Similarly moisture supply in control crop (once in three days) did not affect diffusive process of phosphorus absorption to a detrimental level. Hence the phosphorus content in the plant has been almost uniform in all fertigated crops as well as control crop.

The temperature regime in the soil was not lower enough to affect the diffusion process as indicated from soil temperature data (Table 22). Earlier workers have found that phosphorus absorption can be changed, only if any change in diffusion process like high variation in soil moisture and soil temperature (Maher, 1978 and Tindall *et al.*, 1990).

5.3.3 Potassium

The data on potassium content of the plants observed at three growth stages are given in Table 12. Throughout the growth period the control crop produced plants with lower potassium. Though the mean effect of fertilizer was invisible at 30 DAP, this was not sustained at later growth stages and crop receiving different fertilizer levels in the fertigation treatments did not differ between them. At early stages, the levels of irrigation in fertigation treatments did not change the potassium content in plants. But at final stage the different irrigation levels in the fertigation treatment had a remarkable effect on potassium content and the crop receiving irrigation at 0.3 PE remained with significantly lower potassium content. A higher content of potassium was seen throughout the crop growth, when the crop was irrigated at 0.6 PE irrespective of fertilizer levels or at 0.3 or 0.9 PE at 150 per cent fertilizer level. Potassium is generally absorbed by the plants through mass flow and the addition to external application of potassium, huge quantity of natural potassium available in soil is absorbed by the plant. Throughout the growth stages, a continuous supply of moisture as well as nutrients has enabled the plant to absorb sufficient amount of potassium both applied and native source in the fertigation treatments when compared to split application of potassium and furrow irrigation at three days interval in control crop. This has created a visible difference between control crop and fertigation treatment crop in potassium content and latter having higher content of potassium. It is seen that at different stages of observation 50 per cent recommended dose accompanied by 0.6 PE irrigation produced plants with high potassium content than others in fertigation treatments except one receiving 150 per cent recommended dose with 0.9 PE irrigation at final stage of observation. In the former case we have seen that the yield level was comparably lower which allowed concentration of nutrients in the biomass. In the latter case, abundant supply of moisture and nutrients have ensured enormous absorption of potassium thereby increasing content of K. It has been already established that abundant supply of moisture and abundant supply of nutrients ensure luxurious consumption of K by crop plants. Supply of moisture to a level not interfering with the mass flow provided an atmosphere for luxurious consumption of K in crop plants (Brady, 1996).

5.3.4 Calcium, magnesium and sulphur

The results on calcium content in the plant (Table 13) has indicated that at lower levels of fertilizer application, lower levels of moisture was sufficient to have a higher content of calcium in plants. But when higher levels of NPK fertilizer are applied, more moisture was required through higher levels of irrigation to have a higher content of Ca in plants. At the final stage of observation i.e., 90 DAP, irrespective of fertilizer levels and moisture levels in fertigation treatments, the crop had a higher level of Ca compared to control crop receiving irrigation once in three days and 100 per cent fertilizer in three splits. The different levels of irrigation or fertilizer within the fertigation treatments had no effect on Ca content of the crop.

The mean Mg content of the crop was not altered in general by different fertigation treatments or control crop (Table 14). Sulphur also followed the same pattern of Mg (Table 15). If height of the plants was considered as an indicator of total biomass accumulation in the plant due to various fertigation treatments (since LAI was not altered by the treatments), the biomass production was increased in plants in proportion to levels of irrigation as well as fertilizer. It was also established that moisture level in the soil has not gone down to any critical level to induce stress in the plant through a soil moisture stress especially in fertigation treatments. It was believed that the mobility and availability of those nutrients (Ca, Mg and S) was not affected by the soil moisture levels and crop has absorbed those nutrients in tune with its biomass production. Hence, content of Ca, Mg and S was not seriously affected by different fertigation treatments. In order to check the incidence of bacterial wilt, lime application has been resorted to the plants at 20 DAP. This external application of $CaCO_3$ has enabled the plant to absorb more of it when the crop was provided with daily irrigation through drip. Whereas in case of control crop, irrigation once in three days might have diluted the availability of Ca and its utilization. Hence a better Ca content was not observed in control plots. Winsor and Adams (1987), reported that availability of Ca to tomato plants and its accumulation in plant parts depends on availability of this nutrient as well as moisture content, since Ca moves almost exclusively through the xylem.

5.3.5 Iron, Manganese, Zinc and Silica

Accumulation of Fe in the crop plant has progressively increased as the growth stage advanced, irrespective of the treatments (Table 16). Though the effect of irrigation was not perceptible during early stages, the higher levels of irrigation increased content of Fe in the plants at 60 and 90 DAP and 0.9 and 0.6 PE irrigation levels were on par at 90 DAP. The accumulation of Fe in the plant was not altered at mid and later stages of growth of the plant due to different fertilizer levels. Availability and utilisation of Fe mostly depends upon moisture content and

Fe is more absorbed by the plant when it is available in the soil. The absorption is mainly through diffusion. Here, in the present investigation more absorption was seen when the moisture availability was increased with higher levels of irrigation.

Similar to Fe content the accumulation of Mn in the plant (Table 17) progressed as the growth advanced. In general, the control crop as well as fertigated crop had a similar Mn content irrespective of growth stages. Different fertigation levels could not create any consistent variation in the Mn content of the plant excert at 90 DAP, 0.3 PE irrigation combined with 50 per cent recommended fertilizer dose produced higher Mn content crop compared to 0.9 PE with 150 per cent fertilized crop. Overall results indicated that the crop has no interference either due to moisture content or fertilizer levels to interfere with absorption of Mn in the soil.

The content of Zn (Table 18) was almost doubled when the crop stage advanced from 30 to 60 DAP and thereafter it remained same. This showed that the crop absorbed a substantial quantity of Zn when it completed two third of its growth period. More Zn was utilised by the crop at higher levels of irrigation as well as higher levels of fertilizer application. At lower levels of irrigation Zn content was higher probably because of lower biomass accumulation in plants as observed from height of the plants. Similarly a higher content of Zn was absorbed at 50 per cent fertilizer dose because of lower biomass production by the plant. The data indicated that the overall Zn availability of the plant was not hindered due to soil moisture stress. According to Das (1996) availability of Zn to a plant depends mainly on moisture content. In the present investigation also control crop has concentrated a lowest Zn content in its biomass.

The tomato crop contained sufficient amount of silica similar to N, K and Ca (Table 19). The crop contained on an average 1.36 per cent Si at 60 DAP and 1.86 per cent at 90 DAP in control crop. A similar quantity was seen in fertigated crop at the respective stages. The various fertigation treatments has remarkably affected the Si content when finally observed at 90 DAP. Irrigation levels has affected the Si content at final stage of observation, contemplating that higher level of irrigation more Si was absorbed. A lower level of Si was absorbed when application of NPK fertilizers exceeded 100 per cent recommended dose at early stage. It may be due to a higher biomass production. The overall data indicated that tomato crop absorb substantial quantity of Si and its content increased with moisture levels.

Hassan (1978) observed that uptake of Si was mainly depend upon moisture availability and content in the plant vary with biomass production.

5.4 NPK content of the soil after cropping

The basic status of available nitrogen, phosphorus and potassium content of the soil is provided with the Table 1. After the experimentation, soil was again analysed for this contents (Table 20) and data indicated that there was build up of available N content in the soil both in the control crop as well as in the fertigated crop. The different levels of moisture or fertilizer did not cause significant variation between those levels. This indicated that the crop has been able to use the nutrients efficiently. Due to controlled irrigation level, the loss of nutrients through leaching has been minimised. Hence apparently all the fertigation levels showed similar available N values after cropping except in case of the treatment where 50 per cent fertilizer dose with 0.3 PE irrigation showing lowest level of available N, and 150 per cent fertilizer plot under 0.3 PE irrigation the highest. This might be due to the fact that a higher dose of fertilizer at lower moisture level could not be absorbed by the crop. The equal left over N in the soil in all the plots in general indicated that the nutrient supply to the crop was adequate in tune with the crop growth as well as moisture supply. A differential left over of nutrients in the soil after cropping is an indication of differential response to the nutrients by the crop (Veeraputhiran, 1996).

