# MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER

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**KERALA, INDIA**

**2021**

# MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER

*by*

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**(2019-11-204)**

**THESIS**

**Submitted in partial fulfilment of the**

**requirements for the degree of**

**MASTER OF SCIENCE IN AGRICULTURE**

**Faculty of Agriculture**

**Kerala Agricultural University**

**DEPARTMENT OF AGRONOMY**

**COLLEGE OF AGRICULTURE**

**VELLAYANI, THIRUVANANTHAPURAM-695 522**

**KERALA, INDIA**

**2021**

# DECLARATION

I, hereby declare that this thesis entitled "**MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER**" is a bonafide record of research work done by me during the course of research and the 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

Place: Vellayani,

Date : 09-12-2021.

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# CERTIFICATE

Certified that this thesis entitled **"MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER"** is a record of research work done independently by Ms. Saniga N. S. (2019-11-204) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Vellayani,

Date : 09-12-2021

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(Major Advisor, Advisory Committee)

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We, the undersigned members of the advisory committee of Ms. Saniga N. S (2019-11-204), a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled **"MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER"** may be submitted by Ms. Saniga N. S., in partial fulfilment of the requirement for the degree

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## ACKNOWLEDGEMENTS

*First and foremost, I thank the Almighty God for his blessings and for making me optimistic and hopeful at all times, enabling me to complete this work successfully.*

*I express my profound sense of gratitude and indebtedness to my major advisor,* ***Dr. T. Sajitha Rani,*** *Professor and Head, Instructional Farm, College of Agriculture, Vellayani for her prodigious guidance, constant encouragement, affectionate advice, and insightful decision that assisted me to overcome every problem that came in my way during the period of this investigation. The successful completion of this thesis work would not have been possible without her valuable help and support.*

*With immense pleasure, I express my heartful thanks to the members of the advisory committee,* ***Dr. Shalini Pillai P.*** *Professor and Head, Department of Agronomy,* ***Sri. V Jayakrishnakumar*** *Associate Professor, Department of Agronomy and* ***Dr. B. Rani,*** *Professor and Head, Department of Soil Science and Agricultural Chemistry for their valuable guidance, constructive criticisms and timely help during the entire period of my study and research work.*

*I extend my sincere gratitude and respect to all the faculty members of the Department of Agronomy, especially for their sincere encouragement and support throughout my course work. I thankfully acknowledge each and every non teaching staff of Agronomy Department and Instructional Farm for their whole hearted cooperation during my research work.*

*I wish to express my sincere thanks to all the labourers, especially,* ***Lalan Chettan, Rajesh Chettan, Manikandan Chettan, Sanal Chettan,*** *and* ***Suresh Chettan****, for their valuable support and immense help during my field experiment.*

*I am in dearth of words to express my whole hearted regards to my dear friends, especially* ***Varsha, Manisha, Anju, Achu, Arya, Vaishu, Alin, Shalmu, Chiru, Riya, Kuttan, Kiran, Abhi, Aswin, Hari, Jacky, and bts*** *for the countless help, support, motivation and care during the course of my study.*

*I have infinite pleasure to express my loving thanks to all my batchmates and dear seniors* ***Namitha, Jessim, Deepthi, Merin, Navya, Arun, Greeshma, Sreeku, Elzu, Karthik, Krishna, Rabeen, Seethal, Jayalakshmi, Madhu, Aashiq, Sandra, Shilpa chichi, Sandra chechi, Vijay chettan, Gritta chechi, Aparna chechi*** *and* ***Anusree chechi*** *for their help and support. Words are inadequate to express my sincere regards to* ***Neethu, Pathu, Sisilu, Akshaja,*** *and* ***Kuttu*** *for their valuable advices, love, help and affection during the course of study.*

*I do not have words to express my love and affection towards my beloved father Sri.* ***Santhosh N. A ,*** *my dearest mother Smt.* ***Gigi Santhosh*** *and my loving sister Kumari* ***Anjana N. S*** *and all my family members for their constant prayers, personal sacrifices, unstinted motivation, unbounding care and support contributed to me during the course of the study.*

*I once again express by sincere gratitude and heartfelt thanks to all those who helped me in the successful completion of my study and research work.*

***Saniga N. S***

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# LIST OF ABBREVIATIONS AND SYMBOLS

| Abbreviation / symbol | Expansion |
|---|---|
| @ | at the rate of |
| % | per cent |
| ºC | degree celsius |
| ₹ | rupees |
| ºN | degree north |
| ºE | degree east |
| ANOVA | analysis of variance |
| B:C ratio | benefit cost ratio |
| CD(0.05) | critical difference at 5% level |
| Cm | centimeter |
| $cm^2$ | square centimeter |
| $cm^3$ | cubic centimeter |
| DAT | days after transplanting |
| DMP | dry matter production |
| $dSm^{-1}$ | deci siemens per meter |
| ET | evapotranspiration |
| *et al.* | co-workers |
| Fig. | figure |
| FYM | farm yard manure |
| FWUE | field water use efficiency |
| G | gram |
| *i.e.,* | that is |
| K | potassium |
| K. lux | kilo lux |
| Kg | kilogram |

| | |
|---|---|
| kg $ha^{-1}$ | kilogram per hectare |
| L | Litre |
| L $h^{-1}$ | litre per hour |
| LAI | leaf area index |
| $m^{-2}$ | Per square meter |
| Max. | maximum |
| Mg | milligram |
| Min. | minimum |
| Mm | milli metre |
| N | nitrogen |
| NS | not significant |
| P | phosphorus |
| POP | package of practices |
| RDF | recommended dose of fertilizers |
| RH | relative humidity |
| SEm | standard error of mean |
| SSDI | sub surface drip irrigation |
| t $ha^{-1}$ | tonnes per hectare |
| TSS | total soluble solids |
| UV | ultra violet |
| *Viz.* | namely |

# LIST OF APPENDICES

# ***INTRODUCTION***

# 1. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.), also known as “poor man’s orange,” is a popular solanaceous vegetable grown in the tropics and subtropics of the world. It is widely grown in almost all regions of India due to its wider adaptability to diverse agro climatic conditions. Tomato is the world’s second most important vegetable crop, next to potato in terms of area and first in terms of processing, and they top the list of canned vegetables in the world. Tomatoes can be eaten raw, cooked, or processed in a variety of ways, including salad, soup, sauce, chutney, puree, and whole canned fruits. Tomato is regarded as protective food with high nutritious value, and play a key role in the Indian cuisine. They are rich sources of vitamins A and C, dietary fibers, minerals, and organic acids. The natural antioxidants, lycopene and carotene found in tomatoes are proven to lower cancer and cardiovascular disease risks; hence consuming one tomato per day is extremely beneficial to human health (Singh *et al.,* 2021).

Tomatoes are always in high demand to satisfy the requirements of the culinary and processing industries. Considering the high demand, the productivity of tomato needs to be boosted. The major impediments to enhanced tomato production technology include the unavailability of improved seed at the time of sowing, lack of irrigation water, high cost of irrigation, lack of disease resistant varieties, and lower prices at harvesting time (Jat *et al*., 2012). Water is one of the major constraints that have a considerable impact on the quality and output of tomato. Use of good quality seeds and fertilizers even fails to achieve their full potential if the crop does not receive optimum irrigation. Being a tropical plant, it requires a constant supply of water, and hence scarcity of water can adversely affect crop growth and yield (Kumar and Khanna, 2019).

Water is an inevitable input in agriculture, particularly in developing countries like India. The availability of water in adequate quantity and quality is very limited as a result of the rapid growing population and high demand from various sectors (Fanish, 2011). The agriculture sector alone consumes approximately 83 per cent of all available water. About 50-70 per cent of water is wasted through conveyance, evaporation, and field losses in conventional irrigation methods. As a result, water resources should be utilized more efficiently and productively. This could be accomplished by implementing improved irrigation techniques and better water management strategies (Kumar and Kumar, 2020). Micro irrigation is one such approach that is gaining momentum to address water scarcity.

Micro irrigation also known as localised irrigation, is a novel method of irrigation that ensures a consistent supply of water in the root zone, resulting in 30 to 70 per cent water savings in various orchard crops and vegetables compared to conventional methods of irrigation (Zaman *et al.,* 2001). Among the different types of micro irrigation, drip irrigation is the most popular and commonly used method around the world.

Drip irrigation is the practice of slowly dripping a small amount of water into surface of the soil or directly onto the plant root zone through emitters (Kumari and Kaushal, 2014). Panigrahi *et al.* (2010) found that drip irrigation produces higher crop yields and maintains balanced soil moisture in the active crop root zone with little water losses, saving 17.9 per cent to 36.6 per cent of water when compared to conventional furrow irrigation.

Drip irrigation can be made more versatile for irrigating a variety of agronomic, horticultural, and fruit crops by putting the laterals below the soil surface, which is known as sub surface drip irrigation. It applies an exact amount of water to the soil *via* drippers installed below the soil surface, with the same discharge rates as surface drip irrigation (ASAE Standards). The buried drip tubes are less vulnerable to damage due to UV radiation, cultivation or weeding (Jeelani *et al*., 2017). Sub surface drip irrigation offers several other advantages like efficient fertilizer application, fewer weed and disease problems, lower labour costs, reduced evaporation, deep percolation losses, and surface runoff elimination than conventional drip irrigation systems (Hashem *et al*., 2018).

Rain hose irrigation, also known as rain pipe irrigation, is a new low-cost spray irrigation technology suitable for closely spaced crops like green gram, black gram, onion, groundnut and other vegetable crops. Rain hoses are flexible pipes with drip hole patterns created using nano-punching technology. The rain hose delivers water in precise amounts, ensuring a consistent water flow. It is simple to set up, and is less expensive to run than drip and sprinkler irrigation systems. Other advantages include reduced leaching losses, less clogging, increased water efficiency, and portability from one location to another (Ayyadurai *et al*., 2020).

In addition to the improvement of irrigation systems and schemes, the assessment of crop management strategies can also lead to more efficient and sustainable agricultural water management (Mancosu *et al*., 2015). Mulching, which is commercially implemented in most of the vegetables grown in Kerala, is one of the water management strategies proposed to boost water use efficiency.

A mulch is a layer of plant residues or other materials, either organic or inorganic spread on the surface layer of soil. Organic mulches proved to be more advantageous than the plastic mulches because of the high cost of production and due to the difficulty in the disposal of plastic debris after cropping. Apart from that, they are eco-friendly, add organic matter to the soil, maintain soil thermal regime, minimize soil erosion, prevent weed growth, and reduce unproductive evaporation. Mulching reduces rainwater runoff by retaining it at the soil surface, giving it more time to seep into the soil and thus increasing water use efficiency (Ranjan *et al.,* 2017). Crop residues from previous crops are readily available in fields, so mulching is cost effective, and farmers can benefit from organic mulch in a variety of ways. Hence, there is considerable scope for the practice and application of mulching in crop production for soil and water conservation.

Keeping the above aspects in consideration, a field study entitled "Micro irrigation and mulching for yield optimization of tomato in rain shelter" was carried out with the following objectives:

1. To evaluate the efficacy of different micro irrigation methods and mulching on growth and yield of tomato
2. To work out the economics of tomato production

# ***REVIEW OF LITERATURE***

# 2. REVIEW OF LITERATURE

Water is an important natural resource that has an impact on the agricultural production and productivity. Being a scarce resource, it must be used wisely to ensure humanity's survival. Although India has plentiful water resources, the usable water for irrigation is rapidly being depleted due to a variety of physiographic limits, existing legal and regulatory constraints, and also due to the current mode of exploitation. As a result, the urgent need is to maximise production per unit quantity of water. In order to enhance crop yield and maintain productivity levels, a lot of attention is being placed on developing an efficient and economically viable irrigation management system. Micro irrigation is a new sophisticated irrigation technique that was implemented in agriculture to save water and improve water use efficiency. When compared to traditional methods, micro irrigation saves 10-30 per cent water in orchards and vegetables. Conventionally, mulching improves water use efficiency to a large extent by supplementing the water status at the root zone. Hence, the current investigation was designed to determine the effectiveness of micro irrigation and mulching on growth and yield of tomato. The available literature on research carried out by researchers related to the types of micro irrigation and mulching in general with particular reference to tomato has been reviewed and presented in this chapter.

## 2.1 DRIP IRRIGATION

### 2.1.1 Effect on Growth and Growth Attributes

Kadam and Sahane (2002) found that tomatoes grown under drip irrigation produced taller plants (28.9, 54.4, 71.4, and 78.5 cm) than surface irrigation (24.2, 48.7, 63.5 and 70.5 cm) at different growth stages. Similarly, surface drip irrigation produced the highest total dry matter yield (2527 kg $ha^{-1}$) than surface mode of irrigation (2184 kg $ha^{-1}$).

The study conducted by Kaholn *et al.* (2007) in tomatoes observed a significant difference in growth attributes such as plant height, leaf area index, and number of branches under drip irrigation compared to furrow irrigation.

Mahajan *et al.* (2007) in an investigation to evaluate the performance of red hot pepper under surface drip and check basin methods of irrigation observed higher plant height and number of branches per plant with surface drip irrigation scheduled at 1.0 Epan compared to check basin method of irrigation.

Shadeed *et al*. (2009) observed a higher average plant height, leaf area index, and dry matter production in tomato under drip fertigated treatments than the furrow irrigated ones.

According to Imamsahab *et al.* (2011), applying water soluble fertilizers *via* surface drip at 80 per cent ET produced higher growth components of tomato such as average plant height (96.70 cm), number of primary branches (18.25), leaf area index (3.49) and stem diameter (2.06 cm).

Ali and Rahman (2012) noticed a higher leaf area (0.304 $m^2$), leaf area index (2.4) and biomass production (53.3 g per plant) under surface drip irrigation than conventional irrigation in tomato.

Drip irrigation at 80 per cent ET significantly influenced the growth parameters of tomatoes such as plant height (94.15 cm), primary branches per plant (19.17), the least days to 50 per cent flowering (43.67 days) and the leaf area index (2.85) (Kishore *et al*., 2018).

### 2.1.2 Effect on Yield and Yield Attributes

In comparison to surface irrigation, Ahire *et al.* (2000) opined that drip irrigation enhanced the number of tubers per plant (5.58), tuber size (16.08 cm), tuber weight (145.5 g) and potato tuber yield (20.43 t $ha^{-1}$).

Patel *et al.* (2009) found that scheduling of drip irrigation at 0.8 pan evaporation produced the maximum fruit yield (20.79 kg $ha^{-1}$) in okra, which was 46.25 per cent greater than surface irrigation.

According to Gupta *et al*. (2010), drip fertigation at 80 per cent ET along with 80 per cent RDN significantly increased the fruit yield of capsicum (36.64 t $ha^{-1}$) than flood irrigation.

Panigrahi *et al*. (2010) in a study on the effect of furrow and drip irrigation on yield and water use efficiency of tomatoes noticed that surface drip irrigation scheduled at 100 per cent ETc enhanced the yield (18.09 t $ha^{-1}$) by 15.4 per cent compared to the traditional flood irrigation method practiced by the farmers.

Pandey *et al*. (2013) investigated effects of drip irrigation, spacing, and nitrogen fertigation on chilli and found that the fruit yield was higher for drip irrigation (10.50 kg $m^{-2}$) with an increase of 60. 30 per cent more yield in comparison to flood irrigation.

Jha *et al.* (2017) conducted a study on the influence of drip and furrow irrigation in improving yield and economics of various vegetables in the eastern plateau and hill regions of India, finding that the yield obtained under drip irrigation was higher in the case of vegetables like pea (65.08 %), tomato (58.70 %), cauliflower (57.7 %), french bean (39.1 %), and potato (38.2 %).

Kumar *et al.* (2018) in a study on drip irrigation scheduling in tomato reported that the highest average fruit weight (7.49 kg) and fruit yield (63.01 t $ha^{-1}$) can be obtained when three-hour water is applied through drip irrigation at every three days interval compared to surface application.

Drip irrigation with 100 per cent RDF obtained a 48.50 per cent increase in yield of tomato over conventional irrigation and fertilization method (Kale *et al*., 2019). Scheduling drip irrigation for four hours at four-day intervals had significantly increased the average fruit yield of tomatoes (1.001 kg) compared to furrow irrigation, and they opined that drip irrigation is highly efficient in the yield enhancement of tomatoes and saving substantial amount of water (Kumar and Khanna, 2019).

Makkar *et al*. (2020) noticed that the yield of chilli obtained under weekly fertigation with RDN was 20.67 per cent more under drip irrigation compared to surface irrigation.

### 2.1.3 Effect on Quality Attributes

Mahajan and Singh (2006) observed an increase in ascorbic acid content (85.9 per cent) and total soluble solids (5.7 $^{o}$ brix) in tomatoes grown in a greenhouse under drip irrigation at 0.5 pan evaporation compared to the check basin method of irrigation.

Kaholn *et al.* (2007) studied the efficiency of drip irrigation and furrow irrigation in tomatoes and reported that the quality aspects of fruits were superior under drip irrigation. They obtained a higher TSS (6.70 º brix) and ascorbic acid (25.2 me 100 $g^{-1}$) under drip irrigation scheduled at 0.7 IW/Epan than the TSS (6.37) and ascorbic acid (24.2 me 100 $g^{-1}$) under furrow irrigation.

Sanchita *et al.* (2010) reported improvement in quality parameters like total soluble solids, ascorbic acid, juice percentage under 100 per cent drip fertigation whereas titratable acidity was higher under 50 per cent drip fertigation. The continuous availability of soil moisture under drip irrigation resulted in higher quality parameters of tomatoes such as pH, TSS, total acidity, and lycopene concentration (Pawar *et al.,* 2013).

As per the study by Gupta *et al.* (2015), the combination of 80 per cent ET through surface drip and fertigation with 80 per cent of the recommended NPK resulted in an improved quality parameters of tomatoes such as TSS (5.03 %), vitamin C content (18.93 mg 100$g^{-1}$), lycopene content (7.91 mg 100$g^{-1}$) and total soluble sugar (3.95 %).

### 2.1.4 Effect on Water Use Efficiency

Singh *et al.* (1999) in chilli found that drip fertigation had a higher water use efficiency (5.17 kg $ha^{-1}$ $mm^{-1}$) and saved 40 per cent more water than the check basin irrigation (4.90 kg $ha^{-1}$ $mm^{-1}$).

Ali and Rahman (2012) carried out an experiment to compare water use efficiency of tomato plants under various methods of irrigation. They found that among various methods, surface drip irrigation enhanced the water use efficiency of tomato by two-fold (37.88 kg $m^{-3}$) when compared to flood irrigation (19.88 kg $m^{-3}$).

In tomatoes, the adoption of drip irrigation has resulted in higher water use efficiency (4.87 kg $m^{-3}$) than furrow irrigation (1.66 kg $m^{-3}$). Drip irrigation also saved

56.4 per cent of the water while increasing yield significantly over furrow method of irrigation (Tagar *et al*., 2012).

In bhindi, drip fertigation with 100 per cent of the recommended dose of water soluble fertilizers is ideal for increasing water use efficiency and water productivity (Mahendran *et al*., 2013). They also revealed that the surface method of irrigation uses 22 per cent more water than drip irrigation, resulting in low water use efficiency and water productivity.

Gebremedhin (2015) conducted a study in onion using drip and furrow irrigation methods and concluded that drip irrigation obtained higher water use efficiency at 60 per cent ETc (7.60 kg $m^{-3}$) and the lowest (4.75 kg $m^{-3}$) with furrow irrigation.

Deshmukh *et al*. (2016) observed that drip irrigation with 0.60 IW/ETc resulted in a 54 per cent improvement in water use efficiency and 64 per cent water saving over furrow method of irrigation in tomatoes.

According to Kumar *et al.* (2016), the adoption of drip irrigation resulted in the highest field water use efficiency (61.48 kg $ha^{-1}m^{-1}$) with a 35 per cent water saving in brinjal.

Adawadkar *et al.* (2019) compared the drip fertigation and traditional application of fertilizers on brinjal and noticed that drip fertigation at 150 percent RDF recorded the highest water use efficiency (7.33 q $ha^{-1}cm^{-1}$) compared to the traditional irrigation.

## 2.2 SUB SURFACE DRIP IRRIGATION

### 2.2.1 Effect on Growth and Growth Attributes

In chilli, Prabhakara (2008) found that daily sub surface drip fertigation at 10 cm depth resulted in increased plant height (71.8 cm), and total dry matter production (176.7 g per plant), when compared to other irrigation systems.

The performance of surface and sub surface drip irrigation for cauliflower was compared by Parshuram (2014), who revealed that sub surface placement of laterals at a depth of 15 cm increased plant height, number of leaves, stem diameter, leaf area index, and root length density of cauliflower.

Abdelhady *et al.* (2017) found that growth parameters of tomato like plant height, number of branches, shoot dry weight, shoot: root ratio was higher under sub surface drip irrigation along with 100 per cent NPK fertilization rate than the surface method of drip irrigation.

Ragab *et al.* (2019) investigated the effects of various irrigation systems on the growth, quality, yield, and water use efficiency of tomatoes and noticed that the SSDI system increased plant height, number of leaves per plant, total leaf area per plant, number of flowers, fresh and dry weights of leaves per plant significantly more than the control plot.

### 2.2.2 Effect on Yield and Yield Attributes

Field studies to analyse the effect of surface and sub surface drip irrigation on fruit quality and yield of tomato revealed that under limited water supplies, sub surface drip irrigation is an excellent way for processing tomatoes. Sub surface irrigation at 50 per cent ETc increased the yield by 66.5 per cent compared with the surface treatment (del Amor and del Amor, 2007).

A three-year study was carried out to determine the appropriate depths for drip tape installation at various irrigation levels, Patel and Rajput (2007) confirmed that applying 23.6 cm of irrigation water and installing the drip tape at a depth of 10.0 cm enhanced potato yield in the years 2002-2003 and 2004-2005 respectively.

Singh and Rajput (2007) investigated the effects of sub surface drip irrigation at various lateral depths, including 5 cm, 10 cm, and 15 cm. In comparison to surface drip, inline drip laterals positioned at 0.10 to 0.15 m below the soil surface produced the highest yield (13.4 %) in okra. Vadar *et al.* (2019) found that subsurface drip irrigation at 1.0 IW/ CPE resulted in a higher yield of summer okra (15.46 t $ha^{-1}$) than other irrigation regimes.

As per the study conducted by Rakesh *et al.* (2011), tomato irrigated with a lateral placed at a depth of 25 cm obtained an average yield of 50.5 t $ha^{-1}$ and 49.7 t $ha^{-1}$ in the years 2005 and 2006, respectively, in comparison to surface drip irrigation.

Vadar and Subbaiah (2016) studied the performance of summer cowpea under sub surface drip irrigation and concluded that the combination of 1.0 IW/ CPE level and drip lateral placement at 15 cm depth produced the maximum yield (18.31 t $ha^{-1}$) in clay loam soil.

Tripathi *et al.* (2016) conducted a study on the influence of drip lateral placement and municipal wastewater on eggplant (*Solanum melongena* L.) growth and yield, finding that sub surface drip at 15 and 30 cm depths produced 12.4 and 8.5 per cent higher yields, respectively, than surface drip.

Patil and Tiwari (2018) carried out an experiment to compare the yield response of okra to sub surface drip irrigation and furrow irrigation at various irrigation levels, and revealed that the yield response of okra under sub surface drip laterals placed at 10 cm was 56.4 per cent higher than the yield response of furrow irrigation.

A study was conducted in tomatoes to optimize different lateral placement depths of sub surface drip irrigation and revealed that the mean fruit yield of tomato can be enhanced using sub surface drip laterals placed at 0.05-0.25 m depths as compared to surface drip irrigation (Singh *et al*., 2020a).

Singh *et al.* (2020b) conducted a study on the growth and yield of cauliflower under surface and sub surface drip irrigation with treated municipal wastewater and found that the curd yield increased by 7.58 per cent and 8.49 per cent under surface and sub surface pressure-compensating drip laterals when compared to groundwater-irrigated treatments.

