STUDIES ON THE EFFECT OF SOME CROP MANAGEMENT PRACTICES ON GROWTH AND YIELD IN TOMATO (*Solanum lycopersicum* L.)

Thesis

by

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(H-2016-35-D)

submitted to

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CERTIFICATE-I

This is to certify that the thesis titled **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)"**, submitted in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)- 173 230, India is a bonafide research work carried out by **Mrs Shilpa (H-2016-35-D)** daughter of Sh. Santosh Kumar under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

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CERTIFICATE-II

This is to certify that the thesis titled, **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)"**, submitted by **Mrs Shilpa (H-2016-35-D)** daughter of Sh. Santosh Kumar to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)- 173 230, India in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy Vegetable Science in the discipline of **Horticultural Sciences** has been approved by the student's advisory committee after an oral examination of the same in collaboration with the external examiner.

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"Sarasvati Mahaa-Bhaage Vidye Kamala-Locane |
Vidyaa-Ruupe Vishaal-Aakssi Vidyaam Dehi Namostute | |

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Date
Place: **(Shilpa)**

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ABBREVIATIONS USED

%	:	Percent
&	:	and
/	:	Per
@	:	At the rate of
+	:	Plus
a m s l	:	Above mean sea level
ANOVA	:	Analysis of variance
B: C	:	Benefit cost ratio
BPM	:	Black polythene mulch
CD	:	Critical difference
cm	:	Centimeter
cv.	:	Cultivar
DAT	:	Days after transplanting
Df	:	Degree of freedom
et al.	:	Co-worker (and others)
Fig	:	Figure
FYM	:	Farm yard manure
g	:	Gram
g/l	:	Gram per litre
ha	:	Hectare
HP	:	Himachal Pradesh
i.e.	:	Id est (that is)
Kg	:	Kilogram
L/ltrs	:	litres
m	:	meter
M	:	Mulching
m^2	:	Square meter
ml	:	Millilitre
mm	:	Millimeter

MOP	:	Muriate of potash
NHB	:	National Horticulture Board
NPK	:	Nitrogen: Phosphorus: Potassium
NS	:	Non significant
^{o}C	:	Degree celsius
P	:	Planting methods
pH	:	negative log of H ion concentration
pv	:	Pathovar
q	:	Quintals
RCBD	:	Randomized complete block design
RDF	:	Recommended dose of fertilizers
RH	:	Relative humidity
RPF	:	Recommended package of fertilization
Rs.	:	Rupees
sp. / Spp.	:	Species
SSP	:	Single super phosphate
T	:	Training
t	:	Tonnes
TSS	:	Total soluble solids
var.	:	Variety
viz.	:	Videlicet (namely)
w.r.t.	:	With respect to

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Chapter-1

INTRODUCTION

In the last few decades, India has made a quantum jump in vegetable production, securing the second position after China in the world with an area of 10.26 million hectares and production of 184.40 million tonnes (Anonymous, 2018), however, the production is much less than the requirement if balanced diet is provided to every individual. There are different ways and means to achieve this target *viz.*, bringing additional area under vegetable crops, using hybrid seeds and use of improved agro-techniques etc. Our demand of vegetables will be 225 million tonnes by 2020 and 350 million tonnes by 2030, to meet out the requirement of 300 g per capita per day for balanced diet (Anonymous, 2011). The use of herbicides and other chemicals in agriculture are becoming limited, because of their expense and environment issues which have recently caused much concern. Therefore, new approaches to control weeds and improve yield are necessary both for assuring an adequate crop yield and for respecting the environment. Sustainable management practices, such as raised bed planting methods, mulching applications and suitable training systems can improve crop conditions, soil fertility and environmental conditions too. Weed suppression and improved yield because of useful micro-organisms activity have become a suitable causes for sustainable crop production.

In the era of crop diversification, vegetable cultivation in Himachal Pradesh in general and in mid-hills in particular is gaining significant importance on account of favourable agro-climatic conditions for growing quality off-season vegetables, *e.g.* pea, tomato, capsicum cauliflower, cabbage, french bean, okra etc.

Tomato (*Solanum lycopersicum* L.), a solanaceous vegetable originated in Peruvian and Mexican region is one of the most important, popular and widely grown vegetables in India as well as in the world. Because of its popularity in India, it is being grown on an area of 789 thousand hectares with an annual production of 19,759 thousand metric tonnes (Anonymous, 2018). In Himachal Pradesh, it is grown during summer and rainy seasons and fetches better remunerative prices as an off-season produce. It is considered as ‘Protective food’ as it has some special nutritive value and antioxidant properties due to the presence of lycopene and flavonoids (Sepat *et al*., 2013). Tomato is recognized globally for its

nutraceutical value. Tomato has attained the status of high value crop in India in recent years and occupies a pride place among vegetables in Indian cuisine because of its delicacy and pleasant flavour. It is consumed widely and is also a major source of vitamins, minerals, organic acids, essential amino acids and dietary fibers. It is a rich source of vitamin-A (4.04 mg/100g), vitamin-C (15-30 mg/100g), total soluble solids (4-7%), acidity (7.5-10 mg/100ml) as well as antioxidant such as lycopene (1.82-5.24 mg/100g) which helps to keep cholesterol down and boost resistance to cancer. The pulp and juice is digestible, promoter of gastric secretion and blood purifier. In terms of value, it comes next only to potato and sweet potato in India, but as a processing crop, it ranks first among vegetables. Because of its high nutritive value, it is sometimes called as “Poor man’s orange”.

Tomato cultivation has been tremendously increased due to its multifarious uses like raw as salads, cooked alone or mixed with other vegetables and processed in many forms. The high market price is attributed to the heavy demand from the urban consumers. There is a good demand for its export too. The export market needs fruits with longer shelf life, attractive colour and good taste. However, the supply is inadequate due to low productivity of the crop.

Tomato is an important off-season vegetable crop of Himachal Pradesh. The state is a leading supplier of fresh market tomatoes to the plains as high temperature and continuous rains limits its production during rainy season in such areas. Thus, tomatoes from hills find ready market in the northern plains as it is usually grown as a summer and rainy season crop bringing lucurative returns to the hill farmers. The annual production of tomato in Himachal Pradesh is 502.42 metric tonnes from an area of 11.75 thousand ha (Anonymous, 2018). Despite the economic importance, growers are not in a position to produce good quality tomato with high productivity due to various biotic (pest and diseases), abiotic (rainfall, temperature, relative humidity and light intensity) and crop factors which hamper vegetable production. Hence, there is a prime need to increase the productivity and production of tomato in the country and the state as well.

Basically tomato is a warm season tropical crop and lacks adaptability to varied environmental conditions. Various agro-techniques are being employed for getting the higher production and quality fruits in tomato. Among different agronomical practices, raised bed planting method, mulching, and training systems are considered important and can be utilized

to overcome the problems being faced during the growing period and ultimately attaining the higher production of quality fruits.

In the present scenario, the consumer is more concerned about the quality and the producer also needs a production system that can provide higher yields of quality fruits. Therefore, special practices are needed to increase summer and rainy season tomato production so as to increase the cash flow to the farm families. Production of tomato during this period is highly remunerative and need oriented. For this purpose, indeterminate tomato varieties are best suited, however, the yield of quality fruits can be improved by manifesting various cultural practices *viz.* planting methods, mulching and training systems in a right combination.

At present, cultivation of tomato in open fields on flat beds is a wide spread practice in Himachal Pradesh but the tomato crop grown on flat beds is exposed to various abiotic and biotic stresses. Therefore, it is not possible to produce high quality tomato in terms of size, shape, and colour, free from diseases and pests as compared to raised bed planting. During the last decade, practice of raised bed planting has been emerged with a greater pace especially in high value crops including vegetables.

The major concern of this system is to enhance the productivity and save the irrigation water. Potential agronomic advantages of raised beds include improved soil structure due to reduced compaction through controlled trafficking, reduced water logging and timely machinery operations due to better and improved surface drainage. Warmth in raised beds is higher than on level soil and this increases the rate of growth of the seedlings, thus reducing their susceptibility to diseases compared to slow emergence. Beds also create an opportunity for mechanical weed control and improved fertilizer placement. Permanent beds also provide the opportunity for diversification to water logging sensitive crops not suited to conventional flat layouts, and the ability to respond rapidly to market opportunities. There are several reports of reduced irrigation amounts or time, with similar or higher yields, for vegetable crops on beds compared to conventional tilled vegetable crops, from farmer participatory trials and researcher plots (Naresh *et al.,* 2010 and Singh *et al.,* 2010). Typical irrigation savings range from 18 to 30-50 per cent (Singh *et al*., 2010). Flood irrigation on flat ground has been associated with low water use efficiency, soil degradation and without proper nutrient management it has led to nitrate pollution of surface and subsurface water. Raised bed cultivation has been used in fields with side-fall or other water management issues. These

factors have also shown improved nutrient management and cultivation. One of the most important advantages of raised bed cultivation is that it avoids the incidence of soil borne diseases as minimum soil is disturbed in this system of planting specially during monsoons.

Therefore, it makes imperative to take up tomato cultivation on raised beds as compared to flat beds particularly, when production of tomato is done for sending it to distinct markets. Also, raised bed and mulched raised bed planting decrease water consumption, increase water use efficiency and produce higher yields than flat bed planting methods (Zhang *et al.*, 2007).

Mulching is an important practice that entails placing of organic or synthetic material on the soil close to the plants to provide a more favourable environment for growth and development (Nagalakshmi *et al.*, 2002). Plastic mulch has been used increasingly in agriculture, since the middle of 20th century. Most of the mulches whether organic or synthetic types, are helpful in reducing disease incidence, controlling weed population, reducing the impact of falling rain drops, regulating soil temperature and conserving soil moisture among others, resulting in increased yield and earlier harvest (Hill *et al.*, 1982; Shogren, 2000; Schonbeck, 1998 and Schonbeck and Evanylo, 1998). The mulch has been reported to modify hydrothermal regime of soil, reduce loss of plant nutrients through leaching and provide a barrier to soil pathogen, thereby, resulting in an increased economic yield and harvest of improved quality fruits. Black mulch warms the soil by absorbing light and transferring heat by conduction method to the underlying soil layers, provided that the mulch is in close contact with the soil. White or reflective plastic mulch, decrease soil temperatures (Unger, 1984).

Tomato yield could be increased substantially through improved production technique like training system (Mantur and Patil 2008). Training is also an important and effective cultural operation being practiced especially in indeterminate tomatoes. Training methods vary with different growth habits of tomato cultivars and for different plant densities. Therefore, training the plants to two or three shoots will not only facilitate easy training operations, but also permit closer planting, early ripening of fruits and higher yields of larger sized fruits. The training system emphasizes the ability of the plant to obtain proper space and sunlight for optimum growth and development. It is also important to maintain sufficient air circulation around the plants to reduce risks of pests. The leaves of a well-trained plant dry

off faster, so bacterial and fungal pathogen have less opportunity to spread. Trained tomato plants are much easier to harvest and less damage is done to the vines. Training the plant to two or three shoots is generally practiced for indeterminate and semi-determinate cultivars in some countries like Europe and Japan either in open field or in glass house conditions. Hesamil *et al.* (2012) found that trained tomato plants yielded higher than untrained.

Properly trained and trellised plants are usually benefited from mulches to save moisture and are more exposed to sun and other environmental factors. The traditional system of staking makes plants bushy and dense resulting in less crop yields per unit area, whereas, training in indeterminate tomatoes help in accommodating more plants per unit area. Hence, proper training system may help in efficient utilization of resources, both land and space to get uniform and superior quality of tomato fruits.

Hence, to obtain a good quality produce and production during off season, there is a need to cultivate tomato (*Solanum lycopersicum* L.) with better planting methods, mulching and training systems. Therefore, the present investigation entitled "Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)" has been planned with the following objectives:

i) To evaluate the effect of planting methods, mulching and training systems on fruit yield, quality, severity/incidence of various diseases, weeds, soil temperature and soil moisture in tomato.

ii) To study the economics of tomato production.

Chapter-2

REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops of Himachal Pradesh. The enhancement of production merely by increasing the area under a crop to feed ever increasing population is not feasible as land being the fixed entity. Therefore, the remedy lies upon exploiting full genetic potential of available varieties/hybrids by adoption of different production techniques to enhance productivity. With the increasing zeal for its cultivation, the farmers are aptly looking towards improved crop management practices to meet out the higher standards of quality and quantity. Therefore, it is essential to know the causes and effects of scientific efforts made in developing agro-techniques in the past for boosting its productivity and production before planning and executing future research.

Since the beginning of civilization, man has developed technologies to increase the efficiency of food production. Among the various agronomic techniques adopted to improve the crops productivity, soil tillage plays an important role of considerable interest. Vegetable production, characterized by high dynamics and different types of cultivated species, is sector in which such practices are particularly important. The higher number of soil tillage operations that are normally performed during vegetable production, together with the low organic matter content and agricultural vehicle traffic, can often lead to soil compaction and fertility depletion that greatly limit the potential yield of crops (Hamza and Anderson, 2005). The soil compaction results in reduced water penetration, changes in the activity of soil microorganisms, lower activity of earthworms, difficult penetration of the roots into the soil, presence of water stagnation and reduced air content in the soil. Therefore, to overcome these drawbacks, the use of raised bed is increasing. Polyethylene mulches are widely used in vegetable production and have contributed significantly to reduction of losses due to weed competition (Ngouajio and Ernest, 2004).

Mulch is well known for modifying energy and water balance both at beneath and above the surface of soil and creating more favourable conditions for plant growth and development. Mulches conserve soil moisture by retarding evaporation but effect on soil temperature varies depending upon composition and optical properties of the mulch material.

Plastic mulches are readily available and economic enough to be used for commercial application on large scale (Lamont, 2005). Black polyethylene mulch (BPM) has been widely used in production of fresh-market field tomatoes. Polyethylene has excellent mechanical properties, light weight and relatively low price. Beneficial responses of tomatoes to BPM include higher yield, earlier production and better fruit quality. These favorable economic plant responses have been attributed, in part, to greater efficiency of water and fertilizer use, reduced competition with weeds, higher soil temperature, reduced soil pathogens, and even the breakdown of phytotoxic substances. Black mulch warms the soil by absorbing light, then transferring heat by conduction to the underlying soil, provided that the mulch is in close contact with the soil. All these factors affect crop growth, which subsequently affect fruit yield and quality of the fruits too. Mulching also stimulates the microbial activity in soil through improved agro-physical properties, therefore minimizes the use of N fertilizer and improves the soil physical condition. So, the soil under plastic mulch remains loose, friable and well aerated, roots have access to adequate oxygen and microbial activity is enhanced. Silver or black reflective mulch also results in a slight increase or even a slight decrease in soil temperature compared to bare soil, tending to minimize changes in soil temperature, because they reflect back to the plant canopy most of the incoming solar radiation.

Training tomato vertically with the help of ropes or wires claimed to result in early ripening, less disease incidence, easier inter-culture and harvesting, clean and healthy fruits and higher yields of better quality fruits. Training of branches, pruning of leaves and side shoots also reported to enhance the ultimate yield in various ways. Training maximizes the plant's ability to obtain the sunlight needed for growth and development. It is also important to maintain adequate air movement around the plant to reduce risk of fungus and insect problems. A dense canopy of leaves shades the fruits causing them to be pale. Relatively high perishability has made tomato plants to be more vulnerable to intensive crop management and unfavorable environmental conditions. Excessive pruning of leaves sometimes causes the plants to cease producing flowers. Therefore, it is important to maintain sufficient foliage on the plant for adequate rates of photosynthesis. Manipulation of canopy architecture through pruning and training together with appropriate spatial arrangements has been identified as key management practices for getting maximum marketable yield. Training the plants to two shoots or three shoots will not only facilitate easy training operation, but also permit closer planting, early ripening of fruits and higher yields of larger sized fruits as compared to untrained plants.

In the present study, the main emphasis was given on appropriate cultural practices such as planting methods, mulching applications and training systems in order to enhance the production per unit area by utilizing the available space and utilization of the resources. Therefore, efforts have been made in this chapter to collect the scientific information on agro-techniques to identify the causes of problems related to low productivity of tomato.

The relevant and important literature pertinent to the present investigation entitled "Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)" has been reviewed here under the following heads:

2.1 To evaluate the effect of planting methods, mulching and training systems on fruit yield, quality, incidence of various diseases and weeds; soil temperature and soil moisture in tomato.

2.2 To study the economics of tomato production.

2.1.1 EFFECT OF PLANTING METHODS ON GROWTH, YIELD, QUALITY, INCIDENCE OF VARIOUS DISEASES, WEEDS, SOIL TEMPERATURE AND SOIL MOISTURE IN TOMATO

Appropriate soil cultivation significantly affect soil organic matter contents and thereby improve the soil microbial activity (Kabaş *et al.,* 2017). The improved soil structure, texture and biological activity of the soil largely depend on enriched soil organic matter content and soil porosity. In vegetable cultivation practices, raised bed planting system helps to regulate soil moisture, increase soil temperature and microorganism activity (Marschner *et al.,* 2004; Bohme and Bohme 2006; Saha *et al.,* 2008; Zhang *et al.,* 2012 and Ozer 2017). According to Velev (1973), raised beds improve soil drainage thereby increasing the soil temperature in the root zone of the plant. He further revealed that raised beds were more suitable than flat beds for growing of vegetable crops.

Alagoz and Ozer (2019) carried out a study to determine the effects of seedling types (grafted and non-grafted) and different planting systems (raised-bed and flat planting) on growth, yield and quality of tomato (*Solanum lycopersicum*) cv. Depar F_1 plants organically grown in open-field conditions in Samsun. Their results revealed that soil microbial biomass-C increased by 25 per cent and soil CO_2 content by 16 per cent in raised-bed systems. The highest fruit shape index (1.21) and yield (1.95 kg plant^{-1}) were obtained from grafted seedlings of the raised-bed planting systems. They also reported that the highest soil

temperature (32.1 °C) was also measured in raised-bed planting system as compared to the lowest soil temperature (14.7 °C) which was measured in flat planting system.

Anand *et al*. (2016) conducted an experiment on Ashwagandha (*Withania somnifera*), for two years on the field of seven farmers. Method of broadcasting, line sowing on raised bed and transplanting of 20-25 days old seedling were assessed with the help of observation on growth components, yield and economic returns and quality of roots. Their results revealed that line sowing on raised bed method was found better in respect of growth, root yield (4.73 q/ha), economic return (Rs. 32410/ha) and root quality.

Deepak *et al.* (2016) developed an effective management practice against stem rot of bell pepper by integration of cultural components, chemical and biological control. They revealed that combination of ridge planting + *E. globules* (10 %) + Bavistin (0.1 %) was the most effective treatment with minimum disease incidence (22.15 %) and maximum disease control (77.17 %) followed by raised bed + *Eucalyptus globulus* + Bavistin, flat field + *Eucalyptus globulus* + Bavistin and ridge planting + Bavistin, raised bed + Bavistin.

Nicoletto *et al.* (2016) evaluated the effect of raised beds in comparision to traditional soil management on the morpho-dimensional traits of different vegetable species. They considered seven vegetable crops like lettuce, zucchini, green beans, rocket salad, variegated-leaved Italian chicory, long-stemmed Italian chicory and chard which were transplanted and seeded in raised beds and on flat soil. Their results showed the positive effect of raised beds especially for transplanted crops (lettuce and zucchini), which increased yield by more than 15 per cent. Also the positive results for raised bed were recorded for rocket salad with a weight gain of the aerial part higher than 50 per cent.

Kumar *et al.* (2015) conducted an experiment comparing furrow irrigated raised beds with flat beds under irrigated conditions, during 2010. They concluded that raised bed system was more appropriate for growing high value crops that are more sensitive to temporary water logging stress. Their results showed that system of raised bed planting of crops may be particularly advantageous in areas where groundwater levels are falling. The experimental results indicated that FIRB technique not only saved the resources like nutrients and labour but also facilitated the improved productivity of garlic crop which ultimately improved the physical properties of soil and profitability of the system.

Miah *et al.* (2015) studied the effect of raised bed technology at farm level through a follow-up survey conducted at Durgapur Upazila of Rajshahi district. The findings of their survey showed that the raised bed technology had a strong demonstration effect and were adopted well (56 %) by the respondent farmers. According to them, this emerging technology increased crop productivity and farmers' income to some extent.

Dasa *et al.* (2014) conducted field experiments for seven consecutive years to evaluate the crop performance, production and energy balance of cropping sequences under raised and sunken bed (RSB) systems in mid-hills (950 m above mean sea level) of subtropical Meghalaya. Five vegetable-based cropping sequences on raised beds and six rice based sequences on sunken beds were tested. Their results showed that on raised beds, tomato–okra–French bean gave highest rice equivalent yield (REY; 44.7 t/ha) followed by carrot–okra–French bean (42.5 t/ ha). Among raised bed sequences, the greatest production efficiency (162 kg/ha/day) was recorded from tomato–okra–French bean and carrot–okra–French bean recorded highest land use efficiency (77 %).

Muriungi *et al.* (2014) evaluated the effects of cow manure application, transplanting, planting on raised beds and varying watering interval on *Rhizoctonia* damping-off of tomato as measured by per cent seedling survival at 5-30 days after planting (DAP), disease severity at 30 DAP, per cent crop stand at 60 DAP and fruit yield at maturity. Their results revealed that planting on raised beds and medium irrigation interval when used singly or in combination with other cultural strategies produced good disease control and also resulted in higher yield of tomato. They found that planting tomato on raised beds increased the per cent seedling survival, decreased damping-off severity, increased crop stand and increased both quality and quantity of yield as compared to flat beds.

Bahadur *et al.* (2013) conducted a field experiment to determine the response of tomato crop to three planting systems and three mulch materials. Their results indicated that planting systems significantly influenced the soil moisture regimes, weed growth and water use efficiency. Black polythene, transparent polythene and paddy straw mulch saved 17, 11.3 and 15.4 per cent water than unmulched control. They found maximum dry matter production (231.03 g/plant), fruit yield (449.36 q/ha) and water use efficiency (143.57 kg/ha-mm) under raised bed planting coupled with paddy straw mulching.

Kumari *et al.* (2013) conducted the studies consecutively during two *Rabi* seasons of 2008-2009 and 2009-2010 to ascertain the effects of planting techniques, irrigation and weed management on disease severity of wilt (*F. oxysporum* f.sp. *pisi*), rust (*Uromyces fabae*), powdery mildew (*Erysiphe pisi*) and grain yield of field pea (*Pisum sativum* L.). They found that wilt and powdery mildew were higher in raised bed planting and also in plots without irrigation while rust (28.3 %) was more severe in flat bed planting. Yield was found higher in raised bed planting and irrigation at critical stages of the field pea crop.

Ijoyah and Jimba (2011) conducted field experiments during 2009 and 2010 at Makurdi, Nigeria to evaluate the effects of planting methods, planting dates and intercropping systems on sweet potato-okra yields. The results obtained showed that the greatest yields of sweet potato and okra were obtained when both crops were planted by raised flattened top bed planting method. Highest land equivalent ratio (LER) of 1.97 and 2.00 and a greater percentage of land area saved 49.2 and 50.0 per cent when planting of sweet potato and okra was done by ridge planting method.

Hatterman-Valenti and Hendrickson (2006) conducted the field trials to evaluate the effect of planting configurations (raised bed and no bed) and reservoir tillage on onion (*Allium cepa*) yield and grade when a cereal grass or cool-season broadleaf species was used as a companion crop. Their results revealed that planting onion seed in raised beds with reservoir tillage resulted in more large-diameter bulbs compared to planting without a bed configuration.

Locher *et al.* (2003) evaluated the effect of black plastic mulch and raised bed on soil temperature and on yield and fruit quality of sweet pepper (*Capsicum annuum* L. cv. Karpia). They observed that the soil temperature was highest in covered raised bed treatment, about 2 ^{0}C higher than the uncovered raised bed which resulted in better yield of sweet pepper i.e. 19 per cent and 14 per cent increase during 2001 and 2002, respectively.

Raised beds are commonly used in vegetable production to increase crop yield. According to Kumar *et al.* (2001), growing tomato (*Lycopersicon esculentum*) on raised beds increased mean fruit weight, fruit diameter, number of fruits and fruit yield per plant, and marketable fruit yield compared to planting on a flat bed.

Babik and Dudek (2000) reported that cultivation on the ridges enable the higher yield of better quality. Most of the roots were well shaped and much longer than those sown on the flat beds. In a study conducted by Cavero *et al*. (1996) it was reported that higher yields were obtained with raised beds than with flat ground sowing of pepper cv. Piguillo de Lodosa.

Rubatzky *et al.* (1990) reported that well prepared seed beds whether raised or flat, improved uniformity of soil depth and subsequent emergence of seedling development. Raised beds improved drainage and soil aeration and facilitated furrow irrigation, cultivation and other cultural operations. Raised beds in cooler climates can also contribute to slightly increased soil temperature, which in some situations can reduce the growing period by several days to as much as 1-2 weeks.

Millette and Vigier (1981) studied the effect of seed bed preparation on carrot production by seeding on the flat or on raised beds to determine the cultural method that would provide the best yield of quality fresh market carrots *(Daucus carota* L.) without adversely affecting the soil structure. Raised beds offered no yield advantage in wet season and no yield reduction in a dry season. In a wet season, however, bed system favoured harvesting operation by reducing soil moisture and rendering field surface firmer.

2.1.2 EFFECT OF MULCH ON GROWTH, YIELD, QUALITY, INCIDENCE OF VARIOUS DISEASES, WEEDS, SOIL TEMPERATURE AND SOIL MOISTURE IN TOMATO

Mulching develop a microclimate beneath of the sheet, which generally elevates the level of carbon dioxide due to the enhanced activities of beneficial soil microorganisms. The mulching facilities provide many cost effect advantages as followed like it is completely impermeable to water. The mulches prevent the loss of water through the process of evaporation from the soil and thus lessens the water losses and conserves moisture and promotes early germination. Mulching also maintains the warm temperature inside the mulch even during night time which helps seeds to germinate faster and for developing seedlings to rapidly establish a strong root and shoot growth system. Mulching can reduce the loss of plant nutrient through leaching as well. Polythene mulch material also plays a major role in soil solarization process. Mulching can also create a physical barrier to soil pathogens to perpetuate (Kumari *et al.*, 2018).

Angmo *et al.* (2018) studied the influence of black polyethylene mulch (BPM) on growth and yield of tomato. They conducted their studies with mulch treatments (mulch and unmulch) and cultivars (3 hybrids, and 2 OP varieties). Their results revealed that the mean marketable yield varied from 27.8 ± 2.5 t ha^{-1} in open-pollinated varieties with non mulch treatments to 81.2 ± 11.9 $t.ha^{-1}$ in hybrid tomatoes with BPM. According to them, with BPM, total marketable yield in hybrid varieties increased by 102 per cent and 107 per cent in 2014 and 2015, respectively. Yield increase due to mulching in open-pollinated varieties was 86 per cent and 80 per cent in 2014 and 2015, respectively. They also observed increase in early fruiting under BPM in all the five varieties studied. BPM reduced 57 per cent weed and save 74 per cent time in manual weeding.

Kumari *et al.* (2018) conducted the trials at semi tropical upland rainfed ecosystem during summer season in poly house. The Black polythene sheet has been utilized for providing mulching in experiment. Their results revealed that black polythene sheet with the thickness of 25 micron recorded best result in comparison to unmulched treatment combination for plant height (92.20 cm), minimum days took for 50 per cent flowering (72.50 days), maximum number of primary branches (115.30), number of secondary branches (225.30), dry matter (38.20), fruit weight (84.30 g), leaf area index (2.25) and yield (33.2 ton/ha).

Liberato (2018) conducted a study to find best eco-friendly net covers and mulch on growth and yield of two tomato varieties under off-season production. Split-Split Plot in Factorial Randomized Complete Block Design using three blocks, three floating row covers (UV Film, EFNC Blue, EFNC Green), two tomato varieties (Marimar F1 and Diamante Max F1) three mulching materials (Plastic mulch, Sawdust, Carbonized Rice Hull), were employed. They found that mulching materials significantly affected the growth and yield parameters. Carbonized Rice Hull increased number of flowers, fruiting percentage and fruits developed, whereas, plastic mulch produced highest yield with 3681.13 kg/ha.

Zangoueinejad *et al.* (2018) compared the effects of six types of non-living mulches (wheat straw, sawdust, coco peat, peat moss, transparent and black plastic) with metribuzin on yield and yield components of tomato cv "CH". Their results revealed the highest number of fruits (marketable plus unmarketable fruits) per plant (208.33) were noticed under black plastic mulch treatment. Tomato yield in plots covered with transparent plastic and black

plastic were 20.93, 8.31 kg m^{-2}, respectively and were significantly different from those treated with herbicide (6.06 kg m^{-2}).

Helaly *et al.* (2017) studied the response of husk tomato plants (*Physalis pubescens* L.) cv. (local variety) to polyethylene mulching black and double face (white on black). Their results showed that the significant maximum value of plant height, stem diameter, number of branches per plant and leaf area were obtained from white on black mulching treatment. Results appeared that the significant maximum value of total soluble solids, vitamin C, total sugar and total carotenoids were obtained from white on black mulching treatment. Significant maximum value of number of fruits per plant, total yield and early yield per plot were obtained from (white on black) mulching treatment followed in a descending order by black treatment, while bare soil treatment recorded the minimum value in both seasons.

Sanda *et al*. (2017) conducted an experiment which consisted of fractional combinations of two irrigation intervals (four (I_4) days irrigation and seven (I_7) days irrigation intervals), and two mulching levels (with mulch and without mulch). The treatments were coded as MI_4, MI_7, UMI_4, and UMI_7: assigned as mulch with 4 days irrigation interval, mulch with 7 days interval, without mulch with four days irrigation interval, without mulch with seven days irrigation interval, respectively. Their results revealed that that mulch application yielded higher total fruit yield of tomato 29.9 t ha^{-1} which is higher than no mulch plot (23.63 t ha^{-1}) and also the highest percentage of marketable fruit yield i.e. 56.15 per cent higher than no mulch plot with 50.41 per cent.

Singh *et al.* (2017) carried out a study at Research Farm, Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during 2016 and 2016-17. Their experiment consists of nine different mulch treatments i.e. i.e., red colour plastic mulch (M_1), yellow colour plastic mulch (M_2), blue colour plastic mulch (M_3), green colour plastic mulch (M_4), transparent plastic mulch (M_5), black colour plastic mulch (M_6) and double shaded plastic mulch (M_7) along with straw (M_8) and control (no mulch) (M_9).They reported significantly highest fruit yield of tomato i.e. 10.9 kg/m^2 under double shaded plastic mulch (M_7) and it was statistically at par with black colour plastic mulch (M_6). Mulch showed significant variation in number of fruits/plant. M_7 i.e. double shaded plastic mulch (40.40) remained statistically at par with M_6 (39.50) which produced significantly more number of fruits per plant. Significantly highest net returns (Rs.147.6/m^2) were observed in M_7 as compared to other mulches. They concluded that use of double shaded and black colour synthetic mulch

significantly increased the growth, yield and yield contributing characters in addition to net returns in tomato under the protected environment.

Abhivyakti *et al.* (2016) studied the performance of tomato (cv. All rounder) under both polyhouse and open conditions with different plastic mulches. Their studies revealed that highest yield (73.9 t ha^{-1}) was obtained under the black mulch within the polyhouse, the corresponding value being 37.30 t/ha for black mulch outside the polyhouse. Among different mulches, the highest soil temperature was recorded under transparent mulch followed by silver black, black and no mulch plot. They also stated that the soil temperature was found to be higher by about 1 to 10 ºC as compared to no mulch plot inside and outside the polyhouse. They further concluded that after 10th week, soil temperature was found 2 to 4 ºC higher under no mulch plot as compared to transparent mulch under polyhouse.

Basamma and Shanmugasundaram (2016) conducted an experiment during December 2013 to March 2014 to study the effect of drip fertigation and mulching on tomato hybrid Deepthi. The experiments were laid out in factorial randomized block design (FRBD) with nine treatments which included three mulching levels such as 25 µ thickness plastic mulch, 50 µ thickness plastic multh and control and three fertigation levels including 80 %, 100 % and 120 % RDF which were replicated thrice. From their experiment, they reported the highest plant height in T_3 i.e. 25 µ plastic mulch + 120 % RDF, followed by T_2 (25 micron plastic mulch + 100 % RDF) and lowest plant height found in T_7 (control + 80 % RDF). Highest number of branches were also found in T_3 i.e. 25 µ thickness plastic mulch at 120 % RDF followed by T_2 i.e. 25 µ thickness plastic mulch at 100 % RDF and T_6 i.e. 50 µ thickness plastic mulch at 120 % RDF.

Dishani and De Silva (2016) compared the growth, yield and quality parameters of tomato (*Solanum lycopersicum L.*) variety Thilina grown with mulch when subjected to temperature and water stress. Their experiment consisted of two different irrigation applications (no water stress by irrigation to field capacity moisture level and, water stress by irrigating only up to the 50 % of the available water capacity), two mulch materials i.e. coir dust and saw dust and three different temperature regimes (34°C maximum temperature poly tunnel/32°C maximum temperature polytunnel/open space-ambient temperature). Their results revealed that mulching of saw dust and coir dust improved the yield of tomato even at 34 °C temperature treatment.

Khan *et al.* (2016) conducted an experiment with two factors i.e. mulching materials (Wheat straw, Saw dust, Transparent plastic, Black plastic, Unmulched) and chilli cultivars (Pusa Jawala, Sky Star, Hot Green, Green Star) to evaluate the effect of different mulching materials on the weed and yield of chilli cultivars. They concluded that cultivar Sky Star along with black plastic mulch proved better with respect to weed control and yield. they further narrated that the lowest soil moisture content (16.1 %) and minimum yield (0.70 t/ha) were recorded from unmulched plots.

Petrikovszki *et al.* (2016) investigated the effect of leaf litter mulch on the pests of tomato, especially on the weed flora and on three important plant protection problems: late blight (*Phytophthora infestans*), cotton bollworm (*Helicoverpa armigera*) and root-knot nematodes (*Meloidogyne spp*.). They reported that in the beginning of the growing season mulching suppressed weed cover.

Rao *et al.* (2016a) conducted an experiment on tomato (*Lycopersicon esculentum* L.) during 2013-14 and 2014-15. Their treatments consisted of inorganic mulches (red, black and silver), organic mulch and control. Their results of the study indicated highest values of plant height, number of flowers per cluster, fruit weight, yield and soil temperature were observed more in red mulch followed by black and silver plastic mulch. Their results revealed that all coloured mulches had significantly higher marketable yield of tomato compared to organic mulch and control. Marketable yield increased by 64.54 per cent in red coloured mulch followed by 57.45 per cent in black, 45.40 per cent in silver, 21.98 per cent in organic mulched crop over control.

Rahman *et al.* (2016) conducted an experiment during September 2007 to January 2008 to find out the effect of different mulch materials on growth and yield of tomato. In their experiment, there were four levels of treatments covering different mulch materials, *viz.*, M_0=Control, M_1=Black polyethylene sheet, M_2=Clear polyethylene sheet and M_3=Rice straw. Their results revealed that the plant height, number of leaves per plant and number of branches per plant differed at different stage of transplanting (DAT) while, number of flowers per cluster (5.53), number of flower cluster per plant (8.63), number of flowers per plant (58.09), number of fruits per cluster (4.70), number of fruits per plant (39.65), average weight of individual fruit (88.43), fruit weight per plant (2.46 kg) and yield ha^{-1} (92.13 t) were recorded higher from the treatment M_1 (Black polyethylene sheet).

Tesfaye *et al.* (2016) conducted an experiment to evaluate the effect of different colored plastic sheets as mulching (black, blue and clear plastic mulch) on the performance of tomato yield, quality parameters and soil temperature. Their results revealed that the average fruit diameter varied from 38.57 mm (control) to 43.46 mm (Blue colored plastic mulch). The highest root length was recorded from clear plastic (75.36 cm) followed by blue colored (71.03c m) plastic mulch. Highest average temperatures was recorded under clear polyethylene mulch at 6:00 am (19.6 °C), 1:00 pm (22.9 °C) 6:30 pm (25.3 °C) and the least soil temperature was recorded from the control at 6:00 am (14.6 °C).

Abhivyakti and Kumari (2015) conducted an experiment to study the effect of polyhouse and various plastic mulches on yield, quality and shelf life of tomato. Their results showed that fruit yield was improved by mulching treatments. In both the growing seasons, they were of the opinion that the fruit quality in terms of total soluble solids and lycopene content were slightly improved by mulching treatments. However, fruit size and shelf life were also affected and fruit firmness improved by mulching. Their result also revealed that by using simplified open system with mulch improved plant productivity and quality of tomato fruits in terms of fruit size, shelf life and firmness.

Bhujbal *et al.* (2015) conducted an experiment to study the effects of different types of mulches on flowering, fruiting, yield and incidence of pest and diseases of tomato (*Lycopersicon esculentum* Mill.) var. Dhanashree. They used eight different types of mulch materials, *viz.,* T_1 i.e. black colour on silver polythene mulch (BSPM) (25 microns); T_2 i.e. silver colour on black polythene mulch (SBPM) (25 microns); T_3 i.e. transparent polythene mulch (TPM) (30 microns); T_4 i.e. blue polythene mulch (BPM) (30 microns); T_5 i.e. sugarcane trash mulch (STM) (10 cm thickness); T_6 i.e. soybean straw mulch (STM) (10 cm thickness); T_7 i.e. dry grass mulch (DGM) (10 cm thickness) and T_8 i.e. no mulch (control). They observed that the flowering and fruiting attributes like lowest number of days for initiation of flowering of tomato (30.40 days), maximum number of flowers per plant (39.86), minimum number of days to first picking of tomato (83.40 days), maximum per cent of fruit set (70.36 %) and minimum per cent of fruit drop (12.51 %) were obtained in black colour on silver polythene mulch treatment. The yield attributes like maximum number of fruits per plant (26.66), maximum weight of fruit (72.40 g), maximum volume of fruit (77.33 ml), maximum yield of tomato (1.63 kg/plant) and (60.61 MT/ha) and the pest-disease attributes like minimum leaf curl incidence (6.43 %), minimum spotted wilt incidence (2.26 %),

minimum incidence of late blight (6.61 %) and minimum fruit borer incidence (5.06 %) was observed in black colour on silver polythene mulch treatment.

Mtui *et al.* (2015) studied the effect of pesticide spray regimes and use of mulch on 'Tanya VF' and 'Tengeru 97' tomato varieties. Their experiment comprised of two varieties, mulching and three fungicide spray regimes. They also reported that use of mulch significantly led to higher fruit number per plant ($p = 0.020$). Similarly, mulching significantly reduced American bollworm and blossom end rot ($p = 0.012$, $p = 0.003$, respectively).

Subba Reddy *et al.* (2015) studied the effect of different types of irrigation and growing methods on growth, yield, water-use efficiency and economics of tomato (*Lycopersicon esculentum* Miller). Their experiment comprised of different irrigation regimes, black polythene mulch and trellising system (T_1: Furrow irrigation, T_2: Furrow irrigation with black polythene mulch, T_3: Furrow irrigation + black polythene mulch with trellising, T_4: Drip irrigation, T_5: Drip + black polyethylene mulch, T_6: Drip + black polyethylene mulch with trellising and T_7: control). They concluded that the drip irrigation + polythene mulch + trellising gave maximum values for fruit yield (62.21 t/ha), plant height (91.22 cm), fruit weight (88.33 g), plant dry matter (49.32 g), less weed growth (6.12 gm^{-2}) and highest net income (161134 Rs/ha) in tomato crop compared to drip irrigation + polythene mulch and drip irrigation alone.

James *et al*. (2013) reported that in tomato crop, fruits obtained from the red and black mulches were very large and plant growth was found to be vigorous. It was also observed that the plants grown under black plastic mulch grew more vigorously, flowered earlier and significantly produced more yields as compared to the other treatments.

Parmar *et al.* (2013) conducted the field experiment on watermelon (*Citrullus lanatus* Thunb) cv. Kiran during summer season of 2010 to study the effect of different mulching material on growth, yield and quality of water melon. They stated that all the plant growth, yield and quality characters were superior with silver on black polyethylene mulch while, plants without mulch (control) resulted poor growth and yield. From economic point of view, silver on black mulch resulted in the highest net return and found to be more economical with highest cost: benefit ratio.

Samih (2013) revealed the significant differences among mulch treatments in response to tomato plant growth including plant height, stem diameter, and dry matter of leaves and stems. Fruit average weight also significantly responded to various mulches. Therefore, based on the results of this study, application of black mulch were found to be vegetatively and productively efficient and was recommended for growing tomato crop under plastic house conditions when using drip irrigation system.

Bala (2012) investigated the effect of mulch, spacing and training system on yield and quality of tomato. The experiment comprised of four plant spacings (S_1=45 x 30 cm, S_2=60 x 30 cm, S_3=90 x 30 cm and S_4=120 x 30 cm), three mulches (M_1=black polyethylene, M_2= straw mulch and M_3=control) and three training systems (T_1=one stem, T_2=two stem and T_3= untrained). They observed that the black polyethylene mulch proved to be most effective to lower the incidence of buckeye rot and minimum *Alternaria* leaf blight severity.

Belel (2012) evaluated the effect of grassed and synthetic mulching materials on the growth and yield of sweet pepper (*Capsicum annuum* L.). Result of their study showed that BPM (black polythene mulch) recorded highest mean fresh fruit yield of 23.75 g per plant with 95.0×10^{-2} tons/ha total yield, while GM (grass mulch) and WPM (white polythene mulch) recorded 18.97 g and 19.07 g, and 75.9×10^{-2} and 76.3×10^{-2} tons/ha for mean fresh fruit weight and total yield, respectively, as against 11.7 g and 46.8×10^{-2} the control plot. Their results also revealed that BPM recorded the highest mean values for all the growth parameters. They concluded that BPM showed better results than synthetic and grass mulch.

Huang *et al*. (2012) found that the film mulching (white, black mulch) could obviously improve fresh fruits yield. The yield was 51475.7 kg h^{-1} and 51976.0 kg h^{-1} in white film and black film mulching treatment, respectively. These treatments increased the yield by 17.7 per cent and 18.9 per cent, respectively, over control. The number of the medium sized sweet potato by white film and black film were 3.0 and 3.2 per plant, respectively.

Nikolic *et al.* (2012) achieved the best results with plants grown on soil covered with mulch foils. In their experiment, they used wheat straw and wood sawdust (materials of organic origin) and black and red coloured plastic foils for land mulching. The control was soil without mulch materials. They stated that the application of the red foil resulted in the best vegetative growth of plants, and the greatest number, weight and size of fruits, as well as

the highest total yield. The yield with the red foil treatment was 3.55 kg (per plant) and 3.27 kg (per plant) with the black foil treatment. The yield with the soil covered with the straw and the sawdust was lower, with almost equal values of 2.53 kg (per plant) and 2.52 kg (per plant), respectively. They concluded that the lowest tomato yield (2.47 kg per plant) was obtained on the soil without any mulch.

Rajablariani *et al*. (2012) conducted the field experiment on tomato, in a randomized complete block design with three replicates. Treatments consisted of five coloured polyethylene mulch (clear, black, blue, red and silver on black) with bare soil (weed free) and un-weeded as controls. They revealed that the plants grown on silver/black mulch produced maximum marketable yield, fruit weight and fruit size. The silver/black and black plastic mulches resulted in a 95-98 per cent reduction in weed biomass also.

Singh and Kamal (2012) studied the effect of black plastic mulch on tomato yield and reported that black plastic mulch significantly increased tomato yield. The yield increased with black plastic mulch was 29.8 per cent higher as compared to bare soil.

An experiment was conducted by Ashrafuzzaman *et al.* (2011) on chilli pepper for two years with three mulching treatments (transparent, black and blue plastic sheets) along with a control (bare soil). Mulching produced more fruits per plant compared to control meaning that mulch had positive influence on fruit setting in chilli. The highest number of fruits per plant was observed in black plastic mulch, followed by blue and transparent mulch. Whereas, control produced the lowest number of fruits per plant.

Berihun (2011) conducted an experiment to evaluate the effect of mulch and amount of water on the yield of tomato under drip irrigation system and to assess the potential of deficit irrigation to improve the economic efficiency of tomato production. A factorial combination of three levels of water (namely 315, 440 and 565 mm) combined with three mulch treatments (namely without mulch (WM), black plastic mulch (PM) and straw or crop residue mulch (STM)) amid three replications and two days irrigation interval was used. Significant difference was shown between mulch treatments on number of fruits, unmarketable, marketable and total fruit yield/ha. Based on the partial budget analysis, the highest net benefit was obtained via 440 mm water with straw mulch amid a net benefit (52,959.40 birr/ha and a marginal rate of return (MRR) 690 per cent. Therefore, application

of 440 mm/ha water in two days interval with straw mulch is found to be economically and agronomically feasible.

An experiment was conducted to examine the effect of coloured plastic mulches on soil temperature, growth, yield and photosynthetic response of potato plants in Northeast Mexico by Jimenez *et al*. (2011) and the treatments included were: black plastic mulch (BPM), white-on-black plastic mulch (W/B), silver-on-black (SPM), aluminum-on-black plastic mulch (APM) and a control that consisted of bare soil cultivated plants. Treatments were arranged in a randomized complete block design with four replications. The results suggested that average daily mean soil temperature was linearly and negatively correlated with total yield and yield of first-quality tubers. Total yield and yield of first-quality tubers of plants mulched with white-on-black plastic mulch (W/B), silver-on black (SPM), aluminum-on-black plastic mulch (APM) was found to be significantly higher than those of control plants.

Samaila *et al.* (2011) conducted an experiment to evaluate the effect of mulching, nitrogen and irrigation interval on the nutritional quality of tomato at Shika, Nigeria. Treatments consisted of three mulching (no mulch, rice-straw mulch and black polythene mulch) four nitrogen rates (0, 45, 90 and 135 kg N ha^{-1}) and three irrigation intervals (5, 10 and 15 days). Mulching significantly increased the dry matter, protein and carbohydrate contents in fruits, but decreased the crude fiber content. Rice-straw mulch + 90 kg N ha^{-1} or polythene mulch in combination with 45 kg N ha^{-1} had more carbohydrates in fruits.

Field experiment was conducted by Quezada *et al*. (2011) to evaluate the effect of seven plastic mulches of different colors on the yield and micro environmental conditions and their influence on physiological parameters in bell pepper (*Capsicum annuum* L.) cv. Capistrano. The results showed that the highest yield was observed in plants mulched with white or black plastics, overcoming 75 and 60 per cent to the blue mulch and overcoming 190 and 166 per cent the clear mulch too.

Anzalone *et al*. (2010) carried out a field trial for three years in Zaragoza, Spain, using different biodegradable mulch materials in processing tomatoes. The aim of their study was to evaluate weed control with several biodegradable mulches as alternatives to black polyethylene (PE) mulch. Their study revealed that tomato yield was highest for PE followed by paper, manual weeding, biodegradable plastic, and rice straw and was clearly related to

weed control. According to their study, biodegradable plastic, and rice straw are potential substitutes for PE and herbicides.

Campiglia *et al.* (2010a) evaluated the effect of hairy vetch (*Vicia villosa* Roth.) residues used as mulches on weed control and yield in tomato production. Mulch treatments reduced weeds in density and above-ground biomass compared to conventional treatments (on an average 72 % and 40 %, respectively) at 25 days after transplanting. At tomato harvesting, the weeds were well suppressed by mulch above all where the mulches were in strips.

Diaz-Perez (2010) conducted an experiment in Tifton, GA, in the fall of 2002 and the spring of 2003 using eight coloured plastic mulches. In the fall season, during the first 28 days after transplanting and at final harvest, plant growth attributes were highest in silver mulches and the lowest in black mulches. Both marketable and total yields were higher on silver mulches and lowest on black mulch in the fall, whereas they were in general higher on silver with black strip mulch and lowest on white mulch in the spring.

Mehta *et al*. (2010) reported that the maximum plant height, harvest duration, fruit weight and minimum incidence of tomato fruit rot was observed with application of mulching and staking plots and also reported significantly higher yield in tomato under black plastic mulch which was due to effective soil temperature, weed control, and conservation of soil moisture.

Wang *et al.* (2010) conducted an experiment at Florida in which they suggested that the application of organic mulch combined with plastic mulch can improve bell pepper yield and quality as a result of the improvement of soil fertility, especially the early harvests of winter fresh market fruits.

Aruna *et al*. (2007) conducted an experiment with different mulches and fertigation on tomato. Increased plant height (127.20 cm), earlier flowering (29.30 days), increased number of fruits per plant (32.7 no), single fruit weight (65.25 gm) and yield per plant (6.40 kg) was observed by mulching with black polythene mulch along with the application of 100 per cent of recommended dose in the form of urea + phosphoric acid + potassium sulfate. The quality attributes was also high. Increased total soluble solids (3.60 degrees brix), acidity content (0.79 %) and ascorbic acid content (64.20 mg/100 gm) were observed in the

treatment M_1S_6 (mulching with black polythene mulch along with the application of 100 per cent of recommended dose in the form of ammonium sulfate + super phosphate + potassium chloride).

Awodoyin *et al*. (2007) carried out field experiments in the 1998 and 2004 cropping seasons to assess the impacts of different mulching materials on weed control, soil temperature, soil moisture depletion and performance of tomato (*Lycopersicon esculentum* Mill.) in Ibadan. They found that compared to unweeded control that had the least total fruit yield (2.7 t/ha in 1998 and 4.2 t/ha in 2004), mulch types and hand weeded treatments increased the fruit yield by 152-237 per cent in 1998 and 188-202 per cent in 2004. The weed control efficiencies of the mulches ranged between 91 and 100 per cent. They also concluded that the differences between morning and afternoon soil temperatures at 5 cm depth were low under grass mulch, woodchip mulch and unweeded control (5.0-5.9 ^{o}C) but high under plastic mulch and hand weeded control (8.7-8.9 ^{o}C).

Radics *et al.* (2006) examined and compared weed control and yield increasing effect of 8 different types of mulches in tomato during 2000-2006, with different weather conditions. The best results were found in plastic covered and paper covered treatments in tomato both dry and humid conditions for weed control.

Gupta *et al.* (2005) studied the efficiency of blue, yellow, white, green and black polythene mulches in tomato leaf curl virus in infecting tomatoes in the field experiment in Himachal Pradesh, during 1997-1998. Mulching with yellow polythene film resulted in the lowest disease incidence and highest crop yield.

Locher *et al*. (2005) conducted a two year field study to determine the influence of coloured mulches on soil temperature and yield of sweet pepper which resulted in increase in soil temperature. In case of light coloured mulches, the soil temperature was 2.5-2.9°C higher than un-mulched one, whereas, in case of dark colour mulches there was 1.4-2.1°C soil temperature increase. According to the higher soil temperatures, mulched treatments produced higher yields than the un-mulched treatment.

Singh *et al.* (2005) conducted an experiment on the effect of transplanting time and mulching on growth and yield of tomato in Abohar, Punjab, during the winter of 1998-2000 to study the effect of transplanting time (10 and 30 December, and 20 January) and mulching

(black and clear polythene, sugarcane trash and rice straw) on the growth and yield of tomato cv. Rupali. Among different mulching materials, black polythene retained higher soil moisture and temperature compared to another mulching materials and the control. Fruit yield was also highest with black polythene mulching. The highest net returns (Rs.52700/ha) were recorded with transplanting on 10th December and mulching with black polythene treatment combination, which was significantly superior over all other treatment combinations.

Dey and Hundal (2003) in their study reported that the polyethylene mulch treatment recorded the highest soil temperature and showed an average overall increase of 2.2 ^{o}C over the control in the morning (07.30 hrs) and 2.7^{o}C in the afternoon (14.20 hrs).

Sannigrahi and Borath (2002) conducted a field experiments in Assam, India to evaluate the effectiveness of different organic mulches including black polythene sheet on tomato production under rain fed conditions. The mulch treatment was black polythene sheet, rice straw, spent straw, water hyacinth (*Eichhornia crasipes*), thatch grass (*Imperata cylindraca*) and no mulch (control mulch). Their results revealed that mulching increased the tomato fruits per plant and had higher yield than the crop yield during both years. The rate of weed emergence was low in tomato plots, while black polythene mulch was most effective treatment for weed control (83.50 %).

Lyimo *et al.* (1998) studied the effect of mulching and staking on the development of early and late leaf blight of tomato caused by *Alternaria solani* and *Phytophthora infestans* respectively. Their results concluded that mulching and staking significantly reduced the incidence of early and late blight by 5 to 20 per cent and increased fruit yield more than two fold compared to unmulched and unstaked control, whereas, the apparent rate of infection of the two pathogen was also significantly lower in mulched and staked tomato. They were of the view that mulching was more effective than staking in suppressing early and late blight diseases in tomato crop.

2.1.3 EFFECT OF TRAINING SYSTEMS ON GROWTH, YIELD, QUALITY, INCIDENCE OF VARIOUS DISEASES, WEEDS, SOIL TEMPERATURE AND SOIL MOISTURE IN TOMATO

Anand *et al.* (2018) studied the influence of training and nutrition on yield of tomato (*Solanum lycopersicum* L.) under protected condition during *rabi* 2017-2018. Among different treatment combinations of training and nutrition levels, the highest number of fruits

per plant (57.42), yield per plot (61.61 kg/ha), yield per hectare (184.83 t/ha) were found highest in T_2N_6 (Two stem + 75% RDF + Protein hydrolysates (1.5 g/litre) + PSB (2 kg/ha) + VAM (2 kg/ha)) treatment.

Ansari *et al*. (2017) conducted a study to evaluate the effect of planting geometry and training on growth and seed yield of tomato (*Solanum lycopersicum* L.) using cultivar Solan Lalima during *Kharif* 2013. Analysis of variance showed that the treatment combination Y_1S_7 (single stem and plant spaced at 90×30 cm) resulted in maximum ripe fruit length and width (5.86 cm and 5.06 cm, respectively), maximum number of seeds/fruit (110.67), minimum days to ripe fruit harvest (71.00) and maximum harvest duration (59.84 days) but gave low seed yield. The combination Y_2S_5 (double stem and 90×15 cm) resulted highest seed yield i.e. 519.71 kg per hectare.

Singh *et al*. (2017a) conducted an experiment during spring-summer 2016 and autumn-winter 2016-17 seasons to study the influence of spacing and pruning on growth characteristics, yield and economics of tomato (*Solanum lycopersicum* L.) grown under protected environment. Their results revealed that plants spaced at 70 × 30 cm with 2 stems pruning had minimum days to 50 per cent flowering, minimum days to first harvest, maximum plant height, higher yield/m^2 area, net returns and output: input ratio.

Yadav *et al*. (2017) conducted an experiment to study the effect of spacing and training on vegetative growth characteristics and yield of tomato under polyhouse. The experimental results revealed that maximum stem diameter (7.36 cm), number of branches per plant (24.53), number of clusters per plant (15.93), total yield per plant (8.48 kg) and yield per square meter (20.96 kg) were exhibited by T_3 (triple stem training). The maximum yield per square meter was observed in interaction S_2T_3 (45 x 45 cm, triple stem). while number of branches per plant (30.33), number of clusters per plant (19.67), number of fruits per cluster (6.77), number of fruits per plant (125.87) and total yield per plant (12.88 kg) were observed in treatment combination S_4T_2 (60 x 60 cm, double stem training).

Alam *et al.* (2016) carried out a study to find out the response of plants to staking and pruning treatments on yield, fruit quality and cost of production. The plants were pruned to two stem, three stem, four stem and no pruning as control. They found the highest total number of fruits per plant (37.10), marketable fruits per plant (33.70), yield per plant (1.68 kg) and total yield (44.60 t/ha) by the plants having the treatment string staking with four

stem. The highest fruit set (43.50 per cent) was found in the plants staked with string having three stems. Plants grown on string staking allowing two stem gave maximum length (4.71 cm), diameter (4.83 cm) and weight (53.40 g) of single fruit as well as maximum fruit firmness (3.43 kg^{-} f cm^{-2}).

Kanwar *et al.* (2016) carried out an experiment to study the effect of different plant geometries and training levels on the seed quality of tomato cultivar 'Solan Lalima' during *Kharif* season, 2013. They found that the treatment combination Y_2S_5 (double stem and 90 × 15 cm) gave a higher seed yield per hectare (519.71 kg) over all other treatments. This treatment also gave highest benefit: cost ratio (5.17:1).

Muhammad *et al.* (2016) conducted field trials during the 2007 and 2008 rainy seasons to determine the growth and yield response of tomato (var. UC82B) to stem pruning and weeding frequency. Treatments consisted of three pruning levels (three-stem, two-stem and unpruned) and four weeding frequencies (weedy-check, three-weeding, two-weeding and weed-free). The results obtained in their study showed that plant height and mean fruit weight were significantly ($P<0.05$) higher in two-stem pruned plants; leaf Area index (LAI) and fruit number per plant were favored by unpruned treatment while the highest yield was recorded by three-stem pruned plants in both 2007 and 2008 and the combined years.