The same observation like available N has been made in case of available P, after cropping is seen (Table 20). The availability status of soil after cropping, in general was similar in all treatments except that a higher content of P was seen in case of 0.6 PE under 50 per cent recommended dose and the lowest in 0.3 PE and 0.6 PE irrigation with 100 per cent recommended dose. These treatments differed each other. However, levels of irrigation or fertilizer did not cause any variation in the P available in the soil after cropping. There was a build up of available P in soil during the course of investigation, which meant that some of the applied P was not either required by the crop or was not utilized by the crop. P is a nutrient subjected to chemical fixation (Brady, 1996).

The status of available K in soil was not altered after the cropping in all the treatments. This indicated that application of K to the soil was in tune with the requirement of the crop decided by the soil moisture status as well as fertigation level. Such a positive nutrient balance in the soil may be useful for sustainable agriculture. The different fertilizer or moisture levels did not alter the residual available K in the soil. In general, if the applied K was deficient, crops absorbed more of soil K to satisfy its requirements (Biswas and Mukherjee, 1994).

5.5 Incidence of leaf curl and bacterial wilt incidence

During the course of investigation the incidence of diseases viz., leaf curl and bacterial wilt were observed to find out whether the treatments would cause substantial variation to it (Table 21). Accidentally it was observed that the control crop receiving irrigation at three days interval without mulch was seriously affected by leaf curl disease and 72 per cent of the plants were infested with the virus disease. But the disease incidence was observed only to the tune of 40 per cent plants in fertigation treatment.

The result indicated that either the mulching which caused an increasing soil temperature or the continuous supply of nutrients through irrigation water in incremental dosage have enabled the plant to be healthier and tolerate the disease.

In case of bacterial wilt, the control crop has only 14 per cent infestation. Whereas the fertigated crops have subjected to the extent of 16 per cent. This variation does not seem to be substantial. An increase in temperature necessarily enhanced bacterial wilt, according to observations made by Gallegely and Walker (1949). A higher air temperature during the crop growing season (summer) of the present investigation have contributed to moderate wilt infestation in the field.

5.6 Soil temperature

During the course of investigation, observation of soil temperature has been made at four different depths (5, 10, 15 and 20 cm) at morning 7-30 IST and evening 2-30 IST. The observation was made for a period of 14 days continuously and the mean temperature variation was worked out (Table 22 and 23). When the crop was mulched, the soil temperature increased on an average by 3.3°C in morning hours and 2.6°C in the evening hours compared to non mulched field. As the irrigation frequency increased from 0.3 to 0.6 and then 0.9 PE, the relative increase in temperature due to mulching was reduced both in morning and evening. This effect is graphically represented in Fig. 6. The enhancement of soil temperature over control was observed up to 20 cm depth i.e., the maximum depth of observation and a high temperature regime was visible up to this depth. As the depth increased, there was slight decline in the increment of temperature. Mulching generally increased soil temperature (Wein *et al.*, 1993; Cebula, 1995 and Ravinder *et al.*, 1997) mainly through prevention of extra terrestrial radiation return to the atmosphere from soil surface. This solarization effect has been recorded in the present investigation also. Increasing soil temperature enables the crop to have better root temperature, better air passage and diffusability of nutrients.

5.7 Water use efficiency

The fruit yield per unit of water applied, expressed as FWUE is given in Table 24. The details of irrigation given in the Table 3 has indicated that the crop

Fig. 6. Relative change in soil temperature (°C) at four different depths due to different irrigation levels and mulching over the control

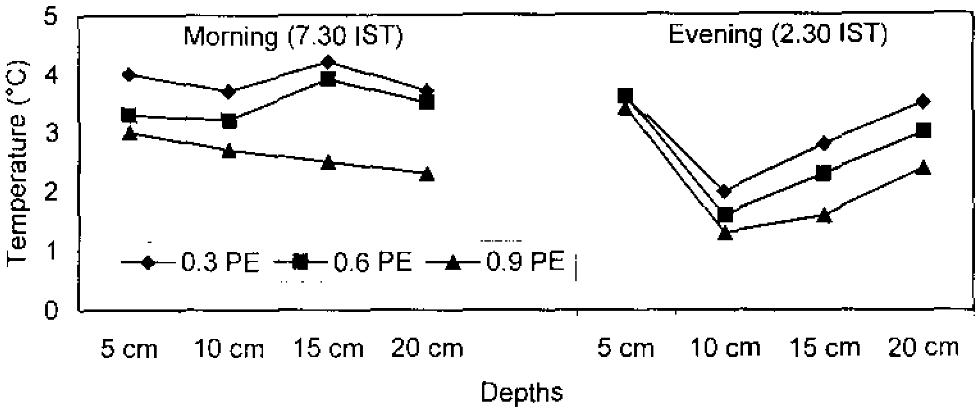
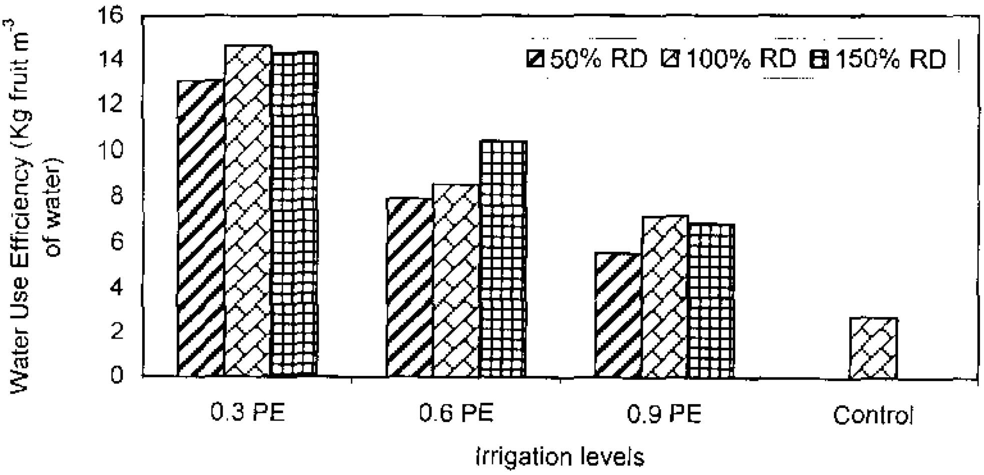


Fig. 7. Water use efficiency of various treatments



receiving irrigation at 0.3, 0.6 and 0.9 PE levels were provided with 210, 358 and 506 mm of water but control crop was given 700 mm water. There was a progressive increase in FWUE with decline in irrigation levels and increasing fertilizer level. The overall picture of FWUE with respect to irrigation and fertilizer levels are graphically represented in Fig. 7.

Since the crop was provided with drip irrigation in the fertigation treatments, a field balance method of computation of consumptive use was not possible. Hence the quantity of field water applied in total was considered in the denominator for the computation of FWUE. The general trend of increasing FWUE with decreasing irrigation levels was perceptible in the present trial. Similarly with increase in fertilizer use, there has been increasing FWUE, as seen in several crops (Deolankar and Firake, 1999; Tumbare *et al.*, 1999; Veeranna *et al.*, 2001).

When we consider the yield output per unit area as well as quantity of water used to produce such output there should be a balance in the economic output commensurating with quantity of water applied. The data on control crop yield (Table 7) has indicated that yield level is remarkably poor but water applied to the crop is enormous i.e. 700 mm against 506 mm in 0.9 PE irrigation or 358 in 0.6 PE or 210 mm in 0.3 PE. Yield data per plant has showed that fertigation level of 150 per cent dose combined with 0.6 PE irrigation has produced maximum yield and a comparably higher yield was provided only by the crop receiving irrigation at 0.9 PE and fertilized at 100 or 150 per cent recommended dose. The FWUE data indicated that the FWUE of former crop was 10.41 kg fruits m^{-3} of water but the respective values for the latter treatments were 7.17 and 6.86. The former treatment i.e., 0.6 PE irrigation and 150 per cent recommended dose consumed only 358 mm of water against 506 mm by the later crop i.e., 0.9 PE irrigation with 100 or 150 per cent fertilizer doses. Hence there is a saving of 41.34 per cent water due to 0.6 PE irrigation compared to 0.9 PE irrigation. So when a water deficit situation arises 0.6 PE irrigation with 150 per cent dose of fertilizer may be more economic for saving water.

