CROP WEATHER SIMULATION MODEL IN TOMATO
(*Solanum lycopersicum* L.)

By

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(2016-11-119)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL METEOROLOGY

COLLEGE OF HORTICULTURE

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KERALA, INDIA

2018

DECLARATION

I hereby declare that the thesis entitled **" Crop weather simulation model in tomato (*Solanum lycopersicum* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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ACKNOWLEDGEMENT

Gratitude takes three forms "a feeling from the heart, an expression in words and a giving in return". I sincerely thank all those who directly or indirectly made this research possible.

I feel immense pleasure to express my gratefulness towards each and every member of my advisory committee and I consider myself fortunate to have enjoyed the privilege of being guided by them during my research program. First of all, I wish to place on record my deep sense of gratitude and respect to ***Dr. B. Ajithkumar,*** *Chairman of my advisory committee and Assistant Professor and Head of the Department of Agricultural Meteorology, for his inspiring and precious suggestions, untiring interest and constructive criticisms throughout the course of my study period.*

I consider it as my privilege to express my deep-felt gratitude to ***Dr. Laly John C.*** *member of my advisory committee and Professor of the Department of Agricultural Statistics, for helping me in the statistical analysis. I am extremely thankful to her for the unforgettable care, well-timed support, constructive suggestions and critical evaluation of the manuscript which greatly improved the thesis.*

I feel great pleasure to express my indebtedness to ***Dr. Indira P.*** *Member of my advisory committee and Professor and Head of the Department of Vegetable Science, for the valuable advices, ever-willing help and encouragement during my field study and for the relevant suggestions during the preparation of the manuscript.*

It is with immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude to ***Dr. Beena V. I.*** *Assistant Professor, Soil Science and Agricultural Chemistry, AICRP on STCR, College of Horticulture, Vellanikkara and member of my advisory committee for her constant support, valuable suggestions and critical scrutiny of the manuscript.*

I am deeply obliged ***Smt. P. Lincy Davis and Shajeesh Jan sir,*** *Department of Agricultural Meteorology, for their invaluable help, guidance and critical assessment throughout the period of work. I thank them for all the help and cooperation they has extended to me.*

My heartfelt thanks to ***Dr. Dijee Bastian,*** *UG Academic Officer and* ***Dr. Jessy Thomas,*** *PG Academic Officer, for all sorts of helps rendered throughout the course of study.*

I acknowledge the relevant suggestions that I received from the teachers of the College of Horticulture during the thesis defense seminar.

I take this opportunity to thank ***Mr. Gangadharan, Mr. Paulose*** *of my Department for their immense help for the completion of my research work.*

I take this opportunity to thank ***Mr. Sreejith, Ms. Anu, Mrs. Deena Biju, Mrs. Mini, Mrs. Suchithra, Ms. Likitha, Mrs. Remisha, Mrs Amani,*** *of my Department for the unconditional help and co-operation provided by them in these two years.*

I express my deep sense of gratitude to staff members of AICRP on STCR, Mr. ***Anantha Krishnan, Mr. Srinath, Mr. Akhil, Ms. Sreetha, Mrs. Bijini*** *for their support and help during investigation period and preparation of manuscript.*

I sincerely acknowledge the help and support of ***Mrs. Reji, Mrs. Indira, Mrs, Shaji, Mrs. Savitha*** *and all other staffs of the Department of Soil science and Agricultural chemistry for all sorts of helps rendered by them.*

I sincerely acknowledge the help and support of ***Mrs. Sreela*** *and all other staffs of the Department of Agronomy for all sorts of helps rendered by them.*

With immense pleasure, I thank my seniors, ***Mr. Arjun, Mrs. Sushna Narayan, Ms. Smitha, Ms. Aswini, Ms. Aswathy C, Mr. Jasti venkata satish, Mr. Raghunath H. N, Mr. Lokesh, Mr. Veeresh, Ms. Supritha, Ms. Ramya, Ms, Deepa*** *for the constant support and indispensable help provided by them.*

I extend my loving gratitude to my juniors, ***Anu nayana, Haritha raj, Megha*** *who had contributed in some way or other towards the completion of this work.*

I wholeheartedly thank my friends, ***Athira, Dharini, Kavya, Shilpa, Pooja, Ashwini, Veena, Kavya, Anjali, Chaitra, Deepa, Spandu , Navya, Rekha , Chitra, Geetha, Nagendra, Kiran, Jagga, Amith*** *and all other batch-mates for their love, co-operation and help.*

On my personal ground, I cannot forget the fondness, constant support and encouragement showered by my loving family. I deeply express my special whole hearted thanks to my loving parents, ***Mr. Sundar and Mrs. Shylaja*** *and to my cousins* ***Nandish. S, Nandish. N, Naveen, Nithin, Megha , Navya, Naveen, Usha, Ulhas, Divya, Kavya*** *for their boundless affection, support, prayers, blessings and personal sacrifices for me.*

*I owe my thanks to **Dr. A. T. Francis,** Librarian, College of Horticulture and with all regards, I acknowledge the whole-hearted co-operation and gracious help rendered by each and every member of the College of Horticulture during the period of study. I sincerely thank the facilities rendered by the College Library, Computer Club and Central Library.*

*I express my special thanks to **Mr. Aravind** of Students' computer centre for his valuable support and affection to me. I am obliged to Kerala Agricultural University for granting me the Junior Research Fellowship.*

Once again, I thank all those, who extended help and support during the course of study and a word of apology to those, I have not mention in person.

Above all, I gratefully bow my head before the Almighty, for the blessings showered upon me in completing the thesis successfully. It would be impossible to list out all those who have helped me in one way or another in the completion of this work. I once again express my heartfelt thanks to all those who helped me in completing this venture in time.

Navya 31/8/18

NAVYASHREE S.

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INTRODUCTION

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is known as protective food because of its special nutritive value and wide spread production. As it is short duration crop and gives high yield, it is important from economic point of view and hence area under its cultivation is increasing day by day. It is grown in an area of 4.5 million hectares worldwide with annual production of 152.9 million tons and productivity of 32.8 t ha^{-1}. In India, it ranks third after potato and onion and is cultivated in an area of 3,50,000 hectares with an annual production of 5.3 million ton and productivity of 19.5 t ha^{-1} (Indian Horticulture Database, 2011). In Kerala, productivity of tomato is 15 to 30 t ha^{-1}. Tomato is a rich source of minerals, vitamins, essential amino acids and dietary fibers and healthacids and used in many preserved products like ketch-up, sauce, chutney, soup, paste, puree (Kalloo, 1993).

Planting time is one of the most important factors among the various cultural practices followed for the production of tomato that greatly influence its growth and yield. There is a wide range of planting time, which may affect its yield and quality due to varying climatic conditions at different stages of crop. The variation in planting time also affects the plant vigour and spread, which further affects the yield and quality of fruits.

Weather parameters play an important role in the growth and yield of tomato. The crop is sensitive to low and high temperature. During transplanting, low temperature leads to poor stand of crop. Whereas, high temperature leads to excessive flower drop which interferes with fruit set. Hence it has become more essential to find out the optimum date of transplanting so that the plants may be exposed to most conducive atmosphere during their growth period for fruit set and higher total yield.

Moisture stress is one of the major problems for the cultivation of tomato, which affects the production adversely. Hence much attention has to be paid on the use of soil cover. The practice of mulching has been utilized in crops and has been proven to significantly conserve moisture, maintain favorable soil temperature, prevent erosion and reduce weed growth, which results in better plant growth and development (Rao *et al.*, 2016).

The wide gap between potential and actual growth and yield of tomato largely depends on the various weather factors like temperature, rainfall, solar radiation and relative humidity that prevail during the growing season. In order to study the impact of various weather parameters in the actual field conditions, the use of a suitable model becomes mandatory. In this context, crop growth simulation models are emerging technological tools with potential uses for interpreting research. The CROPGRO model is a dynamic simulation model that simulates growth and development of tomato and it uses standard input files for weather and soil condition as well as crop management.

In this context, the present study entitled " Crop weather simulation model in tomato (*Solanum lycopersicum* L.) " was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2017-2018 with the following objectives

- To calibrate the genetic coefficients for tomato using DSSAT CROPGRO-Tomato model
- To evaluate the micrometeorological aspects of tomato under different growing environments

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Weather parameters like rainfall, temperature, humidity, wind and solar radiation play an important role in the growth and yield of tomato. The plants under mulched conditions in all transplanting dates gave better performance in terms of yield, growth and water use efficiency (Elsayed *et al*., 2012). Crop growth simulation models are emerging technological tools with potential uses for interpreting research and it is a dynamic simulation model that simulates growth and development of tomato.

The relevant literature to the present experiment entitled "Crop weather simulation model in tomato (*Solanum lycopersicum* L.)" has been reviewed and presented in this chapter.

2.1. WEATHER PARAMETERS

According to Adegoroye and Jolliffe (1987), uneven ripening and sunscald injury are the two disorders due to direct effects of light on tomato fruits. Sunscald injury increased with irradiance and air temperature and by their combined effects.

Cockshull *et al.* (1992) reported that a cool and low-light environment, 23% shade reduced the yield by 20%. Field-grown fruit exposed to sunlight were more likely to develop cracks compared to shaded fruit (Emmons and Scott, 1997).

Tomato fruits are more sensitive to elevated temperature, it affected the rates of fruit growth in volume. Low temperatures reduced volume growth rates and delayed the time at which the absolute growth rate became maximal. Fruits at high (26.8^{o} C) and low (14.8^{0} C) temperature regimes combined with less flower numbers and low fruit set at 26.8^{o} C, resulted in low fruit yields. The shoot dry matter content also affected by temperature (Adams *et al.,* 2001).

Dorais *et al*. (2001) concluded from the study influence of electric conductivity management on greenhouse tomato yield and fruit quality that the high light intensity can lead to several disorders in development and appearance of tomato fruit that affected quality. Benefit of shading was less blossom end rot and cracked skin.

Ahmad and Singh (2005) conducted study on effects of staking and row-spacing on the yield of tomato in the Sokoto Fadama, Nigeria. The study revealed that the heavy tropical rains caused mechanical damage to flowers along with high humidity that created a favourable environment for pests and diseases which resulted in poor quality of its fruit and low yield.

Marsic *et al.* (2005) conducted a study on the influence of different climatic conditions on fruit yield and quality of tomato cultivars. The experiment was conducted in the mediteranean and central regions of Slovenia. The results showed that low temperatures and high precipitation in summer contribute to the variability of field tomato yielding leading to worsen the quality of the yield.

According to Van Ploeg and Heuvelink (2005), temperature has a high effect on all aspects of tomato crop development. Truss and leaf initiation rates decrease linearly with decreasing temperature. At sub-optimal temperatures, as a result of poorer pollen quality fruit set is reduced.

Adekiya and Agbede (2009), conducted experiment on effects of tillage methods on soil properties, nutrient content, growth and yield of tomato on an alfisol of Southwestern Nigeria. The results showed that the phenological events like days to flowering, fruiting and maturity of the crop were important in determining the productivity of the crop. Temperature has an important role in phenological development and productivity of crop plants. High temperature influences crop to mature. However production level is relatively affected by high amount of rainfall and unevenly distribution rainfall during the rainy season.

The study, effect of black polyethylene mulch on yield of field-grown cucumber carried out in Poland showed that, depending on the species and the developmental stage meteorological elements have a differential impact to the height and the quality of yield of crop plants (Spiżewski *et al.,* 2010).

Oladitan *et al.,* (2014) conducted studies on influence of weather elements on phenological stages and yield components of tomato varieties in rainforest ecological zone, Nigeria. The results confirmed that rainfall had positive effect during vegetative growth and negative effects during reproductive growth. However significant negative correlation were noticed between the yield and relative humidity.

Li *et al.* (2015) confirmed that growth and yield of the tomato was effected by day and night temperature difference. Set DIF as 6 °C (25/19 °C), 8 °C (26/18 °C), 10 °C (27/17 °C) respectively. The growth and development of the tomato significantly improved at DIF 6 °C, DIF 8 °C. DIF 10 °C reduced the seedling's growth and flowering, the plant height decreased by 12.0% - 18.3%.

Nduwimana and Wei (2017) claimed that during flowering stage high temperatures desperately affected the plant development and more numbers of aborted flowers were noted at temperatures higher than $35/25^0$ C (day/night temperatures). Flower initiation and multiplication however affected less. Growers should ensure that the hottest months of the year do not coincide with the flowering periods.

2.2. MICROMETEOROLOGICAL PARAMETERS

Gutal *et al.* (1992) noticed that the use of plastic mulches helped to increase the production per unit area for all types of crops, colored polyethylene mulch films increase soil temperature by 5-7 °C, leads to faster germination and better root proliferation and checks weed growth, preserving the soil structure, retaining soil moisture and increasing CO_2 contents around the plants.

Agele *et al.* (1999) reported that an experiment on effect of mulching and plant density on the performance of late-season tomato in Southern Nigeria, showed that use of straw mulch increased soil moisture at 10cm depth and decreased soil temperature at 5cm depth throughout tomato growth compared to bare ground.

The soil temperature under black plastic mulch was 3^0 C higher at 5 cm depth and 1.6°C higher at 10 cm depth compared to that of bare soil. With the use of plasticulture, the crops showed increase in earliness, yield and fruit quality (Lamont, 1999).

Usman *et al.* (2005) noticed that black mulch conserved significantly maximum moisture (13.33%), while minimum moisture was found in plots with hand weeding twice (6.49%).

Mamkagh (2009) conducted study on effect of tillage time and plastic mulch on growth and yield of okra (*Abelmoschus esculentus*). Field experiments were conducted during 2005 and 2006 at Agricultural Research Station, Faculty of Agriculture, Mutah University, Jordan. The application of black mulch in okra resulted in significantly maximum soil moisture content of 25.94 % while non-mulched plot recorded minimum soil moisture content of 20.58 %

The study comparison of different mulch materials in a tomato (*Solanum lycopersicum* L.) crop showed that, the mean soil temperature under different mulches *viz.* biodegradable (27.8ºC), aluminized (28.7ºC) and polyethylene (31.8ºC) were significantly different (Moreno, 2009).

Singh *et al.* (2009) claimed that with polyethylene much in tomato the soil temperature was 2-3°C above the control and soil moisture was 43.7 - 62.5% higher than control.

Moolchand (2010) found that in the experiment on pea, black mulch saved significantly maximum soil moisture (13.3%) followed by straw mulch (8.8%), while minimum moisture was noticed in control.

Ashrafuzzaman *et al.* (2011) conducted an experiment on effect of plastic mulch on growth and yield of chilli in Brahmaputra flood plain and reported that maximum difference in soil temperatures between polythene mulch and control plots was 5.1 to 5.7°C at 5 cm soil depth at 3pm. The transparent polythene mulch apparently showed highest soil moisture (21.1%) followed by black (20.4%) and blue (19.2%) polythene mulches. The lowest moisture (14.6%) was recorded in the control plot.

Anderson *et al.* (2012) noticed that afternoon soil temperature at 10cm depth during April and May generally ranged from 25 to 31ºC and was usually 2 to 4ºC higher under black mulch than the other mulch treatments.

Rajablariani *et al.* (2012) claimed that use of plastic mulch increased soil temperature from 3.3 to 6.6°C compared to without mulch in tomato.

Singh and Kamal (2012) conducted study on the effect of mulching with black plastic sheets on soil temperature and tomato yield and confirmed that the difference in temperature between mulched and bare soil was 2.2 – 3.4 °C during May at 10 cm depth. The mean temperature of soil without mulching was 31.9°C and black plastic mulch was 34.4°C.

According to Samuel *et al.* (2013), mulching significantly reduced soil temperatures and soil temperature under grass mulch were less compared with polythene mulch and unmulched plots (bare ground). Compared to unmulched plots the average soil temperature under dry grass mulching was 3°C lower. Increased in the soil moisture content also noticed at 10 cm depth compared with unmulched treatment.

Dalorima *et al.* (2014) stated that the use of plastic mulch and straw mulch resulted in higher soil moisture content (83.60% and 80.73% respectively) when compared to all other treatments.

Mahadeen (2014) conducted a study on effect of polyethylene black plastic mulch on growth and yield of two summer vegetable crops under rain-fed conditions under semi-arid region conditions at Jordan. The results confirmed that in summer vegetable crops, soil moisture content was retained more under the black polyethylene mulch which was about 27 and 18.1 percent, while the non-mulched plots retained lower soil moisture content of 22.9 and 15.5 percent at 30 and 60 days after planting respectively.

Aniekwe (2015) conducted experiment on comparative effects of organic and plastic mulches on the environment, growth and yield of okra and revealed that temperature under black plastic mulch was the highest (28.4 °C) when compared to unmulched plots (27.6 °C).

2.3. SOIL NUTRIENTS

Borthakur and Bhattacharya (1992) claimed that, the influence of mulches on soil pH was found to be maximum in water hyacinth and paddy husk mulch (5.56 pH) and minimum in treatment with no mulch (4.98).

Shashidhar *et al.* (2009) stated that in the study differential effects of mulches on soil pH and organic carbon conducted at Bangalore, the more soil pH (neutral) and organic carbon (0.66%) was noticed in mulched plots. Whereas in unmulched plots organic carbon content was 0.48%.

Sinkeviciene *et al.* (2009) reported from the experiment influence of organic mulches on soil properties and crop yield, conducted at Lithuanian University of Agriculture. Throughout the experiment higher crop yields were noticed in grass-mulched plots. The maximum nutrient inputs to the soil occurred when grass mulch was used. Grass mulch readily decomposed when compared to other mulches and it is a constant and quick supplier of available nutrients for plants.

In the 25-year fertilizer experiment, wheat straw incorporation on soil properties and crop yields in a crop rotation system in semiarid conditions in China showed that the activity levels of invertase, urease and alkaline phosphatase in the topsoil (0–15 cm) were higher with straw manure combined with chemical fertilizer compared with the control (Zhao *et al.* 2009).

Siczek and Frac (2012) claimed that the straw mulch caused stimulation of the bacteria total number (50.4 ×108 cfu kg^{-1}) and enzymatic activity in the soil, dehydrogenases (7.6 cm^3 H^2 kg^{-1} d^{-1}), alkaline phosphatases (23.2 mmol PNP kg^{-1} h^{-1}) and acid phosphatases (39.5 mmol PNP kg^{-1} h^{-1}), while the unmulched treatment recorded lowest bacteria total number (39.7 ×108 cfu kg^{-1}) and enzymatic activity in the soil, dehydrogenases (6.1 cm^3 H^2 kg^{-1} d^{-1}), alkaline phosphatases (9.3 mmol PNP kg^{-1} h^{-1}) and acid phosphatases (32.6 mmol PNP kg^{-1} h^{-1}).

More *et al.* (2014) noticed that maximum available N (321.33 kg ha^{-1}), P_2O_5 (68.33 kg ha^{-1}) and K_2O (341.33 kg ha^{-1}) in soil under black top white bottompolythene mulch, while the minimum available N (251.33 kg ha^{-1}), P_2O_5 (42.67 kg ha^{-1}) and K_2O (291.67 kg ha^{-1}) were recorded under control (no mulch). Paddy straw mulch has recorded 277 kg ha^{-1}, 56.67 kg ha^{-1} and 304 kg ha^{-1} of available N, P_2O_5 and K_2O respectively in tomato.

Singh *et al.* (2015) reported that pine needle mulch recorded lowest soil pH (7.08), EC (0.239dS m^{-1}), maximum available nitrogen (314.75 kg ha^{-1}), phosphorus (46.28 kg ha^{-1}) and potassium (400.43 kgha^{-1}) which was on par with black polythene mulch, while the highest soil pH (7.19), EC (0.255dS m^{-1}), minimum available nitrogen (297.49 kg ha^{-1}), phosphorus (38.86 kg ha-1) and potassium (366.25 kg ha^{-1}) were recorded in unmulched treatment in tomato.