Singh *et al.* (2021) compared the performance of tomato under subsurface drip irrigation laterals placed at various depths in inceptisols and found that the maximum yield of tomato (52.85 t $ha^{-1}$) was obtained under SDI with laterals placed at 10 cm depth below soil surface, followed by sub surface drip at 15 cm and 5 cm depths of placement.

### 2.2.3 Effect on Quality Attributes

Wang *et al*. (2018) reported that sub surface drip irrigation at a depth of 20 cm is effective in boosting tomato fruit quality parameters such as lycopene, soluble protein and vitamin C.

Sub surface drip irrigation at 20 cm significantly improved the fruit quality parameters, photosynthetic pigments, leaf mineral content, relative leaf water content of tomato plants compared to control (Ragab *et al.,* 2019)

### 2.2.4 Effect on Water Use Efficiency and Water Productivity

Nisha (2007) investigated the performance of sub surface drip irrigation on okra in sandy clay loam soils and found that the crop water use efficiency recorded under sub surface drip irrigation (11.24 kg $ha^{-1}mm^{-1}$) was higher than the surface drip irrigation (7.18 kg $ha^{-1}$ $mm^{-1}$).

Parshuram (2014) compared the surface and sub surface drip fertigation for cauliflower, and noticed that sub surface drip irrigation had a higher water use efficiency (87.05 kg $ha^{-1}mm^{-1}$) than drip irrigation (78.82 kg $ha^{-1}mm^{-1}$) and surface irrigation (28.52 kg $ha^{-1}mm^{-1}$).

A study on onion productivity was conducted using sub surface drip versus furrow irrigation systems with an internet-based irrigation scheduling programme, and the results showed that sub surface drip irrigation had the highest irrigation water use efficiency when compared to furrow irrigation (Enciso *et al.,* 2015).

According to Mali *et al.* (2017), installing sub surface laterals at 5, 10, and 15 cm depths increased bitter gourd water productivity by 23.2, 39.2, and 32.7 per cent, respectively. Among different lateral depths, the highest water productivity was recorded when the drip tube was installed at a depth of 10 cm.

According to Al-Ghobari and Dewidar (2018), the maximum water use efficiency obtained was higher under sub surface drip irrigation (19.7 kg $m^{-3}$) than under surface drip irrigation (18.3 kg $m^{-3}$) in tomatoes and they concluded that the use of modern irrigation systems in conjunction with deficit irrigation strategies can improve both irrigation water use efficiency and tomato fruit quality.

## 2.3 RAIN HOSE IRRIGATION

Ayyadurai *et al.* (2020) reported that in groundnut, rain hose irrigation produced a 40.5 per cent maximum yield and a highest water use efficiency (7.28 kg $ha^{-1}$ $mm^{-1}$ ), saving of 49 per cent more water than surface irrigation. The net return (₹ 62,850 $ha^{-1}$) and B: C ratio (2.95) was also higher under rain hose irrigation.

## 2.4 ECONOMICS OF DRIP AND SUB SURFACE DRIP IRRIGATION

An experiment was carried out to compare the effects of drip irrigation and black polyethylene mulch on tomato yield and economics and, it was found that drip irrigation at 80 per cent ET resulted in increased net returns (₹ 34, 431 $ha^{-1}$) and B: C ratio (1.76) in tomato (Singh and Kumar, 2007).

According to Dunage *et al.* (2009) the maximum net returns of ₹ 3.62 lakhs $ha^{-1}$ could be obtained by the application of FYM using drip irrigation at 100 per cent ET with a benefit-cost ratio of 5.19 in tomato.

In a study to compare the effectiveness and cost economics of fertigation for brinjal under drip irrigation and furrow irrigation, Bhogi et al. (2011) observed a higher net income (₹ 57088 $ha^{-1}$) and B: C ratio (4.99) under drip irrigation and the lowest net income (₹ 41345 $ha^{-1}$) and B: C ratio (3.72) was obtained under furrow irrigation.

In a study on the economic evaluation of drip irrigation in sweet pepper, Singh *et al.* (2011) found that the gross income from the drip irrigation system was ₹ 2.83 lakhs $ha^{-1}$. Drip irrigation technology has a higher benefit cost ratio (2.55:1) than traditional irrigation (2.07:1), implying superior returns.

Drip irrigation system increased the net seasonal income 54 per cent as compared to conventional surface irrigation without mulch with a benefit cost ratio of 2.01 in tomato (Paul *et al.*, 2013). The adoption of drip irrigation at 80 per cent ET yielded the highest net returns (₹4.02 lakhs $ha^{-1}$) compared to furrow irrigation (₹1.05 lakhs $ha^{-1}$) (Reddy *et al.*, 2013).

## 2.5 MULCHING

### 2.5.1 Effect on Growth and Yield Parameters

Mahmood *et al.* (2002) found out that in potato, the maximum growth rate was 43 per cent higher than the non mulched treatment. Similarly yield gained under grass mulch was higher than the control with a 43.2 per cent increase above the control.

According to Chattha and Hayat (2005), the maximum tomato yield was obtained with wheat straw mulching (96.45 t $ha^{-1}$), whereas the minimum yield was produced with control (55.41 t $ha^{-1}$). Wheat straw boosts tomato yield by 43 per cent over control.

Ghosh *et al.* (2006) revealed that straw mulch yielded 17-24 per cent higher pod yield and 16 per cent more haulm yield in groundnut than polythene mulch. Kayum *et al.* (2008) obtained the maximum plant height (123.20 cm), number of leaves (65.73), leaf area (1007.00 $cm^2$), number of fruits per plant, and dry weight of leaves, stem, and roots in tomato under water hyacinth mulch, followed by straw and banana leaf mulch.

According to Bahadur *et al.* (2009) pea-straw mulch significantly increased the height of plant, number of pods per plant, pod weight, and fresh pod yield over the non-mulched control. Similarly mulched okra plants yielded 31.4 per cent more pods than the non-mulched okra plants.

Norman *et al.* (2011) found that okra had a higher mean fruit weight under dry grass mulch and the maximum mean fruit weight of pepper was under sawdust mulch than the control.

The experiment conducted by Singh *et al*. (2013) revealed that the combination of vermicompost and organic mulching with 5 cm thick crop residues have significantly improved plant height (106.5 cm), average leaf weight (1301 mg per leaf), leaf area (40.6 $cm^2$), fruit weight (92.9 g), and fruit yield (4.01 kg per plant) of tomato.

Marichamy *et al.* (2016) evaluated the effect of different mulches on vegetative and reproductive components of chilli and reported that fruit set, number of fruits per plant, fruit length, fruit girth, fruit weight, fruit yield per plant and total yield kg $m^{-2}$ were higher under organic mulches with leaf litter and crop residues than control.

Tomar *et al*. (2018) found that tomatoes cultivated with paddy straw as biomulch registered the maximum number of flowers per inflorescence, number of inflorescence per plant and harvest duration. However, the minimum number of flowers per inflorescence and inflorescence per plant was recorded under no mulch.

Navyashree *et al.* (2019) investigated the impact of mulches on soil chemical properties on tomato yield and observed that that straw mulch treatment resulted in higher yield per plant, the maximum number of trussels per plant, and the number of fruits per plant when compared to the unmulched control treatment.

Chaurasia and Sachan (2020) compared the effects of organic and inorganic mulches on summer squash and found that plant height, plant spread, collar diameter, number of leaves per plant, number of fruits per plant, days to the first harvest, number of harvesting, yield per plant, total yield were superior under organic much than the control plot.

In a study on the influence of various mulching materials on the growth and yield of chilli, Rani *et al.* (2020) observed that paddy straw mulch produced higher plant height, average number of fruits per plant, average weight of fruit, and fruit yield per plant than the control treatment.

### 2.5.2 Effect on Water Use Efficiency

Acharya and Kapur (2001) revealed that the use of pine-needle mulching with 60 kg N $ha^{-1}$ showed significantly higher water-use efficiency in potato than no mulch. Moreover, the mulching also resulted in the saving of one irrigation, resulting in a 50 per cent and 22 per cent higher yield of potato during autumn and spring, respectively.

In a study on the effect of irrigation and mulching on potatoes, Narolia (2013) reported that mulching with sugarcane leaves and paddy straw produced the maximum number of tubers and resulted in a higher yield of potatoes compared to black polythene and without mulch.

Singh (2016) reported that the use of rice straw mulch at 6 t $ha^{-1}$ improved total water use efficiency (11.09 kg bulb $ha^{-1}$ $mm^{-1}$) over no mulch plots in onion.

Goel *et al.* (2020) in an experiment to evaluate the effectiveness of locally available organic mulches on moisture retention, yield, and irrigation water use efficiency in a tomato crop observed higher crop water use efficiency under rice straw mulch (26.6 %) followed by wheat straw mulch (12.5 %) and pine needle mulch (8.9%) over no mulch.

## 2.6 COMBINED EFFECT OF DRIP IRRIGATION AND MULCHING ON GROWTH AND YIELD OF CROPS

Nijamudeen and Dharmasena (2002) revealed that adoption of a drip irrigation system increased chilli yield by 48 and 33 per cent in two seasons, 1999 and 2000, respectively. Drip irrigation with rice straw mulch could increase chilli yield by 32 per cent while reducing water use by 28 per cent.

Choudhary *et al.* (2012) evaluated the impact of surface drip irrigation and different mulching materials on the growth, yield, and economics of okra and reported that drip irrigation recorded significantly higher vegetative characters, *viz.*, plant height, number of leaves, branches per plant, and chlorophyll content in leaves and fruits. Among the mulches, organic mulch recorded the significantly highest vegetative growth, yield, quality, and economic parameters.

Yadav and Choudhary (2012) carried out an investigation on the influence of drip irrigation and different mulches on the growth, yield and water use efficiency of tomatoes revealed that combination of drip irrigation at 85 per cent ET and organic mulches are effective for obtaining higher plant growth and yield attributes in tomatoes.

Shilpa (2019) reported that combination of surface drip with organic mulch produced more number of fruits (89.64), fruit yield per plant (762.02 g), fruit yield $m^{-2}$ (3.69 kg), and total dry m

atter production (6697 kg $ha^{-1}$) in chilli. Similarly, use of organic mulch also improved the height of the plant, the number of branches per plant, and the leaf area index compared to no mulch.

Devi *et al.* (2020) opined that a combination of drip irrigation with mulch has resulted in the maximum number of leaves and plant height. Similarly, the highest yield per plant (1548 g) and yield $m^{-2}$ (3490 g) were also observed under drip irrigation with mulching. The use of drip in combination with mulch resulted in 62 per cent saving of irrigation water than the conventional method.

## 2.7 ECONOMICS OF MULCHING

Biswas *et al.* (2015) reported the highest net return, incremental net return, and incremental benefit-cost ratio (7.03) for 50 per cent irrigation with straw mulch over black polythene mulch in tomato.

Rao *et al.* (2016) revealed that in the case of organic mulch, net return (₹ 2, 68,200 $ha^{-1}$) and the incremental net return (₹ 55,800 $ha^{-1}$)obtained were higher than the treatment without mulch (₹ 2,12,400 $ha^{-1}$ ) in tomato.

Highest B: C ratio of 3.3:1 was obtained with application of organic mulch @ 12 t $ha^{-1}$ and found more economically beneficial as compared to other treatments like black polythene, silver black polythene and black silver polythene mulches in chilli (Singh, 2016).

Tegen *et al.* (2016) opined that the highest net benefit was obtained from grass mulch with a marginal rate of return of 70 per cent compared to black plastic mulch, white plastic mulch and no mulch.

In chilli, higher net returns and BCR were obtained with organic mulch and it was 58.51 per cent and 27.89 per cent more compared to no mulch (Shilpa, 2019). Wheat straw mulch recorded the maximum BCR of 1.52 and the lowest BCR (1.33) was recorded without mulch treatment in pigeon pea (Jadav *et al*., 2020).

The literature reviewed in the previous sections clearly demonstrated that various crops responded better to micro irrigation and mulching, resulting in increased yield and quality. Considering the scarcity of water and the need to increase crop water use efficiency, studies on micro irrigation and mulching in crops such as tomato will undoubtedly highlight these aspects. However, there is a research gap in combined studies on the effect of different micro irrigation methods and mulching on crops. Thus, the study was carried out with the previously stated objectives of investigating the efficacy of micro irrigation and mulching on growth, yield, and economics of tomato.

# MATERIALS AND METHODS

# 3. MATERIALS AND METHODS

An investigation entitled "Micro irrigation and mulching for yield optimization of tomato in rain shelter" was carried out from February to May, 2021 at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala to evaluate the efficacy of micro irrigation and mulching on growth, yield and economics of tomato in rain shelter. An overview of the materials and methods used during the field experimentation are briefly discussed in this section.

## 3.1 EXPERIMENTAL SITE

### 3.1.1 Location

The field experiment was carried out at the Instructional Farm attached to the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is located at 8˚25'43" North latitude and 76˚59'19" East longitude and at an altitude of 29 m above mean sea level.

### 3.1.2 Season

The field experiment was conducted during the *summer* season of 2021.

### 3.1.3 Weather Conditions

The meteorological parameters such as maximum and minimum temperature, relative humidity, and light intensity were measured inside the rain shelter and are shown in Appendix 1 and graphically depicted in Fig. 1.

### 3.1.4 Soil

The soil was found to be sandy clay loam in texture. Before conducting the field experiment, composite soil samples from 0-30 cm depth were randomly collected from various locations and the physical and chemical properties were determined. The data obtained are presented in Table 1.

Table. 1. Physical and chemical properties of the soil of the experimental site

| S. No. | Fractions | Content in soil | Method used |
|---|---|---|---|
| 1. | Bulk density ($Mg\ m^{-3}$) | 1.47 | Core sampler method Blake (1965) |
| 2. | Field capacity (%) | 19.25 | Field method (Misra and Ahmed, 1987) |
| 3. | Permanent wilting point (%) | 7.63 | Field method (Misra and Ahmed, 1987) |
| 4. | Soil reaction (pH) | 6.1 (Slightly acidic) | Soil : water ratio of 1:1.25 using pH meter ( Jackson, 1973) |
| 5. | Organic carbon (%) | 1.21 (High) | Walkley and black rapid titration method (Jackson, 1973) |
| 6. | Available N ($kg\ ha^{-1}$) | 252 (Medium) | Alkaline permanganate method (Subbaiah and Asija, 1956) |
| 7. | Available P ($kg\ ha^{-1}$) | 68.2 (High) | Bray colorimetric method (Jackson, 1973) |
| 8. | Available K ($kg\ ha^{-1}$) | 242 (Medium) | Ammonium acetate method (Jackson, 1973) |

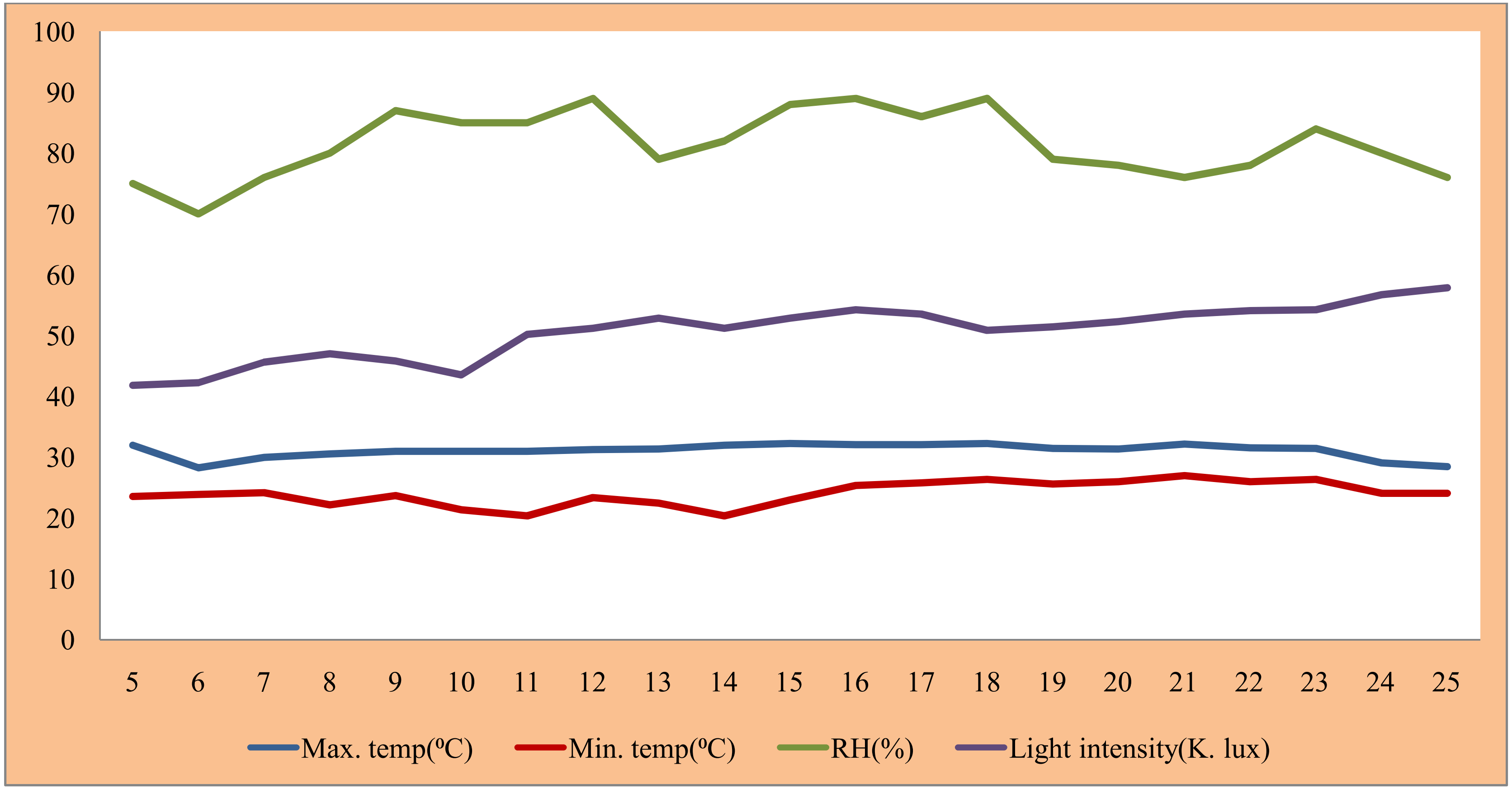


Fig. 1. Weather parameters during the cropping period inside the rain shelter (February- May 2021)

## 3.2 MATERIALS

### 3.2.1 Variety

The variety of tomato, Vellayani Vijai was used as the test crop. This was released in 2006 from the College of Agriculture vellayani. It was an introduction and selection from CLN1621F (AVRDC, Taiwan). This variety is resistant to bacterial wilt disease, which is a serious problem in tomato cultivation.

### 3.2.2 Seeds

The seeds of the variety Vellayani Vijai were obtained from the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala.

### 3.2.3 Manures and Fertilizers

Farm Yard Manure (FYM) @ 20 t $ha^{-1}$ was applied as basal during land preparation. Fertilizer requirement of tomato 264:130: 281 kg NPK $ha^{-1}$ was given through fertigation as per the *Adhoc* POP recommendation for precision farming (KAU, 2013). Rajphos @ 325 kg $ha^{-1}$ was given as basal dose. Major nutrients required for the crop were given as water soluble fertilizers.

## 3.3 METHODS

### 3.3.1 Design and Layout

Design : Split Plot Design

Treatments : 10

Replications : 4

Variety : Vellayani Vijai

Spacing : 60 cm × 60 cm

Plot Size : 3.0 m × 2.4 m

***3.3.1.1 Treatments***

**Main plot: Types of Micro irrigation (I)**

$i_1$: Surface drip irrigation

$i_2$: Rain hose irrigation

$i_3$: Sub surface drip irrigation at 10 cm

$i_4$: Sub surface drip irrigation at 15 cm

$i_5$: Sub surface drip irrigation at 20 cm

**Sub plot: Mulching Material (M)**

$m_1$: No mulch

$m_2$: Organic mulch (crop residues)

**3.3.2 Details of Cultivation**

***3.3.2.1 Nursery***

Seedlings of tomato were raised in protrays. Potting mixture made by mixing coir pith and dried cow dung in equal proportion was filled in protrays. Seeds were plugged in each hole, @ one seed per hole. The protrays were watered twice daily and the seedlings were ready for transplanting after one month.

***3.3.2.2 Land Preparation***

The field was cleaned and deep ploughing was carried out by means of tractor drawn disc plough, and the soil was pulverized using a rotavator. Farmyard manure (FYM) @ 20 t $ha^{-1}$ was given as basal during land preparation and the field was laid out as per the design. The drip tubes were installed at different depths as per the treatment.

***3.3.2.3 Planting***

Healthy one month old tomato seedlings were transplanted in the field at a plant spacing of 60 cm × 60 cm.

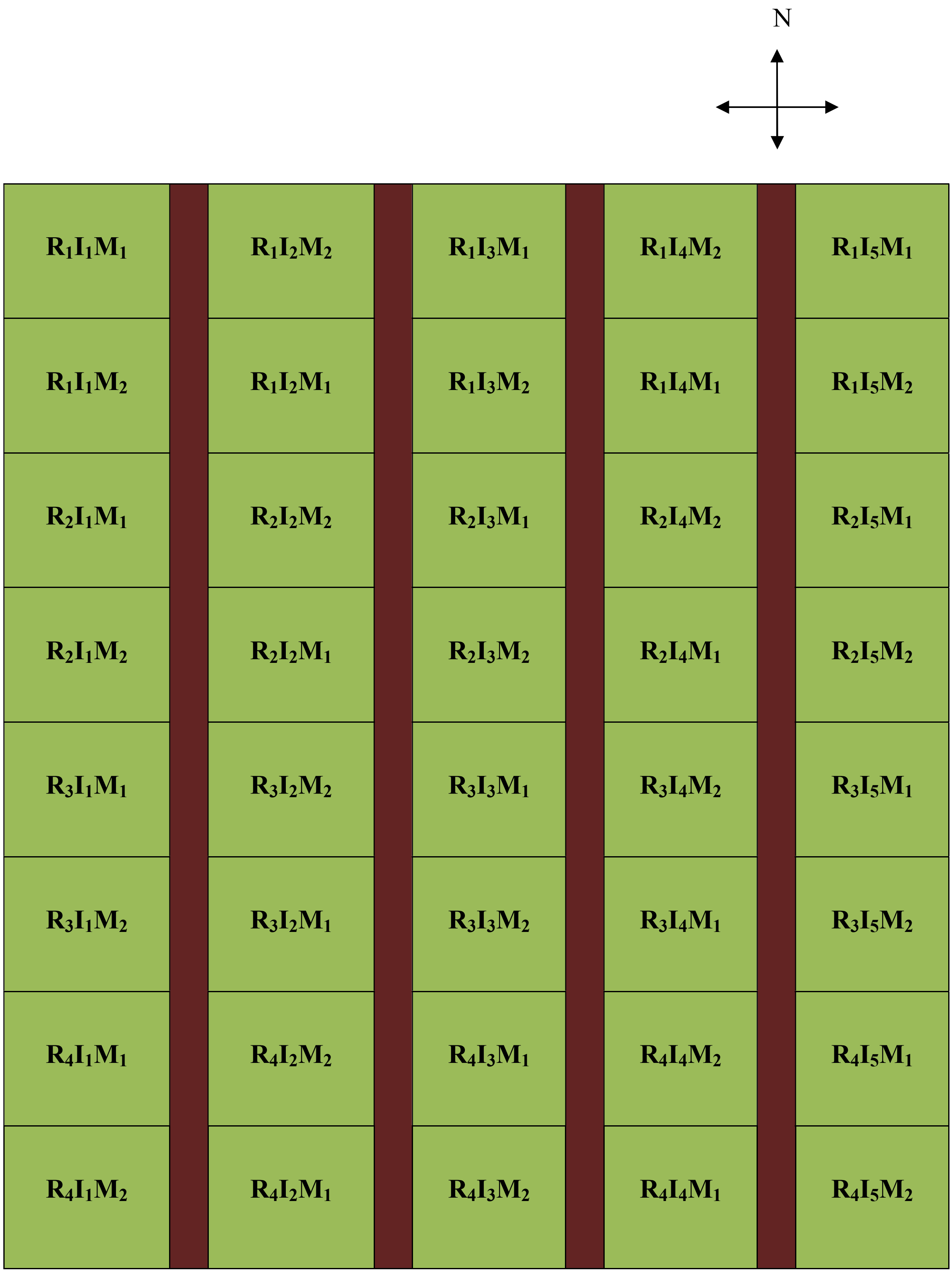


**Fig. 2. Layout plan of the experiment**

Plate 1: Surface drip

Plate 2: Rain hose

Plate 3: Sub surface drip at 10 cm

Plate 4: Sub surface drip at 15 cm

Plate 5: Sub surface drip at 20 cm

Plate 6:  Layout with dry banana leaves

Plate 7: Crop at seedling stage

Plate 8: Crop at flowering stage

Plate 9: General view of the experimental plot

*3.3.2.4 Mulching*

Dry banana leaves @10 t $ha^{-1}$ collected from the premises of College of Agriculture, Vellayani were applied to the sub plots as per the treatments.