The crop receiving 100 per cent recommended dose of fertilizer but with 0.9 PE irrigation produced a similar yield as that of 0.6 PE with 150 per cent fertilizer dose. Though there is a saving of 148 mm of water with 0.6 PE irrigation, there is an addition of 50 per cent more fertilizer to achieve this yield level. If there is sufficiency of water, a 100 per cent fertilizer dose can yield similarly but with 0.9 PE irrigation. Hence in such situation, higher quantity of fertilizer requirement can be replaced by higher water application schedule. It has been already established that there was an interactive mechanism operating between fertilizer and water use and depending upon situation one can replace the effect of other complementarily (Yadav *et al.*, 1998).

A better WUE was observed in the fertigation treatment compared to control crop. The mulching provided to the crop, the overall benefit of controlled and continuous supply of moisture, and continuous and incremental supply of nutrients in the fertigation treatments, and accompanied benefit of increasing root zone temperature have favoured higher WUE in the fertigated crops, amounting to an overall improvement in water use efficiency to the tune of 257 per cent due to fertigation treatment over control.

5.8 Soil moisture distribution pattern

The distribution of moisture observed at different grid points at various radial and vertical distances from the plant are given in Table 25, 26 and 27. Since drip irrigation was a continuous point source irrigation, moisture distribution pattern would be studied only after the final harvest of the crop.

In general soil moisture content at 15 cm surface depth was more or less uniformly distributed within the distance of 15-30 cm from the plant indicating that the soil moisture at surface layer was uniformly distributed at each irrigation level. But moisture observed at 30 cm depth either at 15 or 30 cm radial distance from the plant was considerably lower compared to its 15 cm depth. Further as the radial distance increased from 15 to 30 cm the moisture available in the soil at this depth level of 30 cm was getting reduced. Moreover, at this depth the soil moisture content shrunk to a level nearer to PWP or below that. A relatively higher moisture content was seen in case of 0.9 PE irrigation at 15 cm surface level both at 15 or 30 cm radial distance. Graphical representation of moisture content is given in Fig. 8a, 8b and 8c). The graphical representation of data shows that, a higher peak of moisture content in case of 0.3 PE irrigation and sudden drop of moisture contents with increase in radial distance. But in case of 0.6 PE irrigation, there is a uniform distribution of moisture in the surface layer showing a plateau nature of curve and gradual reduction in soil moisture as the radial distance increases. A similar trend is observed in case of 0.9 PE irrigation. In case of 0.3 PE irrigation, the peak in the curve indicates that the minimum amount of irrigation is field capacity at any point

Fig. 8a. Variation in soil moisture content (% w/w) at 15 and 30 cm depths (D) at radial (R) distance of 15 and 30 cm away from right (r) and left (l) of the plant and at 15 and 30 cm perpendicular (p) to the radial distance (0.3 PE irrigation)

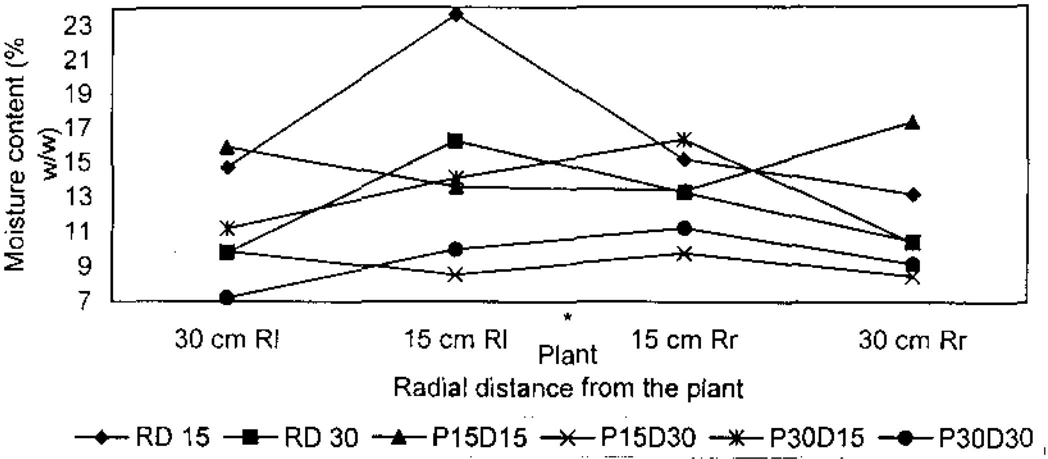


Fig. 8b. Variation in soil moisture content (% w/w) at 15 and 30 cm depths (D) at radial (R) distance of 15 and 30 cm away from right (r) and left (l) of the plant and at 15 and 30 cm perpendicular (p) to the radial distance (0.6 PE irrigation)

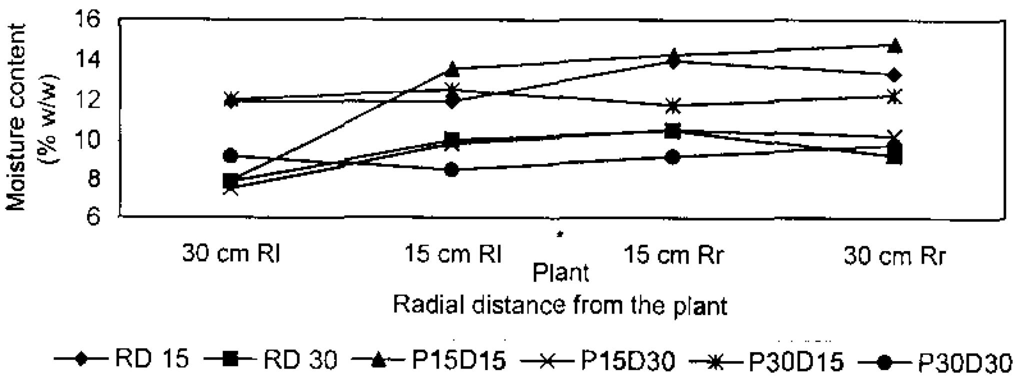


Fig. 8c. Variation in soil moisture content (% w/w) at 15 and 30 cm depths (D) at radial (R) distance of 15 and 30 cm away from right (r) and left (l) of the plant and at 15 and 30 cm perpendicular (p) to the radial distance (0.9 PE irrigation)

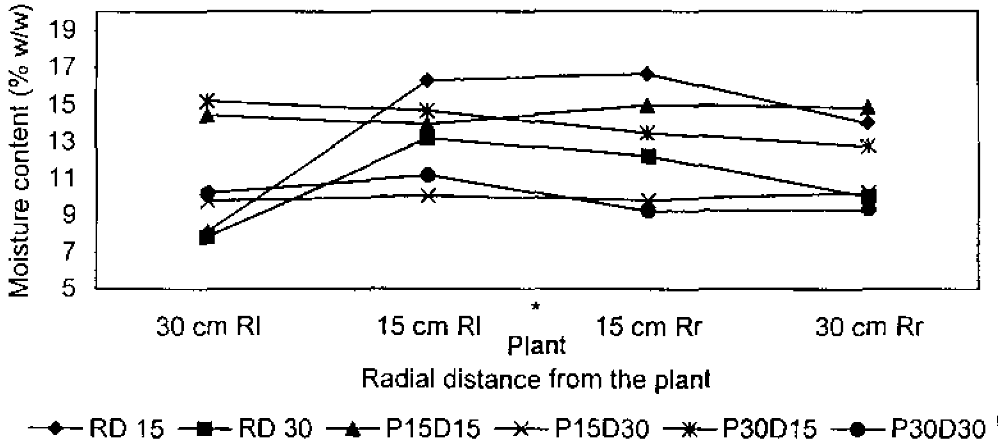


Fig. 9a. Moisture content at 15 and 30 cm depths (D) at 15 and 30 cm away from the plant at radial plain under varying levels of irrigation

