EFFECT OF MULCH ON SOIL PROPERTIES AND YIELD OF TOMATO (*Solanum lycopersicum* L.)

Thesis

by

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CERTIFICATE - I

This is to certify that the thesis entitled **"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)"** submitted in partial fulfilment of the requirements for the award of degree of **M. Sc. (Ag.)** in the discipline of **Soil Science** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173230 is a bonafide research work carried out by **Mr. Rajesh Bajia (F-2016-58-M)** son of Sh. Bhag Chand Bajia 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.

Place: Nauni,Solan
Dated:

(Er. Ghanshyam Agrawal)
Chairman
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CERTIFICATE - II

This is to certify that the thesis entitled, **"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)"** submitted by **Mr. Rajesh Bajia (F-2016-58-M)** son of Sh. Bhag Chand Bajia to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (Ag.) Soil Science** has been approved by the Student's Advisory Committee after the viva-voice examination of the same in collaboration with the external examiner.

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Nauni, Solan **(Rajesh Bajia)**
Date: Author

CONTENTS

ABBREVIATIONS USED

%	:	Per cent
^0C	:	Degree celcius
B:C	:	Benefit cost
Ca	:	Calcium
CD	:	Critical difference
cm	:	Centimeter
Cu	:	Copper
cv.	:	Cultivar
d Sm^{-1}	:	Deci Siemens per meter
EC	:	Electrical conductivity
et al.	:	Co-worker
FC	:	Field capacity
Fe	:	Iron
FYM	:	Farm Yard Manure
ha^{-1}	:	Per hectare
HP	:	Himachal Pradesh
Hrs	:	Hours
K	:	Potassium
Kg	:	Kilogram
M	:	Meter
m^2	:	Meter square
mg	:	Milligram
Mg	:	Magnesium
mm	:	Millimeter
Mn	:	Manganese
MOP	:	Murate of Potash
N	:	Nitrogen
NO_3^-N	:	Nitrate
NHB	:	National Horticulture Board
N.S	:	Non-significant
OC	:	Organic carbon
P	:	Phosphorus
PWP	:	Permanent wilting point

Q	:	Quintal
RBD	:	Randomized Block Design
RDF	:	Recommended dose of fertilizer
$SO4^{2-}$ S	:	Sulphate sulphur
SSP	:	Single Super Phosphate
T	:	Tonne
var.	:	Variety
viz.	:	Videlicet
WUE	:	Water use efficiency
Zn	:	Zinc
Mg m^{-3}	:	Mega-gram per cubic meter
ANOVA	:	Analysis of variance
TSS	:	Total Soluble solid (^{o} Brix)
w/w %	:	percentage of moisture (weight basis)
pH	:	*Puissance de Hydrogen*
IU	:	International unit
i.e	:	That is
>	:	Greater than
<	:	Less than
WSA	:	Water stable aggregates
MWD	:	Mean weight diameter
MWHC	:	Maximum water holding capacity
q ha^{-1}	:	Quintal per hectare
@	:	At the rate of
AM	:	Ante meridiem
PM	:	Post meridiem
cm hr^{-1}	:	Centimeter per hour
mm	:	Millimeter
t ha^{-1}	:	Tonne per hectare
g	:	Gram
kg ha^{-1}	:	Kilogram per hectare

LIST OF TABLES

LIST OF FIGURES

Chapter-1

INTRODUCTION

The scarcity of water resources is one of the main challenges in the world especially for developing countries like India. It is becoming a limiting factor for optimum agricultural production and economic development of the nation. The demand on water resources is increasing with time for both agriculture and non-agriculture sectors. Rainfed agriculture is predominant in arid, semi-arid and sub-humid regions of the country. These regions are home to about 81 per cent of rural poor in the country. Hence, rainfed agriculture has a crucial role to play in sustaining the economy and food security of India. At present, about 52 per cent of the net sown area is rainfed contributing 40 per cent of the total food production, supports 40 per cent of human and about 70 per cent of livestock population. However, aberrant behaviour of monsoon rainfall, scarcity of irrigation water, declining ground water table and poor resource base of the farmers are major constraints for low and unstable yields in rainfed areas. Furthermore, climate variability including extreme weather events resulting from global climate change poses serious threat to agriculture.

The climate of India is generally tropical with an average annual rainfall of 1190 mm. However, the pattern of rainfall is characterized by uneven distribution over various regions and there is strong fluctuation from year to year in terms of quantity and timing. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in-situ*. With climate change posing a major challenge for rainfed agriculture and the constraints in further expansion of irrigated area in the country, *in-situ* moisture conservation for efficient water use is inevitable option to sustain agriculture. Various *in-situ* moisture conservation techniques such as mulch farming, crop residue management, conservation tillage etc. increase the soil moisture availability and significantly increase the yield of the crop.

Tomato (*Solanum lycopersicum* L.) also known as wolf apple, belongs to family Solanaceae. It is the most important vegetable crop of tropical and subtropical regions. Tomato is the world's largest vegetable crop after potato and sweet potato, but it tops the list of canned vegetables. In the World, 177 million tons fresh fruit is produced on 4.7 million hectare area with average productivity of 37.01 t ha^{-1} (FAOSTAT, 2016). India is one of the major tomato growing country and ranked second after China in production. Tomato is an important and an economic proposition for the farmers among the horticulture crops grown in India. The major tomato producing states are Bihar, Karnataka, Uttar Pradesh, Maharashtra, Madhya Pradesh, Orissa, Himachal Pradesh and West Bengal. In India, it is grown under an area of 0.80 million hectare with production of 19.69 million tons with average productivity of 24.62 t ha^{-1}. In Himachal Pradesh, the total area, production and average productivity of tomato are 11,080 hectares, 4,89,96 tons and 44.22 t ha^{-1}, respectively (Anonymous, 2017).

Tomato is one of the important and widely consumed vegetable crops in Himachal Pradesh. Its commercial cultivation as an off season vegetable crop for remunerative returns, more demand in the markets of neighbouring plains and improved nutritional awareness of people have attracted the farmers to bring larger area under its cultivation. Although, the average productivity of the crop in the state is higher than that of national and global levels. However, low productivity also occurs in several parts of the state due to lack of irrigation facilities and unscientific use of scarce irrigation water. The farmers are largely dependent upon rains and are unable to achieve higher yield of better quality for sustaining the crop productivity. To overcome the problem of water scarcity and poor irrigation facilities, most appropriate *in-situ* moisture conservation technique i.e. application of mulches is a viable option.

Mulching is a technique which cover soil surface around the plant to create favourable hydro thermal conditions for its growth. Mulches are either organic or inorganic. Organic mulches are those derived from plant and animal materials. Those most frequently used include plant residues such as straw, hay, peanut hulls, leaf mold and compost, wood products such as sawdust, wood chips and shavings and animal manures. The inorganic mulch such as polyethylene mulch of different thickness is largely used nowadays because of limited availability of organic mulches. The plastic materials used as mulch are polyvinyl chloride or polyethylene films. Owing to its greater permeability to long wave radiation, it can increase temperature around the plant during night in winter. Hence, polyethylene film mulch is preferred as mulch material for production of horticulture crops.

Both organic and inorganic mulches have numerous benefits. The conservation of soil moisture through mulching is one of the important purposes. It reduces soil temperature in summer and raises it in winter. Mulch reduces irrigation frequency and amount of irrigation water. Mulching increase the total intake of water due to formation of loose soil surface. The rain drops on mulched soil do not seal the particles as they do on unmulched soil. This non-sealing effect of rain drops reduces loss of water through erosion. Hence, mulch reduces runoff and soil erosion. It reduces fertilizer leaching during excessive rainfall (Kumar and Bhardwaj, 2012). Organic mulches return organic matter and plant nutrients to the soil and improve the physical, chemical and biological properties of the soil after decomposition, which in turn increases crop yield. Hence, both organic and inorganic mulches play an important role for obtaining higher quality and quantity of the produce and fetching better economic returns of the crop.

The information on the effect of various types of organic and inorganic mulches on soil properties, moisture conservation, temperature moderation, crop growth and yield of tomato in the mid hill zone of Himachal Pradesh is meagre. Quantitative knowledge of changes in hydro-physical and chemical properties brought under various mulches is necessary, which can obviously help to select a particular mulch to provide suitable environment for higher crop production. It was therefore, considered pertinent to investigate the effect of various mulches on soil properties and yield of tomato with the following major objectives:

Objectives:

- To study the effect of mulching on the soil properties.
- To study the effect of mulching on growth and yield of tomato.

Chapter-2

REVIEW OF LITERATURE

Efficient utilization of available water resources is crucial for our country which shares about 17 per cent of global population with only 2.4 per cent of land and 4.0 per cent of the water resources. Due to population explosion and shrinking of available land for horticulture; there is an urgent need to enhance the productivity and quality of fruit and vegetables. The growth and yield of tomato are very much affected by availability of water which is a limiting factor during the growing season. Proper management of available water and moisture conservation for longer duration in the root zone plays an important role in enhancing the yield and quality of the produce.

The mid-hill zone of Himachal Pradesh receives sufficient annual rainfall i.e. 1100 mm, but its spatial and temporal distribution is not uniform. More than 75 per cent of total annual rainfall is received during monsoon period. Low productivity in the rainfed areas is the main problem due to inadequate soil moisture content in the root zone during different growth stages of plant. Moreover, uneven distribution of rains, occurrences of run-off and soil loss during rains further add to the factors leading to low productivity. The ill effects of water deficient can be overcome by irrigation or adopting in-situ moisture conservation techniques such as use of mulches (Shinde *et al.*1980). Mulching has also been identified by many researchers as a method to provide a favourable soil environment by minimizing the crusting at the soil surface and keep it stable. Soil surface crusting which generally occurs after every little shower due to loose and dispersed soil mass is another problem. Moreover, the soil underneath mulch remained protected from splash erosion during high intensity rains.

For successful tomato crop production, 233 mm water applied through drip irrigation is reported in loamy sand soils of Nauni - Solan (Raina *et al.* 1999). Sufficient irrigation facilities are not available in all the regions of the country. Sometimes, many of the farmers are unable to provide adequate irrigation due to scarcity of irrigation facilities or even can’t afford the expenses of irrigation. Under this situation, mulching could be a viable option to conserve soil moisture. Mulching has been reported to increase yield by creating favourable soil temperature and moisture regimes (Rahman *et al.* 2016).

In this chapter, an attempt has been made to review the pertinent literature available on the study entitled "**Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)**". The literature has been reviewed under the following sub- heads:

2.1 Effect of mulches on soil moisture content

2.2 Effect of mulches on soil temperature

2.3 Effect of mulches on soil physical properties

2.4 Effect of mulches on soil chemical properties

2.5 Effect of mulches on growth, yield and quality of crop

2.6 Effect of mulches on benefit cost ratio and water use efficiency

2.1 Effect of mulches on soil moisture content

Soil moisture plays a crucial role in growth and development of plants. Presence of adequate moisture in the soil is vital to plant growth not only because plants need water for physiological process but also because water contains nutrients in solution. Water stress may inhibit or even completely stop one or more physiological process (Shephard, 1972, Hsiao, 1973, Ackerson *et al.* 1977, Vanloon, 1981, Ringel, 1981 and Shimshi *et al*. 1983). Conservation of soil moisture through mulching is one of the best methods.

Khan *et al.* (2005) studied response of tomato on soil moisture contents of 19.26, 18.91, 17.53, 14.5 and 13.96 per cent were observed in transparent mulch, wheat straw, grass mulch, black plastic mulch and control, respectively in tomato crop. A study on influence of mulching on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in North Indian plains was conducted and recorded the highest soil moisture content of 43.7 per cent under polyethylene mulch (Singh, 2005).

Singh *et.al* (2005) studied the effect of different mulches including black plastic, clear plastic, sugarcane trash and rice straw on soil moisture and revealed that the maximum average soil moisture content of 14.9 per cent was observed under black plastic mulch followed by 13.2 per cent under clear plastic and the lowest of 9.6 per cent under without mulch. Raina (1998) reported that pine needles and hay mulches recorded maximum soil moisture contents over unmulched throughout the growing season in apple nursery.

Sharma and Kathiravan (2009) assessed the effect of mulches on soil hydrothermal regimes and growth of plum in mid hill region of Himachal Pradesh and revealed that all types of mulches including black plastic mulch, bicoloured polythene mulch, transparent polythene mulch, pine needles mulch and grass mulch maintained comparatively higher soil moisture contents i.e. 45.1-52.8, 40.4-60.4, 37.8-48.8, 30.9-42.8 and 25.0-48.6 per cent, respectively over control in 0-15 cm depth. Black plastic mulch recorded the highest soil moisture content of 28 per cent followed by 19 per cent under rice straw mulch and the lowest of 12 per cent under without mulch in tomato (Pandey and Mishra, 2012).

Deshmukh *et.al* (2013) assessed that the maximum soil moisture content was found under black plastic mulch followed by paddy straw mulch and the lowest in without mulch. They reported that the soil moisture content was found maximum at 10 cm depth as compared to 30 cm depth under black plastic and paddy straw mulches, while it was found higher at 30 cm depth than at 10 cm depth in case of without mulch.

Ashrafuzzaman *et.al* (2011) studied the effect of plastic mulch on soil moisture contents and observed that the transparent polythene mulch observed highest moisture content of (21.15%), followed by black plastic mulch (20.4%), blue plastic mulch (19.2%) and the lowest moisture content of (14.6%) under the control plot in chilli crop. The highest average soil moisture content (18.0%) was found under straw mulch, while the lowest (16.2%) was recorded under control in strawberry (Taparauskiene and Miseckaite, 2014).

Sharma and Kumar (2014) assessed the effect of mulching on soil moisture distribution and found that the black plastic mulch conserved maximum soil moisture (18.4 and 20.2%) followed by pine needle (18.1 and 19.8%) and grass mulch (16.5 and 18.6%) in 0-7.5 and 7.5-15 cm depths, respectively. Minimum soil moisture contents of 12.7 and 13.7 per cent in 0-7.5 and 7.5-15 cm soil depths, respectively were recorded under without mulch.

Sharma and Meshram (2015) observed the effect of mulches on soil moisture in capsicum crop and found that black plastic mulch saved significantly higher soil moisture contents of 49 and 44 per cent as compared to paddy straw mulch at 0-15 cm and 15-30 cm depths, respectively.

Narayan *et.al* (2017) assessed the effect of plastic and organic mulches on soil moisture in chilli crops and data revealed that all types of mulches retained higher moisture content as compared to the control. The black polythene mulch showed the highest soil moisture content (16.7%) followed by double coated white polythene (15.2%) and the lowest in control (10.1%).

Nair (2018) studied the effect of different mulches (black, silver and transparent polyethylene) on soil moisture content under tomato cultivation and observed that the application of black mulch retained 13.08 per cent higher soil moisture as compared to without mulch plots. The corresponding values for transparent mulch and silver mulches were 10.47 and 3.19 per cent as compared to without mulch plots.

2.2 Effect of mulches on soil temperature

Soil temperature is one of the most important factor that control the microbiological activities and various other processes involved in crop production. Soil temperature varies daily and seasonally which may result from changes in radiant energy and energy changes takes place through the soil surface. Mulching reduces soil temperature in summer, raises it in winter and prevents the extremes of temperatures. In general, the effect of mulching on the temperature regime of the soil varies according to the capacity of the mulching material to reflect and transmit solar energy. It governs the soil physiochemical and biological processes and also influences the interspheric processes of gas exchange between the atmosphere and the soil.

Abu-Bakr *et al.* (2003) found the higher soil temperature under plastic mulches than the control. The soil temperature was increased by 5.6, 5.2 and 3.9˚C at morning and 6.1, 5.7 and 3.3˚C at mid day under the clear, green and black mulches, respectively as compared to the control. The plots mulched with rice-straw or sugarcane trash showed slightly higher temperature values of 0.9˚C to 1.7˚C than the control in tomato (Singh *et al*. 2005).

Locher *et al.* (2005) studied the effect of coloured mulches on soil temperature in sweet pepper crop. They observed that light coloured mulches (clear, violet, light green) increased the soil temperature by 2.5-2.9˚C than that of the without mulch (control), while the dark coloured mulches (black, dark green, red) increased the soil temperature by 1.4-2.1˚C as compared to the control treatment.

Singh *et al.* (2005) assessed the effect of different plastic mulches on soil temperature and results indicated that the highest soil temperature was found under clear mulch (27.8˚C) followed by ordinary clear mulch (27.4˚C), black mulch (26.1˚C) and the lowest (24˚C) under control treatment in tomato crop.

Ramakrishna *et al.* (2006) studied the effect of mulches on soil temperature and reported that different mulch materials showed variable effect on soil temperature and found that the polythene mulch increased the soil temperature by about 6.8 and 4.8˚C at 5 and 10 cm depths, respectively. Straw mulching lowered both maximum and minimum soil temperatures by 8.9˚C and 2.3˚C, respectively at 5 cm depth in hybrid chilli (Kaur *et al*. 2008).

Awodoyin *et al.* (2007) assessed the effect of mulches on tomato crop at transition Zone of Nigeria. The experimental results indicated that the differences between morning and afternoon soil temperature at 5 cm depth were 5.0˚C under grass mulch, woodchip mulch and control. Higher soil temperature by 5-8˚C and 1-4˚C was found in clear plastic and black plastic mulches, respectively than that of control in melon crop (Ekinci and Dursun, 2009).

Sharma and Kathiravan (2009) studied the effect of mulches on soil thermal regimes and growth of plum in mid hill region of Himachal Pradesh and revealed that all types of mulches including black polythene mulch, bicoloured polythene mulch, transparent polythene mulch, pine needles mulch and grass mulch considerably increased the soil temperature and followed the order as transparent polythene mulch > black polythene mulch > bicoloured polythene mulch > pine needles mulch > grass mulch > unmulched at 7:30 AM and transparent polythene mulch > black polythene mulch > bicoloured polythene mulch > unmulched > grass mulch > pine needles mulch at 2:30 PM.

Wang *et al*. (2009) reported that an increase of daily mean soil temperature by 2–9˚C with mulch than that of without mulch, especially during the early growing period of potato crop. Similarly, the highest soil temperature was obtained under black plastic mulch. The difference in temperature between mulched and without mulch treatment was observed in the range of 2.2 to 3.4˚C in tomato crop (Kamal and Singh, 2011).

Rajablariani *et al*. (2012) revealed that the highest soil temperature (30.7˚C) was recorded under blue mulch, followed by red, clear plastic and the lowest (25˚C) in without mulch in Iran. Results indicated that the soil temperature under the various colour mulches was 3 to 6˚C warmer as compared to bare soil.

Hamid *et al*. **(**2012**)** found that soil temperature under polyethylene mulch was increased by 3.3 to 6.6˚C as compared to without mulch in tomato. The highest soil temperature (30.7˚C) was recorded under blue mulch followed by red plastic mulch (30.1˚C) and clear plastic mulches (29.5˚C). Among the plastic mulches, silver had the lowest soil temperature.

Aniekwe (2013) studied the comparative effects of organic and plastic mulches in okra. Experimental results indicated that the highest average daily temperature (28.4˚C) was observed under black plastic mulch followed by grass mulch (27.8˚C) and the lowest (27.6˚C) under without mulch. Soil temperature in tomato was recorded higher by 3 to 6˚C under various coloured plastic mulches than in bare soil (Dixit *et al.*, 2015).

Sharma and Kumar (2014) assessed the effect of mulch in cauliflower at Nauni, Solan and found that black plastic mulch recorded the highest soil temperature at both 7.5 and 15 cm depths. Black mulch raised the minimum and maximum soil temperatures by 1.3-1.7˚C and 0.5-1.0˚C, respectively over unmulched treatment. Higher soil temperature in covered plots than in the plot without covers at a depth of 10 cm was observed in tomato. Minimum soil temperature was increased by 1.3˚C at 8:00 hrs and maximum soil temperature by 1.7˚C at 14.00 hrs in covered plots (Kosterana, 2014).

Dalorima *et.al* (2014) recorded the highest soil temperature (32.07˚C) under polythene mulch followed by control plot (31.03˚C), sawdust mulch (30.77˚C) and the lowest (29.73˚C) in plot mulch with sorghum straw in okra crop. White plastic mulch attained higher soil temperatures by 1.17, 2.48 and 3.78˚C as compared to black plastic mulch, without mulch and grass mulch, respectively (Habtamu *et.al* 2015).

Sharma and Meshram (2015) found that the average minimum soil temperature under black plastic mulch at 7:30 AM was 1.29˚C and 1.93˚C higher as compared to paddy straw mulch and without mulch, respectively. At 2:00 PM, the average maximum soil temperature was increased by 4.6 and 1.62˚C under black plastic mulch as compared to paddy straw and without mulch, respectively in capsicum crop.

Rana *et al.* (2015) observed that the highest mean morning soil temperature of 20.6 and 22.6˚C was recorded under black plastic mulch at surface and at 15 cm depth, respectively. The highest mean evening soil temperature of 30.8˚C under clear plastic mulch and 27.6˚C under black plastic mulch at surface and at 15 cm depth, respectively.

Negi (2015) studied the effect of mulches on soil temperature under nectarine and found the maximum soil temperature under black polythene mulch and minimum under grass mulch. Plastic mulching increased average annual temperature by 3.3˚C. Contrarily, plant mulching materials showed a decreasing trend and annual average temperature decreased by 0.5˚C in case of corn stalk mulch (Han *et al*. 2015).

Moursy *et al.* (2015) studied the effect of polyethylene and rice straw mulches on soil temperature in tomato crop and reported that the temperature was 5˚C higher in transparent polyethylene mulch as compared to the without mulch. Application of transparent plastic mulch increased soil temperature by 1.15, 2.08 and 2.47˚C as compared to black plastic mulch, rice straw mulch and without mulch, respectively.

Sibale *et al.* (2015) measured the soil temperature at 5 cm and 15 cm depths. The minimum soil temperature (20.38˚C) was found maximum at 15 cm depth and maximum soil temperature (25˚C) was found at 5 cm depth under black plastic mulch. Clear plastic mulch increased the soil temperature by 4.8˚C at 5 cm depth and 3.5˚C at 10 cm depth as compared to bare soil in cucumber (Aniekwe and Anike, 2015).

Abhivyakti *et al* (2016) recorded the highest soil temperature under transparent mulch followed by silver, black and minimum in without mulch plot during tomato crop. It was found up to 10˚C higher soil temperature under transparent plastic mulch as compared to without mulch treatment.

Nair (2018) studied effect of different mulches (black, silver and transparent polyethylene) on soil temperature under tomato cultivation and observed that transparent mulch raised the maximum temperature by 1.5 to 4.5ºC and minimum temperature by 1.5 to 4.4ºC over without mulch plots. Black polyethylene mulch did not alter the maximum temperature however it increases minimum temperature by 1.0 to 3.1ºC over without mulch plots. In silver mulch plots, maximum temperature was decreased by 0.4 to 3.5ºC and minimum temperature was increased by 0.5 to 2.7ºC over without mulch treatment.

Manal *et.al.* (2018) assessed the effect of polyethylene mulch on soil temperature under tomato and observed that the temperature was increased by 1.2ºC under black mulch, 1.1ºC under blue mulch, 1ºC under red mulch, 0.80ºC under transparent mulch, 0.76ºC under green mulch and 0.74ºC under rice straw mulch over control.

2.3 Effect of mulches on soil physical properties

Mulches have been found to improve soil physical properties like bulk density, porosity, water holding capacity, aggregation and infiltration by enhancing biological activities of soil fauna and also increased the soil fertility (Ystass, 1971 and Vleeschauwer *et al*. 1978).

Ghosh *et al.* (2006) reported that the highest bulk density (1.43 Mg m^{-3}) was observed under transparent polythene mulch while the lowest value (1.35 Mg m^{-3}) under wheat straw mulch. Studies on effect of tillage and plastic mulch on soil properties showed the lower bulk density (1.10 and 1.26 Mg m^{-3}) under tilled clear and tilled black plastic mulch plots when it was compared to no-tilled clear and no-tilled black plastic mulched plots (Anikwe *et al.* 2006).

Mulumba and Lal (2008) assessed the effect of mulching on soil physical properties of a silt loam soil. The results demonstrated that the mulch significantly increased the available water content by 18-35 per cent and total porosity by 35-46 per cent while soil bulk density was not affected by mulching.

Zhang *et al.* (2008) obtained maximum soil bulk density (1.21 Mg m^{-3}) under plastic mulch followed by control (1.18 Mg m^{-3}) and minimum under straw mulch (1.12 Mg m^{-3}). Highest saturated hydraulic conductivity (57.2 mm h^{-1}) was observed under straw mulch followed by plastic mulch and minimum in control (51.2 mm h^{-1}) in North Western loess plateau of China.

Narayan and Lal (2009) reported that mulching with sun hemp coupled with improved tillage in sorghum recorded the maximum infiltration rate (5.6 cm hr^{-1}), porosity (47.6%), water holding capacity (37.1%) and the lowest bulk density (1.38 Mg m^{-3}). Pervaiz *et al.* (2009) reported that mulch increased soil organic matter

(1.32 g kg^{-1}) but decreased bulk density (1.35 Mg m^{-3}) and soil strength (464 k Pa) as compared to control.

Pandey *et al.* (2016) assessed the efficiency of mulch on soil properties and results indicated that water holding capacity of 46.4, 43.2, 41.6 and 38.5 per cent were obtained under rice husk, black polythene, control and white polythene mulch, respectively in strawberry.

2.4 Effect of mulches on soil chemical properties

Rana *et al.* (2005) revealed that mulch improves soil organic carbon content as compared to non mulched soil. The maximum organic carbon (2.50%) and available potassium (496.66 kg ha^{-1}) was observed under farm yard manure mulch. While, the maximum amount of available phosphorous (37.65 kg ha^{-1}) and available nitrogen (487.02 kg ha^{-1}) were recorded with forest litter mulch as compared to other treatments in squash field at Uttarakhand.

Khan *et al.* (2005) revealed that mulching material did not affect soil pH and EC. Maximum organic carbon (0.90 g 100 g^{-1}) was found under black plastic mulch and the lowest (0.68 g 100 g^{-1}) under control treatment. Highest nitrogen (0.36%), phosphorus (5.10 mg kg^{-1}) and potassium (127 mg kg^{-1}) contents were found in wheat straw mulch and the lowest nitrogen and phosphorus found under control treatment.

Ogundare *et al.* (2015) studied the response of tomato crop under different mulch materials and found that there was no significant effect of mulches on soil pH. However, mulch had significantly effect on available nitrogen, available phosphorous and soil organic matter. Availability of macro nutrients was significantly higher under the mulch treatments. The contents of available N, P, K, Ca and SO_4^{2-}-S was found higher under black plastic mulch followed by pine needle and grass mulch over without mulch (Sharma and Kumar, 2014).

Bakshi *et al.* (2015) reported that the different types of mulches had non-significant effect on soil pH and soil electrical conductivity in aonla, but there was significant effect on soil organic carbon, N, P, K, Ca and Mg and leaf N, P, K and Ca due to mulching.

Pandey *et al.* (2016) studied the effect of different mulches (rice husk, black and white polythene) on different soil chemical properties and found that the maximum soil pH (7.49), available phosphorus (37.4 kg ha^{-1}) and available potassium (473.3 kg ha^{-1})

were recorded under black polythene mulch whereas, maximum volume of soil organic carbon (0.62 %) and available nitrogen (424.5 kg ha^{-1}) were under rice husk mulch.

Kumar *et al.* (2017) studied the effect of mulches on cauliflower at Nauni, Himachal Pradesh. Experimental results showed that the highest available N (353.8 kg ha^{-1}), P (48.9 kg ha^{-1}), K (261.8 kg ha^{-1}), Ca (702.3 kg ha^{-1}), Mg (430.8 kg ha^{-1}), and SO_4^{2-}S (67.7 kg ha^{-1}) were found in black plastic mulch as compared to other treatments. The percentage increase from initial values in availability of nitrogen (3.6-4.1%), phosphorus (27.6-35.1%), potassium (3.4-3.7%) and calcium (1.3%) were observed. However, the higher content of soil organic carbon was found under organic mulching i.e. grass & pine needle mulch.

2.5 Effect of mulches on growth, yield and quality of crop

The effect of mulching on plant is operative through the effect of mulches on soil moisture, soil temperature and soil erosion. Mulching reduced evaporation is major reason for high plant growth and high crop production. In addition, mulching also provides a favourable environment for growth and development of plants as results in more vigorous, healthier plant which may be more resistant to pest and disease.

2.5.1 Plant height

Hudu *et al*. (2002) observed the significant increase in plant height in mulched tomato as compared to plants grown on bare soil. The maximum plant height (83.5 cm) was observed under rice straw, while the lowest height (57.1 cm) observed in control (un-mulched) under saline soil in tomato (Rahman *et al*. 2006).

Singh *et al.* (2005) studied the effect of mulches on plant height and the maximum plant height (75.7 cm) was observed under black polyethylene mulch followed by clear polyethylene, sugar cane trash, rice straw and the lowest (52.3 cm) in control in tomato crop. The maximum plant height (93 cm) was observed under plot mulched with wheat straw as compared to control in tomato (Khan *et al*. 2005).

Singh *et al.* (2005) studied the effect of plastic mulch on plant height of tomato at Indian Agricultural Research Institute, New Delhi. Experimental results showed that maximum plant height (40.6 cm) was found in clear mulch followed by black mulch (38.8 cm), ordinary clear mulch (37.4 cm) and the lowest (32.2 cm) under control treatment.

Singh *et al.* (2009) studied the effect polyethylene mulch on plant height in tomato crop. The highest plant height (85.5 cm) was found in 80 per cent drip irrigation with black plastic mulch followed by 100 per cent drip irrigation with black plastic mulch (83.4 cm) and the lowest (75.3 cm) found in surface irrigation with black plastic mulch.

Rajablariani *et al*. (2011) observed that mulch colour had significant effect on plant height. Straw mulch enhanced plant height, while live-mulch of cowpea and plastic mulch reduced the height of pepper plants. The maximum height of capsicum plant was recorded under black polyethylene mulch (Choudhary *et al*. 2012).

Ashrafuzzaman *et al.* (2011) assessed the effect of plastic mulch on growth of chilli crop at Bangladesh. At maturity, the maximum plant height (78.45 cm) was observed in transparent mulch followed by black (77.58 cm) and blue plastic mulch (77.03 cm). The minimum plant height (61.15 cm) was observed in control plot.

Berihum (2011) reported the effect of mulches (black and straw) on tomato yield under drip irrigation condition at Ethiopia. The experiment results showed the maximum plant height (54.50 cm) under black plastic mulch followed by straw mulch (50.50 cm) and the lowest (49.33 cm) in without mulch.

Choudhary and Bhambri (2013) assessed the effect of mulches on growth of capsicum under drip irrigation system at Raipur. The experimental findings showed that the maximum plant height (63.1 cm) was observed in black plastic mulch followed by paddy straw mulch (62.1 cm), transparent mulch (58.5 cm) and minimum (56.5 cm) in without mulch.

Bhujbal *et al.* (2015) reported the effect of mulches on growth and yield of tomato and the maximum plant height (83.48 cm) was found in black plastic mulch followed by silver plastic mulch (79.52 cm), transparent mulch (79.52 cm), sugar cane trash mulch (77.14 cm), blue plastic mulch (76 cm), dry grass mulch (72.76 cm) and the lowest (71.14 cm) in control.

Singh *et al.* (2015) assessed the effect of mulch on plant height of tomato at Nauni, Solan in Himachal Pradesh. Experimental results showed the highest plant height (2.32 m) under black plastic mulch followed by pine needle (2.12 m) and the lowest (2.0 m) in control.

Rao *et al.* (2016) assessed the effect of different mulches (black, silver, red and organic) on growth and yield of tomato. It was found that maximum plant height (160.73 cm) under red mulch followed by black mulch (158.98 cm), silver mulch (158.14 cm), organic mulch (156.72 cm) and the lowest (155.02 cm) in without mulch. Maximum plant height (90.74 cm) was obtained under red followed by black (85.54 cm), white plastic (83.42 cm) and minimum (75.67 cm) under control (Agrawal *et al.* 2010).

Jaysawal *et al.* (2018) studied the effect of different mulches on plant height of carrot and observed that the maximum plant height (61.70 cm) was recorded under black polyethylene mulch followed by blue mulch, white mulch and minimum (44.92 cm) under control.

2.5.2 Number of fruits per plant

Sannigrahi and Borah (2002) evaluated the effectiveness of different organic mulches and black polyethylene mulch under rainfed conditions in tomato and found that mulching increased the number of fruits per plant than the control where no mulch was applied.

Rahman (2006) obtained the highest number of fruits per plant in tomato crop using black plastic mulch as compared to without mulched treatment. Maximum number of fruits per plant was recorded under plots mulched with 4 inches thick grass as compared to control in tomato (Khan *et al*. 2005).

Singh *et al.* (2005) studied the effect of mulches on number of fruit per plant. Maximum fruits (28.8 plant^{-1}) were found in black plastic mulch followed by clear plastic and the lowest fruits (21.7 plant^{-1}) in control treatment.

Uddain *et al*. (2010) studied the effect of different mulches and black polyethylene mulch was found most suitable for getting higher number of fruits per plant and yield per plant. The maximum number of fruits per plant (28.21) was observed when black polyethylene mulch was applied, while the minimum number of fruits per plant (22.34) obtained with no mulch (Rashidi *et al*. 2010).

Ashrafuzzaman *et al.* (2011) assessed the effect of plastic mulch on yield of chilli crop at Bangladesh. The highest number of fruits per plant (472) was observed under black plastic mulch followed by blue plastic mulch (443) and transparent mulch (434). In contrast, control showed the lowest fruits per plant (335).

Pandy and Mishra (2012) assessed the effect of mulch on fruit yield of tomato at Jharkhand. Experimental results indicated that the maximum fruits (20.59 fruit plant^{-1}) was found under rice straw mulch followed by without mulch (19.36 fruit plant^{-1}) and the minimum (17.86 fruit plant^{-1}) under black plastic mulch. Maximum numbers of fruits per vine (3.23) were observed under silver plastic mulch followed by black plastic mulch (2.97) and the lowest (2.17) under without mulch under watermelon (Parmar *et al.* 2013)

Rahman *et al.* (2016) studied the effect of different mulch materials (black, transparent, rice straw) on growth and yield of tomato in Bangladesh and revealed that the maximum fruits (39.65 fruits plant^{-1}) was obtained under black plastic mulch followed by rice straw, transparent and the lowest (28.50 fruits plant^{-1}) under control. Maximum fruits (140 fruits plant^{-1}) were obtained under black polythene and the lowest (55 fruit plant^{-1}) in without mulch plot in chilli crop in Jammu and Kashmir (Narayan *et al.* 2017).