Khoshkam *et al.* (2014) carried out an experiment to study the impact of different plant training systems (one, two and four training systems) on quantitative and qualitative parameters of tomato cultivars. They reported that double stem pruning in tomato resulted in highest productivity per unit area, whereas one stem plants produced improved quality fruits in terms of titratable acidity, ascorbic acid, TSS and total sugars.

Muhammad *et al.* (2014) studied the effect of training, intra-row spacing and pruning on the growth of tomato (*Solanum lycopersicum* var. Roma VFN). Their experiment comprised of two levels of training (staked and unstaked) and three pruning levels (three-stem, two-stem and unpruned). Their results revealed that pruning and training resulted in early flowering of tomato.

Mbonihankuy *et al.* (2013) have shown that indeterminate new tomato breeding lines produce high yields of large fruits. They carried out the study to evaluate the effect of pruning levels (non pruning, single stem, two stems and three stems) on plant developmental

cycle, yield, and quality of five indeterminate tomato breeding lines and one commercial cultivar was conducted from November 2009 to March 2010. Their results showed that two stem pruned plants gave the highest number of marketable fruits per plant. The highest number of non marketable tomato fruits per hectare was observed in unpruned plants.

An experiment was conducted by Razzak *et al*. (2013) in a greenhouse to study the effect of pruning systems (single stem and double stem) on cherry tomato for better yield under protected cultivation. They concluded that double stem pruning resulted in highest productivity per unit area, whereas one stem plants produced improved quality fruits in terms of titratable acidity, vitamin C, TSS and total sugars.

Satpute *et al.* (2013) studied the effect of spacing and plant architecture on yield and economics of capsicum under net house condition. They revealed that four shoot pruned plants grown at 45 cm x 30 cm spacing recorded significantly higher yield per hectare. However, four shoot pruned plants grown at 45 cm x 45 cm spacing recorded the highest net returns and benefit: cost ratio.

Singh *et al*. (2013) conducted an experiment in a polyhouse on the effect of pruning of capsicum for better yield under protected cultivation. They concluded that plants trained to four stems resulted into higher number of fruits per plant, yield per plant, yield per square meter, net returns and benefit: cost ratio. Best results for plant height, fruit length, fruit breadth, average fruit weight and pericarp thickness were recorded in plants trained to two stems.

Sowley and Damba (2013) carried out a study to determine the effect of staking and pruning on growth and yield of tomato. The factors were pruning (pruning and un-pruning), staking (staking and un-staking) and variety (three). They concluded that staking and pruning gave clean and bigger fruits with an increase in total marketable fruit yield by weight.

Maboko *et al.* (2011) conducted a study in 2009 to 2010 and 2010 to 2011 to investigate the effect of plant population and fruit and stem pruning of hydroponically grown tomatoes in a 40 per cent (black and white) shade-net structure. They found that plants pruned to two stems with zero fruit pruning or pruned to six fruits produced significantly higher marketable and total yield, as compared to the other treatments. Plant population of 3

plants/m^2, resulted in significantly higher marketable yield of tomatoes, compared to 2.5 and 2 plants/m^2.

Shukla *et al.* (2011) studied the effect of training system on growth and other traits of the bell pepper in polyhouse and reported that two stem training system was best for most of the traits except number of flowers per plant which was best under control (unpruned plants).

Arzani *et al.* (2009) studied the effect of pruning on growth and development of tomato and found that limitation of vegetative growth enhances assimilate transport to either roots or fruits. Thus proper balance between vegetative and reproductive growth improved faster growth of fruits as compared to unpruned plants.

Ece and Darakci (2009) reported that the plants pruned to multi-stem, completed their vegetative growth in a shorter time than that of single stemmed plants. The multi-stemmed plants had more number of leaves, more number of flowers per cluster, but low percentage of fruit set than that of the single stemmed plants. However, there was no difference in yield between the two stemmed plants. The single stemmed plants hastened the maturity of fruits.

Saurabh (2009) recorded maximum fruit length (77.21 mm) and plant height (104.50 cm) resulted from the plants spaced at 30 x 60cm and fertilized with 100kg NPK/ha. Maximum fruit weight (154.30 g) was recorded from plants spaced at 30 x 90cm and fertilized with 200kg NPK/ha. Interaction between 30 x 60 cm spacing and 4 stern training system recorded maximum number of fruits per plant (19.68) and yield per plant (2.560 kg). Maximum fruit weight was observed from treatment combination where plants were pruned to two stems and spaced at 30 x 90 cm.

Franco *et al.* (2009) also obtained higher fruit production from the plants trained to two shoots.

Si Li Shan *et al*. (2009) studied the effect of 3 pruned methods (2 stems, 3 stems and 4 stems) in sweet pepper and showed that per plant yield and weight of single fruit were significantly increased under 3 and 4 stems pruned method as compared to 2 stem pruned method.

Ara *et al.* (2007) studied the effect of spacing (40 and 50 cm) and stem pruning (one stem, two stem, three stem and no pruning) on the yield of indeterminate type BARI Tomato-

6 variety at Regional Agricultural Research Station, Ishurdi, Pabna during 2005-2006. Their results showed that wider spacing (50 cm) gave the higher marketable yield (82.39 t/ha) and closer spacing gave the lowest marketable yield (68.32 t/ha) and number of fruits/plant. Two stem pruning yielded the highest marketable yield (87.18 t/ha) and one stem pruning gave the lowest number of fruits/plant.

Lee *et al*. (2007) conducted an experiment to study the effect of suitable training method on cultivation of sweet pepper under low plastic film greenhouse. They reported that method of training had significant effect on marketable fruit yield.

Muhammad and Singh (2007) examined the effect of training and pruning on growth and yield of tomato variety Roma VFN. Their treatments consisted of factorial combination of two levels of training (staked and unstaked) and three levels of pruning (three-stem, two-stem and unpruned) and three levels of intra-row spacing (20, 40 and 60 cm) laid out in a split-plot design replicated thrice, with training allocated to main plots and pruning intra-row spacing to sub-plots. Their results revealed that the pruning enhances the fruit length, diameter, fruit weight and total fresh fruit yield in three stem and two stem pruned plants than unpruned plants.

Kanyomeka and Shivute (2005) studied the influence of pruning on tomato production and found that pruning does not increase fruit yield, but improve the fruit quality and plant health.

Marim *et al.* (2005) reported the significant effect of training systems and staking methods on marketable fruit yield and total yield. Vertical staking increased the production of big fruits and reduced the production of medium sized fruits and non-marketable fruits. Plants with only one stem produced larger fruits of higher commercial value, whereas plants with two stems produced higher number of small and medium-sized fruits.

Singh and Kumar (2005) conducted an experiment on cherry tomato to know the effect of three plant spacings (60×30, 60×60 and 60×90 cm) and two training systems (single main stem and two main stems). The highest number of fruit-bearing trusses (30.33/plant) was recorded under the widest spacing with two main stems on each plant, while the greatest average fruit weight (10.1g/fruit) was recorded when the crop was planted at the widest spacing with single stem on each plant. Although, the highest fruit yield/plant (5.1 kg/plant) was obtained from plants with two main stems on each plant adjusted at the widest spacing,

the highest fruit yield per ha (912.0 q/ha) was obtained when the cherry tomato plants were trained to two main stems and grown at the closest spacing.

Silva *et al*. (2005) evaluated the influence of three plant staking and two training systems of the tomato production, two experiments were conducted during August 1999 and 2000 in Viçosa, Brazil. Staking methods tested were: T_1, traditional (two bamboo stakes as an inverted V frame); T_2, triangular staking or; T_3, vertical staking with polypropylene cord. Plants were conducted with one or two stems per plant. Their results regarding the conduction system, showed that the tomato cultivated with only one stem produced bigger fruits with higher commercial value, while the plants conduced with two stems produced more fruits of medium and small size.

Thakur *et al.* (2005) studied the effect of spacing and training system on the performance of tomato (cv. Naveen-2000). They reported that yield per plant (1.35 kg) and per hectare (675.0 quintal), net return (201503.45 rupees) and benefit: cost ratio (2.94: 1) was highest under spacing of 90 cm x 30 cm with double leader training system.

Tsedal (2005) concluded that yield per truss increased steadily with intensity of pruning in tomato due to increase in fruit size and fruit number per truss. Thus total yield was not affected by pruning.

Michalik and Wierzbicka (2001) conducted a study to investigate the effect of two types of pruning on the pattern of flowering, number of fruits, fruit weight, early and total yield of bell pepper grown in a greenhouse. The plants were pruned and trained to 2 and 4 branches. The highest yield and fruit number were obtained when the plants were trained to 4 branches. Stability in the production and highest early yield were obtained when plants were trained to 2 branches.

2.2 EFFECTS OF MULCHES ON ECONOMICS OF TOMATO PRODUCTION

Singh *et al.* (2017b) studied the effect of various mulches on growth and yield of tomato and also worked out the economics of cultivation under protected environment. Their results revealed that significantly highest fruit yield of 10.9 kg/m^2 was obtained in M_7 i.e. double shaded plastic mulch and was statistically at par with M_6 i.e. black colour plastic mulch (10.2 kg/m^2). Significantly highest net returns (Rs.147.6/m^2) were observed in M_7, as compared to other mulches.

Rao *et al.* (2016) recorded highest net return (Rs 4,22,460/ha) and the incremental net return (Rs 2,10,060/ha) in red mulch followed by black and silver mulched plots in tomato. In case of organic mulch, net return (Rs 2,68,200/ha) and the incremental net return (55,800Rs/ha) were obtained. The lowest net return (Rs 2,12,400) was obtained in no mulched plots. Incremental BCR was recorded the highest (4.70) for red mulch, followed by black (4.07) and silver (3.00) mulch than organic (1.80) mulch.

Rao *et al.* (2017) obtained highest net returns in different mulches as compared to control or no mulch condition. Watermelon under silver colored mulch film recorded higher net monitory returns (Rs 3,57,050) and lowest net monitory return under no mulch condition (Rs 73,150). The maximum cost benefit ratio was obtained with treatment silver mulch (3.02) as compared to no mulch (1.47).

Biswas *et al.* (2015) recorded the highest net return (US 7098 ha^{-1}) and the incremental net return (US 1556 ha^{-1}) in straw mulch with 50 per cent irrigation regime and concluded that the use of mulch with drip irrigation is a good option not only for water saving but also for improved yield. The maximum yield of 81.12 and 79.49 t ha^{-1} were obtained under polyethylene and straw mulch, respectively, with water supply of 50 per cent crop water requirement through drip system.

Patil and Patil (2009) found that net return was maximum in treatment of drip irrigation with black plastic mulch (Rs. 58,900/ha) as compared to conventional irrigation method with no mulch (Rs 30,700/ ha) and resulted in an increase of Rs. 28,200 in net seasonal income.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)"** was carried out at the Experimental Farm of the Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during *Kharif* seasons of 2017 and 2018. The details of the materials used and the methods employed during the course of investigation are discussed in this chapter.

3.1 EXPERIMENTAL SITE

3.1.1 Location and Climate

The Experimental Farm is situated at 35°5' N latitude and 77°11' E longitude at an elevation of 1270 m above msl at Nauni, about 15 km away from Solan city on Solan-Rajgarh road (HP). The place is characterized by mild summers and cool winters. May and June are the hottest months, while December and January are the coldest. Agro-climatically, the farm area falls in the mid-hill zone of Himachal Pradesh and is characterized by sub-temperate to sub-tropical climate with moderate rainfall (1000-1300 mm).

Meteorological data (rainfall, temperature and relative humidity) recorded at the Meteorological Observatory of the Department of Environmental Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the cropping period (March-September, 2017and 2018) has been presented in Figure 3.1 and 3.2 and appended in Appendix- Ia and Ib. Mean temperature during the cropping season varied from 21.30 to 24.00 ^{0}C (2017) and 19.80 to 24.30 ^{0}C (2018) while the relative humidity varied from 44 to 82 per cent (2017-2018) and 33 to 77 per cent (2018). Rainfall varied from 57.80 to 233.80 mm during 2017-2018 and 39.60 to 340.20 mm during 2018-2019.

3.1.2 Soil

The soil structure of the experimental farm was characterized as gravelly loam to gravelly clay loam comprised of sand (46.09 %), silt (32.12 %) and clay (25.01 %) with pH range of 6.85 – 7.04.

3.2 EXPERIMENTAL MATERIAL

3.2.1 Planting Material

Tomato cultivar 'Solan Lalima' was used for the present study. It bears medium sized and round shaped fruits of deep red colour having TSS 4-5 ^{0}Brix. It is a self pollinated indeterminate variety developed by selection. The crop is ready for first picking in 70-80 days after transplanting. Average fruit weight is 70-80 g and the average yield is 75-85 t/ha. Healthy seedlings were transplanted on 12th April, 2017 and April, 2018 at a spacing of 90 cm x 30 cm. All cultural operations and plant protection measures were adopted to maintain uniform plant population and ideal conditions for proper growth and development of plants.

The seeds of 'Solan Lalima' were procured from the Seed Sale Counter of the Directorate of Extension Education, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan was used in the studies.

3.2.2 Organic Manures

Well rotten farmyard manure (FYM) procured from the dairy section of the Department of Silviculture and Agroforestry UHF, Nauni, Solan (HP).

3.2.3 Inorganic Fertilizers

Nitrogen (N), Phosphorus (P) and Potassium (K) were used as inorganic fertilizers in the form of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

3.2.4 Mulch materials

Black polyethylene mulch and silver/black mulch of 50µ (200 gauge thickness) were applied in different plots according to the treatment combinations. Black mulch and silver/black mulch used in the experiment were procured from the open market.

3.3 EXPERIMENTAL LAYOUT

The experiment was laid out in a Randomized Block Design (Factorial) with three replications comprising of twelve treatment combinations of planting mehods *viz.* raised bed and flat bed, mulch materials *viz.* black polythene mulch and silver/black mulch and training systems *viz.* two stem training system and three stem training system. The experimental field was ploughed thoroughly with the help of a tractor followed by planking well in advance before transplanting. Seedlings were transplanted on 12th April, 2017 and 12th April, 2018 at a spacing of 90 cm x 30 cm in a plot having dimensions of 1.8 m x 6.3 m,

Fig. 3.1 Graphical representation of mean monthly data pertaining to temperature, rainfall and relative humidity during the cropping period (April, 2017-September, 2017)

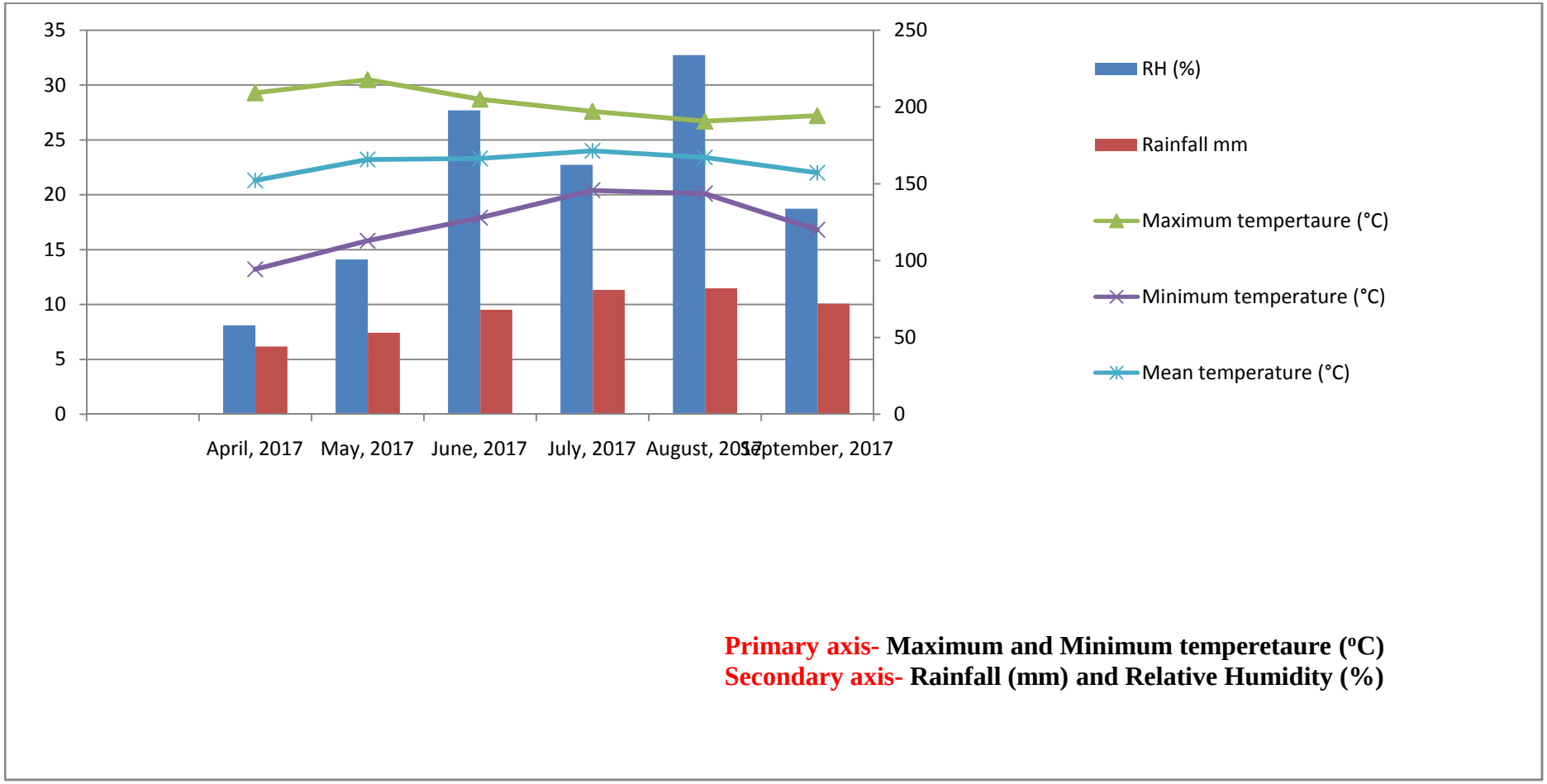
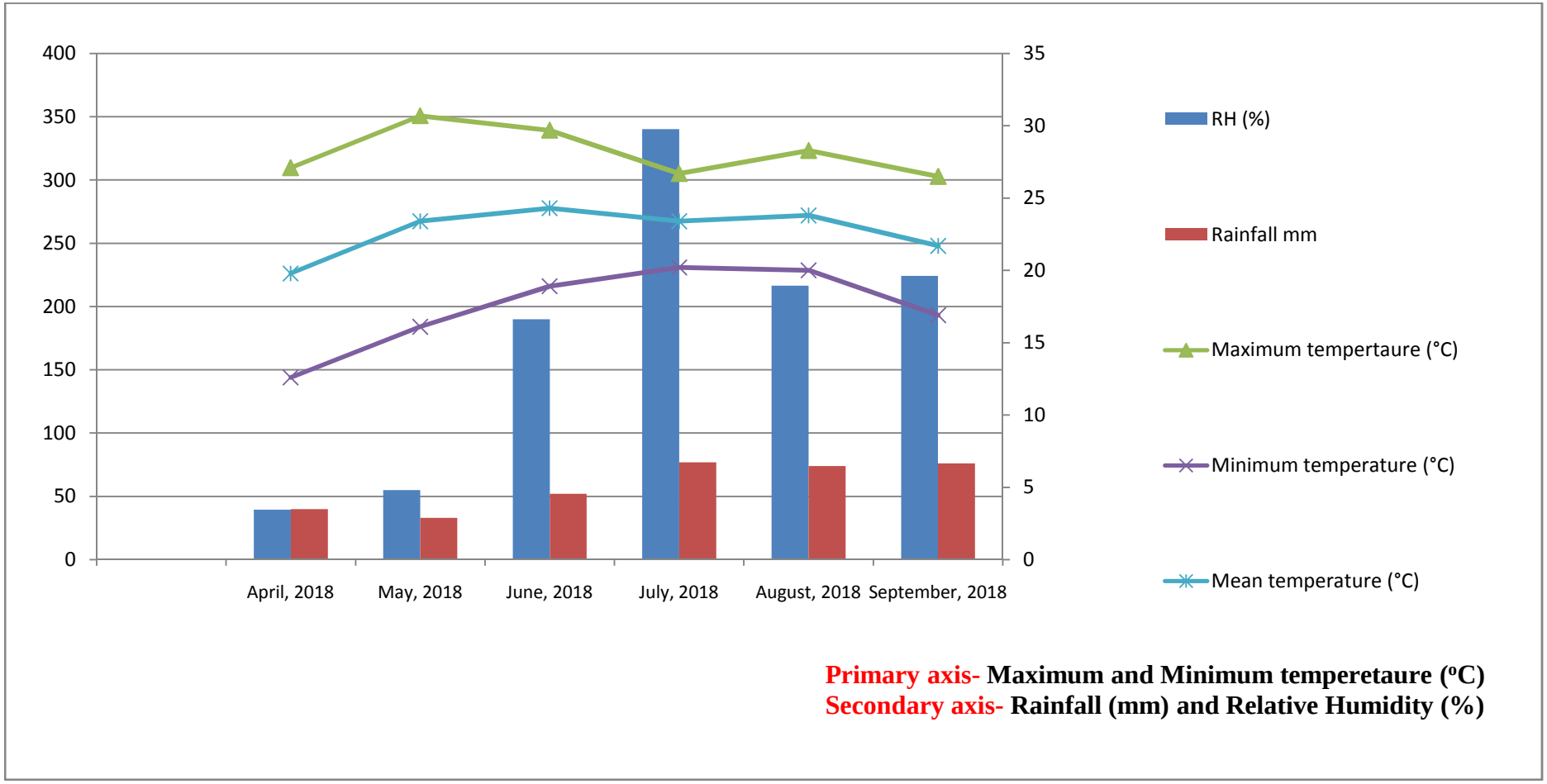


Fig. 3.2 Graphical representation of mean monthly data pertaining to the temperature, rainfall and relative humidity during the cropping period (April, 2017-September, 2018)



accommodating 42 plants per plot. Details of the treatments are used have been presented in Table 3.3.

Design of Experiment : Randomized Block Design (Factorial)

Number of replication (s) : 03

Number of treatments : 12

Number of factors : 03

Crop : Tomato
Variety : Solan Lalima
Plot size : 1.80 × 6.30 m
Spacing : 90 × 30 cm
Date of nursery sowing : 10 March, 2017 and 2018
Date of Transplanting : 12 April, 2017 and 2018
Number of Plots : 36 (12 × 3)
Number of plants per row : 21
Number of plants per plot : 42
Number of factors

1. Planting method (02) : P_1 - Raised bed
P_2 - Flat bed

2. Mulch (03) : M_1 - Black polythene mulch
M_2 - Double coloured mulch i.e. silver/black
M_3 - No mulch

3. Training system (02) : T_1- Two stem
T_2- Three stem

In all, there were twelve treatment combinations including two planting methods, three mulch materials and two training systems. The details of all the twelve treatment combinations as per experimental layout details are given in Table 3.3 below.

Table 3.1: Detail of treatments used in the studies

S. No.	Treatment code	Treatment details		
1	$P_I M_1 T_I$	Raised bed	+ Black mulch	+ Two stem training
2	$P_I M_1 T_2$	Raised bed	+ Black mulch	+ Three stem training
3	$P_I M_2 T_1$	Raised bed	+ Silver/black mulch	+ Two stem training
4	$P_I M_2 T_2$	Raised bed	+ Silver/black mulch	+ Three stem training
5	$P_I M_3 T_1$	Raised bed	+ No mulch	+ Two stem training
6	$P_I M_3 T_2$	Raised bed	+ No mulch	+ Three stem training
7	$P_2 M_1 T_I$	Flat bed	+ Black mulch	+ Two stem training
8	$P_2 M_1 T_2$	Flat bed	+ Black mulch	+ Three stem training
9	$P_2 M_2 T_1$	Flat bed	+ Silver/black mulch	+ Two stem training
10	$P_2 M_2 T_2$	Flat bed	+ Silver/black mulch	+ Three stem training
11	$P_2 M_3 T_1$	Flat bed	+ No mulch	+ Two stem training
12	$P_2 M_3 T_2$	Flat bed	+ No mulch	+ Three stem training

3.4 CULTURAL PRACTICES

3.4.1 Seed sowing and raising of seedlings

The seeds of cultivar 'Solan Lalima' were sown at experimental farm under special care in 1.5 x 1 x 0.15 m seed beds. The soil of seed bed was prepared thoroughly to obtain good tilth to provide feasible conditions for vigorous growth of young seedlings. Weeds, stubbles and dried roots of previous crops were removed. Well decomposed FYM was applied to the prepared nursery bed at the rate of 5 kg/m^2. Seed sowing was carried out on March 10, 2017 and 2018. The seeds were sown in the rows 5 cm apart and thereafter covered with a mixture of sand + FYM and finally with a layer of dried grass and watered with the help of a rose-can. Regular watering was done to maintain proper moisture for growing the seedling. After complete germination of seeds, dry grass was removed to expose the tender seedling to sunlight for better growth. Nursery was kept weed free by way of hand weeding and to prevent the attack of damping off, one drenching of Diathane M-45@ 0.25 % + Bavistin @ 0.1 % was given when the plants were 15 days old. All the precautions in raising healthy nursery were observed. The seedlings were ready for transplanting after 40 days of sowing.

3.4.2 Field preparation

The experimental field was ploughed thoroughly with the help of a tractor followed by planking well in advance before the date of transplanting. Stones, pebbles and residues of previous crop were removed manually. Field was leveled for proper drainage of water. Beds were raised 15 cm above the ground level and separated by 45 cm distance to cover with plastic mulches as per the treatments. Eighteen raised and eighteen flat beds having size of 11.34 m^2 were prepared in accordance with the experimental design with appropriate provisions for drainage. The layout of the experiment was carried out with manual labour.

3.4.3 Application of manure and fertilizers

Well rotten FYM @ 200 q/ha was applied at the time of field preparation. Full quantity of fertilizers was applied before mulching in mulched plots. In non mulched plots, the inorganic fertilizers in the form of Urea, SSP and MOP were applied @ 400, 475 and 90 kilogram per hectare in individual plots before the transplanting of seedlings. Half of the recommended dose of Urea and whole of SSP and MOP were applied as basal dose.

Plate 1. Preparation of field for transplanting seedlings

Plate 2. Placement of mulch over beds before transplanting of seedlings

Plate 3. A view of healthy seedlings of tomato in well managed nursery bed

Plate 4. General view of tomato crop grown over raised beds covered with black plastic mulch and three stem training system

Remaining half dose of urea was applied in two splits at one month interval after transplanting of seedlings.

3.4.4 Application of plastic mulch before transplanting

The plots were mulched with black and double coloured plastic mulch as per lay out plan one week before transplanting. The mulching operation was done in such a way that the whole plot was covered first and then the sides were tightened with sufficient soil from all the four sides. After covering the sides, the holes were made at a distance of 30 cm within a row as per treatment details.

3.4.5 Transplanting of seedlings in the main field and intercultural operations

Healthy and uniform sized seedlings were transplanted in each plot at 90 × 30 cm spacing between and within rows, respectively thus accommodating forty two seedlings/plot (11.34 m^2) on 12.04.2017 and 12.04.2018. The seedlings were uprooted carefully from the seed bed to avoid any damage to the root system. To minimize the damage to roots of seedlings, the seedbeds were watered one hour before uprooting. Transplanting was done in the afternoon hours. A considerable number of seedlings were also planted in the border of the experimental plots for gap filling later on, if necessary.

3.4.6 After care

The experimental plots were regularly visited. Irrigation was provided through drip as and when required. Various intercultural operations *viz.* gap filling, watering/irrigation, weeding, top dressing and plant protection measures were performed as per standard cultural practices recommended in the Package of Practices of Vegetable Crops published by the Directorate of Extension Education, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) to produce a healthy crop of tomato (Anonymous, 2014).

3.4.7 Training system (T)

After the transplants had fully established, the lateral shoots were pinched out to keep two or three main shoots. Regular pinching of side shoots was done throughout the growing season.

The plants were trained in two different training systems as:

T1: **Two stem training system -** In this system, the first two appearing healthy branches preferably at first node of the plants were retained to obtain double shoots to bear fruits for yield and quality production.

T2: **Three stem training system -** Two healthy lateral shoots preferably at first and second node of the plants were retained to obtain triple shoots to bear fruits for yield and quality production.

In both systems, plant was allowed to grow on two stem or three stem with horizontal string tied at the base with another end to the wire string which run parallel above the plant surface throughout entire bed so as to keep plant in upright position.

3.5 OBSERVATIONS RECORDED

The observations pertaining to various parameters *viz.* growth, yield, quality, weed and soil parameters were recorded as below:

3.5.1 GROWTH AND YIELD PARAMETERS

The data were recorded on ten randomly selected plants for all the characters except quality attributes for which a composite sample of ten fruits in each plot at second harvest was used. The observations were recorded on the following parameters:

3.5.1.1 Days to 50 per cent flowering

The experimental area was visited daily. Days to 50 per cent flowers were recorded as number of days taken from date of transplanting to the date when first flower emerged (pre-anthesis stage) in 50 per cent of the plants in a plot.

3.5.1.2 Number of flower clusters per plant

Flower clusters from ten randomly selected plants in each plot were counted and mean flower clusters per plant were calculated.

3.5.1.3 Number of fruits per cluster

Number of fruits in each cluster of ten randomly selected plants was counted to arrive at mean number of fruits per cluster in each treatment.

3.5.1.4 Days to marketable maturity

It was recorded as number of days taken from the date of transplanting to the date of first marketable picking.

3.5.1.5 Number of fruits per plant

The total number of fruits harvested from ten randomly selected plants in different pickings was summed up and average value per plant was worked out.

3.5.1.6 Fruit length (cm)

During third picking, length of 10 randomly selected fruits from each plot was measured in centimeters with the help of a Digital Vernier Calliper and average value was worked out.

3.5.1.7 Fruit breadth (cm)

After recording the fruit length, the same fruits were used for measuring fruit breadth with a Digital Vernier Calliper and averages worked out to express in centimeters.

3.5.1.8 Fruit weight (g)

The fruits which were used for recording fruit length and fruit breadth were also used to record fruit weight which was expressed in grams.

3.5.1.9 Pericarp thickness (mm)

After recording length and breadth, pericarp thickness of the same ten fruits was measured by cutting them transversely. Measurements were taken with a Digital Vernier Calliper and averages worked out to express in millimeter.

3.5.1.10 Number of pickings

The total number of pickings of marketable fruits was counted starting from the first picking to last picking and averages worked out.

3.5.1.11 Harvest duration (days)

Numbers of days were calculated from the date of first picking to the last picking of fruits and averages worked out.

3.5.1.12 Fruit yield per plant (kg)

Yield per plant was calculated by pooling the weight of the all the fruits harvested from every picking to arrive at yield per plant and was expressed in kilogram.

3.5.1.13 Yield per plot (kg)

Yield per plot was calculated by pooling the weight of the all the fruits harvested from all every picking in a given plot and was expressed in kilogram.

3.5.1.14 Yield per hectare (q)

On the basis of yield obtained from each plot in kilogram, yield per hectare was calculated by multiplying with a suitable factor and expressed in quintals.

3.5.1.15 Leaf area index

Leaf area index (LAI) was determined after third harvesting of the fruits. Ten plants were selected randomly from each plot for this character and five leaves were taken randomly from randomly selected ten plants. The leaf area of the selected leaves on these plants was recorded using Area measurement system MK-2 (Delta-T Device Ltd. Burwell, Cambridge, England). For convenience of presentation and interpretation, above values were converted into total leaf area per plot and thus average leaf area was calculated by digital leaf area meter. Then total leaf area was calculated which was divided by unit land surface area to get leaf area index as per the formula given by Redford (1967) here under:

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

3.5.1.16 Plant height (cm)

Plant height of 10 randomly selected plants from each plot was measured from the soil level to the highest tip of the plant at the end of the cropping season in each plot and was expressed in centimeters

3.5.2 QUALITY PARAMETERS

3.5.2.1 TSS (^{0}Brix)

Total soluble solids were estimated with the help of a refrectrometer and expressed as ^{0}Brix. Randomly 5 fruits were selected from each plot and mean was calculated.

3.5.2.2 Ascorbic acid (mg/100 g)

It was estimated by using 2, 6-dichlorophenol-indophenol dye by visual method given by AOAC (1970). Aliquots were prepared by grinding well mixed fruit samples along with metaphosphoric acid solution and titrated against 2, 6-dichlorophenol indophenol dye to pink end point.

Dye factor was calculated by using the following formula:

Dye factor = 0.5 / Titre value (Standardization of dye with standard ascorbic acid)

The vitamin C content was calculated by using the formula as given below:

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Titre value x dye factor x volume made up}}{\text{Aliquot of extract x weight of sample (g)}} \times 100$$

3.5.2.3 Lycopene content (mg/100g)

Lycopene content of ripe tomato fruits was determined according to the method described by Ranganna (1995) and was expressed as mg per 100 g of fruit weight. Tomato pulp was repeatedly extracted with acetone using pestle and mortar until the residue was colourless. The acetone extracts were transferred to a separating funnel containing about 20 ml of 5 per cent sodium sulphate solution, until two layers appeared. These layers were separated and petroleum ether extracts were kept in brown bottle containing about 10 g anhydrous sodium sulphate. Petroleum ether extracts were then decanted into 100 ml volumetric flasks and absorbance was measured in Spectrophotometer at 503 nm using petroleum ether as blank.

3.5.2.4 Shelf life (days)

Vine ripe fruits of each treatment were kept at room temperature (22 + 2° C) and their firmness was recorded at harvest and subsequently after a gap of two days. When the firmness dropped below 500 g per 0.503 cm^2 the fruits were considered as unmarketable and discarded. The number of days were noted till the fruits remained marketable.

3.5.3 INCIDENCE/SEVERITY OF DISEASE (S)

3.5.3.1 Incidence of buckeye rot (%)

The incidence of Buckeye rot was recorded as per cent of infected fruits in ten randomly marked plants at each harvest and average incidence was worked out with the following derivation.

$$\text{Incidence of Buckeye rot (\%)} = \frac{\text{Number of infected fruits per plot}}{\text{Total number of fruits per plot}} \times 100$$

3.5.3.2 Severity of *Alternaria* leaf blight (%)

In order to record the occurrence of the disease, observations were recorded periodically. The leaf blight severity in different treatments was recorded as per the scale given by Shekhawat and Chakarvarti (1974) as shown in Table 3.2:

Table 3.2: Scale used for recording severity of *Alternaria* leaf blight (%)

Grade	(%) Plant area infected by the disease	Category
0	0.00	Highly resistant
1	10.1-15.0	Resistant
2	15.1-30.0	Moderately resistant
3	30.1-50.0	Moderately susceptible
4	50.1-75.0	Susceptible
5	75.1 and above	Highly susceptible

The disease severity was worked out according to Mckinney (1923) as given below:

$$\text{Disease severity (\%)} = \frac{\text{Sum of all the disease ratings}}{\text{Total number of ratings} \times \text{Maximum disease grade}} \times 100$$

3.5.3.3 Severity of bacterial leaf spot (%)

In order to record the occurrence of the disease, the observations were recorded periodically. The bacterial leaf spot severity in different treatments was recorded as per the scale given by Shekhawat and Chakarvarti (1976) mentioned in Table 3.3:

Table 3.3: Scale used for recording severity of bacterial leaf spot (%)

Grade	(%) Plant area infected by the disease	Category
0	0	Highly resistant
1	0.1-5.0	Resistant
2	5.1-10	Moderately resistant
3	10.1-25	Moderately susceptible
4	25.1-50	Susceptible
5	>50	Highly susceptible

The disease severity was worked out according to Mckinney (1923) as given below:

$$\text{Disease severity (\%)} = \frac{\text{Sum of all the disease ratings}}{\text{Total number of ratings} \times \text{Maximum disease grade}} \times 100$$

3.5.3.4 Incidence of *Fusarium* wilt (%)

The incidence of *Fusarium* wilt was recorded as per cent infected plants in ten randomly marked plants and average incidence was worked out with the following derivation.

$$\text{Disease Incidence (\%)} = \frac{\text{Number of diseased plants}}{\text{Total number of plants observed}} \times 100$$

3.5.4 WEED PARAMETERS

3.5.4.1 Weed count (Number of weeds/m^2)

Weed count data were collected from each plot with the help of a quadrate of 1× 1 m dimension. For this, quadrate was placed randomly in each plot and total number of weeds growing within this quadrate was counted.

3.5.4.2 Fresh and dry weight of weeds (g/m^2)

Observations on fresh and dry weight of weeds were recorded from each plot from an area of 1 m^2 in each plot. Fresh weight was recorded just after the collection of weeds from the field while dry weight was recorded after complete drying the weeds in an oven at 68 ^{0}C for 48 hours and expressed as gram/m^2.

3.5.4.3 Weed control efficiency (%)

The weed control efficiency (WCE) was calculated by using the formula given by Patel *et al.* (1987) and expressed in percentage.

$$\text{Weed control efficiency (\%)} = \frac{DMC - DMT}{DMC} \times 100$$

Where,

DMC = Dry weight of weeds in control plot

DMT = Dry weight of weeds in treated plot

3.5.4.4 Weed intensity (%)

Weed intensity was calculated as specific number of weeds/m^2 to the total number of weeds /m^2. Weed intensity was calculated as:

$$\text{Weed intensity (\%)} = \frac{\text{Number of specific weed}}{\text{Total number of weeds}} \times 100$$

3.5.5 SOIL PARAMETERS

3.5.5.1 Soil moisture content (%)

For estimation of soil moisture content, the data were recorded at fortnightly interval. Soil moisture content was measured for each treatment with the help of an augar from 0-15 cm soil depth. Gravimetric Method was used for drying soil samples, drawn from each treatment in aluminium boxes. After taking fresh weight of samples these were dried in an electric oven at 105 ^{o}C till constant weight and soil moisture percentage was achieved on oven dry weight basis with the help of formula given below.

$$Mp = \frac{Fw - Dw}{Fw} \times 100$$

Where;

Mp = moisture percentage on oven dry weight basis

Fw = fresh weight of soil sample

Dw = dry weight of soil sample

3.5.5.2 Soil temperature (^{0} C)

Weekly soil temperature was recorded from three randomly selected plots, one each from black polyethylene mulch, silver/grey polyethylene mulch and un-mulched plots with the help of a thermometer put in the soil at a depth of 0-5 cm. The observations were recorded twice in a day at 7.30 A.M. and 2.30 P.M. starting from the date of sowing till the harvest of the crop. Mean temperature was worked out and expressed in ^{0}C

3.6 ECONOMICS OF TREATMENTS

The economics of treatments is the most important consideration for making any recommendation to the farmer for its adoption. The cost of production under different treatments was studied to work out economics of tomato production. The prices of inputs that were prevailing at the time of their use were considered for working out the cost of cultivation. Gross return was worked out for each treatment on the basis of market price of the produce at the time when the produce was ready for sale.

Net return (Rs/ha) was calculated by deducting cost of cultivation (Rs/ha) from gross income. Benefit: cost ratio was worked out as follows:

$$\text{B: C ratio} = \frac{\text{Net returns (Rs/ha)}}{\text{Cost of cultivation (Rs/ha)}}$$

ANALYSIS OF VARIANCE (ANOVA)

Statistical Analysis:

The data recorded was analysed by using MS-Excel and OPSTAT. The mean value of data was subjected to analysis of variance as described by Panse and Sukhatme (2000) using Randomized Block Design (RBD) Factorial.

The analysis of variance (ANOVA) was calculated as follows:

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Sum of Squares (MSS)	F. value Calculated
Replications	$(r-1)$	S_r	$\frac{S_r}{(r-1)}$	$\frac{M_r}{M_e}$
Treatments	$(t-1)$	S_t	$\frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Planting method (P)	$(a-1)$	S_a	$\frac{S_a}{(a-1)}$	$\frac{M_a}{M_e}$
Mulch (M)	$(b-1)$	S_b	$\frac{S_b}{(b-1)}$	$\frac{M_b}{M_e}$
P × M interaction	$(a-1)\times(b-1)$	S_{ab}	$\frac{S_{ab}}{(a-1)\times(b-1)}$	$\frac{M_{ab}}{M_e}$
Training system (T)	$(c-1)$	S_c	$\frac{S_c}{(c-1)}$	$\frac{M_c}{M_e}$
P × T interaction	$(a-1)\times(c-1)$	S_{ac}	$\frac{S_{ac}}{(a-1)\times(c-1)}$	$\frac{M_{ac}}{M_e}$
M × T interaction	$(b-1)\times(c-1)$	S_{bc}	$\frac{S_{bc}}{(b-1)\times(c-1)}$	$\frac{M_{bc}}{M_e}$
P × M × T interaction	$(a-1)\times(b-1)\times(c-1)$	S_{abc}	$\frac{S_{abc}}{(a-1)\times(b-1)\times(c-1)}$	$\frac{M_{abc}}{M_e}$
Error	$(t-1)\times(r-1)$	S_{tr}	$\frac{S_{tr}}{(t-1)\times(r-1)}$	$\frac{M_{tr}}{M_e}$
Total	$(tr-1)$	$S_{(tr-1)}$		

Where,

r = Number of replications

t = Number of treatments

a = Planting method

b = Mulch

c = Training system

The calculated ‘F’ values were compared with the tabulated ‘F’ values at 5 per cent level of significance. When the calculated ‘F’ value was higher than the tabulated, it was considered to be significant.

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

$$SE\ (m) = \pm (Me/r)^{1/2}$$

$$SE\ (d) = \pm (2Me/r)^{1/2}$$

Critical Difference (CD) = SE(d) × t (5%) value at error degrees of freedom.

Chapter-4

RESULTS AND DISCUSSION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops of every kitchen in the world. It belongs to family Solanaceae with diploid chromosome number (2n=24) and is a typical categorized self-pollinated day neutral plant (Yadav *et al.*, 2017). Tomato is one of the most popular and widely grown vegetables in the world, ranking second followed by potato.

Generally consumers do not prefer poor quality vegetable produce, which fetches less price in the market. The biological value of vegetables depends mainly on the genetic factors, still it is influenced by the environment, e.g. temperature, light, humidity, soil type, content of minerals in the soil and agrotechnical factors such as cultivation system, fertilization and irrigation (Singh *et al.*, 2017). Hence, techniques like use of raised-bed and flat bed planting methods, synthetic mulches (black and silver/black), and training systems (two stem and three stem) under open-field conditions are best approaches to produce high yielding and improved quality vegetables. In Himachal Pradesh, the growing season of tomato coincides with monsoon season, thus indeterminate varieties are most suitable because the determinate types are more prone to insect pest and diseases due to rain splashes.

Raised bed planting method offers the opportunity to the farmers to increase their production from decreasing farm area. Raised beds are especially helpful to farmers with limited farming space and those who have difficulty with fine-textured, clayey soils which do not dry early (due to proper drainage facility). Various efforts are being employed to improve undesirable soils which are concentrated in the particular growing area. The advantages of raised beds are that they drain and warm up very early in the spring, which permits the planting of warm season vegetables at recommended planting dates. Raised bed can be prepared as early as possible after rains or irrigation because they inhibit the compaction of soils. The percolation of water will be better during the heavy rains and hence there will be less danger of soil erosion. Raised beds are easy to prepare for planting the crops and after care throughout the growing season of a particular vegetable crop. Sayre (2007) reported that the raised bed planting method for row-spaced crops in many parts of the world is gaining

importance. According to the study of various researchers, it can save 25-30 % irrigation water, increase water use efficiency (Malik et *al.,* 2005 and Choudhary *et al.,* 2008) and provide better opportunities to leach salts from the furrows (Bakker *et al.,* 2010). Choudhary *et al.* (2008) reported that under saline conditions, increased salt accumulation on top of the bed due to the upward movement of salts through capillary rise in response to evaporation gradients.

Mulching is also one of the effective and promising management practices to reduce dry season salinity and conserve moisture in plant root zone, as it can decrease soil water evaporation, increase infiltration and regulate soil water and salt movement (Devkota *et al.,* 2015). The use of plastic mulch in agriculture has been increased dramatically in the last ten years throughout the whole world. Mulching is one of the most important agro-techniques or practices which includes covering the soil surface that provides more favourable conditions for plant growth, development and efficient crop production also. It also reduces the crop weed competition, and nutrient losses through leaching, improves the activity of beneficial microorganism residing in the soil and also improves the hydrothermal regimes of soil (Singh, 2005). Black polyethylene plastic mulch has been reported as standard plastic mulch for vegetable production. Polyethylene mulches are widely used in open field conditions for vegetable production because mulches have contributed significantly to reduce the yield losses due to crop weed competition for nutrients, water and many other resources.

According to Yadav *et al.* (2017), the role of training system is very clear as it prevents overcrowding of branches for sunlight and assimilates and competition for nutrients, thus avoids the poor fruit set, delayed maturity as well as improves air circulation through the plants under humid and moist conditions where such tomato plants are more prone to the attack of various diseases. For effective training, staking is the most important operation being practiced especially during the rainy season for improving quality, yield and protecting the crop from attack of soil borne pathogens. It also provides proper space and light for its growth and development. By proper training, more number of plants can be accommodated per unit area thereby increasing the yield. Vertical training with ropes or wires has been claimed to result in early ripening, less disease incidence, easier inter-culture and harvesting, more clean and healthy fruits and increased yields of better quality fruits. Pruning helps to produce two/three stemmed plants and staking have been claimed to achieve the higher yield from the larger fruits. Excessive pruning of leaves sometimes causes the plants not to

complete their reproductive phase. Therefore, it is of utmost importance to maintain enough foliage on the plant for enhanced rate of photosynthesis. Therefore, manipulation of canopy architecture by means of sufficient pruning and training together with appropriate spatial arrangements has been justified as the key for getting maximum marketable yield through such agricultural management practices.

In this study the main emphasis was given on appropriate cultural practices such as planting methods, mulch application and training systems in order to enhance the production per unit area by utilizing the available space and utilization of the resources. Keeping, in view the above perspectives, the present studies were conducted to investigate the effects of above said agro-techniques on fruit yield, quality and benefit: cost ratio in the tomato fruit production programme.

The present investigation **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum Lycopersicum* L.)"** was conducted at Experimental Farm of the Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, (HP) during *Khraif* seasons of 2017-18 and 2018-19. Data on different parameters were analyzed statistically and significance of results was verified. The results obtained with respect to various growth, yield, quality, disease, weed and soil parameters have been presented and discussed with possible scientific explanations and supportive evidences based on available literature in this chapter with a view to find out the cause and effect relationship among different treatments, for sorting out the information of practical value. The results have been discussed under the following heads.

4.1 GROWTH AND YIELD PARAMETERS

4.1.1 Days to 50 per cent flowering

4.1.2 Number of flower clusters per plant

4.1.3 Number of fruits per cluster

4.1.4 Days to marketable maturity

4.1.5 Number of fruits per plant

4.1.6 Fruit length (cm)

4.1.7 Fruit breadth (cm)

4.1.8 Pericarp thickness (mm)

4.1.9 Fruit weight (g)

4.1.10 Number of pickings

4.1.11 Harvest duration (days)

4.1.12 Fruit yield per plant (kg)

4.1.13 Fruit yield per plot (kg)

4.1.14 Fruit yield per hectare (q)

4.1.15 Leaf area index

4.1.16 Plant height (cm)

4.2 QUALITY PARAMETERS

4.2.1 TSS (^{0}B)

4.2.2 Ascorbic acid content (mg/100 g of fresh weight)

4.2.3 Lycopene content (mg/100 g of fresh weight)

4.2.4 Shelf life (days)

4.3 INCIDENCE/SEVERITY OF DISEASE (S)

4.3.1 Incidence of buckeye rot (%)

4.3.2 Severity of *Alternaria* leaf blight (%)

4.3.3 Severity of bacterial leaf spot (%)

4.3.4 Incidence of *Fusarium* wilt (%)

4.4 WEED PARAMETERS

4.4.1 Weed count (m^{-2})

4.4.2 Weed control efficiency (%)

4.4.3 Fresh weight of weeds (g)

4.4.4 Dry weight of weeds (g)

4.4.5 Weed intensity (%)

4.5 SOIL PARAMETERS

4.5.1 Soil temperature (^{0}C)

4.5.2 Soil moisture content (%)

4.6 Economics of Tomato Cultivation (Benefit: Cost Ratio)

4.7 Effect of Weather on Tomato in Respect of Growth, Yield, Quality, Disease, Weed and Soil Parameters

4.1 GROWTH AND YIELD CHARACTERS

The analysis of variance (Appendix-V) showed significant differences among various treatments for all the growth and yield parameters *viz.*, days to 50 per cent flowering, number of flower clusters per plant, number of fruits per cluster, days to marketable maturity, number of fruits per plant, fruit length (cm), fruit breadth (cm), pericarp thickness (mm), fruit weight (g), number of pickings, harvest duration (days), fruit yield per plant (kg) / plot (kg) / ha (q), leaf area index and plant height (cm).

4.1.1 Days to 50 per cent flowering

Earliness is an important character from point of view of premium harvest and higher yield. Though it is considered as genetically controlled trait, other factors like environmental and cultural practices can also influence it to an appreciable extent.

It is clear from the data presented in Table 4.1 that there was a significant effect of different planting methods, mulches and training systems on days to 50 per cent flowering during both the years of study. Minimum number of days i.e. 29.82 were recorded in P_1 (raised bed) while 31.45 days were recorded in P_2 (flat bed). Similar trend was followed during both the years of study. Similarly, 29.10 days were recorded when the plants were raised using black mulch (M_1). This treatment also produced significant differences with silver/black mulch i.e. M_2 (29.62 days) while maximum days (33.19) were recorded when the plants were raised without mulch (M_3). Similar trend was followed during both the years of study. As regards training systems, the plants which were trained with two stem (T_1) took least (30.32) number of days to 50 per cent flowering, while the plants with three stem training system (T_2) came into flower a bit later (30.95 days). Similar trend was observed for 2017-2018 and 2018-2019 years of the study.

The results pertaining to two way interaction of P × M (planting methods and mulching treatments) as presented in Table 4.2 (pooled data) revealed that minimum number of days (28.06) was recorded in treatment combination P_1M_1 (raised bed and black mulch) which was significantly superior over P_1M_2 (raised bed and silver/black mulch) which took 28.63 days to 50 per cent flowering. The treatment combination P_2M_1 (flat bed and black mulch) was statistically at par with P_2M_2 (flat bed and silver/black mulch) and maximum number of days i.e. 33.60 was recorded when the plants were raised on flat bed without any mulch (P_2M_3). Non significant results were obtained during the year 2017-2018 for P × M

interaction. Regarding M × T (mulching treatments and training systems) interaction, minimum values (28.64 days) were recorded in treatment combination M_1T_1 (black mulch and two stem training) which was significantly better over M_2T_1 (silver/black mulch and two stem training), which took 29.21 days for 50 per cent flowering. The treatment combination M_1T_2 (black mulch and three stem training) produced non-significant effects with M_2T_1 (silver/black mulch and two stem training), which took 29.21 days for 50 per cent flowering. Maximum number of days 33.28 were recorded when plants were raised with no mulch and three stem training system (M_3T_2), whereas, non significant results were obtained during the year 2017-2018 for P × T interaction. Analysis of variance (Table 4.2, pooled data) depicted significant differences with P × T (planting methods and training systems) interaction. Maximum (31.62) number of days to 50 per cent flowering were recorded in P_2T_2 (flat bed and three stem training). Minimum number of days (29.36) was recorded, when the plants were grown on raised bed with two stem training system (P_1T_1). This treatment combination was significantly superior over P_1T_2 (raised bed and three stem training) and P_2T_1 (flat bed and two stem training) which took 30.28 and 31.27 number of days to 50 per cent flowering, respectively. Non significant results were obtained during the year 2017-2018 for P × T interaction.

Table 4.1 Effect of planting methods, mulches and training systems on days to 50 per cent flowering and number of flower clusters per plant in tomato

Treatments	Days to 50 per cent flowering			Number of flower clusters per plant		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	29.86	29.79	29.82	10.97	11.51	11.24
P_2	31.17	31.72	31.45	9.92	10.18	10.05
$CD_{0.05}$	**0.46**	**0.14**	**0.24**	**0.31**	**0.39**	**0.39**
Mulches (M)						
M_1	29.20	28.99	29.10	11.37	11.84	11.60
M_2	29.43	29.80	29.62	10.96	11.63	11.29
M_3	32.91	33.47	33.19	9.02	9.06	9.04
$CD_{0.05}$	**0.60**	**0.17**	**0.29**	**0.38**	**0.16**	**0.16**
Training Systems (T)						
T_1	30.34	30.29	30.32	10.70	10.96	10.83
T_2	30.69	31.22	30.95	10.19	10.73	10.46
$CD_{0.05}$	**0.46**	**0.14**	**0.24**	**0.31**	**0.19**	**0.19**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

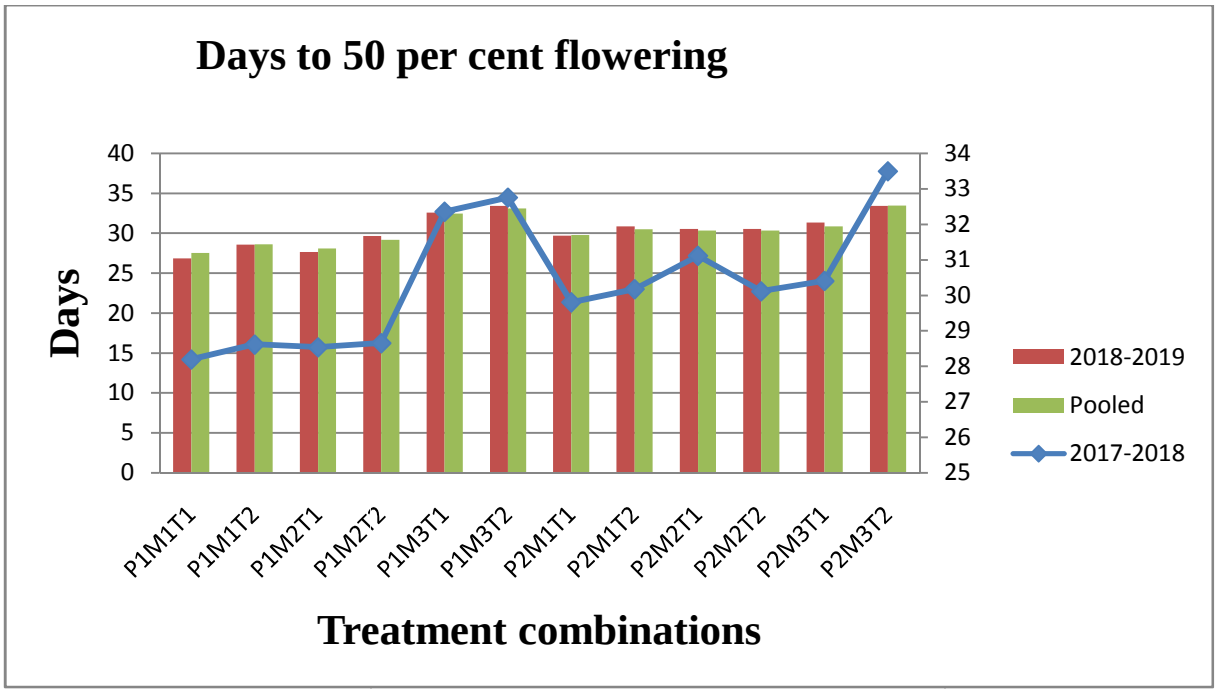


Fig. 4.1 Effect of planting methods, mulching and training levels on days to 50 per cent flowering in tomato

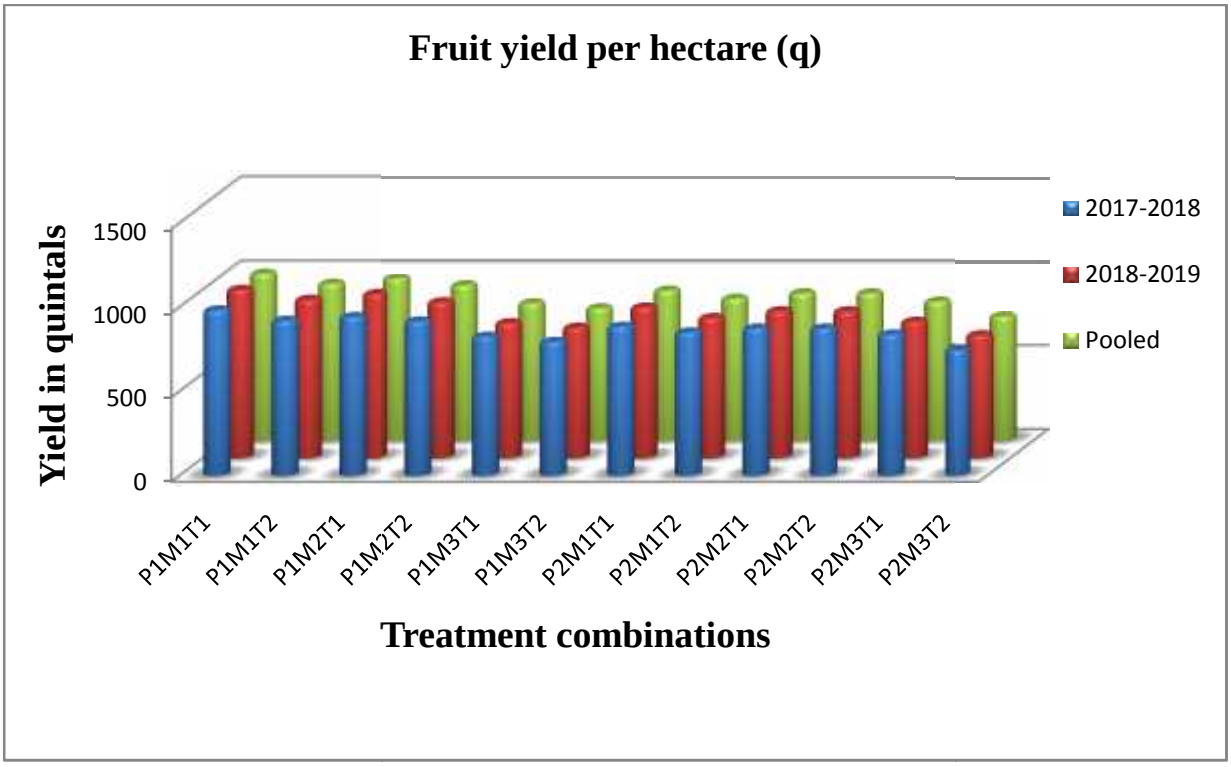


Fig. 4.2 Effect of planting methods, mulching and training levels on yield per hectare (q)

Table 4.2 Effect of two way interactions P × M, M × T and P × T on days to 50 per cent flowering and number of flower clusters per plant in tomato

Treatment combination	Days to 50 per cent flowering			Number of flower clusters per plant		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	28.41	27.71	28.06	12.02	12.59	12.30
P_1M_2	28.60	28.66	28.63	11.50	12.26	11.88
P_1M_3	32.56	33.00	32.78	9.40	9.68	9.54
P_2M_1	30.00	30.28	30.14	10.72	11.09	10.90
P_2M_2	30.27	30.94	30.60	10.41	10.99	10.70
P_2M_3	33.25	33.95	33.60	8.63	8.45	8.54
$CD_{0.05}$	**NS**	**0.24**	**0.41**	**NS**	**NS**	**NS**
M_1T_1	29.01	28.27	28.64	11.78	11.98	11.88
M_1T_2	29.40	29.72	29.56	10.95	11.70	11.33
M_2T_1	29.33	29.10	29.21	11.22	11.81	11.52
M_2T_2	29.53	30.50	30.02	10.69	11.44	11.07
M_3T_1	32.68	33.51	33.10	9.11	9.09	9.10
M_3T_2	33.13	33.44	33.28	8.93	9.04	8.98
$CD_{0.05}$	**NS**	**0.24**	**0.41**	**NS**	**NS**	**NS**
P_1T_1	29.70	29.02	29.36	11.25	11.61	11.43
P_1T_2	30.01	30.55	30.28	10.69	11.41	11.05
P_2T_1	30.98	31.57	31.27	10.15	10.32	10.24
P_2T_2	31.36	31.88	31.62	9.69	10.04	9.86
$CD_{0.05}$	**NS**	**0.19**	**0.34**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

The pooled data pertaining to three way interaction (Fig. 4.1) with regards to number of days to 50 per cent flowering which has been presented in Table 4.3 showed non-significant differences for various treatment combinations. Minimum number of days (27.52), however, was recorded in $P_1M_1T_1$ treatment combination (raised bed, black mulch and two stem training) where as $P_2M_3T_2$ (flat bed, no mulch and three stem training) recorded maximum (33.47) number of days to 50 per cent flowering.