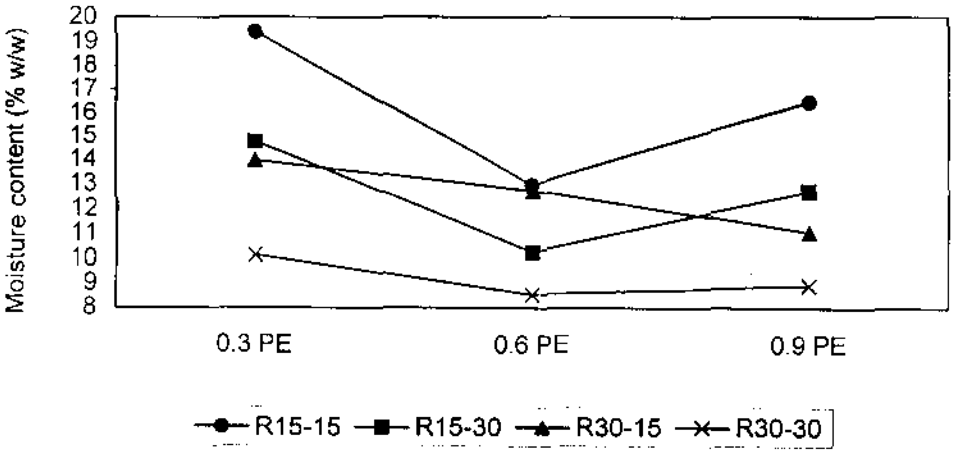


Fig. 9b. Moisture content (% w/w) at 15 and 30 cm depths (D) at 15 cm perpendicular (P) to 15 and 30 cm radial distances under varying levels of irrigation

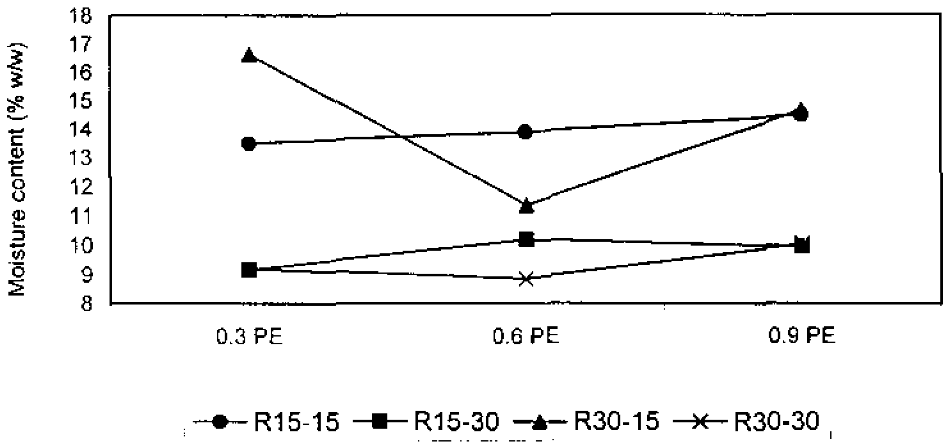
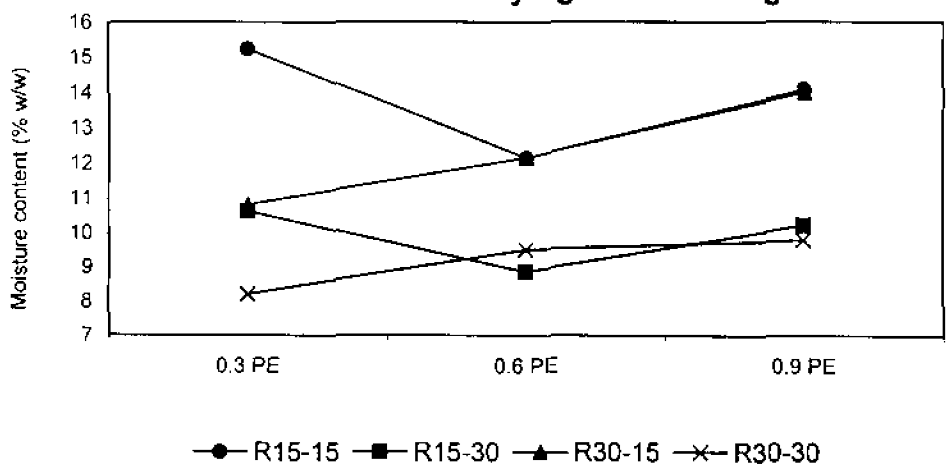


Fig. 9c. Moisture content (% w/w) at 15 and 30 cm depths (D) at 30 cm perpendicular (P) to 15 and 30 cm radial distances under varying levels of irrigation



of irrigation. From the point of irrigation, moisture distribution is gradual based on gravitational pull or due to total soil moisture stress. A uniform distribution of moisture within the root zone at 0.6 or 0.9 PE level indicated higher efficiency in the soil moisture distribution and utilization and thereby facilitating better utilization by plants.

The grids of moisture distribution provided in the Table 26 indicated that as the vertical and horizontal distance increased from the point of irrigation, the soil moisture content got reduced. At the point of intersection of two moisture curves of adjacent drippers, the moisture content available was comparatively higher than the moisture available at mid points. The data also indirectly indicated that (Fig. 9a, 9b and 9c) the soil moisture curve for the available soil moisture regime assumes an elliptical shape below the point of irrigation.

5.9 Economics of production

Acceptance of any new technology in farming sector mainly depends on the economic feasibility of it. Fertigation technology has gained enormous popularity in the world, mainly due to its economic viability in terms of higher WUE, fertilizer use efficiency and net profit. In the present investigation, higher dose of fertilizer (150%) coupled with 0.6 PE irrigation gave a maximum net profit of Rs.89,102 per hectare, followed by the treatment which received recommended dose under 0.9 PE irrigation, which has a net profit of Rs.87,121 per hectare. The net profit of this two treatments were 157 and 151 per cent higher than the furrow irrigated crop. Similarly the BC ratio were 1.91 and 1.92 in the above said fertigated treatments respectively, but the BC ratio in the furrow irrigated crop was only 1.56. Several reports suggest that application of nutrients through irrigation water has economic advantage over conventional farming practices in many crops (Berad *et al.*, 1998, Deolankar and Berad, 1999 and Shinde *et al.*, 1999). Besides economic advantage, practice of drip system also saved considerable amount of water. This water can be used for further expansion of cultivable area. In the current investigation also, upto 342 and 194 mm water was saved by the treatments which gave higher net profits. The water thus saved can be utilised for growing the tomato crop in additional area of 0.95 and 0.38 ha respectively. The results are in consonance with the results obtained by Sheela (1988) and Sunilkumar (1998).

Summary

SUMMARY

A field experiment was conducted in the summer rice fallows of the Agricultural Research Station, Mannuthy during December, 2000 to April, 2001, to find out growth, development and yield of tomato (*Lycopersicon esculentum* Mill.) as influenced by fertigation, as well as to provide information on development of plant under progressive addition of nutrients through irrigation water.

The soil of the experimental field was sandy clay loam with the bulk density ranging from 1.50 to 1.52 g cm^{-3} at 0-30 cm depth and acidic in reaction. The soil was medium in organic carbon as well as phosphorus, but low in available potassium.

The technical programme included factorial combination of three levels of irrigation at 0.3, 0.6 and 0.9 PE daily through drip and three levels of nutrients (100,50 and 150% recommended dose) through irrigation water in comparison with one control (20 mm furrow irrigation at 3 days interval and normal soil application of 100 percent recommended dose of fertilizers) treatment. The experiment was laid out in randomised block design with three replications. All the treatments except control were mulched using black LDPE sheet. The recommended dose of fertilizer was 70:40:25 kg N, P_2O_5 and K_2O ha^{-1} respectively. In case of fertigation treatments the quantity of fertilizer nutrients was progressively increased daily and the application of the total nutrients was distributed to 60 days after initiation of the treatment. Tomato variety Shakthi (LE 79) was tried in the experiment. The salient results obtained during the course of investigation are presented below.