Singh *et al.* (2017) studied the influence of different mulches (red, blue, green, yellow, transparent, black, double shaded and straw) on growth and yield of tomato in Himachal Pradesh. Highest fruits (40.4 fruits plant^{-1}) was observed in double shaded mulch followed by black plastic mulch (39.5 fruits plant^{-1}), red plastic mulch (38.6 fruits plant^{-1}), yellow, green, blue, control, transparent and the lowest under straw mulch (36.2 fruits plant^{-1}). The highest number of fruits per plant (27.10) was recorded under red mulch and the lowest in control (24.60) in tomato crop (Agrawal *et al*. 2010).

2.5.3 Average fruit weight and average fruit diameter

Singh *et al.* (2005) assessed the effect of mulch on fruit weight of tomato in Punjab. The highest fruit weight (76.8 g) was found under black plastic mulch followed by clear mulch, sugarcane trash, rice straw mulch and the lowest (70.9 g) in control. Maximum average fruit weight (27.27 g) was observed under black plastic mulch followed by without mulch (26.64 g) and the lowest (26.46 g) under straw mulch (Berihum 2011).

Gandhi and Bains (2006) reported the highest tomato fruit weight (28.08 g) under straw mulch as compared to no mulch (27.86 g). The maximum average weight of fruits (33.45 g) under red mulch followed by black mulch (32.82 g), white mulch (32.27 g) and the lowest (25.32 g) in control. Similarly maximum fruit diameter

(6.73 cm) was observed under red plastic mulch followed by black plastic mulch (5.46 cm), white plastic mulch (5.30 cm) and the lowest (5.04 cm) in control treatment under tomato (Agrawal *et al*. 2010).

Ashrafuzzaman *et al.* (2011) studied the effect of plastic mulch on yield of chilli crop. The maximum fruit diameter was observed under black plastic mulch (0.84 cm) followed by blue mulch (0.82 cm), transparent mulch (0.81 cm) and minimum in control (0.76 cm).

More *et al*. (2013) reported that the seedlings of Gujarat Tomato-2 mulched with black polythene gave highest average fruit weight (43.57 g). The maximum fruit weight (75 g) was observed under black plastic mulch and the lowest (62 g) under without mulch in tomato (Pandy and Mishra, 2012).

Rajablariani *et al.* (2012) studied the effect of colour plastic mulch on yield of tomato. Experimental results showed the maximum average fruit weight (99 g) under silver mulch followed by blue mulch (94.4 g), clear mulch (94.0 g), red mulch (93.9 g), black mulch (91.2 g) and lowest in bare soil (84.9 g). The average fruit weight (g) 125, 121, 116, 106.67 and 89.33 were obtained under straw (6 cm thickness), straw (3 cm thickness), transparent, black plastic mulch and control, respectively under tomato (Moursy *et al.* 2015).

Rao *et al.* (2016) assessed the effect of different mulches (black, silver, red and organic) on growth and yield of tomato crop and experimental results revealed that the maximum fruit weight (118.18 g) was observed in red mulch followed by black mulch (115.70 g), silver mulch (113.63 g), organic mulch (107.34 g) and the lowest (104.51 g) under without mulch.

Rahman *et al*. (2016) reported the effect of different mulches (black, transparent, rice straw) material on growth and yield of tomato and found that maximum average fruit weight (88.43 g) was observed under black plastic mulch followed by transparent (87.32 g), rice straw (87.27 g) and the lowest (83.98 g) in control.

Singh *et al*. (2017) studied the influence of different mulches (red, blue, green, yellow, transparent, black, double shaded and straw) on growth and yield of tomato at Himachal Pradesh. The maximum fruit weight (60.2 g) was observed in double shaded mulch while the lowest (53.6 g) in control. Highest average fruit weight (4.67 g) was found in organic mulch @ 12 t ha^{-1} and the lowest (4.23 g) in control treatment under chilli in Tamil Nadu (Sathiyamurthy *et al.* 2017).

Manal *et.al* (2018) assessed the effect of polyethylene mulch on average fruit weight of tomato and maximum fruit weight (121.40 g) was observed under red polyethylene mulch followed by green mulch, transparent mulch, blue mulch, black mulch, rice straw mulch and the lowest (81.12 g) under without mulch.

Rannu *et al.* (2018) studied the irrigation and mulch effect on average fruit diameter of strawberry and the maximum fruit diameter (3.37 cm) was found under rice straw mulch with irrigation after five days interval followed by black mulch with irrigation after five days interval and the lowest (3.01 cm) under rice straw mulch with irrigation after fifteen days interval.

2.5.4 Fruit yield and total soluble solids

Mahmood *et al.* (2002) reported that mulching had positive effect on potato yield. Highest yield (18.42 t ha^{-1}) was recorded under white polythene sheet followed by black polythene sheet (17.6 t ha^{-1}). Overall increase in yield i.e. 60.45 per cent under white plastic sheet, 49.04 per cent under black plastic sheet, 53.31 per cent under perforated black plastic sheet and 43.2 per cent under grass mulch over no mulching was found.

Chaudhary *et al*. (2002) recorded the highest yield of tomato (28.69 t ha^{-1}) under green plastic mulch followed by red plastic mulch (22.70 t ha^{-1}) and the lowest (15.84 t ha^{-1}) under black plastic mulch treatment. Transparent and black polyethylene mulches increased total tuber yield by 16 and 8 per cent, respectively and average tuber weight by 14 and 12 per cent, respectively, as compared with without mulch (Kang *et al.* 2003).

Hedau *et al.* (2002) studied the effect of different mulches (transparent, silver, black polyethylene and pea straw) on the productivity of tomato and observed that the highest fruit yield (76.42 t ha^{-1}) under silver polyethylene mulch, followed by black polyethylene mulch (73.51 t ha^{-1}). Total yield under reflective mulch, black mulch and no mulch treatments were 122.85, 104.99 and 95.68 t ha^{-1}, respectively in tomato (Yoltas *et al.* 2003).

Singh *et al.* (2005) assessed the mulch effect on yield of tomato at Punjab. The highest fruit yield (412.8 q ha^{-1}) was found in black plastic mulch followed by clear mulch, sugarcane trash, rice straw mulch and the lowest (292.4 q ha^{-1}) in control.

Singh *et al.* (2005) studied the effect of plastic mulch on fruit yield of tomato and the maximum (81.08 t ha^{-1}) fruit yield obtained under clear mulch followed by ordinary clear mulch, black plastic mulch and the lowest (47.29 t ha^{-1}) in control.

Khan *et al*. (2005) obtained the maximum yield of (96.45 t ha^{-1}) of tomato with 4 inches wheat straw mulch as compared to control (55.41 t ha^{-1}). Similarly tomato crop grown with straw mulch produced the highest yield (49.63 t ha^{-1}) as compared to no mulch (47.85 t ha^{-1}) (Gandhi and Bains, 2006).

Rahman (2006) obtained the highest fruit weight per plant and yield from tomato plants grown under black plastic mulch as compared to non-mulched plants. Use of black polyethylene mulch plus drip irrigation further raised the tomato yield by 57.87 t ha^{-1} (Singh *et al*. 2009).

Awasthi *et al*. (2006) recorded higher per cent of brinjal fruit yield per plant i.e. 84 and 77 under black and white polyethylene mulches over control, respectively. The red, black and white plastic mulch increased the yield of tomato by 45.52, 40.06 and 35.30 per cent, respectively over the control (Agrawal *et al*. 2010).

Agrawal *et al*. (2010) assessed the effect of different colour mulches on yield and quality of tomato at Chhattisgarh region. Total per cent soluble solids were obtained 6.94, 6.56, 5.71 and 4.34 in red, black, white and control, respectively.

Anzalone *et al*. (2010) recorded the highest tomato yield under polyethylene mulch followed by paper, manual weeding, biodegradable plastic and the lowest under rice straw mulch. Mukherjee *et al*. (2010) recorded significantly higher yield of tomato with black polythene mulch than the paddy straw mulch. Among mulches, black polythene treatment produced significantly higher fruit yield of tomato (Hedau *et al*. 2010).

Gordon *et al*. (2010) reported that tomato with plastic mulch produced early and higher total yield when compared with other mulches. The maximum yield (11.4 t ha^{-1}) was observed when black polyethylene mulch was applied, while the minimum yield (7.36 t ha^{-1}) was obtained from control plots (Rashidi *et al*. 2010).

Singh *et al*. (2011) conducted the experiments at Conoor (Tamil Nadu) and reported that the highest tuber yield (18.66 t ha^{-1}) was recorded with mulching of white polythene sheet and followed by 17.42, 17.94 and 16.79 t ha^{-1} under black polythene, perforated black polythene and water hyacinth, respectively. Lowest yield was obtained in control.

Huang *et al.* (2012) assessed that the plastic film mulching improves fresh fruits yield. The yield was observed 51.47 t h^{-1} and 51.97 t h^{-1} in white film and black film mulching treatments, respectively. These treatments increased the yield by 17.7 per cent and 18.9 per cent, respectively, over control.

Ashrafuzzaman *et al.* (2011) studied the effect of plastic mulch on yield of chilli crop and revealed that the maximum fruit yield (21.33 t h^{-1}) was observed under black plastic mulch followed by blue plastic mulch (19.15 t h^{-1}), transparent plastic mulch (18.45 t h^{-1}) and control showed the lowest fruit yield (13.46 t h^{-1}). Maximum fruit yield (61.65 t h^{-1}) was found under black plastic mulch followed by straw mulch (54.14 t h^{-1}) and the lowest (49.30 t h^{-1}) yield found in control (Berihum, 2011).

Singh and Kamal (2012) reported that tomato yield from plants grown on bare soil was significantly lower as compared to those grown with black plastic mulch and the yield increased under black plastic mulch was found 21.7 to 29.8 per cent higher as compared to bare soil. Black plastic mulch recorded the highest yield of capsicum, which was 60.25, 26.12 and 28.48 per cent higher than paddy straw, transparent and without mulch, respectively under capsicum crop (Choudhary and Bhambri, 2013).

Pandy and Mishra (2012) studied the effect of plastic mulch on yield of summer tomato. The highest yield per plant and per hectare (1.41 kg $plant^{-1}$ and 282 q ha^{-1}) was obtained under rice straw mulch followed by black plastic mulch and the lowest in control.

Dixit *et al.* (2015) studied the mulch effect on tomato and it was found that highest fruit yield (81 t ha^{-1}) under clear much, ordinary clear (68 t ha^{-1}), black (62.25 t ha^{-1}), the lowest (51.01 t ha^{-1}) under without mulch. The highest tomato yield (285.44 q ha^{-1}) was observed by using black plastic mulch and the lowest (249.96 q ha^{-1}) with the without mulch (Lushi *et al*., 2012).

Bhujbal *et al.* (2015) studied the effect of mulches on yield of tomato and the highest yield (1.63 kg $plant^{-1}$ and 60.61 t ha^{-1}) was found under black plastic, followed by silver, transparent, sugar cane trash, blue plastic, dry grass and the lowest in control (0.88 kg $plant^{-1}$ and 40.59 t ha^{-1}).

Singh *et al.* (2015) assessed the effect of mulch on yield of tomato at Nauni, Himachal Pradesh. It was observed that the highest yield (2.83 kg $plant^{-1}$ and 83.89 q ha^{-1}) was observed under black plastic mulch followed by pine needle mulch and the lowest (2.39 kg $plant^{-1}$ and 70.66 q ha^{-1}) in control.

Jaysawal *et al.* (2018) studied the effect of different mulches on plant yield of carrot and observed that the maximum root yield (54.69 t ha^{-1}) was recorded under black polyethylene mulch followed by blue polyethylene mulch (51.40 t ha^{-1}), white polyethylene mulch (51.29 t ha^{-1}) and minimum (32.48 t ha^{-1}) in control.

2.6 Effect of mulches on benefit cost ratio and water use efficiency

Rahman *et al*. (2006) found the highest benefit cost ratio (5.65) under rice straw mulch followed by water hyacinth (5.56), wastage of rice straw (5.01) and the lowest in no mulch (4.51) in tomato.

Sharma and Kathiravan (2009) reported that the seasonal income under black polythene mulch, bicoloured polythene mulch, transparent polythene mulch, pine needle mulch and grass mulch were 1.06, 1.20, 1.58, 1.12 and 1.09 times higher than in unmulched (control), respectively.

Agrawal *et al.*(2010) studied the effect of different mulch colours (red, black and white) on water use efficiency (WUE) of tomato and the WUE of 0.57, 0.42, 0.37 and 0.21 q ha^{-1} mm^{-1} were observed in red, black, white mulch and control, respectively. The WUE was increased by 63, 50 and 43 per cent in red, black and white mulch, respectively as compared to the no mulch plot.

Choudhary and Bhambri (2013) assessed the mulch effect on WUE of capsicum and observed that black polyethylene mulch recorded the maximum WUE (736 kg ha^{-1} cm^{-1}) followed by paddy straw mulch, transparent mulch and the lowest (532 kg ha^{-1} cm^{-1}) under no mulch.

Pandey and Mishra (2012) observed that mulching with rice straw resulted in maximum gross and net income per hectare of ₹ 1,97,400/- and 1,56,400/-, respectively and B:C ratio (5.33) as compared to black plastic mulching (4.82). More *et al*. (2014) achieved the marketable fruit yield of 49.65 t ha^{-1} under black polythene mulch with early transplanting date (5th November) with highest B:C ratio of 2.05: 1, which was closely followed by and sugarcane trash mulch with 5th November planting (43.08 t ha^{-1}) and B:C ratio of 1.87:1. Parmar *et al.* (2013) recorded the highest B:C ratio (1.65:1) in silver plastic mulch followed by black plastic mulch (1.56:1) and the lowest in control.

Rao *et al.* (2016) observed the highest B:C ratio (4.70) for red mulch, followed by black mulch (4.07) and silver mulch (3.00) than organic mulch (1.80). The highest B:C ratio (2.80) was found in black on white plastic mulch followed by organic mulch (2.05) and the lowest in without mulch as reported by (Sathiyamurthy *et al.* 2017).

Sakariya *et al.* (2018) studied the WUE of papaya under plastic mulch and that maximum WUE (334.03 kg ha^{-1} mm^{-1}) was observed under silver plastic mulch followed by black mulch (298.24 kg ha^{-1} mm^{-1}) and the lowest (162.12 kg ha^{-1} mm^{-1}) in control treatment.

Chapter-3

MATERIALS AND METHODS

With an aim to achieve objectives of present study entitled **"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)",** field experiments were conducted during two seasons from March 2017 to August 2017 and February 2018 to July 2018 in the Research Farm, Department of Soil Science & Water Management, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. Details of the field experiment, soil and plant studies undertaken and the adopted methodology have been presented under the following broad headings:

3.1 General description of the study area

3.2 Experimental details

3.3 Soil studies during the period of experimentation

3.4 Plant growth, yield and quality parameters

3.5 Soil analysis

3.6 Water requirement and water use efficiency

3.7 Benefit cost ratio

3.8 Statistical analysis

3.1 General description of the study area

3.1.1 Location and climate

The experimental site is situated at the Research Farm, Department of Soil Science and Water Management, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. It is located at 30˚52′ N latitude and 77˚11′ E longitude and elevation of 1175 m above mean sea level. The study area falls in sub-temperate, sub humid agro-climatic zone of Himachal Pradesh. The average annual rainfall in the area is about 1100 mm and more than 75 per cent of annual rainfall is received during the monsoon period (mid June - mid September). Winter rains are scanty during the months of January and February. The data on rainfall, maximum and minimum temperature coupled with pan evaporation of the study area for both the years of experimentation were collected from the Meteorological Observatory, Department of Environmental Science, Dr

Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh).

3.1.2 Soils

The soils of the study area belong to Typic Eutrochrept at sub-group level according to Soil Taxonomy of USDA. Physico-chemical properties of the experimental soil for surface (0-15 cm) and subsurface (15-30 cm) layers are presented in Table 3.1

Table 3.1: Physico-chemical properties of experimental soil before the start of experiment

Physico-chemical properties	0-15 cm	15-30 cm
Bulk density (Mg m^{-3})	1.25	1.29
Particle density (Mg m^{-3})	2.50	2.49
Porosity (%)	46.87	45.67
Maximum water holding capacity (w/w, %)	39.23	38.21
Saturated hydraulic conductivity (cm hr^{-1})	3.97	4.01
Water stable aggregates (> 0.25mm) (%)	60.76	57.38
Soil pH	6.24	6.37
EC (d Sm^{-1})	0.21	0.19
Organic Carbon (g kg^{-1})	16.6	14.9
Available N (kg ha^{-1})	337.6	328.6
Available P (kg ha^{-1})	50.03	48.79
Available K (kg ha^{-1})	335.9	310.3
Exchangeable Ca [cmol (p^+) kg^{-1}]	4.52	4.41
Exchangeable Mg [cmol (p^+) kg^{-1}]	2.90	2.68
Sulphate sulphur (kg ha^{-1})	53.38	47.87
Available Zn (mg kg^{-1})	2.23	1.77
Available Mn (mg kg^{-1})	10.53	10.25
Available Cu (mg kg^{-1})	3.37	3.92
Available Fe (mg kg^{-1})	15.56	15.64
Moisture retention at 0.33 bar (w/w, %)	19.22	18.76
Moisture retention at 15 bar (w/w, %)	6.37	6.28
Available water (w/w, %)	12.85	12.48

Before laying out the experiment, random samples were collected from the different spots in the experimental field at 0-15 and 15-30 cm depths and the composite

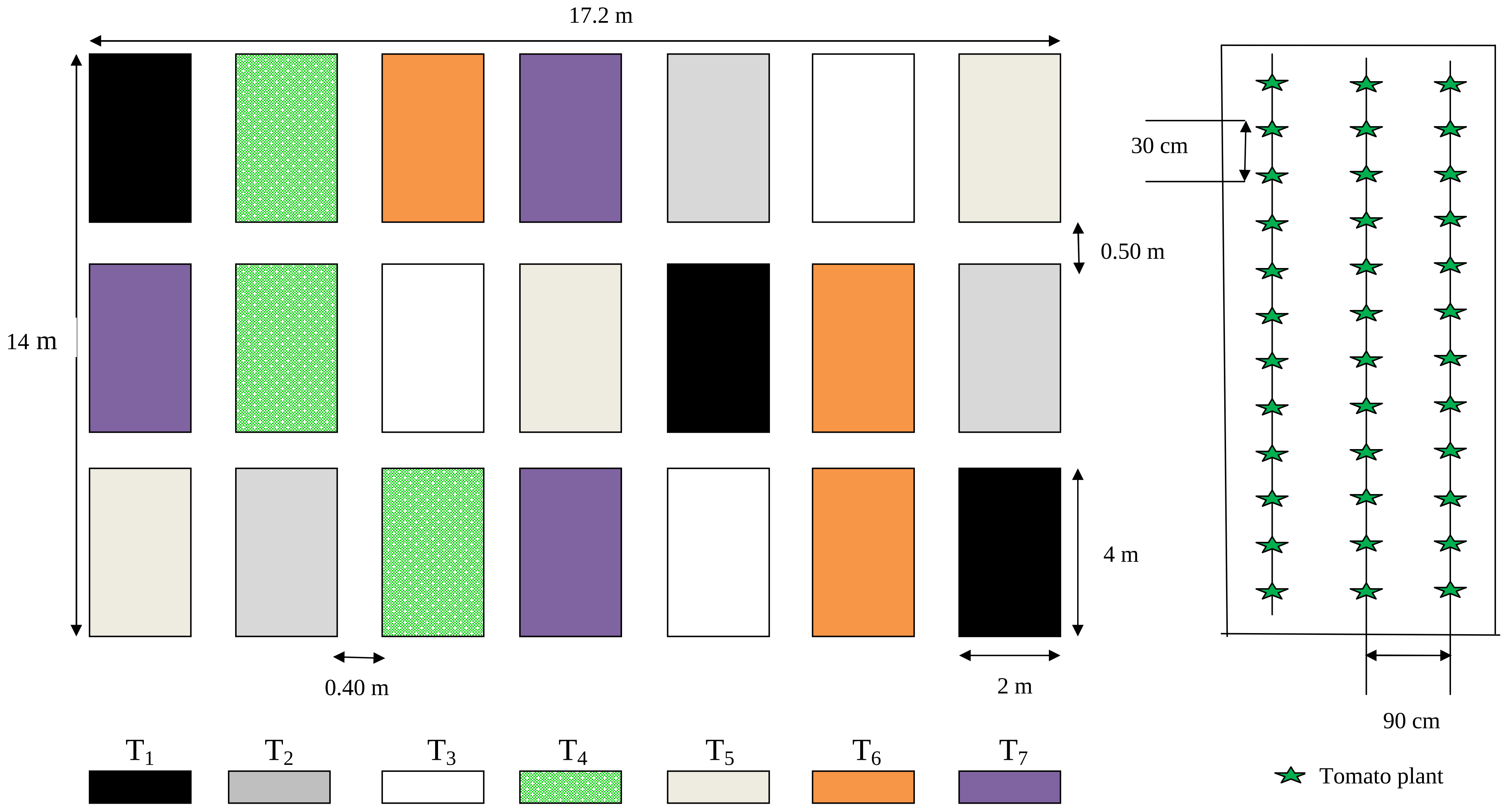

Fig. 3.1. Experiment field layout for tomato

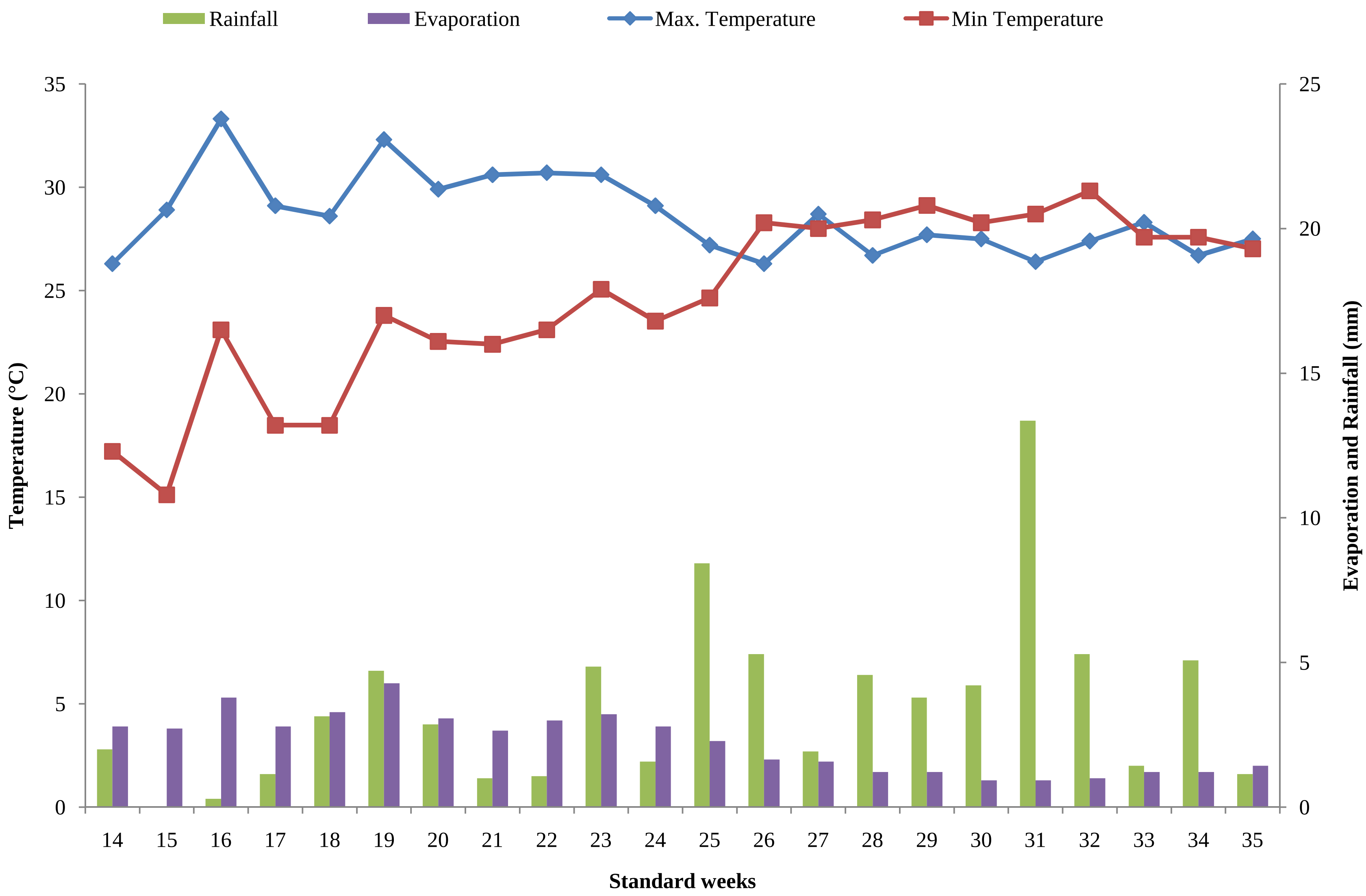

Fig. 3.2 : Weekly meteorological data during experimental period in year 2017

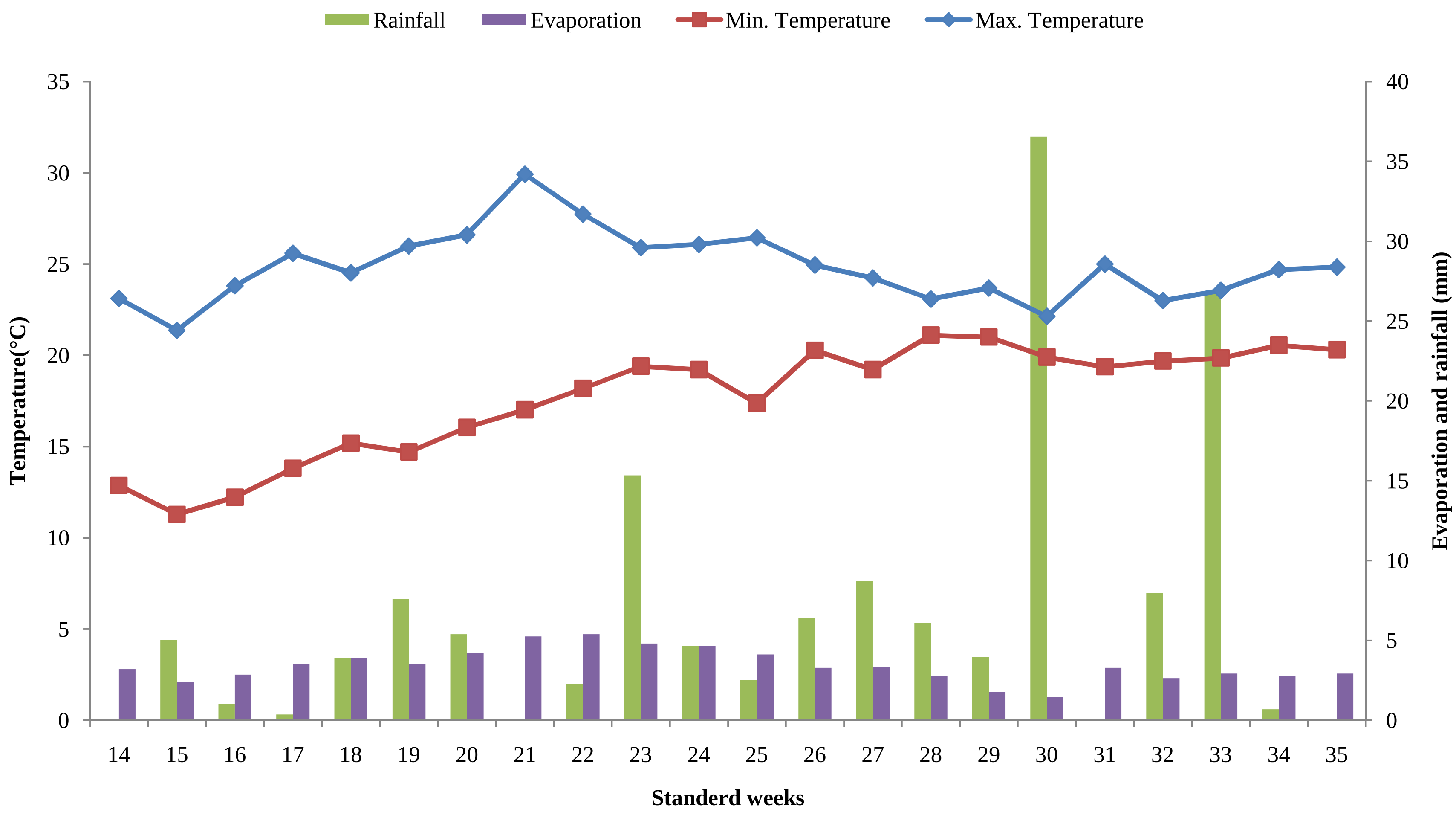

Fig. 3.3 : Weekly meteorological data during experimental period in year 2018

representative samples for 0-15 and 15-30 cm depths were prepared and analyzed for various physico-chemical properties of the soil. The information on chemical characteristics and available nutrient status of the experiment soil before the start of the experiment is enumerated in Table 3.1.

3.2 Experimental details

3.2.1 Treatment details

There were seven treatments consisting of six mulches (M) and one no mulch under the field experiment. The details of treatments are given below:

- T_1 –BM : Black polyethylene mulch (thickness 25 µ)
- T_2-SM : Silver polyethylene mulch (thickness 25 µ)
- T_3-TM : Transparent polyethylene mulch (thickness 25 µ)
- T_4-MM : Mulch mat (thickness 90 GSM)
- T_5-GM : Grass mulch (air dry @ 10 t ha^{-1})
- T_6-PM : Pine needle mulch (air dry @ 10 t ha^{-1})
- T_7-NM : No mulch

3.2.2 Nursery raising

The tomato seeds of Solan Lalima cultivar were sown in well prepared nursery beds one month before transplanting. Seeds were sown on nursery beds to raise seedlings for transplanting in the field. Raised beds of size 3 m × 0.6 m with 15 cm height were prepared. Sowing were done thinly in lines spaced at 5 cm distance. Seeds were sown at 2 cm depth and covered with a fine layer of soil followed by light watering by water can. The beds were then covered with dry straw/grass to maintain required temperature and moisture. The surface of beds was smooth and well levelled. Well-decomposed farm yard manure @ 8 kg m^{-2} was added at the time of bed preparation. Raised beds were necessary to avoid problem of water logging in heavy soils. All the precautions for raising healthy nursery were observed.

3.2.3 Field preparation

Before the execution of experiment, the field was well ploughed by tractor followed by planking 15 days prior to transplanting of seedlings. Weeds, stones, pebbles etc. were removed from the field. Twenty one raised plots of dimension of 4 m × 2 m were prepared for transplanting.

3.2.4 Manure and fertilizers

Farm yard manure (250 q ha^{-1}) as well as different levels of N, P_2O_5 and K_2O nutrients were added as per the schedule of the experiment in the form of urea (300 kg ha^{-1}), single super phosphate (475 kg ha^{-1}) and muriate of potash (90 kg ha^{-1}) as per recommended doses in University package of practices. The whole dose of FYM, P and K fertilizers were applied at the time of field preparation. The nitrogen fertilizer was applied in three split doses, first dose at the time of field preparation, second dose at the time of transplanting and third dose at the time of fruit development.

3.2.5 Transplanting of seedlings

Seedlings of 10-15 cm in length were transplanted at the spacing of 90 cm × 30 cm. Each plot had three rows accommodating 36 plants and total 756 seedlings were transplanted in twenty one plots. After transplanting, drenching operation was done by applying bavistine solution at a rate of 2g l^{-1} to protect the seedlings from fungal infection.

3.2.6 Gap filling and crop establishment

In case of failure of some seedlings after transplanting, proper attention was given to replace the weaker seedling with the healthier one from the stock saved in the nursery for filling the gap. Up to two weeks after transplanting, the light irrigation was given daily at morning and evening hour to the crop with the help of water can for their proper establishment.

3.2.7 Irrigation

After crop establishment, only one irrigation of 4 cm was applied. Ample amount of rainfall was received during the rest crop growth period.

3.2.9 Mulching

Six types of mulches viz. black plastic, silver plastic, transparent plastic, mulch mat, grass mulch, pine needle mulch were applied. Plastic sheets cut in rectangular shape, slightly larger than the dimension of plots and circular holes were made with the help of hot steel glass so as to fit the plant in the holes. The mulch sheet was laid in the plots before the transplanting of seedlings. The mulch sheets were placed beneath the soil at the periphery of plot to prevent it from being blown by wind. The air dried grass and pine needles mulch material were spread evenly in the plots to have uniform mulch at the rate of 10 t ha^{-1} just after the establishment of the seedlings (15 days after transplanting).

During second year, beds were prepared and mulches were applied as that of first year. All the cultural operations were done and doses of nutrients were applied as per the treatment details. The plastic mulches and mulch mat were removed after the completion of the experiment. The partially decomposed grass and pine needle mulch was allowed to remain in the plot which was later on mixed with soil.

3.3 Soil studies during the period of experimentation

3.3.1 Soil moisture

Soil moisture contents were determined gravimetrically in mulched plots and no-mulched (control) plots up to (0-15 and 15-30 cm depths) at weekly interval during the period of experimentation.

3.3.2 Soil temperature

Soil temperatures under different treatments were recorded at 15 and 30 cm depths on alternate day with the help of soil thermometers. The minimum and maximum soil temperatures were recorded at 7:30 hrs in morning and 14:30 hrs in afternoon, respectively.

3.3.3 Weather parameters

The data on weather parameters i.e. rainfall (mm), evaporation (mm), maximum and minimum temperatures (°C) were collected from Meteorological Observatory, Department of Environmental Sciences, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh and are presented in the Fig. 3.2 and Fig. 3.3.

3.4 Plant growth, yield and quality parameters of tomato

Randomly five plants per plot were selected from each treatment and tagged for recording data on vegetative growth parameters.

3.4.1 Plant height

The height of the randomly selected plants was measured in centimetres from base to the apex of main shoot at final harvest.

3.4.2 Number of fruits per plant

The number of fruits per plant was calculated by adding the number of fruits of all harvesting.

3.4.3 Average fruit weight

The ripe fruits harvested from the five randomly selected plants from each treatment on each picking per plant were weighed. The average fruit weight was calculated by dividing the total weight of fruits from each plant by total number of fruits. Electronic balance was used to measure fruit weight.

3.4.4 Average fruit diameter

Ten fruits of different grades were selected randomly and weighed these selected fruits. Average weight of fruits was worked out in centimetres.