*3.3.2.5 Drip Fertigation System*

Micro irrigation was practiced for all treatments. From the existing tank in the field, irrigation water was diverted to the experimental area using a pump. Delivery of water to individual beds was done through laterals connected to the sub mains. Pressure compensating drippers, each with a discharge rate of 2 L $h^{-1}$ at 60 cm spacing were connected to the laterals to deliver water to individual plants. Rain hose was also used as one treatment. A rain hose is a flexible hose with a drip hole pattern made with nano punching technology to ensure a consistent flow of water. Water soluble fertilizers, *viz.,* Urea @ 327 kg $ha^{-1}$, polyfeed (19:19:19) @ 198 kg $ha^{-1}$, mono ammonium phosphate (12:61:0) @ 44 kg $ha^{-1}$ and potassium nitrate (13:0:45) @ 540 kg $ha^{-1}$ were given along with the irrigation water. Fertigation was given at 3 days interval using a fertilizer venturi system.

*3.3.2.6 Estimation of Crop Water Requirement*

Water requirement for the tomato crop was computed using the following relationship:

$V= E_p \times K_c \times K_p \times W_p \times S_p$

V : Water requirement in litre/day/ plant

$E_p$ : Average pan evaporation (8 mm)

$K_c$ : Crop coefficient

(Initial stage-0.40; Development stage-0.70; Maturity Stage- 0.90; End stage- 0.85)

$K_p$ : Pan coefficient (0.7)

$W_p$ : Wetted area (0.9 $m^2$ for closely spaced crops)

$S_p$ : Spacing of crop in $m^2$ (0.6m x 0.6m) (Reddy and Reddy, 2019)

*3.3.2.7 Scheduling of Irrigation*

As the roots were short during the seedling stage, manual watering was done for a period of one week to ensure that the roots get enough water to survive. After one week, irrigations were scheduled based on the crop water requirement of the crop. The discharge rate of the emitter was 2 L $h^{-1}$ spaced at 60 cm apart.

***3.3.2.8 Staking***

Staking was provided to each plant at 45 days after transplanting. Staking was done using wooden sticks and plants were tied with the help of plastic twine. Separate plastic twine was provided to each plant and to each branch to avoid the breaking up of branches.

***3.3.2.9 Weeding***

Weeds interfere with the growth of the crop by absorbing water and nutrients. Therefore, periodical removal of the weeds was essential to maintain an optimum growth rate for the crops. Hand weeding was done at monthly intervals.

***3.3.2.10 Plant Protection***

Plant protection measures using the recommended dose of chemicals were adopted to prevent the incidence of pest and disease attacks. Imidacloprid @ 3mL per 10 L of water was sprayed against whitefly and Chlorantraniliprole @ 2.5mL per 10L of water was sprayed twice against *Spodoptera litura* attack.

***3.3.2.11 Harvest***

Harvest of fruits started from 60 DAS and the first picking was done when fruits were fully developed and turned red in colour. Further pickings varied with respect to the treatments.

## 3.4 OBSERVATIONS

### 3.4.1 Growth Attributes

***3.4.1.1 Plant Height***

To study growth attributes, five plants per plot were identified and tagged randomly. At monthly intervals and at harvest, the height of the plant was measured from the base of the observational plant to the top of the longest leaf using a metre scale. The average height calculated was expressed in cm.

***3.4.1.2 Number of Branches per Plant***

The actual number of primary branches per plant at 50 per cent flowering and at final harvest was recorded from the tagged observational plants and their averages were computed.

***3.4.1.3 Days to 50 Per Cent Flowering***

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

***3.4.1.4 Leaf Area Index***

The leaf area was calculated using a general relationship, LA = k (L × W), where k is a coefficient (0.5) (Carmassi *et al.,* 2007). The length and breadth of two leaves from the bottom, middle and top of the plants from each of the observational plants were taken in case of all treatment plots and the leaf area index at 50 per cent flowering was worked out using the following formula developed by Watson (1947)

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

***3.4.1.5 Root-Shoot Ratio***

Root and shoot dry weights were measured separately for each treatment at harvest and root to shoot ratio was worked out.

***3.4.1.6 Dry Matter Production***

Total dry matter production was calculated at the final harvest of tomato. The samples were dried to a constant weight in a hot air oven at 60±5˚C and dry weights were recorded and expressed in kg $ha^{-1}$.

**3.4.2 Root Parameters**

***3.4.2.1 Root Depth***

Randomly selected five sample plants from each treatment were uprooted carefully, root portion was separated, cleaned and the length at the harvest stage of the crop was measured. The mean value was calculated and expressed in cm.

### *3.4.2.2 Root Volume*

The water displacement method (Misra and Ahmed, 1987) using a graduated cylinder was used to measure the root volume of the observational plants in each treatment and the volume was expressed as $cm^3$. Root volume was taken at the final harvest.

## 3.4.3 Yield Attributes

### *3.4.3.1 Number of Fruits per Plant*

At the time of each picking, the number of fruits picked per plant was recorded from observational plants for each treatment and the mean was calculated.

### *3.4.3.2 Average Fruit Weight*

At the time of each picking, tomato fruits of each observational plant were taken and weighed separately for each treatment.

### *3.4.3.3 Fruit Yield per Plant*

The fruit yield per plant from the five randomly selected observational plants from each treatment was recorded separately and the mean yield was calculated in kg.

### *3.4.3.4 Total Fruit Yield $m^{-2}$*

Fruit yield in the net plot area was converted to yield $m^{-2}$.

## 3.4.4 Quality Aspects of Fruits

### *3.4.4.1 Total Soluble Solids (TSS)*

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

### *3.4.4.2 Ascorbic Acid*

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

***3.4.4.3 Lycopene***

Lycopene content of fresh ripe fruits was measured by colorimetric method using petroleum ether procedure as suggested by Srivastava and Kumar (2002). Fresh ripe fruit from tagged plants of each treatment was taken and lycopene content was determined and expressed as mg 100 $g^{-1}$.

**3.4.5 Plant Analysis**

The N, P, and K content of tomato plants were analyzed by standard procedures. The uptake of N, P and K were calculated as the product of the content of these nutrients and the plant dry weight and expressed in kg $ha^{-1}$.

***3.4.5.1 Nitrogen Content***

N content was determined by distillation and titration method (Jackson, 1973).

***3.4.5.2 Phosphorus Content***

Diacid digestion of plant sample was done to determine the P content by Vanadomolybdo phosphoric yellow colour method (Jackson, 1973).

***3.4.5.3 Potassium Content***

K content in diacid digest was estimated using flame photometer (Jackson, 1973).

**3.4.6 Soil Analysis**

***3.4.6.1 Available NPK and Organic Carbon Before and After the Experiment***

Composite soil samples were collected from the experimental area before the experiment and plot wise after the experiment. The air-dried samples passed through a 2 mm sieve were used for the determination of physico-chemical properties. The air-dried samples were analysed for organic carbon by Walkley and black titration method (Jackson, 1973), available nitrogen by the alkaline potassium permanganate method (Subbaiah and Asija, 1956), available phosphorus by Bray’s colorimetric method and available potassium by ammonium acetate method (Jackson, 1973).

#### *3.4.6.2 Soil Moisture at 15 and 30 cm Depth*

Soil moisture content was measured by the gravimetric method. The moisture content of the soil after irrigation at 15 and 30 cm depths was recorded at monthly intervals in all the plots.

### 3.4.7 Soil Moisture Studies

#### *3.4.7.1 Water Productivity*

Water productivity was calculated using the following formula (Kijne *et al.,* 2003) and expressed in kg m$^{-3}$.

$$\text{Water productivity} = \frac{\text{Total biomass produced (kg)}}{\text{Total water utilized (m}^3\text{)}}$$

#### *3.4.7.2 Field Water Use Efficiency*

Field water use efficiency was computed by the following formula (Condon and Hall, 2004) and expressed as kg m$^{-3}$ of water.

$$\text{Field water use efficiency} = \frac{\text{Fruit yield (kg)}}{\text{Total water utilized (m}^3\text{)}}$$

### 3.4.8 Meteorological Parameters (Inside Rain Shelter)

Meteorological parameters like maximum and minimum temperature, relative humidity and light intensity inside the rain shelter were recorded at weekly intervals.

#### *3.4.8.1 Maximum and Minimum Temperature*

The maximum (at 2.30 pm) and minimum (at 7.30 am) air temperatures in $^{o}$C were measured inside the rain shelter using a mercury thermometer (0-50 $^{o}$C) at canopy height, and averages were calculated.

#### *3.4.8.2 Relative Humidity*

The relative humidity inside the rain shelter was measured using a wet bulb and a dry bulb thermometer at 2.30 pm and 7.30 pm, and was expressed in per cent (0 to 100 %).

***3.4.8.3 Light Intensity***

Lux metre was used to measure light intensity between 11 am and 12 pm inside the rain shelter and expressed in K. lux.

## 3.5 INCIDENCE OF PESTS AND DISEASES

Incidence of pest and diseases was monitored during the entire cropping period.

## 3.6 ECONOMIC ANALYSIS

Economics of cultivation for the experiment was determined considering the cost of cultivation and the prevailing market price of tomato. The net returns and benefit cost ratio was calculated as follows:

Net returns (₹ $ha^{-1}$) = Gross returns – Cost of cultivation

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

## 3.7 STATISTICAL ANALYSIS

Data generated from the experiment were statistically analysed by applying analysis of variance (ANOVA) for split plot design (Snedecor and Cochran, 1980) and significance was tested. Critical difference (CD) was calculated using standard techniques at a 5 per cent probability level in cases where the effects are significant.

# ***RESULTS***

# 4. RESULTS

A field experiment entitled "Micro irrigation and mulching for yield optimization of tomato in rain shelter" was carried out at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during the period February to May 2021. The objective was to assess the effectiveness of various micro irrigation methods and mulching for improving the growth, yield and economics of tomato in rain shelter. The experimental data collected on various parameters were statistically analysed and the findings are presented in this chapter.

## 4.1 EFFECT OF TYPES OF MICRO IRRIGATION AND MULCHING ON TOMATO

### 4.1.1 Growth and Growth Attributes

#### *4.1.1.1 Plant Height*

The data pertaining to average plant height influenced by the types of micro irrigation and mulching are presented in Table 2.

Different types of micro irrigation had a significant influence on plant height at all phases of the plant growth.

At 30 DAT, the maximum plant height was recorded in sub surface drip irrigation at 10 cm depth ($i_3$) (55.76 cm) followed by sub surface drip irrigation at 15 cm depth ($i_4$). The treatment surface drip irrigation ($i_1$) was in turn on par with rain hose irrigation ($i_2$) at 30 DAT. The lowest plant height was recorded in sub surface drip irrigation at 20 cm depth ($i_5$) (40.29 cm). At 60 DAT, plant height was significantly higher in sub surface drip irrigation at 10 cm depth ($i_3$) (90.91 cm). The treatment sub surface drip irrigation at 15 cm depth ($i_4$) was in turn on par with sub surface drip irrigation at 20 cm depth ($i_5$). The lowest plant height was recorded in rain hose irrigation ($i_2$) (70.56 cm).

At 90 DAT and at harvest, the maximum plant height was recorded in the treatment sub surface drip irrigation at 10 cm depth ($i_3$) (107.41cm, 114.98 cm) and it was on par with sub surface drip irrigation at 15 cm depth ($i_4$). The treatment sub surface drip irrigation at 15 cm depth ($i_4$) was in turn on par with sub surface drip irrigation at 20 cm depth ($i_5$). The lowest plant height was recorded in the treatment rain hose irrigation ($i_2$) (87.74 cm, 101.57 cm) and was on par with surface drip irrigation ($i_1$).

At all phases of plant development, mulching had a significant influence on plant height. Significantly higher plant height was recorded for organic mulch ($m_2$) at 30 DAT (50.16 cm), 60 DAT (83.70 cm), 90 DAT (98.76 cm), and at harvest (110.22 cm).

The interaction effect of micro irrigation and mulching had no significant influence on plant height at all stages of plant growth.

#### *4.1.1.2. Number of Branches per Plant*

The data pertaining to number of branches per plant recorded at 50 per cent flowering and at harvest are given in the Table 3.

Different types of micro irrigation had a significant influence on the number of branches per plant at 50 per cent flowering and at harvest. At 50 per cent flowering, the maximum number of branches per plant was produced in sub surface drip irrigation at 10 cm depth ($i_3$) (8.01) and it was on par with sub surface drip irrigation at 15 cm depth ($i_4$). The lowest number of branches per plant was produced in the treatment rain hose irrigation ($i_2$) (5.22) and it was on par with surface drip irrigation ($i_1$).

At harvest, the maximum number of branches per plant was produced in sub surface drip irrigation at 10 cm depth ($i_3$) (13.61) and it was on par with sub surface drip irrigation at 15 cm depth ($i_4$) and sub surface drip irrigation at 20 cm depth ($i_5$). The lowest number of branches per plant was produced in the treatment rain hose irrigation ($i_2$) (11.15) and it was on par with surface drip irrigation ($i_1$).

Mulching had a significant influence on the number of branches per plant at 50 percent flowering and at harvest. The treatment organic mulch ($m_2$) recorded the maximum number of branches per at 50 per cent flowering (7.07) and at harvest (12.88) compared to no mulch ($m_1$).

Table 2. Effect of types of micro irrigation and mulching on plant height of tomato, cm

| Treatments | Plant height | | | |
|---|---|---|---|---|
| | 30 DAP | 60 DAP | 90DAP | Harvest |
| **Types of micro irrigation (I)** | | | | |
| $i_1$ Surface drip irrigation | 45.07 | 76.69 | 89.69 | 104.10 |
| $i_2$ Rain hose irrigation | 44.40 | 70.56 | 87.74 | 101.57 |
| $i_3$ Sub surface drip irrigation at 10 cm | 55.76 | 90.91 | 107.41 | 114.98 |
| $i_4$ Sub surface drip irrigation at 15 cm | 52.38 | 85.66 | 102.32 | 112.00 |
| $i_5$ Sub surface drip irrigation at 20 cm | 40.29 | 83.75 | 98.30 | 110.02 |
| SE m (±) | 0.87 | 1.39 | 1.72 | 1.02 |
| CD (0.05) | 2.839 | 4.533 | 5.616 | 3.336 |
| **Mulching (M)** | | | | |
| $m_1$ No mulch | 45.00 | 79.33 | 95.42 | 106.85 |
| $m_2$ Organic mulch | 50.16 | 83.70 | 98.76 | 110.22 |
| SE m (±) | 0.78 | 0.50 | 0.46 | 0.52 |
| CD (0.05) | 2.449 | 1.586 | 1.457 | 1.636 |
| **Interaction (I × M)** | | | | |
| $i_1m_1$ | 40.67 | 74.07 | 87.07 | 100.77 |
| $i_1m_2$ | 49.48 | 79.30 | 92.30 | 107.42 |
| $i_2m_1$ | 41.59 | 68.40 | 86.17 | 99.87 |
| $i_2m_2$ | 47.21 | 72.72 | 89.32 | 103.26 |
| $i_3m_1$ | 53.66 | 90.40 | 106.90 | 112.71 |
| $i_3m_2$ | 57.85 | 91.43 | 107.93 | 117.26 |
| $i_4m_1$ | 51.20 | 86.72 | 101.38 | 111.71 |
| $i_4m_2$ | 53.57 | 88.60 | 103.26 | 112.30 |
| $i_5m_1$ | 37.88 | 81.04 | 95.59 | 109.19 |
| $i_5m_2$ | 42.70 | 86.45 | 101.00 | 110.85 |
| SE m (±) | 1.74 | 1.12 | 1.03 | 1.16 |
| CD (0.05) | NS | NS | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

Table 3. Effect of types of micro irrigation and mulching on number of branches per plant of tomato

| Treatments | Number of branches per plant | |
|---|---|---|
| | 50 per cent flowering | Harvest |
| **Types of micro irrigation (I)** | | |
| $i_1$ Surface drip irrigation | 5.31 | 11.27 |
| $i_2$ Rain hose irrigation | 5.22 | 11.15 |
| $i_3$ Sub surface drip irrigation at 10 cm | 8.01 | 13.61 |
| $i_4$ Sub surface drip irrigation at 15 cm | 7.69 | 13.04 |
| $i_5$ Sub surface drip irrigation at 20 cm | 6.44 | 12.84 |
| SE m (±) | 0.22 | 0.39 |
| CD (0.05) | 0.010 | 1.290 |
| **Mulching (M)** | | |
| $m_1$ No mulch | 6.01 | 11.88 |
| $m_2$ Organic mulch | 7.07 | 12.88 |
| SE m (±) | 0.01 | 0.13 |
| CD (0.05) | 0.726 | 0.415 |
| Interaction (I × M) | | |
| $i_1m_1$ | 4.44 | 10.10 |
| $i_1m_2$ | 6.19 | 11.55 |
| $i_2m_1$ | 4.67 | 10.18 |
| $i_2m_2$ | 5.78 | 12.11 |
| $i_3m_1$ | 7.66 | 13.33 |
| $i_3m_2$ | 8.37 | 13.88 |
| $i_4m_1$ | 7.48 | 12.33 |
| $i_4m_2$ | 7.89 | 13.74 |
| $i_5m_1$ | 5.78 | 12.55 |
| $i_5m_2$ | 7.11 | 13.13 |
| SE m (±) | 0.22 | 0.29 |
| CD (0.05) | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

The interaction effect between the types of micro irrigation and mulching had no significant influence on the number of branches per plant at either growth stages.

***4.1.1.3 Days to 50 Per Cent Flowering***

Results on days to 50 per cent flowering as influenced by the types of micro irrigation and mulching are illustrated in Table 4.

Different types of micro irrigation, mulching and their interaction did not significantly influence the days to 50 per cent flowering in tomato.

***4.1.1.4 Leaf Area Index (LAI)***

The effect of various treatments on LAI at 50 per cent flowering is given in Table 4.

The data revealed that types of micro irrigation did not significantly affect the LAI at 50 per cent flowering.

Mulching had a significant influence on the LAI at 50 per cent flowering. The treatment organic mulch ($m_2$) obtained a higher LAI (0.92) compared to no mulch ($m_1$) (0.88).

The interaction effect of micro irrigation and mulching did not show any significant difference in LAI.

***4.1.1.5 Root-Shoot Ratio***

The effect of types of micro irrigation and mulching on the root shoot ratio of plants at harvest is provided in Table 5.

The different types of micro irrigation had a significant influence on root-shoot ratio at harvest. The maximum root-shoot ratio was obtained in sub surface drip irrigation at 10 cm ($i_3$) (0.27) and it was on par with sub surface drip irrigation at 15 cm ($i_4$) and the lowest root-shoot ratio was recorded in surface drip irrigation ($i_1$) (0.18) and was on par with rain hose irrigation ($i_2$).

Mulching had a significant influence on root-shoot ratio at harvest. The root-shoot ratio was higher in the treatment organic mulch ($m_2$) (0.26) compared to no mulch ($m_1$).

The interaction between the types of micro irrigation and mulching did not have a significant influence on root-shoot ratio.

#### *4.1.1.6 Dry Matter Production*

The data on dry matter production revealed that types of micro irrigation, mulching and their interaction had a significant influence on dry matter production and are presented in Table 5.

The dry matter production was recorded at harvest and the results revealed that sub surface drip irrigation at 10 cm depth ($i_3$) (4751 kg $ha^{-1}$) obtained significantly higher dry matter production followed by sub surface drip irrigation at 15 cm depth ($i_4$) (4423 kg $ha^{-1}$) and sub surface drip irrigation at 20 cm depth ($i_5$) (4153 kg $ha^{-1}$) respectively. The lowest dry matter production was obtained in the treatment rain hose irrigation ($i_2$) (3761 kg $ha^{-1}$) and it was on par with surface drip irrigation ($i_1$).

Between mulches, the treatment organic mulch ($m_2$) obtained higher dry matter production (4244 kg $ha^{-1}$) and was superior to the treatment no mulch ($m_1$).

The treatment combination sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) obtained significantly higher dry matter production (4835 kg $ha^{-1}$) and the lowest dry matter production was recorded in the treatment combination rain hose irrigation with no mulch ($i_2m_1$) (3719 kg $ha^{-1}$).

### 4.1.2 Root Parameters

#### *4.1.2.1 Root Depth*

The data on root depth presented in Table 6. indicate that different types of micro irrigation and mulching significantly influenced the root depth at harvest.

The results revealed that significantly highest root depth was obtained in sub surface drip irrigation at 20 cm ($i_5$) (46.46 cm) than rest of the irrigation treatments.

Table 4. Effect of types of micro irrigation and mulching on days to 50 per cent flowering and leaf area index of tomato

| Treatments | Days to 50 per cent flowering | Leaf area index ( at 50 per cent flowering) |
|---|---|---|
| **Types of micro irrigation (I)** | | |
| $i_1$ Surface drip irrigation | 43.60 | 0.85 |
| $i_2$ Rain hose irrigation | 42.65 | 0.83 |
| $i_3$ Sub surface drip irrigation at 10 cm | 40.16 | 0.97 |
| $i_4$ Sub surface drip irrigation at 15 cm | 40.90 | 0.94 |
| $i_5$ Sub surface drip irrigation at 20 cm | 41.16 | 0.91 |
| SE m (±) | 1.24 | 0.05 |
| CD (0.05) | NS | NS |
| **Mulching (M)** | | |
| $m_1$ No mulch | 42.03 | 0.88 |
| $m_2$ Organic mulch | 41.36 | 0.92 |
| SE m (±) | 0.29 | 0.01 |
| CD (0.05) | NS | 0.039 |
| **Interaction (I × M)** | | |
| $i_1m_1$ | 45.13 | 0.82 |
| $i_1m_2$ | 42.06 | 0.89 |
| $i_2m_1$ | 42.67 | 0.81 |
| $i_2m_2$ | 42.63 | 0.85 |
| $i_3m_1$ | 40.20 | 0.96 |
| $i_3m_2$ | 40.13 | 0.98 |
| $i_4m_1$ | 40.93 | 0.94 |
| $i_4m_2$ | 40.87 | 0.95 |
| $i_5m_1$ | 41.20 | 0.87 |
| $i_5m_2$ | 41.13 | 0.94 |
| SE m (±) | 0.64 | 0.03 |
| CD (0.05) | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

Table 5. Effect of types of micro irrigation and mulching on root-shoot ratio and dry matter production of tomato

| Treatments | Root-shoot ratio | Dry matter production ( kg $ha^{-1}$) |
|---|---|---|
| Types of micro irrigation (I) | | |
| $i_1$ Surface drip irrigation | 0.18 | 3867 |
| $i_2$ Rain hose irrigation | 0.20 | 3761 |
| $i_3$ Sub surface drip irrigation at 10 cm | 0.27 | 4751 |
| $i_4$ Sub surface drip irrigation at 15 cm | 0.27 | 4423 |
| $i_5$ Sub surface drip irrigation at 20 cm | 0.24 | 4153 |
| SE m (±) | 0.01 | 77.31 |
| CD (0.05) | 0.024 | 250.37 |
| Mulching (M) | | |
| $m_1$ No mulch | 0.21 | 4138 |
| $m_2$ Organic mulch | 0.26 | 4244 |
| SE m (±) | 0.01 | 12.22 |
| CD (0.05) | 0.020 | 38.520 |
| Interaction (I × M) | | |
| $i_1m_1$ | 0.15 | 3874 |
| $i_1m_2$ | 0.21 | 3861 |
| $i_2m_1$ | 0.18 | 3719 |
| $i_2m_2$ | 0.23 | 3802 |
| $i_3m_1$ | 0.23 | 4666 |
| $i_3m_2$ | 0.31 | 4835 |
| $i_4m_1$ | 0.26 | 4352 |
| $i_4m_2$ | 0.29 | 4494 |
| $i_5m_1$ | 0.21 | 4077 |
| $i_5m_2$ | 0.27 | 4229 |
| SE m (±) | 0.01 | 27.33 |
| CD (0.05) | NS | 86.134 |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

The lowest root depth was obtained in rain hose irrigation ($i_2$) (30.95cm) and it was on par with surface drip irrigation ($i_1$).