1. The mean plant height was higher in the fertigated treatments in all the four stages of observation, than control crop. The treatment T_6, which received 0.6 PE irrigation with 150 per cent fertilizer dose produced significantly taller plants (53.07 cm) than all other treatments during the final stage of observation (60 DAP). As irrigation and fertilizer levels were increased from lower levels to higher levels height of the plant significantly increased during final stage of observation.

2. The fertigation treatments variably influenced mean LAI of the plants. Throughout the growth stages, treatments T_6, T_7 and T_9 which received 150, 100 and 150 per cent fertilizer dose with 0.6, 0.9 and 0.9 PE irrigation levels respectively produced higher LAI. At all stages of observation 150 per cent recommended dose produced higher LAI than other two fertilizer levels. But irrigation levels did not variably influence LAI.

3. The mean LAD followed the same pattern as that of LAI.The control crop retained leaves for shorter period than fertigated crops. The T_6 treatment produced higher LAD than all other treatments in all observation periods.

4. There was no significant variation in case of number of fruiting branches per plant. Numerically highest number of fruiting branches (17.44) was produced by T_6 treatment and the lowest was seen in T_9 treatment (13.55). The control crop produced 15.32 branches per plant.

5. The highest fruit set percentage (61.74) was seen in T_7 treatment. This was statistically similar to the one recorded in case of crop receiving 50 per cent

fertilizer with either 0.3 (T_2) or 0.6 PE (T_5) irrigation. Significantly lower level of fruit set (42.58%) was seen in control crop. Fertilizer application @ 50 and 100 per cent gave significantly higher fruit set than 150 per cent fertilizer dose.

6. The mean number of fruits per plant was highest in T_6 treatment (41.16). Irrigation or fertilizer level or their interaction did not significantly affect fruit production. All treatments were on par with T_6 treatment except the T_2 and the control crop which produced only 22 fruits per plant.

7. The highest fruit weight per plant was produced by T_6 treatment (1343 g) followed by T_7 (1307 g) and T_9 (1250 g) which were on par with each other. The control crop produced significantly lower yield level of 695 g. This was 93, 88 and 80 per cent lower than the above respective treatments. Irrigation at 0.9 and 0.6 PE produced 1199 and 1155 g fruit weight per plant which were statistically superior to 0.3 PE irrigation which gave only 1058 g per plant. Fertilizer dose of 150 and 100 per cent gave 1225 and 1172 g fruit weight per plant, which were 21 and 16 per cent more than 0.3 PE irrigation which produced 1008 g per plant.

8. The mean yield per hectare followed the same pattern as that of fruit weight per plant. Significantly higher fruit yield levels were produced by T_6 (37.3 t), T_7 (36.3 t) and T_9 (34.7 t). The control crop produced significantly lower yield level of 19.3 tonnes. As fertilizer levels increased from 50 to 100 then to 150 per cent, respective fruit yields also increased from 28 to 32.5 and

then to 34 tonnes. Similarly as irrigation levels increased from 0.3 to 0.6 and 0.9 PE, fruit yield increased from 29.3 to 32 and 33 tonnes per hectare respectively.

9. The varying levels of irrigation or fertilizer or its interaction significantly reduced root growth over control crop. The control crop produced significantly higher vertical length (26.8 cm), lateral length (15 cm) and root dry weight (8.19 g) over fertigation treatments which on an average produced 18.65 cm vertical length, 11.01 cm lateral length and 3.94 g root dry weight.

10. The mean acidity percentage in fruits, was higher under control treatment. Control fruits had 0.440 per cent acidity and this was on par with T_1 and T_2 treatments. Further all other treatments were of lower acidity. Fruits from crop irrigated at 0.3 PE had an acidity of 0.366 per cent, while that at 0.9 PE and 0.6 PE had 0.309 and 0.258 per cent respectively. Similarly 100 and 50 per cent fertilized plants produced more acidic fruits than that from 150 per cent fertilized crop.

11. There was no variation regarding TSS content in fruits by various treatments. Fertigation treatments had a mean TSS content of 4.94° brix and the control crop 4.72° brix.

12. The fruit cracking was not variably influenced by either irrigation or fertilizer application or its interaction in case of fertigation treatments. But the control crop produced higher level of cracked fruits (12%) than fertigated crops (8.11%).

13. Throughout the three stages of nutrient estimation, the control crop contained lower level of mean nitrogen than fertigated treatments. At 30 and 60 DAP, plants under T_6 treatment contained high mean N content. But at 90 DAP, the treatment which received 0.3 PE irrigation with 50 per cent fertilizer dose contained higher mean N content in plants. Crop under irrigation at 0.3 PE contained more N than the one irrigated at 0.9 PE levels.
14. At 30 DAP, different irrigation and fertilizer levels led to high content of P in plants compared to the control crop. But as the growth progressed, this difference faded and all the treatments remained on par with each other.
15. At all the three stages of observation (30, 60 and 90 DAP) the mean K content was higher in fertigated treatments (2.51, 3.13 and 2.20%) compared to control plants (2.34, 3.07, 2.08%). At the final stage of observation (90 DAP) irrigation at 0.9 or 0.6 PE produced higher K content in plants than 0.3 PE level. But there was no variation due to fertilizer levels.
16. The fertigated crops contained higher Ca at 30 and 90 DAP than control crop. The various fertigation levels did not affect Mg content of the plant at all the 3 stages of observation when compared to the control plant. Similarly the fertilizer or irrigation levels or their interaction had no significant influence on sulphur content of the plants at all the three stages of observation.
17. As the growth proceeded the mean content of Fe, Mn and Zn in plants increased. Same trend was observed in case of Si from 60 to 90 DAP. Irrigation at 0.9 PE level significantly increased mean Fe and Si content of

plants (161.6 ppm Fe and 1.90% Si) than either at 0.6 or 0.3 PE level at final stage of observation. Fertilizer application has not significantly influenced Fe, Mn and Si content of the plants. But 50 and 150 per cent fertilizer dose significantly influenced mean Zn content during final stage of observation.

18. The fertigated field contained on an average 315, 25 and 112 kg ha^{-1}, available N, P and K after cropping. The respective values for the control plot were 314, 27 and 111 kg ha^{-1}.

19. The leaf curl incidence was higher under control crop. Seventy two per cent of the control plants were affected by the disease, but only 40 per cent in case of fertigated crops. Similarly 14 per cent of control plants and 16 per cent of fertigated plants were infected by bacterial wilt disease.

20. The LDPE mulching increased soil temperature at four different depths (5, 10, 15 and 20 cm) compared to control. The average increase in soil temperature was 3.3°C in morning hours and 2.6°C in evening hours in fertigated plots over control. Among the fertigation treatments lower temperature was recorded in 0.9 PE compared to either 0.6 or 0.3 PE irrigation levels.

21. The highest field water use efficiency (14.62 kg fruit m^{-3} of water) was seen in the treatment which received 100% fertilizer with 0.3 PE irrigation. Among the irrigation levels the highest FWUE was seen in 0.3 PE irrigation (i.e., 13.99 kg fruit m^{-3} of water) followed by 0.6 PE (8.95). In case of fertigation levels higher FWUE was seen in 150 per cent dose (10.52)

followed by 100 per cent (10.11) and the lowest at 50 per cent fertilizer levels (8.84).

22. The soil moisture content was more or less uniformly distributed in all three (0.3, 0.6 and 0.9 PE) irrigation levels at surface 15 cm depth within the radial distance of 15 and 30 cm from the plant. But as the depth increased from 15 to 30 cm, there was a considerable reduction in the available soil moisture, especially with increase in the radial distance from 15 to 30 cm.

23. The treatment T_6 and T_7 gave the highest net profits of Rs.89102 and Rs.87121 per hectare respectively. The control crop fetched a net profit of only Rs.34693 per hectare. The B.C ratios of T_6, T_7 and control treatments were 1.92, 1.91 and 1.56 respectively.