Raised beds contributed significantly towards early flowering. This might be due to the warming up of the bed because of its bigger exposed surface and absorbance of more radiations which could create a significant difference in soil temperature especially of the root zone as compared to the flat bed mainly during day time. Present findings are in conformity with the findings of Locher *et al.* (2003) in sweet pepper.

Table 4.3 Effect of P × M × T interaction on days to 50 per cent flowering and number of flower clusters per plan
t in tomato

Treatment combination	Days to 50 per cent flowering			Number of flower clusters per plant		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	28.20	26.84	27.52	12.57	12.70	12.64
$P_1M_1T_2$	28.62	28.57	28.60	11.46	12.48	11.97
$P_1M_2T_1$	28.54	27.65	28.10	11.62	12.52	12.07
$P_1M_2T_2$	28.66	29.66	29.16	11.38	12.00	11.69
$P_1M_3T_1$	32.36	32.57	32.46	9.56	9.60	9.58
$P_1M_3T_2$	32.76	33.43	33.10	9.24	9.75	9.50
$P_2M_1T_1$	29.81	29.71	29.76	10.98	11.26	11.12
$P_2M_1T_2$	30.18	30.86	30.52	10.45	10.93	10.69
$P_2M_2T_1$	31.12	30.54	30.33	10.82	11.11	10.97
$P_2M_2T_2$	30.12	30.54	30.33	10.82	11.11	10.97
$P_2M_3T_1$	30.41	31.34	30.87	10.00	10.88	10.44
$P_2M_3T_2$	33.50	33.44	33.47	8.61	8.32	8.47
$CD_{0.05}$	**NS**	**0.33**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

There might be differences in soil temperature among the treatments during the beginning of growing period, when the foliage of the plant did not shadow the surface considerably resulting into enhancement of metabolic activities of cells, which ultimately resulted into completion of vegetative phase bit earlier than other treatments.

Mulches have been shown to influence early flowering in tomato. Plastic mulches directly influence the microclimate around the plant by modifying the radiation budget (absorbitivity vs. reflectivity) of the surface and decreasing the soil water loss. The soil temperature under a plastic mulch depends on the thermal properties (reflectivity, absorbitivity, or transmittancy) of a particular mulch material in relation to incoming solar radiation **(**Abhivyakti *et al.*, 2016). In case of black mulch, soil temperature might have promoted faster crop development and might have contributed towards earliness in the current study. The present results are also in agreement with those of Rahman *et al.* (2016), Tegen *et al.* (2016)**,** Singh *et al.* (2017), Angmo *et al*. (2018) and Kumari *et al.* (2018) in tomato. Therefore, more and earlier flowering could contribute to increased early and total yield. In the present study, tomato plants grown under black plastic mulch hastened reproductive phase (flowering and fruit maturity) compared to plants grown under the remaining treatments. Significantly higher and congenial mean soil temperature (Appendix II and Fig. 4.8, 4.9, 4.10 and 4.11) was obtained for black plastic mulch which might have

Plate 5. General view of tomato crop grown over raised beds with silver/black plastic mulch and two stem training system

Plate 6. General view of tomato crop grown over raised beds without plastic mulch and three stem training system

helped plants to flower earlier. This may be due to warmness produced along with conservation of moisture by mulch application which might have resulted in good vegetative growth compared to the controlled treatments (unmulched).

Training systems also had significant influence on days to 50 per cent flowering. Early flowering might be due to the result of diversion of photosynthates towards flowering branches which could rather have been used for growth of new shoots and leaves. These plants might have completed vegetative phase much early and the photosynthates might have been shifted to the reproductive parts rather than to vegetative parts (Frank, 2000). Similar results were also reported by Ara *et al.* (2007), Muhammad *et al.* (2014), Mbonihankuye *et al.* (2013) and Singh *et al.* (2017) in tomato.

4.1.2 Number of flower clusters per plant

The data recorded on number of flower clusters per plant have been depicted in Table 4.1. Analysis of variance showed significant differences for planting methods, mulches and training systems during both the years of study. Number of flower clusters per plant was more in P_1 (raised bed) during both the years (10.97 during 2017-18 and 11.51 during 2018-19). A perusal of the pooled data also showed more number of flower clusters (11.24) in P_1 (raised bed) and minimum (10.05) in P_2 (flat bed). Regarding the effect of mulches, maximum number of flower clusters per plant was recorded in M_1 (black mulch) followed by M_2 (silver/black mulch) and least in M_3 (no mulch) during both the years of study as well as when the data were pooled. Black mulch (M_1) produced (11.60) flower clusters (pooled data, Table 4.1) which were significantly more (11.29) than in silver/black mulch (M_2). Minimum (9.04) number of flower clusters per plant were, however, recorded when the plants were raised without mulch (M_3). Similar trend was followed during both the years of study. As regards training systems, maximum (10.83) flower clusters per plant were recorded in T_1 (two stem training) which were significantly more than T_2 (10.46 flower clusters per plant). Similar trend was followed during both the years of study.

The data in Table 4.2 depicted the effect of various interactions on number of flower clusters per plant (pooled data). Analysis of variance revealed non-significant differences for P × M interaction (planting methods and mulching treatments). Maximum values (12.30) were, however, recorded in P_1M_1 (raised bed and black mulch) and minimum (8.54) in P_2M_3 (flat bed and no mulch). Similarly, non significant differences were observed in M × T

interaction (mulching treatments and training systems). Maximum values of number of flower clusters (11.88) were observed in M_1T_1 (black mulch with two stem training) and minimum values (8.98) of number of flower clusters per plant were recorded when the plots were not mulched along with three stem training. Similarly, P × T interaction (planting methods and training systems) did not vary significantly for number of flower clusters per plant. Maximum values (11.43) for number of flower clusters per plant were recorded in P_1T_1 (raised bed with two stem training system), whereas, minimum (9.86), however, were observed when the plants were raised on flat bed with three stem training system (P_2T_2).

Analysis of data (Table 4.3) also showed non-significant differences (pooled data) with regards to three way interactions P × M × T (planting methods, mulching treatments and training systems). Maximum number of flower clusters (12.64) were, however, recorded in $P_1M_1T_1$ (raised bed, black mulch and two stem training) which was closely followed by 12.07 flower clusters in $P_1M_2T_1$ (raised bed, silver/black mulch and two stem training). Minimum number of flower clusters per plant (8.47) was recorded when the plants were raised on flat bed with no mulch and three stem training system ($P_2M_3T_2$).

More flower clusters per plant produced by the plants grown on raised bed could be due to the fact that raised bed warms up more quickly due to its higher and more exposed surface (absorbance of more radiations) which drains better and also avoids downward leaching of solutes resulting into efficient use of inputs by the plants for their growth and early development rather than flat beds (Bahadur *et al.,* 2013). Another reason could be the availability of more nutrients because of minimum tillage (Naresh *et al*., 2012) which could possibly because of more number of flower clusters. Raised bed causes a significant difference in the root zone temperature during day time thus hastens the metabolic activities inside the plant cells and thereby approaches the reproductive phase more rapidly rather than vegetative phase (Locher *et al.,* 2003).

The number of flower clusters per plant of tomato was recorded more in black polythene mulched plots. This might be due to the change in the plant microclimate which is attributed to the beneficial effects of black plastic film. Warming up of soil and soil water conservation throughout the growing season might be responsible for better performance which consequently advanced the flowering due to more cell division and cell maturation, hence more number of flower cluster, fruiting and also reduced flower abortion (Jones *et al.,* 1977). All these microclimate modifications might be associated with black plastic mulch

culture. Another possible be reason could be the modification of light environment sufficiently to enhance photosynthetic rate and/or light stimulus of morphogenic development with the use of black plastic mulches; and its effects on crop growth and development. Decoteau *et al.* (1988), Bhujbal *et al.* (2015) and Rahman *et al.* (2016) also showed similar results and narrated that black polyethylene mulch produced the highest number of flower clusters per plant in tomato. The present findings are also in line with those of Rahman *et al.* (2016) in tomato.

Light is one of the limiting factors in crowded branched plants. In case of two stem training system, there would be maximum sunlight penetration and enhanced photosynthetic activity making more assimilates available for flower cluster setting (early shift from vegetative to reproductive phase) as compared to three stem training system, early and higher rate of morphogenesis (cell division, cell differentiation, cell elongation and cell maturation) and also good aeration through the canopy which might be a valid reason to increase the number of flower clusters per plant and ultimately increased fruit set (Ara *et al.,* 2007; Mbonihankuye *et al.,* 2013 and Ansari *et al.,* 2017). Present results are in conformity with the findings of Yadav *et al.* (2017) in Tomato.

4.1.3 Number of fruits per cluster

Number of fruits per cluster is an indication of more yield per plant and is generally dependent on better fruit set. Fruit setting in tomato is optimum, if agro techniques are employed effectively.

It is clear from the data presented in Table 4.4 that there was a significant effect of different planting methods, mulches and training systems on number of fruits per cluster (pooled data). Number of fruits per cluster was more in P_1 (raised bed) during both the years (5.40 during 2017-18 and 6.16 during 2018-19). Similarly, more number of fruits per cluster (5.78) was recorded in P_1 (raised bed) and minimum (5.09) in P_2 (flat bed) while looking into pooled data also. Regarding the effect of mulches, maximum number of fruits per cluster was recorded in M_1 (black mulch) followed by M_2 (silver/black mulch) and least in M_3 (no mulch) during both the years as well as when the data were pooled. Black mulch M_1 produced 5.88 fruits per cluster (pooled data, Table 4.4) which was significantly more (5.72) than in silver mulch (M_2). Minimum (4.71) number of fruits per cluster was, however, recorded when the plants were raised without mulch (M_3). As regards training systems, maximum (5.59) fruits

per cluster were recorded in T_1 (two stem training) which was closely followed (5.28) by T_2 (three stem training), whereas, non significant results were obtained for training systems during the year 2017-2018. Similar trend was followed during both the years of study.

Table 4.4 Effect of planting methods, mulches and training systems on number of fruits per cluster and days to marketable maturity in tomato crop

Treatments	Number of fruits per cluster			Days to marketable maturity		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	5.40	6.16	5.78	74.89	74.85	74.87
P_2	4.90	5.29	5.09	79.46	79.38	79.42
$CD_{0.05}$	**0.26**	**0.19**	**0.17**	**1.78**	**0.69**	**1.04**
Mulches (M)						
M_1	5.58	6.18	5.88	73.18	72.97	73.08
M_2	5.43	6.00	5.72	74.22	74.54	74.38
M_3	4.43	4.99	4.71	84.12	83.82	83.97
$CD_{0.05}$	**0.32**	**0.23**	**0.20**	**2.18**	**0.84**	**1.28**
Training Systems (T)						
T_1	5.26	5.93	5.59	76.73	75.86	76.29
T_2	5.04	5.51	5.28	77.61	78.37	77.99
$CD_{0.05}$	**NS**	**0.19**	**0.17**	**NS**	**0.69**	**1.04**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Data pertaining to two way interaction of P × M (planting methods and mulching treatments) as presented in table 4.5 (pooled data) revealed non-significant differences for P × M interaction (planting methods and mulching treatments). Maximum values (6.27) were, however, recorded in P_1M_1 (raised bed and black mulch) which were closely followed by 6.05 number of fruits per cluster in P_1M_2 (raised bed and silver/black mulch) where as minimum (4.41) were recorded in P_2M_3 (flat bed and no mulch). Similarly, non significant differences were also observed in M × T interaction (mulching treatments and training systems). Maximum values of number of fruits per cluster (6.10) were observed in M_1T_1 (black mulch with two stem training) which were closely followed by 5.87 and 5.66 number of fruits per cluster in M_2T_1 (black mulch with two stem training) and M_1T_2 (black mulch with three stem training). Minimum values 4.61 of number of fruits per cluster were recorded when the plots were not mulched along with three stem training (M_3T_2). Interaction involving P × T (planting methods and training systems) did not vary significantly for number of fruits per cluster. Maximum values (5.94) for number of fruits per cluster were recorded in P_1T_1

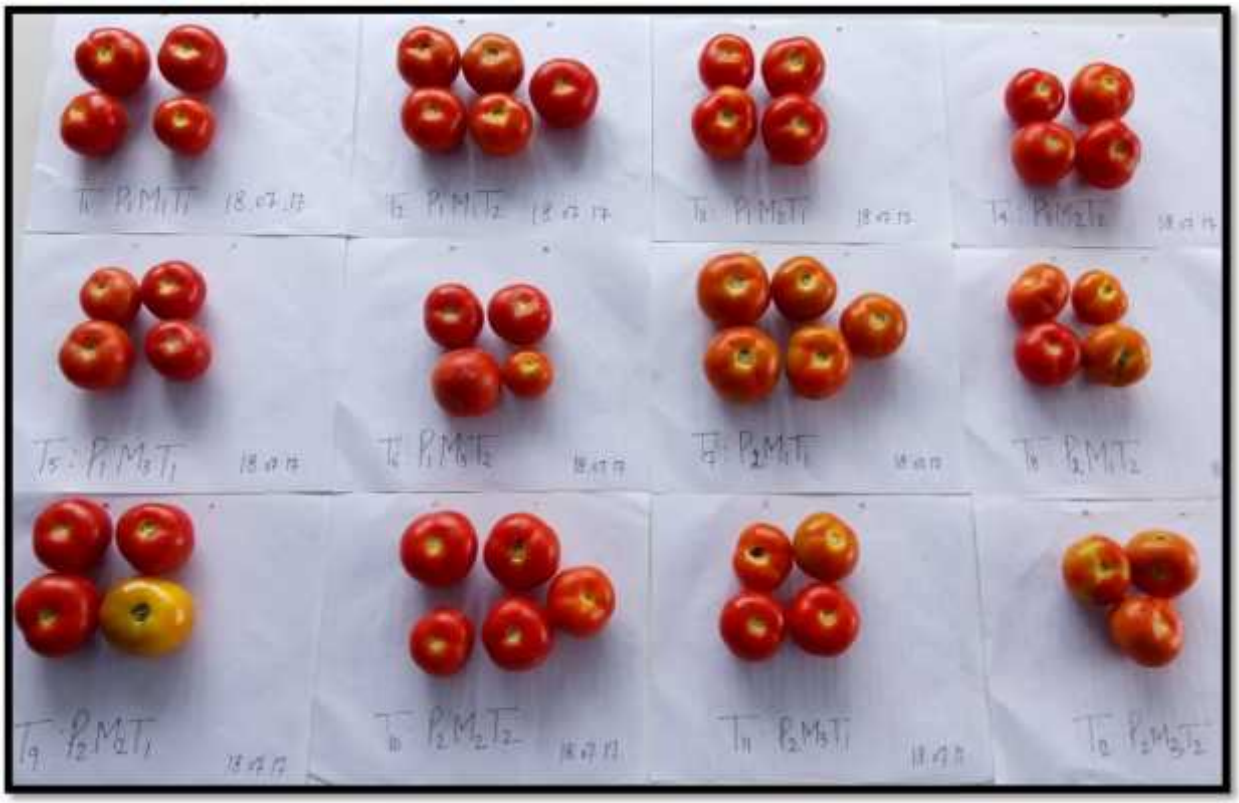


Plate 7. Comparison of tomato for observing shelf life under ambient conditions

Plate 8. General view of tomato crop grown on flat bed without plastic mulch and two stem training system

(raised bed with two stem training system) which was closely followed by 5.62 number of fruits per cluster when the plants were grown on raised bed with three stem training system (P_1T_2) whereas, minimum (4.94) values were observed when the plants were raised on flat bed with three stem training system (P_2T_2).

Table 4.5 Effect of two way interactions P × M, M × T and P × T on number of fruits per cluster and days to marketable maturity in tomato crop

Treatment combination	Number of fruits per cluster			Days to marketable maturity		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	5.83	6.72	6.27	71.17	70.09	70.63
P_1M_2	5.65	6.45	6.05	72.40	72.61	72.50
P_1M_3	4.72	5.31	5.02	81.10	81.85	81.47
P_2M_1	5.33	5.65	5.49	75.20	75.86	75.53
P_2M_2	5.22	5.54	5.38	76.03	76.48	76.26
P_2M_3	4.15	4.67	4.41	87.13	85.79	86.46
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
M_1T_1	5.74	6.46	6.10	72.43	71.09	71.76
M_1T_2	5.42	5.90	5.66	73.93	74.85	74.39
M_2T_1	5.52	6.23	5.87	73.77	73.33	73.55
M_2T_2	5.35	5.77	5.56	74.67	75.76	75.21
M_3T_1	4.52	5.11	4.81	84.00	83.15	83.58
M_3T_2	4.35	4.87	4.61	84.23	84.48	84.36
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**1.19**	**NS**
P_1T_1	5.54	6.35	5.94	74.33	73.10	73.71
P_1T_2	5.27	5.96	5.62	75.44	76.60	76.02
P_2T_1	4.98	5.51	5.24	79.13	78.62	78.88
P_2T_2	4.81	5.06	4.94	79.78	80.14	79.96
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**0.97**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver/black polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

Analysis of data table 4.6 showed non-significant differences with regards to three way interactions i.e. planting methods, mulching treatments and training systems. Maximum number of fruits per cluster (6.51) was, however, recorded in $P_1M_1T_1$ (raised bed, black mulch and two stem training) which was closely followed by 6.23 fruits per cluster in $P_1M_2T_1$ (raised bed, silver mulch and two stem training) and 6.04 fruits per cluster in $P_1M_1T_2$ (raised bed, black mulch and three stem training). Minimum number of fruits per cluster (4.29) was recorded when the plants were raised on flat bed with no mulch and three stem training ($P_2M_3T_2$).

Table 4.6 Effect of P × M × T interaction on number of fruits per cluster and days to marketable maturity in tomato crop

Treatment combination	Number of fruits per cluster			Days to marketable maturity		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	6.01	7.01	6.51	70.40	67.32	68.86
$P_1M_1T_2$	5.65	6.42	6.04	71.93	72.85	72.39
$P_1M_2T_1$	5.76	6.69	6.23	71.67	70.78	71.22
$P_1M_2T_2$	5.55	6.21	5.88	73.13	74.43	73.78
$P_1M_3T_1$	4.84	5.36	5.10	80.93	81.18	81.06
$P_1M_3T_2$	4.61	5.26	4.94	81.27	82.51	81.89
$P_2M_1T_1$	5.46	5.91	5.69	74.47	74.86	74.66
$P_2M_1T_2$	5.19	5.38	5.29	75.93	76.86	76.40
$P_2M_2T_1$	5.28	5.76	5.52	75.87	75.87	75.87
$P_2M_2T_2$	5.28	5.76	5.52	75.87	75.87	75.87
$P_2M_3T_1$	5.15	5.32	5.24	76.20	77.09	76.65
$P_2M_3T_2$	4.09	4.49	4.29	87.20	86.46	86.03
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

More number of fruits per cluster could be due to better drainage in raised beds as compared to ground bed. Locher *et al.* (2003) stated that raised beds have more exposed surface area for absorbance of sunlight which leads to the differences in the soil or root zone temperature as compared to the air temperature of the plant during the beginning period of the plant. All these are related to enhance the metabolic activities within the plant cell thereby leading to more number of flowers per cluster consequently more fruits per cluster which ultimately increases the yield of tomato. Another reason could be that in raised beds, stabilization of soil will be more due to less soil compaction, better drainage, decreased weed population and better care of the crop stand. Bahadur *et al.* (2013) also narrated that better soil aeration and light interception in raised bed planting have contributed to improved plant growth and yield.

Flower per cluster helps to estimate the potential of fruit set per cluster for a particular treatment. Mulch surface allows more photosynthetic activity of the plants. Lamont (1999) reported that mulches ameliorated soil hydrothermal regime, improved vegetative growth, advanced flowering and higher number of fruits per cluster in tomato plants as compared to the plants grown on bare soil. Another possible reason could be that black colour absorbs

more solar radiations. Studies conducted by Bhujbal *et al.* (2015) revealed that maximum temperature was recorded under black polythene mulch as a result of which mulch had least competition from weeds and uniform moisture conservation throughout the growing season might be responsible for better performance leading to higher flowering and fruiting per cluster, hence plants took minimum days to flowering. Ravinder *et al.* (1997) also reported that mulching significantly improved the number of fruits per cluster and per plant. According to them, mulching reduced the percentage of fruit abortion thereby leads to increased fruit yield per plant also. The higher number of fruits per cluster in tomato plant might be the effect of polyethylene mulch leading to increased soil temperature, soil moisture and greater nutrient uptake also. Decoteau *et al.* (1988), Rahman *et al.* (2006) and Angmo *et al*. (2018) in tomato recorded the highest number of fruits per cluster using black polyethylene mulch in tomato production.

Number of fruits per cluster is an indication of more yield per plant and is generally dependent on better fruit set. Fruit setting in tomato is optimum, if agro techniques are employed effectively. The possible reason may be that exposing plants to more sunlight resulted in more fruits due to increased cell division and cell elongation. Yadav *et al.* (2017) also recorded maximum number of fruits per plant (86.59) and number of fruits per clusters (5.50) in T_2 (double stem). Training the plants to three shoots resulted in significantly less number of fruits per plant than plants trained to two shoots. They narrated that it might be due to effective utilization of land, nutrients and sunlight. The findings of the present investigation are in conformity with findings of Dasgan and Abak (2003) in bell peppers, Ara *et al.* (2007) in tomato and Yadav *et al.* (2017) also in tomato.

4.1.4 Days to marketable maturity

Tomato is the main summer and rainy season vegetable crop of mid-hills of Himachal Pradesh. The early produce fetches premium prices in the markets of Northern Indian plains during off-season. Hence, the number of days to first pickings is of utmost importance. Therefore, any technique that can improve fruit quality and early yield is the need of the hour. The agro techniques and cultural practices that promote early fruiting are considered desirable. Days to marketable maturity is an important character and is well known pointer of maturity period in tomato. Earliness leads to early supply of the produce in the market and enable it to fetch remunerative prices.

The data recorded on number of days taken to marketable maturity have been presented in table 4.4 (Pooled data). A perusal of the data revealed that minimum numbers of days (74.87) to marketable maturity were taken when the plants were grown on raised bed (P_1) as compared to those which were raised on flat bed (P_2). Similar trend was followed during both the years of study. Regarding application of mulches, the plants raised on black mulch (M_1) took minimum (73.08) number of days to marketable maturity. This treatment was significantly superior over M_2 (silver/black), which took 74.38 days to marketable maturity. Similar trend was followed during both the years of study. On the other hand, the plants produced without mulch took 83.97 days to marketable maturity. Regarding the effect of different training systems, again significant results were observed (2018-19 and pooled data) and minimum (76.29) number of days was recorded when the plants were trained on two stem (T_1) while, the plants trained on three stem (T_2) took more (77.99) number of days to marketable maturity. Non significant results were obtained during the year 2017-2018 of the study for training system. Similar trend was observed during both the years of study.

Regarding two way interaction of P × M (planting methods and mulching treatments), the data presented in table 4.5 (pooled data) revealed non-significant differences. Minimum number of days (70.63) was, however, recorded when the plants were grown on raised bed with black mulch (P_1M_1) and maximum (86.46) number of days when the plants were produced on flat bed without mulch (P_2M_3). Similarly, non significant differences (pooled data and 2017-2018) were also observed in M × T interaction (mulching treatments and training systems), whereas, significant results were obtained during the year 2018-2019. Pooled analysis of data revealed that minimum (71.76) number of days to marketable maturity was recorded when the plants were produced on black mulch with two stem training system (M_1T_1). Maximum (84.36) numbers of days was, however, recorded in the plants which were raised without mulch along with three stem training system (M_3T_2). Similarly, P × T interaction (planting methods and training system) did not vary significantly for number of days to marketable maturity (pooled data and 2017-2018), however, the results were significant for the year 2018-2019. Pooled analysis of data showed that minimum number (73.71) of days to marketable maturity were observed, when the plants were grown on raised bed and trained to two stem (P_1T_1) whereas, P_2T_2 (flat bed with three stem training) took maximum number (79.96) of days to marketable maturity.

Regarding the three way interaction (pooled data) P × M × T (planting methods, mulching treatments and training systems), data presented in table 4.6 showed non significant

Plate 9. General view of tomato crop grown on flat bed with black plastic mulch and two stem training system

variations among different treatment combinations. Minimum number (68.86) of days to marketable maturity was recorded in $P_1M_1T_1$ (raised bed, black mulch and two stem training system) interaction and maximum number (86.03) of days to marketable maturity was recorded in the plants grown on flat bed without mulch along with three stem training system ($P_2M_3T_2$).

According to Locher *et al.* (2003), it might be due to the reason that raised beds are commonly used to improve soil warming because of more exposed surface area for sunlight penetration and absorbance of more radiations which could create a significant difference in soil temperature especially in the root zone of the plants resulting into the enhancement of metabolic activities which further resulted into the completion of vegetative phase early and enters in reproductive phase which means early flowering which promotes the plant to take less number of days to harvest the fruits. Raised bed facilitate the drainage in high rainfall areas, provides channels for furrow irrigation and warm the soil faster in order to take the advantage of early market (Bracy *et al.*, 1993 and Wilkes and Hobgood, 1969). Raised bed stores more plant-available water for early growth and development of the crop, thereby increases the production (Hamilton *et al*., 2000). It can also be attributed to better assimilation of micro and macro nutrients by the plants, prevention of soil compaction and plant damage by reduced trafficking.

Days to marketable maturity is an important character and is well known indicator of maturity period in tomato. Earliness leads to early supply of the produce to the market and it enable to fetch remunerative prices. An early maturity is probably due to maintenance of favourable temperature during growing season. Black mulch applied to the planting bed prior to planting will warm up the soil and promote faster growth in early season, which generally leads to earlier harvest (Tarara, 2000 and Lamont, 2005). Black polythene mulch induces earliness in flowering and take less number of days to fruit set and harvest in tomato crop over unmulched plots. Beneficial effect of polyethylene mulch on early harvest and higher yield was also reported for watermelon, zucchini, tomato and pepper by Romic *et al.* (2003), Walters (2003) and Hutton and Handley (2007). Therefore, in the present study, the marketable fruit maturity under black polythene mulch was due to better uptake of nutrients and better growth of plants as a result of maintenance of favourable temperatures (high photosynthetic activity) and conservation of moisture during growing season which helped in early flowering, early fruiting and fruit ripening. Another reason was that fruits ripe quicker

in black mulched plots (83.2 days) because of increase in the soil temperature and this process thereby contributed to the absorption and transfer of minerals to the plant through its roots. Black mulch therefore contributed to shortened the growing season and enhanced earliness and yield. Black and Greb (1962), presented evidence in support of an increased efficiency of water and fertilizers use by tomato plants under black polythene mulch. These findings are in agreement with Baki and Spence (1992) in field tomatoes, Bhujbal *et al.* (2015) in tomato, Basamma and Shanmugasundaram (2016) in hybrid tomato, Singh *et al.* (2017) in tomato and Kumari *et al.* (2018) in tomato also.

It might be because of availability of sufficient nutrients and light to the plant due to two stem training that resulted in accumulation of maximum photosynthates and induction of early flowering and early harvest as compared to three stem training system which enhanced better growth and development of the tomato fruit. The findings are also in agreement with those of Singh *et al.* (2017) in tomato who found that early fruit setting coupled with exposure of fruits to sunlight and aeration which could be the reason for early picking in plants pruned to two stems. The present results are also in agreement with the findings of Yadav *et al.* (2017) in tomato. Another possible reason could be that two stem training avoids overcrowding means improves air circulation through the plants and competition among the stems, thus helps in avoiding poor fruit set and delayed maturity. Therefore, it was clear from the above said statements that high temperatures before harvesting in two stem trained plants because of more sunlight penetration induced ripening as the fruits approached towards maturity. The results are also in line with the reports of Alam *et al.* (2016) in tomato. According to them, it might be due to higher number of active leaves that continue photosynthetic activity which regulates the plant to early harvest in two stem trained plants as compared to the three stem trained plants.

4.1.5 Number of fruits per plant

Number of fruits per plant is an important character since it directly influence yield per unit area. More the number of marketable fruits per plant, more will be the yield and hence, give better returns. Therefore, higher number of fruits per plant and optimum size are desirable.

A perusal of data in Table 4.7 (pooled data) revealed that there were significant effect of different planting methods, mulches and training systems on number of fruits per plant

during both the years of study. Pooled analysis of data presented in Table 4.7 shows significant effects of planting methods. Maximum values (38.89) were obtained in the plants produced by the plants grown on the raised bed (P_1) as compared to 36.55 number of fruits produced on flat bed (P_2). Similarly, more number of fruits (39.22) was produced when the plants were raised with black polythene mulch (M_1) which was significantly more (38.72) in the plants produced with silver/black mulch (M_2) and minimum (35.22) in those plants which produced where no mulch (M_3) was used. Same trend was followed in the training systems and significantly more (38.31) number of fruits were produced when the plants were trained with two stem training system (T_1) as compared to those (37.13) which were produced with three stem training system (T_2).

Table 4.7 Effect of planting methods, mulches and training systems on number of fruits per plant and fruit length of tomato

Treatments	Number of fruits per plant			Fruit length (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	38.91	38.87	38.89	4.61	4.83	4.72
P_2	36.96	36.13	36.55	4.33	4.44	4.39
$CD_{0.05}$	**0.28**	**0.36**	**0.22**	**NS**	**NS**	**0.08**
Mulches (M)						
M_1	39.24	39.20	39.22	4.64	4.96	4.80
M_2	38.80	38.63	38.72	4.59	4.72	4.65
M_3	35.77	34.67	35.22	4.18	4.23	4.20
$CD_{0.05}$	**0.34**	**0.44**	**0.27**	**NS**	**NS**	**0.10**
Training Systems (T)						
T_1	38.48	38.14	38.31	4.52	4.77	4.65
T_2	37.40	36.86	37.13	4.41	4.50	4.46
$CD_{0.05}$	**0.28**	**0.36**	**0.22**	**NS**	**NS**	**0.08**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Analysis of data for two way interactions (pooled data) in Table 4.8 for P × M (planting methods and mulching treatments) showed more (40.76) number of fruits which was produced in P_1M_1 (raised bed with black mulch) which produced non significant effects with P_1M_2 (raised bed with silver/black mulch) producing 40.19 number of fruits. This treatment combination i.e. P_1M_2 was significantly superior over P_2M_1 (flat bed and black mulch) which produced non significant effects with P_2M_2 (flat bed with silver/black mulch). Minimum values (34.72) of number of fruits per plant were observed in treatment

combination P_2M_3 (flat bed without mulch). However, the results during individual years were non-significant. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant differences and maximum values (40.01) were recorded in M_1T_1 (black mulch with two stem training system) which was significantly better than other treatment combinations. Minimum (34.97) number of fruits was` however, recorded when the plants were raised without mulch and trained to three stem training system (M_3T_2). The effects of various interactions pertaining to planting method and training systems (P × T) were also found to be non significant. Data pertaining to different years did not produce significant differences regarding M × T interaction (pooled data and individual years Table 4.8). Maximum values (39.50) being recorded when the plants were produced on raised bed and trained to two stem training system (P_1T_1). There was no significant effect of different treatment combinations pertaining to raised bed and training systems on number of fruits per plant and minimum (35.98) number of fruits per plant was recorded in the plants grown on flat bed with three stem training system (P_2T_2). Same trend was observed during both the years of study.

Table 4.8 Effect of two way interactions P × M, M × T and P × T on number of fruits per plant and fruit length of tomato

Treatment combination	Number of fruits per plant			Fruit length (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	40.51	41.01	40.76	4.82	5.25	5.03
P_1M_2	39.89	40.49	40.19	4.76	4.91	4.83
P_1M_3	36.35	35.10	35.72	4.25	4.32	4.28
P_2M_1	37.97	37.38	37.68	4.46	4.67	4.56
P_2M_2	37.72	36.77	37.25	4.43	4.53	4.48
P_2M_3	35.20	34.24	34.72	4.10	4.14	4.12
$CD_{0.05}$	**0.48**	**0.63**	**0.38**	**NS**	**NS**	**0.13**
M_1T_1	39.97	40.06	40.01	4.71	5.17	4.94
M_1T_2	38.50	38.34	38.42	4.57	4.75	4.66
M_2T_1	39.33	39.54	39.43	4.67	4.88	4.77
M_2T_2	38.28	37.72	38.00	4.51	4.56	4.54
M_3T_1	36.13	34.82	35.48	4.20	4.25	4.23
M_3T_2	35.42	34.52	34.97	4.15	4.20	4.18
$CD_{0.05}$	**NS**	**NS**	**0.38**	**NS**	**NS**	**0.13**
P_1T_1	39.52	39.47	39.50	4.64	5.01	4.83
P_1T_2	38.31	38.26	38.28	4.58	4.64	4.61
P_2T_1	37.44	36.80	37.12	4.41	4.52	4.46
P_2T_2	36.49	35.46	35.98	4.25	4.37	4.31
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Regarding the three way interaction P × M × T (planting methods, mulching treatments and training systems), as depicted in Table 4.9, maximum (41.64) number of fruits was recorded in the plants grown on raised bed with black polythene mulch and two stem training system ($P_1M_1T_1$) followed by those grown on raised bed with silver/black mulch and two stem training system ($P_1M_2T_2$). Minimum number of fruits (34.55) was, however, recorded in those plants which were raised on flat bed without mulch and three stem training system ($P_2M_3T_2$). The results pertaining to individual years were reported to be non significant.

It might be due to the reason that raised beds are commonly used to improve soil warming and drainage and to decrease disease incidence. Accordingly the possible reason could be due to increased number of fruits in the covered raised bed treatment set favourable root zone temperature than in the flat bed. Kumar *et al.* (2001) also showed that growing tomato on raised bed increased number of fruits per plant. The results are in line with the findings of Kumar *et al*. (2001) in tomato, Locher *et al.* (2003) in sweet pepper and Bahadur *et al.* (2013) in tomato. The benefits of raised bed planting system includes water saving combined with water use efficiency, improvement of soil physical status and nitrogen use efficiency, better utilization of sunlight, low crop weed competition and enhancement in yield and yield related attributes also (Zhang *et al.,* 2008 and Kumar *et al.,* 2010).

Table 4.9 Effect of P × M × T interaction on number of fruits per plant and fruit length of tomato

Treatment combination	Number of fruits per plant			Fruit length (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	41.46	41.81	41.64	4.84	5.63	5.24
$P_1M_1T_2$	39.55	40.21	39.88	4.79	4.87	4.83
$P_1M_2T_1$	40.25	41.34	40.80	4.81	5.07	4.94
$P_1M_2T_2$	39.53	39.63	39.58	4.70	4.74	4.72
$P_1M_3T_1$	36.85	35.27	36.06	4.27	4.33	4.30
$P_1M_3T_2$	35.85	34.93	35.39	4.24	4.30	4.27
$P_2M_1T_1$	38.48	38.30	38.39	4.57	4.71	4.64
$P_2M_1T_2$	37.45	36.47	36.96	4.35	4.62	4.49
$P_2M_2T_1$	38.41	37.74	38.07	4.53	4.68	4.60
$P_2M_2T_2$	38.41	37.74	38.07	4.53	4.68	4.60
$P_2M_3T_1$	37.03	35.80	36.42	4.32	4.37	4.35
$P_2M_3T_2$	34.99	34.10	34.55	4.07	4.10	4.09
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Helaly *et al*. (2017) also recorded highest number of fruits per plant in the polythene mulched raised plants. It was due to the promotion effect of the polythene mulch on the yield characters of husk tomato plants including the number of fruits per plant, early yield per plot, total yield per plant and per plot. It may be due to low weed population, causing a reduction in competition for nutrients and partly for a better water availability due to moisture conservation by mulching (Shrivastava *et al.,* 1994). Moreover, Mulching increased growth and fruit yield of tomato through modification of the crop growing environment by reducing weed infestation, soil moisture depletion and ameliorating soil temperatures (Awodoyin *et al.,* 2007). On the other hand, it was reported that mulch could improve leaf photosynthetic capacity beside the role of polyethylene for enhanced root growth, as well as absorption of water and nutrients and thereby enhanced metabolic activities within plant during the period of growth and reproduction, which possessed more shoot number per plant, greater leaf area with high leaf chlorophyll content and consequentely more photosynthetic rates. This in turn built high yield of carbohydrates which gave rise to more cell division and enlargement inducing more vegetative vigorous plants producing more total yield in terms of number of fruits as mentioned. Our results are in agreement with those of Locher *et al.* (2003) in sweet pepper, and Rajablariani *et al.* (2012) in tomato. Ashrafuzzaman *et al.* (2011) in chilli also reported increase in the number of fruits per plant of mulched plots probably due to conservation of moisture and improved microclimate both inside and above the soil surface. These suitable conditions enhanced the plant growth and development and produced increased fruit bearing nodes compared to the control. It was clear from their study that fruit number was strongly related to soil moisture content. The present results are also in conformity with the findings of Diaz-Perez (2010) in chilli, Bhujbal *et al.* (2015) in tomato and Angmo *et al.* (2018) in tomato. Another possible reason could be that the black polythene mulch had least competition from weeds as higher temperature under the mulch affected weed growth adversely and uniform moisture conservation throughout the growing season might be responsible for better performance leading to higher flowering and fruiting (Bhujbal *et al.,* 2015).

According to our opinion, two stem training reduces the competition amongst fruits for sunlight and photosynthates as compared to the three stem training system. Marim *et al.* (2005), Ara *et al.* (2007) and Charlo *et al.* (2009) also reported a greater number of fruits on plants of tomato with two stem system of training as compared to other treatments. The

greater number of productive inflorescences in two stem training system could be the reason for higher number of fruits per plant.

Yadav *at al.* (2017) also reported maximum number of fruits per plant (86.59) in double stem training system because the fruits contained higher level of carbohydrates and soluble compounds. Another possible reason could be that in two stem pruned plants, the photosynthetic efficiency will be more because of ample sunlight and better aeration thus less chances of diseases and higher marketable fruits per unit area. Anand *et al.* (2018) also noticed that two stem training system also recorded significant and maximum fruit yield per hectare over other levels of training systems. This is attributed to the presence of higher number of fruits per plant and average fruit weight resulting into highest fruit yield per plant and ultimately yield per plot under two stem systems in tomato. Similar findings were also observed by Maboko *et al.* (2011) and Ansari *et al.* (2017) in tomato crop.

FRUIT SIZE

The size and shape of fruit are important cultivar traits of any vegetable crop which are predominantly determined by genetic character, but can be greatly influenced by different cultivation practices including planting methods, mulching and training systems. The fruit length, breadth and pericarp thickness determine the fruit size. Fruit shape and size account for the marketable quality of fruits. Generally round to slightly oblong fruits are preferred by the consumers, hence, fruit size is a critical factor in tomato.

4.1.6 Fruit length (cm)

Pooled analysis of data (Table 4.7) showed that there was a significant effect of planting methods, mulching treatments and training systems on fruit length whereas, non significant results were found during the year 2017-2018 and 2018-2019. Maximum values (4.72 cm) of fruit length were measured in P_1 (raised bed), while minimum 4.39 cm in P_2 (flat bed). Regarding the effect of mulches, again significant variations were observed. Maximum (4.80 cm) fruit length was measured when the plants were raised on black mulch (M_1), which were significantly superior (4.65 cm) over M_2 (silver/black mulch). Minimum values (4.20 cm) of fruit length was measured in fruits produced by the plants grown without mulch (M_3). Regarding the effect of training systems, again significant differences were observed and maximum (4.65 cm) fruit length was recorded in two stem trained (T_1) plants followed by

those which were trained with three stem (T_2) training system. Same trend was observed during both the years of study.

Pooled analysis of data (Table 4.8) showed the effect of various interactions on fruit length which was found to be significant for planting methods and mulching treatments (P × M) and also for mulching treatments and training systems (M × T) but non significant results were obtained for planting methods and training systems (P × T). There was no effect of various interactions on fruit length during the year 2017-2018 and 2018-2019. Maximum fruit length (5.03 cm) was observed in plants grown on raised bed with black mulch (P_1M_1). This treatment (P_1M_1) was found to be significantly superior (4.83 cm) over P_1M_2 (raised bed with silver/black mulch) and also with all other treatment combinations, while minimum (4.12 cm) in those plants which were grown on flat beds without mulch (P_2M_3) application. Similarly, the plants grown on black mulch and trained to two stem training system (M_1T_1) produced fruits of maximum (4.94 cm) length and this treatment combination was significantly superior over M_2T_1 (4.77 cm), whereas, M_2T_1 found non significant differences with M_1T_2 (plants grown on black mulch and trained to three stem training system). Minimum fruit length (4.18 cm) was observed in plants which were grown on raised bed with black mulch (P_1M_1). The pooled data (Table 4.8) on the effect of P × T interactions indicated maximum fruit length (4.83 cm) in the plants grown on raised bed with two stem training system (P_1T_1), while minimum (4.31 cm) fruit length was measured in those plants which were raised on flat bed and trained to three stem training (P_2T_2). Same trend was followed during 2017-2018 and 2018-2019 in all the treatment combinations.

Regarding the three factor interaction (Table 4.9) again non significant differences were observed on fruit length, though maximum (5.24 cm) fruit length was recorded in fruits harvested from plants grown on raised bed with black mulch and two stem training system ($P_1M_1T_1$), while minimum (4.09 cm) values of fruit length were observed in fruits harvested from plants raised on flat bed without mulch and three stem training system ($P_2M_3T_2$). Same trend was followed during both the years of study.

4.1.7 Fruit breadth (cm)

Pooled analysis of data (Table 4.10) showed that there was a significant effect of planting methods, mulching treatments and training systems on fruit breadth. Maximum values (5.32 cm) of fruit breadth were recorded in P_1 (raised bed), while minimum 4.96 cm in

P_2 (flat bed). Regarding the effect of mulches, again significant variations were observed. Maximum (5.43 cm) fruit breadth was measured when the plants were raised on black mulch (M_1) which observed non significant differences (5.33 cm) with M_2 (silver/black mulch). Minimum values (4.67 cm) of fruit breadth was measured without mulch (M_3). Regarding the effects of training levels, again significant differences were observed and maximum (5.26 cm) fruit breadth was recorded in fruits produced for two stem trained (T_1) plants followed by those which were raised on three stem (5.02 cm). Same trend was observed during both the years of study.

Pooled analysis of data (Table 4.11) showed the effect of various interactions on fruit breadth which was found to be non significant for planting methods and mulching treatments (P × M), mulching treatments and training systems (M × T) as well as for planting methods and training systems (P × T).

Regarding the three factor interactions (Table 4.12), again non significant differences were observed on fruit breadth, though maximum (5.75 cm) fruit breadth was recorded in plants grown on raised bed with black mulch and two stem training system ($P_1M_1T_1$), while minimum (4.34 cm) values of fruit breadth were observed in plants raised on flat bed without mulch and three stem training system ($P_2M_3T_2$). Same trend was followed during both the years of study.

Table 4.10 Effect of planting methods, mulches and training systems on fruit breadth and pericarp thickness of tomato

Treatments	Fruit breadth (cm)			Pericarp thickness (mm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	5.30	5.34	5.32	4.62	4.79	4.71
P_2	4.96	4.96	4.96	4.37	4.56	4.47
$CD_{0.05}$	**0.08**	**0.12**	**0.08**	**0.05**	**0.07**	**0.04**
Mulches (M)						
M_1	5.41	5.44	5.43	4.69	4.83	4.76
M_2	5.32	5.35	5.33	4.62	4.75	4.69
M_3	4.67	4.67	4.67	4.18	4.44	4.31
$CD_{0.05}$	**0.10**	**0.15**	**0.10**	**0.06**	**0.08**	**0.05**
Training Systems (T)						
T_1	5.26	5.26	5.26	4.56	4.74	4.65
T_2	5.00	5.04	5.02	4.43	4.61	4.52
$CD_{0.05}$	**0.08**	**0.12**	**0.08**	**0.05**	**0.07**	**0.04**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

4.1.7 Pericarp thickness (mm)

Pooled analysis of data (Table 4.10) showed that there was a significant effect of planting methods, mulching treatments and training systems on pericarp thickness. Maximum values (4.71 mm) of pericarp thickness were measured in P_1 (raised bed), while minimum 4.47 mm in P_2 (flat bed). Regarding the effect of mulches, again significant variations were observed. Maximum (4.76 cm) pericarp thickness was measured when the plants were raised on black mulch (M_1), which was significantly better (4.69 cm) over M_2 (silver/black mulch). Minimum value (4.31mm) of pericarp thickness was measured without mulch (M_3). Regarding the effect of training levels, again significant differences were observed and maximum (4.65 mm) pericarp thickness was recorded in fruits harvested from two stem trained (T_1) plants followed by those which were harvested from fruits trained to three stem (T_2). Same trend was observed during both the years of study.

Pooled data presented in Table 4.11 showed the effect of various interactions on pericarp thickness which was found to be significant for planting methods and mulching treatments (P × M), while non significant variations were found for mulching treatments and training systems (M × T) as well as for planting methods and training systems (P × T). Maximum pericarp thickness (4.92 mm) was observed in the fruits harvested from the plants grown on raised bed with black mulch (P_1M_1) which was significantly (4.85 cm) followed by P_1M_2 (raised bed and silver/black mulch), while minimum (4.26 mm) pericarp thickness was recorded in those fruits harvested from the plants grown on flat bed without mulch (P_2M_3). Same trend was observed for both the years of study. Similarly, the plants grown on black mulch and trained to two stem training system (M_1T_1) produced fruits of maximum (4.85 mm) pericarp thickness and this treatment combination was significantly superior (4.75 cm) over M_2T_1 (silver/black mulch with two stem training). Minimum pericarp thickness (4.20 mm) was observed in plants when grown without mulch and three stem training system (M_3T_2). The pooled data (Table 4.11) on the effect of P × T interactions indicates maximum pericarp thickness (4.76 mm) in the fruits harvested from the plants grown on raised bed with two stem training system (P_1T_1), while minimum (4.39 mm) pericarp thickness was measured in those fruits harvested from plants which were raised on flat bed and trained to three stem training (P_2T_2). Same trend was followed during 2017-2018 and 2018-2019 in all the treatment combinations.

Regarding the three factor interactions (Table 4.12), again non significant differences were observed on pericarp thickness, though maximum (4.99 mm) pericarp thickness was recorded in plants grown on raised bed with black mulch and two stem training system ($P_1M_1T_1$), while minimum (4.21 mm) values of pericarp thickness were observed in fruits harvested from plants raised on flat bed, without mulch and three stem training system ($P_2M_3T_2$). Same trend was followed during both the years of study.

Table 4.11 Effect of two way interactions P × M, M × T and P ×T on fruit breadth and pericarp thickness of tomato

Treatment combination	Fruit breadth (cm)			Pericarp thickness (mm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	5.59	5.64	5.62	4.86	4.98	4.92
P_1M_2	5.49	5.55	5.52	4.78	4.92	4.85
P_1M_3	4.83	4.84	4.84	4.22	4.49	4.35
P_2M_1	5.23	5.23	5.23	4.52	4.69	4.60
P_2M_2	5.14	5.16	5.15	4.47	4.59	4.53
P_2M_3	4.50	4.50	4.50	4.13	4.39	4.26
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.08**	**0.12**	**0.07**
M_1T_1	5.54	5.53	5.54	4.79	4.92	4.85
M_1T_2	5.29	5.34	5.46	4.59	4.75	4.67
M_2T_1	5.44	5.48	4.79	4.70	4.81	4.75
M_2T_2	5.20	5.22	5.32	4.55	4.70	4.63
M_3T_1	4.80	4.78	5.21	4.21	4.50	4.35
M_3T_2	4.53	4.57	4.55	4.14	4.38	4.26
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
P_1T_1	5.43	5.46	5.44	4.66	4.87	4.76
P_1T_2	5.18	5.23	5.21	4.58	4.72	4.65
P_2T_1	5.09	5.06	5.08	4.47	4.62	4.54
P_2T_2	4.82	4.86	4.84	4.28	4.50	4.39
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.07**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The fruit size and shape are important traits, which are predominantly determined by genetic factors, but can be greatly influenced by different cultivation practices including planting methods, mulching and training systems. The fruit length, fruit breadth and pericarp thickness determine the fruit size. Fruit shape and size account for the marketable quality of fruits. Generally, round to slightly oblong fruits are preferred by the consumers, hence, fruit size is a critical factor in tomato.

The advantages of raising the crops over the raised beds is well known. According to Hatterman-Valenti and Hendrickson (2006), the improved drainage specially in high rainfall

areas, along with quick warming of the soil could attribute to increased size of the bulbs of onion. Kumar *et al.* (2001) has also shown that growing tomato on raised bed increased mean fruit weight, fruit diameter, number of fruits, yield per plant and marketable yield compared to planting on flat beds. Similarly, Cavero *et al.* (1996) also observed increased yield of peppers when grown on raised bed. Arvidsson *et al.* (1999) linked increase in fruit size and other related characters to easy assimilation of macro and micronutrients, more developed root system caused by tillage and greater nutrients availability. Nicoletto *et al.* (2016) also narrated the increase in number of leaves of lettuce grown on raised bed due to better assimilation of micronutrients especially phosphorus. According to Ram *et al*. (2005), raised bed planting system changes the hydrology of the system and allows greater control of irrigation, better surface drainage and possibly better capture and use of rainfall. Another possible reason could be the prevention of soil compaction and reduced trafficking responsible for the increased fruit size of tomato crop. The present results are in agreement with the earlier work carried out by Kumar *et al.* (2015) and Bahadur *et al.* (2013) in tomato. Modification of soil microclimate, availability of sufficient soil moisture, better nutrients uptake and less crop-weed competition for water and nutrients under mulch coupled with better soil aeration and light interception in raised bed planting have contributed to improved plant growth, enhanced photosynthetic activity leading to better source to sink ratios, better assimilates production in the fruits and increased fruit size and yield.

Table 4.12 Effect of P × M × T interaction on fruit breadth and pericarp thickness of tomato

Treatment combination	Fruit breadth (cm)			Pericarp thickness (mm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	5.74	5.76	5.75	4.92	5.06	4.99
$P_1M_1T_2$	5.45	5.53	5.49	4.80	4.90	4.85
$P_1M_2T_1$	5.63	5.70	5.67	4.81	4.98	4.90
$P_1M_2T_2$	5.35	5.39	5.37	4.74	4.85	4.80
$P_1M_3T_1$	4.91	4.92	4.91	4.24	4.56	4.40
$P_1M_3T_2$	4.75	4.77	4.76	4.19	4.42	4.31
$P_2M_1T_1$	5.34	5.30	5.32	4.65	4.77	4.71
$P_2M_1T_2$	5.12	5.16	5.14	4.38	4.60	4.49
$P_2M_2T_1$	5.24	5.26	5.25	4.58	4.63	4.61
$P_2M_2T_2$	5.24	5.26	5.25	4.58	4.63	4.61
$P_2M_3T_1$	5.04	5.04	5.05	4.36	4.55	4.46
$P_2M_3T_2$	4.31	4.37	4.34	4.09	4.33	4.21
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

It might be due to maintenance of soil temperature under black polythene mulch which could possibly be responsible for increased fruit size and yield in tomato (Bhella and Kwolek, 1984 and Taber, 1983). Baki and Spence (1992) also presented the similar evidence in support of increase in fruit size of field tomatoes. The increased fruit size by using black polythene mulch has also been shown by Ashrafuzzaman *et al.* (2011) in chilli. According to them it could be due to conservation of moisture and improved microclimate both beneath and above the soil surface. Thus the suitable conditions created by these factors enhance the plant growth and development, increase fruit bearing nodes which ultimately result into fruit size, number of fruits and fruit yield. Edgar *et al.* (2016) in green pepper also narrated that conservation of appropriate moisture due to lower evaporative losses might be responsible for increased fruit length. Similarly, Alabi *et al.* (2006) reported that the increase in the number of leaves would also increase photosynthetic surface and more photosynthates which would enhance the physiological activity leading to production of more assimilates used to significantly increase the fruit production, fruit size and fruit diameter when the plants were raised under black polythene mulch. Higher fruit length and fruit size by using black polythene mulch has also been recorded by Belel (2012) in pepper. They stated that it might be due to varying soil moisture regimes which ultimately caused conservation of much soil moisture due to low evaporative losses than the grass mulched and unmulched plots. Nagalakshmi *et al.* (2002) obtained maximum number of fruits per plant (97.67), length of fresh fruit (6.93 cm), circumference of fruit (3.57 cm) and yield of chilli (8.60 t/ha) with the application of black LLDPE mulch compared to organic mulch and no mulch. They attributed this effect due to alteration of soil temperature, optimum crop water use, improved crop quality and better control of weeds thereby improving the crop development and increased yield. They further narrated that other possible reasons could be the warming up of soil by absorbing the light energy and then transferring the heat by conduction method to the underlying soil provided that the mulch is in the close contact with the soil. Similar finding were reported also by Manriques (1995), Locher *et al.* (2003) and Helaley *et al.* (2017) who showed that mulches enhanced crop production through soil water conservation and weed control in chilli, bell pepper and tomato crops.