The treatment organic mulch ($m_2$) recorded higher root depth (40.39 cm) compared to treatment ($m_1$) no mulch.

The interaction between the types of micro irrigation and mulching did not have a significant influence on the root depth.

#### *4.1.2.2 Root Volume*

The root volume obtained at harvest is furnished in the Table 6.

The root volume was significantly influenced by the types of micro irrigation and mulching. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) obtained significantly higher root volume (27.06 $cm^3$). The treatment sub surface drip at 15 cm depth ($i_4$) was in turn on par with sub surface drip at depth 20 cm ($i_5$). The lowest root volume was obtained under rain hose irrigation ($i_2$) (17.50 $cm^3$) and was on par with surface drip irrigation ($i_1$).

The treatment organic mulch ($m_2$) obtained significantly higher root volume (22.78 $cm^3$) than the treatment no mulch ($m_1$).

The root volume was not significantly influenced by the interaction between the types of micro irrigation and mulching.

### 4.1.3 Yield and Yield Attributes

#### *4.1.3.1 Number of Fruits per Plant*

The data regarding the number of fruits per plant influenced by the types of micro irrigation and mulching are presented in Table 7.

The data revealed that the types of micro irrigation had a significant influence on the number of fruits per plant at harvest. The number of fruits per plant was significantly higher for sub surface drip irrigation at 10 cm depth ($i_3$) (35.69) than rest of the treatments. The lowest number of fruits per plant was obtained in rain hose irrigation ($i_2$) (25.77) and it was on par with surface drip irrigation ($i_1$).

The effect of mulching on the number of fruits per plant indicated that significantly higher number of fruits per plant was obtained in organic mulch ($m_2$) (31.37) than in no mulch ($m_1$) (28.71).

The interaction effect between types of micro irrigation and mulching was not significant.

#### *4.1.3.2 Average Fruit Weight*

The average fruit weight was found to be significantly influenced by the types of micro irrigation and mulching as shown in Table 7.

Among the different types of micro irrigation, sub surface drip irrigation at 10 cm depth ($i_3$) recorded the highest average fruit weight (43.60 g) and it was on par with sub surface drip irrigation at 15 cm ($i_4$). The average fruit weight recorded was lower in rain hose irrigation ($i_2$) (33.72 g) and it was on par with sub surface drip irrigation at 20 cm depth ($i_5$) and surface drip irrigation ($i_1$).

Data on the effect of mulching on average fruit weight of tomato indicated that organic mulch ($m_2$) recorded higher average fruit weight (39.69 g) compared to no mulch ($m_1$).

The interaction between types of micro irrigation and mulching had no significant influence on average fruit weight.

#### *4.1.3.3 Fruit Yield per Plant*

A perusal of data indicated in the Table 7. revealed that types of micro irrigation and mulching significantly influenced the fruit yield per plant.

Among the different types of micro irrigation, sub surface drip irrigation at 10 cm depth ($i_3$) obtained significantly higher fruit yield per plant (1.41 kg), followed by sub surface drip irrigation at 15 cm ($i_4$) and sub surface drip irrigation at 20 cm ($i_5$)

Table 6. Effect of types of micro irrigation and mulching on root parameters of tomato

| Treatments | Root parameters | |
|---|---|---|
| | Root depth (cm) | Root volume ($cm^3$) |
| **Types of micro irrigation (I)** | | |
| $i_1$ Surface drip irrigation | 33.66 | 17.56 |
| $i_2$ Rain hose irrigation | 30.95 | 17.50 |
| $i_3$ Sub surface drip irrigation at 10 cm | 39.49 | 27.06 |
| $i_4$ Sub surface drip irrigation at 15 cm | 42.94 | 23.83 |
| $i_5$ Sub surface drip irrigation at 20 cm | 46.46 | 21.11 |
| SE m (±) | 0.77 | 0.87 |
| CD (0.05) | 2.500 | 2.85 |
| **Mulching (M)** | | |
| $m_1$ No mulch | 37.01 | 20.04 |
| $m_2$ Organic mulch | 40.39 | 22.78 |
| SE m (±) | 0.45 | 0.25 |
| CD (0.05) | 1.432 | 0.788 |
| **Interaction (I × M)** | | |
| $i_1m_1$ | 31.82 | 16.33 |
| $i_1m_2$ | 35.49 | 18.78 |
| $i_2m_1$ | 29.64 | 16.33 |
| $i_2m_2$ | 32.27 | 18.87 |
| $i_3m_1$ | 38.84 | 24.56 |
| $i_3m_2$ | 40.14 | 29.56 |
| $i_4m_1$ | 40.54 | 22.56 |
| $i_4m_2$ | 45.35 | 25.11 |
| $i_5m_1$ | 44.21 | 20.44 |
| $i_5m_2$ | 48.72 | 21.77 |
| SE m (±) | 1.02 | 0.56 |
| CD (0.05) | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

Table 7. Effect of types of micro irrigation and mulching on yield attributes of tomato

| Treatments | Yield attributes | | | |
|---|---|---|---|---|
| | Number of fruits per plant | Average fruit weight (g) | Fruit yield per plant (kg) | Total fruit yield $m^{-2}$ (kg) |
| **Types of micro irrigation (I)** | | | | |
| $i_1$ Surface drip irrigation | 27.08 | 34.17 | 1.03 | 2.40 |
| $i_2$ Rain hose irrigation | 25.77 | 33.72 | 0.98 | 2.25 |
| $i_3$ Sub surface drip irrigation at 10 cm | 35.69 | 43.60 | 1.41 | 3.44 |
| $i_4$ Sub surface drip irrigation at 15 cm | 31.95 | 40.24 | 1.30 | 3.15 |
| $i_5$ Sub surface drip irrigation at 20 cm | 29.72 | 37.19 | 1.20 | 2.86 |
| SE m (±) | 0.55 | 0.70 | 0.03 | 0.08 |
| CD (0.05) | 1.784 | 2.298 | 0.088 | 0.246 |
| **Mulching (M)** | | | | |
| $m_1$ No mulch | 28.71 | 35.88 | 1.13 | 2.68 |
| $m_2$ Organic mulch | 31.37 | 39.69 | 1.24 | 2.96 |
| SE m (±) | 0.29 | 0.34 | 0.01 | 0.02 |
| CD (0.05) | 0.928 | 1.064 | 0.019 | 0.055 |
| **Interaction (I × M)** | | | | |
| $i_1m_1$ | 25.64 | 32.67 | 1.01 | 2.33 |
| $i_1m_2$ | 28.53 | 35.67 | 1.06 | 2.47 |
| $i_2m_1$ | 24.25 | 32.21 | 0.91 | 2.05 |
| $i_2m_2$ | 27.29 | 35.24 | 1.05 | 2.46 |
| $i_3m_1$ | 34.89 | 40.57 | 1.37 | 3.35 |
| $i_3m_2$ | 36.49 | 46.64 | 1.44 | 3.54 |
| $i_4m_1$ | 29.67 | 38.79 | 1.24 | 2.98 |
| $i_4m_2$ | 34.23 | 41.69 | 1.37 | 3.33 |
| $i_5m_1$ | 29.11 | 35.17 | 1.14 | 2.70 |
| $i_5m_2$ | 30.33 | 39.22 | 1.26 | 3.03 |
| SE m (±) | 0.66 | 0.75 | 0.01 | 0.04 |
| CD (0.05) | NS | NS | 0.043 | 0.123 |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

respectively. The lowest fruit yield per plant was obtained in rain hose irrigation ($i_2$) (0.98 kg) and it was on par with surface drip irrigation ($i_1$).

The effect of mulching on fruit yield per plant revealed that organic mulch ($m_2$) obtained higher fruit yield per plant (1.24 kg) than no mulch ($m_1$).

The interaction between types of micro irrigation and mulching significantly influenced the fruit yield per plant. The treatment combination sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) recorded significantly highest fruit yield per plant (1.44 kg) and the lowest fruit yield per plant was recorded for rain hose irrigation with no mulch ($i_2m_1$) (0.91kg).

#### *4.1.3.4 Fruit Yield $m^{-2}$*

The results on the effect of types of micro irrigation and mulching on fruit yield $m^{-2}$ are presented in the Table 7.

The results proved that there was a significant difference on fruit yield $m^{-2}$ by various types of micro irrigation. Significantly highest fruit yield $m^{-2}$ was observed in sub surface drip irrigation at 10 cm ($i_3$) (3.44 kg) followed by sub surface drip irrigation at 15 cm ($i_4$) and sub surface drip irrigation at 20 cm ($i_5$) respectively. The lowest fruit yield $m^{-2}$ was obtained in rain hose irrigation ($i_2$) (2.25 kg) and it was on par with surface drip irrigation ($i_1$).

The effect of mulching had a significant influence on fruit yield $m^{-2}$ and organic mulch ($m_2$) recorded the maximum fruit yield $m^{-2}$ (2.96 kg) compared to no mulch ($m_1$).

Significant interaction was noticed between the types of micro irrigation and mulching on fruit yield $m^{-2}$. The treatment combination sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) (3.54 kg) obtained significantly highest fruit yield $m^{-2}$ and the lowest fruit yield $m^{-2}$ was obtained in the treatment combination rain hose irrigation without mulch ($i_2m_1$) (2.05 kg).

### 4.1.4 Quality Aspects of Fruits

#### *4.1.4.1 Total Soluble Solids (TSS)*

The results on the influence of types of micro irrigation and mulching on TSS are provided in Table 8.

According to the findings, types of micro irrigation and mulching did not have any significant influence on TSS. Furthermore, the interactions between the treatments were found to be non-significant.

#### *4.1.4.2 Ascorbic Acid*

The data on the ascorbic acid content of ripe tomato fruits are furnished in the Table 8.

Ascorbic acid content of ripe tomato fruits did not vary significantly due to the different types of micro irrigation and mulching. The interaction between the treatments also showed no significant difference in ascorbic acid content.

#### *4.1.4.3 Lycopene Content*

The results on the lycopene content in tomato are presented in Table 8.

The data revealed that types of micro irrigation and mulching had no significant influence on the lycopene content of tomato fruits. The interaction between the treatments was also found to be non significant.

### 4.1.5 Plant Analysis

#### *4.1.5.1 N Uptake*

The data regarding the effects of treatments on N uptake by the plants are presented in Table 9.

N uptake was significantly influenced by the types of micro irrigation. Among the different types of micro irrigation, N uptake was the highest for sub surface drip irrigation at 10 cm depth ($i_3$) (59.09 kg $ha^{-1}$) and it was on par with sub surface drip irrigation at 15 cm depth ($i_4$). The treatment sub surface drip irrigation at 15 cm depth

Table 8. Effect of types of micro irrigation and mulching on quality aspects of tomato

| Treatments | Quality attributes | | |
|---|---|---|---|
| | TSS ($^0$Brix) | Ascorbic acid (mg 100g fruit$^1$) | Lycopene (mg 100g fruit$^{-1}$) |
| **Types of micro irrigation (I)** | | | |
| $i_1$ Surface drip irrigation | 4.16 | 17.81 | 9.82 |
| $i_2$ Rain hose irrigation | 4.12 | 16.88 | 9.60 |
| $i_3$ Sub surface drip irrigation at 10 cm | 4.19 | 17.99 | 10.15 |
| $i_4$ Sub surface drip irrigation at 15 cm | 4.18 | 17.93 | 10.12 |
| $i_5$ Sub surface drip irrigation at 20 cm | 4.17 | 17.66 | 9.78 |
| SE m (±) | 0.04 | 1.07 | 1.05 |
| CD (0.05) | NS | NS | NS |
| **Mulching (M)** | | | |
| $m_1$ No mulch | 4.16 | 17.61 | 9.84 |
| $m_2$ Organic mulch | 4.17 | 17.70 | 9.96 |
| SE m (±) | 0.01 | 0.04 | 0.04 |
| CD (0.05) | NS | NS | NS |
| **Interaction (I × M)** | | | |
| $i_1m_1$ | 4.17 | 17.80 | 9.60 |
| $i_1m_2$ | 4.15 | 17.82 | 9.87 |
| $i_2m_1$ | 4.11 | 16.87 | 9.54 |
| $i_2m_2$ | 4.13 | 16.90 | 9.66 |
| $i_3m_1$ | 4.22 | 17.81 | 10.15 |
| $i_3m_2$ | 4.17 | 18.16 | 10.16 |
| $i_4m_1$ | 4.16 | 17.93 | 10.10 |
| $i_4m_2$ | 4.20 | 17.94 | 10.13 |
| $i_5m_1$ | 4.14 | 17.66 | 9.77 |
| $i_5m_2$ | 4.20 | 17.67 | 9.95 |
| SE m (±) | 0.03 | 0.10 | 0.10 |
| CD (0.05) | NS | NS | NS |

Organic mulch: dry banana leaves @ 10 t ha$^{-1}$; NS : not significant

Table 9. Effect of types of micro irrigation and mulching on NPK uptake by tomato, kg $ha^{-1}$

| Treatments | Nutrient uptake | | |
|---|---|---|---|
| | N uptake | P uptake | K uptake |
| **Types of micro irrigation (I)** | | | |
| $i_1$ Surface drip irrigation | 47.77 | 14.46 | 62.85 |
| $i_2$ Rain hose irrigation | 47.28 | 13.82 | 61.01 |
| $i_3$ Sub surface drip irrigation at 10 cm | 59.09 | 21.43 | 85.94 |
| $i_4$ Sub surface drip irrigation at 15 cm | 57.48 | 18.61 | 77.94 |
| $i_5$ Sub surface drip irrigation at 20 cm | 53.84 | 16.69 | 71.49 |
| SE m (±) | 1.16 | 0.26 | 1.63 |
| CD (0.05) | 3.770 | 0.849 | 5.314 |
| **Mulching (M)** | | | |
| $m_1$ No mulch | 50.29 | 16.17 | 68.69 |
| $m_2$ Organic mulch | 55.89 | 17.83 | 75.00 |
| SE m (±) | 0.27 | 0.91 | 0.49 |
| CD (0.05) | 0.858 | 0.288 | 1.538 |
| **Interaction (I × M)** | | | |
| $i_1m_1$ | 45.84 | 13.43 | 59.66 |
| $i_1m_2$ | 49.70 | 15.50 | 66.04 |
| $i_2m_1$ | 45.13 | 12.99 | 58.26 |
| $i_2m_2$ | 49.43 | 14.66 | 63.76 |
| $i_3m_1$ | 56.92 | 20.12 | 82.45 |
| $i_3m_2$ | 61.26 | 22.73 | 89.44 |
| $i_4m_1$ | 54.26 | 18.19 | 74.68 |
| $i_4m_2$ | 60.70 | 19.03 | 81.21 |
| $i_5m_1$ | 49.33 | 16.14 | 68.41 |
| $i_5m_2$ | 58.35 | 17.24 | 74.57 |
| SE m (±) | 0.61 | 0.20 | 1.09 |
| CD (0.05) | 1.920 | 0.643 | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

($i_4$) was in turn on par with sub surface drip irrigation at depth 20 cm ($i_5$). The lowest N uptake was recorded in rain hose irrigation ($i_2$) (47.28 kg $ha^{-1}$) and was on par with surface drip irrigation ($i_1$).

Mulching had a significant influence on N uptake. The treatment organic mulch ($m_2$) registered higher N uptake (55.89 kg $ha^{-1}$) than no mulch ($m_1$).

The interaction between types of micro irrigation and mulching also showed a significant difference in N uptake. The treatment combination sub surface drip irrigation with organic mulch ($i_3m_2$) obtained higher N uptake (61.26 kg $ha^{-1}$) and it was on par with sub surface drip irrigation at 15 cm depth with organic mulch ($i_4m_2$). The lowest N uptake was obtained for rain hose irrigation without mulch ($i_2m_1$) (45.13 kg $ha^{-1}$) and it was on par with surface drip irrigation without mulch ($i_1m_1$).

#### *4.1.5.2 P Uptake*

The influence of the types of micro irrigation and mulching on P uptake is presented in Table 9.

The data revealed that P uptake was the highest in the treatment sub surface drip at 10 cm depth ($i_3$) (21.43 kg $ha^{-1}$) which was significantly superior to other types of micro irrigation. The lowest P uptake was observed in rain hose irrigation ($i_2$) (13.82 kg $ha^{-1}$) and it was on par with surface drip irrigation ($i_1$).

Mulching also had a significant influence on P uptake and treatment organic mulch ($m_2$) recorded the maximum P uptake (17.83 kg $ha^{-1}$) than no mulch ($m_1$).

There was significant interaction between methods of irrigation and mulching. The combination of sub surface drip at 10 cm depth with organic mulch ($i_3m_2$) recorded the highest P uptake (22.73 kg $ha^{-1}$) and the lowest P uptake was obtained in the combination rain hose irrigation with no mulch ($i_2m_1$) (12.99 kg $ha^{-1}$) which was on par with surface drip irrigation without mulch ($i_1m_1$).

#### *4.1.5.3 K Uptake*

Data on K uptake at harvest influenced by types of micro irrigation and mulching is presented in Table 9.

The data revealed that K uptake was significantly influenced by types of micro irrigation. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) recorded significantly highest uptake of K (85.94 kg $ha^{-1}$) and was superior to all other treatments. Lower uptake of K was observed under rain hose irrigation ($i_2$) (61.01 kg $ha^{-1}$).

K uptake was significantly influenced by mulching. The treatment organic mulch ($m_2$) obtained a higher uptake of K (75.00 kg $ha^{-1}$) than no mulch ($m_1$)

The interaction between the treatments did not have any influence on K uptake.

### 4.1.6 Soil Analysis

#### *4.1.6.1 Organic Carbon*

The data on the organic carbon content of soil after the experiment is given in Table 10a.

The results revealed that different types of micro irrigation, mulching, and their interaction did not have any significant influence on the organic carbon content of soil.

#### *4.1.6.2 Available Nitrogen*

The data on available nitrogen is presented in Table 10a.

Types of micro irrigation had a significant influence on the available nitrogen content. The treatment rain hose irrigation ($i_2$) registered the highest available nitrogen (229.72 kg $ha^{-1}$) and it was on par with surface drip irrigation ($i_1$). The lowest available nitrogen was obtained in sub surface drip irrigation at 10 cm depth ($i_3$) (204.49 kg $ha^{-1}$) and was on par with sub surface drip irrigation at 15 cm depth ($i_4$) and sub surface drip irrigation at 20 cm depth ($i_5$) respectively.

Mulching also had significant influence on available nitrogen. The higher

Table 10a. Effect of types of micro irrigation and mulching on OC and available NPK status of soil after the experiment

| Treatments | OC (%) | Available NPK (kg $ha^{-1}$) | | |
|---|---|---|---|---|
| | | Nitrogen | Phosphorus | Potassium |
| **Types of micro irrigation (I)** | | | | |
| $i_1$ Surface drip irrigation | 1.24 | 222.49 | 88.63 | 280.68 |
| $i_2$ Rain hose irrigation | 1.22 | 229.72 | 90.74 | 282.61 |
| $i_3$ Sub surface drip irrigation at 10 cm | 1.23 | 204.49 | 86.24 | 262.35 |
| $i_4$ Sub surface drip irrigation at 15 cm | 1.22 | 204.52 | 87.82 | 271.86 |
| $i_5$ Sub surface drip irrigation at 20 cm | 1.24 | 206.79 | 88.52 | 274.90 |
| SE m (±) | 0.01 | 4.00 | 1.02 | 12.38 |
| CD (0.05) | NS | 13.05 | NS | NS |
| **Mulching (M)** | | | | |
| $m_1$ No mulch | 1.22 | 203.06 | 86.87 | 269.33 |
| $m_2$ Organic mulch | 1.23 | 224.15 | 89.91 | 279.63 |
| SE m (±) | 0.01 | 3.34 | 0.62 | 2.31 |
| CD (0.05) | NS | 10.531 | 1.950 | 7.294 |
| **Interaction (I × M)** | | | | |
| $i_1m_1$ | 1.23 | 213.53 | 87.51 | 277.81 |
| $i_1m_2$ | 1.24 | 231.45 | 89.75 | 283.54 |
| $i_2m_1$ | 1.20 | 222.25 | 88.67 | 272.44 |
| $i_2m_2$ | 1.23 | 237.19 | 92.81 | 292.79 |
| $i_3m_1$ | 1.22 | 193.64 | 83.95 | 253.84 |
| $i_3m_2$ | 1.23 | 215.35 | 88.54 | 270.86 |
| $i_4m_1$ | 1.21 | 195.99 | 86.60 | 268.85 |
| $i_4m_2$ | 1.23 | 213.05 | 89.04 | 274.87 |
| $i_5m_1$ | 1.23 | 189.89 | 87.63 | 273.72 |
| $i_5m_2$ | 1.24 | 223.70 | 89.41 | 276.08 |
| SE m (±) | 0.01 | 7.47 | 1.38 | 5.17 |
| CD (0.05) | NS | NS | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

Table 10b. Effect of types of micro irrigation and mulching on soil moisture content at 15 cm depth, %

| Treatments | Soil moisture content at 15 cm | | |
|---|---|---|---|
| | 30 DAT | 60 DAT | 90 DAT |
| **Types of micro irrigation (I)** | | | |
| $i_1$ Surface drip irrigation | 9.62 | 10.05 | 9.47 |
| $i_2$ Rain hose irrigation | 9.48 | 9.43 | 9.57 |
| $i_3$ Sub surface drip irrigation at 10 cm | 13.98 | 13.97 | 12.92 |
| $i_4$ Sub surface drip irrigation at 15 cm | 12.82 | 12.97 | 13.89 |
| $i_5$ Sub surface drip irrigation at 20 cm | 11.87 | 11.95 | 11.70 |
| SE m (±) | 0.28 | 0.30 | 0.25 |
| CD (0.05) | 0.930 | 0.976 | 0.809 |
| **Mulching (M)** | | | |
| $m_1$ No mulch | 11.23 | 11.43 | 11.15 |
| $m_2$ Organic mulch | 11.87 | 11.92 | 11.86 |
| SE m (±) | 0.06 | 0.07 | 0.09 |
| CD (0.05) | 0.202 | 0.212 | 0.278 |
| **Interaction (I × M)** | | | |
| $i_1m_1$ | 9.37 | 9.80 | 9.16 |
| $i_1m_2$ | 9.87 | 10.30 | 9.77 |
| $i_2m_1$ | 9.23 | 9.13 | 9.43 |
| $i_2m_2$ | 9.73 | 9.73 | 9.71 |
| $i_3m_1$ | 13.77 | 13.83 | 12.31 |
| $i_3m_2$ | 14.20 | 14.10 | 13.53 |
| $i_4m_1$ | 12.57 | 12.70 | 13.65 |
| $i_4m_2$ | 13.07 | 13.23 | 14.13 |
| $i_5m_1$ | 11.23 | 11.68 | 11.23 |
| $i_5m_2$ | 12.50 | 12.23 | 12.17 |
| SE m (±) | 0.14 | 0.15 | 0.20 |
| CD (0.05) | NS | NS | NS |

Organic mulch: dry banana leaves @ 10 t ha$^{-1}$; NS : not significant

available nitrogen was recorded for organic mulch ($m_2$) (224.15 kg $ha^{-1}$) than no mulch ($m_1$).