Conclusion

The present investigation has indicated the beneficial effect of fertigation technology in tomato crop. Assured supply of water based on PE level and incremental nutrient application throughout its growth period enabled the crop to produce higher yield compared to the furrow irrigated and normally manured crop.

Considerable amount of water can be saved by adopting this technology and the water saved can be utilized for further crop production. Net profit also higher in this technology compared to the furrow irrigation method. Further studies are required for the confirmation of the results and to extend this technology for commercial exploitation.

Future line of work

Based on the results and observations made from the study, the following investigations are suggested for the future.

1. The effect of application of fertilizer nutrients along with surface irrigation
2. The effect of mulching and fertigation through surface irrigation
3. Phasic fertigation with special emphasis on fruit development stage

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RESPONSE OF TOMATO
(*Lycopersicon esculentum* Mill.)
TO VARYING LEVELS OF FERTIGATION

By

D. RAJASEELAN KINGSLY

ABSTRACT OF THE THESIS

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Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680 656
KERALA, INDIA

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ABSTRACT

A field experiment was conducted during 2000-2001 at the Agricultural Research Station, Mannuthy, Thrissur to find out growth and yield as well as water use and nutrient relations of tomato, as influenced by different levels of fertigation i.e. continuous nutrition through drip irrigation. The experiment consisted of combinations of three levels of irrigation (0.3, 0.6 and 0.9 PE) through drip system and three levels of fertilizer (100, 50 and 150% recommended dose) supplied through drip irrigation. The fertilizer nutrients were supplied in progressive increments for sixty days and the fertigated treatments were mulched using black HDPE sheet. A control treatment, which received 20 mm surface irrigation through furrow method once in three days along with normal soil application of fertilizer without mulch cover was also included to compare with fertigation treatments. The experiment was laid out at randomised block design with three replications. The tomato CV Shakthi was tried in the experiment.

The results revealed that the growth parameters viz., plant height, Leaf Area Index (LAI) and Leaf Area Duration (LAD) were higher in the fertigated treatments than in the control crop. The respective values were 50.48 cm, 5.60 and 113.4 in case of fertigated crops and 48.52 cm, 5.46 and 110.9 for the control crop, when observed at final growth stage. The control crop had a significant rooting pattern with higher vertical length (26.8 cm), lateral length (15 cm) and root dry weight of (8.2 g) than the fertigated treatments which had the respective values of 18.65 cm, 11.00 cm and 3.9 g. The ferigated crop produced maximum fruit set of

56.5 per cent and 36 numbers of fruits plant^{-1} with mean yield of 31.51 t ha^{-1}. The respective values for the control crop were 42.6 per cent, 22 and 19.31 t ha^{-1} only.

The treatment which received 150 per cent fertilizer dose with 0.6 PE irrigation gave a maximum yield of 37.3 t ha^{-1} which was 93 per cent more than the control crop. This level of production was comparable with that of the crop receiving 100 or 150 per cent recommended dose of fertilizers with irrigation at 0.9 PE through drip. The TSS content was not influenced by different treatments, but higher acidic fruits were produced by the control crop. The fertigated crops in general contained more nutrients in their biomass compared to control crop. The highest NPK content in plant was recorded at 60 DAP and at the stage these nutrient contents were 4.9, 0.285 and 3.13 per cent in case of fertigated crops and the respective values in control crop were 4.0, 0.245 and 3.07 per cent. The fruit cracking and bacterial wilt incidence were not affected by various treatments. But 72 per cent of control crop suffered by leaf curl virus disease but only 40 per cent, in case of fertigated plants. The mean soil temperature upto 30 cm depth increased under mulched conditions over control treatment during morning (7.30 IST) and evening (2.30 IST) by 3.3°C and 2.6°C respectively. While control crop received 700 mm of water, the crop irrigated through the drip at 0.9, 0.6, 0.3 PE received 506, 358 and 210 mm of water. Field water use efficiency was the highest in the treatment which received 100% fertilizer with 0.3 PE irrigation (14.62 kg fruit per m^{-3} of water). As the irrigation levels reduced and fertilizer application increased FWUE was increased. The moisture content of the soil was more at 15 cm depth both at 15 and 30 cm radial distances, in all irrigation levels. The economic analysis indicated that the crop under recommended dose of fertilizer with 0.9 PE irrigation gave a maximum BC ratio of 1.92 followed by the crop raised under 150 per cent fertilizer dose with 0.6 PE irrigation (1.91). The saving of water through respective treatments, when compared to control enabled 0.38 and 0.95 ha to be additionally brought under irrigated tomato, if respective treatments were employed.

The investigation led to the conclusion that fertigation is a sound technology and produces high yields in tomato. If water is not a limiting factor, adopt irrigation at 0.9 PE using 100 per cent recommended dose of fertilizer and if water availability is constrained, adopt irrigation at 0.6 PE using 150 per cent recommended dose of fertilizer to reap rich harvest.

Appendices

APPENDIX I

Mean monthly normal weather data during the crop growing period for the last fifteen years (1986-2000)

Month	Max. Temp. (°C)	Min. Temp. (°C)	Mean RH (%)	Sunshine hours (h day^{-1})	Wind speed (km hr^{-1})	Evaporation per day (mm day^{-1})	Total rainfall (mm)
December	31.8	22.6	62.7	8.7	8.5	5.6	18.9
January	32.9	22.1	56.8	9.1	9.2	6.5	1.9
February	34.7	22.5	57.8	9.5	6.3	6.6	2.6
March	36.2	23.9	62.3	9.3	5.0	6.6	7.9
April	35.3	24.8	69.3	8.6	4.4	5.9	70.0

APPENDIX II

Daily rainfall and evaporation during the crop growing period

Date	Rainfall (mm)	Evaporation (mm)	Date	Rainfall (mm)	Evaporation (mm)
26-12-2000	0.0	5.6	1-2-2001	12.2	5.2
27-12-2000	0.0	3.0	2-2-2001	0.0	2.8
28-12-2000	3.2	3.0	3-2-2001	0.0	3.2
29-12-2000	0.0	5.2	4-2-2001	0.0	4.8
30-12-2000	2.0	4.0	5-2-2001	0.0	3.2
31-12-2000	2.8	4.0	6-2-2001	0.0	3.5
1-1-2001	0.0	3.9	7-2-2001	0.0	7.4
2-1-2001	0.0	4.0	8-2-2001	0.0	8.0
3-1-2001	0.0	5.0	9-2-2001	0.0	6.0
4-1-2001	0.0	5.0	10-2-2001	0.0	4.3
5-1-2001	0.0	5.6	11-2-2001	0.0	4.2
6-1-2001	0.0	6.7	12-2-2001	0.0	5.8
7-1-2001	0.0	6.0	13-2-2001	0.0	5.6
8-1-2001	0.0	4.8	14-2-2001	0.0	6.7
9-1-2001	0.0	6.0	15-2-2001	0.0	6.0
10-1-2001	0.0	4.2	16-2-2001	0.0	4.6
11-1-2001	0.0	5.8	17-2-2001	0.0	5.0
12-1-2001	0.0	8.2	18-2-2001	0.0	6.0
13-1-2001	0.0	6.0	19-2-2001	0.0	7.0
14-1-2001	0.0	7.0	20-2-2001	0.0	4.0
15-1-2001	0.0	7.0	21-2-2001	0.0	4.2
16-1-2001	0.0	6.1	22-2-2001	0.0	5.8
17-1-2001	0.0	7.9	23-2-2001	0.0	5.0
18-1-2001	0.0	10.3	24-2-2001	0.0	5.2
19-1-2001	0.0	8.0	25-2-2001	0.0	4.7
20-1-2001	0.0	7.1	26-2-2001	0.0	3.8
21-1-2001	0.0	5.6	27-2-2001	0.0	6.0
22-1-2001	0.0	5.7	28-2-2001	0.0	4.0
23-1-2001	0.0	4.4	1-3-2001	0.0	4.2
24-1-2001	0.0	7.7	2-3-2001	0.0	7.6
25-1-2001	0.0	6.6	3-3-2001	0.0	7.8
26-1-2001	0.0	5.0	4-3-2001	0.0	7.8
27-1-2001	0.0	8.2	5-3-2001	0.0	5.2
28-1-2001	0.0	6.2	6-3-2001	0.0	4.0
29-1-2001	0.0	6.3	7-3-2001	0.0	5.8
30-1-2001	0.0	4.2	8-3-2001	0.0	4.0
31-1-2001	0.0	7.0	9-3-2001	2.2	4.7

Contd.