3.4.5 Fruit yield per plant

The weight of total fruits harvested from all pickings per plant was added to calculate the yield per plant in kg.

3.4.6 Total soluble solids

The firmly ripe fruits taken from five randomly selected plants from each treatment in middle of the total pickings per plot were cut into two pieces, their juice was directly dropped on the glass of hand refractometer and the reading on scale was recorded as percent total soluble solids.

3.5 Soil analysis

3.5.1 Collection and preparation of soil samples

Composite soil samples from 0-15 and 15-30 cm depths were collected from each experimental plot with the help of screw type auger. The soil samples, thus collected were dried in shade, stranded, sieved through 2 mm plastic sieve and stored in cloth bags. Sample preparation for analysis was in accordance with the procedure given by Piper (1966). The soil samples were collected before and after harvesting of crop during both experimental years. The samples were analyzed for physico-chemical properties of soil.

Table 3.2: Methods used for the analysis of soil samples

Parameter		Method and Reference
1.	Bulk density	Core sampler method (Singh,1980)
2.	Particle density	Pycnometer method (Gupta and Dhakshinamoorly, 1980)
3.	Porosity	$\text{Porosity} = (1- \frac{\text{Bulk Density}}{\text{Particle Density}}) \times 100$ (Rattan,2009)
4.	Soil texture	Hydrometer method (Bouyoucos, 1927)
5.	Soil moisture retention at 0.33 and 15 bar	Pressure plate apparatus (Richards, 1947)
6.	Maximum water holding capacity (MWHC)	Keen-Raczkowski box having perforated bottom (Singh, 1980)
7.	Plant available water content (PAWC)	Pressure plate apparatus (Richards, 1947)
8.	Saturated hydraulic conductivity (K_s)	Constant head method (Singh, 1980)
9.	Aggregate size distribution	Wet sieving method by Yoder's apparatus (Yoder, 1936)
10.	pH	1:2 Soil : water suspension, measured with digital pH meter (Jackson, 1973)
11.	EC	1:2 Soil : water suspension, measured with digital EC meter (Jackson, 1973)
12.	Organic carbon	Walkley and Black wet digestion method (Walkley and Black, 1934)
13.	Available N	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
14.	Available P	Olsen's method (Olsen *et al*., 1954)
15.	Available K	Ammonium acetate method (Merwin and Peach, 1951)
16.	Exchangeable Ca [cmol (p^+) kg^{-1}]	Ammonium acetate method (Merwin and Peach, 1951)
17.	Exchangeable Mg [cmol (p^+) kg^{-1}]	Ammonium acetate method (Merwin and Peach, 1951)
18.	Sulphate sulphur (kg ha^{-1})	0.15% $CaCl_2$ extractant and turbidimetric determination (Chesnin and Yien, 1950)
19.	DTPA extractable Zn (ppm)	DTPA extractant (Lindsay and Norvell, 1978)
20.	DTPA extractable Mn (ppm)	DTPA extractant (Lindsay and Norvell, 1978)
21.	DTPA extractable Cu (ppm)	DTPA extractant (Lindsay and Norvell, 1978)
22.	DTPA extractable Fe (ppm)	DTPA extractant (Lindsay and Norvell, 1978)

3.6 Water requirement and water use efficiency:

3.6.1 Water requirement

The seasonal water requirement for the tomato crop was computed as follows:

$$WR = IR + ER + \sum_{i=1}^{n} \frac{Mbi - Mei}{100} . ASi . Di$$

Where,

WR	=	Seasonal water requirement (cm)
IR	=	Total irrigation water applied (cm)
ER	=	Seasonal effective rainfall (cm)
Mbi	=	Moisture percentage at the beginning of the season in the i^{th} layer of the soil
Mei	=	Moisture percentage at the end of the season in the i^{th} layer of the soil
ASi	=	Apparent specific gravity of the i^{th} layer of the soil (g cm^{-3})
Di	=	Depth of the i^{th} layer of the soil within the root zone (cm)

The effective rainfall was calculated using balance sheet method (Doorenbos and Pruitt, 1984).

3.6.2 Water use efficiency

The water use efficiency for each treatment was calculated by considering total yield and amount of water applied.

$$\text{Water use efficiency } (t\ ha^{-1} cm^{-1}) = \frac{\text{Yield } (t\ ha^{-1})}{\text{Water applied (cm)}}$$

3.7 Benefit Cost (B: C) Ratio:

The benefit-cost ratio was calculated by considering the cost of variables as well as fixed inputs and prevailing market rates, the expenditure incurred on various inputs and operations. Simultaneously, gross returns were work out for each treatment based on prevailing market prices of the produce. The net returns were also worked out by deducting the cost incurred from the gross returns of the particular treatment. Cost of cultivation has been detailed in Appendix-V

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

3.8 Statistical Analysis:

The data generated from the present investigation were subjected to statistically analysis using the MS excel and OP STAT. Critical difference (CD) at 5 per cent level was used for testing the significant difference among the treatment means.

Table 3.3: Analysis of variance (ANOVA)

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	$F_{(cal)}$
Treatments	(t-1)	S_t	$M_t = \frac{S_t}{(t-1)}$	$\frac{M_t}{M_e}$
Replications	(r-1)	S_r	$M_r = \frac{S_r}{(r-1)}$	$\frac{M_r}{M_e}$
Error	(r-1) (t-1)	Se	$M_e = \frac{Se}{(r-1)(t-1)}$	
Total	(rt-1)	S_T		

Where,

R	=	Number of replications
t	=	Number of treatments
S_r	=	Sum of square due to replications
S_t	=	Sum of square due to treatments
S_e	=	Sum of square due to error
S_T	=	Total sum of squares
M_r	=	Mean sum of square due to replications
M_t	=	Mean sum of square due to treatments
M_e	=	Mean sum of square due to error

The replication and treatment mean sum of square were tested against mean sum of square due to error by ‘F-test’ for (r-1), (r-1) (t-1) and (t-1), (r-1) (t-1) degree of freedom at 5% level of significance.

The calculated F-values were compared with tabulated F-value. When F-test was found significant, critical difference was calculated to find out the superiority of one treatment over the other.

The standard error and critical differences was calculated as follows:

SE (d) ± = $\sqrt{\frac{2me}{r}}$

SE (m) ± = $\sqrt{\frac{Me}{r}}$

$CD_{0.05}$ = S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) df

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference of mean

$CD_{0.05}$ = Critical difference at 5 per cent level of significance

Chapter-4

RESULTS AND DISCUSSION

Present study entitled **"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)"** was conducted at Research Farm, Department of Soil Science and Water Management, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh) during the two years i.e. 2017 and 2018. The results obtained from the study in relation to soil moisture, soil temperature, soil physical properties, soil chemical properties, plant growth and yield characteristics, water requirement, water use efficiency and cost economics have been presented and discussed with relevant references with a view to assess the effect of different treatments under suitable headings as under:

4.1 Effect of mulches on soil moisture

4.2 Effect of mulches on soil temperature

4.3 Effect of mulches on soil physical properties

4.4 Effect of mulches on soil chemical properties

4.5 Effect of mulches on yield and quality parameters

4.6 Effect of mulches on water requirement and water use efficiency

4.7 Effect of mulches on benefit cost ratio

4.1 Effect of mulches on soil moisture

The data on soil moisture contents at 0-15 and 15-30 cm depths during year 2017 had been presented in Fig 4.1 and Fig 4.2, respectively. Similarly for year 2018, the data on soil moisture contents at 0-15 and 15-30 cm depths had been presented in Fig 4.3 and Fig 4.4, respectively. The details of soil moisture data for both the depths (0-15 and 15-30 cm) and for both the years (2017 and 2018) are given in Appendix-II. Appraisal of data revealed that all mulch treatments increased the soil moisture contents over control i.e. T_7-NM (no mulch). The treatment with black polyethylene mulch (T_1-BP) maintained the highest soil moisture content during both the years of study as compared to other treatments, whereas, the lowest soil moisture contents were recorded under T_7-NM.

An inquisition of data on soil moisture contents during year 2017 showed that the highest soil moisture contents were recorded under T_1-BP at 0-15 and 15-30 cm depths, which was ranged between 18.6-29.1 and 20.1-30.0 per cent with mean values of 23.3 and 25.1 per cent, respectively, which was followed by silver polyethylene mulch (T_2-SM) with soil moisture contents ranging from 17.6-27.6 and 18.4-29.9 per cent with mean values of 22.3 and 24.1 per cent at 0-15 and 15-30 cm depths, respectively. The soil moisture contents under transparent polyethylene mulch (T_3-TM) ranged between 16.2-26.8 and 17.0-28.1 per cent with mean values of 21.0 and 22.8 per cent, respectively. Soil moisture contents under mulch mat (T_4-MM) ranged between 14.7-25.8 and 17.3-27.5 per cent with mean values of 20.3 and 22.5 per cent, respectively. Soil moisture contents under grass mulch (T_5-GM) ranged between 16.0-25.2 and 16.9-27.3 per cent with mean values of 20.2 and 22.0 per cent, respectively. Soil moisture contents under pine needle mulch (T_6-PM) ranged between 14.6-25.2 and 16.3-28.5 per cent with mean values of 19.6 and 21.8 per cent, respectively. The lowest soil moisture contents were recorded under T_7-NM at 0-15 and 15-30 cm depths, which was ranged between 14.0-25.7 and 16.0-27.1 per cent with mean values of 19.4 and 21.1 per cent, respectively.

Similarly, the analysis of data on soil moisture contents during year 2018 showed that the highest soil moisture contents were recorded under T_1-BP at 0-15 and 15-30 cm depths, which was ranged between 15.1-24.1 and 16.6-24.2 per cent with mean values of 19.2 and 20.1 per cent, respectively. It was followed by T_2-SM with soil moisture contents ranging from 14.8-23.8 and 15.8-23.8 per cent with mean values of 18.4 and 19.7 per cent at 0-15 and 15-30 cm depths, respectively. The soil moisture contents under T_3-TM ranged between 14.4-23.3 and 15.4-22.2 per cent with mean values of 17.9 and 19.1 per cent, respectively. Soil moisture contents under T_4-MM ranged between 13.8-22.3 and 14.8-22.6 per cent with mean values of 17.3 and 18.6 per cent, respectively. Soil moisture contents under T_5-GM ranged between 13.7-22.2 and 15.4-20.7 per cent with mean values of 16.7 and 18.0 per cent, respectively. Soil moisture contents under T_6-PM ranged between 12.8-22.0 and 13.9-22.3 per cent with mean values of 16.4 and 17.7 per cent, respectively. The lowest soil moisture contents were recorded under T_7-NM at 0-15 and 15-30 cm depths, which was ranged between 12.2-21.5 and 13.0-21.8 per cent with mean values of 15.8 and 16.9 per cent, respectively. The increases in soil moisture content were 20.34, 15.01, 8.58, 4.79, 4.29, 1.28 per cent at surface and 19.08, 14.32, 8.11, 6.72, 4.29, 3.43 per cent at subsurface depth under T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM, respectively as compared to T_7-NM i.e. control in year 2017. The corresponding values were 21.59, 16.49, 13.39, 9.59, 6.65, 3.92% and 18.87, 16.77, 13.39, 10.36, 6.98, 4.94% in year 2018.

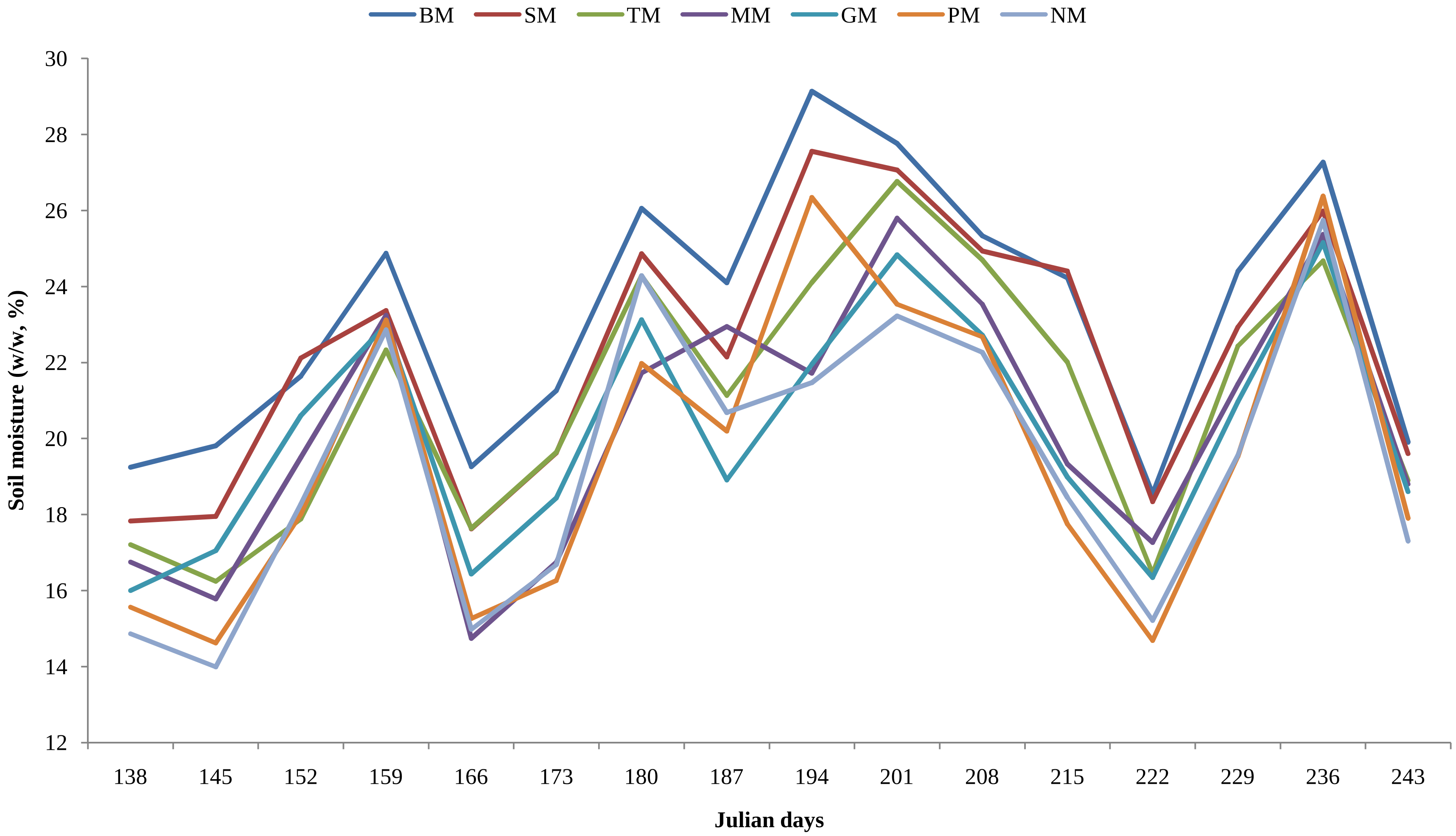

Fig 4.1: Effect of mulches on soil moisture at 0-15 cm depth in year 2017

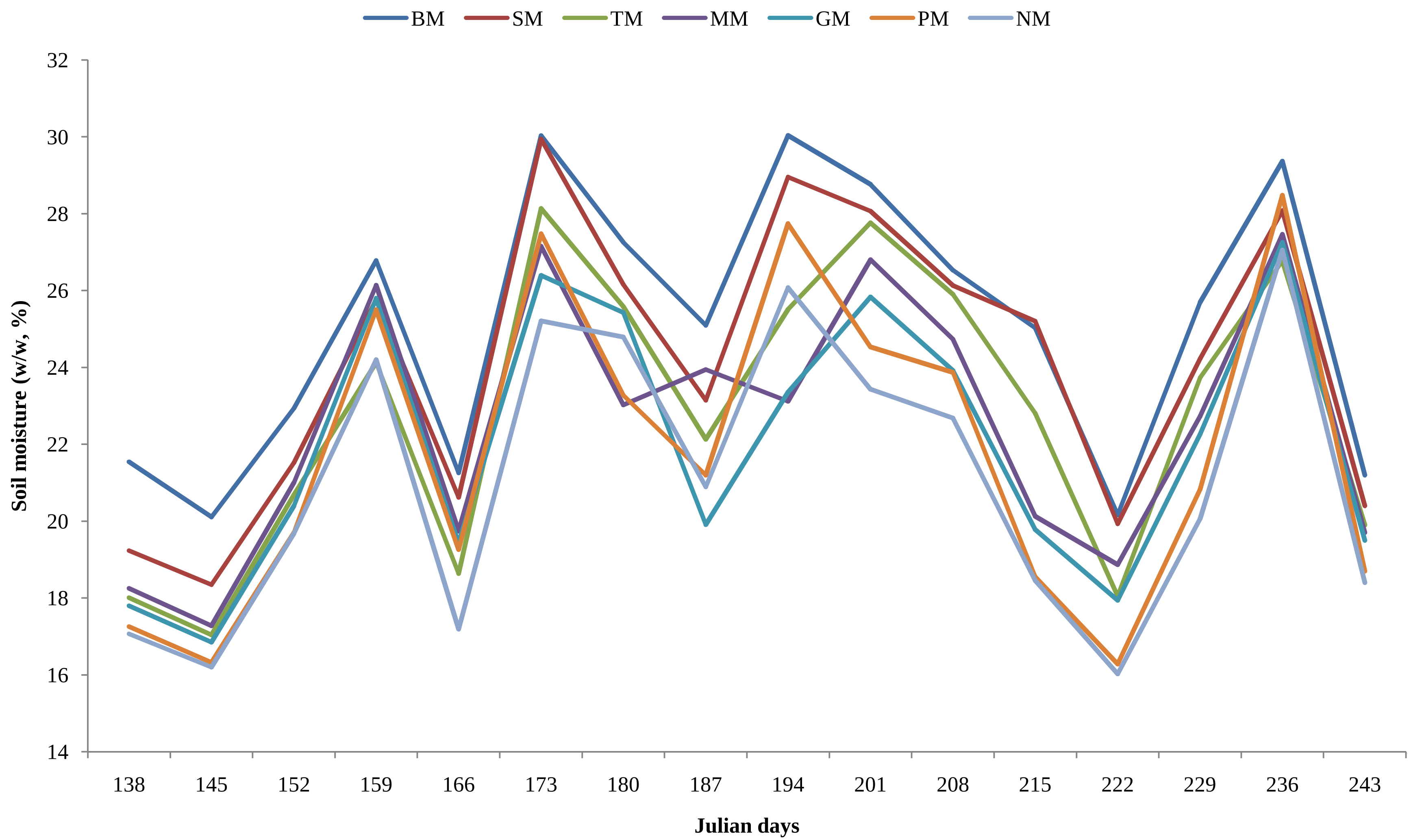

Fig 4.2: Effect of mulches on soil moisture at 15-30 cm depth in year 2017

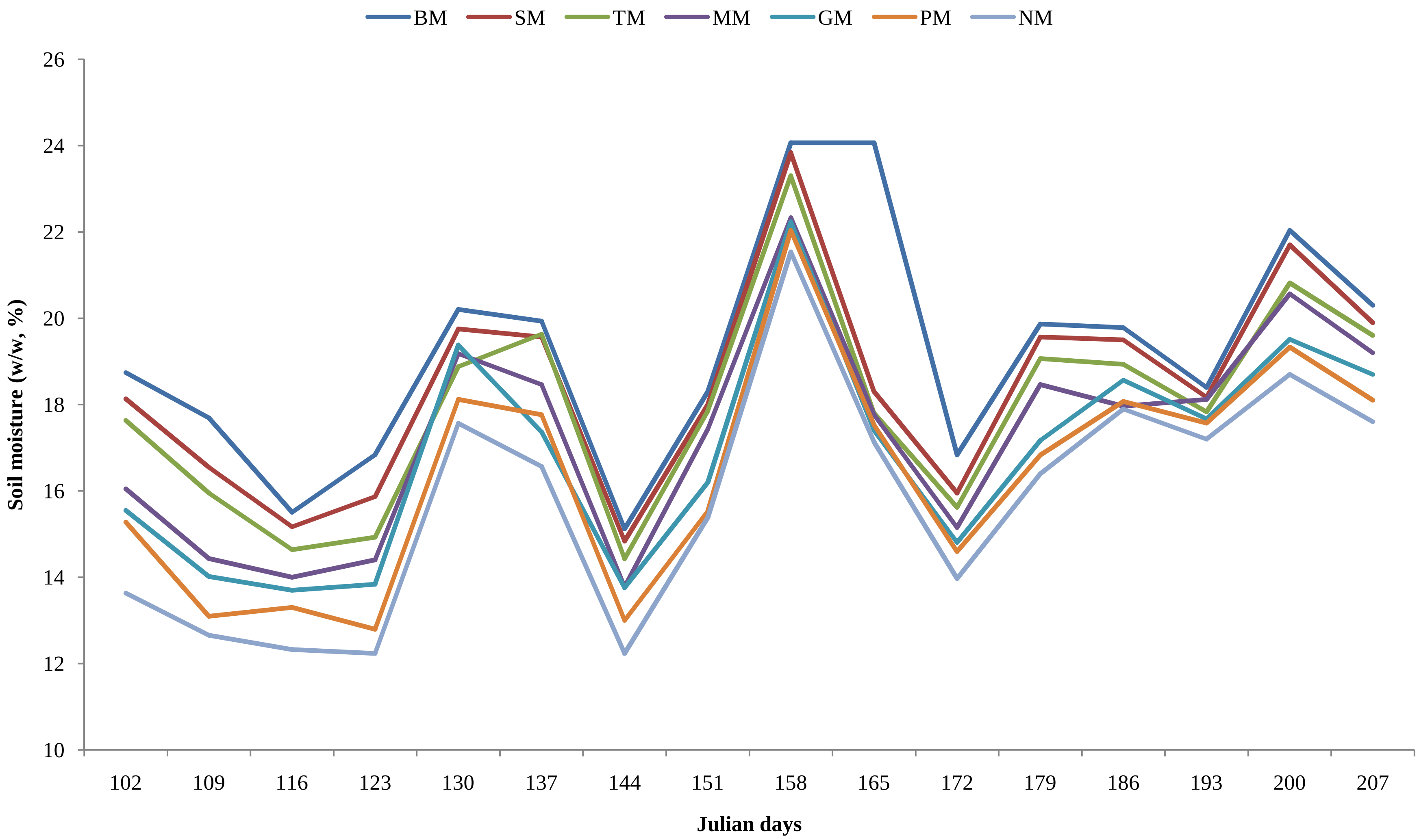

Fig 4.3: Effect of mulches on soil moisture at 0-15 cm depth in year 2018

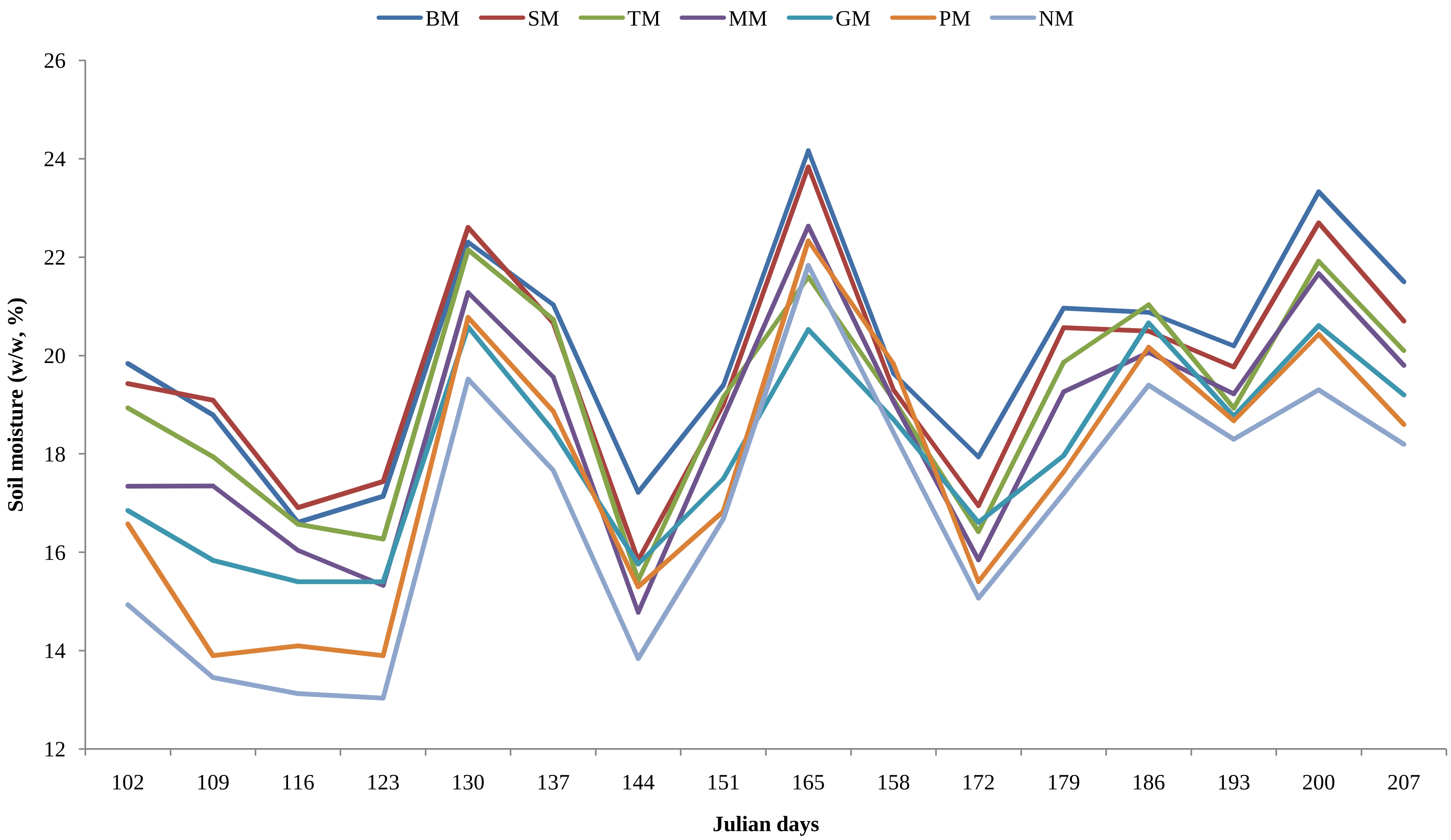

Fig 4.4: Effect of mulches on soil moisture at 15-30 cm depth in year 2018

The examination of data revealed that soil moisture contents recorded under different mulched treatments follow order as black mulch > silver mulch > transparent mulch > mulch mat > grass mulch > pine needle mulch > no mulch for both soil depths (0-15 and 15-30 cm) during both the years (2017 and 2018) of study.

Black polyethylene mulch was found most effective in conserving the soil moisture followed by silver polyethylene mulch and the no mulched treatment conserve minimum soil moisture under the present study. The higher soil moisture contents under all mulching materials were due to shading effect, which prevents evaporation of soil moisture from soil surface and reduce vapor diffusion to the atmosphere. Among different mulches comparatively higher soil moisture content under the black and silver polyethylene mulch may be due to effective weed control and the fact that water after evaporation condense on the bottom side of polyethylene mulch and drips down again on the soil surface. The effectiveness of polyethylene mulch was higher as compared to organic mulch may be attributed to the fact that these materials form relatively more impermeable vapour barrier at the soil surface as compared with organic mulch materials which being porous and allowed diffusion of water under vapour pressure gradient. Similar observations have also been reported by Pandey and Mishra (2012), Sharma and Kumar (2014), Sharma and Meshram (2015) and Narayan *et. al*. (2017).

4.2 Effect of mulches on soil temperature

Average minimum and maximum soil temperatures were recorded on alternate days at 7:30 hrs and 14:30 hrs, respectively during both the years of crop growth period at 15 and 30 cm soil depths. The details of observed temperature data are presented in Appendix-III.

Minimum soil temperature

The data presented in Fig. 4.5 revealed that during year 2017, the highest average minimum soil temperature of 22.9°C (20.7-25.5°C) at 15 cm soil depth was recorded under T_3-TM, followed by under T_1-BP while the lowest average minimum soil temperature of 20.8°C (18.1-23.6°C) under T_7-NM. Similarly, Fig. 4.6 revealed that at 30 cm soil depth, the highest average minimum soil temperature of 23.6°C (21.4-26.2°C) was recorded under T_3-TM followed by under T_1-BP. The lowest average minimum soil temperature of 21.5°C (18.8-24.3°C) was recorded under T_7-NM.

Fig. 4.7, it was revealed that during year 2018 the highest average minimum soil temperature of 26.9°C (16.5-32.2°C) at 15 cm soil depth was recorded under T_3-TM, followed by 26.2°C (16.5-32.0°C) under T_1-BP while the lowest average minimum soil temperature of 24.2°C (15.5-30.1°C) under T_7-NM. Similarly, the Fig. 4.8 revealed that at 30 cm soil depth, the highest average minimum soil temperature of 27.2°C (15.8-33.6°C) was recorded under T_3-TM, followed by 26.1°C (15.4-34.3°C) under T_1-BP. The lowest average minimum soil temperature of 24.7°C (14.4-31.5°C) was recorded under T_7-NM. The increase in minimum soil temperatures were 2.09, 1.61, 1.32, 0.97, 0.66, 0.39°C at surface and 2.10, 1.31, 0.95, 0.67, 0.22, 0.10°C at subsurface depth under T_3-TM, T_1-BM, T_2-SM, T_4-MM, T_5-GM, T_6-PM, respectively as compared to T_7-NM i.e. control in year 2017. The corresponding values were 2.69, 2.0, 1.26, 1.1, 0.56, 0.45°C and 2.52, 1.41, 1.14, 0.93, 0.51, 0.47°C in year 2018.

The examination of minimum soil temperature data revealed that soil temperature recorded under different mulched treatments follows order as transparent mulch > black mulch > silver mulch > mulch mat > grass mulch > pine needle mulch > no mulch for both soil depths during both the years of study.

Maximum soil temperature

Fig. 4.9, it was revealed that during year 2017, the highest average maximum soil temperature of 28.2°C (22.7-35.6°C) at 15 cm soil depth was recorded under T_3-TM, followed by 27.4°C (20.9-34.1°C) under T_1-BP while the lowest average maximum soil temperature of 26.5°C (20.1-33.8°C) recorded under T_7-NM. Similarly, the Fig. 4.10 revealed that at 30 cm soil depth, the highest average maximum soil temperature of 27.8°C (22.6-34.9°C) was recorded under T_3-TM, followed by 27.2°C (20.7-34.0°C) under T_1-BP. The lowest average maximum soil temperature of 26°C (20.5-33.1°C) was recorded under T_6-PM.