The interaction was found to be not significant among the treatments.

#### *4.1.6.3 Available Phosphorus*

Available phosphorus content of the soil after the experiment is tabulated in Table 10a.

The results revealed that the types of micro irrigation did not have any significant influence on the available phosphorus content of the soil.

Mulching had a significant influence on available phosphorus after the experiment. The treatment organic mulch ($m_2$) (89.91 kg $ha^{-1}$) obtained the higher available P in the soil than no mulch ($m_1$).

The interaction between the treatments did not cause any significant influence on available P after the experiment.

#### *4.1.6.4 Available Potassium*

The effect of the types of micro irrigation and mulching on the available potassium status of soil after the experiment is furnished in Table 10a.

The different types of micro irrigation did not have any significant influence on available potassium.

Mulching had a significant effect on available potassium at harvest. The maximum available potassium was noticed under organic mulch ($m_2$) (279.63 kg $ha^{-1}$) than no mulch ($m_1$).

Interaction between the treatments did not have any significant influence on available potassium.

#### *4.1.6.5 Soil Moisture Content at 15 and 30 cm Depth*

The data on soil moisture content at 15 and 30 cm depth at monthly intervals are presented in Table 10b. and Table 10c.

Types of micro irrigation had a significant influence on soil moisture content at monthly intervals. Soil moisture content at 15 cm depth was significantly higher for sub surface drip irrigation at 10 cm depth ($i_3$) at 30 DAT (13.98 %), 60 DAT (13.97 %) and 90 DAT (12.92 %). The lowest moisture content was recorded for rain hose irrigation ($i_2$) (9.48 %, 9.43 %, and 9.57 %) and was on par with surface drip irrigation ($i_1$) at monthly intervals.

Soil moisture content at 30 cm depth was significantly higher for sub surface drip irrigation at 20 cm depth ($i_5$) (12.68 %, 12.64 % and 12.77 %) than the rest of the treatments. The treatment sub surface drip irrigation at 15 cm depth ($i_4$) was in turn on par with sub surface drip irrigation at 10 cm depth ($i_3$) at 30, 60 and 90 DAT. The lowest moisture content was recorded for rain hose irrigation ($i_2$) (8.50 %, 8.47 % and 8.23 %) and was on par with surface drip irrigation ($i_1$).

Mulching had a significant influence on soil moisture content at 15 and 30 cm depth throughout the crop period. The treatment organic mulch ($m_2$) recorded the maximum moisture content than no mulch ($m_1$) at 30, 60 and 90 DAT.

The interaction between types of micro irrigation and mulching did not have any significant influence on the moisture content at 15 cm and 30 cm depth.

### 4.1.7 Soil Moisture Studies

#### *4.1.7.1 Water Productivity*

The data on the effect of types of micro irrigation and mulching on water productivity has been depicted in Table 11.

The results revealed that sub surface drip irrigation at 10 cm depth ($i_3$) recorded significantly higher water productivity (3.80 kg $m^{-3}$) than rest of the treatments. The lowest water productivity was recorded in the treatment rain hose irrigation ($i_2$) (2.45 kg $m^{-3}$) and it was on par with surface drip irrigation ($i_1$).

Mulching significantly influenced water productivity, the treatment organic mulch ($m_2$) recorded higher water productivity (3.15 kg $m^{-3}$) compared to no mulch.

Table 10c. Effect of types of micro irrigation and mulching on soil moisture content at 30 cm depth, %

| Treatments | Soil moisture content at 30 cm depth | | |
|---|---|---|---|
| | 30 DAT | 60 DAT | 90 DAT |
| **Types of micro irrigation (I)** | | | |
| $i_1$ Surface drip irrigation | 8.55 | 8.52 | 8.85 |
| $i_2$ Rain hose irrigation | 8.50 | 8.47 | 8.23 |
| $i_3$ Sub surface drip irrigation at 10 cm | 11.06 | 11.03 | 11.53 |
| $i_4$ Sub surface drip irrigation at 15 cm | 11.54 | 11.50 | 11.77 |
| $i_5$ Sub surface drip irrigation at 20 cm | 12.68 | 12.64 | 12.77 |
| SE m (±) | 0.29 | 0.30 | 0.25 |
| CD (0.05) | 0.957 | 0.956 | 0.810 |
| **Mulching (M)** | | | |
| $m_1$ No mulch | 10.13 | 10.11 | 10.41 |
| $m_2$ Organic mulch | 10.80 | 10.76 | 10.85 |
| SE m (±) | 0.06 | 0.06 | 0.06 |
| CD (0.05) | 0.204 | 0.204 | 0.204 |
| **Interaction (I × M)** | | | |
| $i_1m_1$ | 8.19 | 8.16 | 8.60 |
| $i_1m_2$ | 8.91 | 8.87 | 9.10 |
| $i_2m_1$ | 8.26 | 8.23 | 7.93 |
| $i_2m_2$ | 8.75 | 8.71 | 8.53 |
| $i_3m_1$ | 10.73 | 10.70 | 11.40 |
| $i_3m_2$ | 11.40 | 11.36 | 11.67 |
| $i_4m_1$ | 11.11 | 11.08 | 11.50 |
| $i_4m_2$ | 11.97 | 11.93 | 12.03 |
| $i_5m_1$ | 12.40 | 12.37 | 12.63 |
| $i_5m_2$ | 12.96 | 12.92 | 12.90 |
| SE m (±) | 0.14 | 0.15 | 0.14 |
| CD (0.05) | NS | NS | NS |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

Table 11. Effect of types of micro irrigation and mulching on water productivity and field water use efficiency of tomato, kg m$^{-3}$

| Treatments | Water productivity | Field water use efficiency |
|---|---|---|
| **Types of micro irrigation (I)** | | |
| $i_1$ Surface drip irrigation | 2.60 | 5.21 |
| $i_2$ Rain hose irrigation | 2.45 | 4.89 |
| $i_3$ Sub surface drip irrigation at 10 cm | 3.80 | 7.47 |
| $i_4$ Sub surface drip irrigation at 15 cm | 3.52 | 6.84 |
| $i_5$ Sub surface drip irrigation at 20 cm | 3.13 | 6.21 |
| SE m (±) | 0.06 | 0.16 |
| CD (0.05) | 0.212 | 0.535 |
| **Mulching (M)** | | |
| $m_1$ No mulch | 3.06 | 5.82 |
| $m_2$ Organic mulch | 3.15 | 6.42 |
| SE m (±) | 0.01 | 0.04 |
| CD (0.05) | 0.043 | 0.118 |
| **Interaction (I × M)** | | |
| $i_1m_1$ | 2.61 | 5.06 |
| $i_1m_2$ | 2.60 | 5.36 |
| $i_2m_1$ | 2.42 | 4.44 |
| $i_2m_2$ | 2.47 | 5.33 |
| $i_3m_1$ | 3.73 | 7.26 |
| $i_3m_2$ | 3.87 | 7.67 |
| $i_4m_1$ | 3.44 | 6.47 |
| $i_4m_2$ | 3.61 | 7.21 |
| $i_5m_1$ | 3.08 | 5.85 |
| $i_5m_2$ | 3.19 | 6.57 |
| SE m (±) | 0.03 | 0.08 |
| CD (0.05) | NS | 0.264 |

Organic mulch: dry banana leaves @ 10 t ha$^{-1}$; NS : not significant

Table 12. Effect of types of micro irrigation and mulching on net returns and B: C ratio of tomato

| Treatments | Net returns (₹ lakhs $ha^{-1}$) | B:C ratio |
|---|---|---|
| **Types of micro irrigation (I)** | | |
| $i_1$ Surface drip irrigation | 2.02 | 1.39 |
| $i_2$ Rain hose irrigation | 1.90 | 1.39 |
| $i_3$ Sub surface drip irrigation at 10 cm | 5.14 | 1.99 |
| $i_4$ Sub surface drip irrigation at 15 cm | 4.28 | 1.82 |
| $i_5$ Sub surface drip irrigation at 20 cm | 3.41 | 1.66 |
| SE m (±) | 0.23 | 0.04 |
| CD (0.05) | 0.738 | 0.144 |
| **Mulching (M)** | | |
| $m_1$ No mulch | 2.92 | 1.57 |
| $m_2$ Organic mulch | 3.77 | 1.73 |
| SE m (±) | 0.05 | 0.01 |
| CD (0.05) | 0.165 | 0.031 |
| **Interaction (I × M)** | | |
| $i_1m_1$ | 1.81 | 1.35 |
| $i_1m_2$ | 2.23 | 1.43 |
| $i_2m_1$ | 1.29 | 1.26 |
| $i_2m_2$ | 2.51 | 1.52 |
| $i_3m_1$ | 4.85 | 1.93 |
| $i_3m_2$ | 5.43 | 2.04 |
| $i_4m_1$ | 3.76 | 1.72 |
| $i_4m_2$ | 4.79 | 1.92 |
| $i_5m_1$ | 2.91 | 1.56 |
| $i_5m_2$ | 3.90 | 1.75 |
| SE m (±) | 0.05 | 0.02 |
| CD (0.05) | 0.165 | 0.070 |

Organic mulch: dry banana leaves @ 10 t $ha^{-1}$; NS : not significant

The interaction effect between the treatments was not significant.

#### *4.1.7.2 Field Water Use Efficiency*

The data on effect of types of micro irrigation and mulching on field water use efficiency has been furnished in the Table 11.

The statistical analysis of the data revealed that the types of micro irrigation had significant influence on field water use efficiency. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) obtained significantly higher field water use efficiency (7.47 kg $m^{-3}$) and was superior to the rest of the treatments. The lowest water use efficiency was recorded in the treatment rain hose irrigation ($i_2$) (4.89 kg $m^{-3}$) and it was on par with surface drip irrigation ($i_1$).

Between the mulches, the field water use efficiency was higher in the treatment with organic mulch ($m_2$) (6.42 kg $m^{-3}$) compared to no mulch ($m_1$).

The interaction between different types of micro irrigation and mulching had a significant influence on field water use efficiency. The treatment combination sub surface drip irrigation with organic mulch ($i_3m_2$) obtained significantly higher water use efficiency (7.67 kg $m^{-3}$) and the lowest was obtained in rain hose irrigation with no mulch ($i_2m_1$) (4.44 kg $m^{-3}$).

### 4.1.8 Incidence of Pests and Diseases

The incidence of white fly and *Spodoptera litura* was recorded at 45 DAT. Imidacloprid @ 3mL per 10L of water was sprayed against whitefly and Chlorantraniliprole @ 2.5mL per 10L of water was sprayed twice against *Spodoptera litura* attack.

### 4.1.9 Economics of Cultivation

#### *4.1.9.1 Net Returns*

The net returns influenced by the types of micro irrigation and mulching are presented in Table 12.

The types of micro irrigation, mulching and their interaction had a significant effect on net returns. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) recorded the highest net returns (₹5.14 lakhs $ha^{-1}$) and was significantly superior to rest of the treatments. The lowest net return was observed with rain hose irrigation ($i_2$) (₹ 1.90 lakhs $ha^{-1}$) and it was on par with surface drip irrigation ($i_1$).

Between the mulches, organic mulch ($m_2$) recorded higher net returns (₹ 3.77 lakhs $ha^{-1}$) than no mulch ($m_1$).

The interaction between the types of micro irrigation and mulching had a significant influence on net returns. The treatment combination sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) obtained significantly higher net returns (₹5.43 lakhs $ha^{-1}$) and the lowest net returns was obtained in rain hose irrigation without mulch ($i_2m_2$ ) (1.29 lakhs $ha^{-1}$).

#### *4.1.9.2 B : C Ratio*

The data regarding the effects of types of micro irrigation and mulching on the benefit cost ratio are given in Table 12.

Types of micro irrigation had significant influence on B: C ratio. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) obtained a significantly higher B: C ratio (1.99) and was superior to rest of the treatments. The lowest B: C ratio was obtained in rain hose irrigation ($i_2$) (1.39) and it was on par with surface drip irrigation ($i_1$).

Between the mulches, organic mulch ($m_2$) obtained higher B: C ratio (1.73) than no mulch ($m_1$).

The interaction effect between the types of micro irrigation and mulching had a significant influence on the B: C ratio. The treatment combination sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) resulted in significantly higher B: C ratio (2.04) and the lowest B: C ratio (1.26) was recorded in the treatment combination rain hose irrigation without mulch ($i_2m_1$).

# ***DISCUSSION***

# 5. DISCUSSION

An experiment was conducted to evaluate the efficacy of types of micro irrigation and mulching on yield optimization of tomato in rain shelter. The experimental findings detailed in the previous chapter have been briefly discussed here under.

## 5.1 EFFECT OF TYPES OF MICRO IRRIGATION AND MULCHING ON TOMATO

### 5.1.1 Growth Attributes

Observations on the growth attributes of tomato *viz.,* plant height, number of branches per plant, days to 50 per cent flowering, leaf area index, root shoot ratio, and dry matter production at different growth stages were recorded.

A perusal of the data revealed that types of micro irrigation had a significant influence on the growth attributes of tomato like plant height, number of branches per plant, root-shoot ratio, and dry matter production. Sub surface drip irrigation at 10 cm, 15 cm and 20 cm depths resulted in taller plants compared to surface drip irrigation and rain hose irrigation (Fig.3). Higher availability and uniform distribution of water and nutrients immediately in the vicinity of the root zone for sub surface drip irrigation at different depths might have accelerated cell division, cell elongation, and metabolic activities of the plant throughout the growth phases which resulted in taller plants. Singh and Rajput (2007) reported that plant height was significantly increased in sub surface drip lateral placed at 10 cm depth in okra. Similar results of increased plant height by sub surface drip irrigation were reported by Bhattarai *et al.* (2006) in cotton, Bozkurt and Mansuroglu (2011) in lettuce, Parshuram (2014) in cauliflower, Roopashree *et al.* (2016) in cotton, and Singh *et al.* (2020a) in tomato.

The maximum number of branches per plant was observed in sub surface drip irrigation at 10, 15 and 20 cm depth whereas the lowest number of branches per plant was observed in rain hose irrigation and was comparable with surface drip irrigation at both the growth stages (Table 3). The distribution of water and nutrients at the appropriate time in sub surface drip irrigation systems might have resulted in better vegetative growth, leading to higher number of branches per plant. This was in conformity with the findings of Rajkumar *et al.* (2019) and Ragab *et al*. (2019) in tomato. Root-shoot ratio at harvest was also influenced by types of micro irrigation. The highest root-shoot ratio was observed under sub surface drip irrigation at 10 cm depth which was on par with sub surface drip irrigation at 15 cm depth. Similar findings were reported by Abdelhady *et al.* (2017) in tomato. The lowest root-shoot ratio was observed in surface drip irrigation which was comparable with rain hose irrigation.

The biological efficiency of any crop species would be reflected in the amount of dry matter it produces (Singh *et al*., 2020a). Hence dry matter production is an important parameter in crop growth. The present study revealed that total dry matter production was influenced by different types of micro irrigation (Fig. 5). Sub surface drip irrigation at 10 cm depth obtained significantly the highest dry matter production followed by sub surface drip irrigation at 15 and 20 cm depth respectively compared to surface drip irrigation and rain hose irrigation. This suggests that sub surface drip irrigation at optimum depth had a key role in maintaining leaf and stem growth throughout the growth period of tomato resulting in increased dry matter output (Prabhakara, 2008). More vegetative growth, due to increased plant height, number of branches per plant and better leaf production might be the contributing factor for higher dry matter production in sub surface drip irrigation systems. This result was in agreement with the findings of Hernandez *et al*. (1991).

Mulching had a significant influence on growth attributes of tomato *viz*., plant height, number of branches, leaf area index, dry matter production, and root shoot ratio. Organic mulching was significantly superior to no mulch on favourably influencing growth parameters. Mulch conserves and extends the retention of soil moisture for a longer period of time which is essential for nutrient transporting, translocation of assimilates, cell division and cell differentiation which in turn enhanced the growth parameters of tomato. Shilpa (2019) reported that organic mulch significantly influenced the growth attributes like plant height, number of primary branches, leaf area index and total dry matter production in chilli compared to no mulch. The present study was in corroboration with the results of Kayum *et al*. (2008) in tomato, Bahadur *et al.* (2009) in okra, Saeed and Ahmad (2009) in tomato, Komla

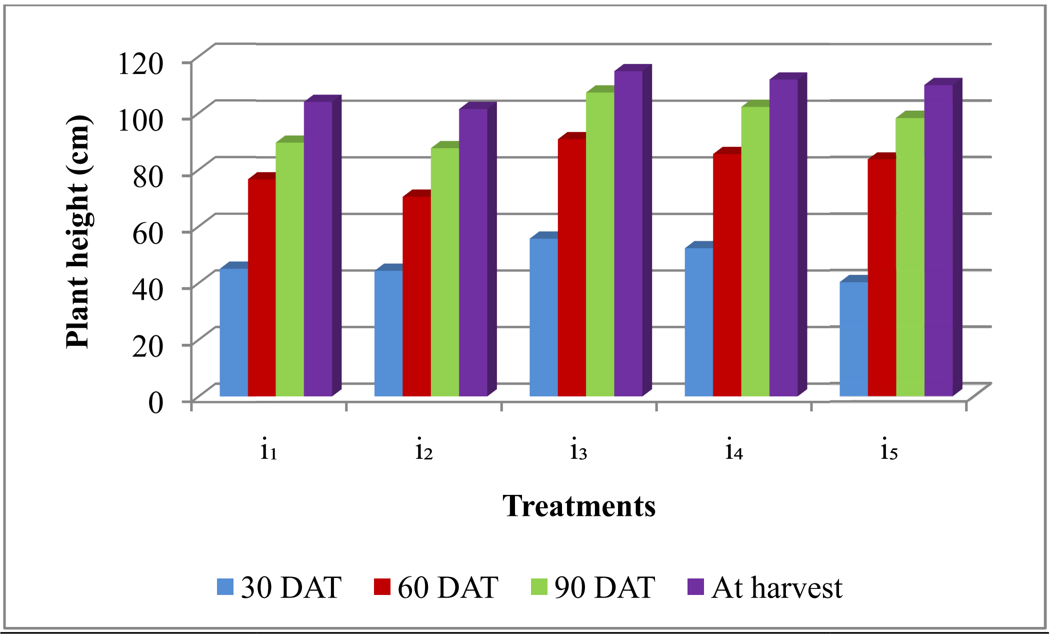


Fig. 3. Effect of types of micro irrigation on plant height, cm

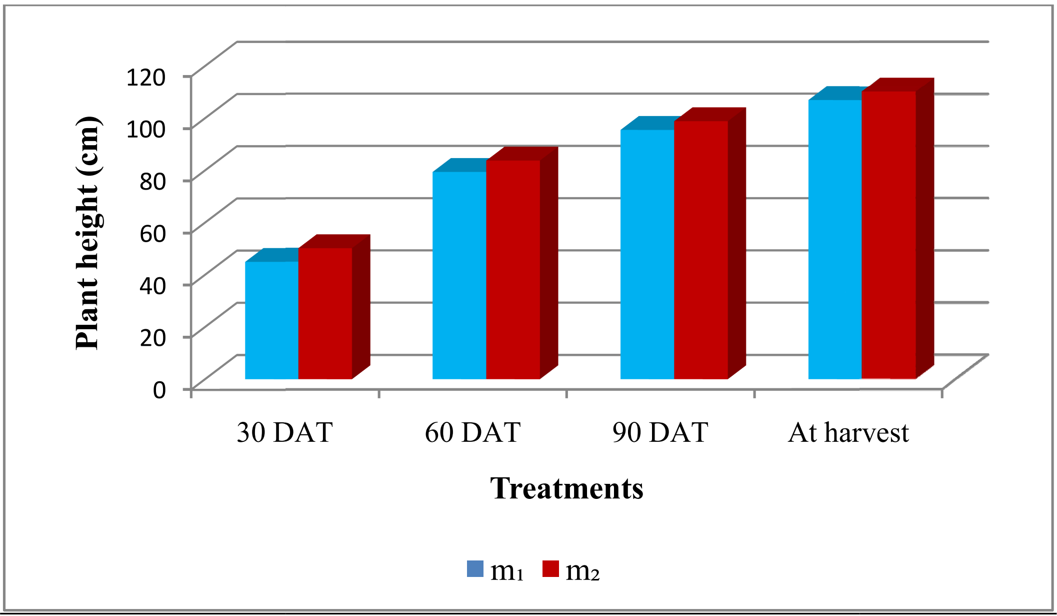


Fig.

4. Effect of mulching on plant height, cm

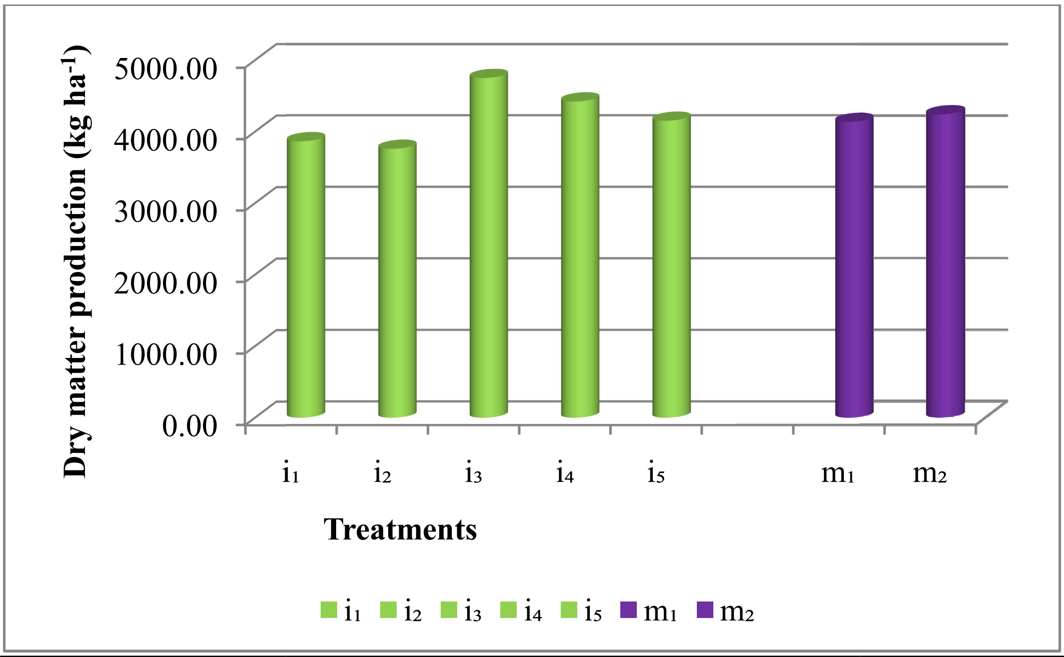


Fig. 5. Effect of types of micro irrigation and mulching on dry matter production, kg $ha^{-1}$

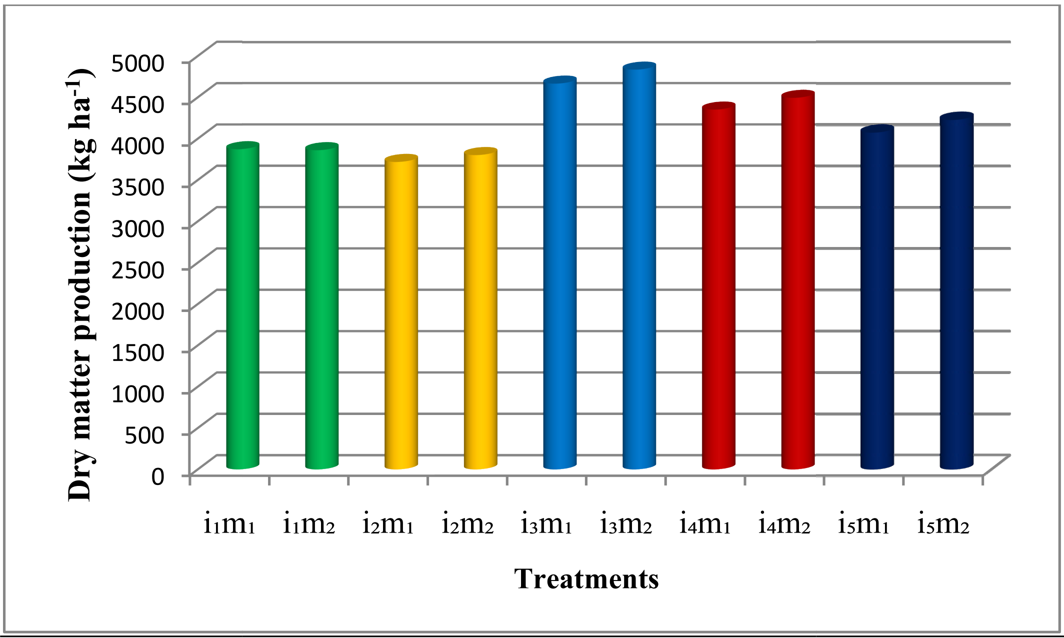


Fig. 6. Interaction effect of types of micro irrigation and mulching on dry matter production, kg $ha^{-1}$

(2013) in sweet pepper, Alamro *et al.* (2019) in tomato, Chaurasia and Sachan (2020) in summer squash and Dukare *et al.* (2021) in tomato.