Appendix II. Continued

Date	Rainfall (mm)	Evaporation (mm)
10-3-2001	0.0	6.2
11-3-2001	0.0	6.2
12-3-2001	0.0	5.8
13-3-2001	0.0	5.6
14-3-2001	0.0	5.8
15-3-2001	0.0	5.8
16-3-2001	0.0	6.0
17-3-2001	0.0	4.0
18-3-2001	0.0	5.8
19-3-2001	0.0	4.8
20-3-2001	0.0	4.8
21-3-2001	0.0	5.6
22-3-2001	0.0	4.8
23-3-2001	0.0	4.6
24-3-2001	0.0	5.3
25-3-2001	0.0	5.6
26-3-2001	0.0	5.9
27-3-2001	0.0	5.4
28-3-2001	0.0	4.7
29-3-2001	0.0	5.8
30-3-2001	0.0	5.6
31-3-2001	0.0	5.8
1-4-2001	0.0	6.0
2-4-2001	0.0	4.9
3-4-2001	0.0	6.4
4-4-2001	3.2	4.6
5-4-2001	0.0	5.6
6-4-2001	0.0	5.4
7-4-2001	0.0	4.8
Total	25.6	496.1

APPENDIX III

Fertilizer applied as per treatment - one plot (g day^{-1})

DAIT*	Date	Fertilizers	50% RD	100% RD	150% RD
1st day	10-1-2001	Vardhaman			
		Blue	0.123	0.246	0.369
		DAP	0.016	0.032	0.048
		Urea	0.015	0.030	0.045
2nd day	11-1-2001	Vardhaman			
		Blue	0.246	0.492	0.738
		DAP	0.032	0.064	0.096
		Urea	0.030	0.060	0.090
3rd day	12-1-2001	Vardhaman			
		Blue	0.369	0.738	1.107
		DAP	0.048	0.096	0.144
		Urea	0.045	0.090	0.135
4th day	13-1-2001	Vardhaman			
		Blue	0.492	0.984	1.476
		DAP	0.064	0.128	0.192
		Urea	0.060	0.120	0.180
5th day	14-1-2001	Vardhaman			
		Blue	0.615	1.230	1.845
		DAP	0.080	0.160	0.240
		Urea	0.075	0.150	0.225
6th day	15-1-2001	Vardhaman			
		Blue	0.738	1.476	2.214
		DAP	0.096	0.192	0.288
		Urea	0.090	0.180	0.270
7th day	16-1-2001	Vardhaman			
		Blue	0.861	1.722	2.583
		DAP	0.112	0.224	0.336
		Urea	0.105	0.210	0.315
8th day	17-1-2001	Vardhaman			
		Blue	0.984	1.968	2.952
		DAP	0.128	0.256	0.384
		Urea	0.120	0.240	0.360
9th day	18-1-2001	Vardhaman			
		Blue	1.107	2.214	3.321
		DAP	0.144	0.288	0.432
		Urea	0.135	0.270	0.405

10^{th} day	19-1-2001	Vardhaman Blue DAP Urea	 1.230 0.160 0.150	 2.460 0.320 0.300	 3.690 0.480 0.450
11^{th} day	20-1-2001	Vardhaman Blue DAP Urea	 1.353 0.176 0.165	 2.706 0.352 0.330	 4.059 0.528 0.495
12^{th} day	21-1-2001	Vardhaman Blue DAP Urea	 1.476 0.192 0.180	 2.952 0.384 0.360	 4.428 0.576 0.540
13^{th} day	22-1-2001	Vardhaman Blue DAP Urea	 1.599 0.208 0.195	 3.198 0.416 0.390	 4.797 0.624 0.585
14^{th} day	23-1-2001	Vardhaman Blue DAP Urea	 1.722 0.224 0.210	 3.444 0.448 0.420	 5.166 0.672 0.630
15^{th} day	24-1-2001	Vardhaman Blue DAP Urea	 1.845 0.240 0.225	 3.690 0.480 0.450	 5.535 0.720 0.675
16^{th} day	25-1-2001	Vardhaman Blue DAP Urea	 1.968 0.256 0.240	 3.936 0.512 0.480	 5.904 0.768 0.720
17^{th} day	26-1-2001	Vardhaman Blue DAP Urea	 2.091 0.272 0.255	 4.182 0.544 0.510	 6.273 0.816 0.765
18^{th} day	27-1-2001	Vardhaman Blue DAP Urea	 2.214 0.288 0.270	 4.428 0.576 0.540	 6.642 0.864 0.810
19^{th} day	28-1-2001	Vardhaman Blue DAP Urea	 2.337 0.304 0.285	 4.674 0.608 0.570	 7.011 0.912 0.855
20^{th} day	29-1-2001	Vardhaman Blue DAP Urea	 2.460 0.320 0.300	 4.920 0.640 0.600	 7.380 0.960 0.900

21st day	30-1-2001	Vardhaman			
		Blue	2.583	5.166	7.749
		DAP	0.336	0.672	1.008
		Urea	0.315	0.630	0.945
22nd day	1-2-2001	Vardhaman			
		Blue	2.706	5.412	8.118
		DAP	0.352	0.704	1.056
		Urea	0.330	0.660	0.990
23rd day	2-2-2001	Vardhaman			
		Blue	2.829	5.658	8.487
		DAP	0.368	0.736	1.104
		Urea	0.345	0.690	1.035
24th day	3-2-2001	Vardhaman			
		Blue	2.952	5.904	8.856
		DAP	0.384	0.768	1.152
		Urea	0.360	0.720	1.080
25th day	4-2-2001	Vardhaman			
		Blue	3.075	6.150	9.225
		DAP	0.400	0.800	1.200
		Urea	0.375	0.750	1.125
26th day	5-2-2001	Vardhaman			
		Blue	3.198	6.396	9.594
		DAP	0.416	0.832	1.248
		Urea	0.390	0.780	1.170
27th day	6-2-2001	Vardhaman			
		Blue	3.321	6.642	9.963
		DAP	0.432	0.864	1.296
		Urea	0.405	0.810	1.215
28th day	7-2-2001	Vardhaman			
		Blue	3.444	6.888	10.332
		DAP	0.448	0.896	1.344
		Urea	0.420	0.840	1.260
29th day	8-2-2001	Vardhaman			
		Blue	3.567	7.134	10.701
		DAP	0.464	0.928	1.392
		Urea	0.435	0.870	1.305
30th day	9-2-2001	Vardhaman			
		Blue	3.690	7.380	11.070
		DAP	0.480	0.960	1.440
		Urea	0.450	0.900	1.350
31st day	10-2-2001	Vardhaman			
		Blue	3.813	7.626	11.439
		DAP	0.496	0.992	1.488
		Urea	0.465	0.930	1.395