According to Wei *et al.* (2015) wheat straw incorporation at a rate of 9000 kg ha^{-1} and 6000 kg ha^{-1} resulted in 39.6% and 27.3% significantly higher phosphatase activity levels than control.

Monsefi *et al.* (2016) found that paddy straw mulch recorded lower pH and EC and the OC over dust mulch. This was due to the fact that residue when left on soil surface and after decomposition increased the organic carbon which lowers downed the electrical conductivity and soil pH.

2.4. PLANT NUTRIENTS

Famoso and Bautista (1983) concluded that mulching increased the number of flowers per plant, the chlorophyll contents of the leaves, dry matter total yield of plant, P and K contents and organic matter contents of the soil.

Wein and Minotti (1987) observed that plastic mulching increased total yield and shoot concentration of N, P, K, Ca, Mg, Cu and B compared to unmulched plants.

Chaudhary *et al.* (2002) conducted a study to investigate the effect of different coloured (black, red and green) plastic mulches on nutrient contents, growth and yield of tomato (*Lycopersicon esculentum* Mill) variety Indian dwarf. Results revealed that total nitrogen contents in plants were higher (4.34%) in the green plastic mulch whereas P and K contents in plants were observed to be significantly higher (0.35 and 3.74%) in black plastic mulch. The N and K contents in fruits showed significant variation among all the mulched treatments but the P contents were found to be non-significant. The data showed significant effect on the yield of tomato. The highest yield (28.69 t ha $^{-1}$) was recorded in green plastic mulch followed by red (22.7 t ha $^{-1}$) and black plastic (15.84 ha $^{-1}$) mulched treatments. The study concluded that the green mulch was the best treatment with regard to tomato production.

Maurya *et al.* (2017) In groundnut, irrigation regimes and mulching did not affect significantly the total N, P, K and S contents However, N, K and S contents decreased with increasing number of irrigation and moisture availability, which was mainly due to dilution effect as a consequence of increased dry matter production. The higher P content in kernels and haulms was recorded with irrigation at 60 mm CPE and in paddy straw mulching. Nutrients uptake by groundnut significantly influenced by irrigation regimes, mulching and INM. Irrigation at 60 CPE and paddy straw mulch recorded maximum N, P, K and S uptake by kernels, haulms and the total nutrients uptake. Better soil moisture conditions prevailing in these treatments could have facilitated more uptake of nutrients.

2.5. BIOMETRIC PARAMETERS

According to Chakraborty and Sadhu (1994), among the mulches of different colours, black and red polyethylene increased the plant height by 23.8 and 30.9 percent, respectively as compared to control.

Schonbeck (1999) reported that use of black polythene mulch can block the weeds except for a few emerging through planting holes. But labour requirements for mulching and transplanting were greater for plastic than for organic mulches. However, two layers of newsprint laid under hay straw significantly enhanced weed suppression.

Hudu *et al.* (2002) conducted an experiment on effect of mulching on growth and yield of irrigated tomato (*Lycopersicon esculentum* Mill.) and weed infestation in semiarid zone of Nigeria. From the results it was clear that plant height under mulched condition was maximum (35.5cm) compared to plants grown on bare soil (25 cm).

Nagalakshmi *et al.* (2002) confirmed that in tomato significantly maximum number of fruits per plant (97.67) and yield (8.6 t ha^{-1}) were obtained from the black plastic mulch plot compared to organic mulch.

Ngouajio and Ernest (2004) conducted a study on Light transmission through coloured polyethylene mulches affected weed population and reported that with the use of plastic mulches weed control is the most benefit thing in vegetable production. The mulches decrease light transmission and prevent development of most weed species.

According to Khan *et al.* (2005) number of fruits per cluster (5.92), maximum plant height (93 cm), and yield (96.45 t ha^{-1}) was obtained in plot with 4 inch straw mulch in tomato compared to bare ground (control) which recorded less number of fruits per cluster (3.54), minimum plant height (78.26 cm), and yield (55.41 t ha^{-1}). Compared to control, straw mulch has increased 43% tomato yield and conserved 27% more moisture.

Sha and Karuppaiah (2005) noticed that in the experiment conducted on integrated weed management in brinjal at Annamalai University, Annamalainagar showed that the black polythene sheet mulching recorded maximum number of

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flowers per plant (53.57) and fruit yield per plant (0.69 kg) compared to fallow which recorded fruit yield of (0.36 kg) per plant and lowest number of flowers (32.54).

Singh *et al.* (2005) conducted an experiment on effect of transplanting time and mulching on growth and yield of tomato at Central Institute of Postharvest Engineering and Technology, Abohar. Between different dates of planting, early planting (10^{th} December) recorded the highest vegetative growth, yield attributes, early and total fruit yield compared to 20^{th} January planting. Among different mulch materials used, black polyethylene maintained higher soil moisture and temperature compared to other materials and control. Fruit yield was higher with black polyethylene mulch compared to other mulch materials.

Gandhi and Bains (2006) conducted an experiment on effect of mulching and date of transplanting on yield contributing characters of tomato at Punjab Agricultural University. From the results it was concluded that, the application of black top white bottompolythene mulch in tomato had increased number of branches (9.1), yield (65.47 t ha^{-1}) and average fruit weight (31.39 g). The lowest number of branches (8.1), fruit weight (29.09 g) and total yield (47.85 t ha^{-1}) was recorded in treatment with no mulch. Hence the mulches modified the microclimate by altering soil temperature and soil moisture and this affected the yield contributing characters of tomato.

The application of rice straw mulch showed significantly highest number of fruits per plant (38.60), maximum plant height (83.2 cm), average fruit weight (83.40 g), highest fruit yield per plant (1.82 kg). However the lowest number of fruit per plant (28.68), plant height (73.2 cm), average fruit weight (54.80 g), fruit yield per plant (1.15 kg) was recorded in control (Rahman, 2006).

Awodoyin *et al.* (2007) observed from an experiment, effects of three mulch types on the growth and yield of tomato (*Lycopersicon esculentum* Mill.) and weed suppression, conducted in Rainforest-savanna Transition Zone of Nigeria. The plastic mulch has recorded significantly maximum plant height (110.3 cm) which was non significantly differed with hand weeding twice (103.9 cm) whereas maximum fruit yield (12.7 t ha^{-1}) was obtained in mulching with wood-chips which was on par with hand weeding twice (12.4 t ha^{-1}) and plastic mulch (12.2 t ha^{-1}) in tomato. Hence mulches are effective in controlling weeds and conservation of soil moisture. These modification in crop growing environment resulted in increased growth and fruit yield of tomato.

Ngouajio *et al.* (2008) stated from the study on field performance of aliphatic-aromatic copolyester biodegradable mulch films in a fresh market tomato production system that complete elimination of weeds with the use of black polyethylene in fresh market-tomato production system.

Firoz *et al.* (2009), conducted a study at the Hill Agricultural Research Station, Khagrachari to find out the effect of mulching method and planting times on the yield attributes of tomato in hill slope. The maximum yield (21.43 t ha^{-1}) was obtained from plant where mulch was given one month before planting. Among three planting times, the maximum yield (15.27 t ha^{-1}) was obtained from 1st October planting. In case of interaction effect, mulching one month before planting with 1st October planting produced the maximum yield (28.06 t ha^{-1}).

The study effect of black plastic mulch on soil temperature and tomato yield conducted in mid hills of Garhwal Himalayas showed that, the use of black polyethylene mulch resulted in significantly highest fruit yield of 57.87 t ha^{-1}, maximum plant height of 85.5 cm, and average fruit weight of 86.6 g, while no mulch treatment recorded lowest fruit yield (29.43 t ha^{-1}), plant height (69.4 cm), and average fruit weight (62.3 g) in tomato (Singh *et al.* 2009).

Islam *et al.* (2010) carried out an experiment at the Horticultural farm of the Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, during September 2006 to April 2007 to investigate growth and yield of sweet pepper as influenced by sowing date. influence of sowing date on growth and yield of sweet pepper. There were seven sowing dates *viz.*, 1st September, 15th September, 1st October, 15th October, 30th October, 15th November and 30th November. The results of the experiment proved that the majority of growth parameters and yield constituents were significantly increased at the earlier sowing (October 1st) with a yield of 19.36 t/ha.

Rashid *et al.* (2010) found that higher plant density (10481 plants ha^{-1}), number of fruits per plant (17.6) and fruit yield (11.4 t ha^{-1}) were observed in black plastic mulch plots compared to non-mulched plots (7350 plants ha^{-1}, 14.2 and 7.36 t ha^{-1} respectively).

Ashrafuzzaman *et al.* (2011) concluded from an experiment, effect of plastic mulch on growth and yield of chilli (*Capsicum annuum* L.) in Brahmaputra Floodplain, that plastic mulch had tremendous effects on the growth and yield of chilli and black plastic mulch showed superior performance among the plastic mulches for yield and yield attributing traits like number of fruits, fruit diameter, number of branches and plant height.

Black mulch used on full ridge and half furrow showed significantly highest fruit number (42.9), fruit yield (3.49 kg), total fruit yield (91.82 t ha^{-1}) per bush, while no mulch treatment recorded the lowest fruit number (34.91), fruit yield (2.88 kg), total fruit yield (75.78 t ha^{-1})in tomato (Hatami *et al.*, 2012).

Kumar *et al.* (2012) reported that an experiment effect of drip irrigation levels and mulches on growth, yield and water use efficiency of tomato conducted at Water Technology Centre, Rajendranagar, Hyderabad showed that use of black polythene mulch had significantly higher plant height (106 cm), number of fruits per plant (51.22), fruit yield per plant (2.56 kg) and fruit yield per hectare (34.03 t) which was on par with paddy straw mulch, while the unmulched control recorded the lowest plant height (95 cm), number of fruits per plant (43.11), fruit yield per plant (2.15 kg) and fruit yield per hectare (28.61 t).

Rajablariani *et al.* (2012) revealed that black polythene mulch showed significantly maximum plant height (82.3 cm) and highest fruit yield (44 t ha^{-1}) when compared to unmulched plot which has recorded minimum plant height (53 cm) and low fruit yield (4.5 t ha^{-1}) in tomato.

Samuel *et al.* (2013) concluded that use of black plastic mulch in tomato increased the plant height (133.4 cm), number of fruits per plant (43.4) and fruit yield (1.39 t ha^{-1}), compared to unmulched control plot in which the plant height was 118.4 cm, number of fruits were 37.3 and fruit yield was 1.17 t $ha^{-1.}$

Ali *et al.* (2014) conducted a field trial on performance of tomato as influenced by organic manure and sowing date during the 2013 dry season at the teaching and research farm of Samaru College of Agriculture, Ahmadu Bello University, Zaria on the growth and yield of tomato. The sowing dates are 8th January, 22nd January, 5th February and 19th February. Results obtained indicated that growth and yield of tomato was highest in 5th February sowing.

Bakht and Khan (2014) conducted an axperiment at the Agricultural Research Farm of the University of Agriculture, Peshawar during 2012 and 2013 to determine the impact of row spacing and weed management strategies on tomato (*Lycopersicon esculantum* Mill.). Variety 'Roma'. Among the treatments, black plastic mulch has recorded significantly highest fruit yield (4.04 t ha^{-1}) which was on par with hand weeding (3.32 t ha^{-1}). The control without weeding recorded the lowest fruit yield (1.4 t ha^{-1}).

Bora and Babu (2014) observed that black polyethylene mulch plus drip irrigation showed significantly highest fruit yield (57.87 t ha^{-1}), maximum plant height (85.5 cm) and highest average fruit weight (86.6 g), compared to the plots without mulch, which recorded lowest fruit yield (29.43 t ha^{-1}), plant height (69.4 cm) and average fruit weight (62.3 g) in tomato.

Hossain *et al.* (2014) observed the effect of sowing dates on yield of tomato genotypes at Agricultural Research Station, BARI, Thakurgaon, Bangladesh during 2009-10. Number of fruits per plant was highest (27.40) in 1st October sowing and the lowest (13.73) was in 30st October sowing. October 1st sowing was found better in respect of yield (74.75 t ha^{-1}) compared to October 15 (58.55 t ha^{-1}) and October 30 (24.60 t ha^{-1}) sowing.

More *et al.* (2014) noticed that black polythene mulch had significantly maximum plant height (108.73cm), more branches per plant (5.32), more number of fruits per plant (29.92), maximum fruit diameter (4.42 cm), highest average fruit weight (43.57 g), more fruit yield per plant (1.22 kg) and highest total fruit yield (45.26 t ha^{-1}), while the control (no mulch) recorded minimum values.

Tegen *et al.* (2014) conducted a study on effects of mulching material on the early fruit yield of tomato (*Lycopersicon esculentum* Mill.) Varieties under polyhouse growing condition. The effect of different mulch types on early fruit yield was found statistically significant. The highest early marketable fruit yield of 10.99 t ha^{-1} and 10.54 t ha^{-1} were recorded when Miya variety was grown with white and black plastic mulch, respectively. Therefore, use of white and black plastic mulches recommended for early tomato fruit yield.

Bhujbal *et al.* (2015) carried out an experiment on effects of mulches on growth and yield of tomato (*Lycopersicon esculentum* Mill.) during rabi season of 2010–11 at Instructional cum Research Farm, Department of Horticulture, College of Agriculture, Latur. The results showed that black polythene mulch recorded significantly maximum height of plant at 120 DAT (83.48 cm), maximum number of branches per plant (6.26), maximum yield per plant (1.63 kg) and more yield per hectare (60.61 t) in tomato.

Singh *et al.* (2015) concluded from an experiment, effect of planting date and integrated nutrient management on the production potential of tomato at the vegetable research farm, Maharajpur. The different date of planting are September 15th (D1), September 30th (D2) and October 15th (D3). The result shown that the growth parameters and yield attributing characters were significantly influenced by different planting dates and sources of nutrients. Planting on September 15th (D1) recorded the highest plant height (254.95 cm),number of leaves per plant (33.47), fruits per plant (80.39), fruit length (6.75 cm), fruit girth (5.53 cm), mean fruit weight (124.26 g), yield per plant (10.39 kg), yield per plot (42.44 kg) and TSS (5.55 °B) content compared to later date of planting.

2.6. PHENOLOGICAL CHARACTERS

Slack and Calvert (1978) noticed a positive correlation between increasing night temperature and early fruit yield in tomato. However final yield was negatively correlated to temperature.

Gent (1988) stated that under a day night temperature difference of 9.0°C, greenhouse tomatoes grew and ripened quickly, resulted in greater yield. Grimstad and Frimanslund (1993) studied that an average daily temperature of 15.0 to 25.0°C reduced the time to first cucumber harvest in greenhouse by 1.6 day $C^{-1.}$

Ho (1996) observed that under low light conditions, more leaves are initiated prior to the inflorescence hence initiation of first inflorescence is delayed in tomato. Temperature affected flower initiation, flower development, fruit set and fruit growth simultaneously.

Anbarasan (2002) claimed that tomato crop during *kharif* season took 60.71 days and whereas it was 55.09 days for fifty per cent flowering in summer.

Islam *et al.* (2010) carried out an experiment on influence of sowing date on growth and yield of sweet pepper. There were seven sowing dates *viz.* September 1st , September 15th , October 1st , October 15th , October 30th , November 15th and November 30th . The results of the experiment proved that the plants of 15th September took less period (97.89 days) for 50% flowering whereas 30th November sowing took the maximum period (116.56 days).

Hossain *et al.* (2014) noticed the effect of sowing dates on yield of tomato genotypes. Among the three sowing dates *viz.* October 1st , October 15th and October 30th , early flowering (52.40 days) as well as early fruit harvesting (119.13 days) was occurred in October 1 sowing, where as sowing on October 30 resulted in delayed flowering (71.73 days) and fruit harvesting (140.67 days), respectively.

Singh *et al.* (2014) stated that in an experiment, influence of mulch and biofertilizers on growth and yield of tomato black polythene mulch recorded significantly maximum harvest duration (76.79 days), minimum number of days to first flowering (42.46), minimum number of days to first harvest (68.09), while no mulch recorded minimum harvest duration (74.25 days), maximum number of days to first flowering (44.72), maximum number of days to first harvest (71.33) in tomato. Date of sowing significantly influenced the days to 50% flowering in tomato.

Tegen *et al*. (2014) conducted a study on effects of mulching material on the early fruit yield of tomato (*Lycopersicon esculentum* Mill.) varieties under polyhouse growing condition. The results showed that white plastic mulch resulted in significantly ($P < 0.05$) earlier flowering, fruit setting and fruit maturity compared to other mulching materials.

Bhujbal *et al.* (2015), the experiment conducted on the effects of different types of mulches on flowering, fruiting, yield and incidence of pest and diseases of tomato. (*Lycopersicon esculentum* Mill.) *Var*. Dhanashree. showed that, the flowering and fruiting attributes like lowest number of days for initiation of flowering of tomato (30.40 days), minimum number of days to first picking of tomato (83.40 days), was observed in treatment black colour on silver polythene mulch treatment.

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2.7. HEAT UNITS

According to Singh *et al* . (1990), a two year study on effect of sowing date on requirement of growing degree days, heliothermal units and photothermal units, and phenology of winter maize (Zea mays) indicated that, days to tasselling, silking and maturity decreased gradually with delay in sowing. On all sowing dates, the accumulation of heat sums, heliothermal units and photothermal units showed similar trends, but at emergence and maturity only the accumulation patterns of heliothermal units and photothermal units were identical. Correlations between cumulative heat sums, cumulative heliothermal units and cumulative photothermal units for various growth stages showed that the onset of growth stages depended more on the temperature than on sunshine hours and daylength.

Mukherjee and Sastri (2000) studied the influence of thermal environment on biomass accumulation in different genotypes of tomato (*Lycopersicon esculentum* Mill.). Tomato cultivars pusa sadabahar, pusa sheetal and pusa gaurav were sown on 15^{th} and 25^{th} January, and 7^{th} February 1999, respectively, in New Delhi. Accumulated heat units (growing degree days, heliothermal units and photothermal units) was analysed and the results showed that among the three AHU studied, photothermal units varied most, but variation decreased as the crops approached maturity. Thermal accumulation were highest in crops sown on 15^{th} January and lowest in crops sown in 7^{th} February. All AHU indices showed correlation with dry plant biomass, but growing degree days had the highest correlation and was the best AHU for predicting biomass yield in tomato.

Sunil and Sarma (2005) conducted a field study on characterization of thermal environment under semiarid conditions in relation to growth and development of bottle gourd and tomato. The study revealed that in all the three transplantings, plants accumulated more degree days. Hence all the three transplanted crops suffered soil and air temperature stress.

Khichar and Niwas (2007) claimed that an experiment, thermal effect on growth and yield of wheat under different sowing environments and planting systems was conducted to study the effect of photothermal units on growth and yield under different sowing and planting systems during two consecutive rabi seasons of 2002–

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03 and 2003–04. Leaf area index, biological yield and grain yield were recorded in all the treatments. Thermal indices *i.e.* photothermal and heliothermal units were computed at different phenological stages of wheat crop. The wheat crop sown on 20th November consumed more photo and heliohermal units as compared to 20thDecember sown crop. The biological and grain yields were also significantly affected by sowing time, planting system and nitrogen level. Delay in sowing after 20^{th} November resulted in decrease in biological and grain yields.

Kumar *et al.* (2008) conducted an experiment on growth and yield response of soybean (*Glycine max L.*) in relation to temperature, photoperiod and sunshine duration at Anand. Field experiment was conducted using one cultivar of Soybean and three dates of sowing. Plant height, number of pods per plant, number of seed per pod, dry matter accumulation, stover yield and grain yield were correlated with GDD, HTU and PTU of agro climatic indices were observed for early sown soybean. The highest HUE of 0.83 g m per °C day for Stover and 0.78 g m^{-2} °C day for grain yield are recorded and GDD directly reflected in dry matter accumulation to soybean as well as Stover yield.