The interaction of different types of micro irrigation and mulching on dry matter production was significant as shown in Fig. 6. The treatment combination of sub surface drip irrigation at 10 cm depth with organic mulch produced the highest dry matter output, while rain hose irrigation without mulch produced the lowest dry matter output. The availability of moisture and nutrients has a positive relationship with the accumulation of dry matter. According to Hebbar *et al.* (2004) fertigation with water soluble fertilizers increases the nutrient availability in the top soil layers and minimizes nutrient leaching. Sub surface drip irrigation delivers nutrients precisely to the crop root zone, reducing leaching, while organic mulch suppresses weed growth and avoids competition for moisture and nutrients. All this might have led to enhanced nutrient availability and uptake by the plants and improved the translocation of assimilates from source to sink, resulting in higher dry matter production in the treatment combination of sub surface drip at 10 cm depth with organic mulch.

### 5.1.2 Root Parameters

Root parameters of tomato, *viz.,* root depth and root volume were significantly influenced by the types of micro irrigation and mulching (Fig. 7, Fig. 8). The data on root depth indicated that sub surface drip irrigation at different lateral depths recorded the highest root depth compared to surface methods of micro irrigation. Significantly highest root depth was observed in sub surface drip irrigation at 20 cm depth than the rest of the treatments. Fereres and Soriano (2007) reported that sub surface drip irrigation can restrict the size of the root system to the wetted volume of soil. In sub surface drip irrigation, as the depth of the emitter increases, the root growth will also increase by balancing the moisture in the crop root zone (Al Harbi *et al.* 2008). Hence the availability of moisture under sub surface drip fertigation might have aided effective absorption and utilization of nutrients and better proliferation of roots, resulting in higher root depth (Singh *et al.,* 2020b). Due to the non uniform root distribution in the vertical direction, more roots were observed in the surface layer. This might have resulted in lower root depth in surface methods of micro irrigation.

Sub surface drip irrigation at 10, 15 and 20 cm depth recorded the highest root volume than the surface methods of micro irrigation such as rain hose and surface drip. Sub surface drip irrigation facilitates better availability of water and nutrients within the active crop root zone that leads to more number of primary roots and greater root density below the emitter and this could explain the significant difference in root volume compared to surface methods of micro irrigation. Shaju (2016) reported that sub surface drip irrigation promotes root growth and produces more number of fibrous roots near the laterals to absorb water and nutrients effectively and improves crop yield and quality. The present study found that root depth and root volume was the highest with organic mulch than without mulch. It may be due to the increased soil moisture content that enhanced root proliferation in mulched treatments (Sharma *et al.,* 1990).

### 5.1.3 Yield Attributes

Yield is the manifestation of various morphological, physiological and growth parameters occurring in any crop. Water is a critical input that directly influences the yield of tomato. Hence the findings of the study revealed that the yield attributes of tomato, *viz.,* number of fruits per plant (Fig. 9), average fruit weight (Fig. 10), fruit yield per plant (Fig. 11), and fruit yield $m^{-2}$(Fig. 13) are positively correlated and appeared to be significantly influenced by the types of micro irrigation and mulching.

The results revealed that significantly higher number of fruits per plant was obtained in sub surface drip irrigation at 10 cm depth, and the lowest number of fruits was obtained in rain hose irrigation, which was comparable with surface drip irrigation. The deep placement of laterals at 10, 15 and 20 cm depths increased the number of fruits by 38.49 per cent, 23.98 per cent and 15.32 per cent over rain hose irrigation. The increase in the number of fruits in the sub surface drip irrigation system might be due to the maintenance of optimum soil moisture and the uniform availability of nutrients directly into the root zone, which resulted in increased flowering and higher flower retention.

The highest fruit weight was obtained in sub surface drip irrigation at 10 cm depth. The lowest average fruit weight was recorded for rain hose irrigation which

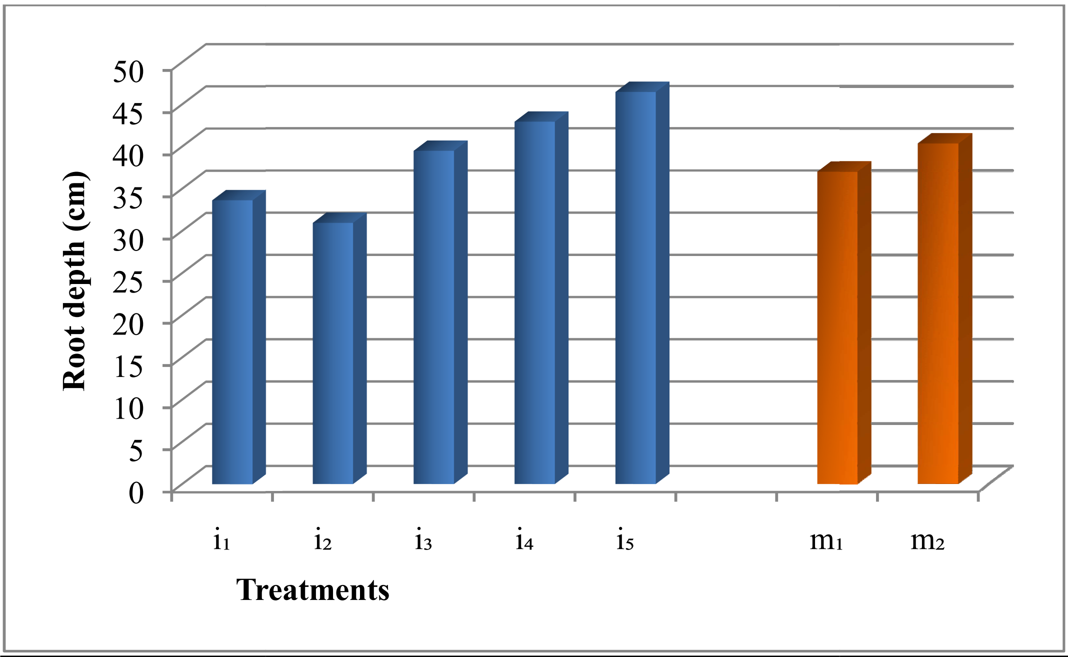


Fig. 7. Effect of types of micro irrigation and mulching on root depth, cm

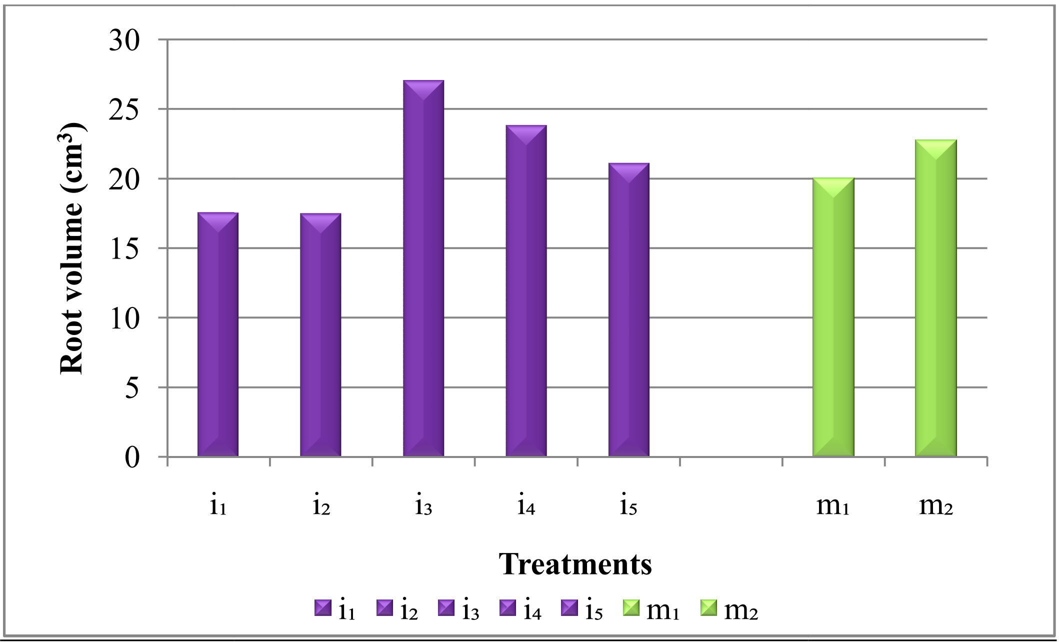


Fig. 8. Effect of types of micro irrigation and mulching on root volume, $cm^3$

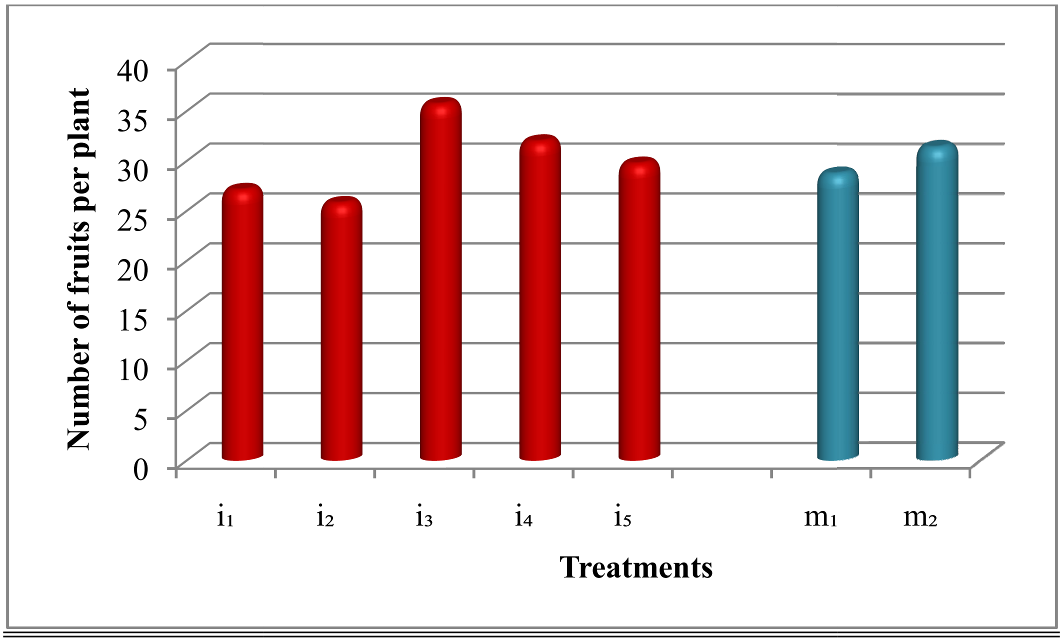


Fig. 9. Effect of types of micro irrigation and mulching on number of fruits per plant

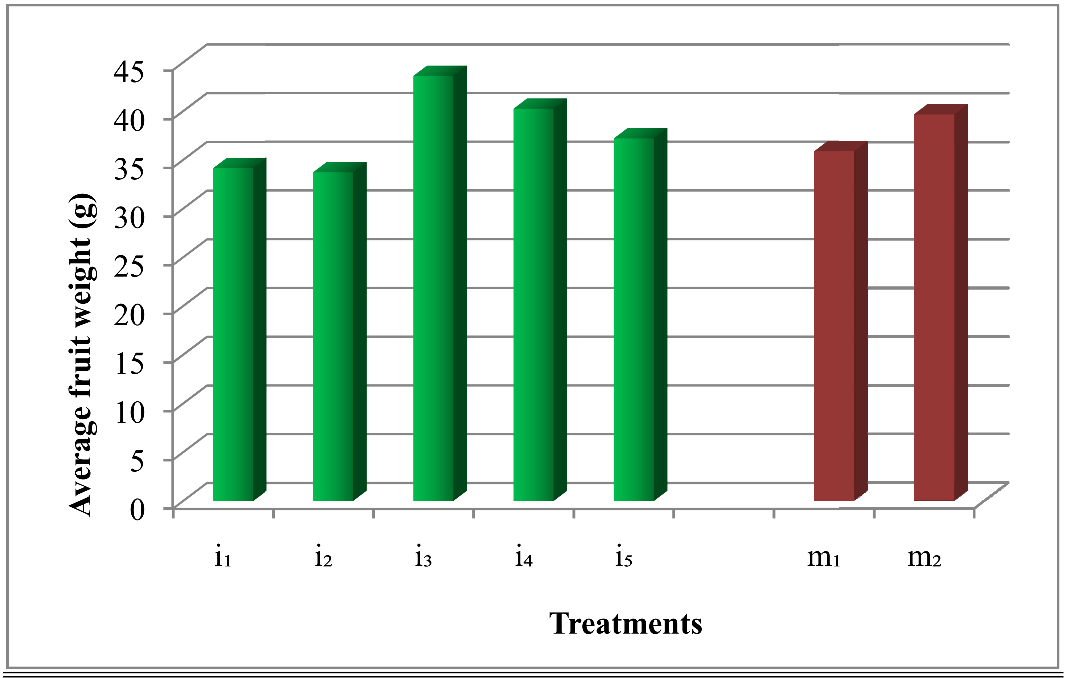


Fig. 10. Effect of types of micro irrigation and mulching on average fruit weight, g

was on par with surface drip irrigation. Fertigation coupled with better water distribution in the active crop root zone area increased the availability of nutrients (Mali *et al.,* 2017) which might have increased the translocation of photosynthates resulting in an increased average fruit weight of tomato fruits. Increased fruit weight under sub surface drip irrigation had been reported by Ragab *et al.* (2019) in tomato.

The fruit yield per plant and fruit yield $m^{-2}$ were significantly higher under sub surface drip irrigation at 10 cm depth, followed by sub surface drip irrigation at 15 cm and 20 cm depth, respectively. The lowest fruit yield per plant and fruit yield $m^{-2}$ was observed under rain hose irrigation and it was on par with surface drip irrigation. The deep placement of laterals at 10 cm, 15 cm and 20 cm depths increased the fruit yield by 43.87 per cent, 32.65 per cent and 22.44 per cent over rain hose irrigation. A similar result was reported by Singh *et al.* (2021), who obtained the maximum yield of tomato under sub surface drip laterals placed at 10 cm depth (14.67%) than surface drip, sub surface drip at 15 cm and 5 cm depth. The reason for the higher yield under sub surface drip irrigation compared to surface drip and rain hose irrigation might be due to the fact that sub surface drip irrigation would deliver water and nutrients in right amounts directly to the crop root zone at a low flow rate and high frequency. The higher availability of moisture in sub surface drip irrigation helped in better root growth, higher nutrient uptake which in turn contributes to higher dry matter production, higher yield components and subsequently more yield. The realization of higher yield under sub surface drip irrigation over surface drip irrigation is in consistent with the findings of Rubieiz *et al.* (1989), Camp (1998), Khodke and Patil (2012), Enciso *et al.* (2015), Ahmed *et al.* (2017), Wang *et al.* (2018), Vadar *et al.* (2019), Singh *et al.* (2020a) and Singh *et al.* (2020b).

The study also revealed that yield varies with the placement of laterals at different depths. The yield produced under sub surface drip irrigation at 10 cm depth was 8.46 per cent and 17.5 per cent more compared to sub surface drip irrigation at 15 cm depth and 20 cm depth respectively. Hence the findings proved that higher yield could be obtained by maintaining optimum soil moisture conductive to plant growth, which is feasible under shallow drip tape installation (Segal *et al.,* 2000). Higher the water content of soil around the emitters, better the water transmission to the surrounding soil. As a result, maintaining the drip tube within the root zone and suitably below the soil surface effectively replenishes the root zone, reducing evaporation losses due to restricted upward capillary flow. Similar findings were also reported by Singh and Rajput (2007) in okra and Patel and Rajput (2007) in potato.

Mulching also had a significant influence on the yield attributes of tomato. The number of fruits, average fruit weight, fruit yield per plant and fruit yield $m^{-2}$ were significantly higher under organic mulch compared to no mulch. Use of organic mulch increased the yield of tomato by 9.73 per cent compared to no mulch. Increased yield attributes of tomato in the mulched plots were probably associated with the conservation of moisture and improved microclimate both beneath and above the soil surface. Mulching reduces soil temperature, evaporation and adds organic matter to the soil which improves the water holding capacity of soil, porosity and reduces the bulk density. Besides this, mulch also improves the soil physical conditions and soil fertility due to the increased biological activity by soil fauna that enhances plant growth and development and subsequently tomato yield. Mulching also improves the partition of photo-assimilates from source to sink and thereby increasing the fruit weight and subsequently increasing the fruit yield (Singh *et al.,* 2013). Similar results were reported by Acharya and Kapur (2001) and Kar and Kumar (2007) in potato, Kayum *et al.* (2008) in tomato, Bahadur *et al.* (2009) in okra, and Shilpa (2019) in chilli.

Interaction between types of micro irrigation and mulching was found significant with respect to fruit yield per plant (Fig. 12) and fruit yield $m^{-2}$(Fig. 14). Significantly higher fruit yield per plant and fruit yield $m^{-2}$ were obtained in the treatment combination of sub surface drip irrigation at 10 cm depth with organic mulch. Rain hose irrigation without mulch resulted in the lowest fruit yield per plant and fruit yield $m^{-2}$. Higher yield with sub surface drip irrigation at 10 cm depth in combination with organic mulch might be due to improved growth and yield attributes resulting from the better metabolic activity of the plant probably due to the consistent supply of soil moisture and nutrients to the root zone as reported by Patel and Rajput (2007).

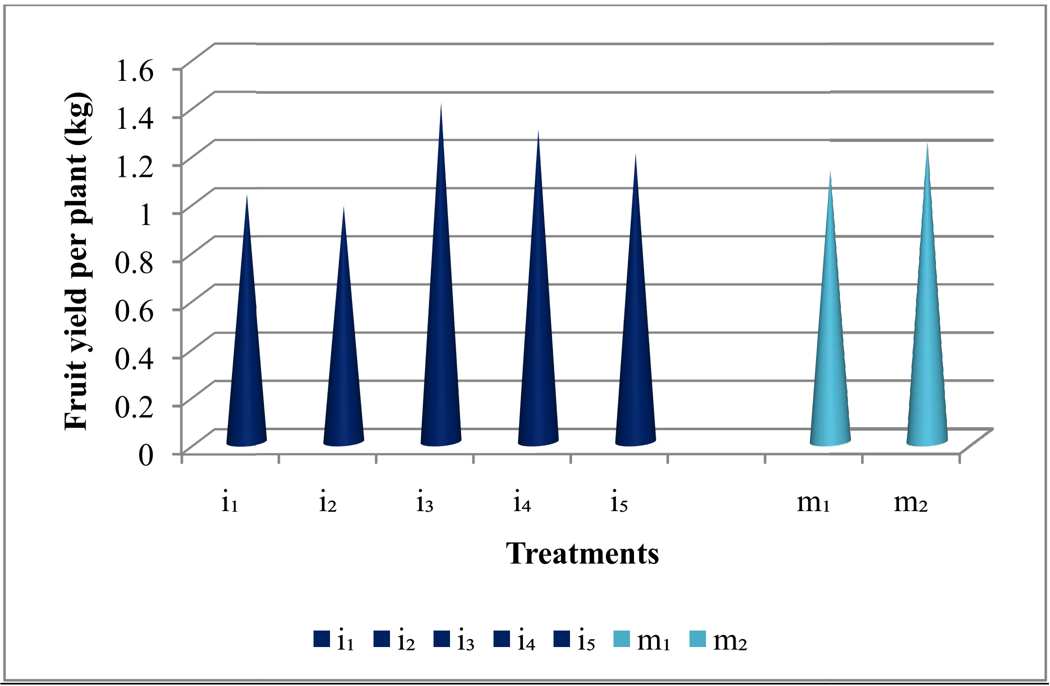


Fig. 11. Effect of types of micro irrigation and mulching on fruit yield per plant, kg

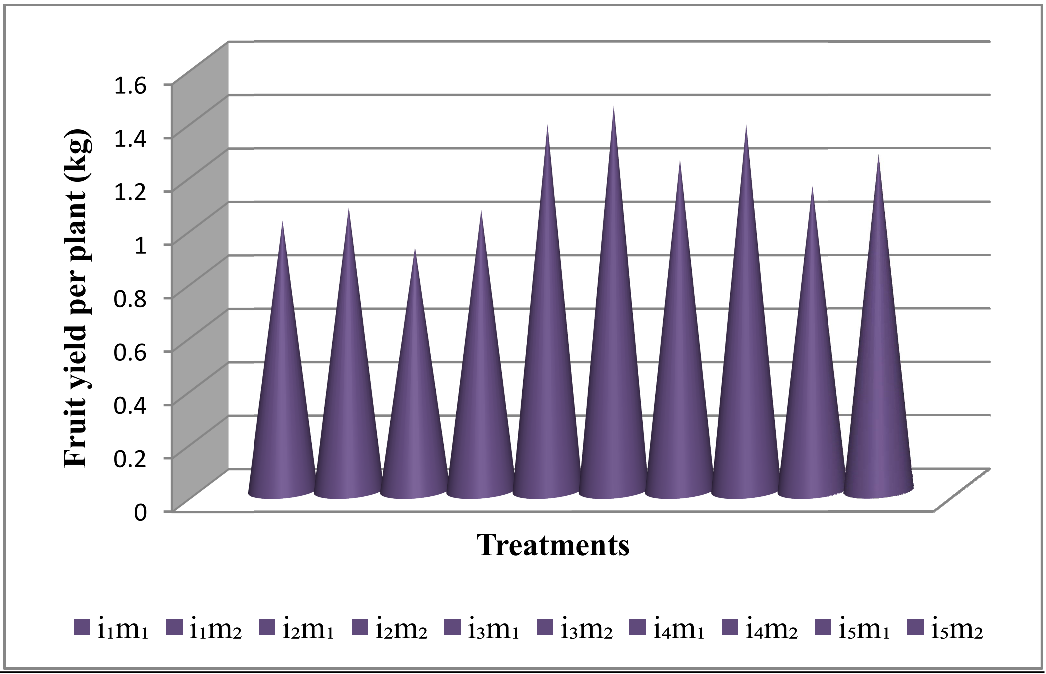


Fig. 12. Interaction effect of types of micro irrigation and mulching on fruit yield per plant, kg