Kamboj and Sharma (2015) in bell pepper stated that two stem training system significantly increased the fruit size. This could be due to higher source to sink ratio. A sufficient amount of assimilates were available for young fruits in double shoot plants, but the reverse situation was under triple shoot, where sink to source ratio was high. So, due to

more sink the assimilates availability was low and it has direct effect on the size of fruit. Alam *et al.* (2016) also obtained the greater fruit size i.e. fruit length, fruit breadth and pericarp thickness in summer tomato in olericulture farm of Ghazipur, Bangladesh. According to them, staking the plant with string and training those to two shoots provided better aeration and better exposure of the foliage to sunlight that enhanced photosynthetic activities, which might be responsible for larger fruit size. While competition for assimilates among the fruits in unpruned plants resulted in smaller sized fruits. Similar results for better fruit size using two stem training system in tomato have also been shown by Khoshkam *et al.* (2014) in tomato. According to them, in case of two stem trained plants, there would be less competition for assimilates among the fruits which leads to increased fruit size as compared to the three stem trained plants Fruit growth and yield are most other developmental processes, primarily dependent on temperature. The higher pericarp thickness under double shoot training may be due to higher physiological activity of two stem trained plants which resulted in more production and accumulation of photosynthates within the plant and ultimately increased the fruit size and pericarp thickness.

4.1. 9 Fruit weight (g)

Average fruit weight is the most important yield contributing character which has a key role in the acceptance of the produce for fresh market tomato.

Pooled analysis of data (Table 4.13) showed that there was a significant effect of planting methods, mulching treatments and training systems on fruit weight. Maximum values (77.98 g) of fruit weight were measured in P_1 (raised bed), while 75.90 g in P_2 (flat bed). Regarding the effect of mulches, again significant variations were observed. Maximum (78.52 g) fruit weight was measured in the fruits harvested from the plants raised on black mulch (M_1), which observed significant variations (77.83 g) with M_2 (silver/black mulch). Minimum values (74.48 g) of fruit weight was measured without mulch (M_3). Regarding the effect of training levels, again significant differences were observed and maximum (77.64 g) fruit weight was recorded in fruits harvested from two stem trained (T_1) plants followed by those which were harvested from three stem trained plants (T_2). Same trend was observed during both the years of study.

Pooled analysis of data (Table 4.14) also showed the effect of various interactions on fruit weight which was found to be non significant for all the interactions (planting methods and mulching treatments (P × M), mulching treatments and training systems (M × T) as well as for planting methods and training systems (P × T).

Table 4.13 Effect of planting methods, mulches and training systems on fruit weight and number of pickings in tomato

Treatments	Fruit weight (g)			Number of pickings		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	77.70	78.26	77.98	18.00	19.44	18.72
P_2	75.79	76.01	75.90	15.67	16.06	15.86
$CD_{0.05}$	**0.79**	**0.59**	**0.50**	**0.39**	**0.45**	**0.29**
Mulches (M)						
M_1	78.18	78.85	78.52	18.50	19.58	19.04
M_2	77.55	78.10	77.83	18.00	17.58	17.79
M_3	74.50	74.46	74.48	14.00	16.08	15.04
$CD_{0.05}$	**0.97**	**0.72**	**0.61**	**0.47**	**0.55**	**0.36**
Training Systems (T)						
T_1	77.40	77.89	77.64	17.39	18.89	18.14
T_2	76.09	76.38	76.24	16.28	16.61	16.44
$CD_{0.05}$	**0.79**	**0.59**	**0.50**	**0.39**	**0.45**	**0.29**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Regarding the three factor interactions (Table 4.15) again non significant differences were observed on fruit weight, though maximum (80.47 g) fruit weight was recorded in fruits produced on plants grown on raised bed with black mulch and two stem training system ($P_1M_1T_1$), while minimum (72.54 g) values of fruit weight were observed in fruits produced on plants raised on flat bed without mulch and three stem training system ($P_2M_3T_2$). Same trend was followed during both the years of study.

According to Locher *et al.* (2003), in raised bed treatment the average fruit weight was significantly higher than the flat bed. They were of the opinion that the main reason behind significantly maximum fruit weight in the fruits produced by raised bed treatment was the more favorable root zone temperature and drainage than in the flat bed. The absolute maximum temperature was highest in the raised bed which was probably due to higher and more exposed surface which could absorb more radiations. Therefore, the differences in soil temperature among the treatments were higher during the beginning of growing period when the foliage of the plant did not shadow considerably. Moreover, the improvement of soil characteristics in raised bed such as better porosity due to reduced soil compaction, improvement of soil temperature and conservation of soil moisture could be the other reasons

for increased fruit weight (Beecher *et al.* 2003). This could also be linked to easy assimilation of macro and micronutrients, reduced tillage and greater nutrients availability (Arvidsson, 1999). The present results are in accordance with the findings of Kumar *et al*. (2001) in tomato, Locher *et al.* (2003) in sweet pepper, Muriungi *et al.* (2014) in tomato, Kumar and Gill (2010) in turmeric, Alagoz and Ozer (2019) in tomato and Islam *et al.* (2018) in potato. Another possible reason could be that the raised beds have the potential to enable diversification and thus increases the yield. On the other hand, increased soil microorganism activity in raised bed planting system enhanced nitrogen fixation, mineralization and enzyme activity and ultimately increased yield and yield related attributes (Zhang *et al.*, 2012).

According to our opinion, main reason of significantly higher average fruit weight using black mulch treatment was due to more favorable root zone temperature conditions compared to unmulched plots. Helaly *et al.* (2017) also indicated that average fruit weight of husk tomato plants significantly increased by mulching rows with polythene. The promotion effect of polyethylene mulch on improving physical characters of husk tomato fruits may be attributed to the enhancement effect of polyethylene treatments (white on black) on vegetative growth, as well as on availability and uptake of both water and nutrients which reflected on increasing sufficient assimilation area and subsequently increased fruit weight, size, diameter, and firmness (Moursi, 2003). Similar finding were also reported by Manriques (1995) who showed that mulches enhanced crop production through soil water conservation and weed control. They also observed improved other biological, physical, and chemical properties of the soil such as bulk density, lower salinity level, oxygen diffusion rate, nutrient uptake, improve P nutrition and elevated soil CO_2 levels. Present results are in agreement with those obtained by Moursi (2003) and Kasirajan and Ngouajiand (2012) on pepper.

The results are in line with the findings of Locher *et al.* (2003) in bell pepper, Bhubal *et al.* (2015) in tomato and Gudugi *et al.* (2012) in tomato. They suggested that increased weight of fruit and yield under drip irrigation and black polythene mulch was due to better water utilization, higher uptake of nutrients and excellent soil-water-air relationship with higher oxygen concentration in root zone.

These findings are in agreement with those of Singh and Kamal (2012) and Gornat *et al.* (1973). As mulch films are nearly impervious to carbon dioxide which is necessary for photosynthesis, 'Chimney effect' might have been created resulting in abundant CO_2 for the plants which might have added higher plant growth, fruit weight and fruit yield grown under different plastic mulches.

Table 4.14 Effect of two way interactions P × M, M × T and P × T on fruit weight and number of pickings in tomato

Treatment combination	Fruit weight (g)			Number of pickings		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	79.39	79.99	79.69	20.00	21.17	20.58
P_1M_2	78.63	79.19	78.91	19.50	20.50	20.00
P_1M_3	75.09	75.60	75.34	14.50	16.67	15.58
P_2M_1	76.97	77.70	77.34	17.00	18.00	17.50
P_2M_2	76.48	77.00	76.74	16.50	14.67	15.58
P_2M_3	73.91	73.32	73.62	13.50	15.50	14.50
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.67**	**0.78**	**0.50**
M_1T_1	78.76	79.70	79.23	19.17	20.33	19.75
M_1T_2	77.61	77.99	77.80	17.83	18.33	18.33
M_2T_1	77.93	78.79	78.36	18.83	20.00	19.42
M_2T_2	77.18	77.41	77.29	17.17	15.17	16.17
M_3T_1	75.51	75.18	75.34	14.17	16.33	15.25
M_3T_2	73.49	73.74	73.61	13.83	15.83	14.83
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.67**	**0.78**	**0.50**
P_1T_1	78.26	79.02	78.64	18.56	20.22	19.39
P_1T_2	77.14	77.50	77.32	17.44	18.67	18.06
P_2T_1	76.53	76.76	76.64	16.22	17.56	16.89
P_2T_2	75.04	75.26	75.15	15.11	14.56	14.83
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**0.64**	**0.41**

Table 4.15 Effect of P × M × T interaction on fruit weight and number of pickings in tomato

Treatment combination	Fruit weight (g)			Number of pickings		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	80.11	80.82	80.47	20.67	22.00	21.33
$P_1M_1T_2$	78.68	79.17	78.92	19.33	20.33	19.83
$P_1M_2T_1$	79.17	79.76	79.47	20.33	21.67	21.00
$P_1M_2T_2$	78.08	78.63	78.35	18.67	19.33	19.00
$P_1M_3T_1$	75.51	76.49	76.00	14.67	17.00	15.83
$P_1M_3T_2$	74.67	74.70	74.69	14.33	16.33	15.33
$P_2M_1T_1$	77.40	78.59	77.99	17.67	18.67	18.17
$P_2M_1T_2$	77.14	76.82	76.68	16.33	17.33	16.83
$P_2M_2T_1$	76.69	77.81	77.25	17.33	18.33	17.83
$P_2M_2T_2$	76.69	77.81	77.25	17.33	18.33	17.83
$P_2M_3T_1$	76.28	76.19	76.23	15.67	11.00	13.33
$P_2M_3T_2$	72.31	72.77	72.54	13.33	15.33	14.33
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**1.10**	**0.71**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

The fact behind increased fruit weight is based on the assumption that developing fruits and vegetatively growing shoots are major synthate sinks and that by eliminating newly formed flowers, more assimilates will be directed to already growing fruits leading to increased fruit weight. Present findings are in conformity with the findings of Decoteau *et al.* (1988) in tomato, Baki and Spence (1992) in tomato, Elkner and Kaniszzewski (1995) in tomato, Mehta *et al.* (2010) in tomato, Ashrafuzzaman *et al.* (2011) in chilli, Locher *et al.* (2003) in sweet pepper, Bhujbal *et al*. (2015) in tomato, Subba Reddy *et al.* (2015) in tomato, Dishani and Silva (2016) in tomato, Khan *et al.* (2016) in chilli, Rahman *et al.* (2006) in tomato, Helaly *et al.* (2017) in tomato and Kumari *et al.* (2018) in tomato.

Average fruit weight is the most important yield contributing character which has a key role in the acceptance of the produce for fresh market tomato. Alam *et al.* (2016) also recorded higher mean fruit weight in two stem trained plants which could be attributed to various reasons. According to them the photosynthetic activities may be enhanced due to better exposure of the foliage to sunlight as a result, fruits accumulate higher assimilates which might be responsible for higher fruit weight in the plants trained to two stems. Their results are also in agreement with Kumar *et al.* (2001) who found increased mean fruit weight of tomato by staking. Ara *et al.* (2007) also noticed that removal of lateral branches resulted in increased fruit weight of tomato plants. The competition for assimilates among the fruits lead to reduced fruit size. Plants pruned to two stems resulted in significantly higher number and mass of large fruits compared to plants pruned to three stems, four stems and no pruning. The results of increased average fruit weight by pruning side shoots was in conformity with the findings of Cebula (1995) who also reported that the fewer shoots per plant produced heavier fruits in pepper. Another possible reason for increased fruit weight could be fewer branches per plant because the fruits contained higher levels of carbohydrates and other soluble compounds (Mantur and Patil, 2008 and De Pinho *et al.*, 2011). Candian *et al.* (2017) presented similar results during their study on tomato regarding the average fruit weight. They narrated that plants with 3 or 4 stems had more inflorescences and more fruits produced which resulted in lower average fruit weights as compared to plants with less stems. The greater number of productive inflorescences may have caused competition for the plant photo assimilates, causing a reduction in fruit diameter and average weight of fruit. One most important reason for higher mean fruit weight could be attributed to less photosynthates demanding shoots which resulted in partitioning of more dry matter to the fruits. Similar

results were reported earlier by Sowley and Damba (2013) and Muhammad *et al.* (2016) in tomato.

4.1.10 Number of pickings

In a multi harvest crop, more number of pickings has an additional advantage of increased yield, which ensures continuous supply of the fruits the market.

The data recorded on number of pickings have been presented in Table 4.13. A perusal of the data showed that the number of pickings taken during the year 2017-2018, 2018-2019 and pooled data follows the same trend. Significant results were obtained and P_1 (raised bed) recorded more (18.72) number of pickings. The black polythene mulch (M_1) recorded more number of pickings (19.04) followed by silver/black mulch (M_2) which recorded 17.79 number of pickings, whereas M_3 (no mulch) recorded minimum (15.04) number of pickings. Same trend was followed during 2017-2018 and 2018-2019. Regarding training systems, maximum (18.14) number of pickings was obtained in T_1 (two stem training) followed by T_2 (three stem training). Same trend was observed during both the years.

Regarding two way interactions (Table 4.14), again significant differences were observed in all the interactions except P × T during 2017-2018. The plants produced under raised bed with black mulch (P_1M_1) produced maximum (20.58) number of pickings followed by P_1M_2 (raised bed and silver/black mulch), P_2M_1 (flat bed and black mulch) treatment combinations which recorded 20.00 and 17.50 number of pickings, respectively and minimum (14.50) number of pickings was recorded when plants were raised on flat bed without mulch (P_2M_3). Similarly, plants raised on black mulch with two stem training (M_1T_1) produced 19.75 pickings which were significantly followed by M_2T_1 (19.42), M_1T_2 (18.33) and M_2T_2 (16.17), whereas, minimum (14.83) number of pickings was recorded in plants produced without mulch with three stem training (M_3T_2) which produced non-significant effects with M_3T_1 (no mulch and two stem training). On the other hand, 19.39 numbers of pickings were recorded in the plants grown on raised bed with two stem training (P_1T_1) followed by 18.06 pickings in P_1T_2 (raised bed and three stem training) and P_2T_1 (16.89).

The data on three way interaction P × M × T (planting methods, mulching treatments and training systems) have been presented in Table 4.15 which revealed significant results produced during the year 2018-2019 as well as when the data were pooled, but non-significant results were observed during 2017-2018. Maximum (21.33) number of pickings were recorded when the plants were grown on raised bed with black mulch and trained to two

stem training ($P_1M_1T_1$) which produced non-significant effects with $P_1M_2T_1$ (raised bed, silver/black mulch and two stem training system) producing 21.00 pickings. This treatment combination was followed by $P_1M_1T_2$ (19.83) and $P_1M_2T_2$ (19.00). Minimum number of pickings (13.33) was produced by the plants grown on flat bed without mulch and two stem training system ($P_2M_3T_1$).

In the present findings, maximum number of pickings were observed in plots treated with black polythene mulch, two stem training system and raised bed planting methods. This could be attributed to two stem trained plants which had more photosynthetic activity as compared to three stem trained plants because of good aeration, more space to grow, less or reduced chances of insect pests and diseases, consequently more number of pickings which might have led to prolonged harvesting of fruits from two stem trained plants.

This may be due to more availability of soil moisture and less crop weed competition resulting in increased availability of nutrients through enhanced activities of micro organisms in the soil leading to better plant growth and physiological activities which resulted into favourable plant growth conditions.

4.1.11 Harvest duration (days)

Prolonged and extended harvest duration ensures premium harvest and higher yield. Pooled analysis of data have been presented in Table 4.16 which showed significant effect of various treatments on harvest duration. Maximum harvest duration (74.27 days) was recorded in those plants which were grown on raised bed (P_1) and minimum (70.15 days) in those which were grown on flat bed (P_2). Similar trend was observed during both the years of study. Maximum harvest duration (74.74 days) was recorded in the plants raised on black polythene mulch (M_1) followed by those (73.61 days) which were raised on silver/black mulch (M_2). On the other hand, minimum harvest duration (68.28 days) was recorded from those plants which were raised without mulch (M_3). Similar trend was observed during both the years of study. The observations recorded on effects of various training systems also produced significant effects and maximum harvest duration (73.08 days) was recorded from those plants which were trained using two stem training system (T_1) as compared to those (71.34 days) plants which were raised using three stem training system (T_2). Similar trend was observed during both the years of study.

Regarding the two way interactions (Table 4.17) non significant differences were obtained in all the interactions during the year 2017-2018, 2018-2019 as well as when the data were pooled.

Table 4.16 Effect of planting methods, mulches and training systems on number of pickings and fruit yield per plant of tomato

Treatments	Harvest duration (days)			Fruit yield per plant (kg)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	73.90	74.63	74.27	3.03	3.05	3.04
P_2	69.38	70.93	70.15	2.80	2.75	2.78
$CD_{0.05}$	**0.76**	**1.13**	**0.73**	**0.04**	**0.04**	**0.03**
Mulches (M)						
M_1	74.24	75.25	74.74	3.07	3.09	3.08
M_2	73.05	74.17	73.61	3.01	3.02	3.02
M_3	67.63	68.92	68.28	2.67	2.58	2.62
$CD_{0.05}$	**0.93**	**1.38**	**0.89**	**0.05**	**0.05**	**0.03**
Training Systems (T)						
T_1	72.80	73.36	73.08	2.98	2.98	2.98
T_2	70.47	72.20	71.34	2.85	2.82	2.84
$CD_{0.05}$	**0.76**	**1.13**	**0.73**	**0.04**	**0.04**	**0.03**

Table 4.17 Effect of two way interactions P × M, M × T and P × T on number of pickings and fruit yield per plant of tomato

Treatment combination	Harvest duration (days)			Fruit yield per plant (kg)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	76.81	77.13	76.97	3.22	3.28	3.25
P_1M_2	75.10	75.96	75.53	3.14	3.21	3.17
P_1M_3	69.79	70.81	70.30	2.73	2.65	2.69
P_2M_1	71.67	73.37	72.52	2.92	2.91	2.91
P_2M_2	70.99	72.39	71.69	2.89	2.83	2.86
P_2M_3	65.48	67.03	66.25	2.60	2.51	2.56
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.07**	**0.07**	**0.05**
M_1T_1	75.07	76.12	75.60	3.15	3.20	3.17
M_1T_2	73.40	74.38	73.89	2.99	2.99	2.99
M_2T_1	73.91	75.25	74.58	3.07	3.12	3.09
M_2T_2	72.18	73.10	72.64	2.96	2.92	2.94
M_3T_1	69.42	68.72	69.07	2.73	2.62	2.67
M_3T_2	65.84	69.12	67.48	2.60	2.55	2.58
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**0.06**	**NS**
P_1T_1	75.28	75.37	75.32	3.10	3.13	3.11
P_1T_2	72.51	73.90	73.21	2.96	2.97	2.96
P_2T_1	70.32	71.36	70.84	2.87	2.83	2.85
P_2T_2	68.43	70.50	69.47	2.74	2.67	2.71
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**0.07**	**0.05**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The pooled data pertaining to the effect of three way interactions (P × M × T) have been presented in Table 4.18. The analysis of variance showed that there was no effect of

various interactions on harvest duration during both the years as well as when the data was pooled, however, maximum (77.84 days) harvest duration was recorded in the plants grown on raised bed with black mulch with two stem training system ($P_1M_1T_1$) and minimum (65.79 days) harvest duration was recorded in those plants grown on flat bed with no mulch and three stem training system ($P_2M_3T_2$).

Table 4.18 Effect of P × M × T interaction on number of pickings and fruit yield per plant of tomato

Treatment combination	Harvest duration (days)			Fruit yield per plant (kg)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	77.72	77.95	77.84	3.32	3.38	3.35
$P_1M_1T_2$	75.89	76.31	76.10	3.11	3.18	3.15
$P_1M_2T_1$	76.43	77.00	76.72	3.19	3.30	3.24
$P_1M_2T_2$	73.78	74.91	74.34	3.09	3.12	3.10
$P_1M_3T_1$	71.70	71.15	71.42	2.78	2.70	2.74
$P_1M_3T_2$	67.87	70.47	69.17	2.68	2.61	2.64
$P_2M_1T_1$	72.42	74.29	73.36	2.98	3.01	2.99
$P_2M_1T_2$	70.91	72.45	71.68	2.87	2.80	2.83
$P_2M_2T_1$	71.40	73.49	72.45	2.95	2.94	2.94
$P_2M_2T_2$	71.40	73.49	72.45	2.95	2.94	2.94
$P_2M_3T_1$	70.58	71.29	70.93	2.83	2.73	2.78
$P_2M_3T_2$	63.81	67.76	65.79	2.53	2.48	2.51
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Prolonged and extended harvest duration ensures premium harvest and higher yield as longest harvest duration is most desirable trait for continuous supply of fresh tomato to the market over longer period and to avoid market glut. According to Locher *et al.* (2003), it might be due to the fact that raised beds warms up quickly in the spring and drain out better allowing a longer growing season (harvesting period) and better growing conditions especially due to the comfortable breathing of the plant roots. There are various reports in literature saying that prolonged harvest period could be due to various reasons. The unbalanced soil water in flat beds ultimately ends up with water stress in plants, therefore, reduced the stomatal conductance which often leads to reduced photosynthetic activity, harvest duration and yield also. In the present studies also, the increased stomatal conductance might have facilitated more photosynthetic activity which is directly related with stress conditions. This increased photosynthetic activity is directly responsible for enhancement of yield and harvest duration (Elad *et al.*, 2007; Taiz and Zeiger, 2008 and Kilic *et al.*, 2010).

According to Singh *et al.* (2017), the prolonged harvest duration might be due to the increased vegetative and reproductive growth in tomato under protected environment which might have led to more number of fruits and hence increased yield. The benefits of mulching on prolonged harvest duration and increased yield have also been shown by Kumar and Lal (2012) especially the benefits of mulching on prolonged harvest duration and increased yield. According to them the advantages of mulching include reduced evaporation, creation of favourable environment for growth and uniform maturity which are some of the factors responsible for prolonged harvest duration. Mulches also protects the surface of the soil against unfavorable factors, reduces nutrient leaching and improves growing conditions for vegetables. All these factors contribute better growth, higher yield and prolonged harvest duration. Acharya and Sharma (1994) also observed that mulched treatments show significantly greater uptake of nitrogen, phosphorus and potassium than unmulched treatments. Probably, this uptake might be responsible for better growth, yield and prolonged harvest duration. These results are similar to those of those of Mehta *et al.* (2010) in tomato.

Prolonged harvest duration due to pruning, training and staking affected size of leaves resulting into more photosynthates. According to them, this might be due to the fact that pruning and training encouraged growth due to more photosynthetic efficiency leading to good assimilation and bigger leaf length as compared to three stem training system in which there was great competition within the canopy resulting into reduced leaf length (Nganga, 1981). He also suggested that two stem training system might probably increase the period of vegetative and reproductive stages of tomato plants by making available more photosynthates for fruit set period because of reduced competition within the plant stems. These results are similar to those of Sanderfed (2006) who also reported that two stem pruned plants have a longer harvest duration than the three stem and unpruned plants. These results are similar to those of Mbonihankuye *et al.* (2013) in tomato who also reported that two stem pruned plants have a long harvest period than other treatments.

4.1.12 Fruit yield per plant (kg)

The main objective of cultivation is to have maximum yield for better returns. Yield is responsible for commercial viability of a variety and is one of the important character attaining highest consideration in the entire research programme.

The data pertaining to the effect of different treatments on yield per plant have been presented in Table 4.16 which reveals significant effects. The plants which were grown on

raised bed (P_1) planting method produced maximum yield (3.04 kg/plant) and this treatment was significantly superior over flat bed planting method (P_2) i.e. 2.78 kg/plant (pooled data). Similar trend was observed during the years 2017-18 and 2018-19. The influence of different types of mulches on yield per plant was also significant (pooled data as well as during both the years). An examination of the pooled data revealed significant differences of different mulches and maximum value (3.08 kg/plant) was recorded in the plants grown on black mulch (M_1) followed by those (3.02 kg/plant) grown on silver/black mulch (M_2), while minimum (2.62 kg/plant) yield per plant was recorded in the plants produced on plots where no mulch (M_3) was applied. Regarding the effect of training systems, maximum (2.98 kg/plant) yield was recorded in those plants which were trained to two stem (T_1) and minimum yield (2.84 kg/plant) was recorded from the plants trained to three stem (T_2). Similar results were observed during both the years of study.

The influence of two way interactions on fruit yield per plant was significant in P × M interaction (pooled data, Table 4.17). Maximum value (3.25 kg/plant) was recorded in the plants grown on raised bed with black mulch (P_1M_1). This treatment combination was significantly superior over P_1M_2 (raised bed with silver/black mulch) producing 3.17 kg/ plant, P_2M_1 (2.91 kg/plant), P_2M_2 (2.86 kg/plant) and P_1M_3 (2.69 kg/plant). Minimum value of yield (2.56 kg/plant) was recorded in plants which were produced on flat bed and where no mulch was applied (P_2M_3). The effect of mulches and training systems (M × T) were non significant for the year 2017-2018 as well as when the data was pooled data, whereas, significant during 2018-2019. Maximum yield per plant (3.17 kg/plant) was recorded in treatment combination M_1T_1 (black mulch with two stem training system). Minimum yield (2.58 kg/plant) was recorded in M_3T_2 (no mulch with three stem training system) treatment combination. Similarly P × T (planting method and training systems) interaction showed significant effect on yield per plant. Maximum value (3.11 kg) for yield per plant was recorded in those plants which were grown on raised bed and trained to two stem training system (P_1T_1) and this treatment combination was significantly superior over all other combinations. Minimum (2.71 kg/plant) fruit yield per plant was recorded in P_2T_2 (flat bed with three stem training system). Similar results were recorded for P × M, M × T and P × T interactions during 2017-18 and 2018-19.

The pooled data pertaining to three way interactions (P × M × T) have been presented in table 4.18. The analysis of variance showed that there was no effect of various interactions on fruit yield per plant during both the years as well as when the data were pooled.

4.1.13 Fruit yield per plot (kg)

The data pertaining to the effect of different treatments on fruit yield per plot have been presented in Table 4.19 which revealed significant effects. The plants which were grown on raised bed (P_1) planting method produced maximum yield (127.57 kg/plot) and this treatment was significantly superior over flat bed planting method (P_2) producing 116.61 kg/plot (pooled data). Similar trend was observed during the years 2017-18 and 2018-19. The influence of different types of mulches on yield per plot was also significant (pooled data as well as during both the years). An examination of the pooled data revealed significant differences of different mulches and maximum value (129.42 kg/plot) was recorded in the plants grown on black mulch (M_1) followed by those (126.64 kg/plot) grown on silver/black mulch (M_2), while minimum (110.20 kg/plot) yield per plot was recorded in the plots where no mulch (M_3) was applied. Regarding the effect of training systems, maximum (125.12 kg/plot) yield was recorded in those plants which were trained to two stem (T_1) and minimum yield (119.06 kg/plot) was recorded from the plants trained to three stem (T_2). Similar results were followed during both the years of study.

Table 4.19 Effect of planting methods, mulches and training systems on fruit yield per plot and fruit yield per hectare of tomato

Treatments	Fruit yield per plot (kg)			Fruit yield per hectare (q)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	127.15	127.99	127.57	897.03	902.89	899.96
P_2	117.74	115.47	116.61	830.60	814.62	822.62
$CD_{0.05}$	**1.59**	**1.63**	**1.14**	**11.19**	**11.51**	**8.03**
Mulches (M)						
M_1	128.93	129.93	129.42	909.53	916.58	913.05
M_2	126.45	126.82	126.64	892.05	894.66	893.37
M_3	111.97	108.44	110.20	789.88	765.02	777.45
$CD_{0.05}$	**1.94**	**2.00**	**1.39**	**13.70**	**14.09**	**9.84**
Training Systems (T)						
T_1	125.22	125.02	125.12	883.36	881.97	882.66
T_2	119.68	118.44	119.06	844.28	835.54	839.91
$CD_{0.05}$	**1.59**	**1.63**	**1.14**	**11.19**	**11.51**	**8.03**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The influence of two way interactions on yield per plot was significant in P × M (planting methods and mulching treatments) interaction (pooled data, Table 4.20). Maximum value was recorded in the plants grown on raised bed with black mulch (136.45 kg/plot). This

treatment combination was significantly superior over P_1M_2 (raised bed with silver/black mulch) producing 133.20 kg/plot yield, P_2M_1 (122.40 kg/plot) and P_2M_2 (120.07 kg/plot). Minimum value of yield (107.36 kg/plot) was recorded in plants which were produced on flat beds without mulch (P_2M_3). The effect of planting method and mulches (M × T) was also significant for the year 2018-2019 as well as when the data were pooled data, but non significant during 2017-2018. Maximum yield per plot (133.23 kg) was recorded in treatment combination M_1T_1 (black mulch with two stem training system). This treatment combination was significantly superior over M_2T_1 (raised bed with silver/black mulch) producing 129.85 kg/plot yield, M_1T_2 (125.61 kg/plot) and M_2T_2 (123.42 kg/plot). Minimum yield (108.13 kg/plot) was recorded in M_3T_2 (no mulch with three stem training system) treatment combination. Similarly P × T (planting methods and training systems) interaction showed non significant effect on yield per plot.

Table 4.20 Effect of two way interactions P × M, M × T and P × T on fruit yield per plot and fruit yield per hectare of tomato

Treatment combination	Fruit yield per plot (kg)			Fruit yield per hectare (q)		
	2017-2018	**2018-2019**	**Pooled**	**2017-2018**	**2018-2019**	**Pooled**
P_1M_1	135.10	137.82	136.45	953.09	972.27	962.64
P_1M_2	131.73	134.69	133.20	929.32	950.16	939.71
P_1M_3	114.63	111.45	113.05	808.68	786.25	797.52
P_2M_1	122.75	122.03	122.40	865.96	860.89	863.45
P_2M_2	121.16	118.95	120.07	854.77	839.16	847.02
P_2M_3	109.30	105.43	107.36	771.08	743.80	757.38
$CD_{0.05}$	**2.75**	**2.83**	**1.97**	**19.37**	**19.93**	**13.91**
M_1T_1	132.30	134.17	133.23	933.31	946.53	939.93
M_1T_2	125.56	125.68	125.61	885.75	886.63	886.17
M_2T_1	128.77	130.92	129.85	908.39	923.63	916.02
M_2T_2	124.13	122.71	123.42	875.70	865.70	870.71
M_3T_1	114.59	109.96	112.27	808.37	775.74	792.04
M_3T_2	109.34	106.92	108.13	771.38	754.30	762.85
$CD_{0.05}$	**NS**	**2.83**	**1.97**	**NS**	**19.93**	**13.91**
P_1T_1	130.06	131.24	130.65	917.51	925.88	921.71
P_1T_2	124.25	124.73	124.48	876.56	879.90	878.20
P_2T_1	120.38	118.79	119.58	849.21	838.05	843.62
P_2T_2	115.10	112.15	113.63	812.00	791.19	801.62
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Maximum value (130.65 kg) for yield per plot was recorded on those plants which were grown on raised bed and trained to two stem training system (P_1T_1) and minimum

(113.63 kg/plot) in P_2T_2 (flat bed with three stem training system). Similar results were recorded for P × M, M × T and P × T interactions during both the years of study.

The pooled data pertaining to the effect of three way interactions (P × M × T) have been presented in Table 4.21. The analysis of variance showed that there was no effect of various interactions on yield per plot during both the years as well as when the data was pooled, however, maximum value (140.71 kg/plot) was recorded in the plants grown on raised bed, black mulch with two stem training system ($P_1M_1T_1$) which was followed (136.16 kg/plot) by $P_1M_2T_1$ (raised bed, silver/black mulch with two stem training system) and minimum (105.26 kg/plot) was recorded in those plants grown on flat bed with no mulch and three stem training system ($P_2M_3T_2$).

Table 4.21 Effect of P × M × T interaction on fruit yield per plot and fruit yield per hectare of tomato

Treatment combination	Fruit yield per plot (kg)			Fruit yield per hectare (q)		
	2017-2018	**2018-2019**	**Pooled**	**2017-2018**	**2018-2019**	**Pooled**
$P_1M_1T_1$	139.49	141.93	140.71	984.06	1001.25	992.64
$P_1M_1T_2$	130.71	133.71	132.20	922.13	943.07	932.64
$P_1M_2T_1$	133.84	138.50	136.16	944.21	977.07	960.58
$P_1M_2T_2$	129.62	130.87	130.25	914.43	923.25	918.84
$P_1M_3T_1$	116.84	113.31	115.09	824.25	799.33	811.91
$P_1M_3T_2$	112.42	109.60	111.01	793.11	773.16	783.12
$P_2M_1T_1$	125.10	126.41	125.76	882.56	891.81	887.21
$P_2M_1T_2$	120.40	117.65	119.03	849.36	829.97	839.69
$P_2M_2T_1$	123.69	123.35	123.53	872.57	870.19	871.46
$P_2M_2T_2$	123.69	123.35	123.53	872.57	870.19	871.46
$P_2M_3T_1$	118.64	114.25	116.60	836.97	808.14	822.58
$P_2M_3T_2$	106.26	104.25	105.26	749.66	735.45	742.58
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

4.1.14 Fruit yield per hectare (q)

The effect of different treatments on fruit yield per hectare have been presented in Table 4.19 which revealed significant effects. The plants which were grown on raised bed (P_1) planting method produced maximum yield (899.96 q/ha) and this treatment was significantly superior over flat bed planting method (P_2) i.e. 822.62 q/ha (pooled data). Similar trend was observed during the years 2017-18 and 2018-19. The influence of different types of mulches on yield per hectare was also significant (pooled data as well as during

individual years). An examination of the pooled data revealed significant differences of different mulches and maximum value (913.05 q/ha) was recorded in the plants grown on black mulch (M_1) followed by 892.05 q/ha in those plants grown on silver/black mulch (M_2), while minimum (777.45 q/ha) fruit yield per hectare was recorded in the plots where no mulch (M_3) was applied. Regarding the effect of training systems, maximum (882.66 q/ha) fruit yield was recorded in those plants which were trained to two stem (T_1) and minimum fruit yield (839.91 q/ha) was recorded from the plants trained to three stem (T_2). Similar results were followed during both the years of study.

The influence of two way interactions (P × M) on yield per hectare was significant (pooled data, Table 4.20). Maximum value (962.64 q/ha) was recorded in the plants grown on raised bed with black mulch (P_1M_1). This treatment combination was significantly superior over P_1M_2 (raised bed with silver/black mulch) producing 939.71 q/ha yield, P_2M_1 (863.45 q/ha) and P_2M_2 (847.02 q/ha). Minimum value of yield (757.38 q/ha) was recorded in plants which were produced on flat bed where no mulch was applied (P_2M_3). The effects of mulching treatments and training systems (M × T) were also significant for the year 2018-2019 and when the data were pooled, whereas, non significant for 2017-2018. Maximum yield per hectare (939.93 q) was recorded in treatment combination M_1T_1 (black mulch with two stem training system). This treatment combination was significantly superior over M_2T_1 (raised bed with silver/black mulch) producing 916.02 q/ha, M_1T_2 (886.17 q/ha) and M_2T_2 (870.71 q/ha). Minimum yield (762.85 q/ha) was recorded in M_3T_2 (no mulch with three stem training system) treatment combination. Similarly P × T (planting methods and training systems) interaction showed non significant effect on yield per hectare. Maximum value (921.71 q) for yield per hectare was recorded on those plants which were grown on raised bed and trained to two stem training system (P_1T_1) and minimum (801.62 q/ha) in P_2T_2 (flat bed with three stem training system). Similar results were recorded for P × M, M × T and P × T interactions during both the years of study.

The pooled data pertaining to the effect of three way interactions (P × M × T) have been presented in Table 4.21 and figure 4.2. The analysis of variance showed that there was no effect of various interactions on yield per hectare during both the years as well as when the data were pooled, however, maximum value (992.64 q/ha) was recorded in the plants grown on raised bed with black mulch and two stem training system ($P_1M_1T_1$) which was followed (960.58 q/ha) by $P_1M_2T_1$ (raised bed, silver/black mulch with two stem training

system) and minimum (742.58 q/ha) was recorded in those plants grown on flat bed with no mulch and three stem training system ($P_2M_3T_2$).

The increased yield of tomato fruits on raised beds may be due to higher soil organic matter content along with higher phosphorus and potassium levels. This may be because of increased enzymatic activity of microorganisms which consequently facilitated the mineralization of organic matter (Daza *et al.*, 2016), whereas, Aykas *et al.* (2005) were of the opinion that soil compaction in the flat beds decreased nutrients which were mineralized from the soil organic matter. Alagoz and Ozer (2019) observed that soil compaction in flat planting system was higher values in raised bed planting system and compaction values increased through the soil profile. They further narrated that oxygen intake form the atmosphere is decreased by excessive soil compaction in the flat beds. It was also pointed out that higher relative humidity, reduced oxygen concentration and increased carbon dioxide concentration in the root zone and such conditions ultimately ended up with an anaerobic conditions ultimately resulting into accelerated root development. In the present case also, less soil compaction and increased oxygen intake from the atmosphere might have helped the plant to perform better resulting into conditions that favors better growth and higher yield. Other reasons for increased yield on raised beds could be longer growing period, warming up of the bed, improved drainage, better management of water, fertilizers, mulch and other soil amendments and reduced foot trafficing (Berle and Westerfield, 2013). The present results are in line with the findings of Kumar *et al*. (2001) in tomato, Locher *et al.* (2003) in sweet pepper, Hatterman-Valenti and Hendrickson (2006) in onion and Bahadur *et al.* (2013) in tomato. The higher yield in the plants grown on raised bed covered with black mulch was also due to the natural drainage facility, reduced incidence of diseases and also one more important thing is favourable root zone temperature which is considerably important for flowering and fruiting. Raised bed warmed up better because of their bigger surface which could absorb more radiation and that is why difference in soil temperature between the two treatments developed mainly during day time. Differences in soil temperature among the treatments were higher during the beginning of growing period when the foliage of the plants did not shadow the surface considerably. Optimum soil temperature requirement was met to the highest degree in the covered raised bed treatment. Similarly, raised bed planting system improved other soil quality parameters like decreasing soil compaction, increased soil bacteria, enhanced fertility due to increased soil microorganisms activity and ultimately increased yield. These factors are in accordance with the findings of Kumari *et al.* (2013) in

field pea, Kumar *et al.* (2015) in garlic, Kumar and Gill (2010) in turmeric, Anand *et al.* (2016) in ashwagandha, Deepak *et al.* (2016) in bell pepper, Islam *et al.* (2018) in potato and Alagoz and Ozer (2019) in tomato. The present results are in agreement with those of Khurshid *et al.* (2006) who attributed increased yield due to increased soil porosity and reduced soil compaction.

According to Sarkar and Singh (2007), black mulching enhanced growth and yield of plants, while they also concluded that mulching especially black mulch reduced leaching of nutrients, reduced weed problem, reduced evapotranspiration of soil water and increased water use efficiency. According to them, maintenance of optimum soil moisture was responsible for optimum crop growth throughout the growing season. It was also pointed out that increased growth and yield of tomato through modification of crop growing environment could be due to reduced weed infestation, soil moisture depletion and ameliorating soil temperature. Angmo *et al.* (2018) were also of opinion that reduced competition with weeds, higher soil temperature, reduced attack of soil pathogens and breakdown of phytotoxic substances are responsible for higher yield in the plants grown on black mulch. Our results are in agreement with those obtained by Baki *et al*., (1996) in tomato, Awodoyin *et al.* (2007) in tomato, Inusah *et al.* (2013) in onion, Panchal *et al.* (2001) in green and red chilli and Ashrafuzzaman *et al.* (2011) in chilli. In the present case also, there is 17.44 per cent increased yield in black mulched plots as compared to unmulched plots, which could be due to conservation of soil moisture and improved microclimate both beneath and above the soil surface. Moreover, mulching could improve the leaf photosynthetic capacity, thereby enhanced metabolic activities within the plant during the period of active growth and reproduction processes, which increased leaf area with high chlorophyll content. This in turn built high yield of carbohydrates which gave rise to more cell division and cell enlargement induced more vegetative vigorous plants, which reflected to produce more growth and fruit yield of tomato. Such conditions enhanced the plant growth and development and produced fruit bearing nodes compared to unmulched plots. Gao *et al.* (2001) observed higher yield in mulched plots which promoted flower bud differentiation, enhanced yield and also improved fruit quality in tomato as compared to plastic mulch and no mulching. Vander Zaag *et al.* (1986) attributed increased yield and profits due to better weed management, reduced weed growth and clean crop. They were of the opinion that mulches provides a physical barrier which reduces the germination and nourishment of many weeds by suppressing their germination and growth. The present results are in line with the findings of Samaila *et al.*

(2011) in tomato, Mehta *et al.* (2010) in tomato, Rajablariani *et al.* (2012) in sweet pepper, Locher *et al.* (2003) in sweet pepper, Bhujbal *et al*. (2015) in tomato, Bakht and Khan (2014) in tomato, Kosterna (2014) in tomato, Abhivyakti *et al.* (2016) in tomato, Helaley *et al.* (2017) in tomato, Angmo *et al*. (2018) in tomato, Kumari *et al.* (2018) in tomato and Sowinska and Turczuk (2018) also in tomato crop.

Growth and yield are functions of a large number of metabolic processes, which are affected by environmental and genetic factors. A number of researchers also recommended training as a cultural practice that improves the yield and quality of tomato. Plant growth analysis is considered to be a standard approach to plant productivity. Tomato yield could be increased substantially through improved agronomic techniques like training. The two stem training system noticed significant and maximum fruit yield over other levels of training systems. Increased yield in two stem training system might be attributed to availability of more space for individual plant growth, more leaf area for better photosynthesis, ample sunlight and aeration. These findings are in conformity with the work of Bhattarai *et al.* (2015) and Singh and Kumar (2005) in cherry tomato. Ara *et al.* (2007) also recorded higher yield in two stem pruned plants as compared to single stem pruned. The present results are in conformity with those of Lim and Chen (1989). The plants pruned to two stem recorded an increase of 5.09 percent yield of fruits as compared to those which were trained to three stem training system. This could be due to the competition for assimilates between the growing fruits. Razzak *et al.* (2013) in cucumber reported reduced fruit size and low yield in three stem training system. This could be due to reduced fruit size and weight in three stem training system because of reduced assimilates availability in the source and increased demand in the sink. Mantur and Patil (2008) in tomato also found a larger number of fruits per plant with the increament in the number of pruned tomato branches per plant. De Pinho *et al.* (2011) also recorded heavier fruits and more yield from fewer branches per plant because of higher carbohydrates content in the fruits. Two stem training diverts more nutrients to flower clusters and fruits on the main stem and allows more efficient air circulation. It might be due to the more number of fruits per unit area which ultimately leads to higher yield. The results are in accordance with the findings of Maboko *et al.* (2011) in tomato, Khoshkam *et al.* (2014) in tomato, Rahmatian *et al.* (2014) in tomato, Mbonihankuye *et al.* (2013) in tomato and Anand *et al.* (2018) in tomato crop who observed higher number of marketable fruits and total yield,.

4.1.15 Leaf area index

Leaf area index has been considered an appropriate index to characterise the interception of radiation in many crops. The larger the LAI, the greater relative interception of incoming photoactive radiation together which increases the soil temperature.

Analysis of data presented in Table 4.22 indicated that during the year 2017-2018, maximum (4.05) values for leaf area index were calculated in P_1 (raised bed) and minimum (3.31) in P_2 (flat bed). Same trend was observed for the year 2018-2019. Pooled analysis of data for both the years indicated the same trend showing maximum values (4.09) in P_1 and minimum (3.59) in P_2. Regarding the application of mulches (Pooled data), black mulch (M_1) produced maximum leaf area index (4.21) followed by silver/black mulch (M_2) which produced 4.05 values of leaf area index. Same trend was followed during both the years and minimum (3.27) leaf area index was calculated in M_3 (no mulch). As regard training systems, maximum values (4.01) were calculated in T_1 (two stem training) during both the years as well as in pooled data also, whereas, minimum values (3.68) were recorded in the treatments involving three stem training system (T_2). Same trend was obtained during both the years also.

Table 4.22 Effect of planting methods, mulches and training systems on leaf area index and plant height of tomato

Treatments	Leaf area index			Plant height (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	4.05	4.14	4.09	177.28	171.95	172.12
P_2	3.31	3.63	3.59	166.25	165.68	165.97
$CD_{0.05}$	**0.50**	**0.16**	**0.11**	**2.70**	**4.09**	**3.14**
Mulches (M)						
M_1	3.80	4.26	4.21	173.13	173.48	173.31
M_2	4.05	4.06	4.05	170.14	169.11	169.63
M_3	3.20	3.34	3.27	164.52	163.85	164.19
$CD_{0.05}$	**0.61**	**0.20**	**0.14**	**3.31**	**5.01**	**3.84**
Training Systems (T)						
T_1	3.73	4.05	4.01	174.44	173.78	174.11
T_2	3.63	3.72	3.68	164.09	163.85	163.97
$CD_{0.05}$	**NS**	**0.16**	**0.11**	**2.70**	**4.09**	**3.14**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The data pertaining to two way interaction i.e. P × M (planting methods and mulching treatments) as shown in Table 4.23 (pooled data) depicted the effect of various interactions

on leaf area index. It is clear from the data that maximum values (4.51) for leaf area index were calculated in the treatment combination P_1M_1 (raised bed and black mulch) which produced non significant effects with P_1M_2 (raised bed and silver/black mulch) treatment combination producing 4.38 values for leaf area index, whereas, P_1M_1 (raised bed and black mulch) treatment combination was significantly superior over all other treatments. Minimum leaf area index of 3.15 was calculated for P_2M_3 (flat bed and no mulch). Regarding the effect of M × T interaction (mulching treatments and training systems), though the results were non-significant, yet maximum values (4.41) of leaf area index were calculated in M_1T_1 (black mulch and two stem training) interaction and minimum (3.15) in M_3T_2 (no mulch and three stem training). Similarly, in P × T (planting methods and training systems) interaction, maximum values (4.22) were calculated for P_1T_1 (raised bed and two stem training) and minimum (3.39) were for P_2T_2 (flat bed and three stem training).

Table 4.23 Effect of two way interactions P × M, M × T and P × T on leaf area index and plant height of tomato

Treatment combination	Leaf area index			Plant height (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	4.42	4.61	4.51	176.68	177.01	176.84
P_1M_2	4.40	4.37	4.38	170.83	170.01	170.42
P_1M_3	3.33	3.44	3.39	169.33	168.84	169.09
P_2M_1	3.19	3.92	3.90	169.58	169.96	169.77
P_2M_2	3.70	3.75	3.72	169.46	168.21	168.83
P_2M_3	3.06	3.23	3.15	159.71	158.87	159.29
$CD_{0.05}$	**NS**	**0.28**	**0.19**	**4.68**	**7.09**	**5.43**
M_1T_1	3.64	4.49	4.41	180.37	180.68	180.53
M_1T_2	3.97	4.04	4.00	165.90	166.29	166.09
M_2T_1	4.27	4.19	4.23	174.35	172.97	173.66
M_2T_2	3.83	3.93	3.88	165.94	165.25	165.59
M_3T_1	3.29	3.47	3.38	168.61	167.69	168.15
M_3T_2	3.11	3.20	3.15	160.44	160.02	160.23
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**7.09**	**5.43**
P_1T_1	4.17	4.27	4.22	179.72	178.37	179.05
P_1T_2	3.92	4.01	3.97	164.84	165.53	165.19
P_2T_1	3.29	3.83	3.79	169.16	169.19	169.17
P_2T_2	3.34	3.43	3.39	163.34	162.17	162.76
$CD_{0.05}$	**NS**	**NS**	**NS**	**3.82**	**5.79**	**4.44**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Perusal of data (Pooled data) regarding the three way interaction P × M × T (planting methods, mulching treatments and training systems), again the results were found to be non-significant (Table 4.24).

Table 4.24 Effect of P × M × T interaction on leaf area index and plant height of tomato

Treatment combination	Leaf area index			Plant height (cm)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	4.59	4.83	4.71	187.49	186.43	186.96
$P_1M_1T_2$	4.24	4.38	4.31	165.87	167.58	166.73
$P_1M_2T_1$	4.51	4.46	4.48	176.71	176.08	176.40
$P_1M_2T_2$	4.29	4.29	4.29	164.95	163.93	164.44
$P_1M_3T_1$	3.42	3.52	3.47	174.97	172.59	173.78
$P_1M_3T_2$	3.24	3.36	3.30	163.69	165.09	164.39
$P_2M_1T_1$	4.02	4.14	4.11	173.25	174.93	174.09
$P_2M_1T_2$	3.69	3.70	3.70	165.92	164.99	165.45
$P_2M_2T_1$	4.03	3.93	3.98	171.99	169.85	170.92
$P_2M_2T_2$	4.03	3.93	3.98	171.99	169.85	170.92
$P_2M_3T_1$	3.37	3.56	3.47	166.92	166.57	166.75
$P_2M_3T_2$	2.97	3.04	3.01	157.18	154.95	156.07
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P_1: Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system; **P:** Planting methods, **M:** Mulching treatments, **T:** Training systems

The benefits of the raised bed-planting system includes water savings combined with enhanced water use efficiency, improvement in soil physical status and nitrogen use efficiency, better utilization of sunlight and all these factors contribute towards higher leaf area and LAI values compared to the plants cultivated on the flat bed. Possibly in raised bed planting system, more and larger area is exposed, therefore plants are able to facilitate more photosynthetic activity and larger leaf area is responsible for higher leaf area index (Alagoz and Ozer, 2019). The present results are in agreement with the findings of Kumar and Gill (2010) in turmeric.

The present study showed that irrespective of covering, plants cultivated on the mulched soil were characterized by higher assimilation of leaf area and LAI values compared to the plants cultivated on the non-mulched plots. The assimilated leaf area depends on the genetic features of the species and cultivar, the density of the plants, their wholesomeness, climatic conditions and agro-technology treatments (Koło-Dziejczyk, 2012). However, according to many authors, leaf area development depends more strongly on the air temperature. Earlier plant growth as a result of mulching allows for higher solar radiation

interception and a rapid increase in leaf area assimilation (Soltani *et al.,* 1995; Ibarra *et al.,* 2001; Wadas and Kosterna 2007 and Olle and Bender 2010). According to Gimenez *et al.* (2002), the transmission of photoactive radiation through polypropylene fibre cover varied from 85 to 65 per cent, depending on dust accumulation on the cover and water vapour condensation on the inner surface of the cover. The reduced irradiance under the covers might have been compensated by the greater leaf area index of the plants, the increased air and soil temperature under the covers, and by improved light distribution within the protected canopy, allowing more crop growth and development. Present results is in agreement with the findings of Kosterna (2014) and Kumari *et al.* (2018) tomato.

More favourable conditions under covers also increased the leaf area index (LAI) which describes better growth of the plants. A higher leaf area assimilation and LAI value in the cultivation of cabbage, beet, spinach and lettuce under covers was found in the study conducted by Gimenez *et al.* (2002).

Leaf area index is defined as the ratio of the total leaf area to the soil area occupied per plant. According to Evans (1974), changes in LAI depend on the relative rate of two processes, increase in leaf area and senescence. It could be due to the reason that although the three-stem trained plants had higher number of leaves than the two stem trained plants, the two-stem plants might have had larger individual leaf area. This might be possible because the assimilates which could have been used in growth of the third shoot in the three-stem plants might have been used for leaf expansion in the two-stem pruned plants. In that case, the larger number of leaves in the three-stem plants are counteracted by the large sized leaves in the two-stem plants (Muhammad *et al.,* 2016). Razzak *et al.* (2013) were also of similar opinion and according to them, the highest leaf area and the heaviest aboveground fresh and dry biomass were found in the plants pruned to two branches. Two stem trained plants produced the tallest plants compared to the other treatments which could be the possible reason for the larger leaf area of the two stem plants because of less competition for space and light which consequently lead to higher leaf area index.

4.1.16 Plant height (cm)

Height of the plant is one of the important factors determining yield and harvest duration especially in plants with indeterminate type of growth habit. Taller plants are

considered to be more desirable because they lead to more number of branches which ultimately bear more number of fruits and result in increased productivity.

Analysis of data (Table 4.22) indicated that during the year 2017-2018, maximum values (177.28 cm) for plant height were recorded in P_1 (raised bed) and minimum (166.25 cm) in P_2 (flat bed). Same trend was observed for the year 2018-2019. Pooled analysis of data for both the years indicated the same trend showing maximum values (172.12 cm) in P_1 and minimum (165.97 cm) in P_2. Regarding application of mulches, black mulch (M_1) produced taller plants (173.31 cm) followed by silver/black mulch (M_2) which produced 169.63 cm taller plants. Same trend was followed during both the years and minimum (164.19 cm) plant height was recorded in M_3 (no mulch). As regards training system, maximum values (174.11 cm) were recorded in T_1 (two stem training) during both the years as well as when the data were pooled, whereas, minimum values (163.97 cm) were recorded in the treatments involving three stem training system (T_2).

The data pertaining to two way interaction (pooled data) of P × M (planting methods and mulching treatments) have been presented in Table 4.23 which showed maximum values (176.84 cm) for plant height in the treatment combination P_1M_1 (raised bed and black mulch). This treatment combination (P_1M_1) produced significant differences with all other treatment combinations. The next best treatment combination was P_1M_2 (raised bed and silver/black mulch) producing 170.42 cm plant height which was at par with other treatment combinations like P_1M_3 (flat bed and black mulch), P_2M_1, P_2M_2 and P_2M_1. Minimum plant height of 159.29 cm was produced in P_2M_3 (flat bed and no mulch) which produced non significant effects with P_1M_3 (raised bed and no mulch) measuring 172.02 cm plant height. Regarding the effect of M × T interaction (mulching treatments and training systems), the results were significant, maximum values (180.53 cm) of plant height were observed in M_1T_1 (black mulch and two stem training) interaction and minimum (160.23 cm) in M_3T_2 (no mulch and three stem training). Similarly in P × T (planting methods and training systems) interaction, maximum values (179.05 cm) were recorded in P_1T_1 (raised bed and two stem training) and minimum (162.76 cm) in P_2T_2 (flat bed and three stem training).