Singh *et al.* (2010) conducted study on effect of date of sowing on nodulation, growth, thermal requirement and grain yield of kharif mungbean genotypes. The study revealed that, there was a drastic reduction in yield in case of delayed sowing in both the years compared to early sowing. Since sufficient amount of heat units was absorbed in early sowings in less time as compared to late sowing.

Ram *et al.* (2012) conducted an experiment on accumulated heat unit requirement and yield of irrigated wheat (*Triticum aestivum* L.) varieties under different crop growing environment in central Punjab. Phenology, accumulation of growing degree days (GDD), helio-thermal unit (HTU), photo-thermal unit (PTU), and performance of wheat (*Triticum aestivum* L.) varieties grown under different sowing dates were studied. The October 25^{th} sown crop took maximum calendar days, growing degree days, photo-thermal unit and heliothermal unit for 75% earing and maturity which got reduced significantly with subsequent delay in sowing time. The grain yield recorded in October 25^{th} was statistically at par with November 5^{th}.

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The significant reduction in grain yield of timely sown varieties was recorded when sowing was delayed beyond November 15th.

Gill *et al.* (2014) studied the thermal requirement of wheat crop in different agroclimatic regions of Punjab under climate change scenarios. The experiment was conducted at two zones of the Punjab state (i.e., Central plain zone, Ludhiana and South-Western zone, Bathinda) to study the phenological behaviour of wheat cultivars under different environments. The two wheat varieties, three sowing dates and four irrigation levels. The growing degree days (GDD), heliothermal units (HTU) and photo thermal units (PTU) were calculated. It was found that the wheat crop sown in central zone acquired more number of days to reach physiological maturity and utilize heat more efficiently resulting in more grain yield as compared to south western zone station grown wheat crop. The number of days required to attain different phenological stages decreased with late sowing condition. It is concluded that timely sown crop exhibit best growth and yield as the favourable environmental conditions coincided with heat unit requirement of different phenophases of wheat in the central zone of Punjab.

Prakash *et al.* (2017) stated that, field experiment thermal utilization and heat use efficiency of sorghum cultivars in middle Indogangetic plains was conducted to study the phenology, accumulation of growing degree days (GDD), heliothermal units (HTU). It include two sowing dates *viz.*16th February and 3rd March in split-plot design. It was observed that in early sowing GDDs and HTU reduced significantly by 45.9 °C days and 663.6 °C days hr respectively. In earlier sown crop significant reduction in grain yield was recorded than the timely sown crop. The phenothermal index increased from emergence to maturity in all the tested cultivars irrespective of sowing date.

Basu *et al.* (2018) conducted an experiment, thermal indices impact on phenology and seed yield of spring-summer green gram under different dates of sowing during the spring-summer seasons in 2011 and 2012 at Bidhan Chandra Krishi Viswavidyalaya, West Bengal. The results on cumulative GDD, HTU and their effect on seed yield showed that both GDD and HTU for all the phenophases positively and significantly affected the seed yield in the first year whereas in second year, the impact was negative.

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2.8. CROP GROWTH MODELS

The Decision Support System for Agro technology transfer was originally developed by international network of scientists, cooperating in the International Benchmark Sites Network for Agro technology Transfer project (IBSNAT, 1993, Tsuji, 1994, Uehara, 1998, Jones et al., 1998). The DSSAT has been in use for the last fifteen years by researchers worldwide. The DSSAT is a collection of independent programs that operate together, where in the crop simulation models are placed at the core. The DSSAT V4.5 includes Cropping System model CSM (2004, 06, 10, 12), CROPGRO module for soybean, peanut, dry bean, faba bean, chick pea, cow pea and other grain legumes. CERES module for maize, rice, wheat, barley, sorghum, millet and other cereal crops. SUBSTOR module for potato and CROPGRO module for cotton, tomato, bell pepper, green bean and cabbage.

Sunil *et al.* (2006) claimed that CROPGRO model can correctly predict biomass, leaf area index and total yield under various thermal environments with in a mean error of 4.5 per cent. So it should be a useful tool for evaluating the potential yield of tomato. It can also simulate growth and development of tomato by using standard input files for weather and soil condition as well as crop management.

Abdou *et al.* (2011) reported that DSSAT software tool run with data on weather, soil and experimental results in order to predict tomato yield under climate change conditions. It was able to simulate tomato crop performance with a difference of only 0.3-0.6 percent from actual yield. Crop growth simulation models are emerging technological tools with potential uses for interpreting research. The CROPGRO-Tomato model with modified cardinal temperature parameters will predict more accurately tomato growth and yield in response to temperature and thus be a useful in model applications (Boote *et al.*, 2012).

Scholberg *et al.*, (2000) conducted a study to update the cardinal temperature parameters of the CROPGRO- TOMATO model affecting the simulation of crop development, daily dry matter production, fruit set and dry matter partitioning of field grown tomato from transplanting to harvest.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled "Crop weather simulation model in tomato (*Solanum lycopersicum* L.)" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2017-2018.

The materials used and methods adopted for undertaking the study are described in this chapter.

3.1. DETAILS OF FIELD EXPERIMENT

3.1.1. Field location

The field experiment was conducted at the STCR plot, College of Horticulture, Vellanikkara, Thrissur, Kerala. Geographically the field is situated at 10° 31' N latitude and 76° 13' E longitude, at an altitude of 22 m above mean sea level.

3.1.2. Climate and Weather

The experimental area was influenced by a typical warm humid tropical climatic condition and benefited by both southwest and northeast monsoons. The experimental area received maximum amount of rainfall during the months of July and August. The mean maximum and minimum temperatures of the location recorded were 33.4 °C and 22.2 °C respectively. The average sunshine recorded for the location is 7.4 h day^{-1}. The recorded mean relative humidity was 65% with forenoon and afternoon relative humidity of 80 % and 50 % respectively. The total rainfall is 548.8mm. The average annual wind speed of the experimental field was 3.2 km h^{-1}. Table 3.1 shows the details of weekly weather parameters during the experimental period

3.1.3. Season

The experiment was conducted from September (2017) to March (2018).

3.2. EXPERIMENTAL MATERIALS AND METHODS

3.2.1. Crop variety

The tomato variety, Anagha was used for the experiment. The variety is long duration, bacterial wilt resistant, open pollinated and is more susceptible to lower and higher temperature. It is branching type, yellow flowered with shiny, dark red, small and fleshy fruits.

Table 3.1. Weekly weather parameters during the experimental period in 2017-2018

Week No.	Tmax (°C)	Tmin (°C)	VPD I (mmHg)	VPD II (mmHg)	RH I (%)	RH II (%)	WS (kmh^{-1})	BSS (h)	RF (mm)	RD (days)	Epan (mm)
37	32.2	23.0	23.0	23.5	97	81	0.8	3.9	210	6.0	2.8
38	30.7	22.4	22.7	22.2	93	68	0.9	5.5	93.4	4.0	3.1
39	30.7	22.8	23.1	22.2	96	70	0.2	3.5	68.3	3.0	2.2
40	31.3	22.8	22.8	22.4	93	71	0.1	3.5	33.5	1.0	2.1
41	31.5	22.6	22.4	22.5	94	76	0.1	4.3	30.4	3.0	2.2
42	31.1	22.4	22.5	23.9	94	75	0.1	3.9	39.5	2.0	2.1
43	31.7	21.6	21.3	21.5	91	62	0.4	6.9	49.3	2.0	2.6
44	33.1	22.6	20.6	21.6	82	62	1.6	6.8	32.7	3.0	3.3
45	32.4	21.6	21.0	20.1	87	57	2.0	6.0	0.7	0.0	2.7
46	33.0	21.2	23.2	20.9	93	58	0.6	7.1	0.0	0.0	2.5
47	33.4	21.5	20.8	20.1	90	55	1.7	6.6	26.1	2.0	3.1
48	31.7	22.5	20.3	20.6	82	62	5.6	3.9	0.0	0.0	3.3
49	33.2	20.9	21.2	19.8	91	56	1.0	8.0	0.0	0.0	2.6
50	32.4	21.6	19.9	19.1	84	56	3.3	4.5	0.0	0.0	2.8
51	32.3	21.4	15.5	14.5	66	41	8.5	10.0	0.0	0.0	5.3
52	32.8	20.2	15.3	13.0	69	36	6.8	9.3	0.0	0.0	5.1
1	33.0	19.8	16.0	14.8	75	41	3.9	8.8	0.0	0.0	4.0
2	32.7	21.8	16.5	13.6	73	39	6.7	7.4	0.0	0.0	3.6
3	33.5	20.7	13.7	12.1	63	33	6.9	21.5	0.0	0.0	5.1
4	33.8	21.4	14.5	14.3	68	39	3.9	8.1	0.0	0.0	5.9
5	34.1	20.5	10.7	10.1	48	26	7.3	9.0	0.0	0.0	4.8
6	35.2	22.3	17.7	16.3	77	40	4.3	8.5	0.0	0.0	3.9
7	35.1	23.2	15.7	14.1	66	35	4.8	9.4	0.0	0.0	4.8
8	36.1	22.5	13.6	9.7	61	23	5.2	10.2	0.0	0.0	5.0
9	37.7	23.0	18.8	10.6	67	21	4.5	9.9	0.0	0.0	8.0
10	38.0	23.7	17.9	10.3	71	22	4.0	9.4	0.0	0.0	6.0
11	35.3	24.3	22.9	20.5	80	57	4.3	6.1	0.9	0.0	4.1
12	36.3	24.5	21.3	17.9	83	42	2.2	7.8	0.0	0.0	5.9
13	36.3	25.5	24.4	21.9	89	53	2.2	7.5	0.0	0.0	6.2
Mean	33.4	22.2	19.2	17.7	80	50	3.2	7.4	584.8	26	3.9

Tmax-Maximum temperature
Tmin-Minimum temperature
BSS- Bright sunshine hours
Epan- Pan Evaporation

RH I- Forenoon relative humidity
RH II- Afternoon relative humidity
VPD I-Forenoon vapour pressure
VPD II- Afternoon vapour pressure

RD- Rainy days
RF- Rainfall
WS-Wind speed

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3.2.2. Design and Layout

The experiment was laid out under split plot design, replicated three times with six dates of planting at 15 days interval from 15th September to 1st December as main plot treatments. The three types of mulching, white top black bottom polythene, black top white bottom polythene, organic mulch (paddy straw) and control (without mulch) as subplot treatments. The plants were planted at a spacing of 60cm x 60cm in three replications and there were total of 72 plots each having 2.16 m^2 area. The layout is provided in Fig 3.1.

3.2.3. Treatments

The experiment had main plot treatments and subplot treatments. Six dates of planting were selected as main plot treatments which included 15th September, 1st October, 15th October, 1st November, 15th November, 1st December during 2017. The three types of mulching, White top black bottom polythene, Black top white bottom polythene, Organic mulch (paddy straw) and Control (without mulch) were selected as subplot treatments. The different treatments in the experiment are described in Table 3.2.

3.3. CROP HUSBANDRY

3.3.1. Nursery management

Nurseries were prepared earlier to each date of transplanting and thirty days old seedlings were transplanted. Adequate irrigation and drainage and plant protection measures were provided

3.3.2. Land preparation and planting

Land was ploughed thoroughly with disc plough and worked with cultivator to produce good tilth and stubbles were removed from the field. Raised beds and furrows were taken and seedlings were planted at a spacing of 60 cm × 60 cm. Twelve seedlings were planted in each plot. Gap filling was done with healthy seedlings, wherever is necessary.

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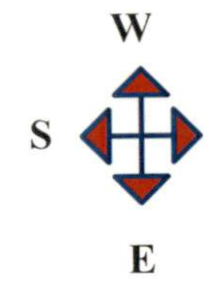
	D6	D2	D1	D3	D4	D5
	M3	M3	M0	M3	M1	M0
	M1	M0	M2	M0	M3	M1
R1	M0	M2	M1	M2	M0	M2
	M2	M1	M3	M1	M2	M3



	D4	D2	D3	D6	D5	D1
	M2	M0	M2	M3	M0	M1
	M0	M2	M3	M2	M3	M3
R2	M3	M1	M0	M0	M1	M2
	M1	M3	M1	M1	M2	M0

	D3	D6	D1	D4	D5	D2
	M1	M2	M3	M2	M0	M3
	M3	M0	M0	M1	M3	M0
	M2	M3	M2	M3	M1	M1
R3	M0	M1	M1	M0	M3	M2

D1- September 15th, D2- October 1st , D3- October 15th , D4- November 1st , D5- November 15th , D6- December 1st

M0- Control (without mulching), M1- White top black bottom polythene, M2- Black top White bottom polythene, M3- paddy straw mulch

Fig. 3.1. Layout of experiment in spilt plot design

Plate 3.1. Land preparation

Plate 3.2. Tomato seedlings ready for transplanting (30 days old)

Plate 3.3. Transplanting

Plate 3.4. Experimental plot view

Plate 3.5. Experimental plot view

Plate 3.6. Plant at flowering stage

Plate 3.7. Plant at fruiting stage

Plate 3.8. Plant at harvesting stage

Table 3.2. Treatments used in the experiment

Main plot treatment	Subplot treatments
Planting time	**Mulching material**
15th September	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)
1st October	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)
15th October	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)
1st November	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)
15th November	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)
1st December	Control (without mulching)
	White top black bottom polythene
	Black top white bottom polythene
	Organic mulch (paddy straw)

3.3.3. Manures and fertilizers

Farmyard manure was incorporated into the field at the rate of 2500 kg ha^{-1} during land preparation. Fertilizers like urea, rock phosphate and muriate of potash were used to supply adequate amount of nutrients such as 75 N, 40 P_2O_5 and 25 K_2O kg ha^{-1}. Half dose of nitrogen, full phosphorus and half of potash applied as basal before transplanting. One fourth of nitrogen and half of potash applied 30 days after planting. The remaining quantity was applied two months after planting.

3.3.4. After cultivation

Hand weeding was done at monthly intervals after transplanting tomato seedlings in main field. Incidence of tobacco caterpillar was noticed in the crop and ekalux spray @ 2 ml L^{-1} of water was done to control pest. Tomato spotted wilt virus was noticed and infected plants were roughed off and disposed far away from field. *Pseudomonas fluorescence* @ 20g L^{-1} was sprayed at 15 days interval to control the spread of the disease.

3.4. OBSERVATIONS

Observations on the following characteristics were done during the field experiment.

3.4.1. Weather data

The daily weather data on maximum temperature, minimum temperature, bright sunshine hours, rainfall, number of rainy days, relative humidity, evaporation and wind speed, vapour pressure deficit were collected from the Agrometeorological observatory during study period. The different weather parameters used in the study are given in Table 3.3.

3.4.2. Micrometeorological observations

Soil temperature (ºC) at different depths 5cm, 15cm and 30cm was taken at morning 7.30 pm and afternoon 2.30 pm on daily basis. Soil moisture (%) at 15cm depth was taken on weekly basis.

Table 3.3. Weather parameters used in the experiment

Sl. No.	Weather parameter	Unit
1	Maximum temperature (Tmax)	^{0}C
2	Minimum temperature (Tmin)	^{0}C
3	Relative humidity (RH) Forenoon relative humidity (RH I) Afternoon relative humidity (RH II)	%
4	Rainfall (RF)	mm
5	Rainy days (RD)	days
6	Bright sunshine hours (BSS)	h
7	Forenoon vapour pressure deficit (VPD I) Afternoon vapour pressure deficit (VPD II)	mm Hg
8	Wind speed (WS)	km h^{-1}
9	Evaporation (Epan)	mm

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3.4.3. Biometric observations

Two plants were selected randomly from each plot and tagged. The following observations were recorded from these sample plants and the mean values were worked out.

3.4.3.1. Plant height

Plant height was recorded at 15 days interval after transplanting from the ground portion up to nodal base of fully opened leaf and mean plant height was noted and expressed in centimeter

3.4.3.2. Number of trusses per plant

Number of trusses per plant was recorded from selected plants and mean value was computed.

3.4.3.3. Number of fruits per plant

Number of fruits per plant was recorded from selected plants and mean value was computed.

3.4.3.4. Fruit yield per plant

Fruit yield per plant was recorded from selected plants and mean value was computed.

3.4.3.5. No of weeds per unit area

Number of weeds per square meter area was recorded at monthly intervals and mean value was computed.

3.4.4. Phenological observations

3.4.4.1. Number of days to first flowering

Number of days required for flowering in selected plants was noted and mean value was computed.

3.4.4.2. Number of days to fifty percent flowering

Number of days required for fifty percent flowering in selected plants was noted and mean value was computed.

3.4.4.3. Number of days to first fruiting

Number of days required for fruiting in selected plants was noted and mean value was computed.

3.4.4.4. Number of days to fifty percent fruiting

Number of days required for fifty percent fruiting in selected plants was noted and mean value was computed.

3.4.4.5. Days to first harvest

Number of days required for first harvest in selected plants was noted and mean value was computed

3.4.4.6. Duration of the crop

Total duration of the selected plants was noted and mean value was computed

3.4.5. Analysis of soil

Soil samples were collected from a depth of 0-15cm and analyzed for pH, OC, major nutrients (N, P and K) and microbial biomass carbon content. The methods followed are detailed below in Table 3.4.

3.4.6. Analysis of plant samples

At the time of harvesting, plants were uprooted carefully, and the plant samples were first washed with tap water in order to remove dirt and adhering soil particles. The plants were again washed with single and double distilled water, and shade dried for a week. The shoot and root portion were separated by using sharp scissors and samples were kept in an oven @ 60 ^{0}C for 10 days. Later these samples were powdered and stored in polythene covers.

From these samples, major nutrients (N, P and K) were analyzed. The methodology followed to determine the above parameters are detailed in Table 3.5.

Table 3.4. Methods of soil analysis

Parameter	Method	Reference
pH	1:2.5 soil water suspension- pH meter	Jackson (1973)
Organic carbon	Walkley and Black method	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorous	Ascorbic acid reduced molybdo phosphoric blue colour method	Jackson (1973)
Available potassium	Neutral normal ammonium acetate extraction followed by flame photometry	
Soil microbial biomass carbon	Fumigation extraction method	Jenkinson and Powlson (1976)

Table 3.5. Methods of plant analysis

Parameter	Method	Reference
Nitrogen	Micro kjeldahl distillation	Jackson, 1973
Phosphorus	Vanado – molybdo – phosphoric (Bartons reagent) yellow colour	
Potassium	Flame photometer method	

3.5. HEAT UNITS

3.5.1. Growing Degree Days (GDD)

The growing degree days (GDD) were calculated for the entire crop growing period and used to relate the effect of GDD with crop duration as well as fruit yield. The formula for calculating GDD was given below. The growing degree days were calculated using Peterson (1965) equation. The base or threshold temperature used in the calculation of GDD is assumed as 5 °C for tomato (Sunil and Sarma, 2005).

$$\text{GDD} = \sum_{i=0}^{n} \frac{Tmax+Tmin}{2} - Tb$$

Where,

n- Number of days from sowing date till the last date of harvesting

Tmax- Maximum temperature (°C)

Tmin- Minimum temperature (°C)

Tb - Base temperature (minimum threshold temperature)

3.5.2. Helio thermal Unit (HTU)

Helio thermal units for tomato were calculated during each phenophases of crop and correlated with growth and yield parameters. The Helio thermal units were calculated using the formula given by Rajput (1980). The calculated Helio thermal unit is expressed in °C day h.

$$\text{HTU} = \sum_{i=0}^{n} \text{GDD X BSS}$$

Where,

GDD = Growing Degree Days

BSS = Actual bright sunshine hours

3.5.3. Photo thermal Units (PTU)

The effect of maximum possible sunshine hours on the crop were studied by calculating photothermal units in °C day h.