32nd day	11-2-2001	Vardhaman Blue DAP Urea	 3.936 0.512 0.480	 7.872 1.024 0.960	 11.808 1.536 1.440
33rd day	12-2-2001	Vardhaman Blue DAP Urea	 4.059 0.528 0.495	 8.118 1.056 0.990	 12.177 1.584 1.485
34th day	13-2-2001	Vardhaman Blue DAP Urea	 4.182 0.544 0.510	 8.364 1.088 1.020	 12.546 1.632 1.530
35th day	14-2-2001	Vardhaman Blue DAP Urea	 4.305 0.560 0.525	 8.610 1.120 1.050	 12.915 1.680 1.575
36th day	15-2-2001	Vardhaman Blue DAP Urea	 4.428 0.576 0.540	 8.856 1.152 1.080	 13.284 1.728 1.620
37th day	16-2-2001	Vardhaman Blue DAP Urea	 4.551 0.592 0.555	 9.102 1.184 1.110	 13.653 1.776 1.665
38th day	17-2-2001	Vardhaman Blue DAP Urea	 4.674 0.608 0.570	 9.348 1.216 1.140	 14.022 1.824 1.710
39th day	18-2-2001	Vardhaman Blue DAP Urea	 4.797 0.624 0.585	 9.594 1.248 1.170	 14.391 1.872 1.755
40th day	19-2-2001	Vardhaman Blue DAP Urea	 4.920 0.640 0.600	 9.840 1.280 1.200	 14.760 1.920 1.800
41st day	20-2-2001	Vardhaman Blue DAP Urea	 5.043 0.656 0.615	 10.086 1.312 1.230	 15.129 1.968 1.845
42nd day	21-2-2001	Vardhaman Blue DAP Urea	 5.166 0.672 0.630	 10.332 1.344 1.260	 15.498 2.016 1.890

43rd day	22-2-2001	Vardhaman			
		Blue	5.289	10.578	15.867
		DAP	0.688	1.376	2.064
		Urea	0.645	1.290	1.935
44th day	23-2-2001	Vardhaman			
		Blue	5.412	10.824	16.236
		DAP	0.704	1.408	2.112
		Urea	0.660	1.320	1.980
45th day	24-2-2001	Vardhaman			
		Blue	5.535	11.070	16.605
		DAP	0.720	1.440	2.160
		Urea	0.675	1.350	2.025
46th day	25-2-2001	Vardhaman			
		Blue	5.658	11.316	16.974
		DAP	0.736	1.472	2.208
		Urea	0.690	1.380	2.070
47th day	26-2-2001	Vardhaman			
		Blue	5.781	11.562	17.352
		DAP	0.752	1.504	2.256
		Urea	0.705	1.410	2.115
48th day	27-2-2001	Vardhaman			
		Blue	5.904	11.808	17.712
		DAP	0.768	1.536	2.304
		Urea	0.720	1.440	2.160
49th day	28-2-2001	Vardhaman			
		Blue	6.027	12.054	18.081
		DAP	0.784	1.568	2.352
		Urea	0.735	1.470	2.205
50th day	1-3-2001	Vardhaman			
		Blue	6.150	12.300	18.450
		DAP	0.800	1.600	2.400
		Urea	0.750	1.500	2.250
51st day	2-3-2001	Vardhaman			
		Blue	6.273	12.546	18.819
		DAP	0.816	1.632	2.448
		Urea	0.765	1.530	2.295
52nd day	3-3-2001	Vardhaman			
		Blue	6.396	12.792	19.188
		DAP	0.832	1.664	2.496
		Urea	0.780	1.560	2.340
53rd day	4-3-2001	Vardhaman			
		Blue	6.519	13.038	19.557
		DAP	0.848	1.728	2.544
		Urea	0.795	1.590	2.385

54th day	5-3-2001	Vardhaman			
		Blue	6.642	13.284	19.926
		DAP	0.864	1.728	2.592
		Urea	0.810	1.620	2.430
55th day	6-3-2001	Vardhaman			
		Blue	6.765	13.530	20.295
		DAP	0.880	1.760	2.640
		Urea	0.825	1.650	2.475
56th day	7-3-2001	Vardhaman			
		Blue	6.888	13.776	20.664
		DAP	0.896	1.792	2.688
		Urea	0.840	1.680	2.520
57th day	8-3-2001	Vardhaman			
		Blue	7.011	14.022	21.033
		DAP	0.912	1.824	2.736
		Urea	0.855	1.710	2.565
58th day	9-3-2001	Vardhaman			
		Blue	7.134	14.268	21.402
		DAP	0.928	1.856	2.784
		Urea	0.870	1.740	2.610
59th day	10-3-2001	Vardhaman			
		Blue	7.257	14.514	21.771
		DAP	0.944	1.888	2.832
		Urea	0.885	1.770	2.655
60th day	11-3-2001	Vardhaman			
		Blue	7.380	14.760	22.140
		DAP	0.960	1.920	2.880
		Urea	0.900	1.800	2.700

* DAIT = Days after initiation of treatments

APPENDIX IV

Labour requirement for cultivation of tomato crop (ha^{-1})

Sl. No.	Particulars	Furrow irrigation			T_6 Treatment			T_7 Treatment		
		M	F	Cost	M	F	Cost	M	F	Cost
1.	Nursery management	1	1	200.00	1	1	200.00	1	1	200.00
2.	Ploughing by tractor (10 hrs)	2.5	-	2300.00	2.5	-	2300.00	2.5	-	2300.00
3.	FYM application	-	20	1600.00	-	20	1600.00	-	20	1600.00
4.	Preparation of ridges and furrows and formation of bunds	50	-	6000.00	50	-	6000.00	50	-	6000.00
5.	Transplanting of seedlings (with basal fertilizer dose application in case of flood irrigation)	-	56	4480.00	-	56	4480.00	-	56	4480.00
6.	Gap filling	-	6	480.00	-	6	480.00	-	6	480.00
7.	Spreading LDPE sheets and making holes at grid points	-	-	-	10	10	2000.00	10	10	2000.00
8.	Top dressing (two times in case of flood irrigation)	50	-	6000.00	-	-	-	-	-	-
9.	Weeding (two times)	-	56	4480.00	-	28	2240.00	-	28	2240.00
10.	Plant protection spraying	5	-	600.00	5	-	600.00	5	-	600.00
11.	Irrigation as per schedule (once in 3 days in flood irrigation 5 men/ha for an irrigation) (one labour/irrigation in case of drip)	150	-	18000.00	90	-	10800.00	90	-	10800.00
13.	Harvesting charges (1 woman labour for 400 kg fruits)	-	48	3840.00	-	93	7440.00	91	-	7280.00
	Total			47980.00			38140.00			37980.00

APPENDIX V

Cost of inputs/hectare

Sl. No.	Particulars	Unit cost (Rs.)	Furrow irrigation (Rs.)	T_6 Treatment (Rs.)	T_7 Treatment (Rs.)
1.	Seed (100 g)	2000/kg	800.00	800.00	800.00
2.	FYM (20 tonnes)	400/tonnes	8000.00	8000.00	8000.00
3.	Urea	4.2/kg	638.00	189.00	126.00
4.	Rajphos	2.9/kg	580.00	-	-
5.	MoP	4.4/kg	185.00	-	-
6.	DAP	10/kg	-	495.00	330.00
7.	Vardhaman Blue	21.25/kg	-	7969.00	5313.00
8.	Lime	2/kg	500.00	500.00	500.00
9.	Ekalux (2l)	380/l	760.00	760.00	760.00
10.	Neem oil (2l)	70/l	140.00	140.00	140.00
11.	Electricity charges		961.00	150.00	225.00

APPENDIX VI

Cost economics of drip system

Sl. No.	Particulars	Unit cost (Rs.)	Total cost (Rs.)
1.	32 mm PVC pipe (400 m)	12.50	5000.00
2.	32 mm PVC ball valve (4)	50.00	200.00
3.	32 mm PVC end cap (4)	1.80	7.20
4.	12 mm HDPE pipe (17368 m)	3.75	65130.00
5.	12 mm end caps (668)	0.6	400.80
6.	12 mm take off valves (668)	4.85	3239.80
7.	4 mm polytubes (28056 m)	1.40	39278.40
8.	4000 l PVC tanks (4)	5000.00	20000.00
9.	Total cost		1,33,256.20
10.	Accessories & installation charges (10%)		13325.62
11.	Depreciation @ 10% per year		14,658.18

APPENDIX VII

Cost economics of mulch sheet

	Particulars	Amount (Rs.)
A.	Cost of sheet @ Rs.40/kg 1 kg/12 m^2 (835 kg/ha)	33400.00
B.	Depreciation @ 20% per annum (considering lifespan of 2.5 years and two growing seasons a year)	6680.00
C.	Interest in capital @ 5% (considering two growing seasons a year)	1670.00