Analysis of data (Table 4.24) regarding the three way interaction P × M × T (planting methods, mulching treatments and training system), showed non-significant (2017-18, 2018-19 and pooled data) differences. Maximum (186.96 cm) values, however, were recorded in

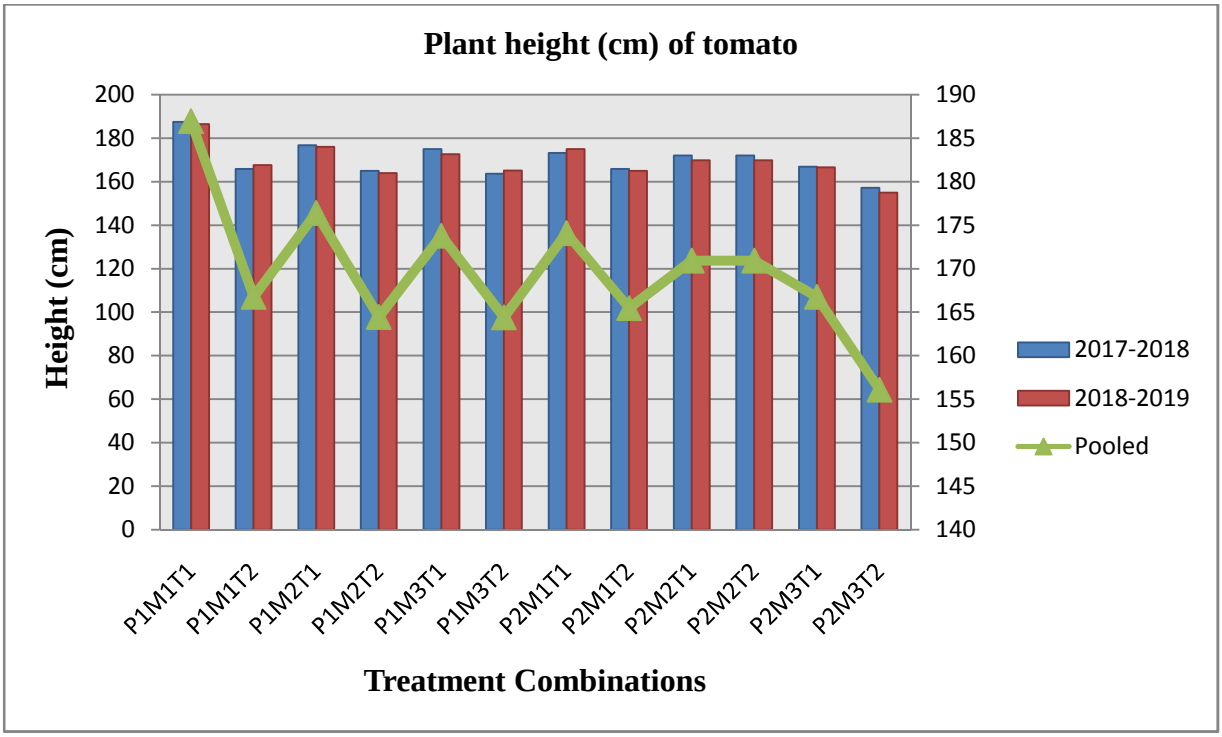


Fig. 4.3 Effect of planting methods, mulching and training levels on plant height (cm) of tomato

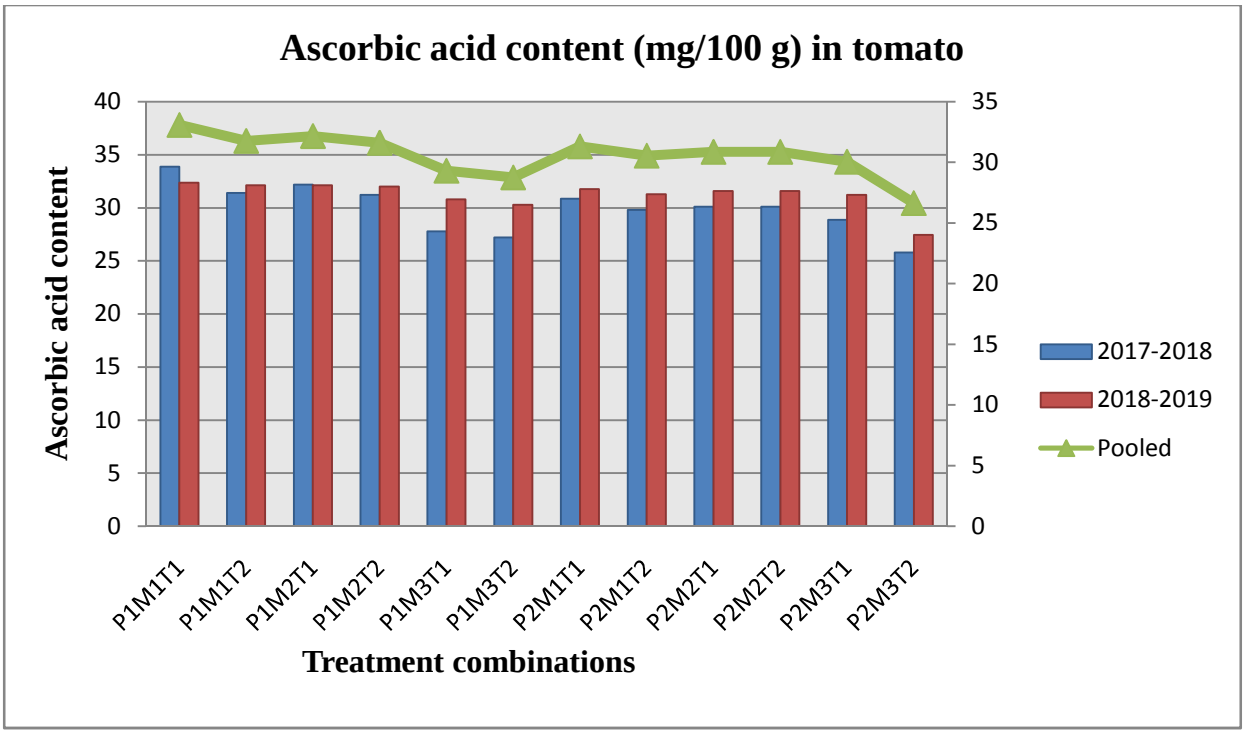


Fig. 4.4 Effect of planting methods, mulching and training levels on ascorbic acid content (mg/100 g) in tomato

$P_1M_1T_1$ (raised bed, black mulch and two stem training) and minimum (156.07 cm) were recorded when the plants were raised on flat bed with no mulch and three stem training ($P_2M_3T_2$). This interaction has been graphically represented in figure 4.3.

The increased plant height of tomato in raised bed planting system might be due to the effective and better assimilation of both macro and micro nutrients, which provide all the essential nutrients to the plants for better crop stand during the initial stages of growth and development also. The present results are in agreement with the finding of Nicoletto *et al.* (2016) in various vegetable crops. Another possible reason for increased plant height could be due to the improved soil structure and reduced compaction through controlled trafficking (Kumar *et al.,* 2015). Similar are the findings of Van Derwerken and Wilcox (1988) in tomato, Kumar and Gill, 2010 in turmeric crop, Anand *et al.* (2016) in ashwangandha and Islam *et al.* (2018) in potato. Therefore, modification of soil microclimate, availability of sufficient soil moisture, better nutrients uptake and less crop-weed competition for water and nutrients under mulch coupled with better soil aeration and light interception in raised bed planting might have contributed towards improved plant growth and yield of tomato. Also, in raised beds, there could be better opportunity for mechanical weed control and improved fertilizers placement.

Plants grown along with mulching have more uniformity, are taller, and are also characterized by a large mass of above ground parts as compared to cultivation without covers. The increased plant height in mulched plants may also be due to better availability of soil moisture (covers reduce evaporation and decreases heat losses at night) reduced effect of higher temperature and less competition from the weeds than the other treatments which improved soil conditions for plant growth and development. Present results are in line with the findings of Awodoyin *et al.* (2007) in tomato, Berihun (2011) in tomato, Inusah *et al.* (2013) in onion and Decoteau *et al.* (1988) in tomato. Moisture stress conditions in non mulched plots might lead to poor cell elongation, low rate of photosynthesis and low carbohydrates assimilation which may result in poor plant growth. This present results are in agreement with the findings of Mehta *et al.* (2010) in tomato, Ashrafuzzaman *et al.* (2011) in chilli, Kosterna (2014) in tomato, Dishani and Silva (2016) in tomato, Angmo *et al*. (2018) in tomato and Kumari *et al.* (2018) in tomato.

Taller plants were observed in two-stem pruned plants which could be due to reduced competition for photosynthates among the branches (Frank, 2000). In two-stem training

system, photosynthates are diverted to two branches only and in three stem, they are diverted towards three branches. Possibly, the increase in plant height of tomato might be due to removal of branches that leads to more flow of nutrients towards apical tissues rather than axillary branches and also in the remaining branches. The present results agree with the findings of Muhammad *et al.* (2014) in tomato, Alam *et al.* (2016) in tomato and Mbonihankuye *et al.* (2013) in tomato. Another reason for the improved plant height is also the greater exposure of plants to light leading to higher cell multiplication and enhanced photosynthetic activity. This result of present studies also agrees with the findings of Muhammad *et al.* (2016) in tomato, Singh *et al.* (2017) in tomato and Yadav *et al.* (2018) in tomato crop.

4.2 QUALITY PARAMETERS

The fruit quality was assessed through various characters like total soluble solids, ascorbic acid content, lycopene content and shelf life of the fruits. Total soluble solids is a desired quality character and high total soluble solids content in tomato is valuable for processed products like juice, ketchup, sauce and puree.

4.2.1 TSS (^{0} Brix)

The data recorded on total soluble solids of fruits as affected by different treatments have been presented in table 4.25. Analysis of variance showed significant effects of various treatments (pooled data). Raised bed planting method (P_1) contributed fruits which had maximum (4.79) TSS (^{0}Brix) while the fruits produced through flat bed planting method (P_2) recorded minimum TSS (4.62 ^{0}Brix). Non significant results were obtained during 2018-19. Similar trend was followed during 2017-18 and 2018-19 years of the study. On the other hand, maximum (4.93) TSS (^{0}Brix) was recorded in those fruits which were produced by the plants grown on black polythene mulch (M_1) and it was closely followed (4.88) by those which were produced on silver/black mulch (M_2) while minimum (4.31) TSS (^{0}Brix) was obtained in no mulch treatment (M_3). Similar trend was followed during 2017-18 and 2018-19 years of the study. Two stem training system (T_1) produced significant results for 2017-2018 and pooled data whereas, non significant results were obtained during 2018-19. Maximum (4.75) TSS (^{0}Brix) was recorded from the fruits produced by two stem training system (T_1) as compared to those (4.66) fruits which were produced on the plants where three stem training system (T_2) was followed. Similar trend was followed during 2017-18 and 2018-19 years of the study.

Table 4.25 Effect of planting methods, mulches and training systems on TSS content and ascorbic acid content in tomato

Treatments	TSS (^{o} Brix)			Ascorbic acid content (mg/100 g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	4.71	4.87	4.79	30.61	31.61	31.11
P_2	4.46	4.79	4.62	28.60	30.54	29.57
$CD_{0.05}$	**0.07**	**NS**	**0.06**	**0.42**	**0.66**	**0.34**
Mulches (M)						
M_1	4.82	5.03	4.93	31.48	31.87	31.67
M_2	4.75	5.02	4.88	30.59	31.74	31.17
M_3	4.18	4.44	4.31	26.74	29.61	28.17
$CD_{0.05}$	**0.09**	**0.10**	**0.07**	**0.52**	**0.81**	**0.41**
Training Systems (T)						
T_1	4.63	4.87	4.75	30.16	31.41	30.79
T_2	4.53	4.79	4.66	29.04	30.74	29.89
$CD_{0.05}$	**0.07**	**NS**	**0.06**	**0.42**	**0.66**	**0.34**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Regarding the two way interactions, non significant differences were obtained in all the interactions (Pooled data, Table 4.26).

Table 4.26 Effect of two way interactions P × M, M × T and on P × T on TSS content and ascorbic acid content in tomato

Treatment combination	TSS (^{o} Brix)			Ascorbic acid content (mg/100 g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	4.99	5.07	5.03	32.63	32.21	32.42
P_1M_2	4.89	5.07	4.98	31.70	32.08	31.89
P_1M_3	4.24	4.47	4.35	27.50	30.54	29.02
P_2M_1	4.65	5.00	4.83	30.32	31.53	30.93
P_2M_2	4.60	4.96	4.78	29.49	31.40	30.44
P_2M_3	4.12	4.41	4.25	25.99	28.67	27.33
$CD_{0.05}$	**0.13**	**NS**	**NS**	**NS**	**NS**	**NS**
M_1T_1	4.87	5.09	4.98	32.36	32.03	32.19
M_1T_2	4.77	4.98	4.88	30.59	31.72	31.15
M_2T_1	4.82	5.04	4.93	31.15	31.86	31.50
M_2T_2	4.68	4.99	4.83	30.04	31.62	30.83
M_3T_1	4.22	4.48	4.35	26.98	30.34	28.66
M_3T_2	4.14	4.41	4.27	26.50	28.87	27.69
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.73**	**NS**	**NS**
P_1T_1	4.78	4.90	4.84	31.28	31.74	31.51
P_1T_2	4.64	4.84	4.74	29.94	31.48	30.71
P_2T_1	4.49	4.84	4.66	29.05	31.08	30.06
P_2T_2	4.42	4.75	4.58	28.15	31.48	29.07
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Analysis of data (Table 4.27) regarding the three way interaction P × M × T (planting methods, mulching treatments and training system) revealed non-significant results during both the years of study as well as when the data were pooled. Maximum (5.10) values, however, were recorded in those fruits which were produced in $P_1M_1T_1$ (raised bed, black mulch and two stem training) treatment combination and minimum (4.23) in those fruits which were raised by the plants raised on flat beds with no mulch and three stem training ($P_2M_3T_2$) for TSS (^{0}Brix).

The best possible reason for the high total soluble solids in the raised bed planting method is the more exposed surface area which allows more absorbance of radiations and greater photosynthetic activities within the plant cells. Therefore, the photosynthates are better partitioned resulting into high TSS of tomato fruits (Locher *et al.*, 2003). Another reason could be the better drainage, maintenance of hydrothermal regime of the soil and more assimilation of macro and micro nutrients in the plants grown on raised beds as compared to the flat bed planting system (Nicoletto *et al.*, 2016).

Table 4.27 Effect of P × M × T interaction on TSS content and ascorbic acid content in tomato

Treatment combination	TSS (^{o} Brix)			Ascorbic acid content (mg/100 g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	5.07	5.13	5.10	33.87	32.38	33.08
$P_1M_1T_2$	4.92	5.00	4.96	31.39	32.14	31.76
$P_1M_2T_1$	4.97	5.08	5.03	32.18	32.14	32.16
$P_1M_2T_2$	4.81	5.06	4.94	31.21	32.02	31.61
$P_1M_3T_1$	4.29	4.49	4.39	27.78	30.80	29.29
$P_1M_3T_2$	4.19	4.45	4.32	27.22	30.28	28.75
$P_2M_1T_1$	4.67	5.04	4.86	30.85	31.77	31.31
$P_2M_1T_2$	4.63	4.96	4.79	29.79	31.29	30.54
$P_2M_2T_1$	4.66	5.00	4.83	30.11	31.59	30.85
$P_2M_2T_2$	4.66	5.00	4.83	30.11	31.59	30.85
$P_2M_3T_1$	4.54	4.92	4.73	28.88	31.21	30.04
$P_2M_3T_2$	4.09	4.36	4.23	25.79	27.46	26.63
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Higher TSS content in the mulched plants could be due to the reason that plastic mulches concentrate carbon dioxide around the plant canopy as the planting holes acts as vents for carbon dioxide escaping from beneath the mulch. This relatively elevated carbon dioxide concentration might have accounted for the increased total soluble solids (Sanders *et al.,* 1989) in tomato. The highest total soluble solids obtained from black mulched plots with increased photosynthesis might be due to the plastic reflective properties, which increased light reception on the leaves and fruits of tomatoes. The reflection of more light on the tomato shoots by black plastic is known to increase transpiration rate, amount of photosynthesis available to fruits and sugar: acid ratio and hence the higher brix value of tomato fruits as reported by Dorais *et al.* (2001) in tomato. Therefore, the relative elevated carbon dioxide concentration might have accounted for increased total soluble solids. Our results are also in agreement with Moursi (2003) in pepper and Helaley *et al.* (2017) in tomato. Another possible reasons could be attributed to low soil water tension maintained by unmulched plots which led to higher water uptake and hence dilution of concentration of the total soluble solids (Muller 1993 and Tan 1995). There might be several other reasons for the high TSS (total soluble solids), like early 50 per cent flowering in the plants raised on black polythene mulch reduced the competition between vegetative and fruit growth for photosynthates which might have increased the amount of photosynthates partitioned to the fruits hence increased the concentration of total soluble solids compared to the plants grown on unmulched plots (Mithchell *et al.,* 1991).

The fruit quality was assessed through total soluble solids and ascorbic acid contents of the fruits. Total soluble solid is a desired quality character and a high total soluble solid is valuable for processed products like juice, ketchup, sauce and puree. Alam *et al.* (2016) reported that maximum (4.44 %) and the minimum (4.24 %) total soluble solid were obtained in the fruits harvested from plants with two stems and no pruning, respectively. They narrated that the fruits which were harvested from the plants with lower number of stems gave higher TSS values as compared to more number of stems per plant. The results were agreed by Malash and Gawish (1989) and Hesamil *et al.* (2012), who noticed that removal of more branches, resulted in increased fruit TSS of tomato. The results are in agreement with those obtained by Razzak *et al.* (2013), Khoshkam *et al.* (2014), Mbonihankuye *et al.* (2013) and Alam *et al. (*2016), in tomato. Another possible reason for higher total soluble solids could be attributed to the high assimilate supply associated with good light conditions for the plants

trained intensively to two stem as compared to the other three stem training system (Ece and Darakci, 2009).

4.2.2 Ascorbic acid content (mg/100 g of fresh weight)

Ascorbic acid content (Vitamin C) is one of the major quality components in tomato as it improves the nutritional quality of fruit. The data recorded on vitamin C content of fruits as affected by different treatments have been presented in Table 4.25. Analysis of variance showed significant effect of various treatments. Fruits produced on plants grown on raised bed planting method (P_1) contributed maximum (31.11) vitamin C content while the fruits produced by plants grown on flat bed planting method (P_2) recorded minimum (29.57) values of vitamin C content. Similar trend was followed during 2017-18 and 2018-19 years of the study. On the other hand, maximum (31.67) vitamin C content was obtained in those fruits which were produced by the plants grown on beds with black polythene mulch (M_1) and it was significantly superior (31.17) by those which were produced on silver/black mulch (M_2) while minimum (28.17) vitamin C content was obtained in no mulch treatment (M_3). Similar trend was followed during 2017-18 and 2018-19 as well as when the data were pooled. Two stem training system (T_1) also produced significant results for 2017-2018, 2018-19 and pooled data also. Maximum (30.79) values of vitamin C content were obtained from the fruits produced by two stem training system (T_1) as compared to those (29.89) fruits which were produced on the plants where three stem training system (T_2) was followed. Similar trend was followed during 2017-18 and 2018-19 years of the study.

Regarding the two way interactions (Table 4.26) non significant differences were obtained in all the interactions (pooled data).

Analysis of data (Table 4.27 and figure 4.4) regarding the three way interaction P × M × T (planting methods, mulching treatments and training systems) revealed non-significant results during both the years of study as well as for pooled data.

Zhang *et al.* (2012) were of the opinion that that raised bed planting system achieved higher vitamin C content in vegetables due to increased soil microorganism's activity which enhances nitrogen fixation, mineralization and enzyme activity and ultimately increased quality and yield. It might be due to the reason that raised bed planting systems also improves the soil quality parameters i.e. temperature, compaction and fertility thus had better quality fruit and improved yield. The increase in the available water content in soil reduces the activity of beneficial soil microorganisms in flat bed planting system which leads to poor

quality. Another possible reason could be the more absorbance of radiations in raised bed planting system because of more exposed surface which enhances the photosynthetic activity within the plant cells which consequently hastens the metabolic processes in the plant system (Locher *et al.* 2003). All these processes are directly related to increased chemical composition of the fruits. The results are in line with the findings of Alagoz and Ozer (2019) in tomato.

Ashrafuzzaman *et al.* (2011) also calculated the increased amount of vitamin-C in chilli in all the mulch applied plants compared to those which were raised on unmulched plots, but among the mulch treatments they found maximum vitamin C content in the fruits which were obtained from the plants grown on black polythene mulch applied plots. The findings are also in agreement with those of Panchal *et al.* (2001) who also reported that black mulches produce higher vitamin-C content in chilli as compared to fruits obtained from those plants which were grown on unmulched plots. Moursi (2003) narrated that the improvement in vitamin C (ascorbic acid) content in tomato fruits according to polyethylene treatments may be due to the promotion effect in plant growth and metabolic processes, which reflected on increasing chemical composition. The results are in conformity with the findings of Helaley *et al.* (2017) and Sowinska and Turczuk (2018) in tomato.

The present results of increased Vitamin C content could be attributed to the high assimilate supply associated with the good light conditions for the plants trained more intensively to double stem when the canopy is not very dense, light can easily penetrate and be distributed within it (Ambroszczyk *et al.,* 2008). Similar findings were reported by Ece and Darakci (2009), who found a positive correlation between the vitamin C content of the fruits and the amount of incident light. Fruits exposed to maximum sunlight in two stem training system, had a higher amount of vitamin C compared to the shaded fruits in other treatments. According to our opinion it might be attributed to the fact that in three stem trained plants, the foliage reduces the light intensity and accumulation of vitamin C content in the fruits. The results also agreed with those obtained by Razzak *et al.* (2013) and Khoshkam *et al.* (2014) in tomato.

4.2.3 Lycopene content (mg/100 g of fresh weight)

The data recorded on lycopene content of fruits as affected by different treatments have been presented in table 4.28. Analysis of variance showed significant effect of various treatments. Raised bed planting method (P_1) contributed fruits which had maximum (5.96)

lycopene content while the fruits produced by flat bed planting method (P_2) recorded minimum (5.50) values of lycopene content. Similar trend was followed during 2017-18 and 2018-19 years of the study. On the other hand, maximum (6.09 mg/100g) lycopene content was obtained in those fruits which were produced by the plants grown on black polythene mulch (M_1) and it was closely followed (5.95 mg/100g) by those which were produced on silver/black mulch (M_2) while minimum (5.15 mg/100g) lycopene content was obtained in no mulch treatment (M_3). Similar trend was followed during 2017-18 and 2018-19 years of the study. Two stem training system (T_1) also produced significant differences during 2017-2018, 2018-19 as well as when data were pooled data. Maximum (5.84 mg/100g) values of lycopene content was obtained from the fruits produced by two stem training system (T_1) as compared to those (5.62 mg/100g) fruits which were produced on the plants where three stem training system (T_2) was followed. Similar trend was followed during 2017-18 and 2018-19 years of the study.

Table 4.28 Effect of planting methods, mulches and training systems on lycopene content and shelf life of tomato

Treatments	Lycopene content (mg/100 g of fresh weight)			Shelf life (days)		
	2017-2018	**2018-2019**	**Pooled**	**2017-2018**	**2018-2019**	**Pooled**
Planting Methods (P)						
P_1	6.10	5.82	5.96	11.42	11.93	11.67
P_2	5.56	5.44	5.50	9.68	11.08	10.38
$CD_{0.05}$	**0.13**	**0.32**	**0.20**	**0.26**	**0.38**	**0.23**
Mulches (M)						
M_1	6.18	5.99	6.09	11.62	12.55	12.09
M_2	6.05	5.86	5.95	10.97	12.22	11.59
M_3	5.25	5.04	5.15	9.08	9.74	9.41
$CD_{0.05}$	**0.16**	**0.40**	**0.25**	**0.32**	**0.47**	**0.28**
Training Systems (T)						
T_1	5.96	5.71	5.84	10.96	11.73	11.35
T_2	5.70	5.55	5.62	10.15	11.27	10.71
$CD_{0.05}$	**0.13**	**NS**	**0.20**	**0.26**	**0.38**	**0.23**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Regarding two way interactions, non significant differences were obtained in all the interactions (pooled data as well as individual years) (Table 4.29) except P × M interaction during 2017-18 in which maximum values (6.49 mg/100 g) of lycopene content were obtained from the fruits produced on the plants grown on raised bed along with black

polythene mulch (P_1M_1) which produced non significant effects with P_1M_2 (6.40 mg/100 g) and minimum (5.11 mg/100 g) lycopene content was obtained in the fruits which were produced the by plants raised on flat bed without mulch (P_2M_3).

Table 4.29 Effect of two way interactions P × M, M × T and P x T on lycopene content and shelf life of tomato

Treatment combination	Lycopene content (mg/100 g of fresh weight)			Shelf life (days)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	6.49	6.14	6.31	13.01	13.02	13.01
P_1M_2	6.40	6.12	6.26	12.10	12.78	12.44
P_1M_3	5.43	5.21	5.32	9.15	9.98	9.57
P_2M_1	5.87	5.85	5.86	10.23	12.09	11.16
P_2M_2	5.69	5.59	5.64	9.83	11.65	10.74
P_2M_3	5.11	4.87	4.99	9.00	9.50	9.25
$CD_{0.05}$	**0.23**	**NS**	**NS**	**0.46**	**NS**	**0.13**
M_1T_1	6.34	6.05	6.20	12.21	12.70	12.45
M_1T_2	6.02	5.94	5.98	11.03	12.41	11.72
M_2T_1	6.17	6.00	6.09	11.53	12.57	12.05
M_2T_2	5.92	5.71	5.81	10.40	11.86	11.13
M_3T_1	5.38	5.07	5.23	9.14	9.92	9.53
M_3T_2	5.16	5.01	5.08	9.01	9.55	9.28
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.46**	**NS**	**0.39**
P_1T_1	6.25	5.87	6.06	11.79	12.20	12.00
P_1T_2	5.96	5.78	5.87	11.05	11.65	11.35
P_2T_1	5.68	5.55	5.62	10.13	11.26	10.69
P_2T_2	5.44	5.32	5.38	9.24	10.90	10.07
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Analysis of data (Table 4.30) regarding the three way interaction P × M × T (planting methods, mulching treatments and training system) revealed non-significant results during both the years of study as well as when the data were pooled.

In vegetable cultivation practices, raised bed planting system regulate soil moisture, increase soil temperature and microorganisms activity (Zhang *et al.*, 2012 and Ozer 2017). In raised bed planting system, the soil microorganism's activity is increased which improves nitrogen fixation, mineralization and enzyme activity. Increasing soil temperature, decreasing soil compaction and increasing soil bacteria also leads to improved quality in raised bed planting systems. The increased lycopene content of the fruits in raised bed planting system might be due to more absorbance of sunlight radiations during the growth and harvest period of the crop. According to Bahadur *et al.* (2013), it might be rapid drying of upper layer of

raised bed in comparison to flat bed which resulted into conservation of soil moisture required for the better plant growth, yield and fruit quality of tomato fruits.

Table 4.30 Effect of P × M × T interaction on lycopene content and shelf life of tomato

Treatment combination	Lycopene content (mg/100 g of fresh weight)			Shelf life (days)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	6.65	6.19	6.42	13.65	13.16	13.41
$P_1M_1T_2$	6.33	6.09	6.21	12.37	12.87	12.62
$P_1M_2T_1$	6.58	6.17	6.38	12.47	13.14	12.81
$P_1M_2T_2$	6.22	6.07	6.14	11.74	12.42	12.08
$P_1M_3T_1$	5.53	5.24	5.39	9.26	10.31	9.79
$P_1M_3T_2$	5.32	5.17	5.25	9.04	9.65	9.35
$P_2M_1T_1$	6.03	5.92	5.98	10.76	12.24	11.50
$P_2M_1T_2$	5.70	5.78	5.74	9.69	11.94	10.82
$P_2M_2T_1$	5.77	5.84	5.80	10.60	12.00	11.30
$P_2M_2T_2$	5.77	5.84	5.80	10.60	12.00	11.30
$P_2M_3T_1$	5.62	5.35	5.49	9.06	11.30	10.18
$P_2M_3T_2$	4.99	4.84	4.91	8.98	9.46	9.22
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

It may be due to the reason that the lycopene content of tomato fruits was significantly influenced with the microclimatic conditions of soil and plant. According to Moursi (2003) the improvement in the lycopene content of the fruits is due to the enhanced metabolic processes of the plant (increasing chemical composition of the fruits) in mulched plots. Abhivyakti and Kumari (2015) also reported that mulches also affect the lycopene content of tomato fruits.

Carotenoids, such as lycopene, are synthesized during ripening with the chlorophyll degradation process. In tomato, the pigment crystals (lycopene content) are deposited in the chromoplasts, which can be distributed along the harvests (Seymour *et al.,* 1993). According to Wien (1997), carotenoids production such as lycopene, is influenced by light exposure. The increase in lycopene content in the fruits of two stem trained plants could be due to effective utilization of sunlight because of wider spacing. Another possible reason could be that the two stem training system that resulted in plants with fewer branches but with larger leaves, and, consequently, with more self-shadowing, also showed the highest lycopene concentration in fruits of tomato.

4.2.4 Shelf life (days)

The data recorded on shelf life (days) of fruits as affected by different treatments have been presented in Table 4.28. Analysis of variance showed significant effects of various treatments. Raised bed planting method (P_1) contributed fruits which had maximum shelf life (11.67 days) while the fruits produced by flat bed planting method (P_2) recorded shelf life of only 10.38 days. Similar trend was followed during 2017-18 and 2018-19 years of the study. On the other hand, maximum (12.09 days) shelf life was recorded in those fruits which were produced by the plants grown on black polythene mulch (M_1) and it was closely followed (11.59 days) by those which were produced on silver/black mulch (M_2) while minimum (9.41 days) shelf life was obtained in no mulch treatment (M_3). Similar trend was followed during 2017-18 and 2018-19 years of the study. Two stem training system (T_1) produced significant results having 11.35 days shelf life as compared to those (10.71 days) fruits which were produced on the plants where three stem training system (T_2) was followed. Similar trend was followed during 2017-18 and 2018-19 years of the study.

The effect of various interactions on shelf life of fruits was also significant (Table 4.29). In P × M (planting methods and mulching treatments) interactions maximum values (13.01 days) were recorded from the plants grown on raised bed along with black polythene mulch (P_1M_1) and this interaction was significantly superior over other interactions. Minimum shelf life (9.25 days) was recorded in the fruits which were produced by plants raised on flat bed without mulch. Similar trend was also observed for both the years of study. However, non significant results were obtained during 2018-2019. During 2017-2018 maximum values of shelf life (12.21 days) were recorded in M_1T_1 and minimum (9.01 days) in M_3T_2. During 2017-18, maximum shelf life (13.01 days) was recorded in P_1M_1 and minimum (9.00 days) in P_3M_2. In M × T interaction (mulching treatments and training systems) maximum (12.45 days) shelf life was recorded in those fruits which were obtained on plants grown on black polythene mulch using two stem training system (M_1T_1) and this treatment combination was significantly superior over all other treatment combinations. The other two interactions i.e. M_1T_2 (11.72 days) and M_2T_1 (12.05 days) produced non significant effects between them and minimum (9.28 days) shelf life was recorded using M_3T_2 (no mulch and three stem training system) combinations, however, this treatment combinations, also produced non significant results with M_3T_1 (no mulch and two stem training system) which produced the fruits having shelf life of 9.53 days. Similar trend was also observed for both the years of study. Non significant results were obtained during 2018-2019. The interaction

between P × T (planting methods and training systems) produced non significant results during both the years of study as well as when the data were pooled.

Three factor interaction P × M × T (planting methods, mulching treatments and training systems), as tabulated in table 4.30 and figure 4.5 did not affect the shelf life of fruits in all the treatment combinations during both the years as well as when the data was pooled.

A raised bed can enable crop growth, yield and quality because of easier availability of soil amendments (Berle and Westerfield, 2013). It could be due to the reason that the translocation and mobilization of assimilates and nutrients are more in plants because of having more absorbance of radiations (greater exposed surface area) in raised beds which leads to better photosynthetic activity in the plants (Locher *et al.,* 2003). All these factors are responsible for firmness of the fruits which enhances the shelf life of fruits.

The shelf life of tomato is also very important quality parameter because it directly influences the market distance thereby getting higher benefits whereas fruits with poor shelf life are vulnerable to long distance transport and disease injury. Extended shelf life with the use of plastic mulch may be due the thicker flesh of the fruits as reflected by the higher dry matter content and also due to the presence of essential nutrients. The fruit firmness is strongly influenced by tomato fruit flesh tissues which ultimately becomes the cause for longer shelf life of the fruits. The results are in agreement with those obtained by Abhivyakti and Kumari (2015) in tomato. They found that among the mulches, the maximum shelf life was recorded under black mulch (25.0/20.0 days) followed by silver black and transparent mulch (18.0/15.0 and 18/12.0 days) and lowest self life was noticed under no mulch (15/11.0 days) treatments. Also, it can be suggested that the high firmness of tomato fruits immediately after harvesting is due to skin strength, which gradually weakens upon ripening and senescence, thus shortens the shelf life of the tomato fruit (Kere *et al.,* 2003).

The two stem trained plants were less prone to diseases attack than the three stem system which could be the possible reason for good shelf life and better quality of the fruits. Otherwise, quality characters are least influenced by the management practices. The yearly, variations may be ascribed to the weather conditions prevailing during both the years. In the present study, the increase in the shelf life of tomato fruits harvested from the two stem trained plants could be attributed to the accumulation of photo-assimilates which might be a possible reason to produce more firm fruit which is directly correlated with the enhanced

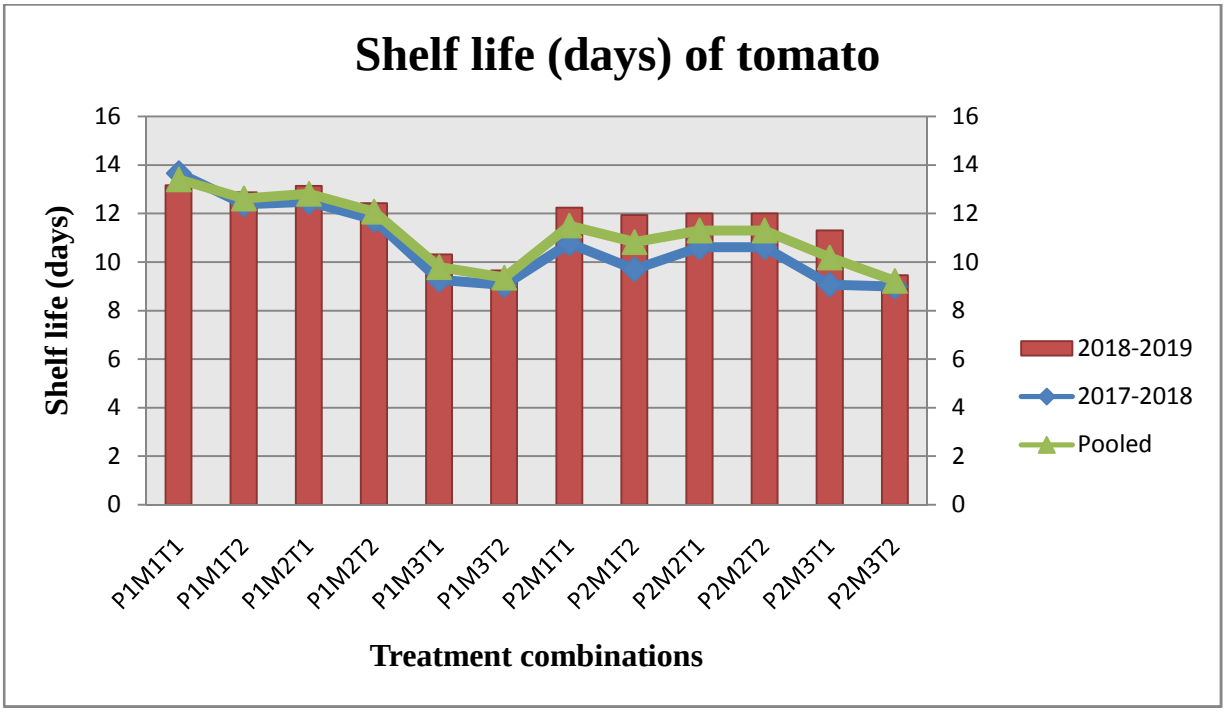


Fig.4.5. Effect of planting methods, mulching and training levels on shelf life (days) of tomato

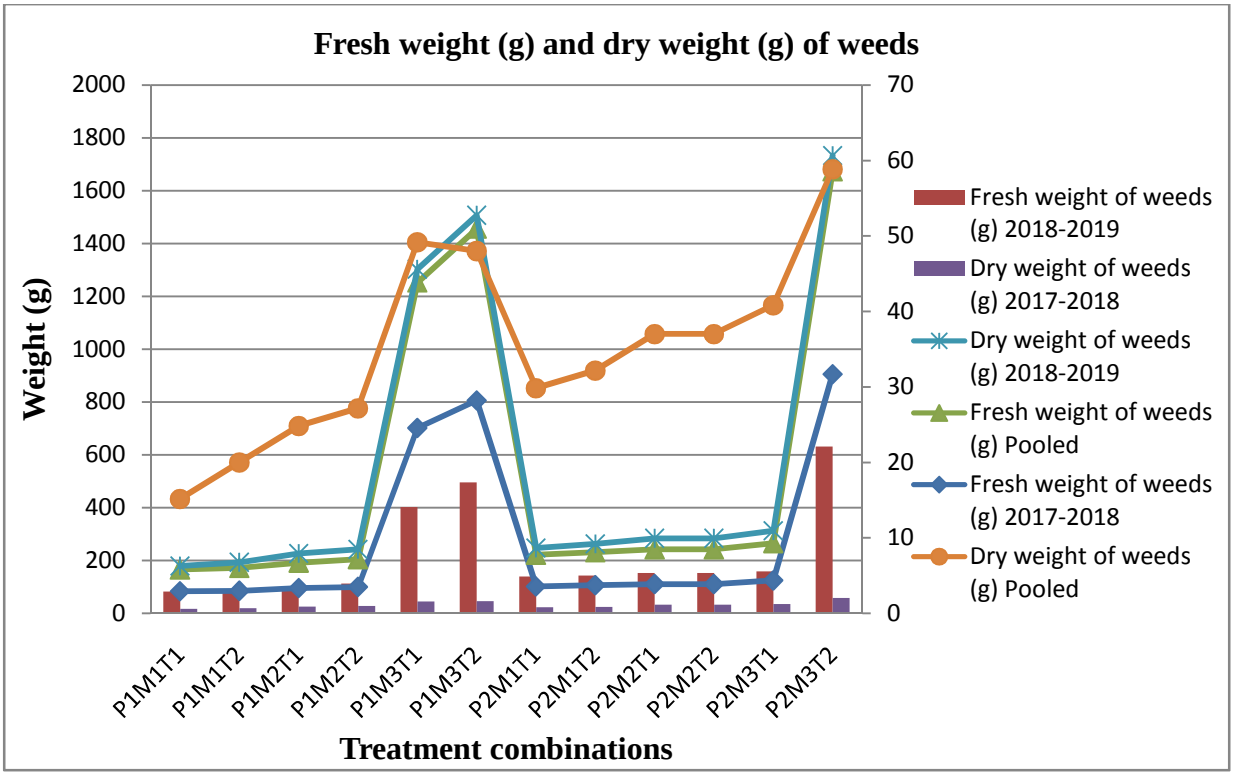


Fig.4.6 Effect of planting methods, mulching and training levels on fresh weight (g) and dry weight (g) of weeds in tomato crop

shelf life of the fruits (Alam *et al.*, 2016). Therefore, it could be ascertained that removal of more branches resulted in increased fruit firmness and hence, shelf life.

4.3 DISEASE PARAMETERS

4.3.1 Incidence of buckeye rot (%)

In the present studies data pertaining to incidence of buckeye rot (%) was significantly affected by various planting methods (Table 4.31). Minimum (14.91 %) incidence was reported in those plants which were grown on raised bed (P_1) and this treatment was significantly better over (17.64 %) flat bed (P_2). Similar, trend was observed during both the years of study. The effect of different mulches also showed significant effects. Minimum buckeye rot (14.15 %) incidence was reported in those plants which were produced using black polythene mulch (M_1). This treatment produced significant effect on silver/black mulch (M_2) which recorded 14.87 per cent disease incidence. Similar, trend was observed during both the years of study. Maximum disease incidence (19.80 %) was recorded from those plants which were not mulched (M_3). Training systems also produced significant effect on the incidence of buckeye rot in tomato fruits. Minimum (15.68 %) disease incidence of buck eye rot was observed in those plants which were trained on two stem training system (T_1) and maximum (16.87 %) incidence in those which were produced on the plants trained to three stem training system (T_2).

Table 4.31 Effect of planting methods, mulches and training systems on incidence of buckeye rot and severity of *Alternaria* leaf blight in tomato crop

Treatments	Incidence of buckeye rot (%)			Severity of *Alternaria* leaf blight (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	15.73 (3.95)	14.09 (3.74)	14.91 (3.85)	10.94 (3.28)	11.87 (3.41)	11.40 (3.35)
P_2	18.84 (4.33)	16.44 (4.04)	17.64 (4.19)	13.65 (3.69)	15.30 (3.90)	14.48 (3.80)
$CD_{0.05}$	**0.04**	**0.03**	**0.02**	**0.07**	**0.03**	**0.03**
Mulches (M)						
M_1	15.04 (3.87)	13.27 (3.64)	14.15 (3.76)	10.41 (3.21)	11.39 (3.35)	10.90 (3.28)
M_2	15.76 (3.96)	13.97 (3.73)	14.87 (3.85)	11.40 (3.36)	12.26 (3.49)	11.83 (3.43)
M_3	21.06 (4.59)	18.54 (4.30)	19.80 (4.45)	15.07 (3.88)	17.11 (4.13)	16.09 (4.01)
$CD_{0.05}$	**0.05**	**0.04**	**0.03**	**0.09**	**0.04**	**0.04**
Training Systems (T)						
T_1	16.71 (4.07)	14.65 (3.81)	15.68 (3.94)	11.80 (3.40)	12.86 (3.55)	12.33 (3.48)
T_2	17.86 (4.21)	15.87 (3.97)	16.87 (4.09)	12.79 (3.56)	14.31 (3.76)	13.55 (3.67)
$CD_{0.05}$	**0.04**	**0.03**	**0.02**	**0.07**	**0.03**	**0.03**

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The P × M (planting methods and mulching treatments) interaction produced significant effects (pooled data) on buckeye rot incidence and minimum (12.85 %) buckeye rot incidence was recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1). This interaction was significantly superior over other interactions and was followed by P_1M_2 (raised bed and silver/black mulch) interaction having 13.38 per cent buckeye rot incidence. Maximum buckeye rot incidence (21.10 %) was observed in the P_2M_3 (flat bed without mulch treatment) treatment combination. Same trend was observed during both the years of study. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects for buckeye rot disease incidence producing minimum values (13.26 %) in those plants which were grown on black mulch using two stem training system (M_1T_1). This treatment combination was significantly superior over all other combinations. Maximum (20.01 %) incidence of buckeye rot was recorded in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction was non significant on incidence of buckeye rot.

Table 4.32 Effect of two way interactions P × M, M × T and on P × T on incidence of buckeye rot and severity of *Alternaria* leaf blight in tomato crop

Treatment combination	Incidence of buckeye rot (%)			Severity of *Alternaria* leaf blight (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	13.61 (3.69)	12.09 (3.47)	12.85 (3.58)	8.48 (2.91)	9.10 (3.01)	8.79 (2.96)
P_1M_2	14.03 (3.74)	12.73 (3.57)	13.38 (3.66)	9.99 (3.15)	10.39 (3.22)	10.19 (3.18)
P_1M_3	19.57 (4.42)	17.43 (4.17)	18.50 (4.30)	14.34 (3.79)	16.12 (4.01)	15.23 (3.90)
P_2M_1	16.47 (4.06)	14.45 (3.80)	15.46 (3.93)	12.34(3.51)	13.67 (3.70)	13.01 (3.61)
P_2M_2	17.50 (4.18)	15.21 (3.90)	16.35 (4.04)	12.81 (3.58)	14.12 (3.76)	13.47 (3.67)
P_2M_3	22.54 (4.75)	19.66 (4.43)	21.10 (4.59)	15.81 (3.98)	18.11 (4.26)	16.96 (4.12)
$CD_{0.05}$	**NS**	**NS**	**0.04**	**0.12**	**0.06**	**0.06**
M_1T_1	14.19 (3.76)	12.34 (3.51)	13.26 (3.64)	9.79 (3.11)	10.52 (3.22)	10.15 (3.16)
M_1T_2	15.89 (3.98)	14.20 (3.77)	15.05 (3.87)	11.03 (3.31)	12.25 (3.49)	11.64 (3.40)
M_2T_1	15.12 (3.88)	13.25 (3.64)	14.19 (3.76)	10.50 (3.22)	11.14 (3.32)	10.82 (3.27)
M_2T_2	16.41 (4.04)	14.69 (3.83)	15.55 (3.94)	12.31 (3.51)	13.37 (3.65)	12.84 (3.58)
M_3T_1	20.82 (4.56)	18.37 (4.28)	19.59 (4.42)	15.11 (3.88)	16.93 (4.11)	16.02 (4.00)
M_3T_2	21.30 (4.61)	18.72 (4.33)	20.01 (4.47)	15.04 (3.88)	17.30 (4.16)	16.17 (4.02)
$CD_{0.05}$	**0.07**	**0.05**	**0.04**	**0.12**	**0.05**	**0.06**
P_1T_1	15.21 (3.88)	14.33 (3.65)	14.33 (3.77)	10.08 (3.14)	11.08 (3.29)	10.58 (3.22)
P_1T_2	16.25 (4.02)	15.49 (3.83)	15.49 (3.92)	11.80 (3.42)	12.66 (3.54)	12.23 (3.48)
P_2T_1	18.20 (4.25)	17.03 (3.97)	17.03 (4.11)	13.51 (3.67)	14.65 (3.82)	14.08 (3.74)
P_2T_2	19.47 (4.41)	18.24 (4.12)	18.24 (4.26)	13.79 (3.71)	15.95 (3.99)	14.87 (3.85)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.10**	**0.04**	**0.05**

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The effect of various three way interactions P × M × T produced significant effects (pooled data) on incidence of buckeye rot in tomato (Table 4.33). Minimum (11.99 %) incidence of disease was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system) which was significantly superior from all other treatment combinations, however, maximum (21.13 %) disease incidence was recorded in those plants which were raised on flat beds without mulch using three stem training system ($P_2M_3T_2$).

Table 4.33 Effect of P × M × T interaction on incidence of buckeye rot and severity of *Alternaria* leaf blight in tomato crop

Treatment combination	Incidence of buckeye rot (%)			Severity of *Alternaria* leaf blight (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	12.83 (3.58)	11.14 (3.34)	11.99 (3.46)	7.53 (2.74)	8.14 (2.85)	7.84 (2.80)
$P_1M_1T_2$	14.38 (3.79)	13.04 (3.61)	13.71 (3.70)	9.43 (3.07)	10.05 (3.17)	9.74 (3.12)
$P_1M_2T_1$	13.61 (3.69)	12.13 (3.48)	12.87 (3.59)	8.47 (2.90)	9.14 (3.02)	8.81 (2.97)
$P_1M_2T_2$	14.44 (3.80)	13.33 (3.65)	13.89 (3.73)	11.51 (3.39)	11.64 (3.41)	11.58 (3.40)
$P_1M_3T_1$	19.19 (4.38)	17.05 (4.13)	18.12 (4.26)	14.23 (3.77)	15.95 (3.99)	15.09 (3.88)
$P_1M_3T_2$	19.95 (4.47)	17.82 (4.22)	18.88 (4.35)	14.45 (3.80)	16.29 (4.04)	15.37 (3.92)
$P_2M_1T_1$	15.54 (3.94)	13.53 (3.68)	14.54 (3.81)	12.04 (3.47)	12.89 (3.59)	12.47 (3.53)
$P_2M_1T_2$	17.40 (4.17)	15.37 (3.92)	16.38 (4.05)	12.64 (3.55)	14.45 (3.80)	13.55 (3.68)
$P_2M_2T_1$	16.62 (4.08)	14.38 (3.79)	15.50 (3.94)	12.52 (3.54)	13.15 (3.62)	12.83 (3.58)
$P_2M_2T_2$	16.62 (4.08)	14.38 (3.79)	15.50 (4.15)	12.52 (3.54)	13.15 (3.62)	12.83 (3.58)
$P_2M_3T_1$	18.38 (4.29)	16.04 (4.00)	17.21 (4.15)	13.10 (3.62)	15.10 (3.89)	14.10 (3.75)
$P_2M_3T_2$	22.64 (4.76)	19.62 (4.43)	21.13 (4.60)	15.63 (3.95)	18.31 (4.28)	16.97 (4.12)
$CD_{0.05}$	NS	NS	0.06	NS	NS	NS

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver/black polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

Buckeye rot appears on tomato under mid-hill conditions any time after May, when the warm and rainy season begins and continues till September or late fall. The disease is caused by *Phytophthora nicotianae* var. *parasitica*. The fungus overwinters in the soil in the form of oospores or chlamydospores and can remain active in soil for at least one year without the support of a susceptible host. With the onset of monsoon rains, in the presence of high soil moisture and moderate temperatures (20-25°C), the chlamydospores and oospores start germinating by producing mycelium and sporangia. The sporangia in turn produce biflagellate zoospores, which are splashed by rain on the fruits. Maximum fruit infection under field conditions occurs at a temperature range of 20-25°C, RH > 80 per cent and high rainfall conditions. The disease is not expected to occur below 20°C, though at 22.5°C or above, even a slight rainfall (10 mm) will result in disease appearance, which is expected to

appear after 4 days of infection. The symptoms develop on fruits after 3-4 day of infection. Infected fruit become mummified and fall down on the ground. The sporangia produced on infected fruits, liberate zoospores which are again splashed by rain and cause secondary infection.

4.3.2 *Alternaria* leaf blight severity (%)

In the present studies, data pertaining to severity of *Alternaria* leaf blight (%) was significantly affected by various planting methods (Table 4.31). Minimum (11.40 %) severity was reported in those plants which were grown on raised bed (P_1) and this treatment was significantly better (14.48 %) over flat bed (P_2). Similar, trend was observed during both the years of study. The effect of different mulches also showed significant effects. Minimum disease (10.90 %) severity was reported in those plants which were produced using black polythene mulch (M_1). This treatment produced significant effects on silver/black mulch (M_2) which recorded 11.83 per cent disease severity. Similar, trend was observed during both the years of study. Maximum disease severity i.e. (16.09 %) was reported from those plants which were not mulched (M_3). Training systems also produced significant effects on the severity of *Alternaria* leaf blight in tomato. Minimum (12.33 %) disease severity was recorded in those plants which were trained by two stem training system (T_1) and maximum (13.55 %) disease severity in those which were trained by using three stem training system (T_2).

The effect of two way interaction (Table 4.32) was also significant. The P × M (planting methods and mulching treatments) interaction produced significant effects (pooled data) on disease severity (%) and minimum (8.79 %) disease severity was recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1). This interaction was significantly superior over other interactions and was followed by P_1M_2 (raised bed and silver/black mulch) interaction having 10.19 per cent disease severity. Two another interactions i.e. P_2M_1 (13.01) and P_2M_2 (13.47 %) produced non significant effects between themselves and maximum (16.96 %) disease severity was recorded in P_2M_3 (raised bed without mulch) combinations. Same trend was observed during both the years of study. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects on disease severity producing minimum values (10.15 %) in those plants which were grown on black mulch using two stem training system (M_1T_1). This treatment combination was significantly superior over all other combinations, but two interactions i.e.

M_3T_1 (16.02 %) and M_3T_2 (16.17 %) were at par with each other. Maximum (16.17 %) severity of bacterial leaf spot was recorded in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction was also significant on disease severity. Minimum (10.58 %) disease severity was recorded in P_1T_1 (raised bed and two stem training system) and maximum (14.87 %) in P_2T_2 (flat bed and three stem training systems). Same trend was observed during both the years of study.

The effect of various three way interactions P × M × T produced non significant effects on severity of *Alternaria* leaf blight (Table 4.33).

The disease is caused by three different species of *Alternaria viz., Alternaria solani Alternaria alternata* and *Alternaria alternata* f.sp. *lycopersici*. *Alternaria* species survive in diseased plants debris and can persist for one to two years. Seed borne nature of *A. solani* has also been reported. Primary infection of lower leaves first takes place through conidia formed on crop debris in soil. Secondary spread of the disease occurs through conidia developed on primary spots. These conidia are blown by wind, water and insects to the neighbouring leaves of plants. The optimum temperature for infection of *A. solani* is 28 to 30°C while for *A. alternata f.* sp. *lycopersici* and *A. alternata*, it ranges between 25-30 and 20-25°C, respectively. Maximum dispersal of conidia occurs in advanced stages of disease development and in between 9 am and 12 noon.

4.3.3 Bacterial leaf spot severity (%)

In the present studies, data pertaining to severity of bacterial leaf spot (%) was significantly affected by various planting methods (Table 4.34). Minimum (4.78 %) severity of bacterial leaf spot was reported in those plants which were grown on raised bed (P_1) and this treatment was significantly better over (5.69 %) flat bed (P_2). Similar, trend was observed during both the years of study. The effect of different mulches also showed significant effects. Minimum disease (4.64 %) severity was reported in those plants which were produced using black polythene mulch (M_1). This treatment produced significant effects on treatments involving silver/black mulch (M_2) which recorded 4.94 per cent disease severity. Similar, trend was observed during both the years of study. Maximum disease severity i.e. 6.14 per cent severity was recorded in those plants which were not mulched (M_3). Training systems also produced significant effects on the severity of bacterial leaf spot disease in

tomato. Minimum (5.02 %) disease severity was recorded in those plants which were trained to two stem training system (T_1) and maximum (5.46 %) disease of severity in those which were produced on the plants trained by using three stem training system (T_2).

Table 4.34 Effect of planting methods, mulches and training systems on severity of bacterial leaf spot and incidence of *Fusarium* wilt in tomato

Treatments	Severity of bacterial leaf spot (%)			Incidence of *Fusarium* wilt (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	5.01 (2.23)	4.56 (2.13)	4.78 (2.18)	9.24 (3.02)	9.91 (3.13)	9.57 (3.08)
P_2	5.94 (2.43)	5.44 (2.33)	5.69 (2.38)	11.43 (3.37)	12.45 (3.52)	11.94 (3.45)
$CD_{0.05}$	**0.04**	**0.06**	**0.03**	**0.03**	**0.03**	**0.02**
Mulches (M)						
M_1	4.83 (2.19)	4.46 (2.10)	4.64 (2.15)	8.55 (2.91)	9.86 (3.13)	9.21 (3.02)
M_2	5.18 (2.27)	4.70 (2.17)	4.94 (2.22)	9.49 (3.07)	10.43 (3.22)	9.96 (3.15)
M_3	6.43 (2.53)	5.85 (2.41)	6.14 (2.47)	12.97 (3.60)	13.24 (3.64)	13.10 (3.62)
$CD_{0.05}$	**0.05**	**0.08**	**0.04**	**0.04**	**0.03**	**0.03**
Training Systems (T)						
T_1	5.34 (2.30)	4.70 (2.16)	5.02 (2.23)	9.75 (3.10)	10.48 (3.22)	10.12 (3.16)
T_2	5.61 (2.36)	5.31 (2.30)	5.46 (2.33)	10.92 (3.29)	11.88 (3.44)	11.40 (3.36)
$CD_{0.05}$	**0.04**	**0.06**	**0.03**	**0.03**	**0.03**	**0.02**

*The figures in parentheses represent square root transformed values
P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The effect of two way interaction (Table 4.35) was also significant. The P × M (planting methods and mulching treatments) interaction produced significant effects (pooled data) on disease severity (%) and minimum (4.10 %) disease severity was recorded when the plants were grown on raised beds using black polythene mulch (P_1M_1). This interaction was significantly superior over other interactions and was followed by P_1M_2 (raised bed and silver/black mulch) interaction having 4.61 per cent disease severity. Two another interactions i.e. P_2M_1 (5.19 %) and P_2M_2 (5.26 %) also produced non significant differences between themselves and maximum (6.63 %) disease severity was recorded in P_2M_3 (raised bed without mulch) combination. Same trend was observed during both the years of study. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects on disease severity producing minimum values (4.23 %) in those plants which were grown on black mulch using two stem training system (M_1T_1). This treatment combination was significantly superior over all other combinations, but two interactions i.e. M_3T_1 (6.07 %) and M_3T_2 (6.20 %) were at par with each other. Maximum (5.06 %) severity of bacterial leaf spot was, however, recorded in M_1T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P

× T (planting methods and training systems) interaction was also significant on disease severity. Minimum (4.44 %) disease severity was recorded in P_1T_1 (raised bed and two stem training system) and maximum (5.78 %) in P_2T_2 (flat bed and three stem training systems), however this treatment i.e. P_2T_2 was at par with P_2T_1 (5.61 %). Same trend was observed during both the years of study.

Table 4.35 Effect of two way interactions P × M, M × T and P × T on severity of bacterial leaf spot and incidence of *Fusarium* wilt in tomato

Treatment combination	Severity of bacterial leaf spot (%)			Incidence of *Fusarium* wilt (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	4.26 (2.06)	3.95 (1.97)	4.10 (2.02)	7.40 (2.71)	8.26 (2.87)	7.83 (2.79)
P_1M_2	4.76 (2.18)	4.47 (2.11)	4.61 (2.15)	8.31 (2.88)	9.16 (3.02)	8.74 (2.95)
P_1M_3	6.02 (2.45)	5.26 (2.29)	5.64 (2.37)	12.01 (3.46)	12.30 (3.51)	12.16 (3.49)
P_2M_1	5.40 (2.32)	4.98 (2.23)	5.19 (2.28)	9.70 (3.11)	11.46 (3.38)	10.58 (3.25)
P_2M_2	5.60 (2.36)	4.93 (2.22)	5.26 (2.29)	10.67 (3.26)	11.70 (3.42)	11.18 (3.34)
P_2M_3	6.83 (2.61)	6.43 (2.53)	6.63 (2.57)	13.92 (3.73)	14.18 (3.76)	14.05 (3.75)
$CD_{0.05}$	**NS**	**NS**	**0.05**	**0.06**	**NS**	**0.04**
M_1T_1	4.47 (2.10)	3.99 (1.98)	4.23 (2.04)	7.81 (2.78)	9.06 (2.99)	8.43 (2.89)
M_1T_2	5.19 (2.28)	4.94 (2.22)	5.06 (2.55)	9.30 (3.04)	10.66 (3.26)	9.98 (3.15)
M_2T_1	5.02 (2.24)	4.52 (2.12)	4.77 (2.18)	8.93 (2.98)	9.76 (3.11)	9.34 (3.05)
M_2T_2	5.34 (2.31)	4.88 (2.21)	5.11 (2.26)	10.05 (3.16)	11.11 (3.33)	10.58 (3.25)
M_3T_1	6.55 (2.56)	5.59 (2.36)	6.07 (2.46)	12.53 (3.54)	12.62 (3.55)	12.58 (3.54)
M_3T_2	6.30 (2.51)	6.10 (2.46)	6.20 (2.49)	13.41 (3.66)	13.86 (3.72)	13.63 (3.69)
$CD_{0.05}$	**0.07**	**NS**	**0.05**	**0.07**	**0.05**	**0.04**
P_1T_1	4.74 (2.16)	4.13 (2.02)	4.44 (2.09)	8.54 (2.90)	9.06 (2.99)	8.80 (2.95)
P_1T_2	5.28 (2.30)	4.98 (2.23)	5.13 (2.26)	9.94 (3.14)	10.75 (3.27)	10.35 (3.21)
P_2T_1	5.95 (2.43)	5.26 (2.29)	5.61 (2.36)	10.96 (3.30)	11.90 (3.45)	11.43 (3.70)
P_2T_2	5.93 (2.43)	5.63 (2.37)	5.78 (2.40)	11.90 (3.44)	0.27 (0.04)	12.45 (3.52)
$CD_{0.05}$	**0.06**	**0.09**	**0.04**	**0.05**	**0.09**	**0.03**

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

The effect of various three way interactions P × M × T also produced significant effects (2017-18, 2018-19 and pooled data) in terms of severity of bacterial leaf spot (Table 4.36). Minimum per cent (3.38 %) disease severity was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system) which was significantly superior over all other treatment combinations, however, maximum (6.69 %) disease severity was recorded in those plants (pooled data) which were raised on flat bed without mulch using three stem training system ($P_2M_3T_2$).