The photothermal units were calculated using the equation given by Wilsie (1962).

$$PTU = \sum_{i=0}^{n} GDD \times L$$

Where,

L is the maximum possible sunshine hours

The maximum possible sunshine hours were calculated using Smithsonian Table

3.6. Statistical analysis

The standard procedure for split plot design was given by Fisher (1947). Analysis of variance was performed to test the significant difference between dates of planting (main plot treatments), varieties (sub-plot treatments) and their interaction. When the ANOVA revealed significance for the above, pair wise comparison were made using the following critical differences.

Critical difference for the comparison of two main plot treatments (dates of planting)

$$CD_1 = t_\alpha \times SE_1$$

Where, t_α = t value at degrees of freedom for main plot error

SE_1 = standard error of difference between two main plot treatment means

$$SE_1 = \sqrt{2 \times E1/rb}$$

Where, E_1 = error mean square value of main plot treatments in ANOVA

r = number of replications

b = number of sub plot treatments

b) Critical difference for the comparison of two subplot treatments (mulches)

$$CD_2 = t_\alpha \times SE_2$$

Where, t_α = t value at degrees of freedom for sub plot error

SE_2= Standard error of difference between two sub plot treatments

$$SE_2 = \sqrt{2 \times E2/ra}$$

Where, E_2=Error mean square value of sub plot treatments in ANOVA

r = Number of replications

a = Number of main plot treatments

c) Critical difference value for the comparison of two main plot treatment means at the same or different levels of sub plot treatment

$$CD_3 = t_\alpha \text{ x } SE_3$$

Where, t_α = t value at degrees of freedom for main plot error

SE3= Standard two main plot treatment means at the same or different levels of sub plot treatment

$$SE_3 = \sqrt{2\,(b-1)E2 + \text{E1/rb}}$$

E_1= Error mean square for main plot treatment in ANOVA

E_2= Error mean square for sub plot treatments in ANOVA

r = Number of replications

b = Number of sub plot treatments

Correlation analysis was carried out to study the influence of weather parameters on biometric and phenological characters of tomato. Weekly weather parameters were also calculated during different growth stages and correlated with yield characters. Microsoft excel and SPSS were used for various analysis.

3.7. CROP WEATHER MODEL

The Decision Support System for Agro technology transfer was originally developed by the International Benchmark Sites Network for Agro technology Transfer project (IBSNAT, 1993; Tsuji, 1994; Uehara, 1998; Jones et al, 1998) is used for modelling the impact of growth and yield of tomato. Calibration of CROPGRO-tomato requires to develop genetic coefficient based on the varietal characters of the variety

3.7.1. Input files

The input and experimental data files required for the CROGRO - tomato model are given in Table 3.6.

Table 3.6. Input files of CROPGRO - Tomato model

Internal file name		External description	Example file name
Experiment	FILEX	Experiment details file for a specific experiment (e.g., tomato at TOVE): Contains data on treatments, field conditions, crop management and simulation controls	TOVE1701.TMX
Weather and soil	FILEW	Weather data, daily, for a specific (e.g., TOMT) station and time period (e.g., for one year)	TOMA1701.WTH
Weather and soil	FILES	Soil profile data for a group of experimental sites in general (e.g., SOIL.SOL) or for a specific institute (e.g., STSANDYCLA.SOL)	SOIL.SOL
Crop and cultivar	FILEC	Cultivar/variety coefficients for a particular crop species and model; e.g., tomato for the 'CROPGRO' model, version 046	TMGR046.CUL[1]
Crop and cultivar	FILEE	Ecotype specific coefficients for a particular crop species and model; e.g., tomato for the 'CROPGRO' model, version 046	TMGR046.ECO[1]
Crop and cultivar	FILEG	Crop (species) specific coefficients for a particular model; e.g., tomato for the 'CROPGRO' model, version 046	TMGR046.SPE[1]
Experiment data files	FILEA	Average values of performance data for a tomato experiment. (Used for comparison with summary model results.)	TOVE1701.TMA
Experiment data files	FILET	Time course data (averages) for a rice experiment. (Used for graphical comparison of measured and simulated time course results.)	TOVE1701.TMA

[1]These names reflect a standard naming convention in which the first two spaces are for the crop code, the next three characters are for the model name, and the final three are for model version.

3.7.2. Output files

The output files are helpful for users to select information needed for a particular application. The output file for CROGRO – tomato model is given in Table 3.7.

Table 3.7. Output files of CROPGRO - Tomato model

Internal file name	External description	File name
OUTO	Overview of inputs and major crop and soil variables	OVERVIEW.OUT
OUTS	Summary information: crop and soil input and output variables; one line for each crop cycle or model run	SUMMARY.OUT
SEVAL	Evaluation output file (simulated vs. observed)	EVALUATE.OUT
OUTWTH	Daily weather	Weather. OUT
OUTM	Daily management operations output file	MgmtOps. OUT
ERRORO	Error messages	ERROR.OUT
OUTINFO	Information output file	INFO.OUT
OUTWARN	Warning messages	WARNING.OUT

3.7.3. Running the crop model

Once all the desired files were created carefully the model was run for all the treatments.

3.7.4. Calibration of CROPGRO–Tomato model

Data obtained from the experiments carried out with tomato cultivars Anagha under six dates of sowing were used for estimating the genetic parameters. The genetic coefficients that influence the occurrence of developmental stages in the CROPGRO–tomato model were derived by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed phenological events as well as the model was calibrated for yield parameter. The genetic coefficients of CROPGRO–tomato model are given in the Table 3.8.

The Root Mean Square Error (RMSE), Mean Absolute percentage Error (MAPE) and D-stat index was used to evaluate the model performances. The equations used for RMSE, MAPE and D-stat index are given below.

$$\text{RMSE} = [\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}]^{0.5}$$

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \frac{|O_i - P_i|}{O_i} \times 100$$

$$\text{D-stat index} = \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum (P_i - O_{iavg}) + (O_i - O_{iavg})^2}$$

Where,

Oi = observed value

Pi = predicted value

Oiavg = average of observed value

n = number of observations

Table 3.8. Genetic Coefficients for the CROPGRO -Tomato model

Genetic Coefficients	Description
CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour)
PPSEN	Slope of the relative response of development to photoperiod with time (positive for short day plants) (1/hour)
EM-FL	Time between plant emergence and flower appearance (R1) (photo thermal days)
FL-SH	Time between first flower and first pod (R3) (photo thermal days)
FL-SD	Time between first flower and first seed (R5) (photo thermal days)
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photo thermal days)
FL-LF	Time between first flower (R1) and end of leaf expansion (photo thermal days)
LFMAX	Maximum leaf photosynthesis rate at 30 C, 350 ppm CO_2, and high light
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photo thermal days)
SDPDV	Average seed per pod under standard growing conditions (#/pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photo thermal days)
THRSH	Threshing percentage. The maximum ratio of (seed/ (seed+shell)) at maturity. Causes seed to stop growing as their dry weight increases until the shells are filled in a cohort.
SDPRO	Fraction protein in seeds (g(protein)/g(seed))
SDLIP	Fraction oil in seeds (g(oil)/g(seed))

RESULTS

4. RESULTS

The results of the study entitled "Crop weather simulation model in tomato (*Solanum lycopersicum* L.)", carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2017-2018 are presented in this chapter.

4.1. PHENOPHASES OF TOMATO CROP

Phenology is the study related to dates of biological events for first occurrence in their annual cycle with seasonal climatic changes. The environmental factors plays a significant role on different developmental stages of tomato.

In this study, based on the morphological characters the phenophases of tomato crop was divided into five development stages and are denoted by P1 to P5.

The phenophases of tomato crop include:

1. P1- Transplanting to first flowering (Vegetative phase)
2. P2- Transplanting to fifty percent flowering (Vegetative phase)
3. P3- Transplanting to first fruiting (Reproductive phase)
4. P4- Transplanting to fifty percent fruiting (Reproductive phase)
5. P5- Transplanting to harvesting (Ripening phase)

All these phenophases come under different growth periods such as vegetative phase, reproductive phase and ripening phase. The developmental stage from transplanting to first flowering (P1) and transplanting to fifty percent flowering (P2) comes under the vegetative period, transplanting to first fruit (P3) and transplanting to fifty percent first fruiting (P4) comes under reproductive period and transplanting to harvest (P5) comes under ripening period. The plants under different mulches showed variations in their phenophases duration for six dates of planting (15^{th} September – 1^{st} December).

4.2. WEATHER OBSERVATIONS

Weather parameters prevailed during the entire crop period was recorded.

The weather parameters like maximum and minimum temperature, forenoon and afternoon relative humidity (RH), rainfall (RF), bright sunshine hours (BSS), number of rainy days (RD), evaporation (Epan), forenoon and afternoon vapour pressure deficit (VPD) and wind speed (WS) were recorded daily and converted to weekly observations. The recorded weather parameters were averaged against standard meteorological weeks which correspond to different phenophases of crop growth and displayed graphically.

4.2.1. Air temperature

The maximum temperature (Tmax), minimum temperature (Tmin), mean temperature (Tmean) and temperature range (Trange) were recorded daily and weekly average was taken during the crop period and displayed graphically in Fig. 4.1. The maximum temperature of 38.0 °C was recorded during 10th week and minimum temperature of 19.8°C experienced during 1st week. The air temperature showed variations and increasing trend towards delayed transplanting.

4.2.2. Relative humidity (RH)

Relative humidity (forenoon and afternoon) for entire crop growing period were recorded and represented graphically in Fig. 4.2 The highest forenoon relative humidity was recorded during 37th week (97%) and lowest forenoon relative humidity was noted during 5th week (48%) and showed a decreasing trend towards delayed dates of transplanting. Afternoon relative humidity also showed variations and decreasing trend towards delayed transplanting. Highest afternoon relative humidity was recorded during 37th week (81%) and lowest afternoon relative humidity was recorded during 9th week (21%).

4.2.3. Rainfall and rainy days (RF and RD)

The rainfall and rainy days were displayed over standard meteorological weeks in Fig. 4.3. The weekly total rainfall and number of rainy days were calculated for the entire crop growing period and for different growth stages of the crop. The highest rainfall of 210 mm obtained in 37th week. The rainfall and rainy days showed declining trend towards delayed date of transplanting.

The amount of rainfall observed during the entire crop period was 584.8 mm. The total number of rainy days for entire crop period was 26 days.

4.2.4. Vapour pressure deficit (VPD)

For the entire crop period, the dry bulb and wet bulb thermometers readings were taken for calculating the vapour pressure deficit (mm Hg) and displayed in Fig. 4.4. The forenoon and afternoon vapour pressure deficit showed variations during entire crop period. The highest and lowest forenoon vapour pressure deficit were recorded on 13^{th} and 5^{th} weeks and their values were 24.4 mm Hg and 10.7 mm Hg respectively. The highest and lowest values of afternoon vapour pressure deficit recorded were 23.9 mm Hg and 9.7 mm Hg and it was on 42^{nd} and 8^{th} weeks respectively.

4.2.5. Bright sunshine hours (BSS) and Pan Evaporation (Epan)

The bright sunshine hours and pan evaporation for the entire crop season were recorded and displayed in Fig. 4.5. Delayed transplanting showed increasing trend for both bright sunshine hours and pan evaporation. The bright sunshine was found to be highest on 8^{th} week and the observed value was 10.2 h. The lowest value of BSS was recorded on 40^{th} week and the observed value was 3.5 h, respectively. Pan evaporation showed undulations during the entire crop growing period and the highest and lowest value recorded was 8mm and 2.1mm during 9^{th} and 42^{nd} week respectively.

4.2.6. Wind speed (WS)

During the different crop growth period wind speed was recorded and displayed graphically in Fig.4.6. The wind speed showed a variations over the crop period and the highest wind speed (8.5 km h^{-1}) was recorded on 51^{st} week and lowest (0.1 km h^{-1}) on 42^{nd} week.

4.3. Weather during different phenophases

4.3.1. Weather during transplanting to first flowering

The weather prevailed during transplanting to first flowering was presented in the Table 4.1 (a and b).