The perusal of data in Fig. 4.11 revealed that during year 2018, the highest average maximum soil temperature of 31.6°C (22.4-36.2°C) at 15 cm soil depth was recorded under T_3-TM, followed by 31.0°C (20.8-35.4°C) under T_1-BP while the lowest average maximum soil temperature of 28.1°C (18.7-32°C) recorded under T_6-PM. Similarly, the Fig. 4.12 revealed that at 30 cm soil depth, the highest average maximum soil temperature of 30.0°C (19.5-34.1°C) was recorded under T_3-TM, followed by 29.0°C (17.4-33.2°C) under T_1-BP. The lowest average maximum soil temperature of 26.8°C (15.6-31.5°C) was recorded under T_6-PM. The increase in maximum soil temperatures were 1.64, 0.90, 0.69, 0.18°C at 15 cm depth and 1.55, 0.98, 0.87, 0.34°C at 30 cm depth under T_3-TM, T_1-BM, T_2-SM, T_4-MM,

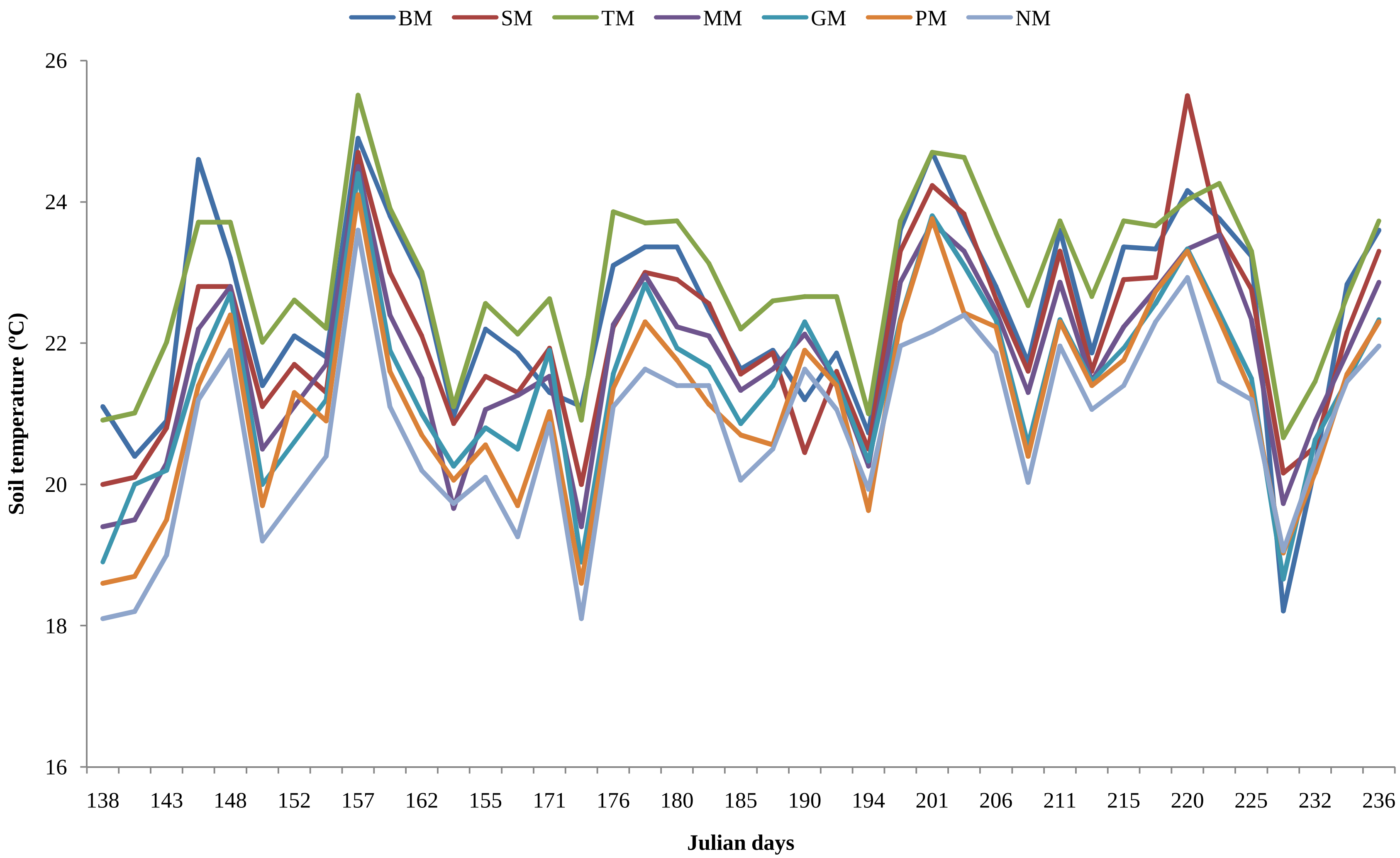

Fig 4.5: Effect of mulches on minimum soil temperature at 15 cm depth in year 2017

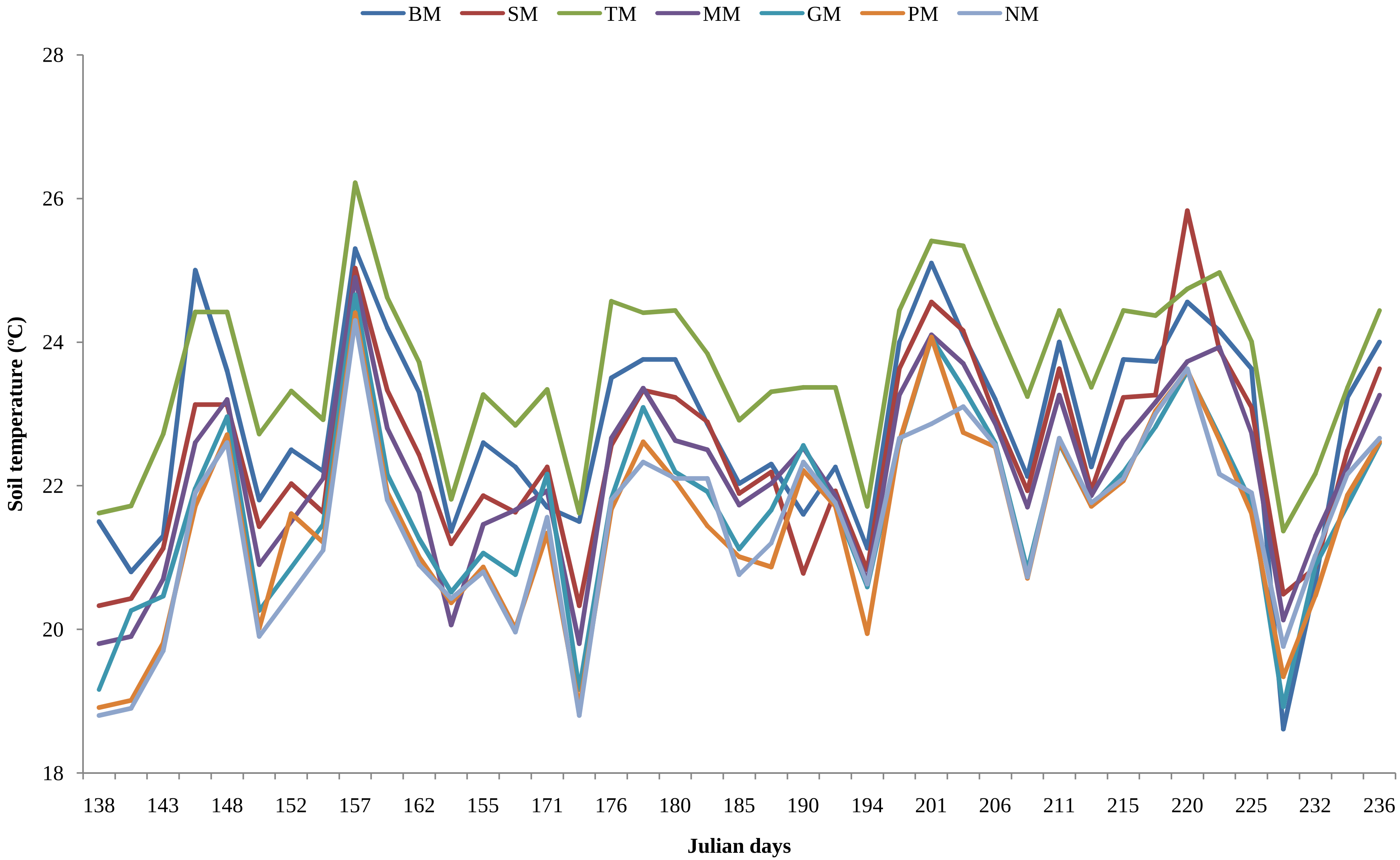

Fig 4.6: Effect of mulches on minimum soil temperature at 30 cm depth in year 2017

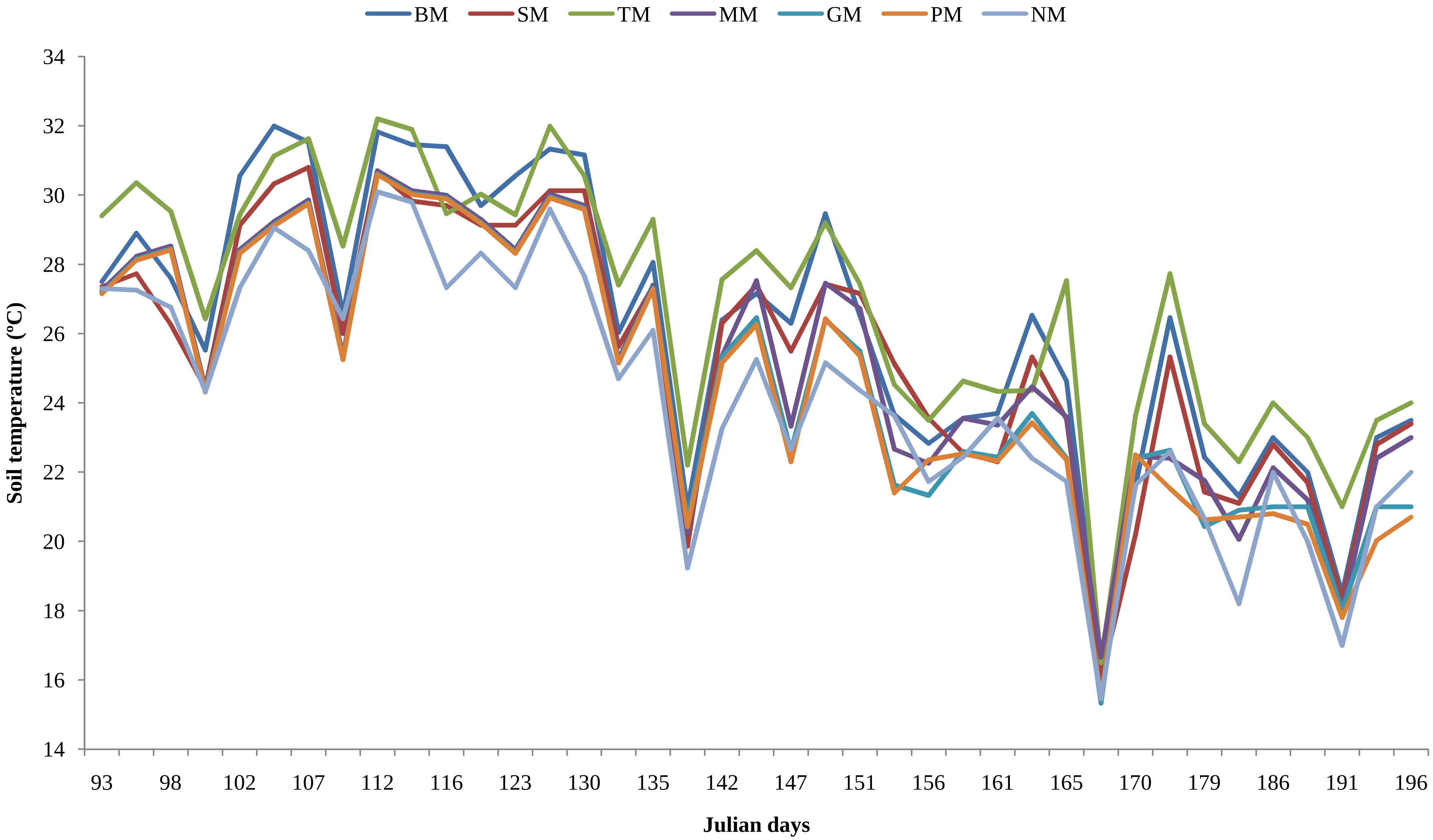

Fig 4.7: Effect of mulches on minimum soil temperature at 15 cm depth in year 2018

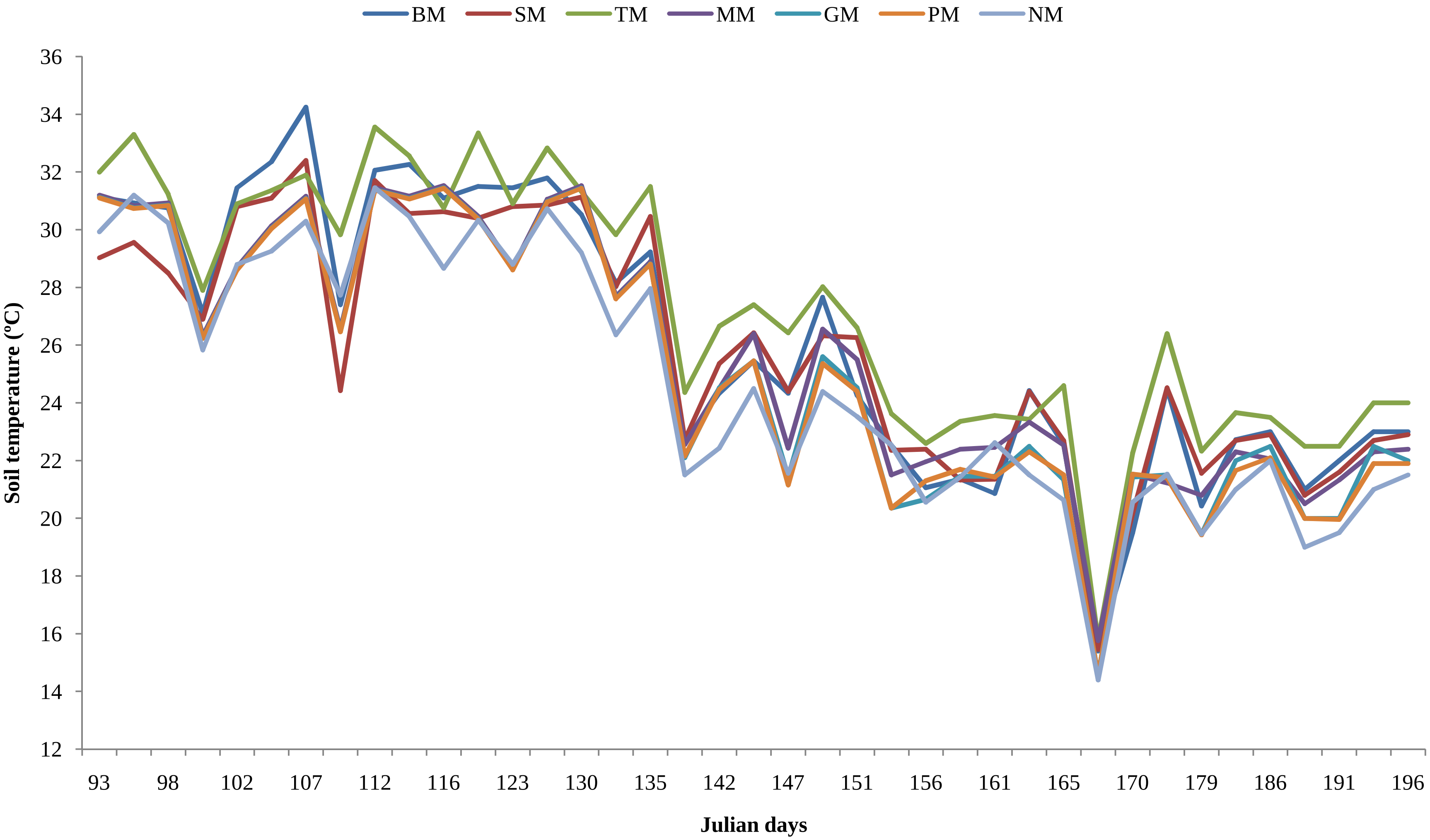

Fig 4.8: Effect of mulches on minimum soil temperature at 30 cm depth in year 2018

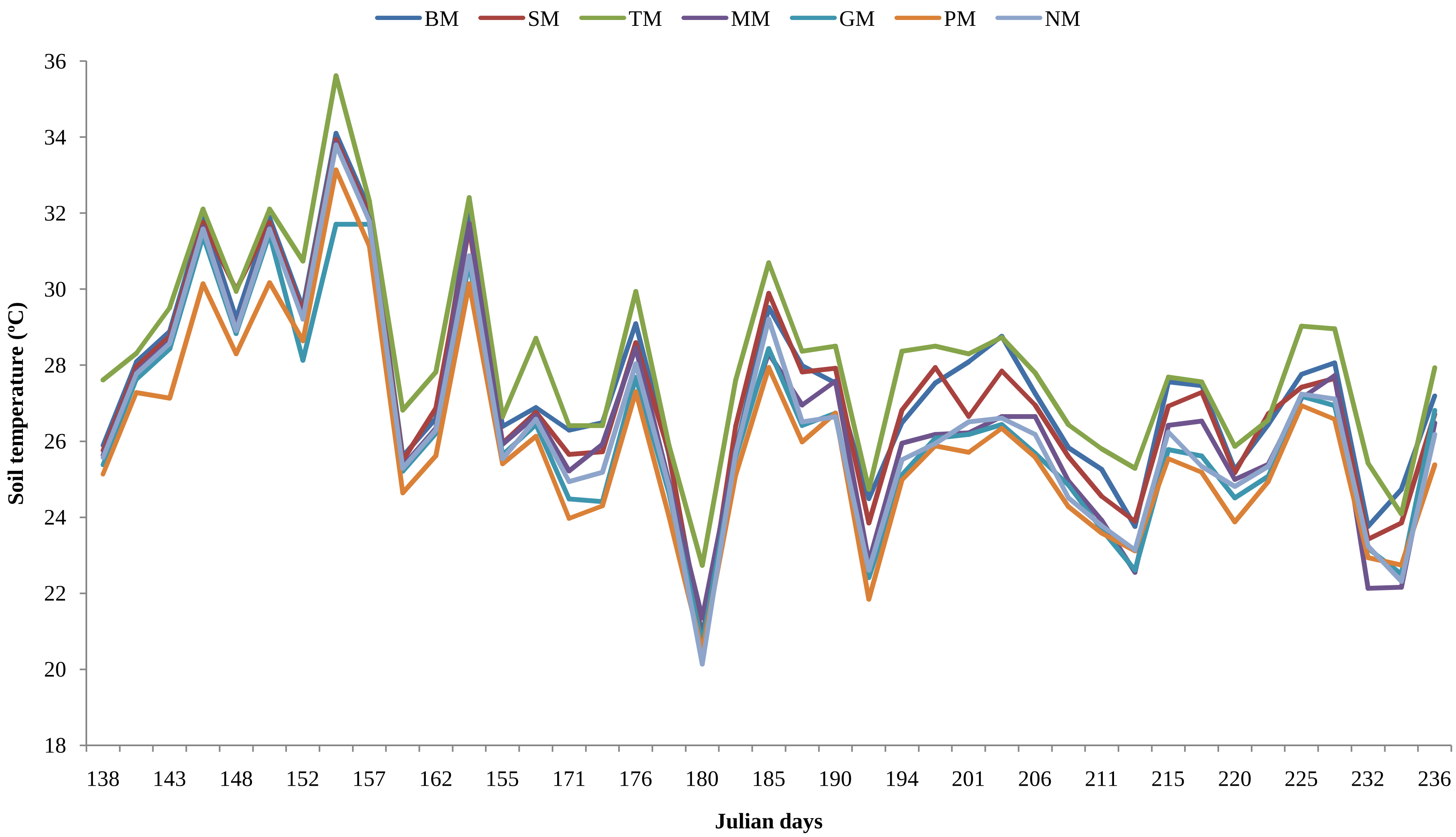

Fig 4.9: Effect of mulches on maximum soil temperature at 15 cm depth in year 2017

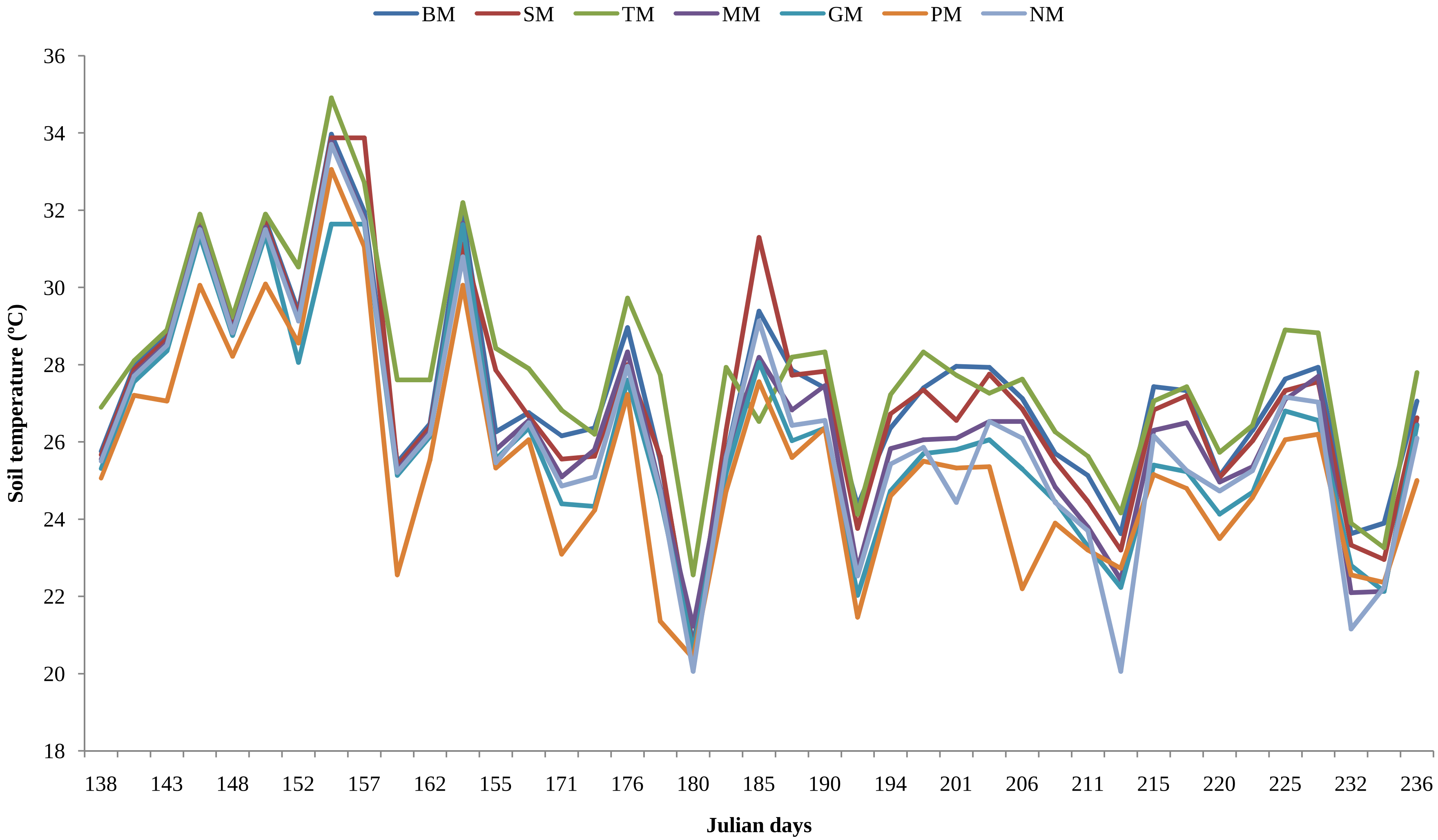

Fig 4.10: Effect of mulches on maximum soil temperature at 30 cm depth in year 2017

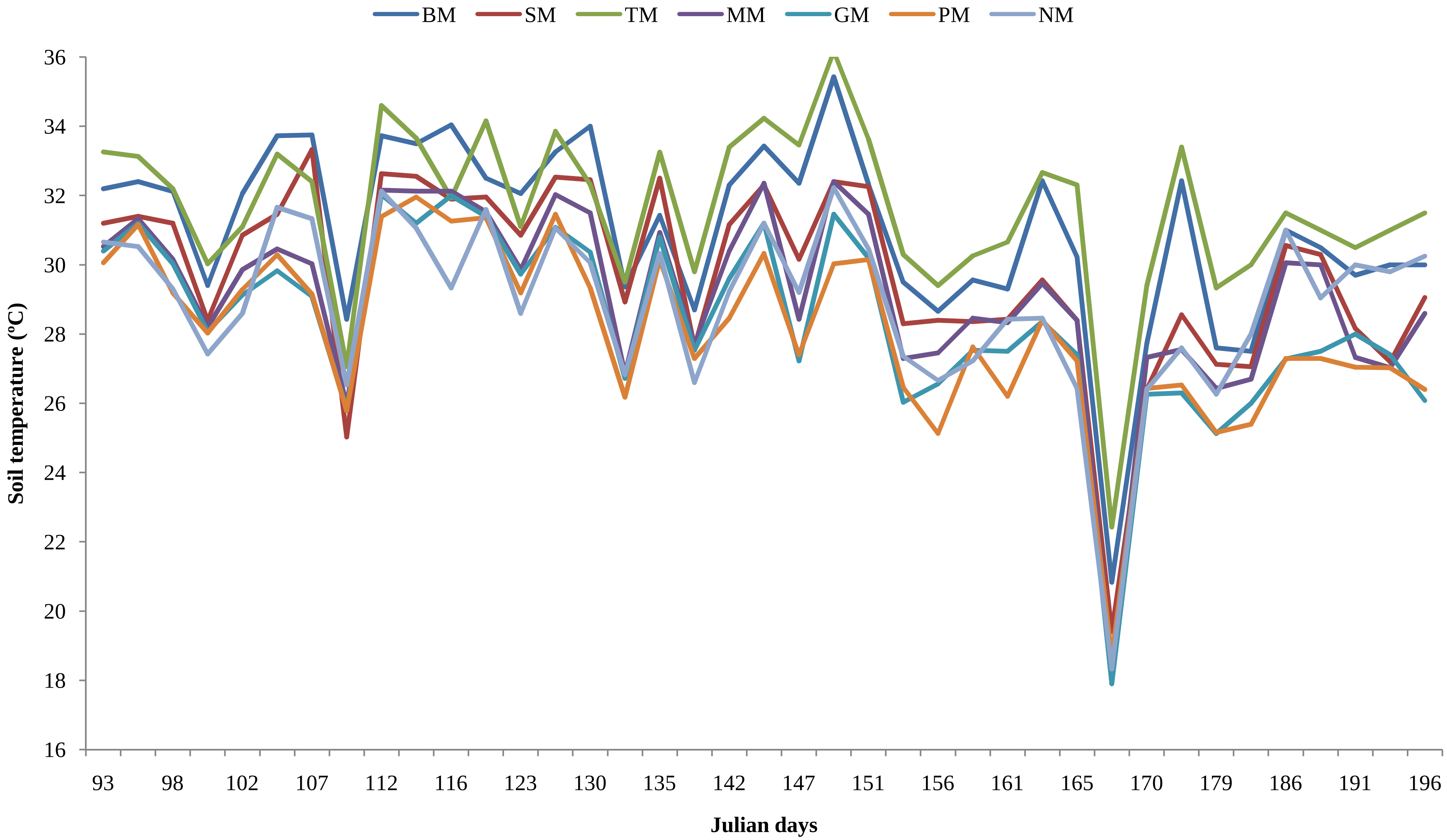

Fig 4.11: Effect of mulches on maximum soil temperature at 15 cm depth in year 2018

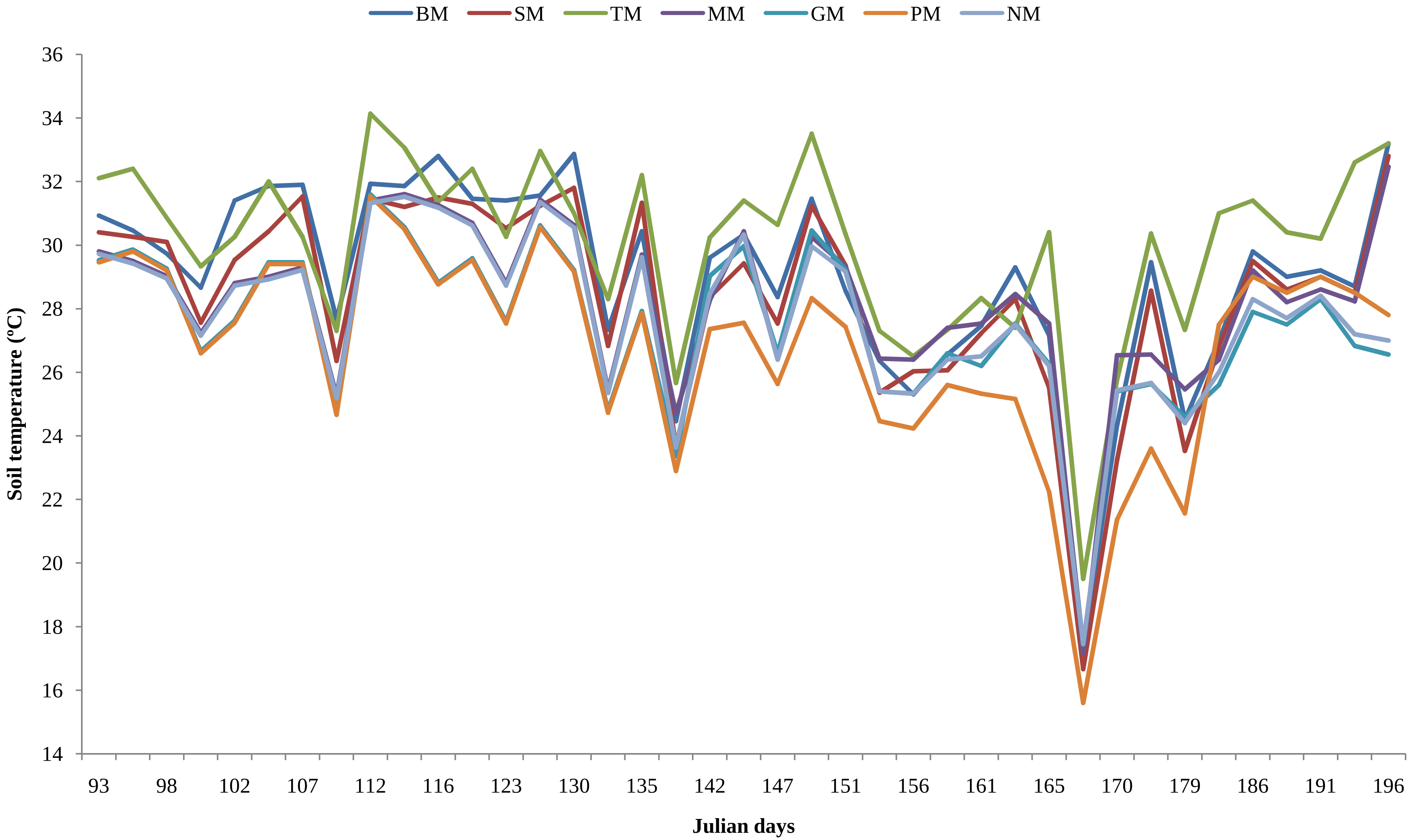

Fig 4.12: Effect of mulches on maximum soil temperature at 30 cm depth in year 2018

respectively as compared to T_7-NM i.e. control in year 2017. The corresponding values were 2.71, 2.11, 0.85, 0.26 $^{\circ}$C and 2.32, 1.32, 0.72, 0.53°C in year 2018. However, the maximum soil temperature was decreased (0.21 and 0.56°C) at 15 cm depth and (0.17 and 0.78°C) at 30 cm depth under T_5-GM and T_6-PM, respectively as compared to control and subsurface soil layers, respectively in year 2017. The corresponding values were 0.29 and 0.91°C in year 2018.

The observations of maximum soil temperature data revealed that soil temperature recorded under different mulch treatment follows order as transparent mulch > black mulch > silver mulch > mulch mat > no mulch > grass mulch > pine needle mulch for both soil depths (15 and 30 cm) during both the years (2017 and 2018) of study.

Soil temperature at both 15 and 30 cm depths was markedly influenced by various mulch materials during both the years of study. Increase in minimum and maximum soil temperatures under transparent mulch is attributed to its greenhouse effect (Hanks *et al.* 1961, Mahrer *et al*. 1984). It has been reported that transparent polyethylene mulch permits the incoming short wave radiation to pass through but its transmissivity to long wave radiation is highly reduced due to formation of water droplets on its lower surface. Black polyethylene mulch also influenced the minimum and maximum soil temperatures. This may be attributed to the fact that black polyethylene mulch absorbs much of the incident radiation due to its black colour but transmits less energy to the soil surface owing to bad conducting air between the black polyethylene and the soil surface. The increase in the minimum soil temperature under organic mulch may be due to the reduction in negative heat flux from soil. Organic mulch decreases maximum soil temperature, which may be due to higher albedo value partially due to greater conversion of solar energy into evaporative flux and increase in diffusion path of heat transfer to the soil. Similar observations have been also reported by Gupta and Acharya (1993), Sharma and Kathiravan (2009), Ashrafuzzaman *et al.* (2011), Moursy *et al.* (2015) and Abhivyakti *et.al* (2016).

4.3 Effect of mulches on soil physical properties

4.3.1 Particle density

The data on soil particle density presented in Table 4.1 showed non-significant effect of mulch on particle density of soil at 0-15 and 15-30 cm depths during both the years of study. Analysis of pooled data revealed that at 0-15 cm depth, the highest particle density (2.65 Mg m^{-3}) was recorded under T_5-GM and the lowest (2.51 Mg m^{-3}) under T_7-NM.

Similar trend was also found at 15-30 cm depth i.e. the highest particle density (2.65 Mg m^{-3}) was recorded under T_5-GM and the lowest (2.51 Mg m^{-3}) under T_7-NM. Analysis of pooled data showed that effects of treatment (T), year (Y) and their interaction (T×Y) on particle density of soil were non-significant at surface (0-15 cm depth) and sub-surface (15-30 cm depth) layers.

Table 4.1: Effect of mulches on particle density

Treatments	Particle density (Mg m^{-3})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	2.57	2.61	2.59	2.58	2.62	2.60
T_2 (SM)	2.52	2.55	2.53	2.53	2.59	2.56
T_3 (TM)	2.57	2.59	2.58	2.55	2.59	2.57
T_4 (MM)	2.59	2.61	2.60	2.59	2.63	2.61
T_5 (GM)	2.61	2.68	2.65	2.63	2.66	2.65
T_6 (PM)	2.59	2.65	2.62	2.62	2.63	2.63
T_7 (NM)	2.50	2.52	2.51	2.50	2.52	2.51
Mean	2.56	2.60		2.57	2.61	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

4.3.2 Bulk density

An inquisition of data cited in Table 4.2 showed non-significant effect of mulch on bulk density of soil at both surface and sub-surface soil layers during both the years of study. Analysis of pooled data revealed that at 0-15 cm depth, the highest bulk density (1.31 Mg m^{-3}) was recorded under T_7-NM and the lowest (1.27 Mg m^{-3}) under T_6-PM. At 15-30 cm depth, the highest bulk density (1.34 Mg m^{-3}) was recorded under T_7-NM and the lowest under T_6-PM and T_5-GM with value (1.29 Mg m^{-3}). An examination of the pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on bulk density of soil were non-significant at 0-15 and 15-30 cm depths.

The lower bulk density was recorded under organic mulches followed by polyethylene mulch and the highest under no mulch treatment at 0-15 and 15-30 cm during both years of the experiment. The change in bulk density under grass and pine needle mulches could be ascribed to addition of organic matter under the treatments of organic mulches. The reduction in bulk density of the soil might be due to the loosening of soil due to decomposition of organic mulches resulting in top soil becoming more friable (Acharya and Sharma, 1994). Mulch prevented the compaction of soil surface as compared to the unmulched treatment. Increased bulk density under no-mulched treatment may be due to compaction of surface soil which had a deleterious effect on crop growth. Lower bulk density under mulched treatments over without mulched treatment has also been reported by Lal (1978), Lal *et al*. (1980), Kathiravan (2007) and Sharma and Kumar (2014).

Table 4.2: Effect of mulches on bulk density

Treatments	Bulk density (Mg m^{-3})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	1.29	1.28	1.29	1.30	1.32	1.31
T_2 (SM)	1.30	1.31	1.30	1.32	1.34	1.33
T_3 (TM)	1.30	1.29	1.30	1.31	1.32	1.32
T_4 (MM)	1.29	1.28	1.29	1.30	1.31	1.30
T_5 (GM)	1.27	1.28	1.28	1.29	1.30	1.29
T_6 (PM)	1.26	1.28	1.27	1.28	1.29	1.29
T_7 (NM)	1.31	1.31	1.31	1.33	1.35	1.34
Mean	1.29	1.29		1.30	1.32	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

4.3.3 Porosity

The analysis of data in Table 4.3 reveals that effect of mulches on soil porosity was significant at surface and sub-surface soil depths during both years of the experiment. At surface layer, the highest porosity of 51.39 and 52.10 per cent was recorded under treatment T_5-GM and the lowest values of 47.39 and 48.02 under T_7-NM in year 2017 and 2018, respectively. However, the highest porosity of 51.13 per cent under T_5-GM and 51.20 per cent under T_6-PM were recorded in year 2017 and 2018, respectively. The lowest porosity of 46.78 and 46.63 per cent was recorded under T_7-NM during year 2017 and 2018, respectively. Analysis of pooled data reported that at 0-15 cm depth, the highest porosity of 51.74 per cent was recorded under T_5-GM which at par with T_4-MM and T_6-PM and the lowest of 47.70 under T_7-NM which at par with T_2-SM. At 15-30 cm depth, highest porosity

51.15 per cent was recorded under T_5-GM which at par with T_6-PM, T_4-MM and the lowest of 46.71 per cent under T_7-NM which at par with T_2-SM. Analysis of pooled data revealed that the effect of treatments (T) on porosity was found to be significant at surface and sub-surface soil layers. However, the effect of year (Y) and their interaction (T×Y) were found to be non significant at both soil depths.