Bacterial leaf spot is caused by *Xanthomonas campestris* pv. *vesicatoria.* It causes symptoms throughout the above-ground portion of the plant including leaf spots, fruit spots

and stem cankers. Since this bacterium can not live in soil for more than a few weeks and survives as inoculum on plant debris, removal of dead plant material is a necessity. Environment plays a great role in bacterial spot of tomato. The bacterium requires high levels of humidity to such an extent that infected plants may not begin to show symptoms until several days after infection if ambient humidity is low. *Xanthomonas campestris* pv. *vesicatoria* is a big problem in greenhouses and nurseries where very high humidity and warm temperatures provide a good environment for the bacteria to grow and wet soils easily transmit the disease from plant to plant.

Table 4.36 Effect of P × M × T interaction on severity of bacterial leaf spot and incidence of *Fusarium* wilt in tomato

Treatment combination	Severity of bacterial leaf spot (%)			Incidence of *Fusarium* wilt (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	3.61 (1.90)	3.14 (1.77)	3.38 (1.84)	6.44 (2.54)	7.07 (2.66)	6.76 (2.60)
$P_1M_1T_2$	4.90 (2.21)	4.75 (2.17)	4.36 (2.19)	8.36 (2.89)	9.46 (3.08)	8.91 (2.98)
$P_1M_2T_1$	4.59 (2.14)	4.14 (2.03)	4.36 (2.09)	7.69 (2.77)	8.11 (2.85)	7.90 (2.81)
$P_1M_2T_2$	4.92 (2.22)	4.79 (2.19)	4.86 (2.20)	8.93 (2.99)	10.21 (3.20)	9.57 (3.09)
$P_1M_3T_1$	6.01 (2.45)	5.12 (2.26)	5.57 (2.36)	11.50 (3.54)	12.01 (3.47)	11.76 (3.43)
$P_1M_3T_2$	6.02 (2.45)	5.40 (2.32)	5.71 (2.39)	12.52 (3.03)	12.59 (3.55)	12.56 (3.54)
$P_2M_1T_1$	5.32 (2.31)	4.83 (2.20)	5.08 (2.25)	9.17 (3.20)	11.06 (3.32)	10.11 (3.18)
$P_2M_1T_2$	5.47 (2.34)	5.12 (2.26)	5.30 (2.30)	10.24 (3.20)	11.87 (3.44)	11.05 (3.32)
$P_2M_2T_1$	5.44 (2.33)	4.89 (2.21)	5.17 (2.27)	10.16 (3.19)	11.41 (3.38)	10.79 (3.28)
$P_2M_2T_2$	5.44 (2.33)	4.89 (2.21)	5.17 (2.27)	10.16 (3.19)	11.41 (3.38)	10.79 (3.28)
$P_2M_3T_1$	5.75 (2.40)	4.96 (2.23)	5.36 (2.31)	11.17 (3.34)	12.00 (3.46)	11.58 (3.40)
$P_2M_3T_2$	5.44 (2.33)	6.80 (2.61)	6.69 (2.59)	14.29 (3.78)	15.13 (3.89)	14.71 (3.83)
$CD_{0.05}$	**0.10**	**0.15**	**0.07**	**NS**	**0.07**	**0.05**

*The figures in parentheses represent square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

4.3.4 Incidence of *Fusarium* wilt (%)

In the present studies data pertaining to incidence of *Fusarium* wilt (%) was significantly affected by various planting methods (Table 4.34). Minimum (9.57 %) incidence (%) was reported in those plants which were grown on raised bed (P_1) and this treatment was significantly better (11.94 %) over flat bed (P_2). Similar, trend was observed during both the years of study. The effect of different mulches also showed significant effects. Minimum *Fusarium* wilt (9.21 %) incidence was reported in those plants which were produced using black polythene mulch (M_1). This treatment produced significant effects on silver/black mulch (M_2) which recorded 9.96 per cent disease incidence. Similar, trend was observed

during both the years of study. Maximum disease incidence i.e. 13.10 per cent was recorded from those plants which were not mulched (M_3). Training systems also produced significant effects on the incidence of *Fusarium* wilt in tomato plants. Minimum (10.12 %) disease incidence was recorded in those plants which were trained on two stem training system (T_1) and maximum 11.40 per cent *Fusarium* wilt incidence in those plants which were trained using three stem training system (T_2).

The effect of two way interaction (Table 4.35) was also significant. The P × M (planting methods and mulching treatments) interaction produced significant effects (pooled data) on *Fusarium* wilt incidence (%) and minimum (7.83 %) values were recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1). This interaction was significantly superior over other interactions and was followed by P_1M_2 (raised bed and silver/black mulch) interaction having 8.74 per cent *Fusarium* wilt incidence. Maximum wilt incidence (14.05 %) was observed in P_2M_3 (flat bed without mulch treatment) treatment combination. Same trend was observed during both the years of study. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects on *Fusarium* wilt incidence producing minimum values (8.43 %) in those plants which were grown on black mulch using two stem training system (M_1T_1). This treatment combination was significantly superior over all other combinations. Maximum (13.63 %) incidence of *Fusarium* wilt was recorded in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction also produced significant effects on incidence of *Fusarium* wilt. Minimum (8.80 %) disease incidence was recorded in P_1T_1 (raised bed and two stem training system) and maximum (12.45 %) in P_2T_2 (flat bed and three stem training systems). This treatment combination was significantly superior over all other combinations. Same trend was observed during both the years of study

The effect of various three way interactions P × M × T also produced significant effect of incidence of *Fusarium* wilt in tomato plants (Table 4.36). Minimum (6.76 %) disease incidence was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system) which was significantly superior over all other treatment combinations, however, maximum (14.71 %) *Fusarium* wilt incidence was recorded in those plants which were raised on flat bed, without mulch using three stem training system ($P_2M_3T_2$).

The *Fusarium* wilt is caused by the fungus *Fusarium oxysporum* Schlechtend f.sp. *lycopersici* (Sacc.) Snyder and Hans. The pathogen is soil borne in nature and overwinters in the infected plant debris and in the soil as mycelium and spore forms especially as chlamydospores. It spreads over small distances by means of water and contaminated farm equipments, and over long distances, primarily in infected transplants or in the soil carried with them. Usually, once an area becomes infested with *Fusarium*, it remains there indefinitely. The optimum soil temperature for disease development varies from 25-31 ^{o}C. Hot dry weather favour wilt development. The disease is more severe in acidic soils (5.6 to 6.5 pH) than in alkaline ones. Presence of root knot nematodes and monoculture enhance the disease further. Low nitrogen and high potassium levels in soil predisposes the plant to this disease. The disease first appears in the field as yellowing of the lower leaves most commonly at the time of flowering stage. The affected leaves die prematurely and the symptoms continue to appear on successively younger leaves. One or more branches may be affected while the others remain symptom less. Browning of the vascular bundles follows rather promptly, and is best seen by cutting of stem or petiole and examining a cross section.

Raised bed method of planting offer better conditions for the plant to grow since they warm up more quickly and drain better. In the present case, better drainage conditions coupled with quick warming of the upper layer as well as beneath of the soil might have created conditions which are not suitable for the development of various disease causing organisms. This might have resulted into less growth of the germinating spores and insufficient disease causing inoculum. Similar are the findings of Sharma *et al.* (2016) who observed that the disease incidence in the bell pepper plants grown on raised beds and ridges were low as compared to the flat beds.

The results of present study also revealed low incidence of buckeye rot in different treatments may be due to the prevalence of non-congenial environmental conditions. However, the incidence was comparatively less in the black polythene as compared to the others. The reduced buckeye rot incidence with black polythene mulch may be due to the fact that mulches mitigate the harmful effect of soil borne fungi and create a barrier to the pathogen which causes the disease. The results are in conformity with the findings of Mehta *et al*. (2010) in tomato. The minimum incidence of early blight was observed in black polythene mulch and it might be due to the reason that plastic mulching acts as a barrier between soil and plant and keeps away the foliage and fruits from soil contact. Mulch also

prevents soil splash on lower canopy as soil often consist disease causing conidial spores (Bhujbal *et al.*, 2015). Mulching (black polythene or other) resulted in increased temperature in soil ecosystem which proves to be lethal to tomato wilt pathogen. Mulching is basically an addition of a thick layer of mulch on the soil surface to help control weeds, optimise soil moisture and keep the soil cooler which influence plant response to *Fusarium* wilt incidence. It helps in disease control by standing as a barrier between the plant parts above the ground and plant pathogen in the soil. Since it helps to control weeds, it also helps in altering the environment for these pathogens thereby creating unfavourable conditions for them and controlling diseases. In order to avoid splashing soil borne diseases on tomato leaves during watering, mulching of the plant is advised. The results are in line with the findings of Caroline *et al.* (2013) in tomato. The unmulched plots remained more saturated for a quite long time without any improvement in the drainage system which might have resulted into more incidence/severity of diseases. In our opinion, improved soil drainage through black plastic mulching could be the reason for less disease incidence/severity. Bala (2012) also observed that the black polyethylene mulch proved to be most effective to lowest incidence of buckeye rot and minimum *Alternaria* blight severity. Lyimo *et al.* (1998) also studied the effect of mulching and staking on the development of early and late leaf blight of tomato caused by *Alternaria solani* and *Phytophthora infestans* respectively. They reported that mulching and staking significantly reduced the incidence of early and late blight by 5 to 20 per cent as compared to unmulched and unstaked control. The apparent rate of infection of the two pathogen was also significantly lower in mulched and staked tomato. Mulching was more effective than staking in suppressing early and late blight diseases in tomato.

In two stem training system, incidence of the disease was low because the plants were more erect as compared to three stem training system and foliage and fruits up to a height of 15-20 cm were removed which could avoid the moist and stagnant air conditions for the pathogen to perpetuate. This might be the suitable reason for less buckeye rot incidence in two stem trained plants. More incidence/severity of different diseases in three stem training system might be due to more number of branches/laterals which could have created suffocative conditions which are desirable for the development of the disease. On the other hand, less number of branches will provides more passage of air and sunlight towards the soil and less suffocative conditions might have resulted into less disease spread. Similar findings on various diseases have also been reported by Mehta *et al.* (2010) in tomato crop.

4.4 WEED PARAMETERS

4.4.1 Weed count (m^{-2})

The data recorded on the effect of various treatments pertaining to weed count have been presented in table 4.37. It is clear from the data that significant variations were observed during 2017-2018, 2018-2019 and when the data were pooled. Minimum (513.67) number of weeds was counted in the plots which were raised (P_1) and maximum (584.08) weed count was taken in those plots which were not raised (P_2). Similar were the observations during both the years. The influence of various mulches on weed count was also noted to be significant. Minimum (252.04) weed count was observed in the plots which were covered with black polythene mulch (M_1) followed by those 334.50 which were covered with silver/black mulch (M_2), whereas, maximum (1060.08) weed count was taken in those plots which were not mulched (M_3). Similar trend was observed for both the years of study. The different training systems also produced significant effects on the weed count during the year 2018-19 in and pooled data whereas, non significant results were obtained during the year 2017-18. Minimum (526.81) values of weed count (pooled data) were recorded in the plots where two stem training system was followed (T_1) and maximum (570.94) in those plots where three stem training system was used (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

Table 4.37 Effect of planting methods, mulches and training systems on weed count and weed control efficiency in tomato crop

Treatments	Weed count ($^{m-2}$)			Weed control efficiency (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	559.44	467.89	513.67	48.24 (48.24)	42.53 (40.24)	45.38 (41.98)
P_2	627.00	541.17	584.08	36.43 (34.17)	28.04 (28.68)	32.23 (31.53)
$CD_{0.05}$	**31.24**	**41.43**	**27.34**	**2.50**	**2.20**	**1.54**
Mulches (M)						
M_1	296.67	207.42	252.04	63.69 (53.02)	62.74 (52.62)	63.21 (52.77)
M_2	367.33	301.67	334.50	48.38 (44.05)	33.08 (34.92)	40.73 (39.58)
M_3	1115.67	1004.50	1060.08	14.94 (19.66)	10.03 (15.84)	12.48 (17.91)
$CD_{0.05}$	**38.26**	**50.74**	**33.49**	**3.06**	**2.69**	**1.89**
Training Systems (T)						
T_1	580.67	472.94	526.81	45.05 (41.69)	38.83 (37.61)	41.94 (39.73)
T_2	605.78	536.11	570.94	39.63 (36.13)	31.74 (31.31)	35.68 (33.78)
$CD_{0.05}$	**NS**	**41.43**	**27.34**	**2.50**	**2.20**	**1.54**

*Figures in the parenthesis represents arc sign root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Analysis of data revealed non significant differences (Table 4.38 and 4.39) for two way and three way interactions pertaining to weed count.

Less number of weeds on the raised beds could be due to less tillage and maintainance of the raised bed since, once the soil in a raised bed is stabilized, compaction is almost non existent, so the need for tillage is minimal. Therefore, the weed population decreased over time in a raised bed which are well cared and managed. Also, raised beds warm up more quickly during the spring season, therefore drains better and provides better conditions for the plants to grow which ultimately result in less crop weed competition. All such situations result in better and early establishment of crop plants allowing less or minimum growth of the weeds. Another possibility could be that better establishment and better care of the plants allows less light to penetrate which is required for carrying out the photosynthetic activities by the weeds, therefore resulting into reduced growth of the weeds.

Table 4.38 Effect of two way interactions P × M, M × T and P × T on weed count and weed control efficiency in tomato crop

Treatment combinations	Weed count ($^{m-2}$)			Weed control efficiency (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	240.33	175.67	208.00	68.61 (55.96)	71.47 (57.92)	70.04 (56.87)
P_1M_2	335.67	285.17	310.42	54.83 (47.78)	40.22 (39.35)	47.53 (43.58)
P_1M_3	1102.33	942.83	1022.58	21.29 (27.21)	15.89 (23.44)	18.59 (25.48)
P_2M_1	353.00	239.17	296.08	58.78 (50.07)	54.01 (47.31)	56.39 (48.68)
P_2M_2	399.00	318.17	358.58	41.94 (40.33)	25.93 (30.49)	33.93 (35.57)
P_2M_3	1129.00	1066.17	1097.58	8.58 (12.10)	4.18 (8.23)	6.38 (10.35)
$CD_{0.05}$	**NS**	**NS**	**NS**	**4.33**	**NS**	**2.67**
M_1T_1	282.50	181.50	232.00	65.09 (53.87)	68.19 (55.96)	66.64 (54.85)
M_1T_2	310.83	233.33	272.08	62.29 (52.17)	57.29 (49.27)	59.79 (50.70)
M_2T_1	348.67	287.67	318.17	50.66 (45.38)	36.04 (36.82)	43.35 (41.14)
M_2T_2	386.00	315.67	350.83	46.11 (42.73)	30.12 (33.02)	38.11 (38.01)
M_3T_1	1110.83	949.67	1030.25	19.39 (25.83)	12.25 (20.05)	15.82 (23.19)
M_3T_2	1120.50	1059.33	1089.92	10.48 (13.48)	7.81 (11.62)	9.15 (12.63)
$CD_{0.05}$	**NS**	**NS**	**NS**	**4.33**	**NS**	**2.67**
P_1T_1	549.33	422.44	485.89	49.51 (44.42)	45.45 (42.07)	47.48 (43.26)
P_1T_2	569.56	513.35	541.44	46.98 (42.88)	39.61 (38.40)	43.29 (40.69)
P_2T_1	612.00	523.44	567.72	40.59 (38.96)	32.21 (33.14)	36.40 (36.20)
P_2T_2	642.00	558.89	600.44	32.27 (29.38)	23.87 (24.21)	28.07 (26.87)
$CD_{0.05}$	**NS**	**NS**	**NS**	**3.54**	**3.11**	**2.18**

*Figures in the parenthesis represents arc sign root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Table 4.39 Effect of P × M × T interaction on weed count and weed control efficiency in tomato crop

Treatment combination	Weed count (m^{-2})			Weed control efficiency (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	236.67	142.00	189.33	69.97 (56.83)	78.26 (62.24)	74.11 (59.42)
$P_1M_1T_2$	244.00	209.33	226.67	67.24 (55.10)	64.68 (52.61)	65.96 (54.32)
$P_1M_2T_1$	317.67	265.33	291.50	56.94 (48.99)	41.93 (40.35)	49.43 (44.68)
$P_1M_2T_2$	353.67	305.00	329.33	52.73 (46.56)	38.52 (38.35)	45.62 (42.48)
$P_1M_3T_1$	1093.67	860.00	976.83	21.62 (27.45)	16.15 (23.64)	18.89 (25.69)
$P_1M_3T_2$	1111.00	1025.67	1068.33	20.97 (26.97)	15.62 (23.24)	18.30 (25.26)
$P_2M_1T_1$	328.33	221.00	274.67	60.22 (50.92)	58.12 (49.68)	59.17 (50.28)
$P_2M_1T_2$	377.67	257.33	317.50	57.33 (49.23)	49.89 (44.94)	53.61 (47.07)
$P_2M_2T_1$	379.67	310.00	344.83	44.39 (41.77)	30.14 (33.29)	37.27 (37.61)
$P_2M_2T_2$	379.67	310.00	344.83	44.39 (41.77)	30.14 (33.29)	37.27 (37.61)
$P_2M_3T_1$	418.33	326.33	372.33	39.98 (30.90)	21.71 (27.69)	30.60 (33.53)
$P_2M_3T_2$	1130.00	1093.00	1111.50	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
$CD_{0.05}$	NS	NS	NS	6.12	5.39	3.78

*Figures in the parenthesis represents arc sign root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Number of weeds per unit area is an important factor relating to plant vigour and yield of the plant. The present results indicate that black polythene mulch was comparatively more effective than silver/black mulch in suppressing the weed growth. According to Ashrafuzzaman *et al.* (2011), this might be due to the prevention of the entry of solar radiations through black polythene mulch as well as due to higher soil temperature and moisture content especially in the upper 5 cm layer. Black plastic mulch allowed the emergence of weeds only through the punch but in very less number and it might be due to lack of light through the black plastic mulch. Similar results were observed by Ashrafuzzaman *et al.* (2011) in chilli, Tetteh *et al*. (2011) in tomato, Bahadur *et al.* (2013) in tomato, Bakht and Khan (2014) in tomato, Iqbal *et al.* (2016) in aonla, Muhammed *et al.* (2015) in okra and Hussain *et al.* (2016) in tomato. Schonbeck (1998) also observed emergence of the weeds through the planting holes and elsewhere no weeds were observed under black polythene mulch whereas, according to Zhang *et al.* (1992), there was 100 per cent control of the weeds in maize using black polythene mulch and these findings are in support of the present experimental results. Similar, are the findings of Iqbal *et al*. (2016) who also observed less weed population under black polythene mulch which they attributed to the preventive effect of mulches on light penetrations that acted as a physical barrier affecting growth of most of the annual and perennial weeds. According to them it might create partially anaerobic conditions for the survival of weed species and thus finally

resulting in very low density. Mulching enhances the soil moisture retention and improves soil temperature which helps boost crop performance making the crop more competitive against the associated weeds.

Reduced number of weeds under the two stem training system might be due to unavailability of visible light spectrum resulting into reduced photosynthetic activity and therefore less number of weeds. Also in the two stem training system, increase in leaf size and more leaf area index was calculated (Table 4.22) which might have resulted into shading effect on the weeds which were present beneath the crop plants. This could result into greater competition for light along with less absorbance of radiations resulting into less emergence of weeds along together with poor growth of germinated seeds.

4.4.2 Weed control efficiency (%)

Data pertaining to weed control efficiency (%) has been presented in Table 4.37 and figure 4.7. An examination of the data revealed significant differences regarding weed control efficiency as affected by different planting methods. Maximum (45.38 %) weed control efficiency (WCE) was computed in those plots which were raised (P_1) and minimum (32.33 %) in those which were flat (P_2). Same trend was observed during both the years of study. Different types of mulches also produced significant effect on weed control efficiency. Maximum (63.21 %) WCE was recorded in those plots which were covered with black polythene mulch (M_1) and this treatment was significantly better (40.73 %) over M_2 (silver/black mulch). Minimum values (12.48 %), were, however, calculated in those plots where no mulch was applied (M_3). Similar observations were recorded for both the years of study. The training system also affected weed control efficiency significantly in the present studies. Maximum (41.94 %) values of WCE were recorded in T_1 (two stem training system) and minimum (35.68 %) in T_2 (three stem training system). Similar trend was observed during both the years of study.

The effect of two way interaction (Table 4.38) was significant for all the interactions during both the years as well as when the data were pooled. Maximum (70.04 %) WCE was recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1). This treatment combination was significantly superior over all other combinations. Minimum (6.38 %) WCE was recorded from those plots which were flat and also without mulch (M_3). Similar observations were recorded during the year 2017-18 and 2018-19. Another

interaction i.e. M × T (mulching treatments and training systems) also produced significant effects on weed control efficiency having maximum (66.64 %) values in those plots which were covered with black mulch using two stem training system (M_1T_1). This treatment combination was significantly superior over all other combinations. Minimum (9.15 %) WCE was calculated for M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction also produced significant effects on weed control efficiency. Maximum (47.48 %) weed control efficiency was calculated for the treatment combination P_1T_1 (raised bed and two stem training system). This treatment combination was significantly superior over all other combinations. Minimum (28.07 %) WCE was computed for P_2T_2 (flat bed and three stem training systems) treatment combination. Same trend was observed during both the years of study.

The effect of various three way interactions P × M × T also produced significant effects on weed control efficiency (Table 4.39). Maximum (74.11 %) of WCE was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system), which was significantly superior over all other treatment combinations. The other four treatment combinations i.e. $P_2M_1T_1$ (flat bed, black mulch and two stem training system), $P_2M_1T_2$ (flat bed, black mulch and three stem training system), $P_1M_2T_1$ (raised bed, silver/black mulch and two stem training system) and $P_1M_2T_2$ (raised bed, silver/black mulch and three stem training system) did not produce significant effects with each other. However, the weed control efficiency was computed as 0.67 per cent in those plots which were flat without mulch using three stem training system ($P_2M_3T_2$). Same trend was observed during both the years of study.

It was observed that weed control efficiency (%) significantly influenced the fruit yield. Weed control efficiency (%) was positively correlated with tomato yield. In the present studies, maximum weed control efficiency was recorded with the application of black polythene mulch and weed control efficiency was less in the unmulched plots, flat bed planting system and three stem training system. Black polythene mulch had suppressed the weed growth and thereby, increased the fruit yield. The probable reason of maximum weed control efficiency using black polythene mulch could be due to conservation of moisture and reduction of temperature in the top soil which suppressed the weed growth. Therefore, black polythene mulched plots remained non-competitive with weeds and this could be one of the reasons. The present findings are in conformity with the report of Awodoyin *et al.* (2007)

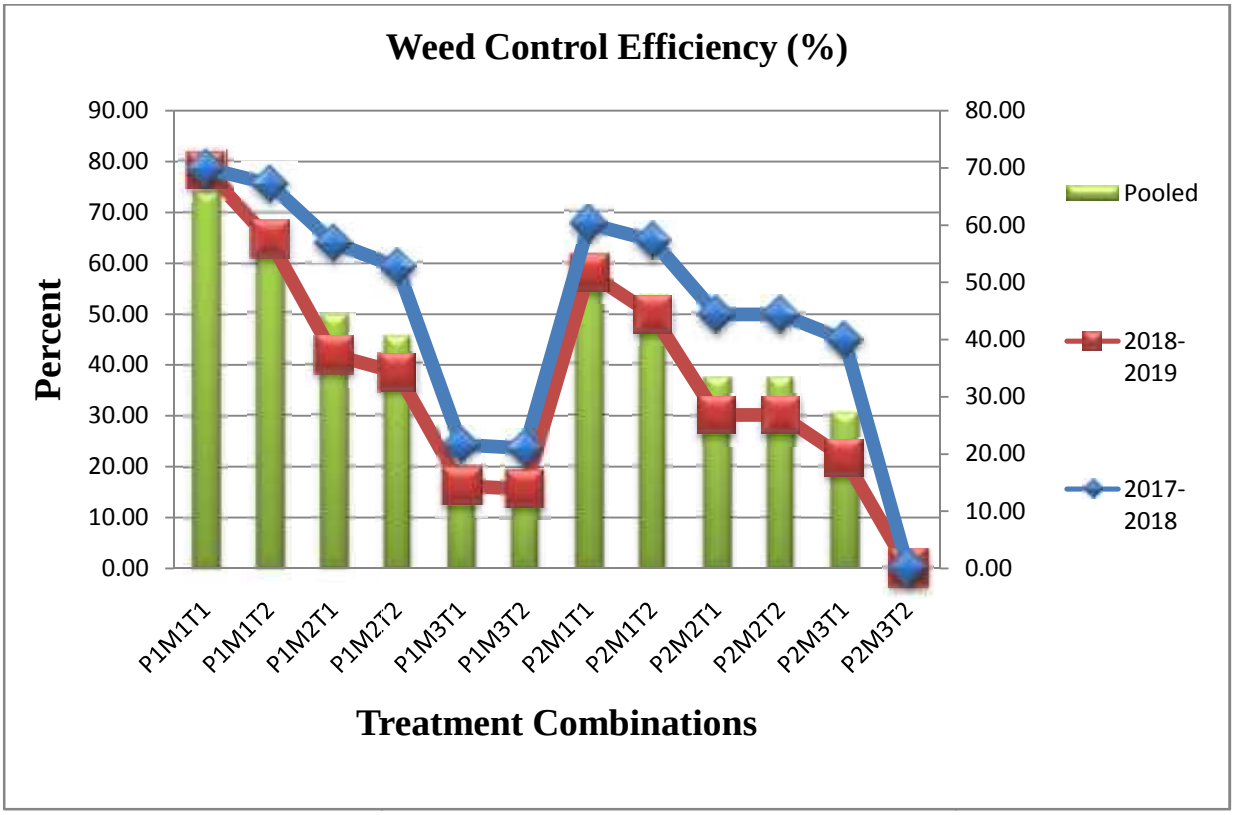


Fig.4.7 Effect of planting methods, mulching and training levels on weed control efficiency (%) in tomato crop

who reported that plastic mulches improve the performance of tomato due to less crop weed competition. Another reason could be less moisture depletion resulting into more water stress to the weeds vis-à-vis better availability of water to the economic part i.e. tomato plant.

4.4.3 Fresh weight of weeds (g)

The data recorded on effect of the various treatments on fresh weight of weeds have been presented in Table 4.40. It is clear from the data that significant results were obtained regarding the effect of planting methods, mulches and training levels on fresh weight of weeds during 2017-2018, 2018-2019 and in pooled data. Minimum (262.53 g) fresh weight of weeds was recorded in the plots which were raised (P_1) and maximum (332.03 g) fresh weight of weeds was noted in those plots which were not raised (P_2). Similar were the observations for both the years. The influence of various mulches on fresh weight of weeds was also noted to be significant. Minimum (103.75 g) fresh weight of weeds was observed in the plots which were covered with black polythene mulch (M_1) followed by those (119.04 g) which were covered with silver/black mulch (M_2), whereas maximum (669.04 g) fresh weight of weeds was noted in those plots which were not mulched (M_3). Similar trend was observed for both the years of study. Different training systems also produced significant effect on the fresh weight of weeds. Minimum (281.52 g) fresh weight of weeds was recorded (pooled data, table 4.40) from the plots where two stem training system was followed (T_1) and maximum (313.03 g) in those plots where three stem training system was used (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of two way interaction (Table 4.41) was significant for all the interactions. The P × M (planting methods and mulching treatments) interaction produced significant results on fresh weight of weeds. Minimum (85.01 g) fresh weight of weeds was recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1) and this treatment combination produced non significant (101.42 g) effect with P_1M_2 (raised bed and silver/black mulch), whereas it was significantly superior from all other combinations. The other two treatments i.e. P_2M_1 and P_2M_2 produced non significant effects between themselves. Maximum (736.92 g) fresh weight of weeds was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during the year 2017-18 and 2018-19. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects for fresh weight of weeds producing minimum (101.57 g) fresh weight of weeds in those plots which were covered with black polythene mulch using two

stem training system (M_1T_1). This treatment combination was statistically at par with M_1T_2 and M_2T_1 which recorded 105.94 g and 114.25 g fresh weight of weeds, respectively.

Table 4.40 Effect of planting methods, mulches and training systems on fresh weight and dry weight of weeds in tomato crop

Treatments	Fresh weight of weeds (g)			Dry weight of weeds (g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	311.78	213.28	262.53	30.06	34.28	30.72
P_2	360.56	303.50	332.03	36.83	43.17	41.44
$CD_{0.05}$	**18.99**	**9.79**	**9.82**	**2.30**	**1.77**	**1.58**
Mulches (M)						
M_1	94.26	113.25	103.75	21.00	22.58	24.29
M_2	107.50	130.58	119.04	30.00	39.92	32.46
M_3	806.75	531.33	669.04	49.33	53.67	51.50
$CD_{0.05}$	**23.26**	**11.99**	**12.02**	**2.81**	**2.17**	**1.94**
Training Systems (T)						
T_1	317.94	245.11	281.52	31.83	36.50	34.33
T_2	354.40	271.67	313.03	35.06	40.94	37.83
$CD_{0.05}$	**18.99**	**9.79**	**9.82**	**2.30**	**1.77**	**1.58**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Table 4.41 Effect of two way interactions P × M, M × T and P × T on fresh weight and dry weight of weeds in tomato crop

Treatment combination	Fresh weight of weeds (g)			Dry weight of weeds (g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	84.35	85.67	85.01	18.17	17.00	17.58
P_1M_2	97.50	105.33	101.42	26.33	35.67	26.00
P_1M_3	753.50	448.83	601.17	45.67	50.17	48.58
P_2M_1	104.17	140.83	122.50	23.83	28.17	31.00
P_2M_2	117.50	155.83	136.67	33.67	44.17	38.92
P_2M_3	860.00	613.83	736.92	53.00	57.17	54.42
$CD_{0.05}$	**32.90**	**16.95**	**17.00**	**NS**	**NS**	**2.74**
M_1T_1	92.65	110.50	101.57	20.17	19.00	22.50
M_1T_2	95.87	116.00	105.94	21.83	26.17	26.08
M_2T_1	103.00	125.50	114.25	28.67	38.17	30.92
M_2T_2	112.00	135.67	123.83	31.33	41.67	34.00
M_3T_1	758.17	499.33	628.75	46.67	52.33	49.58
M_3T_2	855.33	563.33	709.33	52.00	55.00	53.42
$CD_{0.05}$	**32.90**	**16.95**	**17.00**	**NS**	**NS**	**NS**
P_1T_1	293.43	194.11	243.77	29.22	32.56	29.72
P_1T_2	330.14	232.44	281.29	30.89	36.00	31.72
P_2T_1	342.44	296.11	319.28	34.44	40.44	38.94
P_2T_2	378.67	310.89	344.78	39.22	45.89	43.94
$CD_{0.05}$	**NS**	**13.84**	**13.88**	**NS**	**NS**	**NS**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Maximum (709.33 g) fresh weight of weeds was noted in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction also produced significant effects on fresh weight of weeds. Minimum (243.77 g) fresh weight of weeds was recorded in P_1T_1 (raised bed and two stem training system) and this treatment was significantly superior from all other interaction. Maximum (344.78 g) fresh weight of the weeds was recorded in P_2T_2 (flat bed and three stem training systems). Same trend was observed during both the years of study. The results of P × T interaction were, however non significant during 2017-18.

The effect of various three way interactions P x M x T also produced significant effects on fresh weight of weeds (Table 4.42). Minimum (82.81 g) fresh weight of weeds (pooled data) was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system) interaction. This treatment combination was at par with $P_1M_1T_2$, $P_1M_2T_1$ and $P_1M_2T_2$ producing 87.20 g, 96.83 g and 106.00 g fresh weight of weeds. Another four treatments combination i.e. $P_2M_1T_2$, $P_2M_1T_2$, $P_2M_2T_1$ and $P_2M_2T_2$ also produced non significant effects among themselves. However, maximum (768.00 g) fresh weight of weeds was recorded in those plots which were flat, without mulch along with three stem training system ($P_2M_3T_2$). Same trend was observed during both the years of study. The P x M x T interaction was however non significant during 2017-18.

Table 4.42 Effect of P × M × T interaction on fresh weight and dry weight of weeds in tomato crop

Treatment combination	Fresh weight of weeds (g)			Dry weight of weeds (g)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	83.62	82.00	82.81	17.33	13.00	15.17
$P_1M_1T_2$	85.07	89.33	87.20	19.00	21.00	20.00
$P_1M_2T_1$	95.33	98.33	96.83	25.00	34.67	24.83
$P_1M_2T_2$	99.67	112.33	106.00	27.67	36.67	27.17
$P_1M_3T_1$	701.33	402.00	551.67	45.33	50.00	49.17
$P_1M_3T_2$	805.67	495.67	650.67	46.00	50.33	48.00
$P_2M_1T_1$	101.67	139.00	120.33	23.00	25.00	29.83
$P_2M_1T_2$	106.67	142.67	124.67	24.67	31.33	32.17
$P_2M_2T_1$	110.67	152.67	131.67	32.33	41.67	37.00
$P_2M_2T_2$	110.67	152.67	131.67	32.33	41.67	37.00
$P_2M_3T_1$	124.33	159.00	141.67	35.00	46.67	40.83
$P_2M_3T_2$	905.00	631.00	768.00	58.00	59.67	58.83
$CD_{0.05}$	**NS**	**23.97**	**24.04**	**NS**	**NS**	**3.88**

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver/black polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

4.4.4 Dry weight of weeds (g)

The data recorded on the effect of various treatments on dry weight of weeds have been presented in Table 4.40. It is clear from the data that significant results were obtained during 2017-2018, 2018-2019 and when the data were pooled data. Minimum (30.72 g) dry weight of weeds was recorded in the plots which were raised (P_1) and maximum (41.44 g) dry weight of weeds was noted in those plots which were not raised (P_2). Similar were the observations during both the years. The influence of various mulches on dry weight of weeds was also noted to be significant. Minimum (24.29 g) dry weight of weeds was observed in the plots which were covered with black polythene mulch (M_1) followed by those (32.46 g) which were covered with silver/black mulch (M_2), whereas maximum (51.50 g) dry weight of weeds was noted in those plots which were not mulched (M_3). Similar trend was observed during both the years of study. Different training systems also produced significant effects on the dry weight of weeds. Minimum (34.33 g) dry weight of weeds was recorded from the plots where two stem training system was followed (T_1) and maximum (37.83 g) in those plots where three stem training system was used (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of two way interaction (Table 4.41) was non significant for all the interactions except for pooled data for planting methods and mulching treatments. Minimum (17.58 g) dry weight of weeds was recorded when the plants were grown on raised bed using black polythene mulch (P_1M_1) and this treatment combination was significantly superior from all other combinations. Maximum (54.42 g) dry weight of weeds was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of various three way interactions P × M × T also produced significant effects on dry weight of weeds (Table 4.42) only when the data were pooled and not during individual years. Minimum (15.17 g) dry weight of weeds was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system). This treatment combination was superior from all other combinations. Another four treatment combinations i.e. $P_1M_2T_2$ (27.17 g), $P_1M_2T_1$ (24.83 g), $P_2M_1T_1$ (29.83 g) and $P_2M_1T_2$ (32.17 g) also produced non significant effects among themselves. However, maximum (58.83 g) dry weight of weeds was recorded in those plots which were flat, without mulch and having three stem training system ($P_2M_3T_2$). Same trend was observed during both the years of study (Fig. 4.6).

This is an important factor related to crop growth as it determines the amount of essential nutrients taken up by the weed plants and reduce the crop growth which has been reduced due to crop weed competition. In the present studies, minimum fresh and dry weight of weeds was recorded in the plots mulched with black polythene. This may be due to lower weed density and short time of weed crop association to accumulate dry weight by weeds. Appearance of minimum number of the weeds through the holes and 100 per cent (weed cont) control of the weeds could be the reason for reduced fresh weight and consequently minimum dry weight of the weeds. In the present findings, the increased per cent control of the weeds under black polythene mulch might be due to shadowing of the covered weeds disabling them to perform photosynthesis which ultimately might have reduced their competition. Similar results have also been reported by Awodoyin *et al.* (2007) in tomato, Muhammed *et al.* (2015) in okra, Rajablariani *et al.* (2012) in tomato and Iqbal *et al.* (2016) in aonla.

The weed population decreases over time in a raised bed that is well cared, therefore the fresh and dry weight of the weeds also lessens. It might be due to the reason that the soil in a raised bed is more stabilized and therefore compaction is almost non-existent so the need for seasonal tilling is minimal (Berle and Westerfield, 2013). Another reason could be proper drainage facility which allows the plant roots to breathe properly as compared to the weeds, quick warming up of the soil, allowing the longer growing season and better growing conditions for the plants in the raised beds as compared to the flat beds (Locher *et al.*, 2003).

4.4.5 Weed Intensity (%)

4.4.5.1 Weed intensity of Beggars tick (*Bidens pilosa*) (%)

The data recorded on the effect of various treatments on weed intensity of Beggars tick (*Bidens pilosa*) have been presented in table 4.43. It is clear from the data that significant results were obtained during 2017-2018, 2018-2019 and in pooled data of the study. Minimum (0.80 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (1.03 %) was calculated in those plots which were not raised (P_2). Similar were the observations for both the years. The influence of various mulches on weed intensity was also noted to be significant during both the years as well as when the data were pooled. Minimum 0.67 per cent weed intensity was recorded in the plots which where black mulch (M_1) and silver/black mulch (M_2) were applied and maximum (1.40 %) was calculated for those plots where no mulch was used (M_3). Different training systems also produced significant effect on

the weed intensity. Minimum (0.85 %) intensity of weeds was recorded from the plots where two stem training system was followed (T_1) and maximum (0.97 %) in those plots where three stem training system was used (T_2). Similar observations were recorded during 2017-18 and 2018-19.

The effect of two way interaction (Table 4.44) was significant for all the interactions except for P × T interaction pertaining to Beggars tick (*Bidens pilosa*). The P × M (planting methods and mulching treatments) interaction produced significant effects on weed intensity. The weed intensity was recorded minimum (0.67 %) when the plants were grown on raised beds using black and silver/black polythene mulch (P_1M_1 and P_1M_2) and also in those plots which were grown on flat bed using black and silver/black polythene mulch i.e. P_2M_1 and P_2M_2 and these treatment combinations were significantly superior from other combinations. Maximum (1.74 %) intensity of the weeds was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during 2017-18 and 2018-19. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects for weed intensity of *Bidens pilosa* producing minimum (0.67 %) intensity in those plots which were covered with black and silver/black polythene mulch using two stem or three stem training systems i.e. M_1T_1, M_1T_2, M_2T_1 and M_2T_2. Maximum (2.35 %) weed intensity was noted in M_3T_2 (black mulch and three stem training system) interaction. Similar trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction produced non significant effects on weed intensity of Beggars tick (*Bidens pilosa*).

The effect of various three way interactions P × M × T also produced significant effects on weed intensity (Table 4.45) when the data were pooled.

4.4.5.2 Weed intensity of Benghal tick (*Commelina benghalensis*) (%)

The data recorded on the effect of various treatments on weed intensity of Benghal tick (*Commelina benghalensis*) have been presented in table 4.43. It is clear from the data that significant results were obtained during 2017-2018, 2018-19 and when the data were pooled. Minimum (1.27 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (1.54 %) was calculated in those plots which were not raised (P_2). Similar were the observations for both the years. The influence of various mulches on weed intensity was also noted to be significant. The weed intensity was found to be minimum (0.67 %) for

those plots which were covered with black polythene mulch (M_1) and silver/black mulch (M_2) for Benghal tick whereas maximum (2.88 %) was noted in those plots which were not mulched (M_3). Similar trend was observed both the years of study. Different training systems also produced significant effects on weed intensity, minimum values (1.31 %) being recorded in T_1 (two stem training system) and maximum (1.50 %) in T_2 (three stem training system). Similar results were noticed during both the years.

The effect of two way interaction (Table 4.44) was significant for all the interactions except for P × T during the year 2018-19. The P × M (planting methods and mulching treatments) interaction produced significant results on weed intensity. The weed intensity was recorded minimum (0.67 %) when the plants were grown on raised bed using black and silver/black polythene mulch (P_1M_1, and P_1M_2) and also in those plots which were grown on flat bed using black and silver/black polythene mulch i.e. P_2M_1 and P_2M_2 and these treatment combinations were significantly superior from other combinations. Maximum (3.28 %) weed intensity of *Commelina benghalensis* was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during the year 2017-18 and 2018-19. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects for weed intensity producing minimum (0.67 %) in those plots which were covered with black and silver/black polythene mulch using two stem and three stem training systems i.e. M_1T_1, M_1T_2, M_2T_1, and M_2T_2. Maximum (3.16 %) weed intensity was noted in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction also produced significant effect on weed intensity of Benghal tick (*Commelina benghalensis*). Minimum (1.15 %) weed intensity of *Commelina benghalensis* was recorded from those plots which were flat along with three stem training system (P_2T_2) and maximum (1.59 %) from those plots which were raised along with two stem training system (P_1T_1). Similar trend was observed during both the years of study.

The effect of various three way interactions P × M × T also produced significant effects on weed intensity (Table 4.45) of Benghal tick (*Commelina benghalensis*) except during 2018-19. Minimum (0.67 %) weed intensity was recorded (pooled data) in $P_1M_1T_1$, $P_1M_2T_2$ $P_1M_2T_1$, $P_1M_2T_2$, $P_2M_1T_2$, $P_2M_2T_1$, $P_2M_2T_2$, and $P_2M_3T_1$. However, maximum (3.45 %) per cent weed intensity was recorded in those plots which were flat without mulch using three stem training system ($P_2M_3T_2$). Similar trend was observed during 2017-18 also.

Table 4.43 Effect of planting methods, mulches and training systems on weed intensity of *Bidens pilosa* and *Commelina benghalensis* in tomato crop

Treatments	*Bidens pilosa* (%)			*Commelina benghalensis* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	1.15 (1.07)	1.24 (1.10)	0.80 (0.89)	2.29 (1.40)	1.53 (1.19)	1.27 (1.40)
P_2	1.32 (1.13)	1.75 (1.27)	1.03 (0.98)	2.52 (1.45)	2.09 (1.35)	1.54 (1.45)
$CD_{0.05}$	**0.02**	**0.04**	**0.02**	**0.02**	**0.05**	**0.02**
Mulches (M)						
M_1	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
M_2	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
M_3	1.71 (1.30)	2.48 (1.55)	1.40 (1.17)	5.22 (2.28)	3.42 (1.82)	2.88 (1.69)
$CD_{0.05}$	**0.02**	**0.05**	**0.02**	**0.02**	**0.06**	**0.02**
Training Systems (T)						
T_1	1.21 (1.09)	1.35 (1.13)	0.85 (0.91)	2.32 (1.41)	1.62 (1.22)	1.31 (1.08)
T_2	1.26 (1.11)	1.64 (1.23)	0.97 (0.96)	2.50 (1.45)	1.99 (1.33)	1.50 (1.14)
$CD_{0.05}$	**0.02**	**0.04**	**0.02**	**0.02**	**0.05**	**0.02**

Table 4.44 Effect of different interactions P × M, M × T and P × T on weed intensity of *Bidens pilosa* and *Commelina benghalensis* in tomato crop

Treatment combination	*Bidens pilosa* (%)			*Commelina benghalensis* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
P_1M_2	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
P_1M_3	1.45 (1.20)	1.71 (1.29)	1.06 (1.02)	4.87 (2.21)	2.58 (1.58)	2.48 (2.21)
P_2M_1	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
P_2M_2	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
P_2M_3	1.97 (1.40)	3.25 (1.80)	1.74 (1.32)	5.57 (2.36)	4.26 (2.06)	3.28 (2.36)
$CD_{0.05}$	**0.03**	**0.06**	**0.03**	**0.03**	**0.09**	**0.03**
M_1T_1	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
M_1T_2	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
M_2T_1	1.00 (1.00)	1.00 (1.00)	0.67 (1.02)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
M_2T_2	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
M_3T_1	1.64 (1.28)	2.05 (1.40)	1.84 (0.82)	4.95 (2.22)	2.86 (1.66)	2.60 (2.22)
M_3T_2	1.78 (1.33)	2.92 (1.69)	2.35 (1.32)	5.50 (2.34)	3.97 (1.98)	3.16 (2.34)
$CD_{0.05}$	**0.03**	**0.06**	**0.03**	**0.03**	**0.09**	**0.02**
P_1T_1	1.14 (1.07)	1.07 (1.03)	0.74 (0.86)	2.15 (1.37)	1.28 (1.12)	1.15 (1.37)
P_1T_2	1.16 (1.07)	1.40 (1.16)	0.85 (0.91)	2.43 (1.43)	1.77 (1.27)	1.40 (1.43)
P_2T_1	1.28 (1.12)	1.62 (1.23)	0.97 (0.96)	2.43 (1.44)	1.96 (1.32)	1.48 (1.44)
P_2T_2	1.36 (1.15)	1.88 (1.30)	1.08 (1.00)	2.57 (1.46)	2.21 (1.38)	1.59 (1.46)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.02**	**NS**	**0.02**

*Figures in the parenthesis are square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Table 4.45 Effect of P × M × T interaction on weed intensity of *Bidens pilosa* and *Commelina benghalensis* in tomato crop

Treatment combination	*Bidens pilosa* (%)			*Commelina benghalensis* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_1M_1T_2$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_1M_2T_1$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_1M_2T_2$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_1M_3T_1$	1.43 (1.19)	1.22 (1.10)	0.88 (0.94)	4.46 (2.11)	1.85 (1.36)	2.10 (2.11)
$P_1M_3T_2$	1.48 (1.22)	2.21 (1.48)	1.23 (1.11)	5.29 (2.30)	3.31 (1.81)	2.86 (2.30)
$P_2M_1T_1$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_2M_1T_2$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_2M_2T_1$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_2M_2T_2$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_2M_3T_1$	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)	1.00 (1.00)	1.00 (1.00)	0.67 (1.00)
$P_2M_3T_2$	2.09 (1.45)	3.63 (1.90)	1.91 (1.38)	5.71 (2.39)	4.64 (2.15)	3.45 (2.39)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.04**	**NS**	**0.04**

*Figures in the parenthesis are square root transformed values
P: Planting methods, **M:** Mulching treatments, **T:** Training system; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

4.4.5.3 Weed intensity (%) of Motha grass (*Cyperus rotundus*)

The data recorded on the effect of various treatments on weed intensity of Motha grass (*Cyperus rotundus*) have been presented in Table 4.46. It is clear from the data that significant results were obtained during 2017-2018, 2018-19 as well as in pooled data for planting methods and mulching treatments, whereas, non significant results were obtained for training systems. Minimum (10.58 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (11.88 %) in those plots which were not raised (P_2). Similar were the observations during both the years. The weed intensity was found to be minimum (8.39 %) in those plots which were covered with black polythene mulch (M_1) and it was significantly superior (11.21 %) from silver/black mulch (M_2) whereas maximum (14.09 %) was noted in those plots which were not mulched (M_3). Similar trend was observed during both the years of study. The different training systems produced non significant effects on the weed intensity when the data were pooled during both the years.

The effect of two way interaction (Table 4.47) was significant for all P × M interaction. The weed intensity was recorded minimum (7.69 %) when the plants were grown on raised bed using black polythene mulch (P_1M_1) and it was found to be significantly

superior from all other treatments combinations. Maximum (14.74 %) weed intensity was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during the year 2017-18 and 2018-19. Another two interactions i.e. M × T (mulching treatments and training systems) and P × T (planting methods and training systems) produced non significant effects for weed intensity.

Table 4.46 Effect of planting methods, mulches and training systems on weed intensity of *Cyperus rotundus* and *Echinochloa crus-galli* in tomato crop

Treatments	*Cyperus rotundus* (%)			*Echinochloa crus-galli* (%)		
	2017-2018	**2018-2019**	**Pooled**	**2017-2018**	**2018-2019**	**Pooled**
Planting Methods (P)						
P_1	10.31 (3.20)	10.85 (3.26)	10.58 (3.23)	10.66 (3.26)	9.86 (3.10)	10.26 (3.18)
P_2	11.24 (3.34)	12.51 (3.51)	11.88 (3.43)	11.62 (3.40)	11.20 (3.33)	11.41 (3.36)
$CD_{0.05}$	**0.10**	**0.04**	**0.05**	**0.07**	**0.05**	**0.05**
Mulches (M)						
M_1	8.89 (2.98)	7.89 (2.80)	8.39 (2.89)	9.36 (3.06)	7.31 (2.70)	8.34 (2.88)
M_2	10.58 (3.25)	11.84 (3.44)	11.21 (3.35)	10.60 (3.26)	10.86 (3.29)	10.73 (3.27)
M_3	12.86 (3.58)	15.31 (3.91)	14.09 (3.66)	13.46 (3.66)	13.42 (3.66)	13.44 (3.66)
$CD_{0.05}$	**NS**	**0.04**	**0.05**	**0.08**	**0.06**	**0.06**
Training Systems (T)						
T_1	10.50 (3.23)	10.22 (3.26)	10.49 (3.23)	10.76 (3.27)	10.22 (3.17)	10.26 (3.22)
T_2	11.05 (3.31)	10.84 (3.51)	11.18 (3.43)	11.52 (3.29)	10.84 (3.26)	11.41 (3.32)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.07**	**0.05**	**0.05**

Table 4.47 Effect of different interactions P × M, M × T and P × T on weed intensity of *Cyperus rotundus* and *Echinochloa crus-galli* in tomato crop

Treatment combination	*Cyperus rotundus* (%)			*Echinochloa crus-galli* (%)		
	2017-2018	**2018-2019**	**Pooled**	**2017-2018**	**2018-2019**	**Pooled**
P_1M_1	8.37 (2.89)	7.02 (2.65)	7.69 (2.77)	9.00 (3.00)	6.23 (2.49)	7.62 (2.76)
P_1M_2	10.21 (3.19)	11.00 (3.32)	10.61 (3.26)	10.34 (3.21)	10.16 (3.19)	10.25 (3.20)
P_1M_3	12.34 (3.51)	14.53 (3.81)	13.43 (4.01)	12.65 (3.56)	13.18 (3.63)	12.92 (3.59)
P_2M_1	9.41 (3.06)	8.77 (2.96)	9.09 (3.01)	9.72 (3.12)	8.39 (2.90)	9.06 (3.01)
P_2M_2	10.95 (3.30)	12.67 (3.56)	11.81 (3.43)	10.87 (3.30)	11.56 (3.40)	11.21 (3.35)
P_2M_3	13.38 (3.65)	16.10 (4.01)	14.74 (3.91)	14.27 (3.77)	13.65 (3.69)	13.96 (3.73)
$CD_{0.05}$	**0.03**	**0.06**	**0.06**	**NS**	**0.09**	**NS**
M_1T_1	8.84 (0.00)	7.35 (0.00)	8.09 (2.84)	9.16 (3.00)	7.14 (2.49)	8.15 (2.85)
M_1T_2	8.93 (0.00)	8.44 (0.00)	8.69 (2.94)	9.57 (3.21)	7.49 (3.19)	8.53 (2.92)
M_2T_1	10.30 (0.00)	11.32 (0.00)	10.81 (3.29)	10.46 (3.56)	10.56 (3.63)	10.51 (3.24)
M_2T_2	10.86(0.00)	12.36 (0.00)	11.61 (3.40)	10.75 (3.12)	11.16 (2.90)	10.95 (3.31)
M_3T_1	12.36 (1.28)	14.78 (1.40)	13.57 (3.68)	12.67 (3.30)	12.97 (3.40)	12.82 (3.58)
M_3T_2	13.36 (1.33)	15.85 (1.69)	14.60 (3.82)	14.24 (3.77)	13.87 (3.69)	14.05 (3.75)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.03**	**0.06**	**NS**
P_1T_1	10.11 (3.17)	10.35 (3.18)	10.23 (3.18)	10.40 (3.22)	9.72 (3.08)	10.06 (3.15)
P_1T_2	10.50 (3.23)	11.35 (3.34)	10.92 (3.29)	10.92 (3.29)	10.00 (3.13)	10.46 (3.22)
P_2T_1	10.89 (3.29)	11.95 (3.43)	11.42 (3.36)	11.12 (3.32)	10.72 (3.26)	10.92 (3.29)
P_2T_2	11.60 (3.39)	13.07 (3.59)	12.34 (3.49)	12.11 (3.47)	11.68 (3.40)	11.90 (3.43)
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

*Figures in the parenthesis are square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system

Table 4.48 Effect of P × M × T interaction on weed intensity of *Cyperus rotundus* and *Echinochloa crus-galli* in tomato crop

Treatment combination	*Cyperus rotundus* (%)			*Echinochloa crus-galli* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	8.32 (2.88)	6.34 (2.52)	7.33 (2.71)	8.89 (2.98)	5.92 (2.43)	7.40 (2.72)
$P_1M_1T_2$	8.41 (2.90)	7.69 (2.77)	8.05 (2.84)	9.11 (3.02)	6.55 (2.56)	7.83 (2.80)
$P_1M_2T_1$	9.75 (3.12)	10.67 (3.27)	10.21 (3.19)	10.30 (3.21)	10.12 (3.18)	10.21 (3.20)
$P_1M_2T_2$	10.68 (3.27)	11.34 (3.37)	11.01 (3.32)	10.38 (3.22)	10.21 (3.19)	10.29 (3.21)
$P_1M_3T_1$	12.27 (3.50)	14.03 (3.75)	13.15 (3.63)	12.02 (3.47)	13.12 (3.62)	12.57 (3.55)
$P_1M_3T_2$	12.41 (3.52)	15.02 (3.88)	13.72 (3.70)	13.28 (3.64)	13.24 (3.64)	13.26 (3.64)
$P_2M_1T_1$	9.35 (3.05)	8.35 (2.89)	8.85 (2.97)	9.43 (3.07)	8.36 (2.89)	8.89 (2.98)
$P_2M_1T_2$	9.46 (3.07)	9.18 (3.03)	9.32 (3.05)	10.02 (3.16)	8.43 (2.90)	9.22 (3.04)
$P_2M_2T_1$	10.86 (3.29)	11.96 (3.46)	11.41 (3.38)	10.62 (3.26)	11.01 (3.32)	10.81 (3.29)
$P_2M_2T_2$	10.86 (3.29)	11.96 (3.46)	11.41 (3.38)	10.62 (3.26)	11.01 (3.32)	10.81 (3.29)
$P_2M_3T_1$	11.03 (3.31)	13.37 (3.66)	12.20 (3.49)	11.11 (3.33)	12.12 (3.48)	11.62 (3.41)
$P_2M_3T_2$	14.31 (3.78)	16.67 (4.08)	15.49 (3.94)	15.21 (3.90)	14.49 (3.81)	14.85 (3.85)
$CD_{0.05}$	NS	NS	NS	NS	0.12	NS

*Figures in the parenthesis are square root transformed values
P: Planting methods, **M:** Mulching treatments, **T:** Training systems; $\mathbf{P_1}$**:** Raised bed planting method, $\mathbf{P_2}$**:** Flat bed planting method, $\mathbf{M_1}$**:** Black polythene mulch, $\mathbf{M_2}$**:** Silver/black polythene mulch, $\mathbf{M_3}$**:** No mulch, $\mathbf{T_1}$**:** Two stem training system, $\mathbf{T_2}$**:** Three stem training system

The effect of various three way interactions P × M × T also produced non significant effects on weed intensity (Table 4.48) of *Cyperus rotundus*.