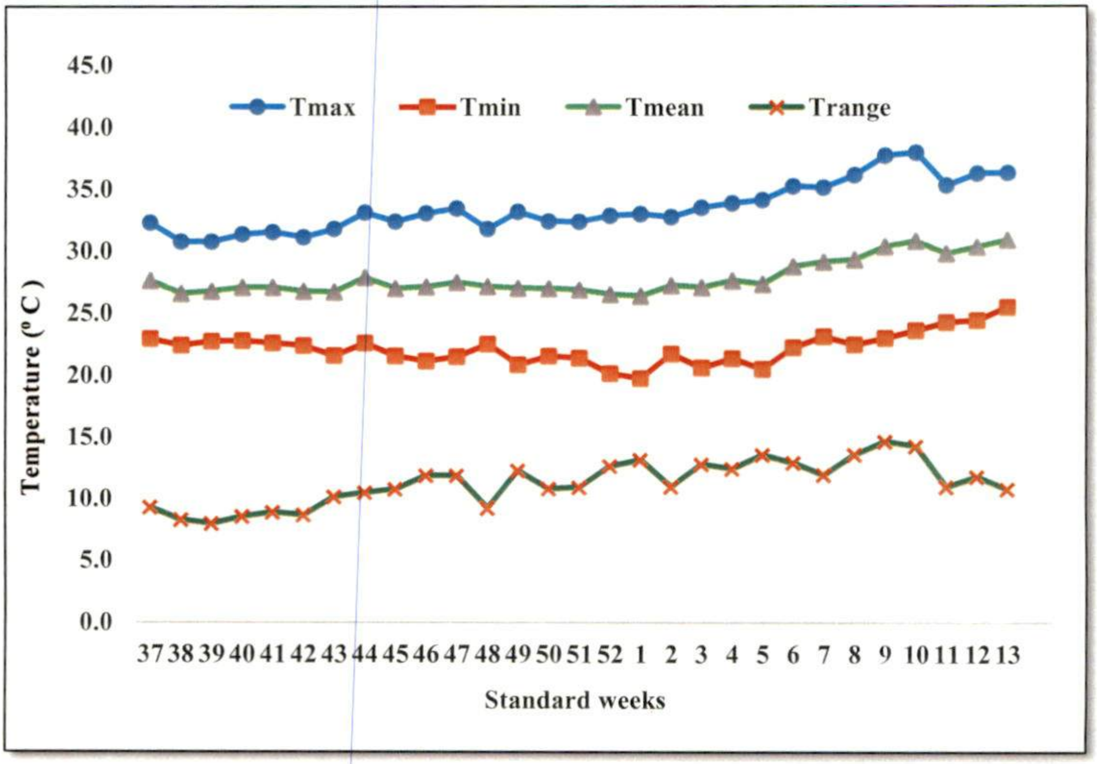

Fig.4.1. Weekly temperatures during the crop period

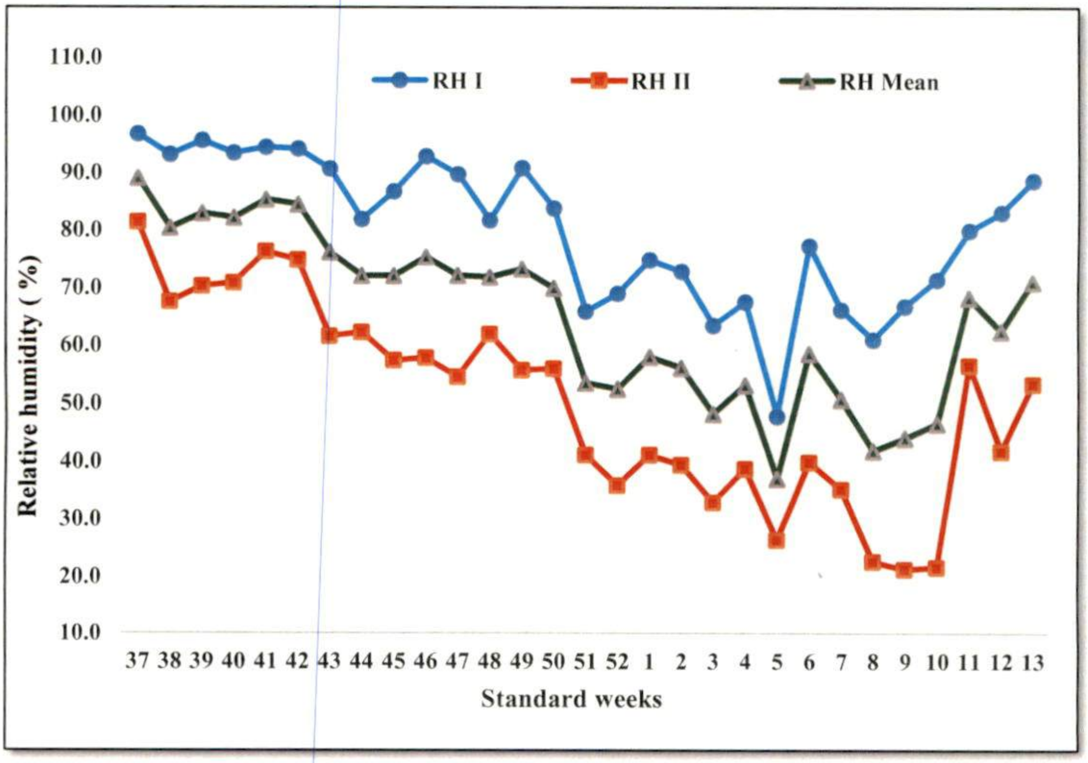

Fig.4.2. Weekly Relative humidity during the crop period

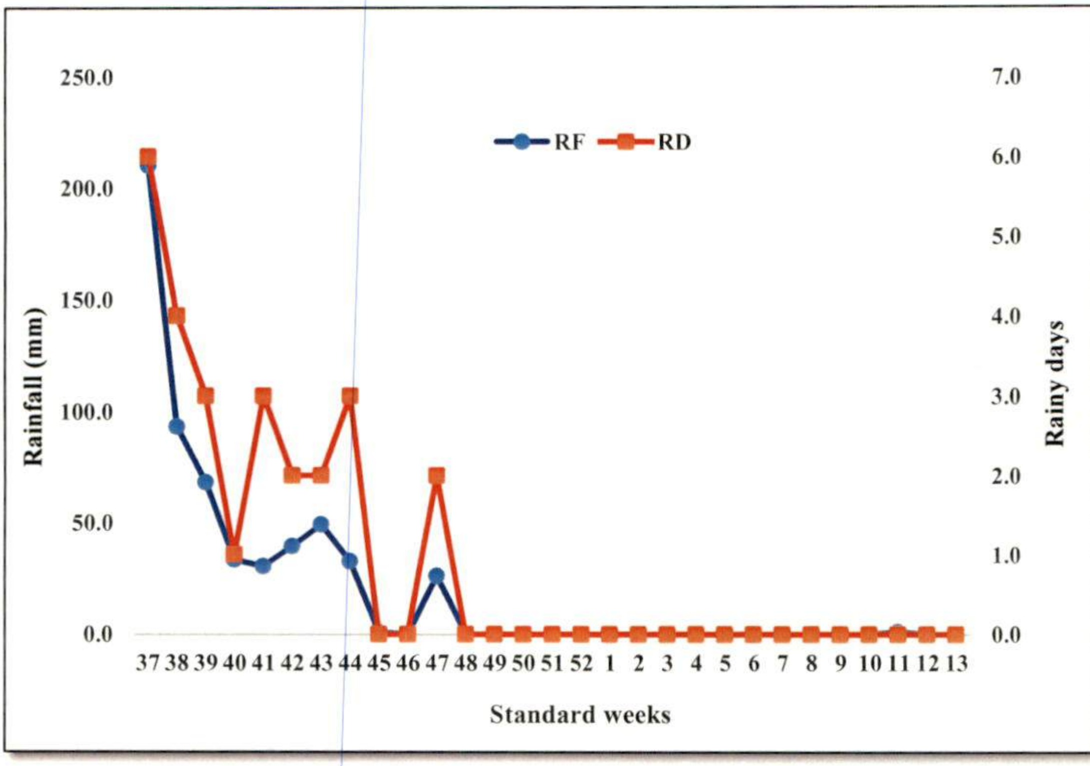

Fig.4.3. Weekly Rainfall and rainy days during the crop period

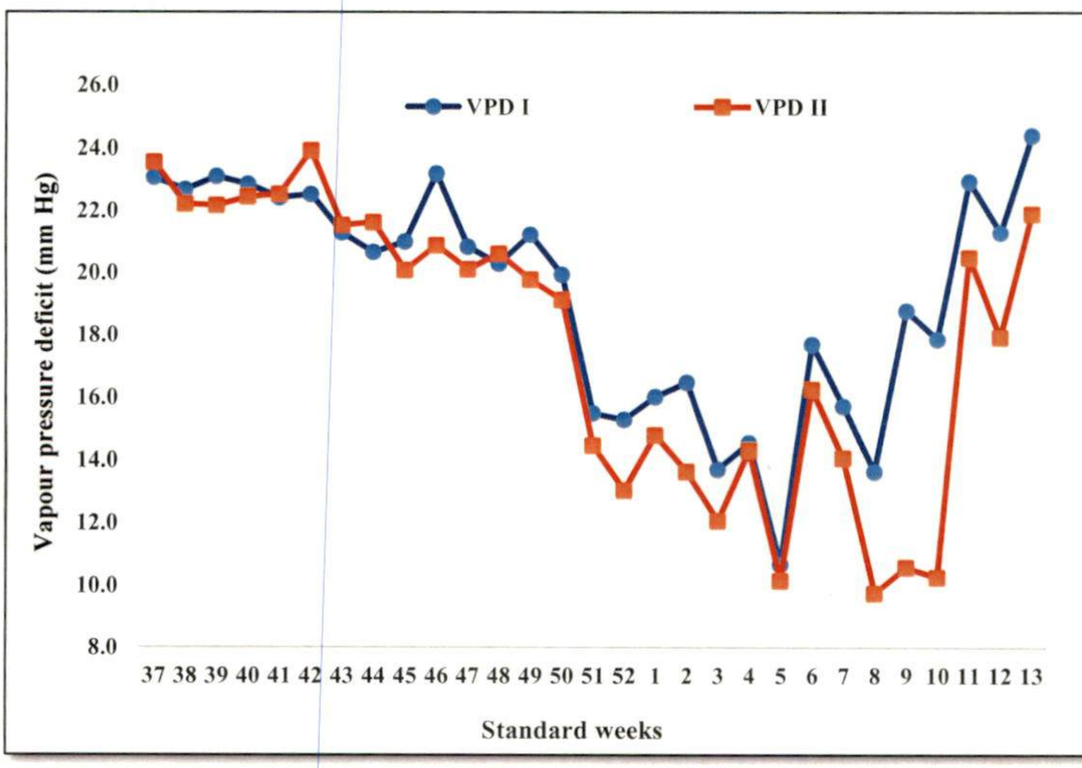

Fig.4.4. Weekly vapour pressure deficit during the crop period

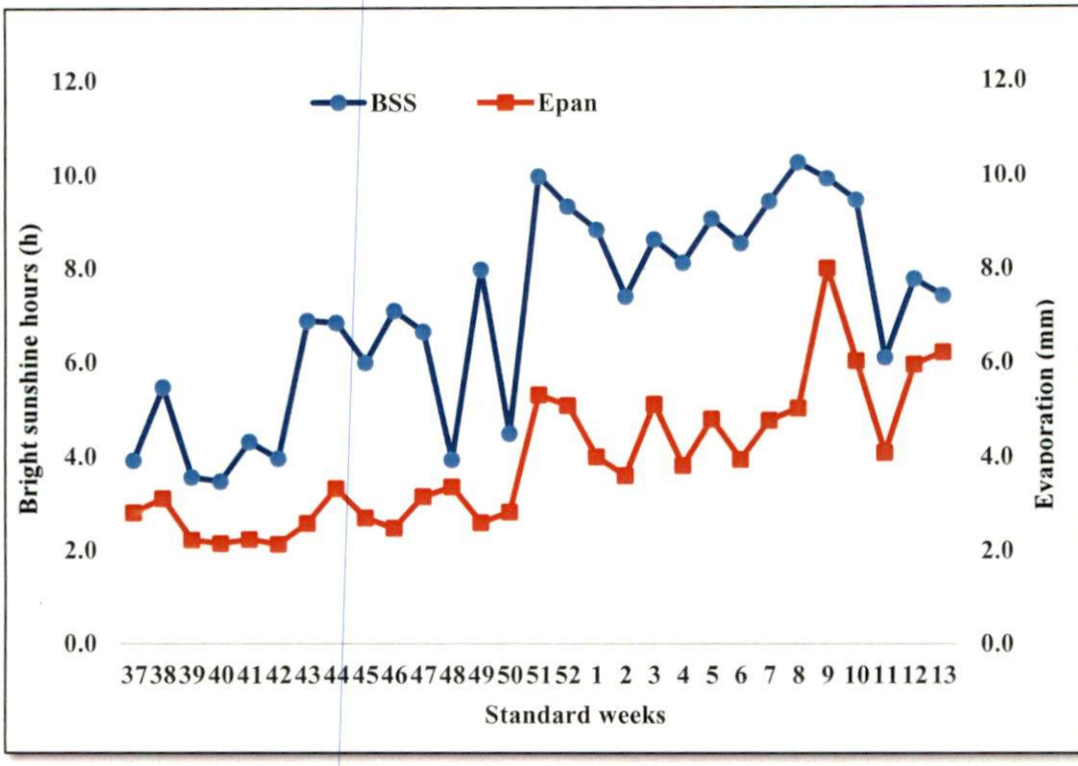

Fig.4.5. Weekly bright sunshine hours and evaporation during the crop period

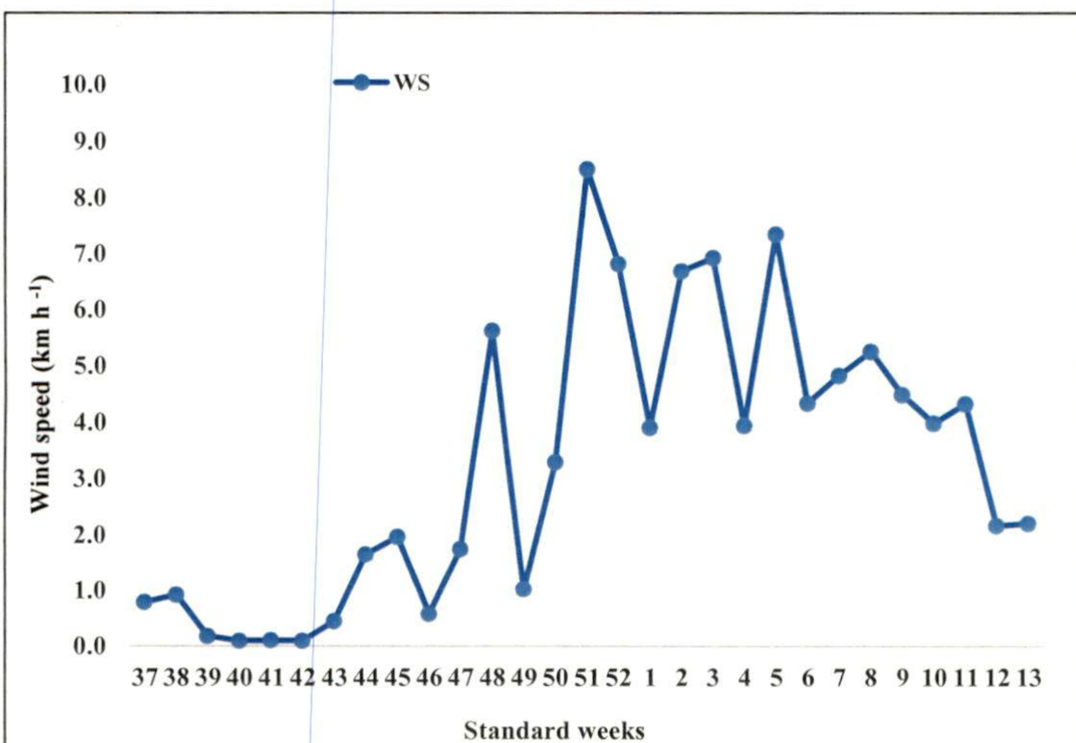

Fig.4.6. Weekly wind speed during the crop period

4.3.1.1. Temperature (Maximum, minimum, mean and temperature range)

The observed minimum and maximum temperature observed under Control, White polythene, Black polythene and Straw mulch were 21.6 °C to 32.9 °C , 21.2 °C to 32.9 °C , 22.7 °C to 32.9 °C and 22.7 °C to 32.9 °C respectively. The mean temperature ranges between 26.8°C to 27.3 °C for Control, White top black bottom polythene, Black top white bottom polythene and Straw mulch. The temperature range recorded for control was 8.4 °C to 11.2 °C, 8.4 °C to 11.3 °C for White top black bottom polythene, Black top white bottom polythene and Straw mulch.

4.3.1.2. Relative humidity (RH I, RH II and RH mean)

The relative humidity range experienced during transplanting to first flower stage of was 78 % to 94% (RH I) and 71% to 49% (RH II) for control, 80% to 94% (RH I) and 51% to 71% (RH II) for white polythene, 81% to 94% (RH I) and 52% to 72% (RH II) for black top white bottom polythene and 79% to 94% (RH I) and 50% to 71% (RH II) for straw mulch. The transplantation during 15th September and 1st October recorded highest (94%) and lowest (78%) forenoon relative humidity for December 1st transplanted one. The afternoon relative humidity reaches its highest during first date of planting (15th September) and second date of planting (1st October). The lowest during sixth date of planting (1st December). The mean relative humidity was highest (83%) during first and second date of planting and lowest (82.5%) during sixth date of transplanting.

4.3.1.3. Vapour pressure deficit (VPD I and VPD II)

The vapour pressure deficit during the experimental period was taken as forenoon vapour pressure deficit (VPD I) and afternoon vapour pressure deficit (VPD II). The recorded vapour pressure deficit range for control, white polythene, black polythene and straw was 21.26, 21.33, 21.35 and 21.31 mm Hg respectively. The highest afternoon vapour pressure deficit (22.7mmHg) under different mulches were recorded for 2nd date of transplanting (October 1st) and lowest afternoon vapour pressure deficit (17.5mm Hg) during 6th date of planting (December 1st).

Table 4.1(a). Weather parameters experienced during transplanting to first flowering stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D1				D2				D3			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^0C)	31.1	31.1	31.1	31.1	31.3	31.3	31.3	31.3	31.9	31.9	31.9	31.9
Tmin (^0C)	22.6	22.7	22.7	22.7	22.4	22.3	22.3	22.4	22.0	22.0	22.1	22.0
Tmean (^0C)	26.9	26.9	26.9	26.9	26.8	26.8	26.8	26.8	26.9	27.0	27.0	27.0
Trange (^0C)	8.4	8.4	8.4	8.4	9.0	9.0	9.0	9.0	9.8	9.8	9.9	9.9
RH I (%)	94	94	94	94	94	94	94	94	88	88	89	88
RH II (%)	71	71	72	71	72	72	72	72	67	66	66	66
RH mean (%)	83	83	83	83	83	83	83	83	78	77	78	77
VPD I (mm Hg)	22.7	22.8	22.7	22.8	22.4	22.3	22.3	22.4	21.3	21.3	21.4	21.3
VPD II (mm Hg)	22.4	22.5	22.5	22.5	22.7	22.7	22.7	22.7	22.1	21.9	21.8	21.9
RF (mm)	332.9	336.5	341.3	336.5	170.9	182.0	182.0	170.9	139.7	139.7	139.7	139.7
RD (days)	11.0	12.0	13.0	12.0	9.0	10.0	10.0	9.0	8.0	8.0	8.0	8.0
BSS (h)	4.4	4.4	4.2	4.4	4.7	4.6	4.6	4.7	5.5	5.6	5.7	5.6
WS (km h^{-1})	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	1.0	1.0	1.0	1.0
Epan (mm)	2.5	2.5	2.5	2.5	2.3	2.3	2.3	2.3	2.6	2.6	2.6	2.6

D1 - 15^{th} September, D2- 1^{st} October, D3- 15^{th} October

Table 4.1(b). Weather parameters experienced during transplanting to first flowering stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D4				D5				D6			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^0C)	32.9	32.9	32.9	32.9	32.7	32.8	32.8	32.8	32.5	32.5	32.5	32.5
Tmin (^0C)	21.7	21.6	21.6	21.7	21.6	21.6	21.6	21.6	21.2	21.4	21.4	21.3
Tmean (^0C)	27.3	27.3	27.3	27.3	27.2	27.2	27.2	27.2	26.8	26.9	26.9	26.9
Trange (^0C)	11.2	11.3	11.3	11.3	11.1	11.2	11.2	11.2	11.2	11.1	11.1	11.1
RH I (%)	88	88	88	88	89	89	89	88	78	80	81	79
RH II (%)	58	58	58	58	59	58	58	58	49	51	52	50
RH mean (%)	73	73	73	73	74	73	73	73	64	65	66	65
VPD I (mm Hg)	21.4	21.4	21.4	21.4	21.5	21.4	21.4	21.4	18.3	18.8	18.9	18.6
VPD II (mm Hg)	20.4	20.5	20.5	20.5	20.6	20.4	20.4	20.5	17.1	17.7	17.9	17.5
RF (mm)	58.3	58.3	58.3	58.3	26.1	26.1	26.1	26.1	0.0	0.0	0.0	0.0
RD (days)	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0
BSS (h)	6.4	6.5	6.5	6.4	6.1	6.3	6.3	6.3	7.2	7.0	6.9	7.1
WS (km h^{-1})	1.6	1.5	1.5	1.6	2.2	2.4	2.4	2.3	5.1	4.8	4.8	5.0
Epan (mm)	2.9	2.9	2.9	2.9	2.8	2.9	2.9	2.9	3.8	3.6	3.6	3.7

D4 - 1st November , D5 - 15th November , D6 -1st December

4.3.1.4. Rainfall (RF) and rainy days (RD)

From transplanting to first flower stage highest rainfall (336.8mm) was received during first date of planting (September 15th) whereas lowest rainfall received during sixth date of planting (December 1st). The rainfall of 145.5, 148.5, 149.4, 146.3 mm was recorded for control, white polythene, black polythene and straw mulch. Transplanting to first flower the mulches got maximum number of rainy days during first date planting (September 15th) (12 RD) and the minimum rainy days (0 RD) were observed during the last date of planting (December 1st). .

4.3.1.5. Bright sunshine hours (BSS)

The bright sunshine hours recorded for control was 4.4 h to 7.2 h and 4.4 h to 7 h, 4.2 h to 6.9 h, 4.4 h to 7.1 h for white polythene, black polythene and straw mulch respectively. The highest sunshine hours recorded during sixth transplanting (December 1st) and lowest during 1st transplanting (September 15th).

4.3.1.6. Wind speed (WS)

The wind speed showed a variations over the crop period and the highest wind speed (4.9 km h^{-1}) was recorded during sixth date of transplanting. The lowest recorded wind speed was 0.4 km h^{-1} on first date of planting. The wind recorded for mulches was 1.7 km^{-1}.

4.3.1.7. Pan evaporation (Epan)

The Evaporation occurred during transplanting to first flowering stage was 2.64 mm for mulches. The highest evaporation (2.9mm) was recorded on 15th December transplanting and lowest recorded range of evaporation was 2.3 mm for 1st October transplanting.

4.3.2. Weather during Transplanting to fifty percent flowering

The weather prevailed during transplanting to fifty percent flowering was presented in the Table 4.2(a and b).

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4.3.2.1. Temperature (Tmax, Tmin, Tmean and Trange)

During transplanting to fifty percent flowering stage there was an increasing trend in temperature towards the fifth date of transplanting and there was a slight decline in temperature during last date of transplanting. The maximum temperature range recorded for control and straw mulch was 31 °C to 32.7 °C and 31.1 °C to 32.7 °C for white polythene, black polythene respectively. The maximum temperature was found to be highest during fourth and fifth date of transplanting. The lowest temperature range recorded was 31.0 °C during first transplanting. In case of minimum temperature mulches recorded an increasing trend towards the last date of planting. The minimum temperature range for control was 20.8 °C to 22.5 °C, 20.9 °C to 22.5 °C for white polythene, black polythene and 20.9 °C to 22.6 °C for straw mulch. The mean temperature observed for mulches is 26.9 °C. The mean temperature is highest for fourth date of transplanting (1st November) and lowest for first date of transplanting (15th September). Temperature range showed an increasing trend towards delayed date of transplanting and it ranges from 8.4 °C to 11.7°C for Control, 8.5°C to 11.7 °C for white polythene and straw mulch and 8.6 °C to 11.7 °C for black polythene mulch.

4.3.2.2. Relative humidity (RH I, RH II and RH mean)

Highest Forenoon and afternoon relative humidity recorded was 95 percent and 73 percent and it was noticed in first date of planting and lowest (77 % and 48%) for last date of planting. The forenoon relative humidity was recorded highest (88 %) for White polythene mulch and 87 percent for control, black polythene and straw mulch. The afternoon relative humidity was lowest (61%) for control and 61 percent for white polythene, black polythene and straw mulch.

4.3.2.3. Vapour pressure deficit (VPD I and VPD II)

Forenoon vapour pressure deficit was recorded highest (22.6 mm Hg) for first date of planting and lowest (17.9 mm Hg) for delayed transplanting. The afternoon vapour pressure was highest (22.6 mm Hg) for first date of planting and lowest (16.6 mm Hg) for last date of planting. The forenoon vapour pressure deficit range for control is 17.5 to 22.6 mm Hg, 17.9 to 22.6 for white polythene, 18.1 to 22.6 for black polythene and 18.1 to 22.7 mm Hg for straw mulch.

Table 4.2(a). Weather parameters experienced during transplanting to fifty percent flowering stage of tomato under different mulches at different dates of planting

Weather Parameters	Dates of transplanting											
	D1				D2				D3			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	31.0	31.1	31.1	31.0	31.7	31.7	31.7	31.7	32.1	32.3	32.3	32.3
Tmin (^{0}C)	22.5	22.5	22.5	22.6	22.4	22.3	22.3	22.3	21.8	21.8	21.8	21.8
Tmean (^{0}C)	26.8	26.8	26.8	26.8	27.1	27.0	27.0	27.0	26.9	27.0	27.0	27.0
Trange (^{0}C)	8.4	8.5	8.6	8.5	9.4	9.4	9.4	9.4	10.3	10.4	10.5	10.4
RH I (%)	95	95	95	95	92	91	90	91	89	90	90	90
RH II (%)	73	73	73	73	69	69	68	69	64	63	63	63
RH mean (%)	84	84	83	84	80	80	79	80	77	77	77	77
VPD I (mm Hg)	22.6	22.6	22.6	22.7	22.0	21.9	21.8	21.9	21.7	21.7	21.7	21.7
VPD II (mm Hg)	22.6	22.7	22.6	22.7	22.4	22.4	22.3	22.4	21.5	21.6	21.5	21.6
RF (mm)	400.4	401.6	401.6	400.4	211.9	215.4	215.4	215.4	139.7	154.1	165.8	154.1
RD (days)	17.0	17.0	17.0	17.0	12.0	13.0	13.0	13.0	8.0	9.0	10.0	9.0
BSS (h)	3.9	4.1	4.3	4.1	5.1	5.1	5.1	5.0	5.9	6.0	6.0	6.0
WS (km h^{-1})	0.3	0.3	0.3	0.3	0.4	0.5	0.7	0.6	0.9	0.9	0.9	0.9
Epan (mm)	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.5	2.6	2.6	2.7	2.6

D1 - 15th September , D2- 1st October , D3- 15th October

Table 4.2(b). Weather parameters experienced during transplanting to fifty percent flowering stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D4				D5				D6			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.5	32.6	32.6	32.6
Tmin (^{0}C)	21.7	21.8	21.8	21.8	21.6	21.6	21.6	21.6	20.8	20.9	20.9	20.9
Tmean (^{0}C)	27.2	27.2	27.2	27.2	27.1	27.1	27.1	27.1	26.7	26.7	26.7	26.7
Trange (^{0}C)	11	10.9	10.9	10.9	11.1	11.1	11.1	11.1	11.7	11.7	11.7	11.7
RH I (%)	87	87	87	87	84	85	87	86	77	78	78	78
RH II (%)	59	58	58	58	54	56	57	56	47	48	48	48
RH mean (%)	73	73	73	73	69	70	72	71	62	63	63	63
VPD I (mm Hg)	21.2	21.2	21.2	21.2	20.1	20.5	20.9	20.6	17.5	17.9	18.1	18.1
VPD II (mm Hg)	20.5	20.4	20.4	20.4	19.1	19.6	20.0	19.7	16.4	16.7	16.8	16.8
RF (mm)	58.3	58.3	58.3	58.3	26.1	26.1	26.1	26.1	0.0	0.0	0.0	0.0
RD (days)	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0
BSS (h)	6.3	6.1	6.1	6.1	6.6	6.4	6.2	6.3	7.5	7.5	7.5	7.5
WS (km h^{-1})	2.2	2.4	2.4	2.4	3.7	3.2	2.9	3.1	5.0	4.9	4.9	4.9
Epan (mm)	2.9	3.0	3.0	3.0	3.3	3.1	3.0	3.1	3.9	3.8	3.8	3.8

D4 - 1st November , D5 - 15th November , D6 -1st December

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The afternoon vapour pressure deficit range for control is 16.4 to 22.6 mm Hg, 16.7 to 22.7 for white polythene, 16.8 to 22.6 for black polythene and 16.8 to 22.7 mm Hg for straw mulch.