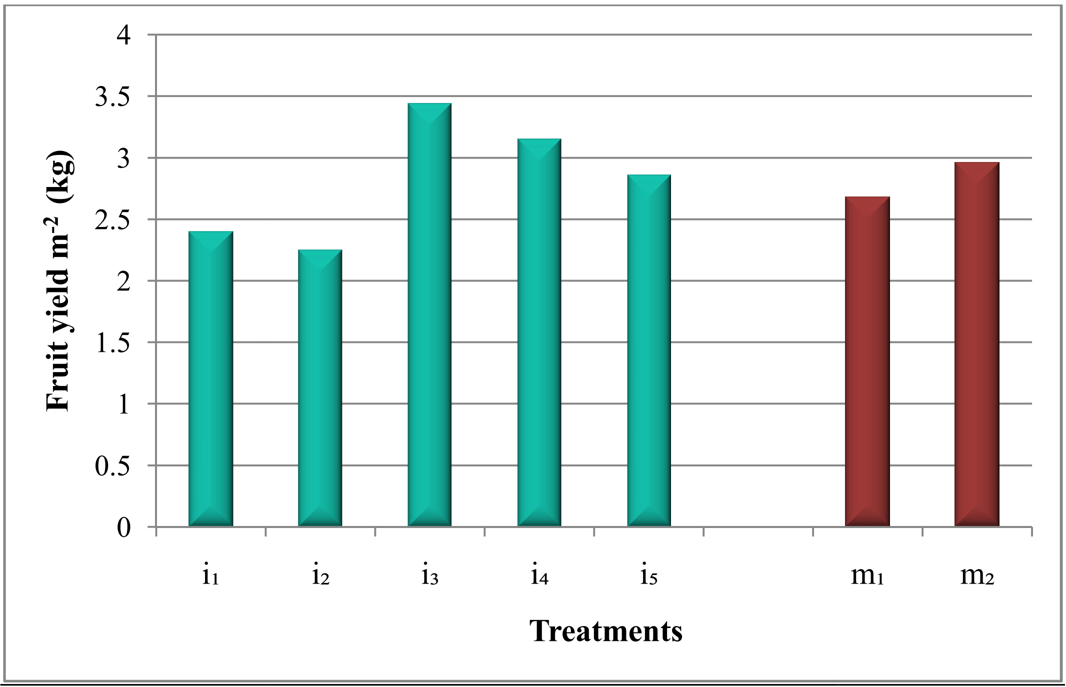


Fig. 13. Effect of types of micro irrigation and mulching on fruit yield $m^{-2}$, kg

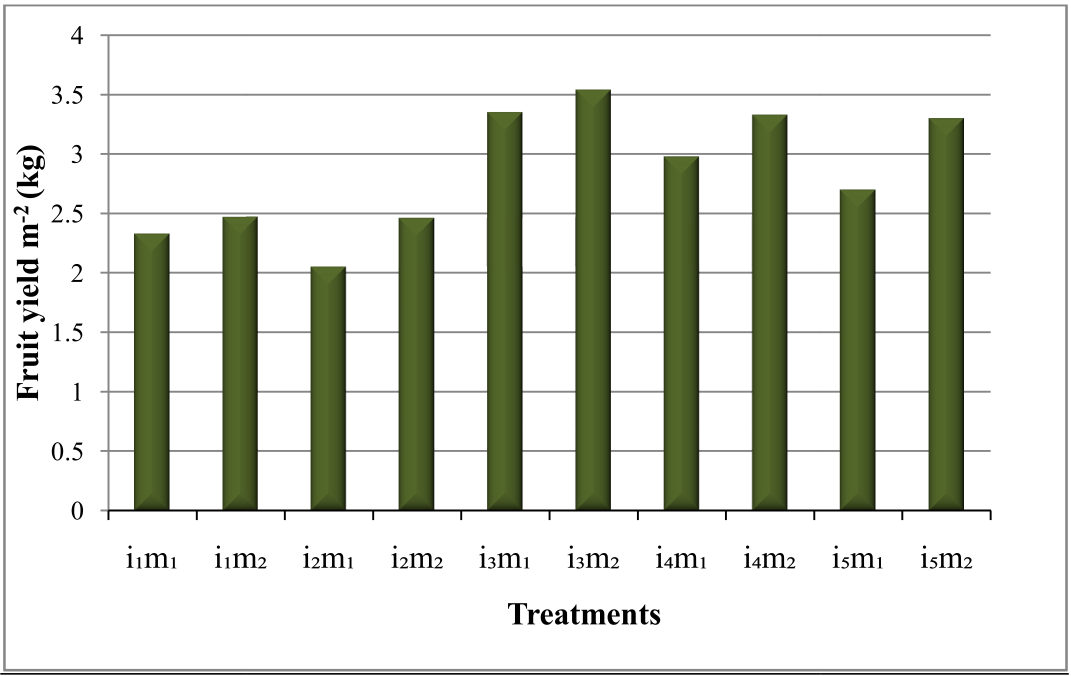


Fig. 14. Interaction effect of types of micro irrigation and mulching on fruit yield $m^{-2}$, kg

### 5.1.4 Nutrient Uptake

Nutrient uptake by the crop was favourably influenced by the types of micro irrigation and mulching (Table 9). N uptake was higher for sub surface drip irrigation at 10 cm, 15 cm and 20 cm depths whereas significantly higher P and K uptake were observed in sub surface drip irrigation at 10 cm depth than rest of the treatments. The N, P, K uptake was lowest in rain hose irrigation and it was on par with surface drip irrigation. The concentration and availability of nutrients in the soil for plant uptake are primarily governed by soil moisture availability. Sub surface drip irrigation involves precise application of water and nutrients at frequent intervals in the root zone coupled with the crop demand. This reduces the variations in nutrient concentration, increases their availability and reduces the leaching beneath the root zones, which ultimately improves the uptake of nutrients by the crop. Enhanced biomass production due to the constant availability of water and nutrients to the crop also resulted in increased nutrient uptake for sub surface drip fertigation. Similar finding of increased uptake in sub surface drip irrigation was reported by Badr and El-Yazied (2007).

Mulching also had a significant influence on nutrient uptake. The treatment with organic mulch resulted in significantly higher uptake of N, P and K than the treatment without mulch. The efficient utilization of nutrients under mulch treatments could be because of the active root growth conditioned by favorable moisture and thermal regimes, resulting in higher uptake of nutrients by plants under mulch. Similar results were reported by Shilpa (2019) in chilli.

The combined effect of types of micro irrigation and mulching favorably influenced N and P uptake. The treatment combination, sub surface drip at 10 cm depth with organic mulch recorded the highest N and P uptake whereas the lowest uptake was observed in rain hose with no mulch. This might be due to the optimum moisture content and frequent availability of nutrients in the soil as a result of irrigation and mulching, combined with the high DMP, resulting in high nutrient uptake in sub surface drip irrigation at 10 cm depth with organic mulch.

### 5.1.5 Soil Analysis

#### *5.1.5.1 Nutrient Status of Soil*

Types of micro irrigation had a significant influence on available nitrogen in the soil after the experiment. Available N was higher under rain hose irrigation and surface drip irrigation. The lowest available N was recorded for sub surface drip irrigation at 10 cm depth, which was comparable with sub surface drip irrigation at 15 cm and 20 cm depth. The available P and K were not significantly influenced by types of micro irrigation. Higher uptake of N in sub surface drip irrigation might have resulted in lower available N status of the soil in sub surface methods of irrigation.

Mulching had a significant influence on available N, P and K. Organic mulch obtained significantly higher available N, P and K compared to no mulch. Higher available nutrients in the mulched plot might be due to the decomposition of organic mulch. This is in corroboration with the findings of Mitra and Mandal (2015) and Shilpa (2019).

#### *5.1.5.2 Soil Moisture Content*

Soil moisture content at 15 and 30 cm depth from the soil surface was measured at monthly intervals as shown in Table 10 (b) and 10(c). Different types of micro irrigation and mulching had a significant influence on soil moisture content. At 15 cm depth, significantly higher moisture content was recorded for sub surface drip irrigation at 10 cm depth than the rest of the treatments. At 30 cm depth from the soil surface, soil moisture content was higher in sub surface drip irrigation at 20 cm depth followed by other treatments. The lowest soil moisture content was observed in rain hose irrigation and it was on par with surface drip irrigation at both 15 and 30 cm depth. The present study revealed that soil moisture distribution was better in sub surface drip irrigation system (Singh and Rajput, 2007). This might be due to the reduced evaporation losses from sub surface drip method of irrigation. Moreover, in sub surface drip irrigation, soil surface remains relatively dry at all burial depths, suggesting the dominance of downward movement of water than its lateral movement due to the predominant role of force of gravity than the capillary force in the sandy

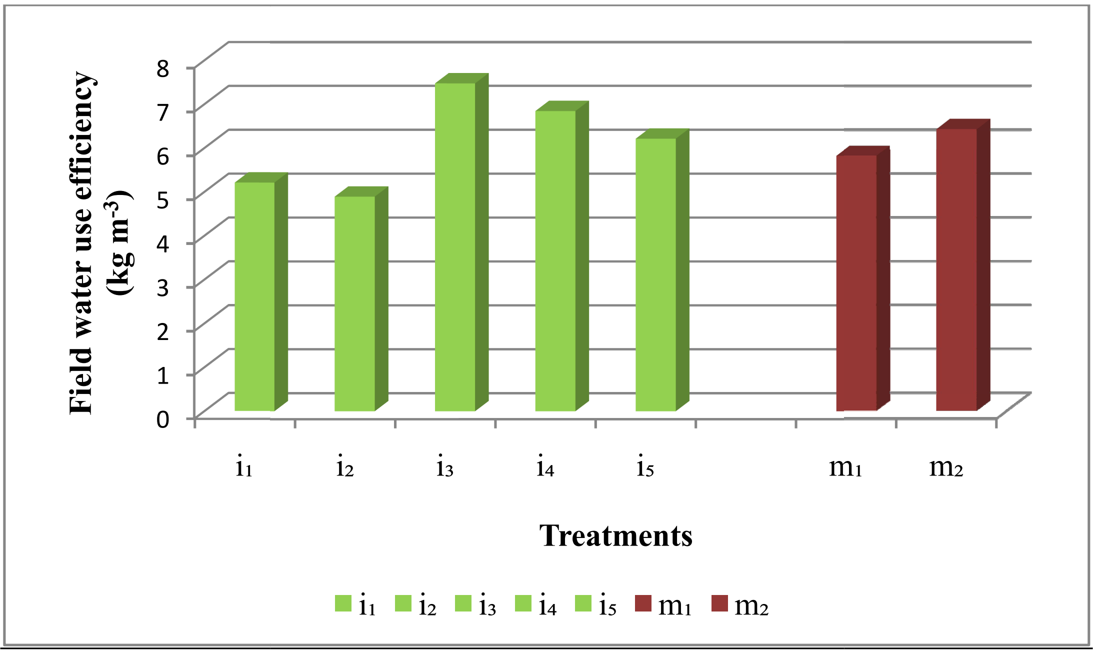


Fig. 15. Effect of types of micro irrigation and mulching on field water use efficiency, kg $m^{-3}$

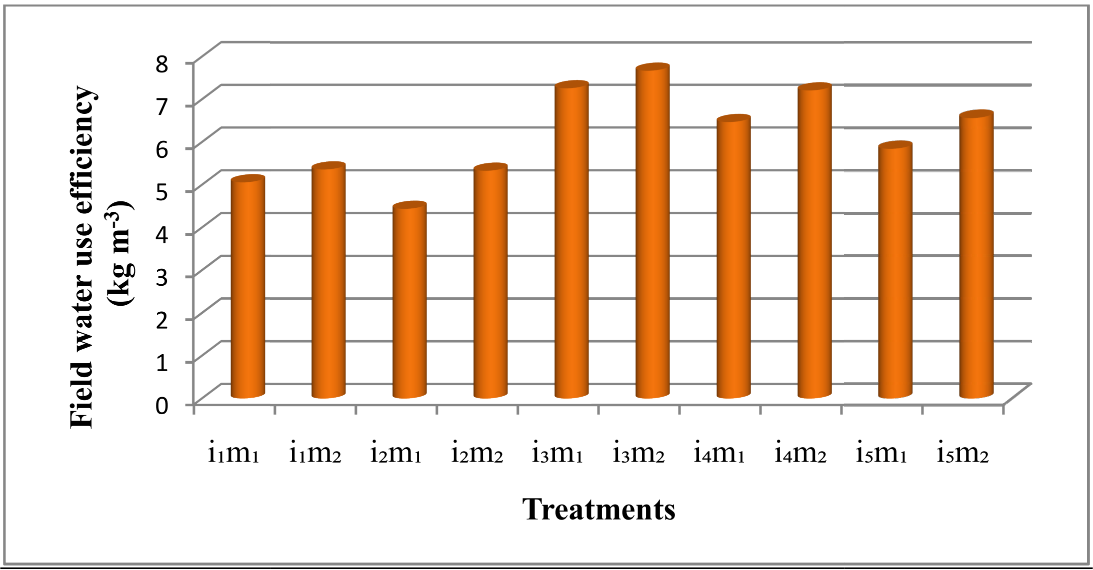


Fig. 16. Interaction effect of types of micro irrigation and mulching on field water use efficiency, kg $m^{-3}$

clay loam soil of the experimental plot. Low moisture content in surface drip and rain hose irrigation might be due to the high rate of infiltration and direct evaporation loss from the soil surface. Nisha (2007) reported that the atmospheric interactions are high at the surface method than the sub surface methods of irrigation.

Mulching also had a significant influence on soil moisture content at 15 cm and 30 cm depth. Organic mulch recorded the highest moisture content at 15 cm and 30 cm depth. High moisture content at 15 cm and 30 cm depth in organic mulched treatments might be due to the absence of restricted capillary rise and less evaporation which maintained moisture longer than unmulched treatments. A similar finding has been reported by Ghosh *et al.* (2006) who recorded more soil moisture content in wheat straw mulch than without mulch in groundnut. The high moisture content in mulched plot compared to no mulch was also reported by Kar and Kumar (2007).

### 5.1.6 Soil Moisture Studies

Data on soil moisture studies revealed that types of micro irrigation and mulching had a significant influence on field water use efficiency (Fig. 15.) and water productivity as shown in Fig. 17. and Fig. 18.

Water use efficiency (WUE) is considered as one of the major attributes that reflects the effectiveness of various irrigation treatments. Field water use efficiency (FWUE) is usually expressed in terms of crop yield and water requirement, since the same quantity of water was given, the trend of FWUE followed a similar pattern as that of tomato yield. Sub surface drip irrigation at 10 cm depth recorded the highest water use efficiency and was significantly superior to all other treatments. The lowest water use efficiency was recorded for rain hose irrigation and it was on par with surface drip irrigation. The FWUE increased to an extent of 43.37 per cent and 52.76 per cent in sub surface drip irrigation at 10 cm depth compared to surface drip and rain hose irrigation. Higher FWUE under sub surface drip irrigation at 10 cm depth was due to the improved crop performance and greater yield by efficient use of available water and nutrients provided at frequent intervals throughout the crop period to fulfil crop demand. Sub surface drip irrigation has the potential to reduce water losses due to evaporation and improve water use efficiency.The evaporation loss from sub surface placement of drip lines is very low because of limited water availability on the soil surface and the low upward movement of water retaining sufficient moisture beneath the soil surface for root uptake (Badr *et al.,* 2010). Similar findings were reported by Singh and Rajput (2007) in okra, Bozkurt *et al.* (2011) in lettuce, Kong *et al.* (2012) in bell pepper, Ahmed *et al.* (2017) in tomato and Singh *et al.* (2020a) in tomato.

Interaction between types of micro irrigation and mulching was found significant with respect to field water use efficiency. Significantly higher water use efficiency was recorded for sub surface drip irrigation at 10 cm depth with organic mulch. The lowest water use efficiency was recorded for rain hose irrigation with no mulch. This could be attributed to the efficiency of organic mulch in moisture conservation by reducing evaporation, as well as the effectiveness of sub surface drip irrigation in maintaining optimum soil moisture throughout crop growth (Biswas *et al.,* 2015), which resulted in higher yield and subsequently high water use efficiency in the combination of sub surface drip with organic mulch compared to rain hose without mulch.

Water productivity was significantly higher in sub surface drip irrigation at 10 cm depth followed by sub surface drip irrigation at 15 and 20 cm depth respectively. The lowest water productivity was obtained in rain hose irrigation and it was on par with surface drip irrigation. Water productivity was 55.10 per cent and 46.15 per cent higher in sub surface drip irrigation at 10 cm depth compared to rain hose irrigation and surface drip irrigation. Placement of drip laterals also has a significant influence on water productivity with an increase of 7.95 per cent and 21.40 per cent in sub surface drip irrigation at 10 cm depth when compared to sub surface drip irrigation at 15 cm and 20 cm depth. The present results are concurrent with the findings of Mali *et al.* (2017) in bitter gourd.

Organic mulch obtained significantly higher water use efficiency and water productivity than no mulch. Organic mulch enhanced the water use efficiency by 10.30 per cent and water productivity by 2.94 per cent over no mulch. The increased field water use efficiency and water productivity in mulched plots were a result of maintenance of soil moisture for a longer period of time and the optimum soil

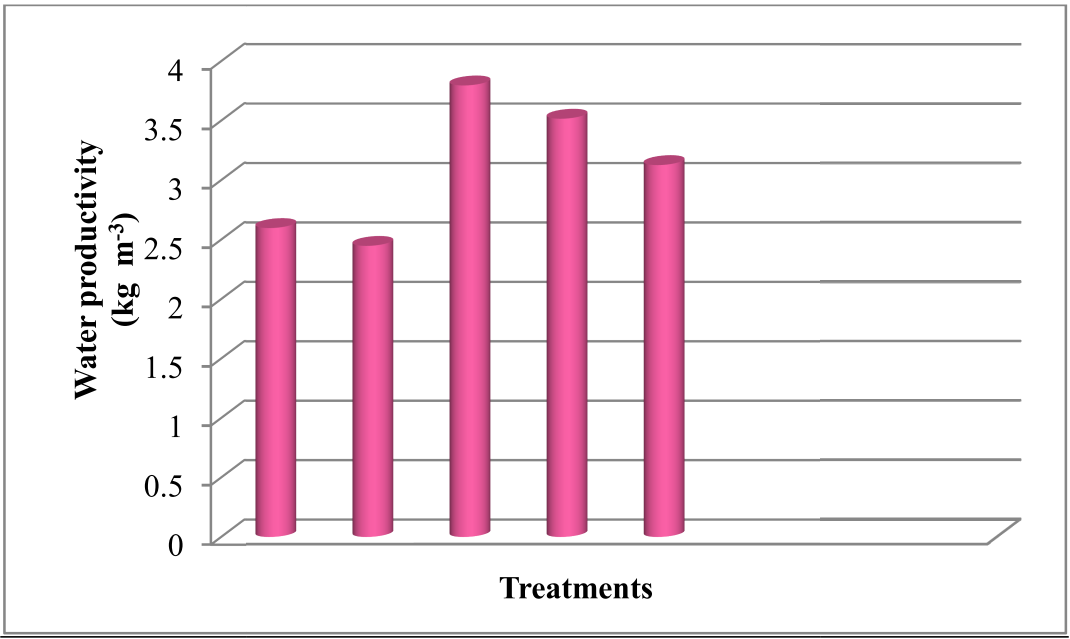


Fig.17. Effect of types of micro irrigation on water productivity, kg $m^{-3}$

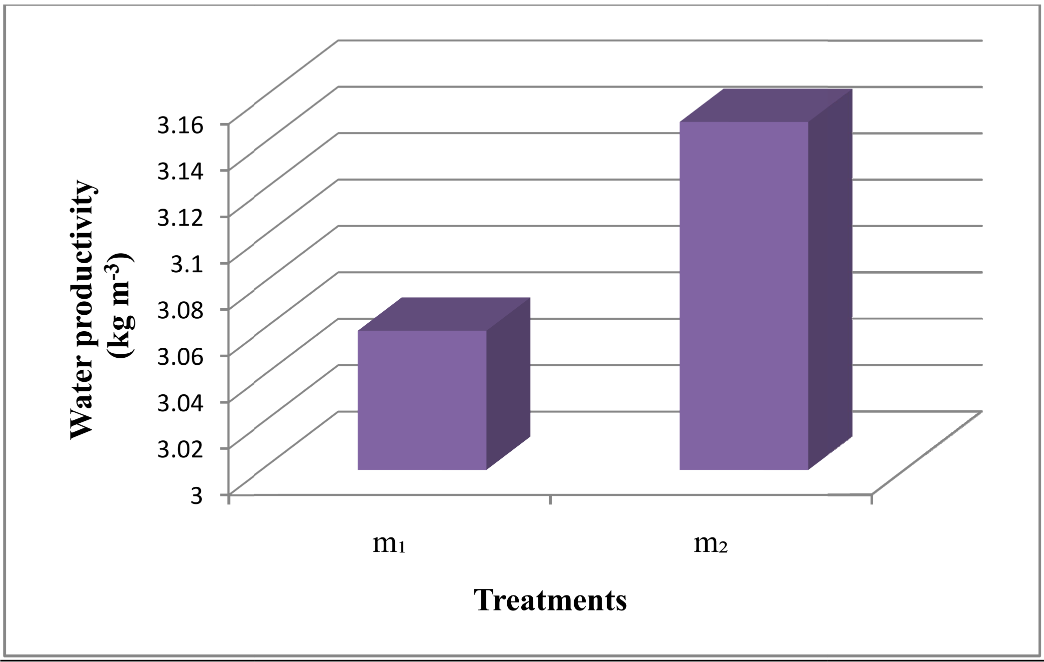


Fig. 18. Effect of types of mulching on water productivity, kg $m^{-3}$

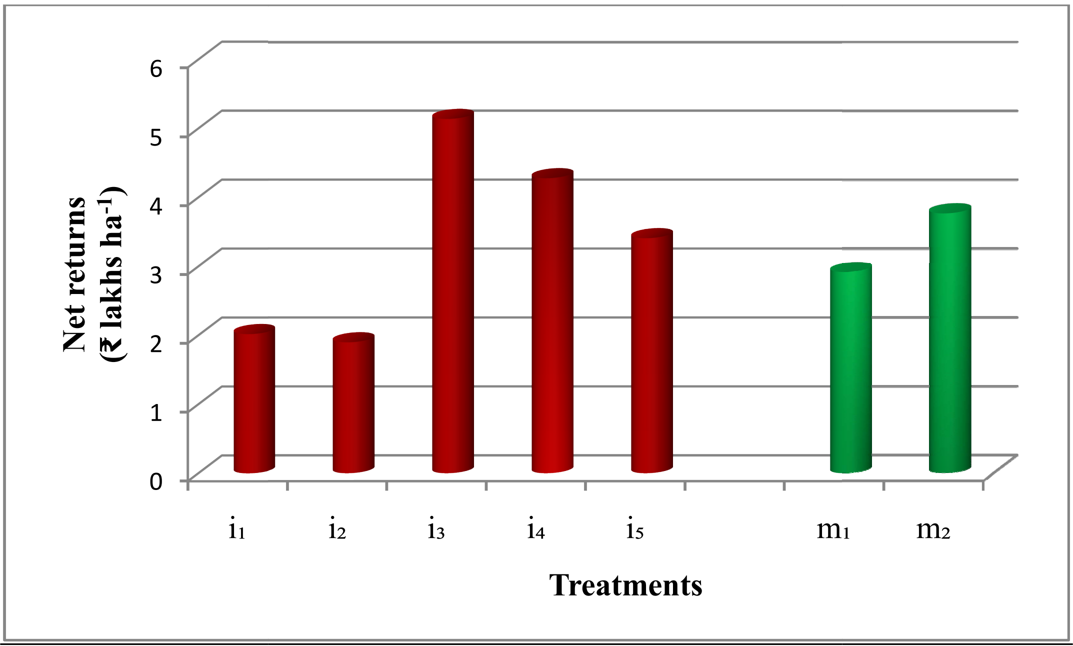


Fig. 19. Effect of types of micro irrigation and mulching on net returns (₹ lakhs ha$^{-1}$)

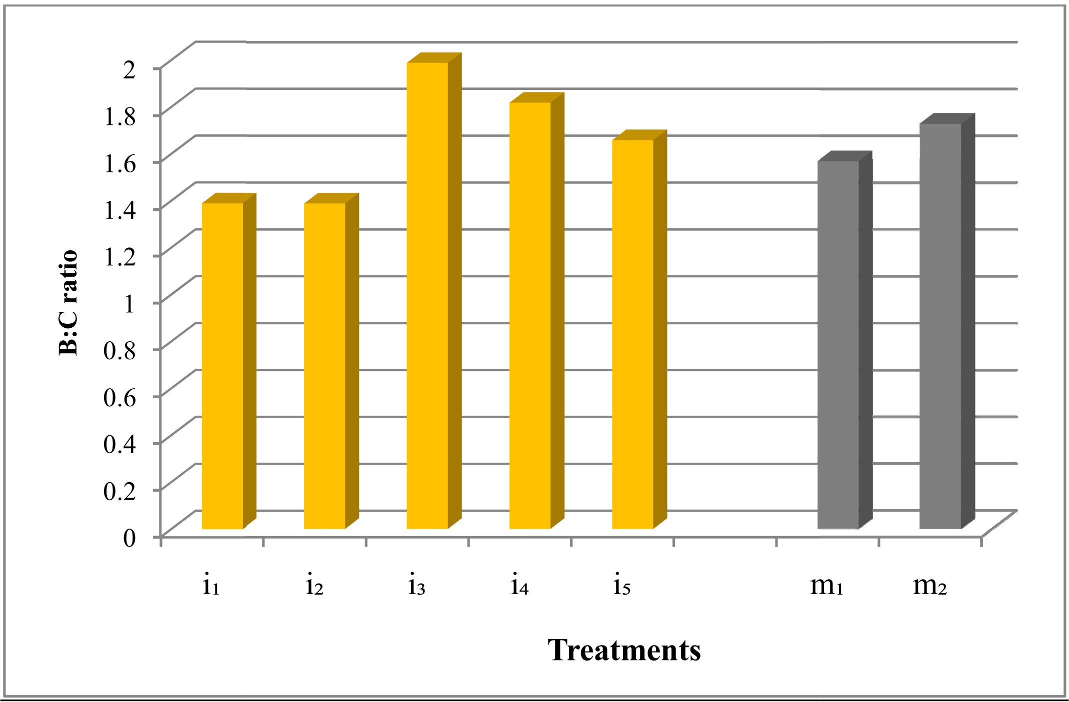


Fig. 20. Effect of types of micro irrigation and mulching on B: C ratio

temperature, which reduced water losses from the soil with a considerate saving of water and yield intensification. Similar findings have been reported by Mukherjee *et al.* (2010) in tomato. Singh (2016) also observed higher water use efficiency under rice straw mulch than without mulch.