4.4.5.4 Weed intensity (%) of Barnyard grass (*Echinochloa crus-galli*)

The data recorded on the effect of various treatments on weed intensity of Barnyard grass (*Echinochloa crus-galli*) have been presented in Table 4.46. It is clear from the data that significant results were obtained during 2017-2018, 2018-19 and in pooled data of the study. Minimum (10.26 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (11.41 %) in those plots which were not raised (P_2). Similar were the observations for both the years. The weed intensity was found to be minimum (8.34 %) in those plots which were covered with black polythene mulch (M_1) and it was found to be significantly superior (10.73 %) from silver/black mulch (M_2), whereas maximum (13.44 %) was noted in those plots which were not mulched (M_3). Similar trend was observed for both the years of study. Different training systems also produced significant effects on weed intensity. Minimum (10.26 %) weed intensity was recorded from the plots where two stem training system was followed (T_1) and maximum (11.41 %) weed intensity in those plots where three stem training system was followed (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of two way interaction pertaining to weed intensity of *Echinochloa crus-galli* (Table 4.47) was non significant during 2017-18 as well as when the data were pooled. However, results were significant during 2018-19. Minimum weed intensity (6.23 %) was noticed in P_1M_1 (raised bed and black mulch) which was significantly superior over all the other combinations, while maximum (13.65 %) weed intensity was noticed in P_2M_3 (flat bed without mulch). Similar observations were recorded during 2018-19. Another interaction i.e. M × T (mulching treatments and training systems) was significant during 2017-18 where, minimum (9.16 %) weed intensity was noticed in those plots which were covered with black polythene mulch using two stem training system (M_1T_1). Maximum (14.05 %) weed intensity was noted in M_3T_2 (black mulch and three stem training system) interaction. Same trend was observed during 2018-19 as well as in pooled data. The effect of P × T (planting methods and training systems) interaction produced non significant effects on weed intensity of Barnyard grass (*Echinochloa crus-galli*).

The effect of three way interactions P × M × T produced significant effects on weed intensity during 2018-19 only (Table 4.48). Minimum (5.92 %) weed intensity was recorded in $P_1M_1T_1$ (raised bed, black polythene mulch and two stem training system). However, maximum (14.49 %) weed intensity of Barnyard grass (*Echinochloa crus-galli*) was recorded in those plots which were flat without mulch and trained to three stem training system ($P_2M_3T_2$). Same trend was observed during 2017-18 as well as when the data were pooled.

4.4.5.5 Weed intensity (%) of Piplu grass (*Galinsoga parviflora*)

The data recorded on the effect of various treatments on weed intensity of Piplu grass (*Galinsoga parviflora*) have been presented in Table 4.49. It is clear from the data that significant results were obtained during 2017-2018, 2018-19 and when the data were pooled. Minimum (14.02 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (15.94 %) in those plots which were not raised (P_2). Similar were the observations during both the years. The weed intensity was found to be minimum (11.03 %) in those plots which were covered with black polythene mulch (M_1) and it was found to be significantly superior (15.01 %) from silver/black mulched (M_2) plots. Maximum (18.91 %) values were noted in those plot which were not mulched (M_3). Similar trend was observed for both the years of study. Different training systems also produced significant effects on the weed intensity.

Table 4.49 Effect of planting methods, mulches and training systems on weed intensity of *Galinsoga parviflora* and *Nicandra physalodes* in tomato crop

Treatments	*Galinsoga parviflora* (%)			*Nicandra physalodes* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
Planting Methods (P)						
P_1	15.87 (3.96)	12.18 (3.45)	14.02 (3.72)	2.68 (1.54)	2.31 (1.41)	1.66 (1.21)
P_2	17.81 (4.20)	14.08 (3.73)	15.94 (3.97)	2.90 (1.60)	2.82 (1.51)	1.91 (1.28)
$CD_{0.05}$	**0.02**	**0.04**	**0.02**	**0.04**	**0.02**	**0.03**
Mulches (M)						
M_1	12.83 (3.58)	9.23 (3.03)	11.03 (3.32)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
M_2	16.89 (4.11)	13.13 (3.62)	15.01 (3.87)	1.88 (1.36)	1.00 (1.00)	0.96 (0.98)
M_3	20.79 (4.56)	17.03 (4.12)	18.91 (4.35)	5.50 (2.34)	5.69 (2.38)	3.73 (1.93)
$CD_{0.05}$	**0.02**	**0.05**	**0.05**	**0.05**	**0.03**	**0.04**
Training Systems (T)						
T_1	2.26 (4.02)	12.59 (3.51)	14.47 (3.78)	2.68 (1.51)	2.49 (1.45)	1.70 (1.21)
T_2	2.65 (4.14)	13.66 (3.67)	15.50 (3.91)	2.90 (1.63)	2.63 (1.47)	1.87 (1.28)
$CD_{0.05}$	**0.02**	**0.04**	**0.02**	**0.04**	**0.02**	**0.03**

Table 4.50 Effect of two way interactions P × M, M × T and P × T on weed intensity of *Galinsoga parviflora* and *Nicandra physalodes* weeds in tomato crop

Treatment combination	*Galinsoga parviflora* (%)			*Nicandra physalodes* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
P_1M_1	11.96 (3.46)	8.06 (2.83)	10.01 (3.16)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
P_1M_2	16.01 (4.00)	12.22 (3.49)	14.11 (3.76)	1.77 (1.32)	1.00 (1.00)	0.92 (0.96)
P_1M_3	19.65 (4.83)	16.25 (4.03)	17.95 (4.24)	5.27 (2.30)	4.92 (2.22)	3.40 (1.84)
P_2M_1	13.71 (3.70)	10.40 (3.22)	12.05 (3.47)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
P_2M_2	17.77 (4.21)	14.04 (3.75)	15.90 (3.99)	1.99 (1.40)	1.00 (1.00)	1.00 (0.99)
P_2M_3	21.94 (4.68)	17.80 (4.22)	19.87 (4.46)	5.72 (2.39)	6.46 (2.54)	4.06 (2.01)
$CD_{0.05}$	**NS**	**0.08**	**0.04**	**0.07**	**0.04**	**0.04**
M_1T_1	12.31 (3.51)	8.56 (2.92)	10.44 (3.23)	1.00 (0.00)	1.00 (1.00)	0.67 (0.82)
M_1T_2	13.35 (3.65)	9.90 (3.14)	11.62 (3.41)	1.00 (0.00)	1.00 (1.00)	0.67 (0.82)
M_2T_1	16.41 (4.05)	12.63 (3.55)	14.52 (3.81)	1.47 (1.21)	1.00 (1.00)	0.82 (0.91)
M_2T_2	17.37(4.17)	13.63 (3.69)	15.50 (3.94)	2.29 (1.51)	1.00 (1.00)	1.10 (1.05)
M_3T_1	20.32 (4.51)	16.58 (4.07)	18.45 (4.29)	5.32 (2.31)	5.48 (2.34)	3.60 (1.90)
M_3T_2	21.27 (4.61)	17.47 (4.18)	19.37 (4.40)	5.67 (2.38)	5.90 (2.42)	3.86 (1.96)
$CD_{0.05}$	**NS**	**NS**	**NS**	**0.07**	**0.04**	**0.04**
P_1T_1	15.32 (3.17)	11.56 (3.36)	13.44 (3.64)	2.54 (1.49)	2.27 (1.40)	1.60 (1.18)
P_1T_2	16.42 (3.23)	12.79 (3.55)	14.61 (3.80)	2.82 (1.53)	2.72 (1.42)	1.79 (1.23)
P_2T_1	17.37 (3.29)	13.62 (3.67)	15.50 (3.91)	2.65 (1.59)	2.35 (1.49)	1.72 (1.24)
P_2T_2	18.24 (3.39)	14.53 (3.79)	16.39 (4.03)	3.15 (1.67)	2.92 (1.53)	2.03 (1.32)
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

*Figures in the parenthesis are square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training system; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Table 4.51 Effect of P × M × T interaction on weed intensity of *Galinsoga parviflora* and *Nicandra physalodes* in tomato crop

Treatment combination	*Galinsoga parviflora* (%)			*Nicandra physalodes* (%)		
	2017-2018	2018-2019	Pooled	2017-2018	2018-2019	Pooled
$P_1M_1T_1$	11.40 (3.38)	7.24 (2.69)	9.32 (3.05)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
$P_1M_1T_2$	12.51 (3.54)	8.88 (2.98)	10.70 (3.27)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
$P_1M_2T_1$	15.47 (3.93)	11.72 (3.42)	13.60 (3.69)	1.37 (1.17)	1.00 (1.00)	0.79 (0.89)
$P_1M_2T_2$	16.54 (4.07)	12.72 (3.56)	14.63 (3.82)	2.16 (1.47)	1.00 (1.00)	1.05 (1.03)
$P_1M_3T_1$	19.09 (4.37)	15.72 (3.96)	17.41 (4.17)	5.25 (2.29)	4.81 (2.19)	3.35 (1.83)
$P_1M_3T_2$	20.20 (4.49)	16.79 (4.10)	18.49 (4.30)	5.29 (2.30)	5.14 (2.24)	3.44 (1.86)
$P_2M_1T_1$	13.22 (3.64)	9.88 (3.14)	11.55 (3.40)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
$P_2M_1T_2$	14.19 (3.77)	10.91 (3.30)	12.55 (3.54)	1.00 (1.00)	1.00 (1.00)	0.67 (0.82)
$P_2M_2T_1$	17.35 (4.16)	13.53 (3.68)	15.44 (3.93)	1.57 (1.25)	1.00 (1.00)	0.86 (0.93)
$P_2M_2T_2$	17.35 (4.16)	13.53 (3.68)	15.44 (3.93)	1.57 (1.25)	1.00 (1.00)	0.86 (0.93)
$P_2M_3T_1$	18.19 (4.26)	14.54 (3.81)	16.37 (4.05)	2.41 (1.55)	1.00 (1.00)	1.14 (1.07)
$P_2M_3T_2$	22.33 (4.73)	18.15 (4.26)	20.24 (4.50)	6.05 (2.46)	6.77 (2.60)	4.27 (2.07)
$CD_{0.05}$	NS	NS	NS	NS	NS	NS

*Figures in the parenthesis are square root transformed values

P: Planting methods, **M:** Mulching treatments, **T:** Training systems; P_1**:** Raised bed planting method, P_2**:** Flat bed planting method, M_1**:** Black polythene mulch, M_2**:** Silver/black polythene mulch, M_3**:** No mulch, T_1**:** Two stem training system, T_2**:** Three stem training system

Minimum (14.47 %) weed intensity was recorded from the plots where two stem training system was followed (T_1) and maximum (15.50 %) weed intensity was noticed in those plots where three stem training system was used (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of two way interaction (Table 4.50) was non in significant all the interactions with regards to weed intensity of Piplu (*Galinsoga parviflora*) except for P × M interaction during 2018-19 and when the data was pooled. Minimum (10.01 %) weed intensity was recorded from the plots where black polythene mulch was applied on raised bed (P_1M_1), whereas, maximum (19.87 %) was recorded in flat bed without mulch (P_2M_2). The effect of various three way interactions P × M × T also produced non significant effects on weed intensity (Table 4.51) of *Galinsoga parviflora*.

4.4.5.6 Weed intensity (%) of Nicandra (*Nicandra physalodes*)

The data pertaining to the effect of various treatments on weed intensity of Nicandra (*Nicandra physalodes*) have been presented in Table 4.49. It is clear from the data that significant results were obtained during 2017-2018, 2018-19 and when the data were pooled. Minimum (1.66 %) weed intensity was recorded in the plots which were raised (P_1) and maximum (1.91 %) in those plots which were not raised (P_2). Similar were the observations during both the years. The weed intensity was found to be minimum (0.67 %) in those plots

which were covered with black polythene mulch (M_1), whereas maximum (3.73 %) was noted in those plots which were not mulched (M_3). Similar trend was observed during both the years of study. Different training systems also produce significant effects on the weed intensity. Minimum (1.70 %) weed intensity of was recorded from the plots where two stem training system was followed (T_1) and maximum (1.87 %) weed intensity in those plots where three stem training system was used (T_2). Similar observations were recorded during the year 2017-18 and 2018-19.

The effect of two way interaction (Table 4.50) was significant for all the interactions except for planting methods and training systems with regards to weed intensity of Nicandra (*Nicandra physalodes*). The P × M (planting methods and mulching treatments) interaction produced significant results (pooled data) on weed intensity. The weed intensity was recorded minimum (0.67 %) when the plants were grown on raised beds using black polythene mulch (P_1M_1) and flat bed using black polythene mulch (P_2M_1). Maximum (4.06 %) weed intensity was recorded from those plots which were flat and also without mulch (P_2M_3). Similar observations were recorded during the year 2017-18 and 2018-19. Another interaction i.e. M × T (mulching treatments and training systems) also produced significant effects for weed intensity. The weed intensity was observed to be minimum (0.67 %) in those plots which were covered with black polythene mulch using two stem training system (M_1T_1) and black polythene mulch using three stem training system (M_1T_2). Maximum (3.86 %) weed intensity was noted in M_3T_2 (black mulch and three stem training system) interaction. Similar trend was observed during both the years of study. The effect of P × T (planting methods and training systems) interaction produced non significant effects on weed intensity of Nicandra (*Nicandra physalodes*).

The effect of various three way interactions P × M × T produced non significant effects on weed intensity (Table 4.51).

As a matter of fact, by providing a physical barrier, mulching reduces the germination and nourishment of many weeds. However, there are some weeds which cropped up through the holes which were made for the plants. If somehow still some of the weeds which were found growing were pale due to lack of photosynthesis and ultimately died of starvation and higher temperature. The mulching, especially black polythene mulch favoured the reduction of evaporation leading to higher soil moisture content in the deeper zone which resulted into reduction in the supply of water to the upper zone along with nutrients. All these processes

might have restricted the root development and root growth of narrow leaved species which are strictly confined to the upper zone, however, survival of broad leaf weed species might be due to availability of more soil moisture and nutrients present in the deeper layer of the soils where the roots of these species are confined. Population of various weeds was significantly reduced with the use of mulches. In black polythene mulched plots, as maximum area of the plots was covered with mulch and weed growth was less due to availability of less space (only plant basal area was exposed to light and rest of the area was covered with mulch). These findings are in conformity with those of Sharma *et al.* (1984), Singh *et al.* (2002) and Kumar *et al.* (2013) in garlic. Maximum weed intensity was recorded in bare soil treatment plots probably due to availability of much light and space for the weeds to grow profusely

According to our opinion the reduced weed intensity in case of two stem training system was because of the larger and wider leaf area of the plants which allows the more photosynthetic activity of the plants as compared to the weeds. Therefore, weeds will not get the much sufficient light to make their own food for proper growth and development because of the greater leaf area index of the two stem trained plants.

4.5 HYDRO-THERMAL STUDIES OF SOIL

Effect of Planting Methods, Mulching Treatments and Training Systems on Soil Temperature and Soil Moisture

The effect of planting methods, mulching treatments and training systems on soil temperature and moisture during growth of tomato are described as follows:

4.5.1 Soil temperature

The mulches played enormous role in maintaining the soil temperature. The soil temperature was observed at weekly interval from May-August at 7:30 hours and 14:30 hours at 0-5 cm soil depth during the year 2017-2018 (Fig. 4.8, 4.9 and Appendix II) and 2018-2019 (Fig. 4.10, 4.11 and Appendix II). The data indicated that application of black mulch in raised bed planting method ($P_1M_1T_1$) along with two stem training system increased the soil temperature by 3.46 ^{0}C, 4.07 ^{0}C, 4.06 ^{0}C and 1.97 ^{0}C during the 4th week of May, June, July and August, 2017-18 and 3.12 ^{0}C, 1.73 ^{0}C, 2.77 ^{0}C and 2.08 ^{0}C, during the 4th week of May, June, July and August, 2017-18 respectively over no mulch application in flat beds along with three stem training system ($P_2M_3T_2$) as recorded during morning and afternoon hours. The soil temperature was also increased by 3.22 ^{0}C, 5.78 ^{0}C, 3.44 ^{0}C and 6.11 ^{0}C during the

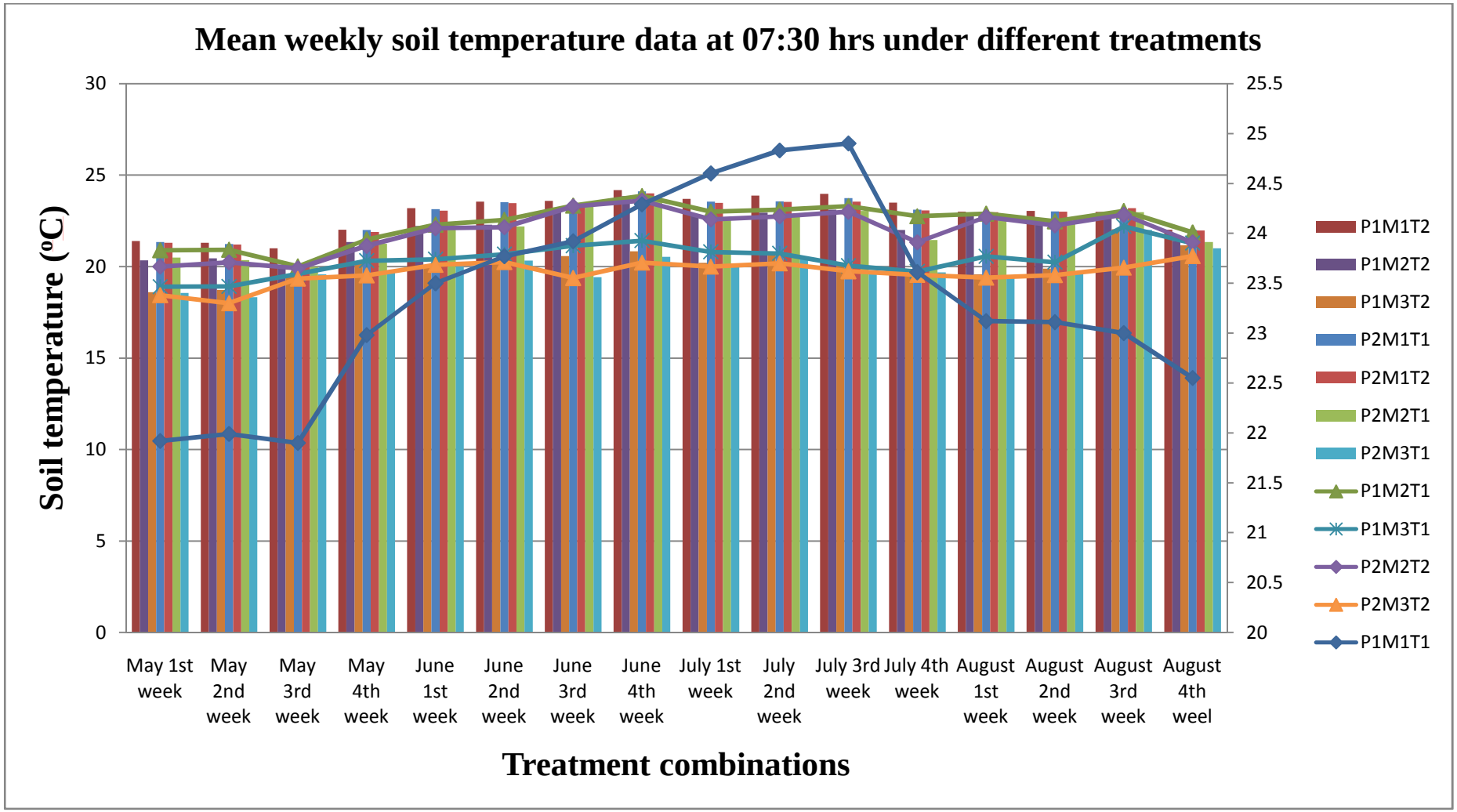


Fig. 4.8 Mean weekly soil temperature (^{o} C at 07:30 hrs) at 0-5 cm soil depth under different treatments during 2017-2018

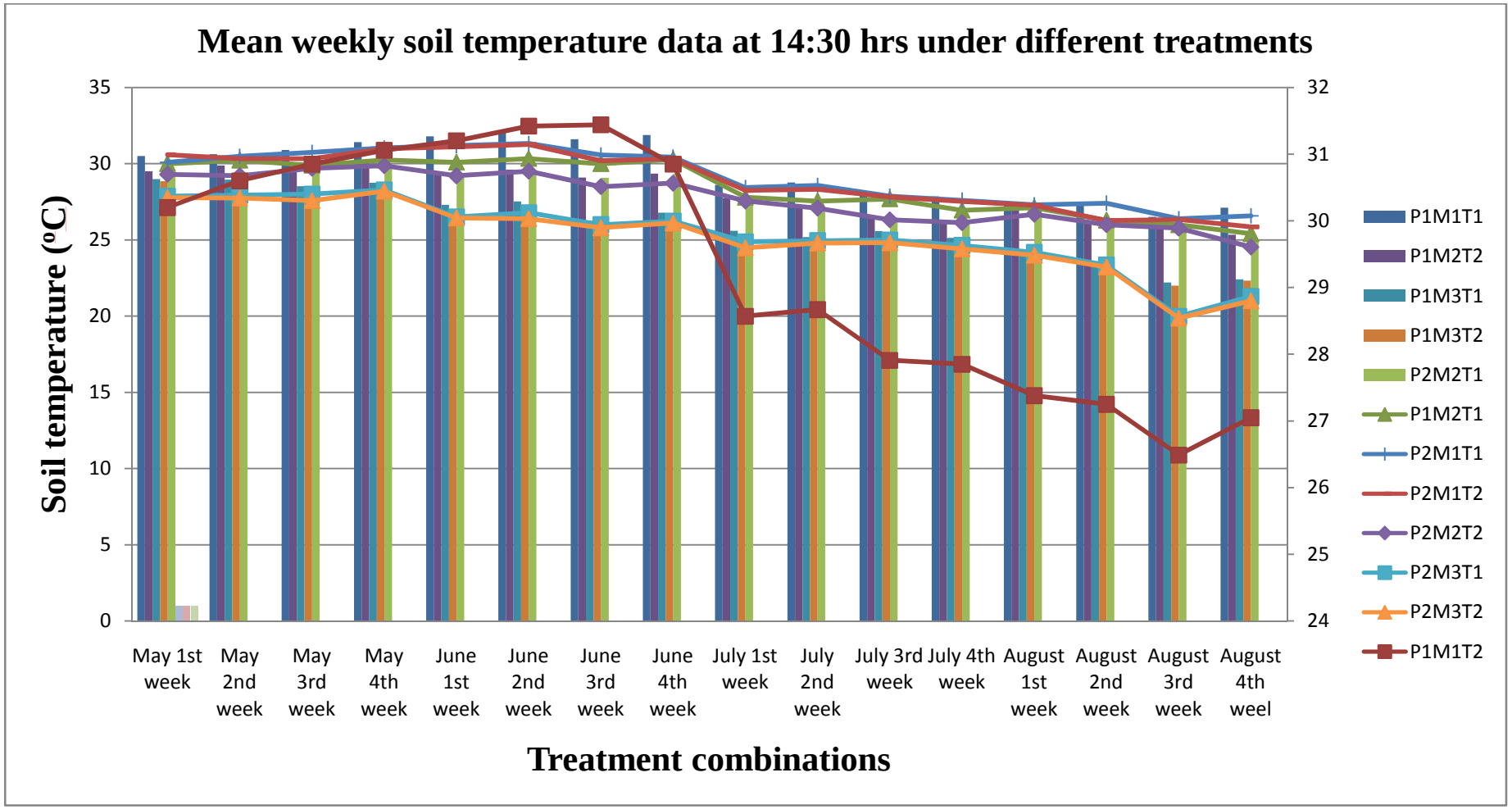


Fig. 4.9 Mean weekly soil temperature (^{o}C at 14:30 hrs) at 0-5 cm soil depth under different treatments during 2017-2018

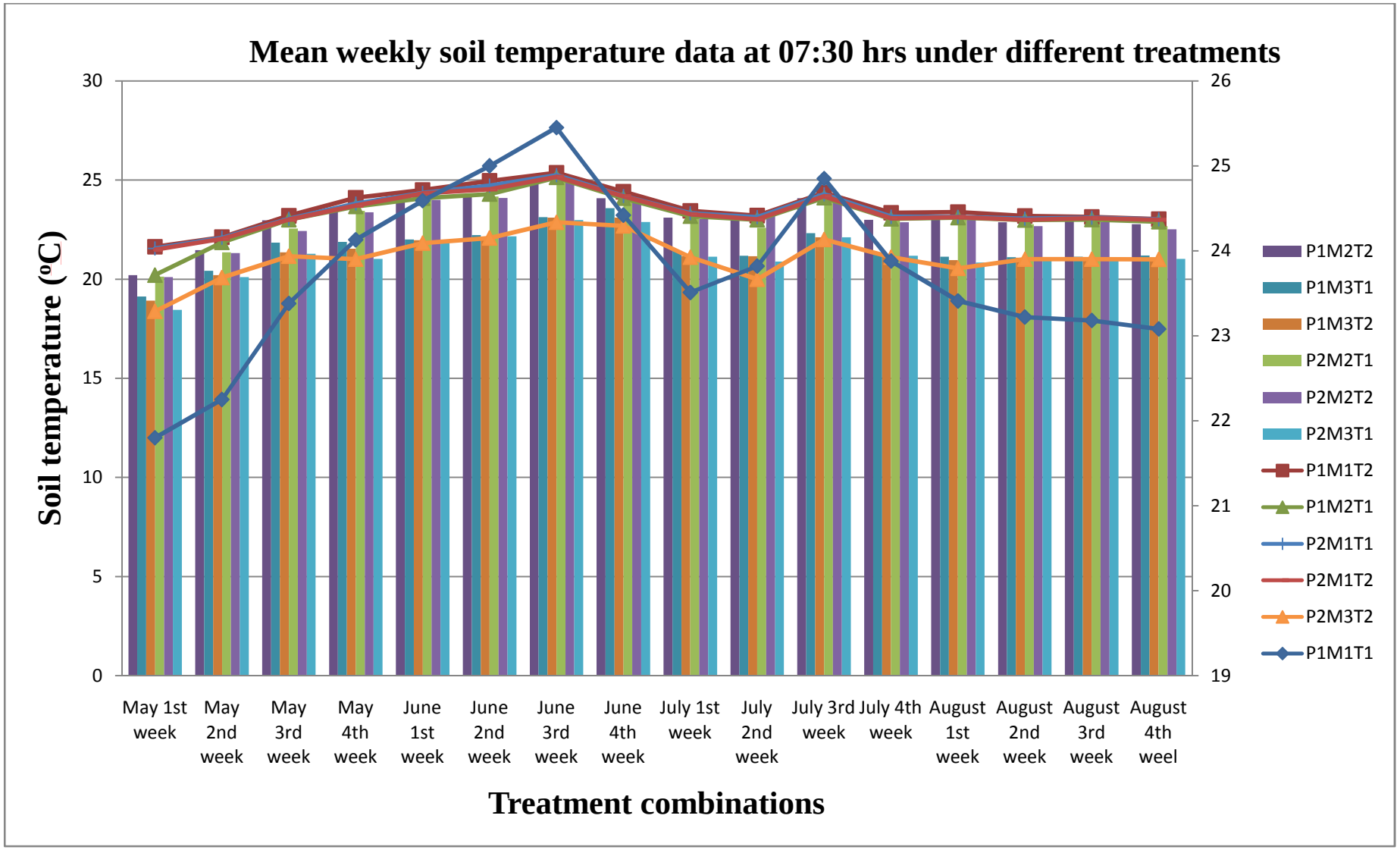


Fig. 4.10 Mean weekly soil temperature (^{o} C at 07:30 hrs) at 0-5 cm soil depth under different treatments during 2018-2019

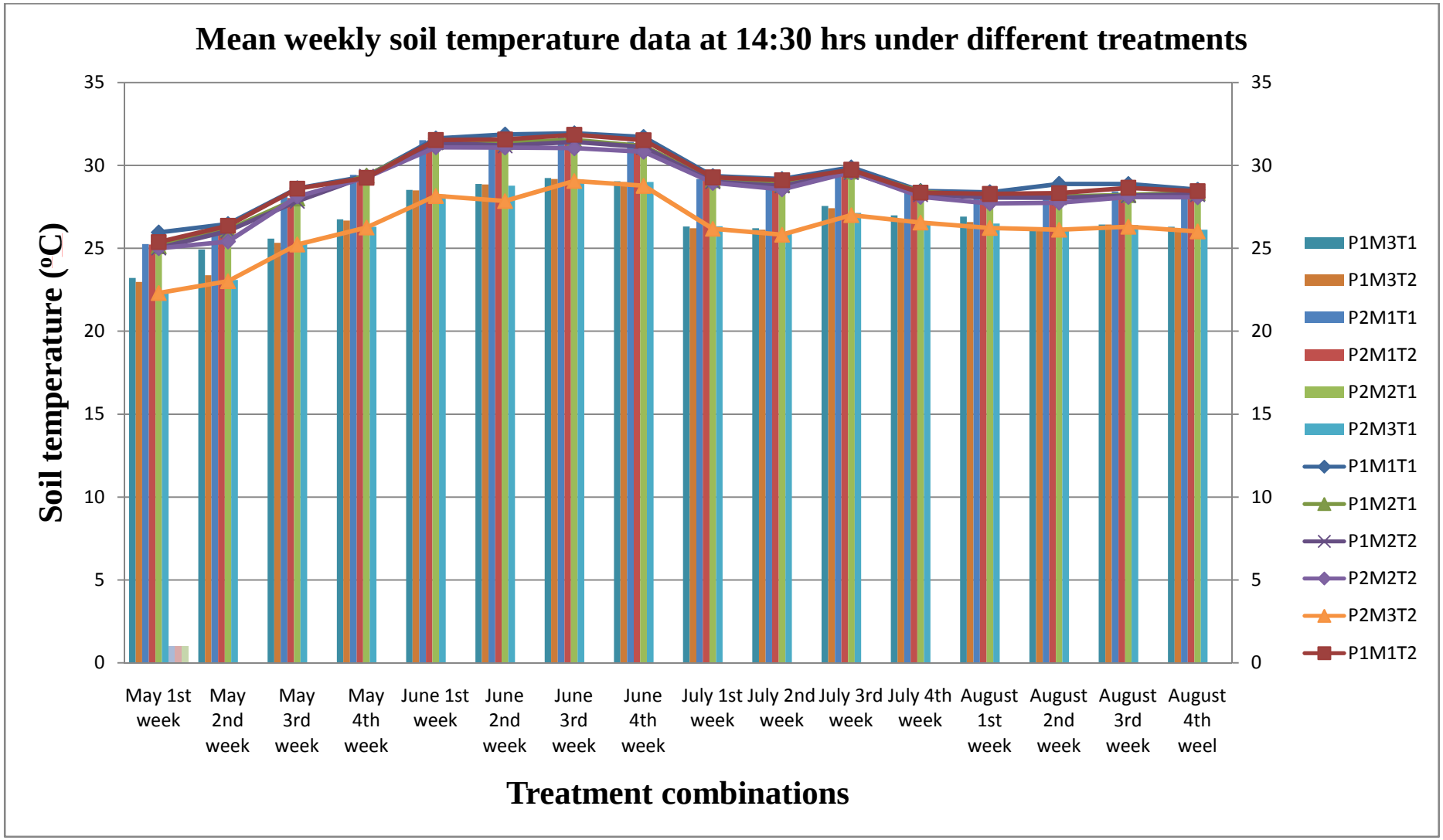


Fig. 4.11 Mean weekly soil temperature (^{o} C at 14:30 hrs) at 0-5 cm soil depth under different treatments during 2018-2019

4th week of May, June, July and August, 2018-19 and 3.10 ^{0}C, 2.95 ^{0}C, 1.91 ^{0}C and 2.52 ^{0}C during the 4th week of May, June, July and August, 2018-19 with the application of black polythene mulch placed on raised beds ($P_1M_1T_1$) along with three stem training system, respectively, during morning and afternoon hours over no mulch application in flat beds along with three stem training system ($P_2M_3T_2$). The same trend was observed during all the weeks of different months during both the years of experimentation. The increase in soil temperature may be attributed to the passing of sun energy through mulch. This process heated both air and soil. The higher soil temperature in the raised bed could be attributed to the wider and more exposed surface area compared to the flat beds.

In general, the effect of mulching on the temperature regime of soil varied depending on capacity of the mulch materials to reflect and transmit solar energy (Lamont, 2005). Black mulch materials have specific optical properties due to which mulches control soil temperature, which can augment or reduce crop yield (Kader *et al.*, 2017). The present results are in agreement with previous studies which have established that plastic film mulching absorbs solar radiations and reduces soil heat loss with a consequent increase in soil moisture and temperature, both of which augment plant growth and improve crop production as, the effects of soil temperature on crop growth are also related to the climatic conditions and locations, where the crop plants are grown. Colour of plastic mulch material determines the energy-radiating factors by influencing the surface temperature of the mulch and the underlying soil temperature. However, the effect of mulching materials on soil temperature is highly variable. The timing of soil temperature measurements and mulching thickness also cause variation in data pertaining to soil temperature.

According to Kumar and Lal (2012), mulching reduces soil temperature in summer and raises it in winter. Mulching also prevents extremes of temperature. The consistent high temperature under black plastic mulch is due to the green house effect that trap the little radiant energy and penetrates into the soil. Little energy is lost through evaporation, resulting in a net gain of soil heat during the day. Though the temperature on the bare plot was low, the poor crop performance obtained on the cultivated plot can be explained by the competition between crop and weeds. Similar are the findings of Teasdale and Baki (1995) in tomato, Awodoyin *et al.* (2007) in tomato, Diaz-Perez (2010) in bell pepper, Ashrafuzzaman *et al.* (2011) in chilli, Kosterna *et al.* (2014) and Angmo *et al.* (2018) in tomato.

4.5.2 Soil moisture

The data pertaining to soil moisture content under different treatment combinations, recorded during the growth and development of tomato for both the cropping periods 2017-18 and 2018-19 at 0-15 cm soil depth at fortnightly interval is shown in Fig. 4.12 and 4.13 (Appendix III). Both the mulches (black mulch and silver/black mulch) were found effective in conserving the soil moisture content. However, the magnitude of moisture conservation varied with the type of mulch material and planting methods. Maximum soil moisture conservation was observed under silver/black mulch followed by black polyethylene mulch placed on flat beds. Application of silver/black polyethylene mulch conserved higher soil moisture content as compared to the unmulched control. The per cent increase in soil moisture content during the cropping period of 2017-18 during the fortnight interval of May, June, July and August was calculated as 20.10, 20.15, 21.26, 25.40, 19.90, 21.15, 26.78, and 29.86 per cent, respectively in the treatment combination $P_2M_2T_1$ as compared to the $P_1M_3T_2$. Similarly, during the year 2018-19, the per cent increase in soil moisture content during the fortnight interval of May, June, July and August was 44.52, 38.99, 17.32, 24.13, 21.16, 16.08, 30.00 and 21.98 per cent, respectively in the treatment combination $P_2M_2T_1$ as compared to the $P_1M_3T_2$. The soil moisture content was higher during the months of July and August due to heavy rains.

The higher moisture content in the flat beds was due to less drainage compared to the raised beds. Kumar *et al*. (2010) also reported low soil moisture under raised bed than flat bed planting method. They attributed that this might be due to the rapid drying of raised bed in comparison to flat bed which resulted into higher soil moisture content in flat beds.

The higher moisture recorded in soil mulched with silver polythene sheet could be attributed to its ability to reflect high amount of sunlight, thereby reducing evapotranspiration and enhancing moisture retention in the soil. Conversely, the significant decrease in the moisture content of soil mulched with black mulch could be linked to relative low abilities of the material to conserve moisture owing to their high transmissibility of solar radiations. Polythene mulching treatment (with hole) constantly stored soil moisture as compared to bare treatments, and therefore the current study recorded higher moisture content in the silver/black mulch treatments. Less moisture depletion under the mulches was a result of prevention of contact between the soil and dry air, which reduced water loss into the atmosphere through evaporation. Because of vapours, the water was further trapped within

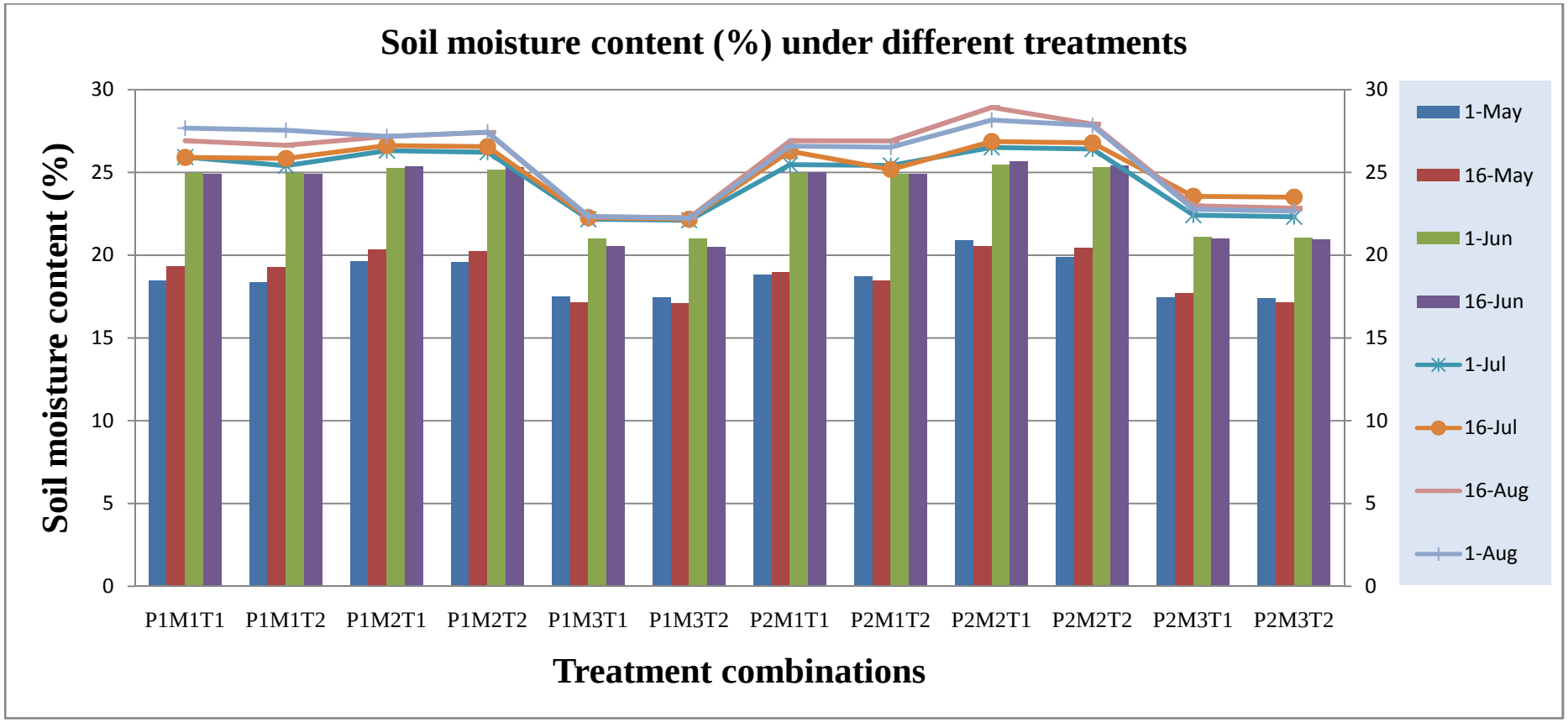


Fig. 4.12 Soil moisture content (%) at 0-15 cm soil depth under different treatments during cropping period of 2017-2018

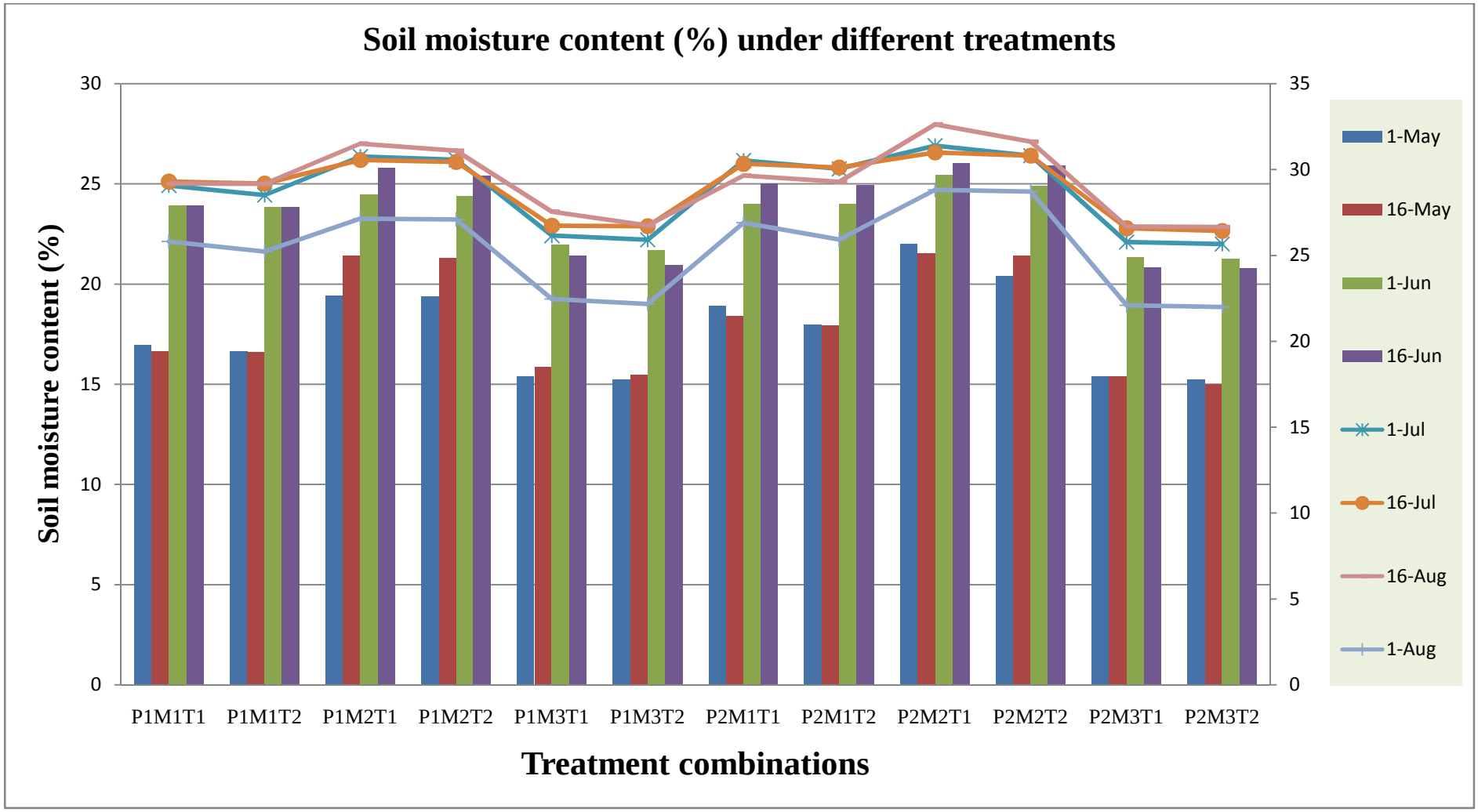


Fig. 4.13 Soil moisture content (%) at 0-15 cm soil depth under different treatments during cropping period year 2018-2019

the mulches, resulting in fog which again dropped into the upper soil layer. Also mulches reduce impact of raindrops and splash, thereby, preventing soil compaction and disease infection, reducing surface run-off and increasing water infiltration. All these resulted into increase in the soil moisture content and reduced moisture depletion. As the moisture depletion was least under silver/grey mulch, the moisture recharging-ability was also least because water infiltration was prevented. None of the less, capillary movement of water molecules through the soil pores from the water table has strongly supplied water to the root zone of the crop grown under silver/grey plastic mulch in the present study. Similar are the findings of Awodoyin *et al.* (2007) in tomato, Diaz-Perez (2010) in bell pepper and Ashrafuzzaman *et al.* (2011) in chilli. The slightly higher water depletion under the bare treatment plots might be due to more water loss into the atmosphere through transpiration from the crop and weeds which was higher than combined water loss through evaporation from the soil surface and transpiration from the crop.

4.6 ECONOMICS OF TOMATO (BENEFIT: COST RATIO)

The adoption of technology in modern agriculture can only be feasible and acceptable to the farmers if it is economically viable. The relevant treatment-wise cost of cultivation, gross returns, net returns and benefit: cost ratio (B: C ratio) of tomato cv. Solan Lalima has been worked out and depicted in Table 4.52 and Appendix-IV, respectively. A perusal of the data revealed that highest cost of cultivation (Rs. 3,23,991.31 /ha) was incurred in $P_1M_2T_2$ i.e. raised bed, silver/black mulch and three stem training system which was followed by $P_1M_1T_2$ i.e. raised bed, black mulch and three stem training system (Rs. 3,15,991.31 /ha), whereas lowest cost of cultivation (Rs. 2,46,404.64 /ha) was observed in $P_2M_3T_1$ i.e. flat bed, no mulch and two stem training system. The economic analysis showed that the highest net return of Rs. 1,18,1364.19 /ha by incurring Rs. 3,07,591.31/- towards cost of cultivation per hectare was obtained from treatment combination $P_1M_1T_1$ (raised bed + black mulch + two stem training system) on account of highest yield (992.64 q/ha) with a highest benefit: cost ratio of 3.84. However, the second highest benefit: cost ratio was 3.78 obtained in treatment combination $P_1M_3T_1$ (raised bed + no mulch + two stem training system) which otherwise recorded comparatively low yield (811.91 q/ha) as well as net returns (Rs. 9,63,060.36/-) as compared to the former treatment combination i.e. $P_1M_1T_1$. This was 'in fact' on account of additional cost incurred on intercultural operations like weeding, hoeing and fertilizer application in raised bed planting method and two stem training system in $P_1M_3T_1$ which in a non mulched treatments. The economic analysis also revealed the lowest benefit: cost ratio

(2.91) which was obtained from the treatment combination $P_2M_2T_2$ (flat bed + silver/black mulch + three stem training system) on account of net returns of Rs. 9,18,284.69/ha by incurring Rs. 3,15,591.31/- towards cost of cultivation per hectare from total yield of 822.58 q/ha. This was due to the additional cost of silver/black mulch and three stem training system as compared to the above mentioned treatments. Statistically, $P_1M_1T_1$ is significantly superior from $P_1M_3T_1$ and all other treatment combinations w.r.t. net returns and benefit: cost ratio (Fig. 4.14).

The present results are in line with the findings of Anand *et al.* (2016) in ashwagandha and Dasa *et al.* (2014) in various vegetable crops. According to the results obtained by Anand *et al.* (2016), the maximum net return (Rs. 32410/ ha) was found in raised bed planting method, but they also stated that it requires some additional cost for field preparation and sowing.

Subba Reddy *et al.* (2015) in tomato also reported similar results regarding benefit cost ratio while using black polythene mulch. They reported that among different types of irrigation, drip irrigation plus black polythene mulch with trellising have given maximum net returns and higher benefit cost ratio (2.83). Singh *et al.* (2009) also found highest net returns and benefit cost ratio with drip irrigation and black polythene mulch while investigating the effect of drip irrigation and polythene mulch on growth, yield and economics in tomato cv. Rupali. Similar results were found by Srivastva *et al.* (1994) while investigating the effect of drip irrigation with black polythene mulch in tomato.

Anand *et al.* (2018) also reported highest Benefit: Cost ratio (3.03) with treatment T_2N_6 (Two stem + 75% RDF + Protein hydrolysates (1.5 g/litre) + PSB (2 kg/ha) + VAM (2 kg/ha)) as compared to lowest benefit cost ratio (0.40). They concluded that it was mainly due to the increased growth and total yield (184.83 t/ha) which fetches more price and produced higher net returns and benefit cost ratio in tomato crop. The results are in conformity with the findings of Singh *et al*. (2017) and Kanwar *et al.* (2016) in tomato. According to Singh *et al.* (2017), the highest net returns (Rs.159.0/m2) were recorded at a closer plant spacing (70 × 30 cm) with 2 stems (G_1), which was significantly higher than wider plant spacing (70 × 60 cm) with 3 stems (G_2) producing Rs.82.4/m^2. Similarly, the highest Output: Input ratio (3.0) was due to closer spacing (70 × 30 cm) along with 2 stems pruning (G_1), which gave significantly higher yield than at wider spacing of (70 × 60 cm) with 3 stems pruning (G_2).

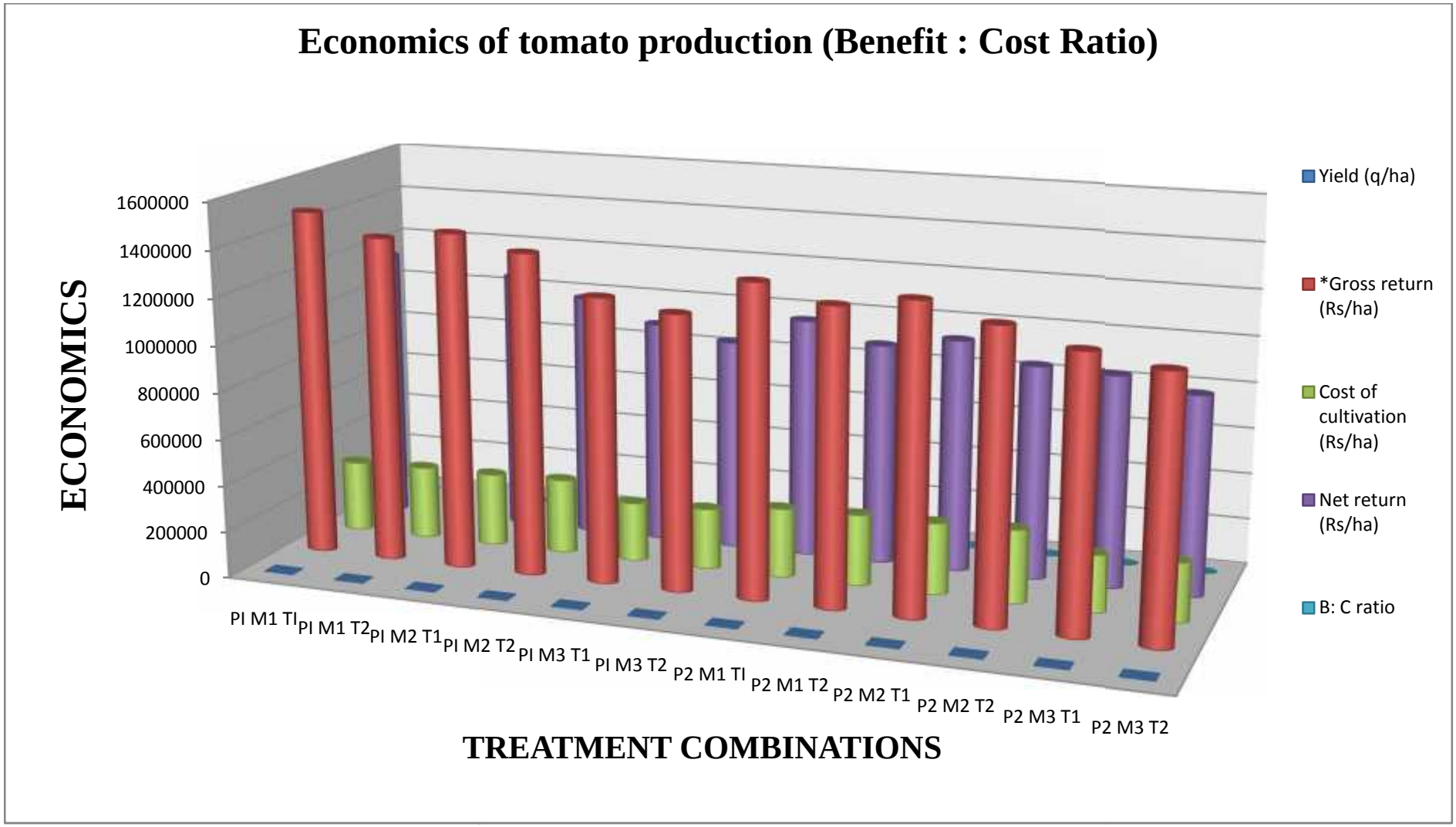


Fig. 4.14 Effect of different treatments on economics of tomato production (Benefit: Cost Ratio)

The present results also showed that tomato production in general is highly dependent on labour and can be described as labour intensive business venture. Among the list of cost items for tomato production technology, only labour accounts for more than 85 per cent (Appendix IV) of cost of production. The remaining cost is distributed among the cost of fertilizers, seeds, fungicides and per cent on mulching. The highest net return of Rs. 1181364.19/ha was obtained from treatment combination $P_1M_1T_1$ (raised bed + black mulch + two stem training system) in the present studies which may be attributed to less expenditure on weeding, hoeing and other cultural operations as mulch controlled maximum weeds. Similar results for increased yield, net return and B: C ratios have also shown by Kumar *et al.* (2015) in garlic crop under irrigated conditions of Uttar Pradesh by using raised bed technology.

Table 4.52 Effect of different treatment modules on economics of tomato production

Treatment code	Treatments Details	Yield (q/ha)	*Gross returns (Rs/ha)	Cost of cultivation (Rs/ha)	Net return (Rs/ha)	B: C ratio
$P_1 M_1 T_1$	Raised bed + Black mulch + Two stem training	992.637	1488955.50	307591.31	1181364.19	3.84
$P_1 M_1 T_2$	Raised bed + Black mulch + Three stem training	932.64	1398960.00	315991.31	1082968.69	3.43
$P_1 M_2 T_1$	Raised bed + Silver/black mulch + Two stem training	960.585	1440877.50	315591.31	1125286.19	3.57
$P_1 M_2 T_2$	Raised bed + Silver/black mulch + Three stem training	918.836	1378254.00	323991.31	1054262.69	3.25
$P_1 M_3 T_1$	Raised bed + No mulch + Two stem training	811.91	1217865.00	254804.64	963060.36	3.78
$P_1 M_3 T_2$	Raised bed + No mulch + Three stem training	783.121	1174681.50	263204.64	911476.86	3.46
$P_2 M_1 T_1$	Flat bed + Black mulch + Two stem training	887.214	1330821.00	299191.31	1031629.69	3.45
$P_2 M_1 T_2$	Flat bed + Black mulch + Three stem training	839.693	1259539.50	307591.31	951948.19	3.09
$P_2 M_2 T_1$	Flat bed + Silver/black mulch + Two stem training	871.458	1307187.00	307191.31	999995.69	3.26
$P_2 M_2 T_2$	Flat bed + Silver/black mulch + Three stem training	822.584	1233876.00	315591.31	918284.69	2.91
$P_2 M_3 T_1$	Flat bed + No mulch + Two stem training	772.173	1158259.50	246404.64	911854.86	3.70
$P_2 M_3 T_2$	Flat bed + No mulch + Three stem training	742.584	1113876.00	254804.64	859071.36	3.37
CD $_{(0.05)}$						0.10

* The gross returns were worked out on the basis of sale price of tomato @ Rs. 15/- kg fixed by the University
P: Planting methods, **M:** Mulching treatments, **T:** Training systems; **P_1:** Raised bed planting method, **P_2:** Flat bed planting method, **M_1:** Black polythene mulch, **M_2:** Silver/black polythene mulch, **M_3:** No mulch, **T_1:** Two stem training system, **T_2:** Three stem training system;

4.7 EFFECT OF WEATHER ON TOMATO IN RESPECT OF GROWTH, YIELD, QUALITY AND SOIL PARAMETERS

Environmental factors are dynamic in determining the extent of growth and development of tomato plants as they play an important role in completion of plant life cycle due to their close association with different phenological stages of crop plants. Basically, the crop environment is represented by soil and atmosphere. The interaction of these two natural entities acting in conjunction with the genetic makeup of plant is compounded by the man's

interference in the form of various inputs supplied by him and decides the pattern of plant growth and ultimately its end product i.e. yield, growth and development of crop plants depend upon judicious management of intrinsic (genetic, hereditary) and extrinsic (environment) factors.

The meterological data have been presented in Appendix 1a and 1b and also illustrated graphically in Figure 3.1 and 3.2. However, weather conditions were more favourable for growth and development of plant during the second year i.e. in 2018 as compared to the first year of experimentation. This might be due to the well distributed rainfall throughout the crop growing season, optimum temperature, requisite relative humidity and bright sunshine for better performance in terms of growth, yield, quality, soil temperature and soil moisture during the second year.

In the present study, various aspects of plant growth, yield, quality, diseases, weed and soil temperature and moisture were assessed for tomato cultivation. The importance of raised-bed planting systems for sustainability of soils suitable for cultural practices was revealed by this study. It was also proved that due to the improved soil physical and chemical properties with raised-bed planting systems the production and productivity of tomato could be enhanced in mid-hill conditions of Himachal Pradesh. In addition, it was determined that fruit yield and quality did not increase in flat planting method in short term even though the same agro-tecniques were followed. Such a case was probably because the soils were not able to create suitable conditions for microorganism's activity due to reduced mineralization which could add organic matter in the soil. In unsuitable soil conditions, enzymatic activity of microorganisms decreases and nutrient quantities mineralized from the organic matter decreases as well. In the present study, the highest values for all parameters were obtained from raised-bed planting systems, black mulch application along with two stem training system. Therefore, from the present findings it was revealed that raised-bed planting system improved mainly the plant yield and fruit quality parameters. Therefore, raised-bed planting system was found to be superior over the flat bed planting system. Planting on raised beds when used singly and in combination with other cultural methods produced good disease control and higher yield that compared favorably to the conventional methods. Based upon present results, it can also be concluded that use of black and silver/black shaded colour synthetic mulches significantly increased the growth, yield and yield contributing characters as compared to the unmulched treatments in tomato in open field conditions. Greater early

and marketable yield, in part, could be attributed to higher soil temperature and weed suppression. Plants under black plastic mulch had higher number of fruits/plant and maximum yield/m^2. This was due to less number of days to first harvest and longer harvest duration in the particular treatment. Quality parameters in terms of self life, total soluble solids, ascorbic acid content and lycopene content etc. of tomato fruits was found to be higher under open field conditions with black mulch. Results of this study showed that different training levels influence plant developmental characteristics, yield and fruit quality of the indeterminate tomato variety. Therefore, taking into consideration all the aspects it is concluded that plants trained to double stem performed best for all the plant growth, yield and quality characters as well. Fruit size dominance in two-stem training system compared to three-stem training raises its marketability and fresh consumption rate also. Pruning and training also resulted in early flowering of tomato plants. Two stem training system per plant should be recommended to tomato growers as the best husbandry practice for increasing marketable fruit yield of medium sized fruits.