4.3.2.4. Rainfall (RF) and rainy days (RD)

During transplanting to first flowering the amount of rainfall received showed decreasing trend towards the delayed date of planting and highest (401mm) amount of rainfall received by during first date of planting and lowest (0 mm) during last date of planting The recorded amount of rainfall for control, white polythene, black polythene and straw mulch was 139.4mm, 142.5mm, 144.5mm and 142.3mm respectively. The number of rainy days showed decreasing trend towards delayed planting, 17days for first date of planting and 0 days for last date of planting. For control rainy days was 7 days, for white polythene 8 days, 9 and 8 days for black polythene and straw mulch.respectively

4.3.2.5. Bright sunshine hours (BSS)

Bright sunshine hours showed increasing trend towards the delayed planting. Highest (7.5 h) bright sunshine hours was observed during last date of planting and lowest (4.1 h) in first date of planting. The Bright sunshine hours for mulches ranged from 3.9h to 7.5h in control, 4.1h to 7.5h in white polythene mulch, 4.3h to 6.2h in black polythene mulch and 4.3h to 6.3h in straw mulch.

4.3.2.6. Wind speed (km h^{-1})

Wind speed showed increasing trend towards the delayed planting. Highest (4.9 km h^{-1}) wind speed was observed during last date of planting and lowest (0.3 km h^{-1}) in first date of planting. The wind speed for mulches ranged from 0.3 to 5 km h^{-1} in control, 0.3 to 4.9 km h^{-1} in white polythene mulch, black polythene mulch and straw mulch .

4.3.2.7. Pan evaporation (Epan)

The pan evaporation showed increasing trend towards the delayed planting. Highest (3.8 mm) pan evaporation was observed during last date of planting and lowest

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(2.4 mm) in first date of planting. Pan evaporation for mulches ranged from 2.4 to 2.9 mm.

4.3.3. Weather during transplanting to first fruiting

The weather prevailed during transplanting to first fruiting was presented in the Table 4.3(a) and 4.3(b).

4.3.3.1. Temperature (Tmax, Tmin, Tmean and Trange)

During transplanting to first fruiting stage there was an increasing trend in temperature towards the fifth date of transplanting and there was a slight decline in temperature during last date of transplanting. The maximum temperature range recorded for control, white polythene, black polythene and straw mulch was 32.7 °C to 31 °C. The maximum temperature was found to be highest during fourth and fifth date of transplanting. The lowest temperature range recorded was 31.0 °C during first transplanting. In case of minimum temperature mulches recorded decreasing trend towards the last date of planting. The minimum temperature range recorded for control, white polythene, black polythene and straw mulch was 20.9 °C to 22.6 °C. The mean temperature observed for mulches is 26.9 °C. The mean temperature is highest for fourth date of transplanting (1^{st} November) and lowest for first date of transplanting (15^{th} September) . Temperature range showed an increasing trend towards delayed date of transplanting and it ranges from 8.5 °C (first date of transplanting) to 11.7°C (last date of transplanting). The Temperature range under mulches is 10.3 °C.

4.3.3.2. Relative humidity (RH I, RH II and RH mean)

Highest Forenoon and afternoon relative humidity recorded was 94 percent and 73 percent and it was noticed in first date of planting and lowest (78 % and 48%) for last date of planting. The forenoon relative humidity was recorded highest (88 %) for White polythene, black polythene and straw mulch and lowest (87%) for control. The afternoon relative humidity was 61 percent for mulches. The mean relative humidity ranged from 63 to 84 percent, highest for first transplanting and lowest for delayed transplanting.

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Table 4.3(a). Weather parameters experienced during transplanting to first fruiting stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D1				D2				D3			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^0C)	31.0	31.0	31.0	31.0	31.7	31.7	31.7	31.7	32.2	32.2	32.3	32.2
Tmin (^0C)	22.6	22.6	22.6	22.6	22.4	22.3	22.3	22.3	21.8	21.8	21.8	21.8
Tmean (^0C)	26.8	26.8	26.8	26.8	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Trange (^0C)	8.5	8.5	8.5	8.5	9.4	9.4	9.4	9.4	10.4	10.4	10.4	10.4
RH I (%)	95	94	94	94	91	91	91	91	89	89	90	90
RH II (%)	73	73	73	73	69	69	69	69	64	64	63	64
RH mean (%)	84	84	84	84	80	80	80	80	77	77	77	77
VPD I (mm Hg)	22.7	22.6	22.6	22.6	22.0	21.9	21.9	21.9	21.7	21.7	21.7	21.7
VPD II (mm Hg)	22.7	22.7	22.7	22.7	22.4	22.4	22.4	22.4	21.6	21.6	21.6	21.6
RF (mm)	400.4	401.6	401.6	401.6	214.7	215.4	215.4	215.4	139.7	139.7	154.1	152.5
RD (days)	17.0	17.0	17.0	17.0	13.0	13.0	13.0	13.0	8.0	8.0	9.0	9.0
BSS (h)	4.1	4.0	4.0	4.0	5.1	5.0	5.0	5.1	6.0	6.0	6.0	6.0
WS (km h^{-1})	0.3	0.3	0.3	0.3	0.5	0.6	0.6	0.5	0.9	0.9	0.9	0.9
Epan (mm)	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.6

D1 - 15th September , D2- 1st October , D3- 15th October

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Table 4.3(b). Weather parameters experienced during transplanting to first fruiting stage of tomato under different mulches at different dates of planting

Weather parameters	Date of transplanting											
	D4				D5				D6			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.6	32.6	32.6	32.6
Tmin (^{0}C)	21.7	21.7	21.8	21.7	21.6	21.6	21.6	21.6	20.9	20.9	20.9	20.9
Tmean (^{0}C)	27.2	27.2	27.2	27.2	27.1	27.1	27.1	27.1	26.7	26.7	26.7	26.7
Trange (^{0}C)	11.0	11.0	10.9	11.0	11.1	11.1	11.1	11.1	11.7	11.7	11.7	11.7
RH I (%)	87	87	87	87	85	86	87	85	77	78	79	78
RH II (%)	58	58	58	58	55	56	57	56	47	48	48	47
RH mean (%)	73	73	73	73	70	71	72	70	62	63	63	62
VPD I (mm Hg)	21.2	21.2	21.2	21.2	20.4	20.6	20.9	20.5	17.7	18.1	18.2	17.8
VPD II (mm Hg)	20.4	20.4	20.4	20.4	19.4	19.7	20.0	19.6	16.5	16.8	16.9	16.6
RF (mm)	58.3	58.3	58.3	58.3	26.1	26.1	26.1	26.1	0.0	0.0	0.0	0.0
RD (days)	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0
BSS (h)	6.3	6.2	6.1	6.2	6.4	6.3	6.2	6.4	7.5	7.5	7.5	7.6
WS (km h^{-1})	2.3	2.3	2.4	2.3	3.4	3.1	2.9	3.2	4.9	4.9	4.9	4.9
Epan (mm)	2.9	3.0	3.0	3.0	3.2	3.1	3.0	3.1	3.9	3.8	3.8	3.8

D4 - 1st November , D5 - 15th November , D6 -1st December

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4.3.3.3. Vapour pressure deficit (VPD I and VPD II)

Forenoon vapour pressure deficit was recorded highest (22.6 mm Hg) for first date of planting and lowest (17.9 mm Hg) for delayed transplanting. The afternoon vapour pressure for highest (22.7 mm Hg) for first date of planting and lowest (16.7 mm Hg) for last date of planting. The forenoon vapour pressure deficit range for control is 17.7 to 22.7 mm Hg, 18.1 to 22.6 for white polythene, 18.2 to 22.6 for black polythene and 17.8 to 22.6 mm Hg for straw mulch. The afternoon vapour pressure deficit range for control is 16.5 to 22.7 mm Hg, 16.8 to 22.7 for white polythene, 16.9 to 22.7 for black polythene and 16.6 to 22.7 mm Hg for straw mulch.

4.3.3.4. Rainfall (RF) and rainy days (RD)

During transplanting to fifty percent flowering the amount of rainfall received showed decreasing trend towards the delayed date of planting and highest (401.3 mm) amount of rainfall received by during first date of planting and least (0 mm) during last date of planting. The recorded amount of rainfall for control, white polythene, black polythene and straw mulch was 139.8 mm, 140.1mm, 142.5 and 142.3 respectively. The number of rainy days showed decreasing trend towards delayed planting, 17 days for first date of planting and 0 days for last date of planting. For control and white polythene rainy days was 7.5 days, for black polythene and straw mulch 7.6 days.

4.3.3.5. Bright sunshine hours (BSS)

Bright sunshine hours showed increasing trend towards the delayed planting. Highest (7.5 h) bright sunshine hours was observed during last date of planting and lowest (4.0 h) in first date of planting. The Bright sunshine hours for mulches ranged from 4.1h to 7.5h in control, 4.0h to 7.5 h in white polythene mulch, 4.0 h to 7.5 h in black polythene mulch and 4.0 h to 7.6 h in straw mulch

4.3.3.6. Wind speed (km h^{-1})

Wind speed showed increasing trend towards the delayed planting. Highest (4.9 km h^{-1}) wind speed was observed during last date of planting and lowest (0.3 km h^{-1}) in first date of planting. The wind speed for mulches ranged from 0.3 to 4.9 km h^{-1} in control, white polythene mulch, black polythene mulch and straw mulch.

4.3.3.7. Pan evaporation (Epan)

The pan evaporation showed increasing trend towards the delayed planting. Highest (3.8 mm) pan evaporation was observed during last date of planting and lowest (2.4 mm) in first date of planting. Pan evaporation for mulches ranged from 2.4 to 2.9 mm.

4.3.4. Weather during transplanting to fifty percent fruiting

The weather prevailed during transplanting to fifty percent fruiting was presented in the Table 4.4(a) and 4.4(b).

4.3.4.1. Temperature (Tmax, Tmin, Tmean and Trange)

During transplanting to fifty percent fruiting stage there was an increasing trend in temperature towards the last date of transplanting. The maximum temperature range recorded for control and straw mulch was 31.2°C to 32.7 °C, 31.3 °C to 32.7 °C for white polythene, 31.4 °C to 32.7 °C black polythene respectively. The lowest temperature range recorded was 31.2 °C during first transplanting. In case of minimum temperature mulches recorded decreasing trend towards the last date of planting. The minimum temperature range for control was 21.0 °C to 22.4 °C, 21.0 °C to 22.4 °C for white polythene and straw mulch, 20.9 °C to 22.4 °C for black polythene mulch. The mean temperature observed for mulches is 26.9 °C. The mean temperature is highest for fourth date of transplanting (1st November) and lowest for first date of transplanting (15th September) and last date of planting (1st December). Temperature range showed an increasing trend towards delayed date of transplanting and it ranges from 8.8 °C to 11.7°C for Control, 8.9°C to 11.8 °C for white polythene, 9 °C to 11.8°C for black polythene mulch and 8.8 °C to 11.7 °C for straw mulch.

4.3.4.2. Relative humidity (RH I, RH II and RH mean)

Highest forenoon and afternoon relative humidity recorded was 94 percent and 71 percent and it was noticed in first date of planting and lowest (76 % and 45%) for last date of planting. The forenoon relative humidity was recorded highest (87 %) for White polythene, black polythene and straw mulch and lowest (86%) for control. The afternoon relative humidity was 59 percent for mulches.

The mean relative humidity ranged from 61 to 82 percent, highest for first transplanting and lowest for delayed transplanting

4.3.4.3. Vapour pressure deficit (VPD I and VPD II)

Forenoon vapour pressure deficit was recorded highest (22.3 mm Hg) for first date of planting and lowest (17.3 mm Hg) for delayed transplanting. The afternoon vapour pressure for highest (22.5 mm Hg) for first date of planting and lowest (15.8 mm Hg) for last date of planting. The forenoon vapour pressure deficit range for control is 17.1 to 22.4 mm Hg, 17.5 to 22.4 for white polythene, 17.5 to 22.3 for black polythene and 17.3 to 22.4 mm Hg for straw mulch. The afternoon vapour pressure deficit range for control is 15.6 to 22.6 mm Hg, 15.9 to 22.5 for white polythene, 15.9 to 22.5 for black polythene and 15.8 to 22.6 mm Hg for straw mulch.

4.3.4.4. Rainfall (RF) and rainy days (RD)

During transplanting to fifty fruiting the amount of rainfall received showed decreasing trend towards the delayed date of planting and highest (465.7 mm) amount of rainfall received by during first date of planting and lowest (0 mm) during last date of planting The recorded amount of rainfall for control, white polythene, black polythene and straw mulch was 152.9 mm, 157.2 mm, 157.7 and 152.9 respectively. The number of rainy days showed decreasing trend towards delayed planting, 19.7 days for first date of planting and 0 days for last date of planting. For control and straw rainy days was 8.1 days, for white polythene 8.3days and for black polythene 8.5 days.

4.3.4.5. Bright sunshine hours (BSS)

Bright sunshine hours showed increasing trend towards the delayed planting. Highest (7.6 h) bright sunshine hours was observed during last date of planting and lowest (4.6 h) in first date of planting. The Bright sunshine hours for mulches ranged from 4.6 h to 7.7 h in control, 4.7 h to 7.6 h in white polythene mulch, 4.8 h to 7.6 h in black polythene mulch and 4.6 h to 7.6 h in straw mulch

4.3.4.6. Wind speed (km h^{-1})

Wind speed showed increasing trend towards the delayed planting.

Table 4.4(a). Weather parameters experienced during transplanting to fifty percent fruiting stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D1				D2				D3			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	31.2	31.3	31.4	31.2	31.8	31.9	31.9	31.9	32.4	32.4	32.4	32.4
Tmin (^{0}C)	22.4	22.4	22.4	22.4	22.2	22.2	22.1	22.1	21.8	21.8	21.9	21.8
Tmean (^{0}C)	26.8	26.9	26.9	26.8	27.0	27.0	27.0	27.0	27.1	27.1	27.1	27.1
Trange (^{0}C)	8.8	8.9	9.0	8.8	9.6	9.7	9.8	9.7	10.6	10.6	10.5	10.6
RH I (%)	94	93	93	94	90	91	91	91	89	89	89	89
RH II (%)	71	70	70	71	67	67	66	67	62	62	62	62
RH mean (%)	82	82	82	82	79	79	79	79	76	76	75	76
VPD I (mm Hg)	22.4	22.4	22.3	22.4	21.8	21.8	21.9	21.7	21.5	21.5	21.4	21.5
VPD II (mm Hg)	22.6	22.5	22.5	22.6	22.0	21.9	21.8	21.8	21.3	21.3	21.3	21.3
RF (mm)	452.1	477.9	480.8	452.1	215.4	215.4	215.4	215.4	165.8	165.8	165.8	165.8
RD (days)	19.0	20.0	21.0	19.0	13.0	13.0	13.0	13.0	10.0	10.0	10.0	10.0
BSS (h)	4.6	4.7	4.8	4.6	5.2	5.3	5.4	5.3	6.0	6.0	6.0	6.0
WS (km h^{-l})	0.4	0. 4	0.4	0.4	0.7	0.7	0.7	0.7	1.1	1.1	1.4	1.1
Epan (mm)	2.4	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.7	2.7	2.8	2.7

D1 - 15th September , D2- 1st October , D3- 15th October

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Table 4.4(b). Weather parameters experienced during transplanting to fifty percent fruiting stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D4				D5				D6			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7
Tmin (^{0}C)	21.6	21.6	21.7	21.6	21.2	21.4	21.5	21.4	21.0	21.0	20.9	21.0
Tmean (^{0}C)	27.2	27.2	27.2	27.2	27.0	27.0	27.1	27.0	26.9	26.8	26.8	26.9
Trange (^{0}C)	11.1	11.1	11.0	11.1	11.5	11.3	11.2	11.3	11.7	11.8	11.8	11.7
RH I (%)	88	88	88	88	82	82	83	82	75	76	76	76
RH II (%)	58	58	59	58	51	52	53	52	44	45	45	45
RH mean (%)	73	73	73	73	67	67	68	67	60	61	61	60
VPD I (mm Hg)	21.2	21.2	21.2	21.2	19.4	19.4	19.9	19.4	17.1	17.5	17.5	17.3
VPD II (mm Hg)	20.4	20.4	20.4	20.4	18.1	18.2	18.8	18.2	15.6	15.9	15.9	15.8
RF (mm)	58.3	58.3	58.3	58.3	26.1	26.1	26.1	26.1	0.0	0.0	0.0	0.0
RD (days)	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0
BSS (h)	6.0	6.0	6.0	6.0	7.1	7.0	6.8	7.0	7.7	7.6	7.6	7.6
WS (km h-^{1})	2.0	2.0	2.0	2.0	4.0	4.1	3.8	4.1	5.4	5.2	5.3	5.2
Epan (mm)	2.8	2.8	2.8	2.8	3.6	3.6	3.4	3.6	4.1	4.0	4.0	4.0

D4 - 1st November , D5 - 15th November , D6 -1st December

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Highest (5.2 km h^{-1}) wind speed was observed during last date of planting and lowest (0.3 km h^{-1}) in first date of planting. The wind speed for mulches ranged from 0.4 to 5.4 km h^{-1} in control, 0.4 to 5.2 km h^{-1}in white polythene mulch and straw mulch and 0.4 to 5.3 km h^{-1} in black polythene mulch.

4.3.4.7. Pan evaporation (Epan)

The pan evaporation showed increasing trend towards the delayed planting. Highest (4.0 mm) pan evaporation was observed during last date of planting and lowest (2.4 mm) in first date of planting. Pan evaporation for mulches ranged from 2.4 to 4.1mm in control, 2.5 to 4.0 mm in white and black polythene mulch and 2.4 to 4.0 mm in straw mulch

4.3.5. Weather during transplanting to harvesting

The weather prevailed during transplanting to harvesting was presented in the Table 4.5(a) and 4.5(b).