The higher porosity was recorded under organic mulches followed by inorganic mulches and the lowest under no mulch. Higher porosity under mulched treatments may be due to higher organic carbon content, lower bulk density and improved soil aggregation under mulched treatments over the un-mulched treatments. These results are in line with those of Sharma *et al*. (1992), Chaudhari *et al*. (2013), Kathiravan (2007) and Nwokocha *et al*. (2007).

Table 4.3: Effect of mulches on porosity

Treatments	**Porosity (%)**					
	0-15 cm			**15-30 cm**		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
T_1 (BM)	49.73	50.62	50.18	49.41	49.80	49.61
T_2 (SM)	48.20	48.75	48.48	47.60	48.18	47.89
T_3 (TM)	49.34	50.03	49.69	48.94	48.95	48.95
T_4 (MM)	50.23	50.83	50.53	49.81	50.08	49.95
T_5 (GM)	51.39	52.10	51.74	51.13	51.18	51.15
T_6 (PM)	51.24	51.32	51.28	51.08	51.20	51.14
T_7 (NM)	47.39	48.02	47.70	46.78	46.63	46.71
Mean	49.65	50.24		49.25	49.43	
C.D $_{(0.05)}$	**1.80**	**1.83**		**2.76**	**1.95**	
T	**1.30**			**1.54**		
Y	**NS**			**NS**		
T×Y	**NS**			**NS**		

4.3.4 Saturated hydraulic conductivity

A scrutiny of data presented in Table 4.4 showed non-significant effect of mulches on saturated hydraulic conductivity at 0-15 and 15-30 cm soil depths during the experimental period. The saturated hydraulic conductivity in mulched treatments was found to be higher than no mulch treatment at 0-15 and 15-30 cm soil depths during both the years of study. An examination of the pooled data showed that the highest values of saturated hydraulic conductivity of 4.24 cm hr^{-1} and 4.26 cm hr^{-1} were recorded under T_5-GM and the lowest values of 3.98 cm hr^{-1} and 3.90 cm hr^{-1} under T_7-NM at surface and sub-surface soil layers, respectively. Analysis of pooled data revealed that the effect of treatments (T) on saturated hydraulic conductivity was found to be significant at surface and sub-surface soil layers. However, the effect of year (Y) and their interaction (T×Y) were found to be non significant at both soil depths.

The higher values of saturated hydraulic conductivity under mulched treatments may be due to improvement in the soil aggregation and porosity in comparison with no mulch treatment, which in turn led to significant improvement in the saturated hydraulic conductivity. Higher saturated hydraulic conductivity under mulched treatments has also been reported by Bhagat and Acharya (1987) and Zhang *et al.* (2008).

Table 4.4: Effect of mulches on saturated hydraulic conductivity

Treatments	Saturated hydraulic conductivity (cm hr^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	4.17	4.11	4.14	4.08	4.07	4.08
T_2 (SM)	4.04	3.96	4.00	3.93	3.88	3.91
T_3 (TM)	4.15	4.12	4.14	4.10	4.06	4.08
T_4 (MM)	4.17	4.18	4.17	4.18	4.12	4.15
T_5 (GM)	4.26	4.21	4.24	4.32	4.19	4.26
T_6 (PM)	4.19	4.17	4.18	4.13	4.16	4.15
T_7 (NM)	3.99	3.98	3.98	3.92	3.88	3.90
Mean	4.14	4.10		4.10	4.05	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	0.17			0.21		
Y	NS			NS		
T×Y	NS			NS		

4.3.5 Aggregate stability

The data perusal in Table 4.5 showed significant effect of mulches on water stable aggregates (WSA) at both soil depths during both the experimental years. In year 2017, significantly highest value of WSA (64.97 and 59.33%) under T_5-GM and the lowest values (60.94 and 56.26%) under T_7-NM at 0-15 and 15-30 cm, respectively were observed. The similar trend was also observed in year 2018. An examination of the pooled data at 0-15 cm depth, the highest value of WSA (64.61%) was recorded under T_5-GM which was statistically at par with T_6-PM (64.07%) and the lowest (61.22%) value was recorded under T_7-NM which at par with T_2-SM (61.85 %). At 15-30 cm depth, the highest value of WSA (59.34%) was recorded under T_5-GM which statistically at par with T_6-PM (58.76%) and T_4-MM (58.34%). The lowest value (56.26%) recorded under T_7-NM which was statistically at par with T_2-SM (56.56%) and T_3-TM (57.23%). Analysis of pooled data revealed that the effect of treatments (T) on water stable aggregates was found to be significant at 0-15 and 15-30 cm depths. However, the effect of year (Y) and their interaction (T×Y) were found to be non significant at both soil depths.

Table 4.5: Effect of mulches on aggregate stability

Treatments	Percent aggregate stability (WSA > 0.25)					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	63.00	62.86	62.93	57.83	57.91	57.87
T_2 (SM)	61.95	61.76	61.85	56.70	56.41	56.56
T_3 (TM)	62.89	62.10	62.50	56.91	57.54	57.23
T_4 (MM)	63.64	63.15	63.40	58.31	58.36	58.34
T_5 (GM)	64.97	64.26	64.61	59.33	59.35	59.34
T_6 (PM)	64.31	63.82	64.07	58.72	58.81	58.76
T_7 (NM)	60.94	61.49	61.22	56.26	56.26	56.26
Mean	63.10	62.78		57.72	57.81	
C.D $_{(0.05)}$	**1.03**	**1.00**		**1.97**	**1.41**	
T	**0.66**			**1.21**		
Y	**NS**			**NS**		
T×Y	**NS**			**NS**		

4.3.6 Mean weight diameter

An inquisition of data cited in Table 4.6 showed non-significant effect of mulch on mean weight diameter (MWD) at 0-15 and 15-30 cm depths during both the years of study. Analysis of pooled data revealed that the highest values of 2.22 mm and 2.19 mm were recorded under T_5-GM and the lowest values of 2.10 mm and 2.11 mm under T_1-BM recorded at 0-15 and 15-30 cm depth, respectively. Analysis of pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on MWD were non-significant at both surface and sub-surface soil layers.

The higher water stable aggregates and MWD under mulched treatments could be ascribed to reduction in the rapid drying up of the soil after rains and greater biological activities. The beneficial effect of mulches in improving soil aggregation was also reported by Gupta and Acharya (1993).

Table 4.6: Effect of mulches on mean weight diameter

Treatments	Mean weight diameter (mm)					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	2.11	2.08	2.10	2.11	2.10	2.11
T_2 (SM)	2.09	2.16	2.13	2.14	2.18	2.16
T_3 (TM)	2.10	2.11	2.11	2.12	2.12	2.12
T_4 (MM)	2.12	2.13	2.13	2.15	2.15	2.15
T_5 (GM)	2.22	2.21	2.22	2.23	2.14	2.19
T_6 (PM)	2.16	2.08	2.12	2.19	2.12	2.15
T_7 (NM)	2.08	2.25	2.17	2.07	2.24	2.16
Mean	2.13	2.15		2.15	2.15	
C.D $_{(0.05)}$	**NS**	**NS**		**NS**	**NS**	
T	**NS**			**NS**		
Y	**NS**			**NS**		
T×Y	**NS**			**NS**		

4.3.7 Maximum water holding capacity

Appraisal of data in Table 4.7 indicates that mulch had non-significant effect on maximum water holding capacity (MWHC) of soil at both surface and sub-surface soil layers during both the years of study. The maximum values of MWHC were recorded under inorganic mulched treatments followed by organic mulched treatments and minimum in no mulch treatment. Analysis of pooled data revealed that the highest values of 43.49 and 43.30 per cent under T_5-GM and the lowest values of 39.43 and 39.37 per cent under T_7-NM were observed at surface and subsurface layers of soil, respectively. Analysis of pooled data revealed that the effect of treatments (T) on MWHC was found to be significant at both 0-15 and 15-30 cm soil depths. However, the effect of year (Y) and their interaction (T×Y) were found to be non significant at both soil depths.

Table 4.7: Effect of mulches on maximum water holding capacity

Treatments	Maximum water holding capacity (w/w,%)					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	41.97	42.19	42.08	41.64	41.43	41.54
T_2 (SM)	39.95	39.77	39.86	40.83	41.11	40.97
T_3 (TM)	41.33	39.77	40.55	41.40	40.56	40.98
T_4 (MM)	43.14	42.44	42.79	42.56	41.85	42.21
T_5 (GM)	43.76	43.23	43.49	44.27	42.32	43.30
T_6 (PM)	43.40	42.34	42.87	43.27	42.85	43.06
T_7 (NM)	39.45	39.40	39.43	39.68	39.06	39.37
Mean	41.86	41.30		41.95	41.31	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	2.65			2.35		
Y	NS			NS		
T×Y	NS			NS		

Highest MWHC was recorded under grass mulch and pine needle mulch which may be due to the addition of organic matter and lower bulk density due to enhanced biological activities of soil fauna. These results are in line with those of Ramesh *et al.* (2008) and Pandey *et al*. (2016).

4.3.8 Field capacity and permanent wilting point

4.3.8.1 Field capacity

The data in the Table 4.8 indicate that mulch had significant effect on field capacity of soil at both 0-15 and 15-30 cm depths during both the years of study. In year 2017, significantly highest values of field capacity (24.84 and 24.10 w/w,%) under T_5-GM and the lowest values (19.20 and 18.87 w/w,%) under T_7-NM at 0-15 and 15-30 cm soil depth, respectively were observed. The similar trend was also observed in year 2018. An examination of the pooled data showed that the highest values of field capacity (24.67 and 23.78 w/w,%) were recorded under T_5-GM which statistically at par with T_6-PM and the lowest values (19.57 and 18.83 w/w,%) recorded under T_7-NM which were at par with T_2-SM at both 0-15 and at 15-30 cm soil depths, respectively.

Analysis of pooled data revealed that the effect of treatment (T) on field capacity was to be significant at surface soil layer. However, the effect of year (Y) and their interaction (T×Y) were found to be non significant at surface layer. In subsurface layer, the effect of treatment (T) and year (Y) were significant and their interaction (T×Y) was found to be non-significant.

Table 4.8: Effect of mulches on field capacity and permanent wilting point

Treatment	Field capacity (w/w,%)						Permanent wilting Point (w/w,%)					
	0-15 cm			15-30 cm			0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	22.33	22.57	22.45	21.87	21.13	21.50	7.63	7.10	7.37	7.47	6.97	7.22
T_2 (SM)	20.40	20.77	20.58	20.07	19.73	19.90	6.87	6.37	6.62	6.73	6.13	6.43
T_3 (TM)	21.17	21.67	21.42	20.87	20.20	20.53	7.33	6.70	7.02	7.17	6.47	6.82
T_4 (MM)	23.13	23.10	23.12	22.77	21.93	22.35	7.87	7.43	7.65	7.83	7.40	7.62
T_5 (GM)	24.84	24.50	24.67	24.10	23.47	23.78	8.41	8.03	8.22	8.30	8.00	8.15
T_6 (PM)	23.90	24.03	23.97	23.33	22.90	23.12	8.27	7.80	8.03	8.07	7.77	7.92
T_7 (NM)	19.20	19.93	19.57	18.87	18.80	18.83	6.27	6.00	6.13	6.17	5.83	6.00
Mean	22.14	22.37		21.70	21.17		7.52	7.06		7.39	6.94	
C.D $_{(0.05)}$	**1.27**	**1.85**		**1.15**	**1.28**		**0.47**	**0.61**		**0.49**	**0.38**	
T	**1.03**			**0.82**			**0.36**			**0.34**		
Y	**NS**			**0.38**			**0.16**			**0.16**		
T×Y	**NS**			**NS**			**NS**			**NS**		

4.3.8.2 Permanent wilting Point

The scrutiny of data presented in Table 4.8 showed that mulch had significant effect on permanent wilting point of soil at surface and sub-surface soil layers during both the experimental years. In year 2017, significantly highest values of permanent wilting point (8.41 and 8.30 w/w,%) under T_5-GM and the lowest values (6.27 and 6.17 w/w,%) under T_7-NM at 0-15 and 15-30 cm, respectively were observed. The similar trend was also observed in year 2018. Analysis of pooled data revealed that the highest values of permanent wilting point (8.22 and 8.15 w/w,%) were recorded under T_5-GM which statistically at par with T_6-PM and the lowest values (6.13 and 6.00 w/w,%) recorded under T_7-NM at 0-15 and 15-30 cm soil depths, respectively. The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on permanent wilting point were found to be significant at 0-15 and 15-30 cm soil depths. However, the effect of their interaction (T×Y) was found to be non significant at both soil depths.

The increase in field capacity and permanent wilting point of soil under different mulches may be due to reduced water and soil losses through surface run off. Organic mulches are capable of storing more water in the soil by reducing storm runoff, increasing soil infiltration and decreasing evaporation. Studies have also shown that higher amount of water is held at field capacity at lower bulk densities. An increase in the field capacity and permanent wilting point under mulched conditions has been reported by Kakaire *et al.* (2015).

4.3.8.3 Plant available water

Table 4.9: Effect of mulches on plant available water

Treatments	Plant available water (w/w,%)					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	14.70	15.47	15.08	14.40	14.17	14.28
T_2 (SM)	13.53	14.40	13.97	13.33	13.60	13.47
T_3 (TM)	13.83	14.97	14.40	13.70	13.73	13.72
T_4 (MM)	15.27	15.67	15.47	14.93	14.53	14.73
T_5 (GM)	16.43	16.47	16.45	15.80	15.47	15.63
T_6 (PM)	15.63	16.23	15.93	15.27	15.13	15.20
T_7 (NM)	12.93	13.93	13.43	12.70	12.97	12.83
Mean	14.62	15.30		14.30	14.23	
C.D $_{(0.05)}$	**1.02**	**1.59**		**1.36**	**1.33**	
T	**0.87**			**0.87**		
Y	**0.40**			**NS**		
T×Y	**NS**			**NS**		

Data presented in Table 4.9 indicate that mulch had significant effect on plant available water content of soil in 0-15 and 15-30 cm depths during both the years of study. In year 2017, significantly highest values of plant available water (16.43 and 15.80 w/w,%) under T_5-GM and the lowest values (12.93 and 12.70 w/w,%) under T_7-NM at 0-15 and 15-30 cm, respectively were observed. The similar trend was also observed in year 2018. Analysis of pooled data revealed that the highest values of (16.45 and 15.63 w/w,%) were recorded under T_5-GM which statistically at par with T_6-PM and the lowest (13.43 and 12.83 w/w,%) recorded under T_7-NM which at par with T_2-SM at 0-15 and 15-30 cm depths, respectively. Analysis of pooled data revealed that the effects of treatment (T) and year (Y) on plant available were significant at 0-15 cm depth. However, the effect of their interaction

(T×Y) was found to be non significant at 0-15 cm depth. At 15-30 cm depth, effect of treatment (T) was significant and effects of year (Y) and their interaction (T×Y) were non-significant.

Plant available water content increases under mulched treatments which may be due to mulch had the highest water retention on lower suction, and control had the lowest water retention on the high suction. Soil water availability was highest in organic mulch type followed by poly mulch type and lowest in control. These results could be concluded that continuous incorporation of organic matter was useful in increasing soil water retention. The results are in accordance with the finding of Rasyid *et al*. (2018), who studied changes in soil water retention under different mulches.

4.4 Effect of mulches on chemical properties of soil

4.4.1 Soil pH

Table 4.10: Effect of mulches on soil pH

Treatments	pH					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	6.46	6.55	6.51	6.60	6.53	6.57
T_2 (SM)	6.37	6.47	6.42	6.44	6.48	6.46
T_3 (TM)	6.65	6.56	6.60	6.61	6.51	6.56
T_4 (MM)	6.41	6.48	6.45	6.48	6.28	6.38
T_5 (GM)	6.49	6.54	6.51	6.62	6.39	6.50
T_6 (PM)	6.64	6.39	6.52	6.68	6.54	6.61
T_7 (NM)	6.26	6.49	6.37	6.49	6.49	6.49
Mean	6.47	6.50		6.56	6.46	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

A scrutiny of data presented in Table 4.10 indicates that mulch had non-significant effect on pH of soil at 0-15 and 15-30 cm depths during both years of the experiment. The soil pH was observed to be slightly acidic to neutral in reaction with values ranging from 6.26 - 6.68. An examination of the pooled data revealed that at 0-15 cm soil depth, the highest pH (6.60) was recorded under T_3-TM and the lowest (6.37) under T_7-NM. At 15-30 cm soil depth, the highest pH (6.61) was recorded under T_6-PM and the lowest (6.38) under T_4-MM. Analysis of pooled data showed that effects of treatment (T), year (Y) and their interaction (T×Y) on soil pH were non-significant at both surface and sub-surface depths.

Mulch treatments did not make any significant changes in soil pH. These findings are in line with those of Niggli *et al*. (1990), who also observed no appreciable changes in soil pH under mulched treatments.

4.4.2 Electrical conductivity

Table 4.11: Effect of mulches on electrical conductivity of soil

Treatments	EC (d Sm^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	0.29	0.31	0.30	0.25	0.24	0.24
T_2 (SM)	0.26	0.28	0.27	0.28	0.29	0.28
T_3 (TM)	0.31	0.26	0.28	0.23	0.24	0.24
T_4 (MM)	0.24	0.23	0.24	0.24	0.24	0.24
T_5 (GM)	0.21	0.25	0.23	0.24	0.25	0.25
T_6 (PM)	0.25	0.31	0.28	0.32	0.31	0.32
T_7 (NM)	0.24	0.25	0.24	0.22	0.24	0.23
Mean	0.26	0.27		0.25	0.26	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

The data enumerated in Table 4.11 showed non-significant effect of mulch on electrical conductivity of soil at surface and sub-surface layers during both the years of study. An examination of the pooled data revealed that at 0-15 cm depth, the highest EC (0.30 d Sm^{-1}) was recorded under T_1-BM and the lowest (0.23 d Sm^{-1}) under T_5-GM. In 15-30 cm depth, the highest EC (0.32 d Sm^{-1}) was recorded under T_6-PM and the lowest (0.23 d Sm^{-1}) under T_7-NM. Analysis of pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on soil EC were non-significant at surface and sub-surface soil layers.

4.4.3 Organic carbon

Table 4.12: Effect of mulches on soil organic carbon

Treatments	Organic carbon (g kg^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	17.95	18.55	18.25	16.75	17.55	17.15
T_2 (SM)	17.35	17.55	17.45	16.45	16.95	16.70
T_3 (TM)	17.15	17.60	17.38	16.25	16.55	16.40
T_4 (MM)	18.05	18.75	18.40	17.15	17.85	17.50
T_5 (GM)	20.20	20.50	20.35	17.90	18.80	18.35
T_6 (PM)	18.92	19.70	19.31	17.50	18.20	17.85
T_7 (NM)	17.08	17.60	17.34	16.68	16.88	16.78
Mean	18.10	18.61		16.95	17.54	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	2.03			NS		
Y	NS			NS		
T×Y	NS			NS		

The data on soil organic carbon in Table 4.12 showed non-significant effect of mulch on soil organic carbon content at 0-15 and 15-30 cm depths during both the year of study. Analysis of pooled data revealed that the highest values of organic carbon (20.35 and 18.35 g kg^{-1}) were recorded under T_5-GM and the lowest values (17.34 and 16.78 g kg^{-1}) under T_7-NM. Analysis of pooled data revealed that the effect of treatment (T) on organic carbon was significant at surface soil layer. However, the effects of year (Y) and their interaction (T×Y) were found to be non significant at 0-15 cm depth. At 15-30 cm depth, effects of treatment (T), year (Y) and their interaction (T×Y) were non-significant.

Highest soil organic matter was observed under mulches which may be attributed to the decomposition and mixing of mulch materials. An increase in the soil organic carbon in mulch has been reported by Marinari *et al.* (2010), Sharma and Kumar (2014) and Pandey *et al*. (2016).

4.4.4 Available N

It is evident from Table 4.13 that available N content in soil was significantly influenced by mulch at surface and sub-surface soil layers during both the years of study. The soil under various mulches was found under medium range of available N. In year 2017, significantly highest values of available N (371.1 and 359.6 kg ha^{-1}) under T_1-BM and the lowest values (343.9 and 332.4 kg ha^{-1}) under T_7-NM were observed at 0-15 and 15-30 cm, respectively. The similar trend was also observed during year 2018.

Table 4.13: Effect of mulches on available nitrogen in soil

Treatments	Available N (kg ha^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	371.1	377.4	374.2	359.6	366.9	363.3
T_2 (SM)	365.9	371.1	368.5	350.5	354.4	352.4
T_3 (TM)	351.2	358.5	354.9	340.8	347.1	343.9
T_4 (MM)	355.4	362.7	359.1	343.9	349.1	346.5
T_5 (GM)	363.8	366.9	365.3	354.4	359.6	357.0
T_6 (PM)	358.5	363.8	361.2	356.5	361.7	359.1
T_7 (NM)	343.9	350.2	347.1	332.4	342.9	337.6
Mean	358.5	364.4		348.3	354.5	
C.D $_{(0.05)}$	**6.19**	**6.33**		**5.33**	**5.65**	
T	**4.44**			**3.94**		
Y	**2.06**			**1.83**		
T×Y	**NS**			**NS**		

Analysis of pooled data assessed that at 0-15 cm soil depth, the highest available N (374.2 kg ha^{-1}) was recorded under T_1-BM followed by T_2-SM and the lowest (347.1 kg ha^{-1}) under T_7-NM while, at 15-30 cm depth, the highest available N (363.3 kg ha^{-1}) was recorded under T_1-BM followed by T_6-PM and the lowest (337.6 kg ha^{-1}) under T_7-NM. The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on available N were found to be significant at 0-15 cm and 15-30 cm depths. However, the effect of their interaction (T×Y) was found to be non significant at both the depths.

4.4.5 Available P

Scrutiny of data on available P in Table 4.14 showed the significant difference with regards to different mulches during both the years of study. Availability of P increased under all mulch treatments over no mulch at 0-15 and 15-30 cm soil depths. In year 2017, significantly highest values of available P (70.09 and 62.75 kg ha^{-1}) under T_1-BM and the lowest values (52.69 and 49.17 kg ha^{-1}) under T_7-NM were observed at 0-15 and 15-30 cm, respectively. The similar trend was also observed in year 2018.

Table 4.14: Effect of mulches on available phosphorus in soil

Treatments	Available P (kg ha^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	70.09	73.97	72.03	62.75	67.20	64.97
T_2 (SM)	61.83	67.79	64.81	57.76	60.12	58.94
T_3 (TM)	53.38	57.50	55.44	49.72	53.54	51.63
T_4 (MM)	54.85	59.72	57.29	57.76	60.71	59.24
T_5 (GM)	56.25	62.70	59.48	52.29	57.17	54.73
T_6 (PM)	56.40	64.12	60.26	50.21	53.74	51.98
T_7 (NM)	52.69	57.35	55.02	49.17	52.98	51.08
Mean	57.93	63.31		54.24	57.92	
C.D $_{(0.05)}$	**4.61**	**4.90**		**4.43**	**4.33**	
T Y T×Y	**1.45** **3.13** **NS**			**2.88** **1.33** **NS**		

Analysis of pooled data observed that at 0-15 cm soil depth, the highest available P (72.03 kg ha^{-1}) was recorded under T_1-BM and the lowest (55.02 kg ha^{-1}) under T_7-NM which statistically at par with T_3-TM. At 15-30 cm depth, the highest available P (64.97 kg ha^{-1}) was recorded under T_1-BM and the lowest (51.08 kg ha^{-1}) under T_7-NM which statistically at par with T_6-PM and T_3-TM. The analysis of pooled data showed that the effects of treatments (T) and year (Y) on available P were found to be significant at 0-15 and 15-30 cm soil depths. However, the effect of their interaction (T×Y) was found to be non significant at both the depths.

4.4.6 Available K

Scrutiny of data on available K in Table 4.15 revealed the significant differences with regards to different mulches. In year 2017, significantly highest values of available K (369.2 and 356.2 kg ha^{-1}) under T_1-BM and the lowest values (342.3 and 318.1 kg ha^{-1}) under T_7-NM were observed at 0-15 and 15-30 cm, respectively. The similar trend was also observed in year 2018.

Analysis of pooled data showed that at 0-15 cm soil depth, the highest available K (371.8 kg ha^{-1}) was recorded under T_1-BM which statistically at par with T_2-SM and the lowest (345.0 kg ha^{-1}) under T_7-NM. At 15-30 cm depth, the highest available K (358.8 kg ha^{-1}) was recorded under T_1-BM and the lowest (322.7 kg ha^{-1}) under T_7-NM. The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on available P were found to be significant at 0-15 and 15-30 cm soil depths. However, the effect of their interaction (T×Y) was found to be non significant at both depths.

Table 4.15: Effect of mulches on available potassium in soil

Treatments	Available K (kg ha^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	369.2	374.5	371.8	356.2	361.4	358.8
T_2 (SM)	367.0	373.0	370.0	351.3	357.7	354.5
T_3 (TM)	356.9	361.0	358.9	348.7	354.7	351.7
T_4 (MM)	355.0	358.4	356.7	344.6	351.3	347.9
T_5 (GM)	357.3	366.6	361.9	347.6	347.6	347.6
T_6 (PM)	352.1	356.5	354.3	331.5	341.6	336.6
T_7 (NM)	342.3	347.6	345.0	318.1	327.4	322.7
Mean	357.1	362.5		342.6	348.8	
C.D $_{(0.05)}$	**6.72**	**6.84**		**6.45**	**6.38**	
T	**4.49**			**4.76**		
Y	**2.08**			**2.20**		
T×Y	**NS**			**NS**		

The availability of macro nutrients (N, P and K) in soil was significantly higher under all mulch treatments over no mulch. The increase in the availability of these nutrients was higher under black polyethylene mulch and silver polyethylene mulch which may be attributed to the efficient weed control (except transparent polyethylene mulch) and better hydro-thermal regimes. The increased availability of nutrient under organic mulches is due to higher organic matter content in organic mulches. The increase in available macro nutrients under black polythene is in line with the findings of Gupta and Acharya (1993), Sharma and Kumar (2015), Pandey *et al.* (2016) and Kumar *et al.* (2017).

4.4.7 Exchangeable Ca

An inquisition of data in Table 4.16 clearly indicates that mulch had non-significant effect on exchangeable calcium content in soil at 0-15 and 15-30 cm depths during both the years of study. An examination of the pooled data revealed that the highest exchangeable calcium values [8.02 and 7.92 cmol (p^+) kg^{-1}] were recorded under T_1-BM while the lowest [7.45 and 7.27 cmol (p^+) kg^{-1}] under T_7-NM at surface and sub-surface soil layers, respectively. Analysis of pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on exchangeable calcium of soil were non-significant at both surface and sub-surface soil layers.

Table 4.16: Effect of mulches on exchangeable calcium in soil

Treatments	Exchangeable Ca [cmol (p^+) kg^{-1}]					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	8.13	7.90	8.02	7.97	7.87	7.92
T_2 (SM)	7.67	7.87	7.77	7.27	8.00	7.63
T_3 (TM)	7.80	7.70	7.75	7.67	7.60	7.63
T_4 (MM)	7.27	8.20	7.73	7.17	7.77	7.47
T_5 (GM)	7.67	7.73	7.70	6.97	7.77	7.37
T_6 (PM)	7.77	7.83	7.80	7.30	7.73	7.52
T_7 (NM)	7.57	7.33	7.45	7.43	7.10	7.27
Mean	7.70	7.80		7.40	7.69	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

Increase in the concentration of exchangeable Ca under mulched treatments could be due to more microbial activity which rendered organic fraction of Ca into available form (Mengal and Krikby 1987). Increase in the concentrations of available Ca under mulched treatments may be attributed to more available form and presence of Ca as a constituent element in single super phosphate (SSP). The findings are also similar to those of Verma (1989) and Kumar (2012).

4.4.8 Exchangeable Mg

The data enumerated in Table 4.17 indicate that mulch had non-significant effect on exchangeable magnesium content in soil at surface and sub-surface soil layers during both the years of study. Analysis of pooled data showed that the highest exchangeable magnesium values [3.48 cmol (p^+) kg^{-1}] and [3.12 cmol (p^+) kg^{-1}] were recorded under T_2-SM and T_5-GM while the lowest values [3.06 cmol (p^+) kg^{-1}] and [2.96 cmol (p^+) kg^{-1}] under T_7-NM and T_6-PM at 0-15 cm and 15-30 cm soil depths, respectively. Analysis of pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on exchangeable magnesium of soil were non-significant at 0-15 and 15-30 cm soil depths.

Table 4.17: Effect of mulches on exchangeable magnesium in soil

Treatments	Exchangeable Mg [cmol (p^+) kg^{-1}]					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	3.52	3.07	3.30	3.15	2.85	3.00
T_2 (SM)	3.43	3.52	3.48	3.04	3.11	3.08
T_3 (TM)	3.41	3.47	3.44	2.99	3.13	3.06
T_4 (MM)	3.34	3.55	3.45	2.94	3.00	2.97
T_5 (GM)	3.12	3.41	3.27	3.23	3.02	3.12
T_6 (PM)	3.08	3.24	3.16	2.71	3.20	2.96
T_7 (NM)	2.94	3.17	3.06	3.13	2.81	2.97
Mean	3.26	3.35		3.03	3.02	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

4.4.9 Available SO_4^{2-} S

An inquisition of data in Table 4.18 revealed that mulch had non-significant effect on SO_4^{2-}S content in soil at 0-15 and 15-30 cm depths during both the years of study. An examination of the pooled data revealed that the highest values of 62.71 kg ha^{-1} under T_1-BM and 60.67 kg ha^{-1} under T_6-PM were recorded at 0-15 and 15-30 cm soil depths, respectively while the lowest values of 56.35 kg ha^{-1} and 55.21 kg ha^{-1} under T_7-NM at were observed at 0-15 and 15-30 cm soil depths, respectively. Analysis of pooled data revealed that the effect of treatment (T) on SO_4^{2-}S was to be significant at surface soil layer. However, the effects of year (Y) and their interaction (T×Y) were found to be non significant at 0-15 cm depth. At 15-30 cm depth, effects of treatment (T) and year (Y) were significant and their interaction (T×Y) were non-significant.

Increase in the concentration of sulphur with applied mulch could be attributed to the additional supply made available by the use of single superphosphate as it has sulphur as constituent. The results are similar with the findings of research work carried out by Verma (1989) and Kumar (2012). Increase in the concentration of sulphate sulphur under mulched treatments could be due to more microbial activity which rendered organic fraction of sulphur into available form Mengal and Krikby (1987).

Table 4.18: Effect of mulch on sulphate sulphur in soil

Treatments	Sulphate sulphur (kg ha^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	62.08	63.33	62.71	58.96	57.71	58.33
T_2 (SM)	59.58	61.46	60.52	56.67	57.29	56.98
T_3 (TM)	58.13	58.96	58.54	56.04	57.71	56.88
T_4 (MM)	57.92	57.71	57.81	55.83	59.17	57.50
T_5 (GM)	61.04	61.25	61.15	57.50	58.33	57.92
T_6 (PM)	61.25	61.88	61.56	58.63	62.71	60.67
T_7 (NM)	57.71	55.00	56.35	54.38	56.04	55.21
Mean	59.67	59.94		56.86	58.42	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	3.25			2.22		
Y	NS			1.03		
T×Y	NS			NS		

4.4.10 Zinc

Table 4.19: Effect of mulches on available zinc in soil

Treatments	Available Zn (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	2.78	2.29	2.53	2.01	2.27	2.14
T_2 (SM)	2.27	2.47	2.37	2.01	1.94	1.97
T_3 (TM)	2.54	2.20	2.37	2.17	2.12	2.14
T_4 (MM)	2.70	2.57	2.64	2.42	2.27	2.35
T_5 (GM)	2.33	2.48	2.40	2.21	2.17	2.19
T_6 (PM)	2.61	2.25	2.43	1.98	2.01	2.00
T_7 (NM)	2.42	2.29	2.36	1.82	2.06	1.94
Mean	2.52	2.36		2.09	2.12	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

The data enumerated in Table 4.19 revealed that mulch had non-significant effect on zinc content in soil at surface and sub-surface soil layers during both the years of study. An examination of the pooled data showed that the highest zinc content value (2.64 and 2.35 mg kg^{-1}) were recorded under T_4-MM and the lowest (2.36 and 1.94 mg kg^{-1}) under T_7-NM at 0-15 and 15-30 cm soil depths, respectively. Analysis of pooled data indicated that effects of treatment (T), year (Y) and their interaction (T×Y) on zinc content of soil were non-significant at both 0-15 and 15-30 cm soil depths.

4.4.11 Cooper

Table 4.20: Effect of mulches on available copper in soil

Treatments	Available Cu (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	3.49	3.84	3.67	4.11	4.20	4.16
T_2 (SM)	4.19	4.33	4.26	4.24	4.05	4.14
T_3 (TM)	4.26	4.83	4.55	3.99	4.37	4.18
T_4 (MM)	4.43	3.97	4.20	4.01	4.07	4.04
T_5 (GM)	4.05	4.07	4.06	3.98	4.05	4.02
T_6 (PM)	4.13	4.50	4.32	4.17	4.12	4.14
T_7 (NM)	4.96	4.74	4.85	4.37	3.97	4.17
Mean	4.22	4.32		4.12	4.12	
C.D $_{(0.05)}$	**NS**	**NS**		**NS**	**NS**	
T	**NS**			**NS**		
Y	**NS**			**NS**		
T×Y	**NS**			**NS**		

An inquisition of data in Table 4.20 revealed that mulch had non-significant effect on copper content in soil at 0-15 and 15-30 cm depths during both the years of study. An examination of the pooled data revealed that the highest copper content of 4.85 mg kg^{-1} under T_7-NM and 4.18 mg kg^{-1} under T_3-TM were recorded while the lowest of 3.67 mg kg^{-1} under T_1-BM and 4.02 mg kg^{-1} under T_5-GM were recorded at surface and sub-surface soil depths, respectively. Analysis of pooled data indicates that effects of treatment (T), year (Y) and their interaction (T×Y) on copper content of soil were non-significant at both 0-15 and 15-30 cm soil depths.

4.4.12 Iron

Scrutiny of data on iron content presented in Table 4.21 revealed that mulch had non-significant effect at 0-15 and 15-30 cm depths during both the years of study. An examination of the pooled data showed that the highest iron contents (18.92 mg kg^{-1} and 16.83 mg kg^{-1}) were recorded under T_1-BM and lowest values of 16.98 mg kg^{-1} under T_2-SM and 15.52 mg kg^{-1} under T_3-TM were observed at 0-15 and 15-30 cm depths, respectively. Analysis of pooled data revealed that effects of treatment (T), year (Y) and their interaction (T×Y) on iron content of soil were non-significant at both 0-15 and 15-30 cm soil depths.