## 5.2 ECONOMICS OF CULTIVATION

The economic analysis was worked out in terms of net returns and benefit cost ratio. Different types of micro irrigation and mulching significantly influenced the net returns and B: C ratio as shown in Table 12 and are graphically depicted in Fig. 19. and Fig. 20. Among the different types of micro irrigation, highest net returns and benefit cost ratio were observed in the treatment sub surface drip irrigation at 10 cm depth followed by sub surface drip irrigation at 15 cm depth and sub surface drip irrigation at 20 cm depth respectively. The lowest net returns and benefit cost ratio was observed in rain hose irrigation and which was on par with surface drip irrigation. The high benefit cost ratio and net returns in sub surface drip irrigation at 10 cm, 15 cm and 20 cm depths might be due to the higher fruit yield obtained in these treatments. High economics of cultivation by sub surface drip irrigation was also reported by Rakesh *et al.* (2011) and Ahmed *et al.* (2017)

Mulching also exerted a significant influence on net returns and the benefit cost ratio. Organic mulch obtained the highest net returns and benefit cost ratio compared to no mulch. Similar findings have been reported by Goswami and Saha (2006), Biswas *et al.* (2015), Rao *et al.* (2016), Shilpa (2019), Jadav *et al.* (2020).

The highest net returns and benefit cost ratio was recorded in the treatment combination of sub surface drip irrigation at 10 cm depth with organic mulch whereas the lowest was recorded for rain hose irrigation without mulch.

# ***SUMMARY***

# 6. SUMMARY

The experiment entitled "Micro irrigation and mulching for yield optimization of tomato in rain shelter" was conducted at the Instructional Farm, College of Agriculture, Vellayani from February to May 2021 to assess the efficacy of micro irrigation and mulching on the growth, yield, and economics of tomato in rain shelter.

The experiment was laid out in split plot design with five types of micro irrigation as main plot treatments and two mulching materials as sub plot treatments. The main plot treatments were $i_1$ (surface drip irrigation), $i_2$ (rain hose irrigation), $i_3$ (sub surface drip irrigation at 10 cm), $i_4$ (sub surface drip irrigation at 15 cm) and $i_5$ (sub surface drip irrigation at 20 cm). The sub plot treatments were $m_1$ (no mulch) and $m_2$ (organic mulch). Organic mulch (dry banana leaves) @ 10 t $ha^{-1}$ was applied as per the treatments. The tomato variety Vellayani Vijai was used for the study. The fertilizers were applied as per the *Adhoc* POP recommendation for precision farming of tomato. Fertilizer recommendation of tomato 264:130:281 kg NPK $ha^{-1}$ was given through fertigation at three days interval. Water requirement of the crop was computed and daily irrigation was given as per the requirement. The data on various parameters were statistically analysed and the summary of salient findings are presented below.

The data on growth attributes of tomato *viz.,* plant height, number of branches per plant, root shoot ratio, and dry matter production observed at different growth stages, were significantly influenced by types of micro irrigation and mulching. Taller plants were observed for sub surface drip irrigation at 10 cm depth ($i_3$) throughout the growth stages (55.76 cm, 90.91 cm, 107.41 cm, 114.98 cm) and were on par with sub surface drip irrigation at 15 cm depth ($i_4$) and sub surface drip irrigation at 20 cm depth ($i_5$) at 90 DAT and at harvest. Sub surface drip irrigation at 10 cm depth ($i_3$) recorded the maximum number of branches per plant at 50 per cent flowering (8.01) and at harvest (13.61) and was comparable with sub surface drip irrigation at 15 cm depth ($i_4$) and 20 cm depth ($i_5$) at harvest. Root shoot ratio was recorded at harvest where sub surface drip irrigation at 10 cm depth ($i_3$) obtained higher root shoot ratio (0.27) and it was on par with sub surface drip irrigation at 15 cm depth ($i_4$). Dry matter production was significantly higher for sub surface drip irrigation at 10 cm depth ($i_3$) (4751 kg $ha^{-1}$) than the rest of the treatments. The combination of sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) registered the highest dry matter production (4835 kg $ha^{-1}$) and was significantly superior to others. Between mulches, organic mulch ($m_2$) obtained significantly higher plant height (45.00 cm, 79.33 cm, 95.42 cm, 106.85 cm), number of branches per plant (7.07, 12.88), leaf area index (0.92), root shoot ratio (0.26), and dry matter production (4244 kg $ha^{-1}$). Micro irrigation, mulching or their interaction, did not had any significant influence on the days to 50 per cent flowering.

Root parameters *viz.,* root depth and root volume at harvest were recorded. Sub surface drip irrigation at 20 cm depth ($i_5$) recorded significantly higher root depth (46.46 cm), whereas the root volume was significantly higher for sub surface drip irrigation at 10 cm depth ($i_3$) (27.06 $cm^3$). Mulching favourably influenced the root depth and root volume. Between mulches, the treatment with organic mulch ($m_2$) registered a higher root depth (40.39 cm) and root volume (22.78 $cm^3$). The interactions among the treatments were not significant.

The present findings revealed that types of micro irrigation had a significant influence on the yield and yield attributes of tomato. The treatment sub surface drip irrigation at 10 cm depth ($i_3$) recorded the highest number of fruits (35.69) and was significantly superior to others. Among different types of micro irrigation, average fruit weight of tomato was higher for sub surface drip irrigation at 10 cm depth ($i_3$) (43.60 g) and was statistically on par with sub surface drip irrigation at 15 cm depth ($i_4$). The fruit yield per plant (1.41 kg) and fruit yield $m^{-2}$ (3.44 kg) were significantly higher for sub surface drip irrigation at 10 cm depth ($i_3$). Between mulches, organic mulch ($m_2$) recorded significantly higher number of fruits per plant (31.37), average fruit weight (39.69 g), fruit yield per plant (1.24 kg), and fruit yield $m^{-2}$ (2.96 kg) compared to no mulch ($m_1$). The combination of sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) obtained the significantly higher fruit yield per plant (1.44 kg) and fruit yield $m^{-2}$ (3.54 kg).

Micro irrigation, mulching or their interaction did not have any significant influence on the quality aspects of fruits. The types of micro irrigation had significant influence on NPK uptake. Among different types of micro irrigation, N uptake was higher for sub surface drip irrigation at 10 cm depth ($i_3$) (59.09 kg $ha^{-1}$) and remained on par with sub surface drip irrigation at 15 cm depth ($i_4$). The highest uptake of P (21.43 kg $ha^{-1}$) and K (85.94 kg $ha^{-1}$) was for sub surface drip irrigation at 10 cm depth ($i_3$) and was superior to others. Mulching also influenced the NPK uptake where the treatment with organic mulch ($m_2$) obtained significantly higher uptake of N (55.89 kg $ha^{-1}$), P (17.83 kg $ha^{-1}$) and K (75.00 kg $ha^{-1}$). The combination of sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) recorded higher uptake of N (61.26 kg $ha^{-1}$) and P (22.73 kg $ha^{-1}$).

Organic carbon status of the soil was not significantly influenced by the types of micro irrigation and mulching. Available N was higher in the treatment rain hose irrigation ($i_2$) (229.72 kg $ha^{-1}$) and was comparable with surface drip irrigation ($i_1$). Available K and P were not significantly influenced by the types of micro irrigation. Between mulches, the treatment with organic mulch ($m_2$) obtained higher available N (224.15 kg $ha^{-1}$), P (89.91 kg $ha^{-1}$) and K (279.63 kg $ha^{-1}$) than without mulch. The interaction between the treatments did not show any significant influence on available NPK. Soil moisture content at 15 cm and 30 cm depth was measured at monthly intervals. Soil moisture content was significantly influenced by the types of micro irrigation and mulching. Among the different types of micro irrigation, sub surface drip irrigation at 10 cm depth ($i_3$) and sub surface drip irrigation at 20 cm depth ($i_5$) obtained the highest moisture content at 15 cm depth and 30 cm depth, respectively. Between mulches, organic mulch ($m_2$) obtained higher moisture content at 15 cm and 30 cm depth at all intervals.

Water productivity and field water use efficiency were significantly influenced by the types of micro irrigation and mulching. Sub surface drip irrigation at 10 cm depth ($i_3$) recorded the highest water productivity (3.80 kg $m^{-3}$) and field water use efficiency (7.47 kg $m^{-3}$) of all the treatments. Between mulches, treatment with organic mulch ($m_2$) obtained significantly higher water productivity (3.15 kg $m^{-3}$) and field water use efficiency (6.42 kg $m^{-3}$). The combination of sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) attained the highest water use efficiency (7.67 kg $m^{-3}$) and was superior to others.

The statistical analysis of data on the economics of cultivation revealed that sub surface drip irrigation at 10 cm depth ($i_3$) recorded the highest net returns (₹ 5.14 lakhs $ha^{-1}$) and B: C ratio (1.99). Between mulches, organic mulch ($m_2$) obtained the highest net returns (₹ 3.77 lakhs $ha^{-1}$) and B: C ratio (1.73) than no mulch. The interaction between the treatments also showed a significant difference on the net returns and the B: C ratio. The combination of sub surface drip irrigation at 10 cm depth with organic mulch ($i_3m_2$) obtained the highest net returns (₹ 5.43 lakhs $ha^{-1}$) and B: C ratio (2.04).

The present investigation revealed that sub surface drip irrigation system can be successfully adopted for tomato cultivation in rain shelter. Sub surface drip irrigation at 10 cm depth with organic mulch (dry banana leaves) @ 10 t $ha^{-1}$ can be recommended for getting higher yield, water use efficiency, and net returns in tomato.

**Future line of work**

- A long-term study is necessary to determine the durability and efficiency of sub surface placement of laterals.
- Standardization of the depth of lateral placement in various vegetables under rain shelter needs to be emphasized.
- The combination of different types of micro irrigation with various mulches on growth and yield qualities, as well as moisture conservation, in diverse vegetables, has to be investigated.

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# ***APPENDICES***

## APPENDIX- I

Weather data inside rain shelter during the cropping period

Weekly averages (1/02/2021- 10/10/2021)

| Standard week | Maximum temperature (˚C) | Minimum temperature (˚C) | Relative humidity (%) | Light intensity (K. lux) |
|---|---|---|---|---|
| 5 | 32 | 23.6 | 75 | 41.87 |
| 6 | 28.3 | 23.9 | 70 | 42.32 |
| 7 | 30 | 24.2 | 76 | 45.65 |
| 8 | 30.6 | 22.2 | 80 | 47.07 |
| 9 | 31 | 23.7 | 87 | 45.86 |
| 10 | 31 | 21.4 | 85 | 43.59 |
| 11 | 31 | 20.4 | 85 | 50.22 |
| 12 | 31.3 | 23.4 | 89 | 51.24 |
| 13 | 31.4 | 22.5 | 79 | 52.87 |
| 14 | 32 | 20.4 | 82 | 51.23 |
| 15 | 32.3 | 23 | 88 | 52.91 |
| 16 | 32.1 | 25.4 | 89 | 54.25 |
| 17 | 32.1 | 25.8 | 86 | 53.56 |
| 18 | 32.3 | 26.4 | 89 | 50.88 |

## APPENDIX II

Cost of cultivation of tomato grown under rain shelter for one season

| Particulars | Cost(₹) |
|---|---|
| Rain shelter | 177777 |
| Drip | 55555 |
| Rain hose | 11111 |
| Manures | 40000 |
| Seed | 34722 |
| Labour | 78755 |
| Fertilizers and other miscellaneous | 16000 |
| Total | 413920 |

- Structure (Rain shelter) Rs 800 per $m^2$ for life span of 15 years

**MICRO IRRIGATION AND MULCHING FOR YIELD OPTIMIZATION OF TOMATO IN RAIN SHELTER**

*by*

**SANIGA N. S**

**(2019-11-204)**

**Abstract of the thesis**

**Submitted in partial fulfilment of the**

**requirements for the degree of**

**MASTER OF SCIENCE IN AGRICULTURE**

**Faculty of Agriculture**

**Kerala Agricultural University**

**DEPARTMENT OF AGRONOMY**

**COLLEGE OF AGRICULTURE**

**VELLAYANI, THIRUVANANTHAPURAM-695 522**

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**2021**

**ABSTRACT**

The investigation entitled "Micro irrigation and mulching for yield optimization of tomato in rain shelter" was carried out during February-May 2021to evaluate the efficacy of micro irrigation and mulching on the growth, yield and economics of tomato in rain shelter.

The experiment was laid out in split plot design with five types of micro irrigation as main plot treatments and two mulching materials as sub plot treatments with four replications. The main plot treatments were $i_1$ (surface drip irrigation), $i_2$ (rain hose irrigation), $i_3$ (sub surface drip irrigation at 10 cm), $i_4$ (sub surface drip irrigation at 15 cm) and $i_5$ (sub surface drip irrigation at 20 cm). The sub plot treatments were $m_1$ (no mulch) and $m_2$ (organic mulch). Organic mulch (dry banana leaves) @ 10 t $ha^{-1}$ was applied as per the treatments. The tomato variety Vellayani Vijai was used for the study.

The growth attributes of tomato were favourably influenced by the types of micro irrigation and mulching. Taller plants were observed in sub surface drip irrigation (SSDI) at 10 cm depth throughout the growth stages and it was comparable with SSDI at 15 cm depth and 20 cm depth at 90 DAT and at harvest. The number of branches per plant was higher in SSDI at 10 cm depth at 50 per cent flowering (8.01) and at harvest (13.61) and was on par with SSDI at 15 cm depth and SSDI at 20 cm depth at harvest. The different types of micro irrigation did not had any significant influence on days to 50 per cent flowering and leaf area index at 50 per cent flowering. The root shoot ratio was higher for SSDI at 10 cm depth (0.27) and was statistically on par with SSDI at 15 cm depth. The highest dry matter production was recorded for SSDI at 10 cm depth (4751 kg $ha^{-1}$) and was significantly superior to rest of the treatments. Between mulches, organic mulch significantly increased the growth attributes of tomato except days to 50 per cent flowering. The combination of SSDI at 10 cm depth with organic mulch recorded significantly higher dry matter production (4835 kg $ha^{-1}$) at harvest.

The root parameters *viz.,* root depth and root volume were significantly higher for SSDI at 20 cm depth (46.46 cm) and SSDI at 10 cm depth (27.06 $cm^3$), respectively.

Between mulches, organic mulch recorded higher root depth (40.39 cm) and root volume (22.78 $cm^3$) compared to treatment without mulch.

The types of micro irrigation and mulching had significant influence on the yield attributes of tomato. The number of fruits per plant was significantly higher for SSDI at 10 cm depth (35.69). The average fruit weight (43.60 g) was higher for SSDI at 10 cm depth was on par with SSDI at 15 cm depth. The fruit yield per plant (1.41 kg) and fruit yield $m^{-2}$ (3.44 kg) were significantly higher for SSDI at 10 cm depth. Between organic mulch and no mulch, organic mulching recorded significantly higher number of fruits per plant (31.37), average fruit weight (39.69 g), fruit yield per plant (1.24 kg) and fruit yield $m^{-2}$ (2.96 kg) than without mulch. The combination of SSDI at 10 cm depth along with organic mulch produced significantly higher fruit yield per plant (1.44 kg) and fruit yield $m^{-2}$ (3.54 kg).

Micro irrigation, mulching or their interaction did not influence the quality attributes of the tomato. The uptake of N (59.09 kg $ha^{-1}$), P (21.43 kg $ha^{-1}$), K (85.94 kg $ha^{-1}$) were higher for the SSDI at 10 cm depth. Between mulches, organic mulch obtained higher uptake of N, P and K compared to no mulch. The combination of SSDI at 10 cm depth with organic mulch registered the highest uptake of N (61.26 kg $ha^{-1}$) and P (22.73 kg $ha^{-1}$).The available N status of soil was higher in rain hose irrigation (229.72 kg $ha^{-1}$) and was on par with surface drip irrigation. Available K and P were not significantly influenced by the types of micro irrigation. Between mulches, the higher available N, P and K were recorded in the treatment with organic mulch.

Water requirement was the same for all the irrigation treatments, where SSDI at 10 cm depth recorded significantly higher field water use efficiency (7.47 kg $m^{-3}$) and water productivity (3.80 kg $m^{-3}$). Between mulches, organic mulch recorded the highest field water use efficiency (6.42 kg $m^{-3}$) and water productivity (3.15 kg $m^{-3}$). The combination of SSDI at 10 cm depth with organic mulch obtained significantly higher field water use efficiency (7.67 kg $m^{-3}$). SSDI at 10 cm depth along with organic mulch recorded significantly higher net returns (₹ 5.43 lakhs $ha^{-1}$) and benefit cost ratio (2.04).

The present investigation revealed that SSDI can be successfully adopted for tomato cultivation. Combination of SSDI 10 cm depth with organic mulch (dry banana leaves) @ 10t $ha^{-1}$ can be recommended for getting higher yield, water use efficiency and economics in tomato.

## സംഗ്രഹം

മഴമറയിലെ തക്കാളിയുടെ വിള ഉത്തമീകരണത്തിനായി സൂക്ഷ്മ ജല പ്രയോഗവും പുതയിടലും എന്ന പരീക്ഷണം വെള്ളായണി കാർഷിക കോളേജിലെ ഇൻസ്ട്രക്ഷണൽ ഫാമിലെ മഴ മറയിൽ ഫെബ്രുവരി മുതൽ മെയ് 2021 വരെയുള്ള കാലഘട്ടത്തിൽ നടത്തുകയുണ്ടായി. സൂക്ഷ്മ ജല പ്രയോഗം, പുതയിടൽ എന്നിവയിലൂടെ തക്കാളിയുടെ വളർച്ച, ഉത്പ്പാദന ക്ഷമത, സാമ്പത്തിക വശം മനസിലാക്കുക എന്നിവയായിരുന്നു പ്രസ്തുത പഠനത്തിന്റെ ലക്ഷ്യങ്ങൾ.

പ്രസ്തുത പഠനത്തിന് സ്പ്ളിറ് പ്ലോട്ട് ഡിസൈൻ എന്ന സ്റ്റാറ്റിസ്റ്റിക്സ് പഠന രീതിയാണ് അവലംബിച്ചത്, അതിൽ അഞ്ചു പ്രധാന പ്ലോട്ട് ഡിസൈനും രണ്ടു ഉപ പ്ലോട്ട് ഡിസൈനും ഉൾപ്പെടുന്നു. അഞ്ചു പ്രധാന പ്ലോട്ട് ഡിസൈനുകൾ പലതരത്തിലുള്ള സൂക്ഷ്മജലസേചനമാണ് (1- മണ്ണിനു മുകളിലൂടെയുള്ള തുള്ളിനന, 2- റൈൻ ഹോസ് നന, 3- മുകൾ മണ്ണിനു 10 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളിനന, 4- മുകൾ മണ്ണിനു 15 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളിനന, 5- മുകൾ മണ്ണിനു 20 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളിനന). ഉപ പ്ലോട്ട് ഡിസൈനുകൾ രണ്ടു തരത്തിലുള്ള പുതയിടലാണ് (1-ജൈവപുത, 2-പുതയിടാതെയുള്ള പരിചരണ രീതി). ജൈവ പുതയായി ഉണങ്ങിയ വാഴയില ഹെക്ടറൊന്നിനു 10 ടൺ എന്ന തോതിൽ ഉപയോഗിച്ചു. വെള്ളായണി വിജയ് എന്ന തക്കാളി ഇനമാണ് പഠനവിധേയമാക്കിയത് .

പ്രധാന പ്ലോട്ട് ഡിസൈനുകളിൽ, മുകൾ മണ്ണിനു 10 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളിനന തക്കാളി ചെടിക്ക് കൂടുതൽ വളർച്ചയും ഉത്പ്പാദന ക്ഷമതയും നൽകി. ഗുണമേന്മ കൂടുതൽ ഉള്ള കായ്കളും ആദായവും മുകൾ മണ്ണിനു 10 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളി നനയിൽ നിന്നാണ് ലഭിച്ചത്. ഉപ പ്ലോട്ട് ഡിസൈനുകളിൽ പുതയിടാതെയുള്ള പരിചരണ രീതിയെ അപേക്ഷിച്ചു ജൈവ പുതയിടൽ മാർഗ്ഗം തക്കാളി ചെടിക്ക് കൂടുതൽ വളർച്ചയും, ഉത്പ്പാദന ക്ഷമതയും, ആദായവും നൽകി.

മഴ മറയിൽ സംയോജിതമായി മണ്ണിനു 10 സെന്റിമീറ്റർ താഴെയുള്ള തുള്ളിനനയും ജൈവ പുതയായി ഒരു ഹെക്ടറിൽ 10 ടൺ എന്ന തോതിൽ ഉണങ്ങിയ വാഴയിലയും തക്കാളിയുടെ ഉത്തമ വളർച്ചയ്ക്കും ഉത്പാദനത്തിനും അനുയോജ്യമെന്ന് ഈ പഠനം തെളിയിക്കുന്നു.