4.3.5.1. Temperature (Tmax, Tmin, Tmean and Trange)

During transplanting to harvesting stage there was an increasing trend in temperature towards the last date of transplanting. The maximum temperature range recorded for control and mulches is 32.4 °C. The lowest temperature range recorded was 31.8 °C during first transplanting and highest temperature range recorded was 32.8 °C during last transplanting. Minimum temperature mulches recorded decreasing trend towards the last date of planting. The minimum temperature range for control was 21.0 °C to 22.2 °C, 21.0 °C to 22.1 °C for white polythene, straw mulch and black polythene mulch. The mean temperature observed for control and mulches is 27 °C. The mean temperature is highest for second date of transplanting (1st October) and lowest for last date of planting (1st December). Temperature range showed an increasing trend towards delayed date of transplanting and it ranges from 9.7 °C to 11.9°C for Control and straw mulch 9.7 °C to 11.8 °C for white polythene, 9.8 °C to 11.8 °C for black polythene mulch

4.3.5.2. Relative humidity (RH I, RH II and RH mean)

Highest forenoon and afternoon relative humidity recorded was 91 percent and 72.2 percent and it was noticed in first date of planting and lowest (74.5 % and 60.8 %) for last date of planting. The forenoon relative humidity was recorded for White polythene mulch and straw mulch is 54.6 percent and 54.5 percent for black polythene and least 54.1 percent for control. The mean relative humidity ranged from 59.2 to 78 percent, highest for first transplanting and lowest for delayed transplanting.

4.3.5.3. Vapour pressure deficit (VPD I and VPD II)

Forenoon vapour pressure deficit was recorded highest (21.8 mm Hg) for first date of planting and lowest (16.85 mm Hg) for delayed transplanting. The afternoon vapour pressure for highest (21.6 mm Hg) for first date of planting and lowest (15.4 mm Hg) for last date of planting. The forenoon vapour pressure deficit range for control is 16.7 to 21.9 mm Hg, 16.9 to 21.9 for white polythene, 17.0 to 21.8 for black polythene and 16.8 to 21.9 mm Hg for straw mulch. The afternoon vapour pressure deficit range for control is 15.3 to 21.7 mm Hg, 15.5 to 21.6 for white polythene, 15.6 to 21.6 for black polythene and 15.5 to 21.6 mm Hg for straw mulch.

4.3.5.4. Rainfall (RF) and rainy days (RD)

The amount of rainfall received during transplanting to harvesting showed decreasing trend towards the delayed date of planting and highest (510.4 mm) amount of rainfall received by during first date of planting and lowest (0 mm) during last date of planting The recorded amount of rainfall in control and mulches was 167 mm. The number of rainy days showed decreasing trend towards delayed planting, 24 days for first date of planting and 0 days for last date of planting. For control and mulches rainy days was 9.3 days.

4.3.5.5. Bright sunshine hours (BSS)

Bright sunshine hours showed increasing trend towards the delayed planting. Highest (7.7 h) bright sunshine hours was observed during last date of planting and lowest (5.3 h) in first date of planting. The Bright sunshine hours for control and mulches ranged from 5.2 h to 7.7 h in control, 5.3 h to 7.7 h in white polythene mulch and straw mulch 5.4 h to 7.7 h in black polythene mulch.

Table 4.5(a). Weather parameters experienced during transplanting to harvesting stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D1				D2				D3			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	31.8	31.9	31.9	31.9	32.2	32.2	32.2	32.2	32.4	32.4	32.4	32.4
Tmin (^{0}C)	22.2	22.1	22.1	22.1	21.9	21.9	21.9	21.9	21.6	21.6	21.6	21.6
Tmean (^{0}C)	27.0	27.0	27.0	27.0	27.1	27.1	27.1	27.1	27.0	27.0	27.0	27.0
Trange (^{0}C)	9.7	9.7	9.8	9.7	10.3	10.3	10.3	10.3	10.8	10.9	10.9	10.8
RH I (%)	91	91	91	91	89	89	88	89	85	84	84	85
RH II (%)	66	66	65	66	62	62	62	62	57	57	57	57
RH mean (%)	78	78	78	78	76	76	75	75	71	71	71	71
VPD I (mm Hg)	21.9	21.9	21.8	21.9	21.4	21.4	21.3	21.3	20.2	20.2	20.2	20.2
VPD II (mm Hg)	21.7	21.6	21.6	21.6	21.1	21.1	20.9	21.0	19.7	19.6	19.6	19.7
RF (mm)	510.4	510.4	510.4	510.4	241.5	241.5	241.5	241.5	165.8	165.8	165.8	165.8
RD (days)	24.0	24.0	24.0	24.0	15.0	15.0	15.0	15.0	10.0	10.0	10.0	10.0
BSS (h)	5.2	5.3	5.4	5.3	5.7	5.7	5.8	5.7	6.5	6.5	6.5	6.5
WS (km h^{-1})	1.1	1.2	1.2	1.2	1.6	1.6	1.8	1.7	2.8	2.9	2.9	2.8
Epan (mm)	2.7	2.7	2.7	2.7	2.7	2.7	2.8	2.8	3.2	3.2	3.2	3.2

D1 - 15th September , D2- 1st October , D3- 15th October

Table 4.5(b). Weather parameters experienced during transplanting to harvesting stage of tomato under different mulches at different dates of planting

Weather parameters	Dates of transplanting											
	D4				D5				D6			
	Control	White	Black	Straw	Control	White	Black	Straw	Control	White	Black	Straw
Tmax (^{0}C)	32.8	32.7	32.7	32.7	32.8	32.8	32.8	32.8	32.9	32.8	32.8	32.8
Tmin (^{0}C)	21.3	21.3	21.3	21.3	21.2	21.2	21.2	21.2	21.0	21.0	21.0	21.0
Tmean (^{0}C)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	26.9	26.9	26.9	26.9
Trange (^{0}C)	11.5	11.4	11.4	11.4	11.6	11.6	11.6	11.6	11.9	11.8	11.8	11.9
RH I (%)	81	81	81	81	78	79	79	78	74	75	75	74
RH II (%)	50	51	51	51	47	48	48	48	43	44	44	44
RH mean (%)	65	66	66	66	63	63	64	63	59	59	60	59
VPD I (mm Hg)	19.0	19.0	19.0	19.1	18.2	18.3	18.5	18.2	16.7	16.9	17.0	16.8
VPD II (mm Hg)	17.7	17.8	17.8	17.9	16.8	16.9	17.1	16.8	15.3	15.5	15.6	15.5
RF (mm)	58.3	58.3	58.3	58.3	26.1	26.1	26.1	26.1	0.0	0.0	0.0	0.0
RD (days)	5.0	5.0	5.0	5.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0
BSS (h)	7.2	7.1	7.1	7.1	7.4	7.3	7.3	7.4	7.7	7.7	7.7	7.7
WS (km h^{-1})	4.0	3.9	3.9	3.9	4.6	4.5	4.4	4.6	5.3	5.3	5.4	5.3
Epan (mm)	3.6	3.6	3.6	3.6	3.9	3.8	3.8	3.8	4.1	4.1	4.1	4.1

D4 - 1st November , D5 - 15th November , D6 -1st December

4.3.5.6. Wind speed (WS)

Wind speed showed increasing trend towards the delayed planting. Highest (5.3 km h^{-1}) wind speed was observed during last date of planting. Lowest (1.1 km h^{-1}) in first date of planting. The wind speed for mulches ranged from 1.1 to 5.3 km h^{-1} in control, 1.2 to 5.3 km h^{-1} in white polythene mulch and straw mulch and 1.2 to 5.4 km h^{-1} in black polythene mulch.

4.3.5.7. Pan evaporation (Epan)

The pan evaporation showed increasing trend towards the delayed planting. Highest (4.1mm) pan evaporation was observed during last date of planting and lowest (2.7 mm) in first date of planting. Pan evaporation for control and mulches ranged from 2.7 to 4.1 mm.

4.4. MICROMETEOROLOGICAL OBSERVATIONS

4.4.1. Soil temperature

Soil temperature during the crop growth period *i.e.*, from September to March (at 7.30 am and 2.30 pm) was influenced by mulching practices

4.4.1.1. Effect of dates of planting on soil temperature

During the 15th September planting (D1) and 1st October planting (D2) the soil temperature at 7.30 am in different treatments was ranging from 27.76°C to 30.26 °C and 27.74 °C to 30.51 °C respectively. Mulches maintained higher soil temperature compared to control throughout the crop period. The temperature was highest under black polythene mulch compared to control (bare soil). At 2.30 pm, temperature in different treatments was ranged from to 29°C to 33.35°C and 29.01 °C to 33.04 °C respectively. The temperature difference were recorded in between 15th September planting (D1) and 1st October planting (D2) and respective values were given in Table 4.6(a and b).

In the 15th October planting (D3) and 1st November the soil temperature at 7.30 am in different treatments was ranging from 28.01 °C to 30.66 °C and 28.10 °C to 30.11 °C respectively. The temperature difference was recorded in 15th October

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Table 4.6(a). Effect of dates of planting on soil temperature

Dates of planting	Control (without mulching)						White top black bottom polythene					
	Forenoon (7.30am)			Afternoon (2.30 pm)			Forenoon (7.30am)			Afternoon (2.30 pm)		
	5cm	15cm	30cm	5cm	15cm	30cm	5cm	15cm	30cm	5cm	15cm	30cm
D1	27.76	28.10	28.38	30.30	29.63	29.00	28.57	29.10	29.76	31.44	31.20	30.47
D2	27.74 (-0.02)	27.97 (-0.10)	28.53 (0.10)	30.25 (-0.05)	29.81 (0.19)	29.01 (0.01)	28.48 (-0.09)	28.91 (-0.19)	29.66 (-0.10)	32.45 (1.02)	31.68 (0.48)	30.51 (0.03)
D3	28.01 (0.25)	28.37 (0.27)	28.77 (0.40)	31.19 (0.89)	30.41 (0.78)	29.65 (0.65)	29.27 (0.70)	29.90 (0.80)	30.36 (0.60)	32.22 (0.78)	31.37 (0.17)	31.17 (0.70)
D4	28.10 (0.34)	28.52 (0.42)	28.91 (0.53)	31.19 (0.89)	30.81 (1.19)	29.73 (0.74)	29.00 (0.43)	29.46 (0.36)	29.93 (0.17)	32.29 (0.86)	31.86 (0.66)	30.74 (0.27)
D5	29.15 (1.39)	29.47 (1.38)	29.91 (1.53)	32.01 (1.71)	31.33 (1.70)	30.66 (1.66)	30.37 (1.80)	30.91 (1.81)	31.46 (1.70)	33.69 (2.25)	32.94 (1.74)	32.20 (1.73)
D6	28.57 (0.81)	28.95 (0.85)	29.44 (1.06)	32.31 (2.01)	31.51 (1.88)	30.11 (1.11)	29.71 (1.14)	30.13 (1.04)	30.59 (0.83)	32.91 (1.47)	32.15 (0.95)	31.16 (0.69)

*Values in parenthesis are difference in soil temperature of different dates of planting with first date of planting

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November , D6 -1st December

Table 4.6(b). Effect of dates of planting on soil temperature

Dates of planting	Black top white bottom polythene						Paddy straw mulch					
	Forenoon (7.30am)			Afternoon (2.30 pm)			Forenoon (7.30am)			Afternoon (2.30 pm)		
	5cm	15cm	30cm	5cm	15cm	30cm	5cm	15cm	30cm	5cm	15cm	30cm
D1	29.07	29.60	30.26	33.35	32.61	30.75	28.17	28.50	28.92	30.58	30.10	29.49
D2	29.09 (0.03)	29.79 (0.19)	30.51 (0.25)	33.04 (-0.31)	31.99 (-0.62)	31.60 (0.85)	28.07 (-0.10)	28.40 (-0.10)	29.03 (0.11)	31.96 (1.38)	30.68 (0.58)	29.91 (0.42)
D3	29.65 (0.58)	30.11 (0.51)	30.66 (0.40)	32.99 (-0.35)	32.49 (-0.12)	31.64 (0.89)	28.52 (0.35)	28.87 (0.37)	29.18 (0.26)	31.99 (1.41)	31.15 (1.05)	29.83 (0.34)
D4	29.38 (0.32)	29.73 (0.13)	30.11 (-0.14)	32.59 (-0.76)	32.28 (-0.33)	30.88 (0.13)	28.50 (0.34)	28.94 (0.44)	29.55 (0.63)	31.81 (1.23)	31.27 (1.17)	30.59 (1.10)
D5	31.01 (1.94)	31.66 (2.06)	32.21 (1.96)	34.60 (1.26)	33.81 (1.20)	33.08 (2.34)	29.74 (1.58)	30.17 (1.67)	30.68 (1.76)	32.67 (2.09)	32.04 (1.94)	31.38 (1.89)
D6	30.33 (1.26)	30.80 (1.20)	31.31 (1.05)	33.41 (0.07)	32.74 (0.12)	31.77 (1.02)	29.10 (0.93)	29.49 (0.99)	29.86 (0.94)	32.52 (1.94)	31.92 (1.820	30.50 (1.01)

*Values in parenthesis are difference in soil temperature of different dates of planting with first date of planting

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November , D6 -1st December

Table 4.7. Effect of mulching on soil temperature

Types of mulch	Forenoon (7.30am)			Afternoon (2.30 pm)		
	5cm	15cm	30cm	5cm	15cm	30cm
M0	28.22	28.56	28.99	31.21	30.58	29.69
M1	29.23 (1.01)	29.74 (1.17)	30.29 (1.30)	32.56 (1.36)	31.87 (1.28)	31.04 (1.35)
M2	29.76 (1.53)	30.28 (1.72)	30.84 (1.86)	33.33 (2.12)	32.65 (2.07)	31.62 (1.93)
M3	28.77 (0.54)	29.18 (0.62)	29.66 (0.67)	31.84 (0.63)	31.28 (0.70)	30.38 (0.68)

*Values in parenthesis are difference in soil temperature of different mulches with control

M0- Control, M1 - White top black bottom polythene , M2 - Black top white bottom polythene
M3 - Paddy straw

Table 4.8. Soil moisture at different dates of planting and mulches

Types of mulch	D1	D2	D3	D4	D5	D6
M0	11.7	9.5	8.3	7.4	5.7	5
M1	14.3	12.2	11.2	9.8	9	7.5
M2	14.8	13.1	12.3	10.7	10	8.3
M3	15.1	12.6	11.6	10	8.4	7.7

D1 - 15th September D4 - 1st November M0- Control
D2- 1st October D5 - 15th November M1 - White top black bottom polythene
D3- 15th October D6 -1st December M2 - Black top white bottom polythene
M3 - Paddy straw MBC – microbial biomass carbon

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planting (D3) and 1st November planting (D4) when compared to 15th September planting (D1). At 2.30 pm, temperature in different treatments was ranged from 29.65 °C to 32.99 °C and 29.73 °C to 32.59 °C and corresponding values were given in Table 4.6(a and b). All throughout the 15th November planting (D5) and 1st December planting (D6), the soil temperature at 7.30 am in different treatments was ranged from 29.15 °C to 32.21°C and 28.57 °C to 31.31 °C. The temperature difference was recorded in 15th November planting (D5) and 1st December planting (D6) when compared to 15th September planting (D1). At 2.30 pm, temperature in different treatments ranged from 30.66 °C to 34.60 °C. And 30.11 °C to 33.41 °C. Respectively. The respective values are given in in Table 4.6(a and b).

4.4.1.2. Effect of mulching on soil temperature

Plastic mulches maintained higher soil temperature compared to control (bare soil) throughout the crop period. At 7.30am, the temperature was higher by 1.53 °C at 5cm, 1.72 °C at 15cm and 1.86 °C at 30cm under black polythene mulch compared to control (bare soil) and it was higher by 1.01 °C and 0.54 °C at 5cm, 1.17 °C and 0.62 °C at 15cm and at 30cm it was 1.30 °C and 0.67 °C under white polythene and paddy straw mulch respectively. At 2.30 pm, the trend of temperature differences was similar to that at 7.30 am. A temperature difference of 2.12 °C at 5cm, 2.07 °C at 15cm and 1.93 °C at 30cm was noticed between black polythene mulch and control (Table 4.7).

4.4.2. Soil moisture

Soil moisture during the crop period (September to March) at 15cm depth was recorded on weekly intervals. The effect of dates of planting and mulch treatments on soil moisture is analyzed and provided in Table 4.8.

4.4.2.1. Soil moisture on different dates of planting

The results on soil moisture showed decreasing trend towards the last date of planting. The highest average soil moisture of 11.7% (control), 14.3% (white), 14.8% (black) and 15.1% (straw) was recorded during the first date of planting (15th September) and lowest soil moisture of 5.0% (control), 7.5% (white), 8.3%(black) and 7.7% (straw) was recorded during last date of planting (1st December) (Table 4.8).