Table 4.21: Effect of mulches on available iron in soil

Treatments	Available Fe (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	18.73	19.10	18.92	16.97	16.70	16.83
T_2 (SM)	15.60	18.35	16.98	16.58	16.89	16.74
T_3 (TM)	17.97	18.42	18.19	15.70	15.33	15.52
T_4 (MM)	18.33	17.65	17.99	16.90	15.97	16.43
T_5 (GM)	17.90	16.12	17.01	16.57	15.47	16.02
T_6 (PM)	16.50	18.92	17.71	16.20	15.27	15.73
T_7 (NM)	17.40	18.89	18.14	16.30	16.30	16.30
Mean	17.49	18.21		16.46	15.99	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

4.4.13 Manganese

An inquisition of data in Table 4.22 revealed that mulch had non-significant effect on manganese contents in soil at surface and sub-surface depths during both the years of study. Analysis of pooled data showed that the highest manganese contents (13.02 and 11.38 mg kg^{-1}) were recorded under T_2-SM and lowest (10.40 and 10.34 mg kg^{-1}) under T_7-NM at 0-15 and 15-30 cm soil depths, respectively. Analysis of pooled data assessed that effects of treatment (T), year (Y) and their interaction (T×Y) on manganese contents of soil were non-significant at 0-15 and 15-30 cm soil depths.

The increased micronutrient concentration reflects better moisture availability as well as their addition to soil through organic matter. The findings are in line with results given by Welch (1995).

Table 4.22: Effect of mulches on available manganese in soil

Treatments	Available Mn (mg kg^{-1})					
	0-15 cm			15-30 cm		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	13.13	11.53	12.33	10.91	11.67	11.29
T_2 (SM)	13.07	12.97	13.02	12.17	11.53	11.85
T_3 (TM)	12.40	12.27	12.33	11.53	11.23	11.38
T_4 (MM)	12.07	12.17	12.12	10.40	10.97	10.68
T_5 (GM)	11.23	13.03	12.13	10.95	10.73	10.84
T_6 (PM)	10.93	10.87	10.90	10.40	10.57	10.48
T_7 (NM)	10.30	10.50	10.40	10.32	10.37	10.34
Mean	11.88	11.90		10.95	11.01	
C.D $_{(0.05)}$	NS	NS		NS	NS	
T	NS			NS		
Y	NS			NS		
T×Y	NS			NS		

4.5 Effect of mulches on yield and quality parameters

4.5.1 Plant height and number of fruits.

4.5.1.1 Plant height

The data presented in Table 4.23 showed the effect of mulch was significant on plant height during both the years of study. The highest (182.0 and 162.4 cm) and the lowest values (151.0 and 146.4 cm) of plant heights were recorded under T_1-BM and T_7-NM, respectively as compared to other mulch during year 2017 and 2018, respectively.

Analysis of pooled data revealed that mulch effect was significant on plant height. Significantly maximum plant height (172.2 cm) was recorded under T_1-BM which statically at par with T_2-SM (168.7 cm) and T_3-TM (165.9 cm) and minimum (148.7 cm) under T_7-NM which statistically at par with T_6-PM (157.4 cm). The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on plant height were found to be significant. However, the effect of their interaction (T×Y) was found to be non significant.

The plant height was moderate by various mulches, all mulch increase plant height due to more moisture content combined with soil temperature moderation helped more root distribution, greater nutrient uptake. The higher plant height under black polyethylene mulch and silver polyethylene mulch might be attributed to better weed control, increased availability of nitrogen and reduced nutrient losses through leaching that stimulates plant growth which resulting in increased growth (Teasdale and Abdul Baki, 1995). The similar results were also reported by Singh *et al.* (2005), Singh *et al.* (2009), Choudhary and Bhambri (2013) and Bhujbal *et al.* (2015).

Table 4.23: Effect of mulches on plant height and number of fruits of tomato

Treatments	Plant height (cm)			Fruits plant^{-1}		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	182.0	162.4	172.2	28.44	28.22	28.33
T_2 (SM)	174.4	163.0	168.7	29.22	27.11	28.16
T_3 (TM)	170.9	160.9	165.9	26.44	23.44	24.94
T_4 (MM)	162.8	154.4	158.6	25.78	26.85	26.32
T_5 (GM)	166.6	151.7	159.1	27.33	27.89	27.61
T_6 (PM)	159.0	155.8	157.4	24.67	24.55	24.61
T_7 (NM)	151.0	146.4	148.7	23.33	24.00	23.67
Mean	166.7	156.4		26.46	26.01	
C.D $_{(0.05)}$	**9.39**	**9.90**		**NS**	**NS**	
T	**2.88**			**3.02**		
Y	**6.22**			**NS**		
T×Y	**NS**			**NS**		

4.5.1.2 Number of fruits

The data on number of fruits as influenced by different mulch treatments are enumerated in Table 4.23. The results indicated that the effect of mulch on number of fruits was not significant during both the years of study. Analysis of pooled data assessed that maximum number of fruits per plant (28.33) was found under T_1-BM followed by T_2-SM (28.16) and minimum (23.67) under T_7-NM. The analysis of pooled data revealed that the effect of treatments (T) on number of fruits was found to be significant. However, the effects of year (Y) and their interaction (T×Y) were found to be non significant.

Number of fruits per plant is one of the principal components which contribute towards yield. Number of fruits was recorded higher under inorganic mulch followed by organic mulch as compared to no mulch. The increased fruit number in both black and silver polyethylene mulch might be results of less weed number, less nutrient losses through leaching, thereby making available more nutrients for plant growth and favorable soil temperature and moisture (Ashworth and Harisson, 1983), thus creating condition for better growth and more number of fruits per plant. Fruit per plant was recorded less under transparent polyethylene mulch which may be due to higher weed growth under this mulch. This is in line with the findings of Singh *et al.* (2005), Ashrafuzzaman *et al.* (2011) and Rahman *et al.* (2016).

4.5.2 Average fruit weight and average fruit diameter

Table 4.24: Effect of mulches on average fruit weight and average fruit diameter of tomato

Treatments	Average fruit weight (g)			Average fruit diameter (cm)		
	2017	2018	Pooled	2017	2018	Pooled
T_1 (BM)	62.9	61.4	62.2	6.12	5.39	5.76
T_2 (SM)	62.9	60.3	61.6	5.94	5.41	5.68
T_3 (TM)	57.5	58.3	57.9	5.62	5.03	5.32
T_4 (MM)	59.9	56.6	58.2	5.61	5.26	5.43
T_5 (GM)	55.4	53.2	54.3	5.36	5.24	5.30
T_6 (PM)	56.3	53.7	55.0	5.36	5.37	5.36
T_7 (NM)	54.9	49.8	52.4	5.16	4.95	5.06
Mean	58.5	56.2		5.60	5.24	
C.D $_{(0.05)}$	**NS**	**5.03**		**NS**	**NS**	
T	**1.89**			**0.19**		
Y	**4.08**			**0.40**		
T×Y	**NS**			**NS**		

4.5.2.1 Average fruit weight

The data on average fruit weight was influenced by different mulch treatments are presented in Table 4.24. On statistical analysis, it was found that effect of mulches on average fruit weight was not significant during year 2017. During year 2018, mulch was significantly affect average fruit weight. The maximum fruit weight (61.4 g) was observed under T_1-BM and the lowest fruit weight (49.8 g) under T_7-NM. Analysis of pooled data observed that the highest fruit weight (62.2 g) was found under T_1-BM which statistically at par with T_2-SM (61.6 g) and the lowest fruit weight (52.4 g) under T_7-NM which statistically at par with T_6-PM (55.0 g) and T_5-GM (54.3 g). The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on average fruit weight was found to be significant. However, the effect of their interaction (T×Y) was found to be non significant.

Fruit weight is one of the most important attribute for tomatoes. Average fruit weight was influenced by mulch materials. The results are similar with the findings of research work carried out by Singh *et al*. (2005), Berihum (2011) and Pandy and Mishra (2012).

4.5.2.2 Average fruit diameter

The data presented in Table 4.24 showed non-significant effect of mulch on average fruit diameter of plant during both years of experiment. Analysis of pooled data indicated that maximum fruit diameter (5.76 cm) was found in T_1-BM followed by T_2-SM (5.68 cm) and the lowest (5.06 cm) under T_7-NM. The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on average fruit weight diameter were found to be significant. However, the effect of their interaction (T×Y) was found to be non significant.

4.5.3 Fruit yield

Table 4.25: Effect of mulches on fruit yield of tomato

Treatments	Fruit yield (t ha^{-1})			
	2017	2018	Pooled	Per cent increase over control
T_1 (BM)	65.1	62.1	63.6	40.08
T_2 (SM)	64.9	58.7	61.8	36.12
T_3 (TM)	53.8	51.4	52.6	15.85
T_4 (MM)	55.5	55.1	55.3	21.80
T_5 (GM)	54.2	53.9	54.0	18.94
T_6 (PM)	48.8	47.9	48.4	6.60
T_7 (NM)	46.6	44.1	45.4	-
Mean	55.5	53.3		
C.D $_{(0.05)}$	**11.67**	**9.44**		
T	**7.19**			
Y	**NS**			
T×Y	**NS**			

The data on fruit yield per hectare was influenced by different mulch treatments are enumerated in Table 4.25. On statistical analysis, it was found that effect of mulches on fruit yield per hectare was significant during both the years of the experiment. Maximum fruit yields (65.1 and 62.1 t ha^{-1}) were observed under T_1-BM and minimum (46.6 and 44.1 t ha^{-1})

under T_7-NM in year 2017 and 2018, respectively. Analysis of pooled data assessed that the highest fruit yield (63.6 t ha^{-1}) was observed under T_1-BM which at par with T_2-SM and the lowest (45.4 t ha^{-1}) under T_7-NM which was at par with T_6-PM. The increases in yield were 40.08, 36.12, 15.85, 21.80, 18.94, 6.60 per cent under T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM, respectively as compared to T_7-NM i.e. control. The analysis of pooled data revealed that the effect of treatments (T) on fruit yield per hectare was found to be significant. However, the effects of year (Y) and their interaction (T×Y) were found to be non significant.

Table 4.26: Effect of mulches on total soluble solid of tomato

Treatments	TSS (^{0}Brix)		
	2017	2018	Pooled
T_1 (BM)	4.81	4.62	4.71
T_2 (SM)	4.78	4.61	4.70
T_3 (TM)	4.72	4.51	4.61
T_4 (MM)	4.62	4.58	4.60
T_5 (GM)	4.57	4.47	4.52
T_6 (PM)	4.45	4.45	4.45
T_7 (NM)	4.52	4.44	4.48
Mean	4.61	4.53	
C.D $_{(0.05)}$	NS	NS	
T	NS		
Y	NS		
T×Y	NS		

The yield of tomato fruits depends upon number of factors like agro climatic condition, region, cultivar, cultural practices, nutrient status and supplying capacity of soil. The increment in the yield of tomato recorded higher in black and silver polyethylene mulch might be attributed to modifying effect on soil hydrothermal regimes and considerable control on weed population. Several researchers reported that improvement into conservation of soil moisture under mulches by retarding evaporation (Hillel, 1982), weed control (El-Sayed *et al*., 1991 and Gutal *et al*., 1992) reduced nutrient leaching, improved microclimate both beneath and above the soil surface, thus helping in maximum plant growth and fruit setting in tomato. Mulch also improves carbon dioxide gas which is necessary for photosynthesis. 'Chimeny effect' might have been created, resulting in abundant CO_2 for the plants which might have added higher plant growth and fruit yield grown under different plastic mulches. Similar types of findings were also reported by Singh *et al.* (2005), Ashrafuzzaman *et al.* (2011), Berihum (2011), Singh and Kamal (2012) and Bhujbal *et al.* (2015).

4.5.4 Total soluble solid

The data presented in Table 4.26 showed non-significant effect of mulch on total soluble solid (TSS) of tomato fruit during both the years of experiment. Analysis of pooled data indicated that maximum TSS (4.71 ^{0}Brix) was observed under T_1-BM and minimum (4.45 ^{0}Brix) under T_6-PM. Analysis of pooled data assessed that effects of treatment (T), year (Y) and their interaction (T×Y) on TSS content of fruit were non-significant.

4.6 Water requirement and water use efficiency

4.6.1 Water requirement of tomato

Table 4.27: Effect of mulches on water requirement

Sr. No.	Treatment	Net depth of water applied (cm)		Effective rainfall (cm)		Increase in soil moisture storage (cm)		Total water requirement (cm)	
		2017	2018	2017	2018	2017	2018	2017	2018
1	T_1 (BM)	4.0	4.0	28.2	38.8	2.15	2.06	30.05	40.74
2	T_2 (SM)	4.0	4.0	28.2	38.8	1.94	1.83	30.26	40.97
3	T_3 (TM)	4.0	4.0	28.2	38.8	1.71	1.65	30.49	41.15
4	T_4 (MM)	4.0	4.0	28.2	38.8	1.66	1.52	30.54	41.28
5	T_5 (GM)	4.0	4.0	28.2	38.8	1.58	1.31	30.62	41.49
6	T_6 (PM)	4.0	4.0	28.2	38.8	1.29	1.08	30.91	41.72
7	T_7 (NM)	4.0	4.0	28.2	38.8	1.12	0.91	31.08	41.89

For optimization of water use and yield of tomato under field conditions, seven treatments viz. black mulch, silver mulch, transparent mulch, mulch mat, grass mulch, pine needle mulch, no mulch were applied. The total effective rainfall of 28.2 and 38.8 cm was computed during experimental period in year 2017 and 2018, respectively. In year 2017, moisture contents of 14.10 and 15.70 per cent were observed before the transplanting and the values of 19.90, 19.60, 18.90, 18.80, 18.60, 17.90 and 17.30 in T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM and T_7-NM, respectively at 0-15 cm soil depth and 21.20, 20.40, 19.90, 19.70, 19.50, 18.70 and 18.40 at 15-30 cm soil depth, respectively were observed after harvesting. In year 2018, moisture contents of 14.80 and 16.20 per cent were observed before the transplanting and the values of 20.30, 19.90, 19.60, 19.20, 18.70, 18.10 and 17.60 in T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM and T_7-NM, respectively at 0-15 cm soil depth and 21.50, 20.70, 20.10, 19.80, 19.20, 18.60 and 18.20 per cent observed at 15-30 cm soil depth, respectively after harvesting.

4.6.2 Water use efficiency

Table 4.28: Effect of mulches on water use efficiency

Treatments	Water use efficiency (t ha^{-1} cm^{-1})			
	2017	2018	Pooled	Per cent increase over control
T_1 (BM)	2.17	1.53	1.85	44.53
T_2 (SM)	2.14	1.43	1.79	39.84
T_3 (TM)	1.76	1.25	1.51	17.96
T_4 (MM)	1.82	1.34	1.58	23.43
T_5 (GM)	1.77	1.30	1.53	19.53
T_6 (PM)	1.58	1.15	1.36	6.25
T_7 (NM)	1.50	1.05	1.28	-
Mean	1.82	1.29		
C.D $_{(0.05)}$	**0.38**	**0.23**		
T	**0.21**			
Y	**0.10**			
T×Y	**NS**			

An inquisition of data in Table 4.28 revealed that effect of various mulches was significant on water use efficiency (WUE) of tomato during both the experimental years. The highest WUE values (2.17 and 1.53 t ha^{-1} cm^{-1}) were observed under T_1-BM and the lowest values (1.50 and 1.05 t ha^{-1} cm^{-1}) under T_7-NM during both years of the study. Analysis of pooled data assessed that the highest WUE (1.85 t ha^{-1} cm^{-1}) was observed under T_1-BM followed by T_2-SM and the lowest WUE (1.28 t ha^{-1} cm^{-1}) under T_7-NM. The percentage increases in WUE were 44.53, 39.84, 17.96, 23.43, 19.53, 6.25 per cent under T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM, respectively over control, The analysis of pooled data revealed that the effects of treatments (T) and year (Y) on WUE were found to be significant. However, the effect of their interaction (T×Y) was found to be non significant.

4.7 Benefit cost ratio

Benefit cost ratio was worked out for different mulch treatments and are presented in Table 4.29 and details of the cost of cultivation and economic returns are given in Appendix-V. A perusal of data reveals that the maximum gross income per hectare (₹ 9.54 lakhs) was recorded in T_1-BM followed by T_2-SM (₹ 9.27 lakhs) and minimum (₹ 6.80 lakhs) under T_7-NM. Similarly, the net return per hectare was found maximum (₹ 7.46 lakhs) under T_1-BM and minimum (₹ 4.13 lakhs) under treatment T_4-MM. The highest B:C ratio of 4.99 was worked out in T_7-NM, but the net return in this treatment was lower. The highest net return was observed under T_1-BM with higher B:C ratio of 4.58 which was rated as the most profitable and cost effective treatment. The lowest B:C ratio of 1.99 was recorded under T_4-NM.

The higher B:C ratio under the treatment black polyethylene and silver polyethylene mulch is a result of comparatively higher yield, better weed control with better hydrothermal regimes and nutrient availabilities. These findings are in agreement with the results reported by Christopher *et al*. (1997), Raina *et al*. (1999), Gautam (2002), Singh *et al*. (2004) and Nedunchezhiyan (2010).

Table 4.29: Effect of mulches on net return benefit cost ratio of tomato

Treatments	Cost of cultivation (₹ Lakhs ha^{-1})	Yield (t ha^{-1})	Gross Income (₹ Lakhs ha^{-1})	Net return (₹ Lakhs ha^{-1})	B:C ratio
T_1 (BM)	2.08	63.62	9.54	7.46	4.58
T_2 (SM)	2.08	61.8	9.27	7.18	4.45
T_3 (TM)	2.39	52.58	7.88	5.49	3.30
T_4 (MM)	4.16	55.32	8.29	4.13	1.99
T_5 (GM)	1.96	54.01	8.10	6.13	4.13
T_6 (PM)	1.96	48.37	7.25	5.29	3.70
T_7 (NM)	1.36	45.35	6.80	5.43	4.99

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled **"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)"** was conducted at Research Farm, Department of Soil Science and Water Management, Dr Y S Parmar University Horticulture and Forestry, Nauni, Solan (Himachal Pradesh) during the year 2017 and 2018. The experiment was laid out in randomized block design with seven treatments and three replications. The treatments were black polyethylene mulch (BM), silver polyethylene mulch (SM), transparent polyethylene mulch (TM), mulch mat (MM), grass mulch (GM), pine needle mulch (PM) and control i.e. no mulch (NM). The study aimed to evaluate the effect of these treatments on soil moisture content, soil temperature, soil physical properties, soil chemical properties, plant growth and yield characteristics, water use efficiency and cost economics of tomato. One month old seedlings were transplanted at 90 cm × 30 cm spacing in 21 plots (each of 4 m × 2 m in size). Fertilizers were applied manually as per given in the package of practices (POP) published by this university.

Salient findings emerged from the present study are summarized here under:

5.1 Physio-chemical properties of soil before the start of experiment

The soil of experimental field was sandy clay loam in texture. The field capacity and permanent wilting point were 19.22 and 6.37 per cent for 0-15 cm soil depth, respectively and the corresponding values were 18.76 and 6.28 per cent for 15-30 cm soil depth. The pH and EC of the soil were 6.24 and 0.21 d Sm^{-1} at 0-15 cm soil depth. However, the corresponding values were 6.37 and 0.19 d Sm^{-1}, respectively at 15-30 cm soil depth. The soil organic carbon was 16.6 and 14.9 g kg^{-1} for 0-15 and 15-30 cm soil depths, respectively. The bulk density was 1.25 and 1.29 Mg m^{-3} for 0-15 and 15-30 cm soil depths, respectively. The available nitrogen (337.6 kg ha^{-1}), phosphorus (50.03 kg ha^{-1}) and potassium (335.9 kg ha^{-1}) were observed at 0-15 cm soil depth before the start of the experiment. The corresponding values of 328.6, 48.79 and 310.3 kg ha^{-1} were at 15-30 cm soil depth.

5.2 Soil moisture

The moisture contents at field capacity were 19.22 and 18.76 per cent at 0-15 cm and 15-30 cm, respectively. During year 2017, the mean maximum moisture contents (23.5 and 25.4%) under T_1-BM and minimum moisture contents (19.5 and 21.3%) under T_7-NM were recorded at 0-15 and 15-30 cm soil depths, respectively. In year 2018, the mean maximum moisture contents (19.2 and 20.0%) under T_1-BM and minimum moisture contents (15.7 and 16.8%) were recorded under T_7-NM at 0-15 and 15-30 cm soil depths, respectively. The order for soil moisture content for both 0-15 cm and 15-30 cm soil depths under different mulches follows as BM > SM >TM > MM > GM > PM > NM.

5.3 Soil temperature

The highest average minimum soil temperature values of 22.9 and 26.9ºC at 15 cm and 23.6 and 27.2ºC at 30 cm soil depth were recorded under the treatment T_3-TM followed by T_1-BM and the lowest values of 20.8 and 24.2ºC at 15 cm and 21.4 and 24.7ºC at 30 cm depth under T_7-NM, in year 2017 and 2018, respectively. Likewise, the highest average maximum soil temperatures of 28.2 and 31.6ºC at 15 cm and 27.8 and 30.0ºC at 30 cm depth were recorded under the treatment T_3-TM followed by T_1-BM and the lowest values of 26.5 and 28.1ºC at 15 cm and 26.0 and 26.8ºC at 30 cm depth under T_6-PM. Hence, the order for minimum soil temperature observed as TM > BM > SM > MM > GM > PM > NM while the order as TM > BM > SM > MM > NM > GM > PM for maximum soil temperature observed at both 15 and 30 cm soil depths under different mulches.

5.4 Soil physical properties

The lowest values of bulk density (1.27 and 1.29 Mg m^{-3}) were recorded under T_5-GM at 0-15 cm and 15-30 cm soil depth, respectively. The highest values for particle density (2.65 and 2.65 Mg m^{-3}) were at 0-15 and 15-30 cm soil depth, respectively recorded under T_5-GM. The maximum porosity values (51.74 and 51.15%) were recorded under T_5-GM at 0-15 and 15-30 cm soil depth, respectively. The maximum hydraulic conductivity values (4.24 and 4.26 cm hr^{-1}) were observed under T_5-GM at 0-15 and 15-30 cm soil depth, respectively. Highest WSA > 0.25 mm (64.61 and 59.34%) and mean weight diameter (2.22 and 2.19 mm) were recorded under T_5-GM at

0-15 and 15-30 cm soil depth, respectively. The highest values of maximum water holding capacity (43.49 and 43.30%) were recorded under T_5-GM at 0-15 and 15-30 cm soil depth, respectively. The highest values of field capacity (24.67 and 23.47%) and permanent wilting point (8.22 and 8.15%) and plant available water (16.45 and 15.63%) were recorded under T_5-GM at 0-15 and 15-30 cm soil depth, respectively.

5.4 Soil chemical properties

The highest values of pH 6.60 and 6.61 were recorded under T_3-TM and T_6-PM at surface and sub-surface soil layers, respectively. The highest EC values of 0.30 d Sm^{-1} and 0.32 d Sm^{-1} were recorded under T_1-BM and T_6-PM at surface and sub-surface soil layers, respectively. The maximum soil organic carbon contents of 20.35 and 18.35 g kg^{-1} were observed under T_5-GM at 0-15 and 15-30 cm soil depth, respectively. Mulch had significant effect on available soil nutrients. The maximum available N (374.2 kg ha^{-1}), P (72.03 kg ha^{-1}), K (371.8 kg ha^{-1}) and sulphate sulphur (62.71 kg ha^{-1}) were recorded under T_1-BM at 0-15 cm soil depth. Similarly, at 15-30 cm of soil depth, the highest values of available N (363.3 kg ha^{-1}), P (64.97 kg ha^{-1}), K (358.8 kg ha^{-1}) and sulphate sulphur (60.67 kg ha^{-1}) were obtained under T_1-BM.

5.6 Plant growth and yield

The maximum plant height (172.2 cm) was recorded under T_1-BM followed by T_2-SM and minimum (148.7 cm) under T_7-NM. The maximum fruits per plant (28.33) were observed under T_1-BM, while the minimum fruits per plant (23.67) under T_7-NM. The highest average fruit weight (62.2 g) and average fruit diameter (5.76 cm) were recorded under T_1-BM, while the lowest average fruit weight (52.4 g) and average fruit diameter (5.06 cm) under T_7-NM.

5.7 Tomato yield

The maximum yield (63.6 t ha^{-1}) under T_1-BM and the minimum yield (45.4 t ha^{-1}) under T_7-NM were recorded. The percentage increase in yield of 40.08, 36.12, 15.85, 21.80, 18.94, 6.60 were obtained under T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM, respectively as compared to T_7-NM. The treatment T_1-BM i.e. black polyethylene mulch is found the most suitable and economical for tomato cultivation.

5.8 Water use efficiency

The highest WUE (1.85 t ha^{-1} cm^{-1}) and the lowest WUE (1.28 t ha^{-1} cm^{-1}) were found under T_1-BM and T_7-NM, respectively. Percentage increase in WUE of 44.53, 39.84, 17.96, 23.43, 19.53, 6.25 were obtained under T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM, respectively over control i.e. no mulch.

5.9 Net return and B: C ratio

The maximum net return per hectare of ₹ 7.46 lakhs with higher B:C ratio of 4.58 was observed under T_1-BM. The lowest net return per hectare of ₹ 4.13 lakhs and lowest B:C ratio of 1.99 were recorded in T_4-MM. However, the highest B:C ratio of 4.99 was obtained in treatment T_7-NM with net return per hectare of ₹ 5.43 lakhs.

Conclusions

From the present study, the following conclusions are drawn:

- Among application of different mulches, black polyethylene mulch resulted the highest percentage increase in soil moisture contents (20.34 and 21.59%) over control at surface and (19.08 and 18.87%) at subsurface layer in year 2017 and 2018, respectively. While the lowest percentage increase (1.28 and 3.92%) at surface and (3.43 and 4.94%) subsurface layer under pine needle was recorded in year 2017 and 2018, respectively.
- Transparent polyethylene mulch observed the highest increase in minimum soil temperature (2.09 and 2.69ºC) at 15 cm and (2.10 and 2.52ºC) 30 cm depths over no mulch in year 2017 and 2018, respectively. While the lowest increase (0.39 and 0.45ºC) at 15 cm and (0.10 and 0.47ºC) 30 cm depth over no mulch under pine needle mulch were recorded in year 2017 and 2018, respectively.
- Transparent polyethylene mulch observed the highest increase in maximum soil temperature (1.64 and 2.71ºC) at 15 cm depth (1.55 and 2.32ºC) over no mulch at 30 cm depth in year 2017 and 2018, respectively. While the higher decrease (0.56 and 0.77ºC) at 15 cm depth and (0.78 and 0.91ºC) at 30 cm depth over no mulch under pine needle mulch were recorded in year 2017 and 2018, respectively.
- The lowest bulk density (1.27 and 1.29 Mg m^{-3}) and highest organic carbon content (20.35 and 18.35 g kg^{-1}) were recorded under T_5-GM which subsequently increases

the porosity (51.74 and 51.15%) at 0-15 and 15-30 cm depths, respectively during study period. The significantly highest plant available water content (16.45 and 15.63%) was found under T_5-GM.

- The black polyethylene mulch recorded significantly highest availability of macro nutrients (N, P, K) in soil and highest water use efficiency (1.85 t ha^{-1} cm^{-1}).
- The significantly highest yield (63.6 t ha^{-1}), highest net return per hectare (₹ 7.46 lakhs) and higher B:C ratio (4.58) were observed under black polyethylene mulch.
- The findings of this research work reveal that use of black polyethylene mulch is most appropriate for increasing water use efficiency, yield and net income of tomato in mid hill zone of Himachal Pradesh.

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APPENDIX- I

Weekly meteorological data during experimental period in year 2017

Months	Standard weeks	Temperature (ºC)		Rainfall (mm)	Evaporation (mm)
		Maximum	Minimum		
APR	14th	26.30	12.30	2.80	3.90
	15th	28.90	10.80	0.0	3.80
	16th	33.30	16.50	0.40	5.30
	17th	29.10	13.20	1.60	3.90
MAY	18th	28.60	13.20	4.40	4.60
	19th	32.30	17.00	6.60	6.00
	20th	29.90	16.10	4.00	4.30
	21st	30.60	16.00	1.40	3.70
JUN	22nd	30.70	16.50	1.50	4.20
	23rd	30.60	17.90	6.80	4.50
	24th	29.10	16.80	2.20	3.90
	25th	27.20	17.60	11.80	3.20
JUL	26th	26.30	20.20	7.40	2.30
	27th	28.70	20.00	2.70	2.20
	28th	26.70	20.30	6.40	1.70
	29th	27.70	20.80	5.30	1.70
	30th	27.50	20.20	5.90	1.30
	31st	26.40	20.50	18.70	1.30
AUG	32nd	27.40	21.30	7.40	1.40
	33rd	28.30	19.70	2.00	1.70
	34th	26.70	19.70	7.10	1.70
	35th	27.50	19.30	1.60	2.00

Weekly meteorological data during experimental period in year 2018

Months	Standard weeks	Temperature (ºC)		Rainfall (mm)	Evaporation (mm)
		Maximum	Minimum		
APR	14th	26.42	12.86	0.0	2.80
	15th	24.42	11.28	4.40	2.10
	16th	27.21	12.22	0.88	2.50
	17th	29.25	13.80	0.32	3.10
MAY	18th	28.02	15.18	3.42	3.40
	19th	29.70	14.70	6.64	3.10
	20th	30.40	16.04	4.71	3.70
	21st	34.20	17.01	0.0	4.60
	22nd	31.70	18.18	1.97	4.71
JUN	23rd	29.60	19.40	13.42	4.20
	24th	29.80	19.21	4.08	4.08
	25th	30.22	17.37	2.20	3.60
	26th	28.51	20.27	5.62	2.88
JUL	27th	27.70	19.21	7.62	2.91
	28th	26.38	21.10	5.34	2.41
	29th	27.07	21.00	3.45	1.54
	30th	25.30	19.90	31.97	1.27
	31st	28.57	19.37	0.0	2.87
AUG	32nd	26.28	19.68	6.97	2.31
	33rd	26.92	19.85	23.37	2.56
	34th	28.22	20.54	0.60	2.41
	35th	28.38	20.30	0.0	2.56

APPENDIX-II

Table 2.1: Periodical soil moisture content at 0-15 cm soil depth under different mulches in year 2017

Julian days	BM	SM	TM	MM	GM	PM	NM
138	19.25	17.83	17.21	16.75	16.00	15.56	14.86
145	19.81	17.95	16.24	15.78	17.05	14.62	13.99
152	21.64	22.12	17.88	19.50	20.60	18.00	18.27
159	24.88	23.37	22.33	23.24	23.00	23.12	22.86
166	19.26	17.62	17.64	14.74	16.44	15.26	14.98
173	21.26	19.62	19.64	16.74	18.44	16.26	16.68
180	26.06	24.86	24.28	21.73	23.13	21.98	24.28
187	24.10	22.15	21.13	22.94	18.91	20.20	20.68
194	29.14	27.56	24.11	21.72	21.96	26.34	21.47
201	27.77	27.07	26.77	25.80	24.83	23.53	23.22
208	25.33	24.93	24.70	23.53	22.72	22.67	22.27
215	24.23	24.40	22.01	19.33	18.98	17.75	18.45
222	18.56	18.33	16.45	17.27	16.34	14.68	15.21
229	24.40	22.93	22.43	21.43	20.97	19.53	19.56
236	27.27	25.98	24.68	25.37	25.16	26.38	25.74
243	19.90	19.60	18.90	18.80	18.60	17.90	17.30
Avg.	**23.30**	**22.27**	**21.02**	**20.29**	**20.20**	**19.61**	**19.36**

Table 2.2: Periodical soil moisture content at 15-30 cm soil depth under different mulches in year 2017

Julian Days	BM	SM	TM	MM	GM	PM	NM
138	21.55	19.23	18.01	18.25	17.80	17.26	17.07
145	20.11	18.35	17.04	17.28	16.85	16.32	16.20
152	22.94	21.52	20.68	21.00	20.40	19.70	19.68
159	26.78	25.77	24.13	26.14	25.80	25.50	24.20
166	21.26	20.62	18.64	19.74	19.44	19.26	17.19
173	30.03	29.94	28.14	27.16	26.40	27.48	25.21
180	27.26	26.16	25.58	23.03	25.43	23.28	24.79
187	25.10	23.15	22.13	23.94	19.91	21.20	20.89
194	30.04	28.96	25.51	23.12	23.36	27.74	26.08
201	28.77	28.07	27.77	26.80	25.83	24.53	23.43
208	26.53	26.13	25.90	24.73	23.92	23.87	22.68
215	25.03	25.20	22.81	20.13	19.78	18.55	18.46
222	20.16	19.93	18.05	18.87	17.94	16.28	16.02
229	25.70	24.23	23.73	22.73	22.27	20.83	20.07
236	29.37	28.08	26.78	27.47	27.26	28.48	27.05
243	21.20	20.40	19.90	19.70	19.50	18.70	18.40
Avg.	**25.11**	**24.11**	**22.80**	**22.51**	**21.99**	**21.81**	**21.09**

Table 2.3: Periodical soil moisture content at 0-15 cm soil depth under different mulches in year 2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
102	18.74	18.13	17.64	16.05	15.55	15.28	13.64
109	17.69	16.55	15.95	14.44	14.02	13.10	12.66
116	15.51	15.17	14.64	14.00	13.70	13.30	12.33
123	16.84	15.87	14.93	14.40	13.84	12.80	12.24
130	20.21	19.75	18.88	19.18	19.38	18.12	17.57
137	19.93	19.57	19.63	18.47	17.37	17.77	16.57
144	15.12	14.84	14.43	13.78	13.76	13.00	12.24
151	18.30	18.00	17.86	17.43	16.20	15.53	15.39
158	24.07	23.83	23.30	22.33	22.23	22.03	21.53
165	24.07	18.30	17.80	17.77	17.40	17.53	17.13
172	16.84	15.95	15.62	15.15	14.81	14.60	13.97
179	19.87	19.57	19.07	18.47	17.17	16.83	16.40
186	19.78	19.50	18.93	17.96	18.57	18.07	17.90
193	18.40	18.17	17.83	18.12	17.67	17.57	17.20
200	22.03	21.70	20.82	20.57	19.51	19.33	18.70
207	20.30	19.90	19.60	19.20	18.70	18.10	17.60
Avg.	**19.23**	**18.42**	**17.93**	**17.33**	**16.87**	**16.44**	**15.82**