Based upon the present present findings, it can be concluded that profitable fruit yield of tomato could be obtained with the treatment combinations of raised bed planting along with the use of black mulch and two stem training system.

Chapter-5

SUMMARY AND CONCLUSIONS

Tomato is an important cash crop of Himachal Pradesh grown during summer and rainy seasons. Although the produce of the tomato fetches lucrative rates in the plains of Northern India, yet, the production is threatened by plethora of factors *viz.*, diseases, insect-pests and weeds which ultimately affect the fruit yield and quality. Thus, present investigation entitled **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum Lycopersicum* L.)"** was carried out at Vegetable Research Farm, Department of Vegetable Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni-Solan located in mid-hill conditions of Himachal Pradesh during April to September 2017-2018 and 2018-2019. The experiment comprised of two levels of planting methods *viz.*, P_1 (raised bed) and P_2 (flat bed), three mulch levels *viz.*, M_1 (black mulch), M_2 (silver/black mulch), and M_3 (no mulch) and two levels of training systems *viz.*, T_1 (two stem) and T_2 (three stem). Thus, there were twelve treatment combinations in all which were replicated thrice in a Randomized Complete Block Design (Factorial). The seeds of 'Solan Lalima' a popular indeterminate variety were sown in the nursery beds on 15th March during both the years and the seedlings were transplanted on 12th April, 2017-18 and 2018-19 in well prepared field. The plot size of 1.8 × 6.3 m and a spacing of 90 cm × 30 cm was followed. The height of the raised beds was 15 cm above the ground level and two beds were separated by 45 cm from proper drainage. The recommended cultural practices and plant protection measures were followed as per package of practices right from sowing up to harvesting. The data on soil moisture content under different treatment combinations were recorded during the growth and development of tomato for both the cropping periods at 0-15 cm soil depth at fortnightly interval. The soil temperature was observed at weekly interval from May-August at 7:30 hours and 14:30 hours at 0-5 cm soil depth during the crop period.

The observations were recorded on days to 50 per cent flowering, number of flower clusters per plant, number of fruits per cluster, days to marketable maturity, number of fruits per plant, fruit length (cm), fruit breadth (cm), pericarp thickness (mm), fruit weight (g), number of pickings, harvest duration (days), fruit yield per plant (kg), / plot (kg), / ha (q), leaf area index, plant height (cm), TSS (^{0}B), ascorbic acid content (mg/100 g of fresh weight), lycopene content (mg/100 g of fresh weight), shelf life (days), incidence of buckeye

rot (%), severity of *Alternaria* leaf blight (%), severity of bacterial leaf spot (%), incidence of fusarium wilt (%), weed intensity (%), fresh and dry weight of weeds (g), weed control efficiency (%), weed count (%), soil moisture content (%) and soil temperature (^{0}C). The benefit: cost ratio of different treatments was also worked out.

The salient findings of the study are summarized below on the basis of pooled data of both the years:

The planting methods, mulch materials and training systems had a significant effect on growth, yield and yield contributing characters.

Different planting methods influenced the growth, yield and yield contributing characters to a greater extent. Raised bed planting method (P_1) proved best for all growth, yield and quality parameters in comparison to the flat bed (P_2) method. It also proved better in reducing the incidence/severity of diseases and lowering the number of weeds, fresh and dry weight of the weeds and weed intensity and therefore improved the weed control efficiency.

- The plants grown on raised bed planting method (P_1) produced significantly more number of flower clusters per plant (11.24), maximum number of fruits per cluster (5.78), highest number of fruits per plant (38.89), maximum fruit length (4.72 cm), fruit breadth (5.32 cm), pericarp thickness (4.71 mm), fruit weight (77.98 g), more number of pickings (18.72), prolonged harvest duration (74.27 days), maximum fruit yield [per plant (3.04 kg), per plot (127.57 kg), per hectare (899.96)], greater leaf area index (4.09) and maximum plant height (172.12 cm).
- The quality attributes *viz.*, TSS (4.79 ^{0}Brix), ascorbic acid content (31.11 mg/100g), lycopene content (5.96 mg/100g) and shelf life (11.67 days) were also significantly higher in those fruits which were harvested from the plants grown on raised beds.
- The plants grown on raised bed planting method (P_1) significantly took minimum number of days to marketable maturity (74.87 days) and to 50 per cent flowering (29.82 days). The incidence/severity of diseases (%) *viz.*, incidence of buckeye rot (14.91 %), severity of *Alternaria* leaf blight (11.40 %), severity of bacterial leaf spot (4.78 %) and incidence of *Fusarium* wilt (9.57 %) were minimum in the plants grown on the raised beds.

- The weed parameters *viz.*, weed count (513.67 m^2), fresh weight (262.53 g) and dry weight of weeds (30.72 g) were minimum, however, weed control efficiency was maximum i.e. 45.38 per cent in raised bed planting method.
- Raised bed planting method also recorded significantly minimum weed intensity of *Bidens* pilosa (0.80 %), *Commelina benghalensis* (1.27 %), *Cyperus rotundus* (10.58 %), *Echinochloa crus-galli* (10.26 %), *Galinsoga parviflora* (14.02 %) and *Nicandra physalodes* (1.66 %).

Effect of mulch materials was also found significant for growth, yield, quality, incidence/severity of diseases and weed parameters. However, black polythene mulch (M_1) was found superior over silver/black mulch (M_2) and no mulch (M_3) treatments.

- The plants grown on black polythene mulch (M_1) significantly produced more number of flower clusters per plant (11.60), maximum number of fruits per cluster (5.88), more number of fruits per plant (39.22), maximum fruit length (4.80 cm), fruit breadth (5.43 cm), pericarp thickness (4.76 mm), fruit weight (78.52 g), more number of pickings (19.04), prolonged harvest duration (74.74 days), maximum leaf area index (4.21), plant height (173.31 cm) and fruit yield [per plant (3.08 kg), per plot (129.42 kg), per hectare (913.05 q)].
- The quality attributes *viz.*, TSS (4.93 ^{0}Brix), ascorbic acid content (31.67 mg/100g), lycopene content (6.09 mg/100g) and shelf life (12.09 days) were significantly higher in those fruits which were harvested from the plants grown on black polythene mulched plots.
- The plants grown on black polythene mulch (M_1) significantly took minimum number of days to 50 per cent flowering (29.10 days) and minimum number of days to marketable maturity (73.08 days). The incidence of diseases *viz.*, buckeye rot (14.15 %), *Fusarium* wilt (9.21 %) as well as severity of *Alternaria* leaf blight (10.90 %) and bacterial leaf spot (4.64 %) were minimum in the plants grown on black polythene mulched plots.
- The weed parameters *viz.*, weed count (252.04 m^2), fresh weight (103.75 g) and dry weight of weeds (24.29 g) were recorded minimum while weed control efficiency was maximum (63.21 %) in black polythene mulched plots, significantly.
- Black polythene mulch also recorded significantly minimum intensity of weeds like *Bidens pilosa*, *Commelina benghalensis*, *Cyperus rotundus*, *Echinochloa crus-galli*,

Galinsoga parviflora and *Nicandra physalodes* i.e. 0.67, 0.67, 8.39, 8.34, 11.03 and 0.67 per cent, respectively.

Training systems had a significant effect on growth, yield, yield contributing characters and quality parameters also. Training of tomato plants to two stem training system resulted in improved growth, yield and quality characters. Two stem training system also helped in minimizing the severity/incidence of diseases as well as weed parameters.

- The two stem trained plants (T_1) significantly produced more number of flower clusters per plant (10.83), maximum number of fruits per cluster (5.59), highest number of fruits per plant (38.31), maximum fruit length (4.65 cm), fruit breadth (5.26 cm), pericarp thickness (4.65 mm), fruit weight (77.64 g), more number of pickings (18.14), prolonged harvest duration (71.34 days), maximum leaf area index (4.01), plant height (174.11 cm) and fruit yield [per plant (2.98 kg), per plot (127.12 kg), per hectare (882.66)].
- The quality attributes *viz.*, TSS (4.75 ^{0}Brix), ascorbic acid content (30.79 mg/100g), lycopene content (5.84 mg/100g) and shelf life (11.35 days) were significantly higher in those fruits which were harvested from the plants trained to two stem training system.
- The two stem trained plants (T_1) significantly took minimum number of days to 50 per cent flowering (30.32 days), minimum number of days to marketable maturity (76.29 days), incidence of buckeye rot (15.68 %) and *Fusarium* wilt (10.12 %) as well as severity of *Alternaria* leaf blight (12.33 %) and bacterial leaf spot (5.02 %).
- The weed parameters *viz.*, weed count (526.81 m^2), fresh weight (281.52 g) and dry weight of weeds (34.33 g), were recorded minimum and weed control efficiency was maximum (41.94 %) significantly in those plants wherein two stem training system was followed.
- Two stem training system also recorded significantly minimum intensity of weeds like *Bidens pilosa* (1.70 %), *Commelina benghalensis* (1.31 %), *Echinochloa crus-galli* (10.26 %), *Galinsoga parviflora* (14.47 %) and *Nicandra physalodes* (1.70 %).

The results from the present investigation also revealed that the combined effects of P × M (planting methods and mulching treatments) interaction proved to be significant for growth, yield, quality, incidence/severity of diseases and weed parameters. The treatment

combination P_1M_1 (raised bed and black mulch) was rated best for most of the growth, yield and quality characters.

- Treatment combination P_1M_1 (raised bed and black mulch) significantly produced more number of flower clusters per plant (12.30), maximum number of fruits per cluster (6.27), highest number of fruits per plant (40.76), maximum fruit length (5.03 cm) and pericarp thickness (4.92 mm), more number of pickings (20.58) and maximum values of leaf area index (4.51), plant height (176.84 cm) as well as fruit yield [per plant (3.25 kg), per plot (136.45 kg) and per hectare (962.64 q)].
- Treatment combination P_1M_1 (raised bed and black mulch) resulted in maximum shelf life (13.01) days of tomato fruits, significantly.
- Treatment combination P_1M_1 (raised bed and black mulch) also recorded significantly minimum number of days to 50 per cent flowering (28.06) and marketable maturity (70.63 days). The treatment combination P_1M_1 (raised bed and black mulch) resulted in significantly minimum incidence of buckeye rot (12.85 %), severity of *Alternaria* leaf blight (8.79 %), severity of bacterial leaf spot (4.10 %) and incidence of *Fusarium* wilt (7.83 %).
- Treatment combination P_1M_1 (raised bed and black mulch) resulted in minimum, fresh weight (85.01 g) and dry weight of weeds (17.58 g).
- Treatment combination P_1M_1 also recorded significantly minimum weed intensity of weeds like *Bidens pilosa* (0.67 %), *Commelina benghalensis* (0.67 %), *Cyperus rotundus* (7.69 %), *Echinochloa crus-galli* (7.67 %), *Galinsoga parviflora* (10.01 %) and *Nicandra physaloides* (0.67 %).
- Treatment combination P_1M_1 also recorded significantly maximum weed control efficiency (56.87 %).

The results from the present investigation also revealed that the combined effect of another M × T (mulching treatments and training systems) interaction proved to be significant for most of the growth, yield, quality, incidence/severity of diseases and weed parameters. The treatment combination M_1T_1 (black mulch and two stem training system) was considered best for most of the growth, yield and quality characters.

- Treatment combination M_1T_1 (black mulch and two stem training system) recorded significantly, maximum number of fruits per plant (40.01), maximum fruit length

(4.94 cm), more number of pickings (19.75) plant height (180.53 cm) and fruit yield [per plot (133.23 kg) and per hectare (939.93 q)].

- Treatment combination M_1T_1 resulted in significantly maximum shelf life (12.45 days) of tomato fruits.
- Treatment combination M_1T_1 (black mulch and two stem training system) recorded significantly minimum number of days to 50 per cent flowering (28.64), incidence of buckeye rot (13.26 %), severity of *Alternaria* leaf blight (10.15 %), severity of bacterial leaf spot (4.23 %) and incidence of *Fusarium* wilt (8.43 %).
- Treatment combination M_1T_1 (raised bed and black mulch) resulted in significantly minimum fresh weight (101.57 g) of weeds.
- Treatment combination M_1T_1 also recorded significantly minimum weed intensity of weeds like *Bidens pilosa* (0.67 %), *Commelina benghalensis* (0.67 %), *Galinsoga parviflora* (10.44 %) and *Nicandra physaloides* i.e. (0.67 %).
- Treatment combination M_1T_1 also recorded significantly maximum weed control efficiency (66.64 %).

The combined effects of another P × T (planting methods and training systems) interaction proved to be significant for most of the growth, yield, quality, incidence/severity of diseases and weed parameters. The treatment combination P_1T_1 (raised bed and two stem training system) was recorded best for most of the growth, yield and yield contributing characters.

- Treatment combination P_1T_1 (raised bed and two stem training system) recorded significantly maximum number of pickings (19.39), plant height (179.05 cm) and fruit yield per plant (3.11 kg).
- Similarly treatment combination P_1T_1 (raised bed and two stem training system) resulted in significantly minimum severity of *Alternaria* leaf blight (10.58 %), bacterial leaf spot (4.44 %) and incidence of *Fusarium* wilt (8.80 %).
- Treatment combination P_1T_1 (raised bed and two stem training system) recorded significantly minimum number of days to 50 per cent flowering (29.36), minimum fresh weight (243.77 g) of weeds and also minimum weed intensity of *Commelina benghalensis* (1.15 %),
- Treatment combination P_1T_1 also recorded significantly maximum weed control efficiency (47.48 %).

Analysis of variance showed significant difference for some growth, disease and weed parameters.

- Treatment combination $P_1M_1T_1$ (raised bed, black mulch and two stem training system) recorded significantly maximum number of pickings (21.33).
- Treatment combination $P_1M_1T_1$ (raised bed, black mulch and two stem training system) recorded significantly minimum incidence of buckeye rot (11.99 %) and *Fusarium* wilt (6.76 %) as well as severity of bacterial leaf spot (3.38 %).
- Treatment combination $P_1M_1T_1$ (raised bed, black mulch and two stem training system) recorded significantly minimum fresh weight (82.81 g) and dry weight (15.17 g) of weeds.
- Treatment combination $P_1M_1T_1$ (raised bed, black mulch and two stem training system) recorded significantly minimum (0.67 %) weed intensity of *Commelina benghalensis* and *Bidens pilosa* (0.67 %).
- Treatment combination $P_1M_1T_1$ also recorded significantly maximum weed control efficiency (74.11 %).

Analysis of data showed non-significant differences with regards to three way interactions (pooled data) P×M×T (planting methods, mulching treatments and training systems) for most of the growth, yield, yield contributing and quality characters as well as incidence of buckeye rot and weed parameters.

- Maximum soil temperature was recorded in the treatment combination $P_1M_1T_1$ (raised bed planting method, black mulch and two stem training system) as compared to $P_2M_3T_2$ (flat bed planting method, no mulch and three stem training system) at weekly intervals at 0-5 cm soil depth from the month of May to August during 2017-18 and 2108-19 years of study.
- Application of silver/black polyethylene mulch conserved higher soil moisture content as compared to the black mulch and unmulched control during both the years of study recorded at fortnightly intervals at 0-15 cm soil depth from May to August month. Maximum soil moisture content was found in the treatment combination $P_2M_2T_1$ (flat bed, silver/grey mulch and two stem training system) as compared to the $P_1M_3T_2$ (raised bed, no mulch and three stem training system).
- Weather conditions were more favourable for growth and development of tomato during the second year i.e. in 2018-19 as compared to first year of experimentation.

CONCLUSION

The present investigation on the effect of planting methods, mulching and training systems showed significant variations for all growth, yield, quality, diseases and weed parameters as well as for soil parameters. Among the individual effects of planting methods, mulching and training systems, the raised bed (P_1), black polythene mulch (M_1) and two stem training system (T_1) were considered best in terms of growth, yield and quality parameters. Among all the treatments, combined effect of two way interactions *viz.*, P_1M_1, M_1T_1 and P_1T_1 was rated best in terms of growth, yield and quality parameters. Studies also revealed that the highest net returns of Rs 1,18,1364.19 /ha were obtained for treatment combination of $P_1M_1T_1$ (raised bed, black mulch and two stem training system) which was also best for yield (992.64 q/ha), gross returns (Rs 1488955.50 /ha) and benefit cost ratio (1:3.84).

On the basis of two years studies, it can be concluded that the treatment combination $P_1M_1T_1$ (raised bed, black mulch and two stem training system) which produced maximum values of yield, gross returns, net returns and cost benefit ratio may be recommended to the farmers after testing the authenticity of results in the farmer's field for another two years.

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APPENDIX-Ia

AGRO-METEOROLOGICAL DATA DURING THE RESEARCH PERIOD

Mean monthly meterological data for Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the period of study (2017)

Month	Temperature (°C)			Rainfall (mm)	Relative humidity (%)
	Max.	Min.	Mean		
April, 2017	29.30	13.20	21.30	57.80	44.00
May, 2017	30.50	15.80	23.20	100.80	53.00
June, 2017	28.70	17.90	23.30	197.80	68.00
July, 2017	27.60	20.40	24.00	162.30	81.00
August, 2017	26.70	20.10	23.40	233.80	82.00
September, 2017	27.20	16.80	22.00	133.80	72.00

APPENDIX-Ib

Mean monthly meterological data for Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) during the period of study (2018)

Month	Temperature (°C)			Rainfall (mm)	Relative humidity (%)
	Max.	Min.	Mean		
April, 2018	27.10	12.60	19.80	39.60	40.00
May, 2018	30.70	16.10	23.40	54.90	33.00
June, 2018	29.70	18.90	24.30	190.00	52.00
July, 2018	26.70	20.20	23.40	340.20	77.00
August, 2018	28.30	20.00	23.80	216.60	74.00
September, 2018	26.50	16.90	21.70	224.30	76.00

Source: Meteorological Observatory, Department of Environmental Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP) - 173 230

APPENDIX-II

Mean weekly soil temperature (^{o}C at 07:30 hrs) at 0-5 cm soil depth under different treatments during 2017-2018

	May				June				July				August			
TC (7:30)	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**
$P_1M_1T_1$	21.92	21.99	21.90	22.98	23.50	23.77	23.92	24.29	24.60	24.83	24.90	23.61	23.12	23.11	23.00	22.55
$P_1M_1T_2$	21.40	21.31	21.00	22.01	23.20	23.55	23.59	24.18	23.70	23.88	23.98	23.50	23.00	23.04	22.99	22.02
$P_1M_2T_1$	20.90	20.93	20.02	21.49	22.30	22.56	23.34	23.87	23.00	23.12	23.31	22.76	22.90	22.48	23.05	21.87
$P_1M_2T_2$	20.34	20.45	20.00	21.35	22.22	22.29	23.22	23.85	22.80	22.95	23.12	22.00	22.87	22.34	23.00	21.41
$P_1M_3T_1$	18.90	18.91	19.60	20.32	20.40	20.68	21.14	21.42	20.80	20.72	20.05	19.73	20.56	20.24	22.20	21.28
$P_1M_3T_2$	18.60	18.73	19.55	20.22	20.00	20.24	20.58	20.83	20.20	20.65	20.04	19.58	19.58	19.89	22.05	21.16
$P_2M_1T_1$	21.34	21.23	20.12	22.00	23.14	23.53	23.44	24.12	23.55	23.56	23.74	23.11	23.00	23.02	22.81	22.01
$P_2M_1T_2$	21.30	21.21	20.03	21.89	23.06	23.47	23.41	24.00	23.49	23.54	23.55	23.07	22.97	23.00	23.20	21.98
$P_2M_2T_1$	20.50	20.35	19.99	21.25	22.14	22.20	23.30	23.76	22.60	22.82	23.05	21.45	22.84	22.33	22.97	21.35
$P_2M_2T_2$	20.00	20.23	19.90	21.13	22.10	22.15	23.29	23.61	22.58	22.75	23.00	21.33	22.71	22.25	22.84	21.33
$P_2M_3T_1$	18.56	18.32	19.58	19.73	20.00	20.33	19.42	20.54	20.15	20.53	19.81	19.68	19.45	19.66	22.00	21.00
$P_2M_3T_2$	18.44	18.00	19.34	19.52	20.10	20.25	19.38	20.22	20.00	20.18	19.75	19.55	19.40	19.54	19.95	20.58

Mean weekly soil temperature (^{o}C at 14:30 hrs) at 0-5 cm soil depth under different treatments during 2017-2018

	May				June				July				August			
TC (14:30)	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**
$P_1M_1T_1$	30.50	30.62	30.90	31.42	31.80	32.04	31.60	31.89	28.61	28.77	28.00	27.86	27.45	27.32	26.51	27.11
$P_1M_1T_2$	30.20	30.60	30.85	31.06	31.20	31.42	31.44	30.85	28.57	28.67	27.91	27.85	27.38	27.25	26.49	27.05
$P_1M_2T_1$	30.00	30.23	29.90	30.25	30.10	30.34	30.00	30.29	27.80	27.54	27.69	26.95	27.12	26.29	26.00	25.41
$P_1M_2T_2$	29.50	29.89	30.00	30.14	29.40	29.61	29.10	29.36	27.74	27.29	26.54	26.24	27.00	26.20	25.90	25.35
$P_1M_3T_1$	29.00	28.95	28.52	28.75	27.30	27.52	26.25	26.78	25.60	25.19	25.58	25.13	24.35	23.31	22.20	22.41
$P_1M_3T_2$	28.85	28.45	28.20	28.47	26.80	27.06	26.20	26.44	24.91	24.98	25.28	25.00	24.21	23.18	22.00	22.33
$P_2M_1T_1$	30.10	30.49	30.75	31.04	31.19	31.33	30.58	30.43	28.44	28.58	27.88	27.61	27.31	27.42	26.40	26.59
$P_2M_1T_2$	30.60	30.33	30.34	31.00	31.11	31.27	30.20	30.33	28.25	28.31	27.82	27.52	27.27	26.26	26.33	25.85
$P_2M_2T_1$	29.44	29.33	29.90	29.91	29.24	29.57	29.08	29.33	27.81	27.15	26.45	26.22	26.98	26.10	25.80	25.00
$P_2M_2T_2$	29.31	29.22	29.70	29.87	29.21	29.51	28.50	28.73	27.56	27.09	26.33	26.14	26.69	26.00	25.78	24.54
$P_2M_3T_1$	27.87	27.94	28.00	28.28	26.50	26.78	26.00	26.24	24.87	24.95	24.99	24.64	24.18	23.35	19.99	21.30
$P_2M_3T_2$	27.77	27.76	27.58	28.20	26.45	26.40	25.80	26.11	24.49	24.80	24.82	24.42	24.00	23.23	19.87	21.00

Mean weekly soil temperature (^{o}C at 07:30 hrs) at 0-5 cm soil depth under different treatments during 2018-2019

	May				June				July				August			
TC (7:30)	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**
$P_1M_1T_1$	21.80	22.25	23.38	24.13	24.59	25.00	25.45	24.42	23.51	23.82	24.85	23.88	23.41	23.22	23.18	23.08
$P_1M_1T_2$	21.64	22.12	23.20	24.11	24.50	24.96	25.37	24.41	23.45	23.21	24.36	23.35	23.39	23.19	23.14	23.03
$P_1M_2T_1$	20.21	21.86	23.00	23.67	24.09	24.29	25.13	24.09	23.18	23.00	24.11	23.04	23.11	22.98	23.01	22.90
$P_1M_2T_2$	20.20	21.47	22.97	23.55	24.08	24.22	25.10	24.08	23.11	22.98	24.09	23.00	23.08	22.87	23.00	22.78
$P_1M_3T_1$	19.13	20.42	21.84	21.88	22.00	22.23	23.13	23.58	21.43	21.18	22.32	21.23	21.13	21.11	21.13	21.20
$P_1M_3T_2$	18.92	20.21	21.36	21.54	21.97	22.13	23.11	23.11	21.17	21.16	22.12	21.19	20.96	21.09	21.08	21.10
$P_2M_1T_1$	21.55	22.09	23.04	23.82	24.36	24.72	25.25	24.20	23.33	23.13	24.28	23.15	23.14	23.06	23.11	23.02
$P_2M_1T_2$	21.49	22.04	23.01	23.72	24.33	24.53	25.16	24.18	23.27	23.02	24.18	23.07	23.13	23.00	23.08	23.00
$P_2M_2T_1$	20.13	21.35	22.56	23.45	24.05	24.17	25.08	24.07	23.10	22.59	24.08	22.96	23.04	22.78	23.00	22.68
$P_2M_2T_2$	20.11	21.32	22.43	23.37	24.00	24.10	25.00	24.00	23.05	23.49	24.01	22.87	23.00	22.68	22.89	22.52
$P_2M_3T_1$	18.45	20.11	21.28	21.03	21.96	22.16	22.98	22.88	21.13	20.89	22.11	21.18	20.84	21.11	21.03	21.02
$P_2M_3T_2$	18.38	20.08	21.16	21.01	21.82	22.08	22.87	22.69	21.11	20.00	22.00	21.11	20.55	21.01	21.01	21.00

Mean weekly soil temperature () (^{o}C at 14:30 hrs) at 0-5 cm soil depth under different treatments during 2018-2019

	May				June				July				August			
TC (14:30)	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**	**1st week**	**2nd week**	**3rd week**	**4th week**
$P_1M_1T_1$	25.96	26.46	28.62	29.35	31.63	31.87	31.94	31.72	29.36	29.18	29.88	28.46	28.38	28.89	28.88	28.54
$P_1M_1T_2$	25.38	26.36	28.60	29.26	31.53	31.57	31.85	31.52	29.28	29.11	29.74	28.36	28.28	28.33	28.65	28.45
$P_1M_2T_1$	25.13	26.11	28.00	29.38	31.40	31.38	31.53	31.15	29.11	28.83	29.63	28.42	28.10	28.12	28.22	28.33
$P_1M_2T_2$	25.02	26.05	27.84	29.34	31.38	31.19	31.42	31.10	29.02	28.77	29.58	28.24	28.06	28.05	28.18	28.25
$P_1M_3T_1$	23.22	24.93	25.58	26.75	28.53	28.88	29.24	29.05	26.31	26.22	27.56	26.99	26.92	26.23	26.43	26.30
$P_1M_3T_2$	22.98	23.38	25.33	26.68	28.49	28.86	29.18	29.00	26.22	26.13	27.42	26.65	26.58	26.22	26.44	26.14
$P_2M_1T_1$	25.26	26.34	28.19	29.43	31.52	31.63	31.83	31.42	29.18	28.88	29.77	28.35	28.19	28.21	28.44	28.25
$P_2M_1T_2$	25.23	26.12	28.03	29.40	31.43	31.42	31.74	31.36	29.24	29.01	29.68	28.34	28.16	28.13	28.33	28.14
$P_2M_2T_1$	25.01	26.01	28.52	29.30	31.18	31.10	31.11	30.98	29.00	28.68	29.63	28.22	28.00	28.00	28.14	28.15
$P_2M_2T_2$	25.00	25.41	28.12	29.27	31.09	31.08	31.04	30.82	28.95	28.55	29.59	28.10	27.70	27.75	28.09	28.08
$P_2M_3T_1$	22.34	23.10	25.32	26.30	28.24	28.78	29.13	29.00	26.33	26.00	27.14	26.60	26.49	26.20	26.41	26.12
$P_2M_3T_2$	22.30	23.01	25.23	26.25	28.16	27.85	29.06	28.77	26.18	25.82	27.00	26.55	26.23	26.12	26.30	26.02

APPENDIX-III

Soil moisture content (%) at 0-15 cm soil depth in different treatments during the cropping periods 2017- 2018 and 2018-2019

TC	1-May-2017	16-May-2017	1-June-2017	16-June-2017	1-July-2017	16-July-2017	1-August-2017	16-August-2017
$P_1M_1T_1$	18.47	19.32	24.93	24.91	25.92	25.91	27.68	26.91
$P_1M_1T_2$	18.35	19.27	24.94	24.86	25.41	25.84	27.55	26.64
$P_1M_2T_1$	19.64	20.34	25.22	25.33	26.32	26.62	27.17	27.17
$P_1M_2T_2$	19.56	20.23	25.12	25.27	26.22	26.55	27.44	27.42
$P_1M_3T_1$	17.47	17.10	21.00	20.51	22.17	22.27	22.35	22.32
$P_1M_3T_2$	17.41	17.07	20.98	20.47	22.11	22.18	22.22	22.27
$P_2M_1T_1$	18.82	18.97	24.94	24.98	25.47	26.28	26.59	26.91
$P_2M_1T_2$	18.72	18.47	24.90	24.92	25.42	25.18	26.52	26.89
$P_2M_2T_1$	20.91	20.51	25.44	25.67	26.51	26.87	28.17	28.92
$P_2M_2T_2$	19.87	20.42	25.27	25.42	26.41	26.78	27.84	27.92
$P_2M_3T_1$	17.41	17.71	21.10	20.98	22.42	23.55	22.78	22.99
$P_2M_3T_2$	17.39	17.12	21.04	20.94	22.32	23.51	22.66	22.84
TC	**1-May-2018**	**16-May-2018**	**1-June-2018**	**16-June-2018**	**1-July-2018**	**16-July-2018**	**1-August-2018**	**16-August-2018**
$P_1M_1T_1$	16.95	16.65	23.93	23.91	24.92	25.11	25.81	25.02
$P_1M_1T_2$	16.66	16.60	23.85	23.84	24.44	25.02	25.22	25.00
$P_1M_2T_1$	19.42	21.41	24.49	25.82	26.37	26.19	27.14	27.00
$P_1M_2T_2$	19.41	21.31	24.42	25.41	26.20	26.09	27.10	26.65
$P_1M_3T_1$	15.41	15.88	21.98	21.42	22.42	22.91	22.47	23.61
$P_1M_3T_2$	15.23	15.49	21.71	20.97	22.21	22.89	22.17	22.93
$P_2M_1T_1$	18.90	18.43	24.01	25.00	26.17	26.00	26.91	25.41
$P_2M_1T_2$	17.97	17.94	24.00	24.93	25.75	25.82	25.92	25.10
$P_2M_2T_1$	22.01	21.53	25.47	26.03	26.91	26.57	28.82	27.97
$P_2M_2T_2$	20.41	21.43	24.92	25.91	26.41	26.41	28.72	27.11
$P_2M_3T_1$	15.40	15.38	21.35	20.85	22.10	22.78	22.10	22.87
$P_2M_3T_2$	15.24	15.00	21.25	20.78	22.00	22.65	22.00	22.85

APPENDIX-IV

Cost of cultivation of Tomato production as affected by different treatments

A.	Fixed cost	Quantity required /ha	Cost Rs/ha
1.	**Cost of seeds** @ Rs 1500/kg	500 g	750.00
2.	**Nursery preparation** (Bed preparation, sowing, irrigation, drenching and weeding)	54 man days	11200.00
3.	**Preparatory tillage** Ploughing & planking with tractor (hour) @ 600/hr	5hr/ha	3000.00
4.	**Mixing of fertilizers**	50 man days	14000.00
5.	**Transplanting**	20 man days	5600.00
6.	**Fertigation**	8 man days	2240.00
7.	**Gap filling**	20 man days	5600.00
8.	**Plant protection** (spraying)	40 man days	11200.00
9.	**Harvesting**	120 man days	33600
10.	**Marketing** (grading and packaging)	30 man days	8400.00
11.	**Manures and fertilizers**		
	a. FYM 250 q @ Rs. 1.60/kg		40000.00
	b. Urea 217 kg @ Rs. 5.45/kg		1182.60
	c. SSP 475 kg @ Rs.7.24/kg		3439.00
	d. MOP 90 kg @ Rs. 17.44/kg		1569.00
12.	**Application of liquid fertilizers** 19:19:19 @ 180/kg	2.92 g/m^2	8640.00
13.	**Plant Protection measures**		
	a. Chloropyriphos/ Copper oxychloride		870.00
	b. Bavistin 200 g @ Rs. 580/500g		200.00
	c. Blitox 500 g @ Rs. 350/500g		350.00
	d. Indofil M-45 500 g Rs. 200/500g		200.00
14.	**Pole fixing**	30 man days	8400.00
15.	**Total**		**160440.59**
16.	**Management + risk factor @ 10 % of working capital**		16044.05
17.	**Depreciation + rental value of land + interest on fixed capital**		10000.00
	GRAND TOTAL		**186484.64**
	B. Variable cost		
A.	**Variable cost**	**Quantity required /ha**	**Cost Rs/ha**
1.	**Preparation of raised beds**	80 man days	22400.00
2.	**Preparation of flat beds**	50 man days	14000.00
3.	**Placement of mulch over beds and making holes**	14 man days	3920.00
4.	**Interculture operations (weeding and hoeing) for unmulched plots**	40 man days	11200.00
5.	**Interculture operations (weeding and hoeing) for mulched plots**	5 man days	1400.00
6.	**Mulch cost**		
	a. Black polythene mulch @ Rs. 22/m^2		58666.67

	b. Silver/black polythene mulch @ Rs. 25/m^2		66666.67
7.	**Stem cut**		
	a. Two stem training system	12 man days	3360.00
	b. Three stem training system	18 man days	5040.00
8.	**Coiling of plants**		
	a. Two stem training system	100 man days	28000.00
	b. Three stem training system	120 man days	33600.00
9.	**Sutli cost @ Rs.100/kg**		
	a. Two stem training system	12 kg/ha	3360.00
	b. Three stem training system	16 kg/ha	4480.00

VARIABLE COST FOR DIFFFERENT TREATMENTS

Treatment code	Treatment cost							
	Variable cost (Rs.)							
	Bed preparation cost	Mulch cost	Placement of mulch over beds and making holes	Coiling cost	Stem cut cost	Sutli cost	Interculture operation	Cost (Rs)
$P_I M_1 T_I$	22400.00	58666.67	3920.00	28000.00	3360.00	3360.00	1400.00	121106.67
$P_I M_1 T_2$	22400.00	58666.67	3920.00	33600.00	5040.00	4480.00	1400.00	129506.67
$P_I M_2 T_1$	22400.00	66666.67	3920.00	28000.00	3360.00	3360.00	1400.00	129106.67
$P_I M_2 T_2$	22400.00	66666.67	3920.00	33600.00	5040.00	4480.00	1400.00	137506.67
$P_I M_3 T_1$	22400.00			28000.00	3360.00	3360.00	11200.00	68320.00
$P_I M_3 T_2$	22400.00			33600.00	5040.00	4480.00	11200.00	76720.00
$P_2 M_1 T_I$	14000.00	58666.67	3920.00	28000.00	3360.00	3360.00	1400.00	112706.67
$P_2 M_1 T_2$	14000.00	58666.67	3920.00	33600.00	5040.00	4480.00	1400.00	121106.67
$P_2 M_2 T_1$	14000.00	66666.67	3920.00	28000.00	3360.00	3360.00	1400.00	120706.67
$P_2 M_2 T_2$	14000.00	66666.67	3920.00	33600.00	5040.00	4480.00	1400.00	129106.67
$P_2 M_3 T_1$	14000.00			28000.00	3360.00	3360.00	11200.00	59920.00
$P_2 M_3 T_2$	14000.00			33600.00	5040.00	4480.00	11200.00	68320.00

TOTAL COST OF CULTIVATION FOR DIFFERENT TREATMENTS

Treatment code	Fixed cost	Variable cost	Total cost of cultivation (Rs.)
$P_I M_1 T_I$	186484.64	121106.67	307591.31
$P_I M_1 T_2$	186484.64	129506.67	315991.31
$P_I M_2 T_1$	186484.64	129106.67	315591.31
$P_I M_2 T_2$	186484.64	137506.67	323991.31
$P_I M_3 T_1$	186484.64	68320.00	254804.64
$P_I M_3 T_2$	186484.64	76720.00	263204.64
$P_2 M_1 T_I$	186484.64	112706.67	299191.31
$P_2 M_1 T_2$	186484.64	121106.67	307591.31
$P_2 M_2 T_1$	186484.64	120706.67	307191.31
$P_2 M_2 T_2$	186484.64	129106.67	315591.31
$P_2 M_3 T_1$	186484.64	59920.00	246404.64
$P_2 M_3 T_2$	186484.64	68320.00	254804.64

APPENDIX-V

Analysis of variance (ANOVA) for growth and yield, quality, disease and weed parameters of tomato as influenced by planting methods, mulches and training systems

Source of variation	Degree of freedom (df)	Mean sum of square (MSS)														
		Days to 50 % flowering	Number of flower clusters per plant	Number of fruits per cluster	Days to marketable maturity	Number of fruits per plant	Fruit length (cm)	Fruit breadth (cm)	Pericarp thickness (mm)	Fruit weight (g)	Number of pickings	Harvest duration (days)	Fruit yield per plant (kg)	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Leaf area index
		2017-2018														
Replication	**2**	1.17	0.95*	0.10	60.92*	0.21	-357.14	0.00	0.00	2.22	0.58	0.59	0.00	5.55	276.23	0.73
Planting methods (P)	**1**	15.62*	9.96*	2.32*	187.69*	34.24*	0.70	1.07*	0.54*	32.99*	49.00*	183.87*	0.45*	798.01*	39715.62*	4.85*
Mulches (M)	**2**	51.66*	18.87*	4.66*	437.23*	42.73*	0.77	1.99*	0.94*	46.59*	73.00*	148.62*	0.57*	1007.06*	50119.71*	2.30*
Training system (T)	**1**	1.08*	2.35*	0.42	6.93	10.44*	0.11	0.59*	0.16*	15.34*	11.11*	48.77*	0.16*	276.20*	13745.95*	0.08
P*M	**2**	0.88*	0.21	0.01	4.96	1.56*	0.04	0.00	0.06*	1.28	4.00*	0.89	0.02*	39.95*	1988.37*	0.70
P*T	**1**	0.01*	0.02	0.02	0.49	0.16	0.02	0.00	0.03*	0.30	0.00	1.73	0.00	0.63	31.51	0.21
M*T	**2**	0.05*	0.32	0.02	1.20	0.43	0.01	0.00	0.01	1.25	1.44*	3.52	0.00	3.53	175.52	0.46
P*M*T	**2**	0.01*	0.27	0.00	0.25	0.49	0.00	0.02	0.00	2.23	0.00	0.51	0.00	7.19	357.65	0.67
Error	**22**	0.45	0.20	0.14	6.61	0.16	32.48	0.01	0.00	1.31	0.31	1.20	0.00	5.26	261.79	0.52

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom	Mean sum of square (MSS)												
		Plant height (cm)	TSS (^{o}B)	Ascorbic acid content (mg/100g)	Lycopene content (mg/100g)	Shelf life (days)	Incidence of Buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of Bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)	Weed count (m^2)	Fresh weight of weeds (g)	Dry weight of weeds (g)	Weed control efficiency (%)
		2017-2018												
Replication	**2**	15.06	0.02	0.23*	0.06	0.39	0.01	0.00	0.02*	0.01	19131.19*	4103.47*	20.11	5.50
Planting methods (P)	**1**	217.81*	0.57*	36.40*	2.70*	27.16*	1.28*	1.49*	0.37*	1.10*	41073.78*	21409.05*	413.44*	808.96*
Mulches (M)	**2**	327.31*	1.48*	76.01*	2.90*	20.91*	1.81*	1.49*	0.39*	1.54*	2471515.11*	1993542.98*	2515.11*	3577.42*
Training system (T)	**1**	229.33*	0.10*	11.31*	0.64*	5.98*	0.19*	0.23*	0.04*	0.32*	5675.11	11966.54*	93.44*	278.93*
P*M	**2**	964.41*	0.04*	0.57	0.13*	5.85*	0.01	0.13*	0.01	0.02*	5587.11	7498.00*	2.78	73.03*
P*T	**1**	53.61*	0.01	0.44	0.01	0.04*	0.00*	0.13*	0.04*	0.02*	215.11	0.53	21.78	145.40*
M*T	**2**	185.01*	0.00	1.25	0.01	1.06	0.02	0.07*	0.04*	0.01*	597.44	8315.87*	10.78	104.13*
P*M*T	**2**	38.24	0.00	0.58	0.01	0.25	0.01	0.02	0.01*	0.00	644.78	114.17	21.78	138.31*
Error	**22**	15.38	0.01	0.37	0.04	0.15	0.00	0.01	0.00	0.00	2042.32	754.96	11.05	13.08

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom (df)	Mean sum of square (MSS)														
		Days to 50 % flowering	Number of flower clusters per plant	Number of fruits per cluster	Days to marketable maturity	Number of fruits per plant	Fruit length (cm)	Fruit breadth (cm)	Pericarp thickness (mm)	Fruit weight (g)	Number of pickings	Harvest duration (days)	Fruit yield per plant (kg)	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Leaf area index
		2018-2019														
Replication	**2**	0.56*	0.10	0.01	9.70*	0.34	-384.22	0.10	0.011	0.04	0.33	0.79	0.00	2.09	104.01	0.06
Planting methods (P)	**1**	33.74*	15.898*	6.85*	184.73*	67.35*	1.32	1.31*	0.51*	45.70*	103.36*	123.40*	0.80*	1409.08*	70127.84*	2.32*
Mulches (M)	**2**	68.38*	28.65*	4.94*	412.22*	73.03*	1.68	2.11*	0.52*	66.15*	37.00*	137.74*	0.92*	1617.75*	80512.97*	2.85*
Training system (T)	**1**	7.70*	0.50*	1.56*	56.68*	14.75*	0.63	0.42*	0.16*	20.58*	46.69*	12.19*	0.22*	389.74*	19396.89*	0.98*
P*M	**2**	2.27*	0.07	0.14	3.46	7.89*	0.12	0.00	0.04*	0.01	16.44*	0.04	0.05	94.96*	4726.14*	0.20
P*T	**1**	3.36*	0.02	0.01	8.83*	0.04	0.11	0.00	0.001	0.00	4.69*	0.84	0.00*	0.048	1.74*	0.04*
M*T	**2**	2.23*	0.08	0.08	4.46*	2.17	0.11	0.00	0.003	0.09	15.44*	5.62	0.02*	28.28	1407.42	0.03
P*M*T	**2**	0.31*	0.09	0.03	2.46	0.02	0.11	0.01	0.001	0.27	7.11*	1.33	0.00*	1.28	63.74	0.01
Error	**22**	0.04	0.25	0.07	0.98	0.27	34.96	0.03	0.01	0.73	0.42	2.65	0.00	5.57	277.03	0.05

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom (df)	Mean sum of square (MSS)												
		Plant height (cm)	TSS (° B)	Ascorbic acid content (mg/100g)	Lycopene content (mg/100g)	Shelf life (days)	Incidence of Buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of Bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)	Weed count (m^2)	Fresh weight of weeds (g)	Dry weight of weeds (g)	Weed control efficiency (%)
		2018-2019												
Replication	**2**	36.68	0.001	1.03	0.06	0.47	0.00	0.01*	0.00	0.00	1884.11	35.53	4.69	1.82
Planting methods (P)	**1**	353.93*	0.054	10.39*	1.32*	6.44*	0.84*	2.14*	0.37*	1.38*	48326.69*	73260.44*	711.11*	1202.61*
Mulches (M)	**2**	278.94*	1.368*	19.38*	3.20*	28.36*	1.56*	2.10*	0.32*	0.88*	2276399.19*	671389.36*	2911.36*	4059.88*
Training system (T)	**1**	886.64*	0.054	4.09*	0.23	1.89*	0.24*	0.40*	0.18*	0.43*	35910.25*	6346.78*	177.78*	357.59*
P*M	**2**	51.49*	0.002	1.42	0.05	0.33	0.00	0.15*	0.02	0.05	6335.19	12597.69*	13.36	32.28
P*T	**1**	76.05*	0.002	1.55	0.04	0.09	0.00	0.01*	0.04*	0.04*	6916.69	1248.44*	9.00	62.27*
M*T	**2**	44.98	0.002	1.42	0.04	0.15	0.04*	0.07*	0.02	0.01*	5291.08	3171.03*	17.19	16.42
P*M*T	**2**	21.27	0.003	0.64	0.03	0.08	0.00	0.00	0.03*	0.05*	1810.19	723.03*	8.08	76.25*
Error	**22**	35.05	0.015	0.91	0.22	0.30	0.00	0.00	0.01	0.00	3592.08	200.44	6.54	10.13

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom (df)	Mean sum of square (MSS)														
		Days to 50 % flowering	Number of flower clusters per plant	Number of fruits per cluster	Days to marketable maturity	Number of fruits per plant	Fruit length (cm)	Fruit breadth (cm)	Pericarp thickness (mm)	Fruit weight (g)	Number of pickings	Harvest duration (days)	Fruit yield per plant (kg)	Fruit yield per plot (kg)	Fruit yield per hectare (q)	Leaf area index
		Pooled														
Replication	**2**	0.21	0.16*	0.02	28.54*	0.00	0.03	0.04	0.00	0.51	0.40	0.44	0.00	1.22	60.95	0.15*
Planting methods (P)	**1**	23.81*	12.76*	4.28*	186.21*	49.41*	0.99*	1.19*	0.52*	39.08*	73.67*	152.13*	0.61*	1081.59*	53829.19*	2.28*
Mulches (M)	**2**	59.53*	23.45*	4.79*	424.38*	56.87*	1.17*	2.05*	0.71*	55.94*	50.25*	143.13*	0.73*	1294.46*	64423.03*	3.06*
Training system (T)	**1**	3.64*	1.25*	0.90*	25.81*	12.50*	0.32*	0.50*	0.16*	17.86*	25.84*	27.43*	0.19*	330.54*	16450.36*	0.98*
P*M	**2**	1.47*	0.12	0.02	1.42	4.05*	0.07*	0.00	0.05*	0.31	8.44*	0.29	0.04*	63.20*	3145.38*	0.16*
P*T	**1**	0.75*	0.00	0.00	3.37	0.01*	0.01*	0.00	0.00	0.07	1.17*	1.25	0.00*	0.10*	5.18*	0.05
M*T	**2**	0.46*	0.16	0.04	2.57	1.03	0.05	0.00	0.01	0.33	6.19*	0.10	0.01*	9.39	467.49	0.03
P*M*T	**2**	0.06	0.03	0.01	0.72	0.15	0.02	0.02	0.00	0.25	1.78*	0.31	0.00	1.51	75.06	0.02
Error	**22**	0.12	0.05	0.06	2.28	0.10	0.01	0.01	0.00	0.51	0.18	1.11	0.00	2.71	134.96	0.03

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom (df)	Mean sum of square (MSS)												
		Plant height (cm)	TSS (^{o} B)	Ascorbic acid content (mg/100g)	Lycopene content (mg/100g)	Shelf life (days)	Incidence of Buckeye rot (%)	Severity of *Alternaria* leaf blight (%)	Severity of Bacterial leaf spot (%)	Incidence of *Fusarium* wilt (%)	Weed count (m^2)	Fresh weight of weeds (g)	Dry weight of weeds (g)	Weed control efficiency (%)
		Pooled												
Replication	**2**	19.40	0.00	0.49	0.03	0.43*	0.001	0.00	0.01*	0.00	7032.77*	848.10*	10.90	1.21
Planting methods (P)	**1**	340.49*	0.24*	21.42*	1.95*	15.02*	1.052*	1.81*	0.37*	1.24*	44626.56*	43469.12*	1034.69*	981.42*
Mulches (M)	**2**	252.59*	1.42*	42.89*	3.05*	24.38*	1.686*	1.78*	0.36*	1.18*	2372403.77*	1244568.30*	2339.15*	3717.75*
Training system (T)	**1**	925.12*	0.07*	7.25*	0.41*	3.65*	0.212*	0.31*	0.09*	0.37*	17534.17*	8935.76*	110.25*	318.84*
P*M	**2**	52.50*	0.01	0.05	0.06	2.16*	0.007*	0.14*	0.01*	0.03*	1242.27	9879.91*	53.97*	49.44*
P*T	**1**	124.57*	0.00	0.09	0.00	0.00	0.000*	0.05*	0.04*	0.03*	1173.06	325.05*	20.25	102.59*
M*T	**2**	41.53*	0.00	0.11	0.01	0.36*	0.028	0.07*	0.02*	0.01*	583.76	5438.94*	0.44	48.62*
P*M*T	**2**	14.10	0.00	0.37	0.00	0.11	0.004*	0.01	0.02*	0.02*	984.90	346.50*	30.56*	105.40*
Error	**22**	20.58	0.01	0.24	0.08	0.11	0.001	0.00	0.00	0.00	1564.36	201.62	5.25	4.99

***Significant at 5 per cent level of significance**

Source of variation	Degree of freedom (df)	Weed intensity (%) Mean sum of square (MSS) 2017-2018					
		Bidens pilosa	*Commelina benghalensis*	*Cyperus rotundus*	*Echinochloa crus-galli*	*Galinsoga parviflora*	*Nicandra physalodes*
		2017-2018					
Replication	**2**	0.00	0.00	0.06	0.00	0.00	0.00
Planting methods (P)	**1**	0.04*	0.02*	0.19*	0.17*	0.51*	0.03*
Mulches (M)	**2**	0.37*	6.58*	1.10	1.15*	2.88*	5.79*
Training system (T)	**1**	0.00*	0.02*	0.06	0.11*	0.14*	0.14*
P*M	**2**	0.04*	0.02*	0.00*	0.02	0.00	0.01*
P*T	**1**	0.00	0.00*	0.00	0.01	0.00	0.00
M*T	**2**	0.00*	0.02*	0.01	0.03*	0.00	0.07*
P*M*T	**2**	0.00	0.00*	0.02	0.00	0.00	0.00
Error	**22**	0.00	0.00	0.02	0.01	0.00	0.00
Source of variation	**Degree of freedom (df)**	**Weed intensity (%) Mean sum of square (MSS) 2018-2019**					
		Bidens pilosa	*Commelina benghalensis*	*Cyperus rotundus*	*Echinochloa crus-galli*	*Galinsoga parviflora*	*Nicandra physalodes*
		2018-2019					
Replication	**2**	0.00*	0.02*	0.00	0.01	0.06*	0.00
Planting methods (P)	**1**	0.26*	0.23*	0.57*	0.46*	0.68*	0.23*
Mulches (M)	**2**	1.19*	2.70*	3.71*	2.85*	3.61*	2.70*
Training system (T)	**1**	0.09*	0.10*	0.23	0.08*	0.22*	0.10*
P*M	**2**	0.26*	0.23*	0.01*	0.09*	0.03*	0.23*
P*T	**1**	0.01	0.02	0.00	0.02	0.01	0.02
M*T	**2**	0.09*	0.10*	0.00	0.00*	0.01	0.10*
P*M*T	**2**	0.01	0.02	0.01	0.02*	0.00	0.02
Error	**22**	0.00	0.01	0.00	0.01	0.00	0.01
Source of variation	**Degree of freedom (df)**	**Weed intensity (%) Mean sum of square (MSS) Pooled**					
		Bidens pilosa	*Commelina benghalensis*	*Cyperus rotundus*	*Echinochloa crus-galli*	*Galinsoga parviflora*	*Nicandra physalodes*
		Pooled					
Replication	**2**	0.00	0.00	0.01	0.00	0.01	0.00
Planting methods (P)	**1**	0.09*	0.06*	0.35*	0.29*	0.58*	0.04*
Mulches (M)	**2**	0.50*	3.05*	2.21*	1.83*	3.19*	4.34*
Training system (T)	**1**	0.02*	0.03*	0.13	0.09*	0.17*	0.04*
P*M	**2**	0.17*	0.06*	0.00*	0.01	0.01*	0.02*
P*T	**1**	0.00	0.01*	0.00	0.01	0.00*	0.00
M*T	**2**	0.02*	0.03*	0.00	0.01	0.00*	0.02*
P*M*T	**2**	0.00*	0.01*	0.01	0.01	0.00	0.00
Error	**22**	0.00	0.00	0.01	0.00	0.00	0.00

***Significant at 5 per cent level of significance**

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Title of Thesis	:	**"Studies on the Effect of Some Crop Management Practices on Growth and Yield in Tomato (*Solanum lycopersicum* L.)"**
Name of student	:	**Shilpa**
Admission No.	:	H-2016-35-D
Major Field	:	Vegetable Science
Minor Field	:	Plant Pathology
Degree Awarded	:	Ph.D. Vegetable Science
Year of Award of Degree	:	2020
No. of Pages in thesis	:	175+X
Name of Major Advisor	:	Dr Y R Shukla

ABSTRACT

The present investigation entitled **"Studies on the effect of some crop management practices on growth and yield in tomato (*Solanum lycopersicum* L.)"** was carried out at the Experimental Farm, Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, (HP) during *Kharif* season year 2017-2018 and 2018-2019. The experiment was laid out in Randomized Complete Block Design (Factorial) with three replications comprising of twelve treatments having two levels of planting methods i.e. P_1=raised bed and P_2=flat bed, three levels of mulches treatments i.e. M_1=black mulch, M_2=silver/black mulch and M_3=no mulch and two levels of training systems i.e. T_1=two stem training system and T_2=three stem training system. A popular variety of tomato 'Solan Lalima' was used as planting material in the present studies. Seedlings of tomato were transplanted on 12th April, 2017-18 and 2018-19 in a plot size of 11.34 m^2 at a spacing of 90 × 30 cm accommodating 42 plants per plot in three replications. The recommended package of practices and plant protection measures were followed from time to time to produce healthy crop. Among the different planting methods, mulching treatments and training systems the plants which were grown on raised bed (P_1) when applied with black mulch (M_1) and trained to two stem training system (T_1) resulted significantly maximum number of flower clusters per plant, number of fruits per cluster, fruit length (cm), fruit breadth (cm), pericarp thickness (mm), fruit weight (g), number of pickings, harvest duration (days), number of fruits per plant, fruit yield/plant (kg), fruit yield/plot (kg), fruit yield/ha (q/ha), leaf area index, plant height (cm), TSS (^{0}Brix), ascorbic acid content (mg/100 g of fresh weight), lycopene content (mg/100 g of fresh weight), shelf life (days), minimum days to 50 per cent flowering, least number of days to marketable maturity, less incidence of buckeye rot (%), minimum severity of *Alternaria* leaf blight (%), minimum severity of bacterial leaf spot (%), less incidence of *Fusarium* wilt (%), minimum weed intensity (%), maximum weed control efficiency (%), less weed count (m^{-2}), minimum fresh and dry weight of weeds. Analysis of variance showed significant differences among two way interaction for most of the characters studied. Among the first order interactions *viz.,* planting methods and polythene mulch, polythene mulch and training system, planting methods and training systems; P_1M_1 (raised bed and black polyethylene mulch), P_1T_1 (raised bed planting method with two stem training system) and M_1T_1 (black polyethylene mulch with two stem training system) significantly affected most of the characters under study. The treatment combination involving raised bed, black mulch and two stem training system ($P_1M_1T_1$) was found superior over all other treatments in terms of growth characters, fruit characters, yield characters, quality attributes, disease parameters, weed parameters and also had maximum benefit: cost ratio. The highest fruit yield (992.64 q/ha) of Solan Lalima with maximum net returns (Rs 1,181,364.19/ha) and highest benefit: cost ratio (3.84) was obtained with the treatment combination involving raised bed planting method, black polyethylene mulch and two stem training system ($P_1M_1T_1$). Therefore, raised bed planting method, black polythene mulch in combination with two stem training system i.e. $P_1M_1T_1$ can be recommended for tomato cultivation in mid-hill of Himachal Pradesh.

Signature of the Major Advisor **Signature of the Student**

Countersigned

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BRIEF BIO-DATA

Name	**:**	**Shilpa**
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Certificate/ Degree	Month & Year	Board/ University	Marks (%)	Class/Grade
Matriculation	April, 2008	HP Board of School Education, Dharmshala	92.83	First
10+2	April, 2010	HP Board of School Education, Dharmshala	88.63	First
B Sc (Hons.) Horticulture	June, 2014	Dr YSP UHF, Nauni, Solan, (HP)	81.10	First
M Sc Vegetable Science	September, 2016	Dr YSP UHF, Nauni, Solan, (HP)	82.50	First

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Scholarship/ Stipend/ Fellowship, any other financial assistance received during the study period : University Merit Scholarship

Place: Nauni, Solan
Dated: **(Shilpa)**