Table 2.4: Periodical soil moisture content at 15-30 cm soil depth under different mulches in year 2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
102	19.84	19.43	18.94	17.35	16.85	16.58	14.94
109	18.79	19.09	17.95	17.35	15.84	13.90	13.46
116	16.61	16.91	16.57	16.04	15.40	14.10	13.13
123	17.14	17.44	16.27	15.33	15.40	13.90	13.04
130	22.31	22.61	22.15	21.28	20.58	20.78	19.52
137	21.03	20.67	20.73	19.57	18.47	18.87	17.67
144	17.22	15.84	15.43	14.78	15.76	15.30	13.84
151	19.40	19.00	19.16	18.73	17.50	16.83	16.69
165	24.17	23.83	21.60	22.63	20.53	22.33	21.83
158	19.63	19.30	19.10	19.07	18.70	19.83	18.43
172	17.94	16.95	16.42	15.85	16.61	15.40	15.07
179	20.97	20.57	19.87	19.27	17.97	17.63	17.20
186	20.88	20.50	21.03	20.06	20.67	20.17	19.40
193	20.20	19.77	18.93	19.22	18.77	18.67	18.30
200	23.33	22.70	21.92	21.67	20.61	20.43	19.30
207	21.50	20.70	20.10	19.80	19.20	18.60	18.20
Avg.	**20.06**	**19.71**	**19.14**	**18.62**	**18.05**	**17.71**	**16.88**

APPENDIX-III

Table 3.1: Minimum soil temperature at 15 cm soil depth under different mulch treatments in year 2017

Julian Days	BM	SM	TM	MM	GM	PM	NM
138	21.10	20.00	20.91	19.40	18.90	18.60	18.10
141	20.40	20.10	21.01	19.50	20.00	18.70	18.20
143	20.90	20.80	22.01	20.30	20.20	19.50	19.00
145	24.60	22.80	23.71	22.20	21.70	21.40	21.20
148	23.20	22.80	23.71	22.80	22.70	22.40	21.90
150	21.40	21.10	22.01	20.50	20.00	19.70	19.20
152	22.10	21.70	22.61	21.10	20.60	21.30	19.80
155	21.80	21.30	22.21	21.70	21.20	20.90	20.40
157	24.90	24.70	25.51	24.50	24.40	24.10	23.60
159	23.80	23.00	23.91	22.40	21.90	21.60	21.10
162	22.90	22.10	23.01	21.50	21.00	20.70	20.20
164	20.97	20.86	21.10	19.66	20.26	20.06	19.73
155	22.20	21.53	22.56	21.06	20.80	20.56	20.10
169	21.86	21.30	22.13	21.26	20.50	19.70	19.26
171	21.30	21.93	22.63	21.53	21.90	21.03	20.86
173	21.10	20.00	20.91	19.40	18.90	18.60	18.10
176	23.10	22.23	23.86	22.26	21.56	21.36	21.10
178	23.36	23.00	23.70	22.96	22.83	22.30	21.63
180	23.36	22.90	23.73	22.23	21.93	21.76	21.40
183	22.46	22.56	23.13	22.10	21.66	21.13	21.40
185	21.63	21.56	22.20	21.33	20.86	20.70	20.06
187	21.90	21.86	22.60	21.63	21.40	20.56	20.50
190	21.20	20.45	22.66	22.13	22.30	21.90	21.63
192	21.86	21.60	22.66	21.46	21.46	21.40	21.06
194	20.73	20.50	21.00	20.26	20.33	19.63	19.93
197	23.60	23.30	23.73	22.86	22.33	22.30	21.96
201	24.70	24.23	24.70	23.70	23.80	23.76	22.16
204	23.70	23.83	24.63	23.30	23.10	22.43	22.40
206	22.80	22.63	23.56	22.46	22.33	22.23	21.86
208	21.73	21.60	22.53	21.30	20.56	20.40	20.03
211	23.60	23.30	23.73	22.86	22.33	22.30	21.96
213	21.86	21.60	22.66	21.46	21.46	21.40	21.06
215	23.36	22.90	23.73	22.23	21.93	21.76	21.40
218	23.33	22.93	23.66	22.76	22.56	22.73	22.30
220	24.16	25.50	24.03	23.33	23.33	23.30	22.93
222	23.76	23.56	24.26	23.53	22.43	22.33	21.46
225	23.23	22.76	23.30	22.33	21.50	21.30	21.20
229	18.21	20.16	20.66	19.73	18.66	19.03	19.06
232	20.26	20.53	21.46	20.90	20.63	20.16	20.33
234	22.83	22.16	22.66	21.86	21.47	21.56	21.46
236	23.60	23.30	23.73	22.86	22.33	22.30	21.96
Max.	**24.90**	**25.50**	**25.51**	**24.50**	**24.40**	**24.10**	**23.60**
Min.	**18.21**	**20.00**	**20.66**	**19.40**	**18.66**	**18.60**	**18.10**
Avg.	**22.41**	**22.12**	**22.89**	**21.77**	**21.46**	**21.19**	**20.80**

Table 3.2: Minimum soil temperature at 30 cm soil depth under different mulch treatments in year 2017

Julian Days	BM	SM	TM	MM	GM	PM	NM
138	21.50	20.33	21.62	19.80	19.16	18.91	18.80
141	20.80	20.43	21.72	19.90	20.26	19.01	18.90
143	21.30	21.13	22.72	20.70	20.46	19.81	19.70
145	25.00	23.13	24.42	22.60	21.96	21.71	21.90
148	23.60	23.13	24.42	23.20	22.96	22.71	22.60
150	21.80	21.43	22.72	20.90	20.26	20.01	19.90
152	22.50	22.03	23.32	21.50	20.86	21.61	20.50
155	22.20	21.63	22.92	22.10	21.46	21.21	21.10
157	25.30	25.03	26.22	24.90	24.66	24.41	24.30
159	24.20	23.33	24.62	22.80	22.16	21.91	21.80
162	23.30	22.43	23.72	21.90	21.26	21.01	20.90
164	21.37	21.19	21.81	20.06	20.52	20.37	20.43
155	22.60	21.86	23.27	21.46	21.06	20.87	20.80
169	22.26	21.63	22.84	21.66	20.76	20.01	19.96
171	21.70	22.26	23.34	21.93	22.16	21.34	21.56
173	21.50	20.33	21.62	19.80	19.16	18.91	18.80
176	23.50	22.56	24.57	22.66	21.82	21.67	21.80
178	23.76	23.33	24.41	23.36	23.09	22.61	22.33
180	23.76	23.23	24.44	22.63	22.19	22.07	22.10
183	22.86	22.89	23.84	22.50	21.92	21.44	22.10
185	22.03	21.89	22.91	21.73	21.12	21.01	20.76
187	22.30	22.19	23.31	22.03	21.66	20.87	21.20
190	21.60	20.78	23.37	22.53	22.56	22.21	22.33
192	22.26	21.93	23.37	21.86	21.72	21.71	21.76
194	21.13	20.83	21.71	20.66	20.59	19.94	20.63
197	24.00	23.63	24.44	23.26	22.59	22.61	22.66
201	25.10	24.56	25.41	24.10	24.06	24.07	22.86
204	24.10	24.16	25.34	23.70	23.36	22.74	23.10
206	23.20	22.96	24.27	22.86	22.59	22.54	22.56
208	22.13	21.93	23.24	21.70	20.82	20.71	20.73
211	24.00	23.63	24.44	23.26	22.59	22.61	22.66
213	22.26	21.93	23.37	21.86	21.72	21.71	21.76
215	23.76	23.23	24.44	22.63	22.19	22.07	22.10
218	23.73	23.26	24.37	23.16	22.82	23.04	23.00
220	24.56	25.83	24.74	23.73	23.59	23.61	23.63
222	24.16	23.89	24.97	23.93	22.69	22.64	22.16
225	23.63	23.09	24.01	22.73	21.76	21.61	21.90
229	18.61	20.49	21.37	20.13	18.92	19.34	19.76
232	20.66	20.86	22.17	21.30	20.89	20.47	21.03
234	23.23	22.49	23.37	22.26	21.73	21.87	22.16
236	24.00	23.63	24.44	23.26	22.59	22.61	22.66
Max.	**25.30**	**25.83**	**26.22**	**24.90**	**24.66**	**24.41**	**24.30**
Min.	**18.61**	**20.33**	**21.37**	**19.80**	**18.92**	**18.91**	**18.80**
Avg.	**22.81**	**22.45**	**23.60**	**22.17**	**21.72**	**21.50**	**21.40**

Table 3.3: Maximum soil temperature at 15 cm soil depth under different mulch treatments in year 2017

Julian Days	BM	SM	TM	MM	GM	PM	NM
138	25.89	25.76	27.61	25.63	25.38	25.13	25.57
141	28.09	27.96	28.31	27.83	27.63	27.28	27.77
143	28.89	28.76	29.51	28.63	28.43	27.13	28.57
145	31.89	31.76	32.11	31.63	31.41	30.14	31.58
148	29.22	29.99	29.94	28.96	28.83	28.30	28.91
150	31.89	31.76	32.11	31.63	31.44	30.17	31.58
152	29.52	29.39	30.74	29.26	28.13	28.64	29.21
155	34.10	33.94	35.62	33.84	31.71	33.14	33.79
157	32.10	31.97	32.32	31.84	31.71	31.13	31.79
159	25.60	25.49	26.82	25.34	25.21	24.64	25.29
162	26.60	26.87	27.82	26.34	26.21	25.62	26.29
164	31.99	31.62	32.41	31.73	30.70	30.14	30.88
155	26.39	25.95	26.64	25.92	25.64	25.41	25.54
169	26.89	26.76	28.71	26.68	26.44	26.13	26.58
171	26.29	25.65	26.41	25.22	24.48	23.97	24.94
173	26.49	25.72	26.41	25.92	24.41	24.30	25.18
176	29.09	28.59	29.94	28.45	27.68	27.30	28.04
178	25.66	25.72	25.90	24.92	24.64	24.03	24.81
180	20.86	20.65	22.73	21.35	20.68	20.47	20.14
183	25.76	26.39	27.60	25.78	25.58	25.11	25.68
185	29.52	29.89	30.70	28.31	28.44	27.94	29.21
187	27.99	27.82	28.37	26.95	26.41	25.98	26.51
190	27.53	27.92	28.50	27.58	26.74	26.74	26.64
192	24.49	23.85	24.73	22.82	22.41	21.84	22.61
194	26.49	26.82	28.37	25.95	25.11	24.98	25.51
197	27.53	27.94	28.50	26.18	26.08	25.88	25.94
201	28.09	26.65	28.30	26.22	26.18	25.71	26.51
204	28.76	27.85	28.73	26.65	26.44	26.34	26.61
206	27.26	26.95	27.80	26.65	25.68	25.58	26.18
208	25.83	25.59	26.43	24.95	24.84	24.28	24.51
211	25.26	24.55	25.80	23.92	23.68	23.58	23.78
213	23.76	23.89	25.29	22.55	22.61	23.11	23.14
215	27.56	26.92	27.69	26.42	25.78	25.54	26.24
218	27.46	27.29	27.56	26.53	25.61	25.18	25.34
220	25.26	25.17	25.86	24.99	24.51	23.88	24.81
222	26.43	26.72	26.56	25.39	25.08	24.94	25.34
225	27.76	27.42	29.03	27.13	27.18	26.94	27.24
229	28.06	27.65	28.96	27.73	26.94	26.58	27.11
232	23.76	23.42	25.43	22.13	23.18	22.94	23.24
234	24.73	23.85	24.09	22.16	22.51	22.74	22.31
236	27.19	26.72	27.93	26.48	26.81	25.38	26.18
Max.	**34.10**	**33.94**	**35.62**	**33.84**	**31.71**	**33.14**	**33.79**
Min.	**20.86**	**20.65**	**22.73**	**21.35**	**20.68**	**20.47**	**20.14**
Avg.	**27.41**	**27.21**	**28.15**	**26.70**	**26.31**	**25.96**	**26.51**

Table 3.4: Maximum soil temperature at 30 cm soil depth under different mulch treatments in year 2017

Julian Days	BM	SM	TM	MM	GM	PM	NM
138	25.76	25.67	26.90	25.56	25.31	25.06	25.50
141	27.96	27.87	28.10	27.76	27.56	27.21	27.70
143	28.76	28.67	28.90	28.56	28.36	27.06	28.50
145	31.76	31.67	31.90	31.56	31.34	30.06	31.50
148	29.09	29.00	29.23	28.89	28.76	28.22	28.83
150	31.76	31.67	31.90	31.56	31.37	30.09	31.50
152	29.39	29.30	30.53	29.19	28.06	28.56	29.13
155	33.97	33.88	34.91	33.77	31.64	33.06	33.71
157	31.97	33.88	32.71	31.77	31.64	31.05	31.71
159	25.47	25.38	27.61	25.27	25.14	22.56	25.21
162	26.47	26.38	27.61	26.27	26.14	25.54	26.21
164	31.86	31.13	32.20	31.66	31.63	30.06	30.80
155	26.26	27.86	28.43	25.80	25.56	25.33	25.46
169	26.76	26.67	27.90	26.56	26.36	26.06	26.50
171	26.16	25.56	26.82	25.10	24.40	23.09	24.86
173	26.36	25.63	26.20	25.80	24.33	24.23	25.10
176	28.96	28.00	29.73	28.33	27.60	27.23	27.96
178	25.53	25.63	27.73	24.80	24.56	21.36	24.73
180	20.73	20.56	22.56	21.23	20.60	20.40	20.06
183	25.63	26.30	27.93	25.66	25.20	24.73	25.60
185	29.39	31.30	26.53	28.19	28.06	27.56	29.13
187	27.86	27.73	28.20	26.83	26.03	25.60	26.43
190	27.40	27.83	28.33	27.46	26.36	26.36	26.56
192	24.36	23.76	24.13	22.70	22.03	21.46	22.53
194	26.36	26.73	27.22	25.83	24.73	24.60	25.43
197	27.40	27.35	28.33	26.06	25.70	25.50	25.86
201	27.96	26.56	27.73	26.10	25.80	25.33	24.43
204	27.93	27.76	27.26	26.53	26.06	25.36	26.53
206	27.13	26.86	27.63	26.53	25.30	22.20	26.10
208	25.70	25.50	26.26	24.83	24.46	23.90	24.43
211	25.13	24.46	25.63	23.80	23.30	23.20	23.70
213	23.63	23.20	24.16	22.43	22.23	22.73	20.06
215	27.43	26.83	27.06	26.30	25.40	25.16	26.16
218	27.33	27.20	27.43	26.50	25.23	24.80	25.26
220	25.13	25.08	25.73	24.96	24.13	23.50	24.73
222	26.30	26.03	26.43	25.36	24.70	24.56	25.26
225	27.63	27.33	28.90	27.10	26.80	26.06	27.16
229	27.93	27.56	28.83	27.70	26.56	26.20	27.03
232	23.63	23.33	23.90	22.10	22.80	22.56	21.16
234	23.90	22.96	23.26	22.13	22.13	22.36	22.23
236	27.06	26.63	27.80	26.45	26.43	25.00	26.10
Max.	**33.97**	**33.88**	**34.91**	**33.77**	**31.64**	**33.06**	**33.71**
Min.	**20.73**	**20.56**	**22.56**	**21.23**	**20.60**	**20.40**	**20.06**
Avg.	**27.25**	**27.14**	**27.82**	**26.61**	**26.09**	**25.49**	**26.26**

Table 3.5: Minimum soil temperature at 15 cm soil depth under different mulch treatments in year 2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
93	27.50	27.36	29.40	27.26	27.18	27.15	27.30
95	28.90	27.73	30.36	28.23	28.15	28.12	27.26
98	27.60	26.26	29.53	28.53	28.45	28.42	26.76
100	25.53	24.43	26.43	24.43	24.35	24.32	24.33
102	30.56	29.13	29.43	28.43	28.35	28.32	27.33
105	32.00	30.33	31.13	29.23	29.15	29.12	29.06
107	31.53	30.80	31.63	29.86	29.78	29.75	28.40
109	26.56	26.00	28.53	25.36	25.28	25.25	26.43
112	31.83	30.70	32.20	30.70	30.62	30.59	30.10
114	31.46	29.83	31.90	30.13	30.05	30.02	29.80
116	31.40	29.70	29.46	30.00	29.92	29.89	27.33
121	29.70	29.13	30.03	29.30	29.22	29.19	28.33
123	30.56	29.13	29.43	28.43	28.35	28.32	27.33
126	31.33	30.13	32.00	30.03	29.95	29.92	29.60
130	31.16	30.13	30.56	29.70	29.62	29.59	27.66
133	26.03	25.63	27.40	25.26	25.18	25.15	24.70
135	28.06	27.36	29.30	27.40	27.32	27.29	26.10
137	20.96	19.86	22.20	20.26	20.60	20.43	19.23
142	26.40	26.30	27.56	25.36	25.33	25.16	23.26
144	27.16	27.40	28.40	27.53	26.46	26.26	25.26
147	26.30	25.50	27.33	23.33	22.60	22.30	22.66
149	29.46	27.43	29.20	27.46	26.40	26.43	25.16
151	26.53	27.16	27.43	26.73	25.50	25.36	24.36
154	23.66	25.13	24.53	22.66	21.63	21.40	23.63
156	22.83	23.56	23.50	22.26	21.33	22.36	21.73
158	23.56	22.56	24.63	23.56	22.60	22.53	22.43
161	23.70	22.30	24.33	23.36	22.43	22.33	23.56
163	26.53	25.33	24.36	24.46	23.70	23.43	22.40
165	24.63	23.53	27.53	23.60	22.40	22.36	21.73
168	16.50	16.03	16.50	16.66	15.33	15.46	15.46
170	21.60	20.20	23.63	22.46	22.40	22.50	21.63
175	26.46	25.33	27.73	22.40	22.63	21.53	22.60
179	22.43	21.43	23.40	21.76	20.43	20.63	20.66
184	21.30	21.10	22.30	20.06	20.90	20.70	18.20
186	23.00	22.80	24.00	22.13	21.00	20.80	22.00
189	22.00	21.70	23.00	21.20	21.00	20.50	20.00
191	18.50	18.30	21.00	18.00	18.00	17.80	17.00
193	23.00	22.80	23.50	22.40	21.00	20.03	21.00
196	23.50	23.40	24.00	23.00	21.00	20.70	22.00
Max.	**32.00**	**30.80**	**32.20**	**30.70**	**30.62**	**30.59**	**30.10**
Min.	**16.50**	**16.03**	**16.50**	**16.66**	**15.33**	**15.46**	**15.46**
Avg.	**26.20**	**25.46**	**26.89**	**25.20**	**24.76**	**24.65**	**24.20**

Table 3.6: Minimum soil temperature at 30 cm soil depth under different mulch treatments in year2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
93	31.13	29.03	32.00	31.20	31.13	31.11	29.93
95	30.93	29.56	33.30	30.83	30.76	30.74	31.20
98	30.76	28.50	31.23	30.93	30.86	30.84	30.23
100	27.10	26.90	27.90	26.33	26.26	26.24	25.83
102	31.46	30.80	30.90	28.70	28.63	28.61	28.80
105	32.36	31.10	31.36	30.13	30.06	30.04	29.26
107	34.25	32.40	31.90	31.16	31.09	31.07	30.30
109	27.40	24.43	29.83	26.56	26.49	26.47	27.73
112	32.06	31.70	33.56	31.46	31.39	31.37	31.46
114	32.26	30.56	32.56	31.16	31.09	31.07	30.46
116	31.10	30.63	30.76	31.53	31.46	31.44	28.66
121	31.50	30.40	33.36	30.46	30.39	30.37	30.33
123	31.46	30.80	30.90	28.70	28.63	28.61	28.80
126	31.80	30.86	32.83	31.06	30.99	30.97	30.73
130	30.53	31.13	31.33	31.53	31.46	31.44	29.20
133	28.17	28.03	29.83	27.70	27.63	27.61	26.36
135	29.23	30.46	31.50	28.90	28.83	28.81	27.96
137	22.66	22.73	24.36	22.56	22.10	22.16	21.50
142	24.33	25.36	26.66	24.50	24.53	24.46	22.43
144	25.46	26.43	27.40	26.40	25.46	25.46	24.50
147	24.33	24.40	26.43	22.43	21.43	21.16	21.56
149	27.66	26.33	28.03	26.56	25.60	25.36	24.40
151	24.26	26.26	26.60	25.50	24.53	24.40	23.53
154	22.53	22.36	23.63	21.50	20.36	20.36	22.53
156	21.06	22.40	22.60	21.96	20.66	21.30	20.56
158	21.36	21.33	23.36	22.40	21.46	21.70	21.43
161	20.86	21.36	23.56	22.46	21.46	21.43	22.63
163	24.43	24.40	23.43	23.33	22.50	22.30	21.50
165	22.56	22.70	24.60	22.53	21.33	21.50	20.63
168	15.40	15.46	15.80	15.76	14.56	14.53	14.40
170	19.50	20.16	22.26	21.53	21.43	21.53	20.56
175	24.50	24.53	26.40	21.23	21.50	21.40	21.53
179	20.43	21.56	22.33	20.80	19.46	19.43	19.46
184	22.73	22.70	23.66	22.30	22.00	21.66	21.00
186	23.00	22.90	23.50	22.06	22.50	22.10	22.00
189	21.00	20.80	22.50	20.50	20.00	20.00	19.00
191	22.00	21.60	22.50	21.33	20.00	19.96	19.50
193	23.00	22.70	24.00	22.30	22.50	21.90	21.00
196	23.00	22.90	24.00	22.40	22.00	21.90	21.50
Max.	**34.25**	**32.40**	**33.56**	**31.53**	**31.46**	**31.44**	**31.46**
Min.	**15.40**	**15.46**	**15.80**	**15.76**	**14.56**	**14.53**	**14.40**
Avg.	**26.14**	**25.86**	**27.25**	**25.66**	**25.24**	**25.20**	**24.73**

Table 3.7: Maximum soil temperature at 15 cm soil depth under different mulch treatments in year2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
93	32.20	31.20	33.26	30.53	30.40	30.06	30.66
95	32.40	31.40	33.13	31.33	31.20	31.16	30.53
98	32.12	31.20	32.20	30.16	30.03	29.19	29.30
100	29.40	28.40	30.03	28.20	28.07	28.03	27.43
102	32.06	30.86	31.10	29.86	29.13	29.29	28.60
105	33.73	31.46	33.20	30.46	29.83	30.29	31.66
107	33.75	33.33	32.40	30.03	29.09	29.16	31.33
109	28.43	25.03	27.06	25.96	25.83	25.79	26.53
112	33.73	32.63	34.60	32.16	32.03	31.39	32.13
114	33.50	32.56	33.66	32.13	31.20	31.96	31.06
116	34.04	31.90	31.93	32.13	32.00	31.26	29.33
121	32.50	31.96	34.16	31.53	31.40	31.36	31.60
123	32.06	30.86	31.10	29.86	29.73	29.19	28.60
126	33.26	32.53	33.86	32.03	31.09	31.46	31.06
130	34.00	32.46	32.33	31.50	30.37	29.33	30.06
133	29.36	28.93	29.50	26.85	26.72	26.18	26.83
135	31.43	32.50	33.25	30.93	30.80	30.16	30.33
137	28.70	27.63	29.80	27.70	27.53	27.30	26.60
142	32.30	31.16	33.40	30.40	29.60	28.46	29.23
144	33.43	32.30	34.23	32.36	31.20	30.33	31.20
147	32.36	30.16	33.46	28.43	27.23	27.40	29.20
149	35.43	32.40	36.16	32.40	31.46	30.03	32.23
151	32.33	32.26	33.63	31.46	30.20	30.15	30.46
154	29.50	28.30	30.30	27.30	26.03	26.46	27.36
156	28.66	28.40	29.40	27.46	26.56	25.13	26.66
158	29.56	28.36	30.26	28.46	27.53	27.63	27.23
161	29.30	28.43	30.66	28.33	27.50	26.20	28.43
163	32.43	29.56	32.66	29.46	28.36	28.40	28.46
165	30.23	28.40	32.30	28.40	27.40	27.23	26.43
168	20.83	19.40	22.43	18.43	17.90	18.70	18.33
170	27.73	26.40	29.40	27.33	26.26	26.43	26.40
175	32.43	28.56	33.40	27.56	26.30	26.53	27.60
179	27.60	27.13	29.33	26.43	25.13	25.16	26.26
184	27.50	27.06	30.00	26.70	26.00	25.40	28.00
186	31.00	30.56	31.50	30.06	27.28	27.30	31.00
189	30.50	30.30	31.00	30.00	27.50	27.30	29.04
191	29.70	28.16	30.50	27.33	28.00	27.04	30.00
193	30.00	27.20	31.00	27.03	27.40	27.03	29.80
196	30.00	29.06	31.50	28.60	26.08	26.40	30.25
Max.	**35.43**	**33.33**	**36.16**	**32.40**	**32.03**	**31.96**	**32.23**
Min.	**20.83**	**19.40**	**22.43**	**18.43**	**17.90**	**18.70**	**18.33**
Avg.	**31.01**	**29.75**	**31.62**	**29.16**	**28.39**	**28.14**	**28.90**

Table 3.8: Maximum soil temperature at 30 cm soil depth under different mulch treatments in year 2018

Julian Days	BM	SM	TM	MM	GM	PM	NM
93	30.93	30.40	32.10	29.80	29.52	29.46	29.72
95	30.46	30.26	32.40	29.50	29.86	29.80	29.42
98	29.73	30.10	30.86	29.03	29.26	29.20	28.95
100	28.66	27.56	29.33	27.23	26.66	26.60	27.15
102	31.40	29.53	30.26	28.80	27.62	27.56	28.72
105	31.86	30.43	32.00	29.00	29.46	29.40	28.92
107	31.90	31.53	30.26	29.30	29.46	29.40	29.22
109	27.66	26.36	27.30	25.26	24.72	24.66	25.18
112	31.93	31.46	34.13	31.40	31.59	31.53	31.32
114	31.86	31.20	33.06	31.60	30.56	30.50	31.52
116	32.80	31.50	31.36	31.26	28.82	28.76	31.18
121	31.46	31.30	32.40	30.70	29.59	29.53	30.62
123	31.40	30.53	30.26	28.80	27.59	27.53	28.72
126	31.56	31.23	32.96	31.43	30.62	30.56	31.35
130	32.86	31.80	31.00	30.63	29.22	29.16	30.55
133	27.33	26.83	28.30	25.43	24.79	24.73	25.35
135	30.43	31.33	32.20	29.70	27.92	27.86	29.62
137	24.46	23.66	25.66	24.70	23.36	22.90	23.63
142	29.60	28.36	30.23	28.26	29.03	27.36	28.46
144	30.33	29.43	31.40	30.43	29.96	27.56	30.33
147	28.36	27.53	30.63	26.43	26.60	25.63	26.40
149	31.46	31.23	33.50	30.26	30.46	28.33	29.96
151	28.56	29.36	30.36	29.33	29.23	27.43	29.16
154	26.36	25.36	27.30	26.43	25.40	24.46	25.40
156	25.30	26.03	26.50	26.40	25.33	24.23	25.33
158	26.56	26.06	27.33	27.40	26.60	25.60	26.40
161	27.46	27.23	28.33	27.53	26.20	25.33	26.50
163	29.30	28.30	27.40	28.46	27.53	25.16	27.50
165	27.16	25.50	30.40	27.53	26.26	22.23	26.20
168	17.40	16.66	19.50	17.16	17.43	15.60	17.46
170	24.33	23.23	25.76	26.53	25.40	21.36	25.43
175	29.46	28.56	30.36	26.56	25.63	23.60	25.66
179	24.50	23.53	27.33	25.46	24.60	21.56	24.40
184	27.00	26.80	31.00	26.40	25.60	27.50	26.00
186	29.80	29.50	31.40	29.20	27.90	29.00	28.30
189	29.00	28.60	30.40	28.20	27.50	28.50	27.70
191	29.20	29.00	30.20	28.60	28.30	29.00	28.40
193	28.70	28.50	32.60	28.23	26.83	28.50	27.20
196	33.20	32.80	33.20	32.46	26.56	27.80	27.00
Max.	**33.20**	**32.80**	**34.13**	**32.46**	**31.59**	**31.53**	**31.52**
Min.	**17.40**	**16.66**	**19.50**	**17.16**	**17.43**	**15.60**	**17.46**
Avg.	**29.02**	**28.43**	**30.02**	**28.23**	**27.41**	**26.79**	**27.70**

APPENDIX-IV

Table 4.1: Calculation of effective rainfall by balance sheet method in year 2017

Date	Rainfall (mm)	Evaporation (mm)	Balance (40 mm)	Effective rainfall (mm)
18-05-2017	0.0	5.4	34.6	-
19-05-2017	18.0	3.4	49.2	18.0
20-05-2017	9.0	4.5	53.7	9.0
21-05-2017	1.8	3.0	52.5	1.8
22-05-2017	5.2	2.5	55.2	5.2
23-05-2017	0.0	4.0	51.2	-
24-05-2017	0.0	4.4	46.8	-
25-05-2017	0.0	4.0	42.8	-
26-05-2017	0.0	4.3	38.5	-
27-05-2017	2.6	3.4	37.7	2.6
28-05-2017	0.0	4.2	33.5	-
29-05-2017	0.0	4.3	29.2	-
30-05-2017	0.0	4.0	25.2	-
31-05-2017	10.2	3.8	31.6	10.2
01-06-2017	0.0	3.8	27.8	-
02-06-2017	0.0	4.5	23.3	-
03-06-2017	0.0	5.1	18.2	-
04-06-2017	0.0	5.6	12.6	-
05-06-2017	0.0	5.8	6.8	-
06-06-2017	0.0	5.5	1.3	-
07-06-2017	32.0	4.0	29.3	32.0
08-06-2017	7.6	4.0	32.9	7.6
09-06-2017	0.0	4.1	28.8	-
10-06-2017	8.2	2.8	34.2	8.2
11-06-2017	8.8	3.2	39.8	8.8
12-06-2017	0.0	4.0	35.8	-
13-06-2017	0.0	4.6	31.2	-
14-06-2017	0.0	4.8	26.4	-
15-06-2017	0.0	5.0	21.4	-
16-06-2017	2.6	3.2	20.8	2.6
17-06-2017	3.8	2.4	22.2	3.8
18-06-2017	0.0	3.2	19.0	-
19-06-2017	6.3	3.1	22.2	6.3
20-06-2017	18.2	2.8	39.6	18.2
21-06-2017	0.0	3.8	35.8	-
22-06-2017	58.3	2.2	72.3	41.7
23-06-2017	0.0	3.9	68.4	-
24-06-2017	0.0	3.5	64.9	-
25-06-2017	0.0	4.0	60.9	-
26-06-2017	10.0	2.2	68.7	10.0

27-06-2017	6.2	2.0	72.3	5.6
28-06-2017	2.0	2.0	72.3	2.0
29-06-2017	27.4	1.7	72.3	1.7
30-06-2017	6.4	2.4	72.3	2.4
01-07-2017	0.0	2.0	70.3	-
02-07-2017	13.8	2.8	72.3	4.8
03-07-2017	0.0	2.3	70.0	-
04-07-2017	0.0	2.4	67.6	-
05-07-2017	0.0	2.3	65.3	-
06-07-2017	0.0	2.3	63.0	-
07-07-2017	3.0	1.5	64.5	3.0
08-07-2017	1.8	1.5	64.8	1.8
09-07-2017	0.0	2.1	62.7	-
10-07-2017	7.4	1.6	68.5	7.4
11-07-2017	5.0	1.5	72.0	5.0
12-07-2017	31.0	1.6	72.3	0.3
13-07-2017	1.6	1.6	72.3	1.6
14-07-2017	0.0	1.8	70.5	-
15-07-2017	0.0	1.7	68.8	-
16-07-2017	0.0	1.9	66.9	-
17-07-2017	0.0	2.0	64.9	-
18-07-2017	14.4	1.5	72.3	8.9
19-07-2017	0.0	1.6	70.7	-
20-07-2017	0.0	1.5	69.2	-
21-07-2017	0.0	1.9	67.3	-
22-07-2017	22.8	1.4	72.3	6.4
23-07-2017	1.2	0.8	72.3	0.8
24-07-2017	23.0	1.3	72.3	1.3
25-07-2017	6.0	1.2	72.3	1.2
26-07-2017	0.0	1.9	70.4	-
27-07-2017	0.0	1.7	68.7	-
28-07-2017	3.4	1.2	70.9	3.4
29-07-2017	7.7	1.2	72.3	2.6
30-07-2017	6.2	1.5	72.3	1.5
31-07-2017	14.0	1.1	72.3	1.1
01-08-2017	1.2	1.4	72.1	1.2
02-08-2017	0.0	1.5	70.6	-
03-08-2017	1.8	1.4	71.0	1.8
04-08-2017	55.0	1.2	72.3	2.5
05-08-2017	52.6	1.3	72.3	1.3
06-08-2017	8.0	1.5	72.3	1.5
07-08-2017	12.2	1.2	72.3	1.2
08-08-2017	10.2	1.3	72.3	1.3
09-08-2017	1.8	1.2	72.3	1.2

10-08-2017	1.0	1.6	71.7	1.0
11-08-2017	3.8	1.2	72.3	1.8
12-08-2017	14.6	1.5	72.3	1.5
13-08-2017	0.0	1.8	70.5	-
14-08-2017	9.0	1.4	72.3	3.2
15-08-2017	0.0	1.6	70.7	-
16-08-2017	0.0	1.7	69.0	-
17-08-2017	0.0	1.9	67.1	-
18-08-2017	0.0	2.0	65.1	-
19-08-2017	5.0	1.3	68.8	5.0
20-08-2017	43.8	1.1	72.3	4.6
21-08-2017	1.4	1.5	72.2	1.4
22-08-2017	3.8	1.8	72.3	1.9
23-08-2017	0.0	1.9	70.4	-
24-08-2017	0.8	1.5	69.7	0.8

Table 4.2: Calculation of effective rainfall balance sheet method in year 2018

Date	Rainfall (mm)	Evaporation (mm)	Balance (40 mm)	Effective rainfall (mm)
05-04-2018	0.0	3.1	36.9	-
06-04-2018	0.0	2.8	34.1	-
07-04-2018	0.0	2.8	31.3	-
08-04-2018	0.0	2.7	28.6	-
09-04-2018	18.2	2.1	44.7	18.2
10-04-2018	3.8	1.9	46.6	3.8
11-04-2018	7.1	1.9	51.8	7.1
12-04-2018	2.0	1.4	52.4	2.0
13-04-2018	0.0	2.3	50.1	-
14-04-2018	0.0	2.5	47.6	-
15-04-2018	0.0	2.8	44.8	-
16-04-2018	1.2	1.7	44.3	1.2
17-04-2018	0.4	1.9	42.8	0.4
18-04-2018	0.0	2.8	40.0	-
19-04-2018	0.0	2.9	37.1	-
20-04-2018	4.6	2.9	38.8	4.6
21-04-2018	0.0	2.8	36.0	-
22-04-2018	0.0	2.9	33.1	-
23-04-2018	0.0	2.9	30.2	-
24-04-2018	0.0	3.0	27.2	-
25-04-2018	0.0	3.4	23.8	-
26-04-2018	0.0	3.5	20.3	-
27-04-2018	0.0	3.6	16.7	-
28-04-2018	0.0	3.4	13.3	-
29-04-2018	2.3	2.3	13.3	2.3
30-04-2018	0.0	3.6	9.7	-
01-05-2018	0.0	3.8	5.9	-
02-05-2018	0.0	3.6	2.3	-
03-05-2018	24.0	2.6	23.7	24.0
04-05-2018	0.0	3.4	20.3	-
05-05-2018	0.0	3.6	16.7	-
06-05-2018	0.0	3.7	13.0	-
07-05-2018	30.0	1.9	41.1	30.0
08-05-2018	0.0	3.5	37.6	-
09-05-2018	15.6	3.0	50.2	15.6
10-05-2018	0.0	3.6	46.6	-
11-05-2018	0.0	3.6	43.0	-
12-05-2018	0.0	3.8	39.2	-
13-05-2018	0.9	2.9	37.2	0.9
14-05-2018	33.0	2.8	67.4	33.0
15-05-2018	0.0	3.7	63.7	-
16-05-2018	0.0	3.9	59.8	-
17-05-2018	0.0	3.8	56.0	-
18-05-2018	0.0	3.9	52.1	-
19-05-2018	0.0	3.9	48.2	-
20-05-2018	0.0	4.1	44.1	-
21-05-2018	0.0	4.2	39.9	-
22-05-2018	0.0	4.4	35.5	-
23-05-2018	0.0	4.6	30.9	-
24-05-2018	0.0	4.6	26.3	-
25-05-2018	0.0	4.7	21.6	-
26-05-2018	0.0	4.8	16.8	-
27-05-2018	0.0	5.0	11.8	-
28-05-2018	0.0	4.7	7.1	-

29-05-2018	0.0	4.7	2.4	-
30-05-2018	0.0	4.8	-2.4	-
31-05-2018	0.0	5.0	-7.4	-
01-06-2018	0.0	4.8	-12.2	-
02-06-2018	13.8	4.0	-2.4	13.8
03-06-2018	0.0	5.0	-7.4	-
04-06-2018	0.0	5.0	-12.4	-
05-06-2018	0.0	5.4	-17.8	-
06-06-2018	69.0	3.8	47.4	69.0
07-06-2018	0.0	4.3	43.1	-
08-06-2018	0.0	4.7	38.4	-
09-06-2018	25.0	3.0	60.4	25.0
10-06-2018	0.0	3.7	56.7	-
11-06-2018	1.0	3.1	54.6	1.0
12-06-2018	0.0	4.5	50.1	-
13-06-2018	0.0	4.8	45.3	-
14-06-2018	0.0	4.9	40.4	-
15-06-2018	0.0	4.7	35.7	-
16-06-2018	12.0	3.8	43.9	12.0
17-06-2018	15.6	2.8	56.7	15.6
18-06-2018	0.6	3.3	54	0.6
19-06-2018	0.0	3.5	50.5	-
20-06-2018	0.0	4.0	46.5	-
21-06-2018	15.0	3.4	58.1	15.0
22-06-2018	0.0	3.2	54.9	-
23-06-2018	0.0	3.7	51.2	-
24-06-2018	0.0	4.1	47.1	-
25-06-2018	0.0	4.3	42.8	-
26-06-2018	1.8	2.2	42.4	1.8
27-06-2018	1.0	3.0	40.4	1.0
28-06-2018	34.0	3.2	71.2	34.0
29-06-2018	1.2	1.8	70.6	1.2
30-06-2018	0.0	2.8	67.8	-
01-07-2018	1.4	2.9	66.3	1.4
02-07-2018	38.0	2.2	72.3	8.2
03-07-2018	15.4	2.6	72.3	2.6
04-07-2018	0.0	2.0	70.3	-
05-07-2018	0.0	2.6	67.7	-
06-07-2018	0.0	3.0	64.7	-
07-07-2018	0.0	3.6	61.1	-
08-07-2018	0.0	4.4	56.7	-
09-07-2018	0.0	4.6	52.1	-
10-07-2018	2.6	1.2	53.5	2.6
11-07-2018	1.2	3.2	51.5	1.2
12-07-2018	0.0	3.0	48.5	-
13-07-2018	1.4	1.6	48.3	1.4
14-07-2018	2.0	2.0	48.3	2.0
15-07-2018	30.2	1.3	72.3	25.3
16-07-2018	0.6	1.5	71.4	0.6
17-07-2018	0.6	1.4	70.6	0.6
18-07-2018	0.0	1.8	68.8	-
19-07-2018	9.6	1.5	72.3	5.0
20-07-2018	0.0	1.9	70.4	-
21-07-2018	1.0	1.2	70.2	1.0
22-07-2018	12.4	1.5	72.3	3.6

APPENDIX-V

Table 5.1 Cost economics of tomato production under different treatments

Fixed Units		**Unit**	**Rate (₹ $unit^{-1}$)**	**Fixed cost (₹ ha^{-1})**	**BM**	**SM**	**TM**	**MM**	**GM**	**PM**	**NM**
1. Preparatory											
a) Ploughing of Land	Hrs	4	600	2400	2400	2400	2400	2400	2400	2400	2400
b) Planking	Hrs	2	600	1200	1200	1200	1200	1200	1200	1200	1200
c) Carriage and application cost of FYM and fertilizers	Man days	15	282	4230	4230	4230	4230	4230	4230	4230	4230
d) FYM	Quintal/ha	150	250	37500	37500	37500	37500	37500	37500	37500	37500
e) SSP	Kg/ha	475	11.66	5539	5539	5539	5539	5539	5539	5539	5539
f) MOP	Kg/ha	90	11.6	1044	1044	1044	1044	1044	1044	1044	1044
g) UREA	Kg/ha	300	6	1800	1800	1800	1800	1800	1800	1800	1800
h) Preparation of plots	Man days	15	282	4230	4230	4230	4230	4230	4230	4230	4230
2. Seed and transplanting cost											
a) Cost of seeds	Gram/ha	400	12000	4800	4800	4800	4800	4800	4800	4800	4800
b) Preparation of beds for nursery	Man days	5	282	1410	1410	1410	1410	1410	1410	1410	1410
c) Transplanting of seedlings	Man days	15	282	4230	4230	4230	4230	4230	4230	4230	4230
d) Mulch application	Man days	25	282	7050	7050	7050	7050	7050	7050	7050	0
3. Irrigations	Man days	10	282	2820	2820	2820	2820	2820	2820	2820	2820
4. Plant protection											
Cost of pesticides											
a) Insecticide (Dichlovroves)	Kg/ha	1.5	360	540	540	540	540	540	540	540	540
b) Fungicide (Copper oxychloride)	Kg/ha	1	400	400	400	400	400	400	400	400	400
c) Total no. of bamboo for staking	ha	3000	9	27000	27000	27000	27000	27000	27000	27000	27000
d) Hand weeding	Man days	25	282	7050	0	0	7050	0	0	0	7050
e) Staking of plants	Man days	25	282	7050	7050	7050	7050	7050	7050	7050	7050
f) Spraying cost	Man days	4	282	1128	1128	1128	1128	1128	1128	1128	1128
5. Harvesting, grading, packing and loading cost	Man days	40	282	11280	11280	11280	11280	11280	11280	11280	11280
6. Transportation cost to local market (within 50 km rang	56.1		100	5610	5610	5610	5610	5610	5610	5610	5610
7. Miscellaneous cost	1 ha				5000	5000	5000	5000	5000	5000	5000
8. Mulch	1 ha				72000	72000	96000	280000	60000	60000	0
9. Total fixed cost				137812	208261	208261	239311	416261	196261	196261	136261

APPENDIX- VI

Analysis of variance table (ANOVA)

Table 6.1. ANOVA for soil pH at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.040467	0.020233	0.092752	0.046376
Treatment	6	0.361124	0.060187	0.143162	0.02386
Error	12	0.429333	0.035778	0.198781	0.016565

Table 6.2. ANOVA for soil electrical conductivity at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.032104	0.016052	0.012013	0.006007
Treatment	6	0.01951	0.003252	0.021415	0.003569
Error	12	0.108612	0.009051	0.133927	0.011161

Table 6.3. ANOVA for soil organic carbon at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.74381	1.371905	16.08	8.04
Treatment	6	22.82203	3.803671	6.293314	1.048886
Error	12	49.94286	4.161905	133.02	11.085

Table 6.4. ANOVA for soil available nitrogen at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	78.87255	39.43627	91.4074	45.7037
Treatment	6	1547.294	257.8823	1691.955	281.9925
Error	12	145.2147	12.10123	107.5875	8.965621

Table 6.5. ANOVA for soil available phosphorus at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	4.737067	2.368533	25.55523	12.77761
Treatment	6	677.2574	112.8762	490.1485	81.69142
Error	12	80.58027	6.715022	74.3939	6.199492

Table 6.6. ANOVA for soil available potassium at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	21.73989	10.86994	7.7312	3.8656
Treatment	6	1476.783	246.1305	3148.425	524.7374
Error	12	170.979	14.24825	157.9179	13.15982

Table 6.7. ANOVA for soil exchangeable calcium at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.70381	0.351905	0.140952	0.070476
Treatment	6	1.229524	0.204921	1.989524	0.331587
Error	12	5.09619	0.424683	3.599048	0.299921

Table 6.8. ANOVA for soil exchangeable magnesium at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.349267	0.174633	0.083343	0.041671
Treatment	6	0.838248	0.139708	0.515562	0.085927
Error	12	2.165067	0.180422	0.858724	0.07156

Table 6.9. ANOVA for soil sulphate sulphur at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	9.52381	4.761905	0.696429	0.348214
Treatment	6	58.55655	9.759425	47.59226	7.932044
Error	12	83.96577	6.997148	33.90774	2.825645

Table 6.10. ANOVA for soil available zinc at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.486257	0.243129	0.413981	0.20699
Treatment	6	0.65219	0.108698	0.683029	0.113838
Error	12	2.88621	0.240517	5.991086	0.499257

Table 6.11. ANOVA for soil available copper at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.019543	0.009771	0.25661	0.128305
Treatment	6	3.482895	0.580483	0.370362	0.061727
Error	12	6.78619	0.565516	4.306524	0.358877

Table 6.12. ANOVA for soil available iron at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	4.875238	2.437619	66.03595	33.01798
Treatment	6	21.6381	3.606349	3.443095	0.573849
Error	12	126.3248	10.52706	19.50905	1.625754

Table 6.13. ANOVA for soil available manganese at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	5.926667	2.963333	5.19201	2.596005
Treatment	6	21.28476	3.54746	8.483762	1.41396
Error	12	45.06667	3.755556	12.75712	1.063094

Table 6.14. ANOVA for soil bulk density at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.000343	0.000171	0.000114	5.71E-05
Treatment	6	0.006067	0.001011	0.006048	0.001008
Error	12	0.00239	0.000199	0.001952	0.000163

Table 6.15. ANOVA for soil particle density at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.016695	0.008348	0.003457	0.001729
Treatment	6	0.031467	0.005244	0.041667	0.006944
Error	12	0.020305	0.001692	0.059276	0.00494

Table 6.16. ANOVA for soil porosity at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	3.423045	1.711523	1.476981	0.73849
Treatment	6	39.50542	6.584236	48.35351	8.058919
Error	12	12.31201	1.026001	28.84329	2.403607

Table 6.17. ANOVA for soil hydraulic conductivity at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.041038	0.020519	0.006429	0.003214
Treatment	6	0.157857	0.02631	0.339248	0.056541
Error	12	0.282829	0.023569	0.554838	0.046237

Table 6.18. ANOVA for soil aggregate size distribution (WSA> 0.25) at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.027743	0.513871	4.603457	2.301729
Treatment	6	33.9464	5.657733	23.41643	3.902738
Error	12	4.047657	0.337305	14.76494	1.230412

Table 6.19. ANOVA for mean weight diameter at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.004638	0.002319	0.005267	0.002633
Treatment	6	0.045581	0.007597	0.0486	0.0081
Error	12	0.047162	0.00393	0.0102	0.00085

Table 6.20. ANOVA for maximum water holding capacity (w/w, %) at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.599895	0.299948	0.37761	0.188805
Treatment	6	52.03598	8.672663	42.83758	7.139597
Error	12	66.4439	5.536992	52.20159	4.350133

Table 6.21. ANOVA for field capacity (w/w, %) at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.919038	0.459519	0.126667	0.063333
Treatment	6	72.14483	12.02414	62.94952	10.49159
Error	12	6.122229	0.510186	5.033333	0.419444

Table 6.22. ANOVA for permanent wilting point (w/w, %) at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.348467	0.174233	0.140952	0.070476
Treatment	6	10.5455	1.757583	10.3981	1.733016
Error	12	0.834133	0.069511	0.919048	0.076587

Table 6.23. ANOVA for plant available water (w/w, %) at 0-15 and 15-30 cm soil depth in year 2017

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.189524	0.094762	0.035238	0.017619
Treatment	6	28.15238	4.692063	22.34952	3.724921
Error	12	3.930476	0.32754	7.064762	0.58873

Table 6.24. ANOVA for plant height and number of fruit per plant in year 2017

Source of Variation	Degree of freedom	Plant height		Fruits $plant^{-1}$	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	92.09524	46.04762	37.91534	18.95767
Treatment	6	1898.37	316.3951	77.36508	12.89418
Error	12	334.2011	27.85009	77.93651	6.494709

Table 6.25. ANOVA for average fruit weight and average fruit diameter in year 2017

Source of Variation	Degree of freedom	Average fruit weight		Average fruit diameter	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	26.97732	13.48866	0.64289	0.321445
Treatment	6	206.5418	34.42363	2.098149	0.349691
Error	12	181.0654	15.08878	2.093587	0.174466

Table 6.26. ANOVA for fruit yield per plant and fruit yield per hectare in year 2017

Source of Variation	Degree of freedom	Fruit yield (plant kg^{-1})		Fruit yield (t ha^{-1})	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.099722	0.049861	129.2403	64.62016
Treatment	6	0.71716	0.119527	929.4398	154.9066
Error	12	0.39834	0.033195	516.2481	43.02067

Table 6.27. ANOVA for fruit T.S.S in year 2017

Source of Variation	Degree of freedom	T.S.S		WUE	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.476474	0.238237	0.124648	0.062324
Treatment	6	0.572465	0.095411	0.896416	0.149403
Error	12	0.719681	0.059973	0.497905	0.041492

Table 6.28. ANOVA for soil pH at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.049524	0.024762	0.0168	0.0084
Treatment	6	0.063029	0.010505	0.1566	0.0261
Error	12	0.148543	0.012379	0.1226	0.010217

Table 6.29. ANOVA for soil electrical conductivity at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.043985	0.021993	0.112158	0.056079
Treatment	6	0.018334	0.003056	0.017672	0.002945
Error	12	0.045653	0.003804	0.12065	0.010054

Table 6.30. ANOVA for soil organic carbon at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.091429	1.045714	16.20857	8.104286
Treatment	6	23.84143	3.973571	11.6496	1.9416
Error	12	25.48857	2.124048	56.57143	4.714286

Table 6.31. ANOVA for soil available nitrogen at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	27.82344	13.91172	41.59966	20.79983
Treatment	6	1375.893	229.3155	1353.414	225.569
Error	12	151.6983	12.64153	120.8697	10.07247

Table 6.32. ANOVA for soil available phosphorus at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	15.40128	7.700639	2.383138	1.191569
Treatment	6	650.9164	108.4861	480.765	80.1275
Error	12	91.14805	7.595671	71.24245	5.936871

Table 6.33. ANOVA for soil available potassium at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	14.93135	7.465676	145.3993	72.69966
Treatment	6	1639.919	273.3198	2364.723	394.1205
Error	12	177.1572	14.7631	154.1559	12.84632

Table 6.34. ANOVA for soil exchangeable calcium at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.02381	0.011905	0.640952	0.320476
Treatment	6	1.222857	0.20381	1.491429	0.248571
Error	12	4.042857	0.336905	2.845714	0.237143

Table 6.35. ANOVA for soil exchangeable magnesium at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.111781	0.05589	0.0566	0.0283
Treatment	6	0.630362	0.10506	0.380962	0.063494
Error	12	3.772552	0.314379	0.833267	0.069439

Table 6.36. ANOVA for soil sulphate sulphur at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	4.05506	2.02753	0.385417	0.192708
Treatment	6	148.8839	24.81399	80.69196	13.44866
Error	12	109.4866	9.123884	56.125	4.677083

Table 6.37. ANOVA for soil available zinc at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.269267	0.134633	0.827838	0.413919
Treatment	6	0.365848	0.060975	0.290657	0.048443
Error	12	3.651467	0.304289	8.349429	0.695786

Table 6.38. ANOVA for soil available copper at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.592467	1.296233	0.138543	0.069271
Treatment	6	2.681324	0.446887	0.316429	0.052738
Error	12	9.562733	0.796894	3.956857	0.329738

Table 6.39. ANOVA for soil available iron at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	34.69215	17.34608	1.183095	0.591548
Treatment	6	19.48998	3.24833	7.920981	1.320163
Error	12	80.00225	6.666854	22.1687	1.847392

Table 6.40. ANOVA for soil available manganese at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.549524	1.274762	2.858095	1.429048
Treatment	6	17.36952	2.894921	4.331429	0.721905
Error	12	14.39048	1.199206	24.20857	2.017381

Table 6.41. ANOVA for soil bulk density at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.000812	0.000406	0.000314	0.000157
Treatment	6	0.002693	0.000449	0.007444	0.001241
Error	12	0.008093	0.000674	0.005196	0.000433

Table 6.42. ANOVA for soil particle density at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.003467	0.001733	0.004829	0.002414
Treatment	6	0.054114	0.009019	0.036362	0.00606
Error	12	0.0316	0.002633	0.032038	0.00267

Table 6.43. ANOVA for soil porosity at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	3.120467	1.560233	1.619924	0.809962
Treatment	6	37.01512	6.169187	48.49136	8.081894
Error	12	12.64893	1.054078	14.17176	1.18098

Table 6.44. ANOVA for soil hydraulic conductivity at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.034924	0.017462	0.098981	0.04949
Treatment	6	0.178629	0.029771	0.288429	0.048071
Error	12	0.230543	0.019212	0.194486	0.016207

Table 6.45. ANOVA for soil aggregate size distribution (WSA> 0.25) at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.485267	0.742633	2.18061	1.090305
Treatment	6	19.72066	3.286776	24.31927	4.053211
Error	12	3.8036	0.316967	7.52079	0.626733

Table 6.46. ANOVA for mean weight diameter at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.000257	0.000129	0.001229	0.000614
Treatment	6	0.080448	0.013408	0.039124	0.006521
Error	12	0.00801	0.000667	0.009905	0.000825

Table 6.47. ANOVA for maximum water holding capacity (w/w, %) at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	5.003838	2.501919	3.462257	1.731129
Treatment	6	45.61273	7.602122	28.12636	4.687727
Error	12	62.1391	5.178258	49.28001	4.106667

Table 6.48. ANOVA for field capacity (w/w, %) at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.400952	1.200476	1.786667	0.893333
Treatment	6	50.63333	8.438889	52.42	8.736667
Error	12	13.01238	1.084365	6.26	0.521667

Table 6.49. ANOVA for permanent wilting point (w/w, %) at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.120952	0.060476	0.675238	0.337619
Treatment	6	10.10952	1.684921	12.35619	2.059365
Error	12	1.399048	0.116587	0.558095	0.046508

Table 6.50. ANOVA for plant available water (w/w, %) at 0-15 and 15-30 cm soil depth in year 2018

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.726667	0.863333	0.11881	0.059405
Treatment	6	15.54952	2.591587	17.86167	2.976944
Error	12	9.613333	0.801111	2.35119	0.195933

Table 6.51. ANOVA for plant height and number of fruit per plant in year 2018

Source of Variation	Degree of freedom	Plant height		Fruits plant^{-1}	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	53.46032	26.73016	46.32187	23.16093
Treatment	6	677.9153	112.9859	69.30039	11.55007
Error	12	371.7989	30.98325	79.97407	6.664506

Table 6.52. ANOVA for average fruit weight and average fruit diameter in year 2018

Source of Variation	Degree of freedom	Average fruit weight		Average fruit diameter	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	21.30347	10.65173	0.262185	0.131092
Treatment	6	315.0592	52.50986	0.591889	0.098648
Error	12	95.96633	7.997194	0.78251	0.065209

Table 6.53. ANOVA for fruit yield per plant and fruit yield per hectare in year 2018

Source of Variation	Degree of freedom	Fruit yield (plant kg^{-1})		Fruit yield (t ha^{-1})	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.274819	0.137409	356.1652	178.0826
Treatment	6	0.526102	0.087684	681.8282	113.638
Error	12	0.260583	0.021715	337.7156	28.14296

Table 6.54. ANOVA for fruit T.S.S and WUE in year 2018

Source of Variation	Degree of freedom	T.S.S		WUE	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.1586	0.0793	0.19443	0.097215
Treatment	6	0.113314	0.018886	0.372209	0.062035
Error	12	0.71	0.059167	0.184359	0.015363

Table 6.55. ANOVA for pooled analysis data on soil pH at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0520	0.026021	0.0515	0.025774
Year	1	0.0083	0.008288	0.1060	0.106002
Treatment	6	0.2065	0.03441	0.2112	0.035202
Year × Treatment	6	0.2177	0.036283	0.0885	0.014758
Error	26	0.6158	0.023686	0.3794	0.014592

Table 6.56. ANOVA for pooled analysis data on electrical conductivity of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0072	0.0036	0.0968	0.048407
Year	1	0.0022	0.002229	0.0004	0.00044
Treatment	6	0.0271	0.004525	0.0383	0.006388
Year × Treatment	6	0.0107	0.001783	0.0008	0.000126
Error	26	0.2232	0.008583	0.2819	0.010844

Table 6.57. ANOVA for pooled analysis data on soil organic carbon at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	4.4719	2.235952	29.2500	14.625
Year	1	2.7056	2.70561	3.6021	3.602143
Treatment	6	46.2693	7.71155	17.3301	2.888343
Year × Treatment	6	0.3942	0.065693	0.6129	0.102143
Error	26	75.7948	2.915183	192.6300	7.408846

Table 6.58. ANOVA for pooled analysis data on available nitrogen of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	39.0369	19.51847	74.3123	37.15617
Year	1	356.1492	356.1492	406.8006	406.8006
Treatment	6	2903.9862	483.9977	3003.7977	500.6329
Year × Treatment	6	19.2007	3.200114	41.5715	6.928585
Error	26	364.5721	14.022	287.1518	11.0443

Table 6.59. ANOVA for pooled analysis data on available phosphorus of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	10.7597	5.379843	20.8945	10.44725
Year	1	303.9877	303.9877	142.6106	142.6106
Treatment	6	1310.8393	218.4732	964.3789	160.7298
Year × Treatment	6	17.3346	2.889094	6.5346	1.089103
Error	26	181.1070	6.965653	152.6802	5.872317

Table 6.60. ANOVA for pooled analysis data on available potassium of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	13.4561	6.728038	47.5449	23.77246
Year	1	305.3166	305.3166	408.8448	408.8448
Treatment	6	3083.0442	513.8407	5416.2603	902.71
Year × Treatment	6	33.6575	5.609587	96.8875	16.14791
Error	26	371.3514	14.28275	417.6594	16.06382

Table 6.61. ANOVA for pooled analysis data on exchangeable calcium of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.4519	0.225952	0.4471	0.223571
Year	1	0.1050	0.105	0.9152	0.915238
Treatment	6	0.9990	0.166508	1.6195	0.269921
Year × Treatment	6	1.4533	0.242222	1.8614	0.310238
Error	26	9.4148	0.362106	6.7795	0.260751

Table 6.62. ANOVA for pooled analysis data on exchangeable magnesium of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.4273	0.21366	0.0748	0.037379
Year	1	0.0797	0.079736	0.0011	0.00105
Treatment	6	0.9127	0.15211	0.1476	0.024593
Year × Treatment	6	0.5559	0.092658	0.7490	0.124828
Error	26	5.9713	0.229667	1.7572	0.067584

Table 6.63. ANOVA for pooled analysis data on sulphate sulphur of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	11.8490	5.924479	0.2686	0.134301
Year	1	0.7533	0.753348	25.7325	25.73251
Treatment	6	100.0558	16.67597	75.9985	12.66642
Year × Treatment	6	107.3847	17.89745	52.2857	8.714286
Error	26	195.1823	7.507011	90.8460	3.494076

Table 6.64. ANOVA for pooled analysis data on available zinc of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0664	0.033181	0.6717	0.33585
Year	1	0.2704	0.270402	0.0078	0.00779
Treatment	6	0.3970	0.066171	0.7484	0.124726
Year × Treatment	6	0.6210	0.103502	0.2253	0.037555
Error	26	7.2268	0.277955	14.9106	0.573486

Table 6.65. ANOVA for pooled analysis data on available copper of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.0809	0.54046	0.0450	0.022502
Year	1	0.1216	0.12161	0.0005	0.000467
Treatment	6	4.9887	0.831444	0.1534	0.025565
Year × Treatment	6	1.1756	0.195926	0.5334	0.0889
Error	26	17.8800	0.687693	8.6135	0.33129

Table 6.66. ANOVA for pooled analysis data on available iron of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	22.3809	11.19047	41.7932	20.89661
Year	1	5.4001	5.400086	2.3242	2.324152
Treatment	6	17.1009	2.850149	8.8047	1.467455
Year × Treatment	6	24.0272	4.00453	2.5593	0.426558
Error	26	223.5135	8.596672	67.1036	2.580907

Table 6.67. ANOVA for pooled analysis data on available manganese of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.1205	0.560238	7.8520	3.926002
Year	1	0.0086	0.008571	0.0326	0.032593
Treatment	6	29.8395	4.973254	10.6645	1.777417
Year × Treatment	6	8.8148	1.469127	2.1507	0.358448
Error	26	66.8129	2.569725	37.1638	1.429377

Table 6.68. ANOVA for pooled analysis data on bulk density of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0003	0.000142	0.0003	0.000163
Year	1	0.0000	1.52E-05	0.0020	0.002042
Treatment	6	0.0079	0.001311	0.0134	0.002241
Year × Treatment	6	0.0009	0.000149	0.0000	7.22E-06
Error	26	0.0114	0.000437	0.0073	0.000279

Table 6.69. ANOVA for pooled analysis data on particle density of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0026	0.001293	0.0043	0.00215
Year	1	0.0149	0.01486	0.0145	0.014486
Treatment	6	0.0826	0.013765	0.0760	0.012675
Year × Treatment	6	0.0030	0.000498	0.0020	0.00033
Error	26	0.0695	0.002672	0.0953	0.003665

Table 6.70. ANOVA for pooled analysis data on porosity of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.5190	0.259487	3.2398	1.619924
Year	1	3.6827	3.682738	0.3420	0.342002
Treatment	6	75.9550	12.65916	96.9827	16.16379
Year × Treatment	6	0.5656	0.09426	0.5580	0.092997
Error	26	30.9855	1.191749	43.7635	1.683211

Table 6.71. ANOVA for pooled analysis data on saturated hydraulic conductivity of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0756	0.037781	0.0493	0.024638
Year	1	0.0123	0.012343	0.0215	0.021488
Treatment	6	0.3283	0.054716	0.6099	0.101658
Year × Treatment	6	0.0082	0.001365	0.0177	0.002955
Error	26	0.5138	0.01976	0.8055	0.030979

Table 6.72. ANOVA for pooled analysis data on aggregate stability of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.3264	1.16321	2.0956	1.047788
Year	1	1.0880	1.088038	0.0738	0.073752
Treatment	6	51.7997	8.633283	47.0747	7.84578
Year × Treatment	6	1.8674	0.311227	0.6610	0.110169
Error	26	8.0378	0.309148	26.9742	1.03747

Table 6.73. ANOVA for pooled analysis data on mean weight diameter of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.0025	0.001267	0.0052	0.002602
Year	1	0.0034	0.003438	0.0000	3.81E-05
Treatment	6	0.0637	0.010622	0.0250	0.00416
Year × Treatment	6	0.0623	0.010383	0.0628	0.01046
Error	26	0.0575	0.002213	0.0214	0.000823

Table 6.74. ANOVA for pooled analysis data on maximum water holding capacity of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	4.4561	2.228031	3.0355	1.517745
Year	1	3.2259	3.225943	4.2752	4.275238
Treatment	6	94.2451	15.70751	66.7091	11.11819
Year × Treatment	6	3.4037	0.567276	4.2548	0.709133
Error	26	129.7307	4.989641	102.2860	3.934076

Table 6.75. ANOVA for pooled analysis data on field capacity of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	2.9758	1.487902	0.8033	0.401667
Year	1	0.5417	0.541736	2.9336	2.933571
Treatment	6	121.6497	20.27496	114.7314	19.1219
Year × Treatment	6	1.1284	0.188069	0.6381	0.106349
Error	26	19.4788	0.749184	12.4033	0.477051

Table 6.76. ANOVA for pooled analysis data on permanent wilting point of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.3601	0.180045	0.1729	0.086429
Year	1	2.2080	2.208021	2.1488	2.14881
Treatment	6	20.5319	3.421982	22.5348	3.755794
Year × Treatment	6	0.1231	0.020521	0.2195	0.036587
Error	26	2.3425	0.090097	2.1205	0.081557

Table 6.77. ANOVA for pooled analysis data on plant available water of soil at 0-15 and 15-30 cm soil depth

Source of Variation	Degree of freedom	0-15		15-30	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	1.3848	0.692381	0.2376	0.11881
Year	1	4.9371	4.937143	0.0610	0.060952
Treatment	6	42.4224	7.070397	35.7233	5.953889
Year × Treatment	6	1.2795	0.213254	0.6690	0.111508
Error	26	14.0752	0.541355	13.8424	0.532399

Table 6.78. ANOVA for pooled analysis data on plant height and number of fruit per plant of tomato

Source of Variation	Degree of freedom	Plant height		Fruits plant^{-1}	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	138.2063	69.10317	74.0599	37.02994
Year	1	1110.8571	1110.857	2.1473	2.147302
Treatment	6	2283.6614	380.6102	125.6100	20.93501
Year × Treatment	6	292.6243	48.77072	21.0554	3.509239
Error	26	713.3492	27.43651	168.0879	6.46492

Table 6.79. ANOVA for pooled analysis data on average fruit weight and average fruit diameter

Source of Variation	Degree of freedom	Average fruit weight		Average fruit diameter	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	17.6842	8.842121	0.7733	0.38665
Year	1	59.0012	59.00115	1.3531	1.353113
Treatment	6	491.6226	81.93709	2.0269	0.337815
Year × Treatment	6	29.9784	4.996402	0.6631	0.110525
Error	26	307.6283	11.83186	3.0079	0.115687

Table 6.80. ANOVA for pooled analysis data on fruit yield per plant and fruit yield per hectare

Source of Variation	Degree of freedom	Fruit yield (plant kg^{-1})		Fruit yield (t ha^{-1})	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.3284	0.164188	485.8860	242.943
Year	1	0.0396	0.039614	24.6724	24.67244
Treatment	6	1.2140	0.20234	1815.7379	302.623
Year × Treatment	6	0.0292	0.00487	11.5613	1.926887
Error	26	0.7051	0.027119	953.5026	36.67318

Table 6.81. ANOVA for pooled analysis data on fruit T.S.S and water use efficiency

Source of Variation	Degree of freedom	T.S.S		WUE	
		Sum of square	Mean sum of square	Sum of square	Mean sum of square
Replication	2	0.4595	0.229754	0.2922	0.146117
Year	1	0.0740	0.074032	2.4078	2.407801
Treatment	6	0.5648	0.094142	1.1914	0.198568
Year × Treatment	6	0.1209	0.020155	0.0772	0.01287
Error	26	1.6052	0.06174	0.7091	0.027273

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Title of the Thesis	**:**	**"Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)"**
Name of the Student	**:**	Rajesh Bajia
Admission Number	**:**	F-2016-58-M
Major Field	**:**	Soil Science
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ABSTRACT

The present study entitled "Effect of mulch on soil properties and yield of tomato (*Solanum lycopersicum* L.)" was conducted at the research farm of the Department of Soil Science and Water Management, Nauni, Solan during the years 2017 and 2018 with seven treatments viz. T_1-BM, T_2-SM, T_3-TM, T_4-MM, T_5-GM, T_6-PM and T_7-NM with three replications in randomized block design with plot size of 4m×2m and spacing 90cm×30cm. Black mulch increased moisture (20.34 and 19.08%) at surface and (21.59 and 18.87 %) at subsurface depths as compared to no mulch in year 2017 and 2018, respectively. The transparent mulch increased maximum and minimum soil temperatures as compared to other treatments at both 15 cm and 30 cm soil depths. The porosity was found the highest (51.74 and 51.15 %) under grass mulch, which was attributed to higher organic carbon contents (20.35 and 18.35 g kg^{-1}) and lower bulk density (1.27 and 1.29 Mg m^{-3}) at 0-15 and 15-30 cm soil depths, respectively. The plant available water was found significantly maximum (16.45 and 15.63 %) under grass mulch at 0-15 and 15-30 cm soil depths, respectively. The availability of macro-nutrients (N, P and K) in soil was recorded significantly higher under the black polyethylene mulch. The highest plant height (172.2 cm), fruit per plant (28.33), fruit weight (62.2 g), fruit diameter (5.76 cm) and yield (63.6 t ha^{-1}) were observed in T_1-BM. The yield under black mulched treatment was 40.08 per cent higher than the control. The maximum water use efficiency (1.85 t ha^{-1} cm^{-1}) was recorded under T_1-BM which was 44.53 per cent higher as compared to no mulch treatment. The maximum net return per hectare ₹ 9.46 lakhs with higher B:C ratio (4.58) was found under T_1-BM. The study has led to a conclusion that maximizing water use efficiency, yield and net economic returns of tomato in mid hill region of Himachal Pradesh, T_1-BM i.e. black polyethylene mulch could be the best.

Signature of Major Advisor **Signature of student**

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