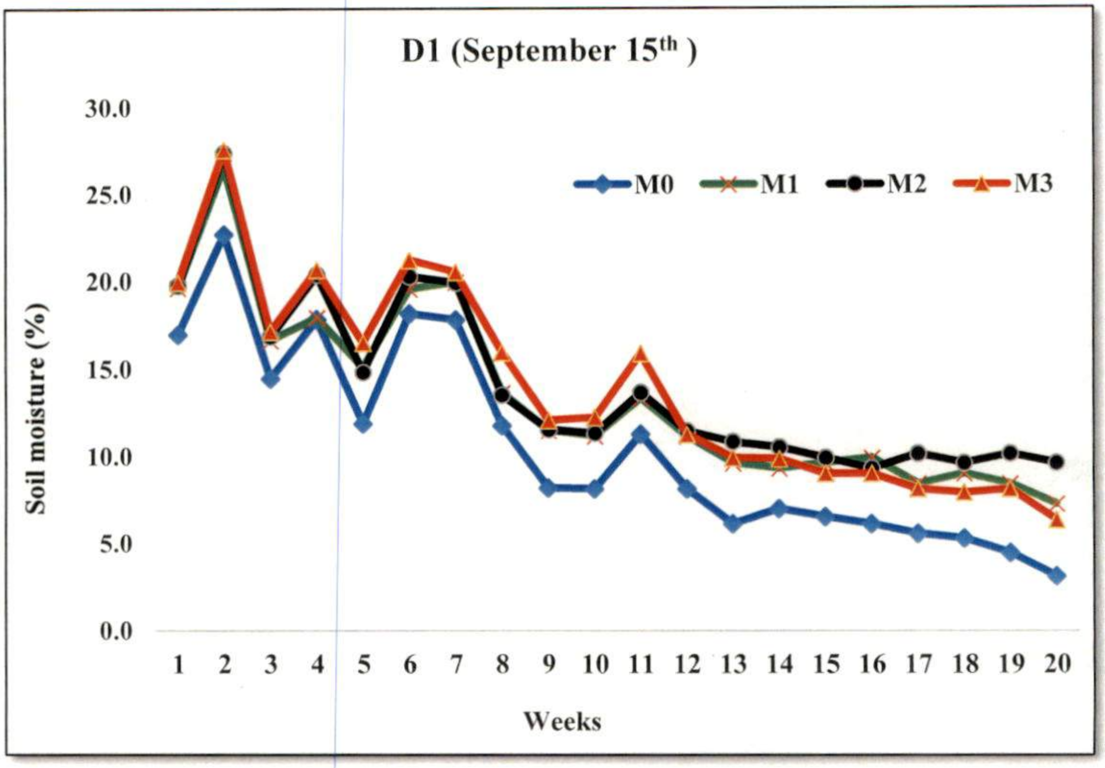

Fig. 4.7(a) Soil moisture during first date of planting

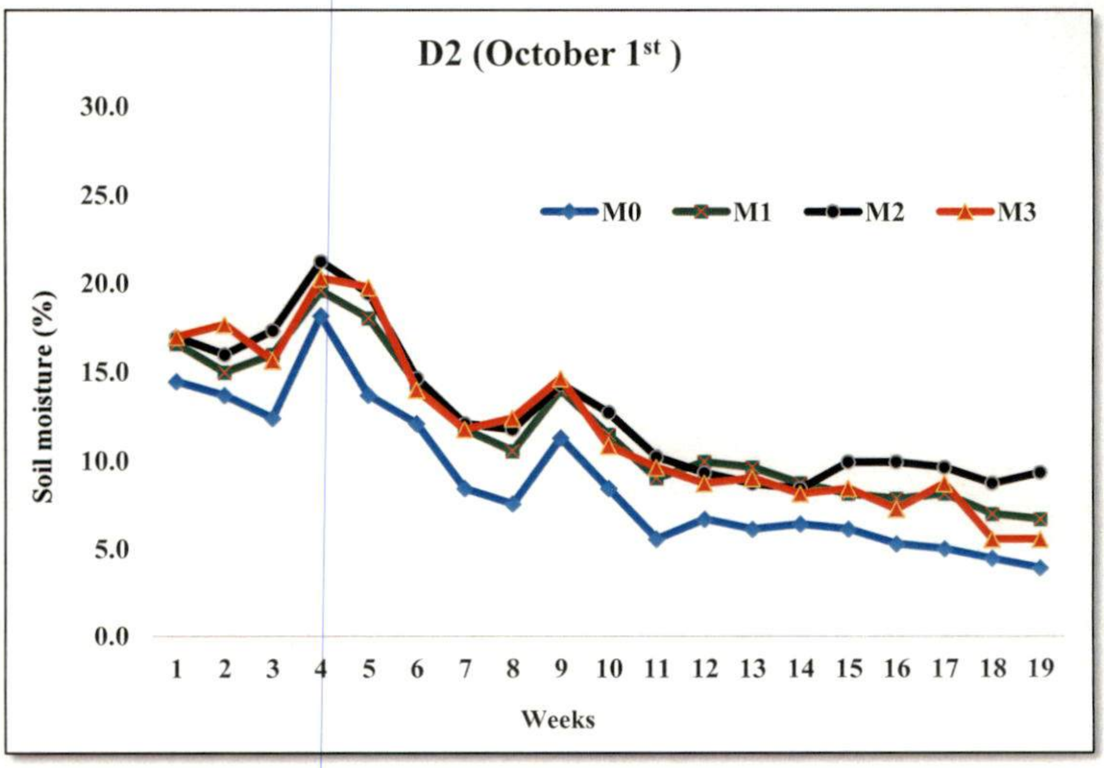

Fig. 4.7(b) Soil moisture during second date of planting

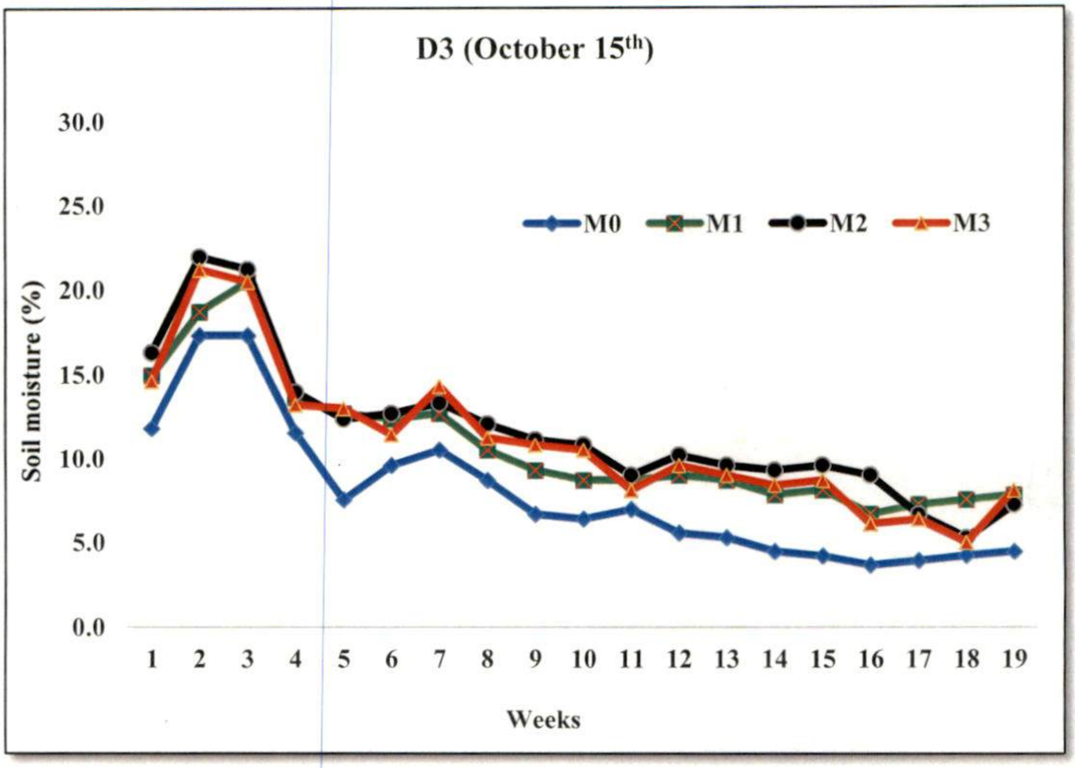

Fig. 4.7(c) Soil moisture during third date of planting

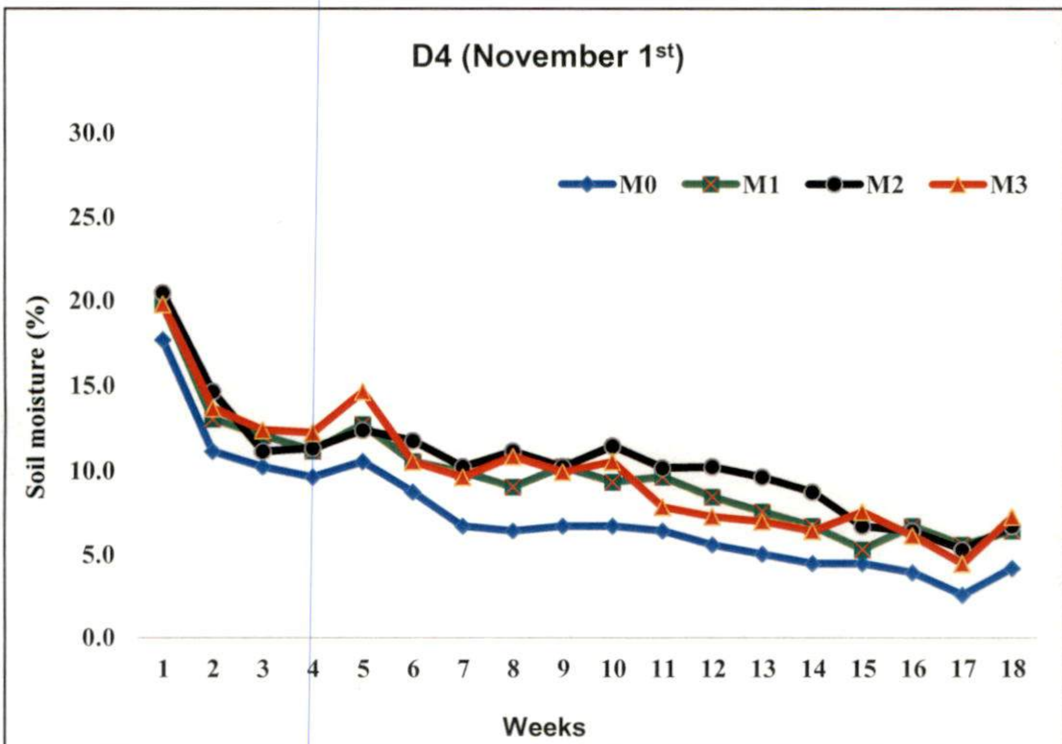

Fig. 4.7(d) Soil moisture during forth date of planting

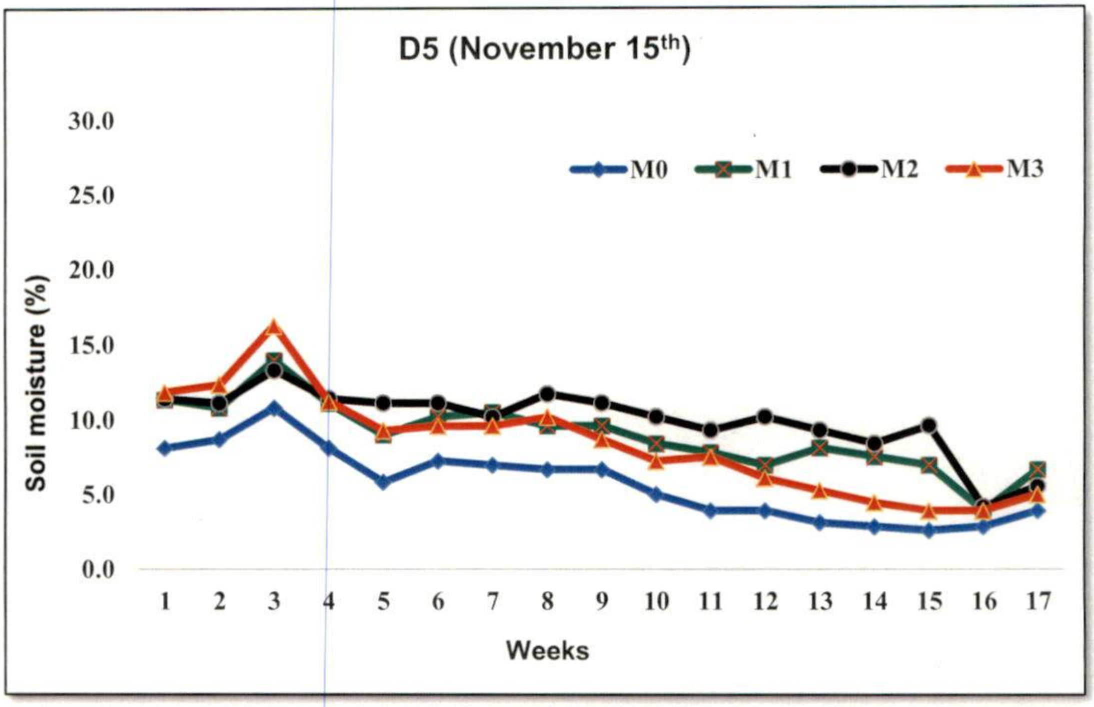

Fig. 4.7(e) Soil moisture during fifth date of planting

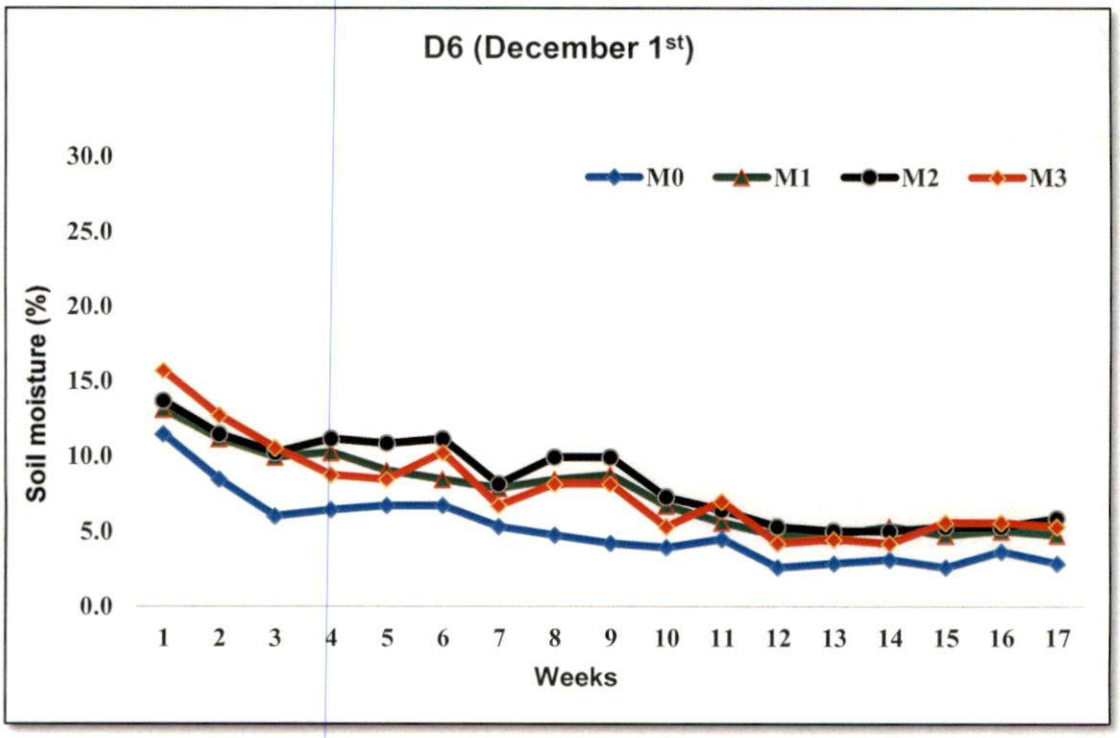

Fig. 4.7(f) Soil moisture during sixth date of planting

4.4.2.2. Soil moisture on different mulches

Soil moisture content under black polythene mulch was high at all the dates of planting. White polythene mulch and paddy straw mulch were also equally effective in maintaining soil moisture but lower than that of black polythene mulch. Lowest moisture content was recorded in control (bare soil)(Table 4.8).

4.5. SOIL PARAMETERS

The soil pH, organic carbon, soil microbial biomass carbon and available nutrient status (N, P and K) of soil was influenced by different mulching practices (Table 4.9(a) and Table 4.9(b)).

4.5.1 Soil pH

The soil pH ranged from 5.8 to 6.55, the lower pH was recorded in control and paddy straw mulch recorded higher pH in all the dates of planting (Table 4.9(a)).

4.5.2. Organic carbon

The organic carbon (%) ranged from 0.72 to 0.97, the lowest organic carbon was recorded in control and mulches recorded highest organic carbon in all the dates of planting and the corresponding values are given in Table 4.9(a).

4.5.3. Soil microbial biomass carbon

Different dates of planting and mulching practices showed influence on microbial biomass carbon of soil (Table 4.9(a)) and ranged from 110 to 209.6 kg C ha^{-1}. The microbial biomass carbon of soil was comparatively low in last dates of planting. Among the control and mulches, control showed less microbial biomass carbon.

4.5.4. Available nitrogen, phosphorus and potassium

The available nitrogen, phosphorus and potassium content of the soil after the harvest of tomato crop did not vary among the different dates of planting. Available nitrogen content in soil ranged from 130.6 to 217.9 kg ha^{-1}, available phosphorus ranged from 19.4 to 46.9 kg ha^{-1} and available potassium ranged from 135.5 to 238.6 kg ha^{-1} and it was higher in all mulching treatments than bare soil (Table 4.9(b)).

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Table 4.9(a). Effect of dates of planting and mulching on soil pH, organic carbon and microbial biomass carbon

Dates of planting	Types of mulch	Soil pH	OC (%)	MBC (kg C ha^{-1})
D1	M0	5.8	0.7	171.6
	M1	5.9	0.8	177.6
	M2	6.0	0.8	184.0
	M3	6.3	0.9	206.8
D2	M0	6.2	0.7	159.6
	M1	6.1	0.9	177.6
	M2	6.2	0.8	187.2
	M3	6.4	0.9	162.9
D3	M0	6.1	0.7	160.4
	M1	6.2	1.0	176.0
	M2	6.0	0.9	184.0
	M3	6.5	0.9	184.4
D4	M0	6.1	0.7	164.4
	M1	6.1	1.0	183.0
	M2	6.3	0.9	176.4
	M3	6.5	1.0	209.6
D5	M0	6.2	0.7	117.2
	M1	6.0	0.9	142.0
	M2	6.2	0.9	144.4
	M3	6.4	1.0	155.2
D6	M0	6.0	0.8	110.0
	M1	6.1	0.9	144.0
	M2	6.1	1.0	143.0
	M3	6.3	1.0	136.0

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November D6 -1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy staw, OC- Organic carbon, MBC- Microbial biomass carbon

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Table 4.9(b). Effect of dates of planting and mulching on available nitrogen, available phosphorus and available potassium

Dates of planting	Types of mulch	N (kg ha $^{-1}$)	P (kg ha $^{-1}$)	K (kg ha $^{-1}$)
D1	M0	141.3	23.0	177.0
	M1	181.4	29.7	198.2
	M2	181.4	30.9	192.6
	M3	194.9	44.5	231.8
D2	M0	130.6	19.4	169.1
	M1	164.9	32.9	205.0
	M2	172.1	35.5	217.3
	M3	195.0	37.6	222.9
D3	M0	150.0	19.8	152.3
	M1	174.0	30.2	178.1
	M2	179.0	36.6	175.8
	M3	195.0	35.5	192.6
D4	M0	160.6	23.1	135.5
	M1	198.0	24.5	191.5
	M2	206.5	29.4	207.2
	M3	217.9	31.9	234.1
D5	M0	161.3	21.4	171.4
	M1	195.0	36.2	197.1
	M2	194.9	38.0	185.9
	M3	217.9	46.9	238.6
D6	M0	137.0	20.7	165.8
	M1	189.0	36.2	203.8
	M2	196.0	35.6	194.9
	M3	217.3	35.1	225.1

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November D6 -1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy staw, N- Nitrogen , P- Phosphorus, K- Potasiu

4.6. PLANT PARAMETERS

4.6.1. Nitrogen content

The nitrogen content in tomato plant differed among different dates of planting and mulching practices. The content of nitrogen varied from 2.45 to 3.7 per cent. Among the dates of planting D5 (15th November) and D6 (1st December) showed less nitrogen content compared to other dates of planting. The plants with mulches showed higher nitrogen content compared to control (Table 4.10).

4.6.2. Phosphorus content

The concentration of phosphorus in tomato plant differed among different dates of planting and mulching practices. The content of phosphorus varied from 0.27 to 0.4 per cent. Among the dates of planting D5 (15th November) and D6 (1st December) showed less phosphorus content compared to other dates of planting. The plants with mulches showed higher phosphorus content compared to control (Table 4.10).

4.6.3. Potassium content

The potassium content in tomato plant vary among different dates of planting and mulching practices. The content of potassium varied from 2.55 to 3.35 per cent. Among the dates of planting D5 (15th November) and D6 (1st December) showed less potassium content compared to other dates of planting. The plants with mulches showed higher potassium content compared to control (Table 4.10).

4.7. STATISTICAL ANALYSIS OF PLANT CHARACTERISTICS

Statistical analysis were performed for biometric observations (plant height, number of trusses per plant, number of weeds per plant, yield per plant and number of weeds per square meter) and phenological observations (number of days to first flowering, number of days to 50% flowering, number of days to first fruiting, number of days to 50% fruiting, number of days for first harvesting and total duration of the crop). The results of analysis of covariance presented are below.

Table 4.10. Effect of dates of planting and mulching on plant parameters

Dates of planting	Types of mulch	N (%)	P (%)	K (%)
D1	M0	0.29	1.75	2.75
	M1	0.27	2.10	3.45
	M2	0.33	1.70	3.25
	M3	0.35	1.60	3.35
D2	M0	0.24	1.55	2.95
	M1	0.35	2.15	3.40
	M2	0.38	2.20	3.10
	M3	0.40	2.35	3.25
D3	M0	0.26	1.50	2.45
	M1	0.29	1.70	3.40
	M2	0.38	2.00	3.30
	M3	0.36	2.25	3.40
D4	M0	0.38	1.75	2.45
	M1	0.30	1.75	3.20
	M2	0.30	1.85	3.35
	M3	0.30	1.90	3.40
D5	M0	0.21	1.55	2.05
	M1	0.22	1.75	2.45
	M2	0.27	1.60	2.20
	M3	0.30	2.05	2.35
D6	M0	0.16	1.60	1.85
	M1	0.22	2.00	2.20
	M2	0.22	1.90	2.10
	M3	0.26	1.85	2.45

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 -1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy staw, N- Nitrogen , P- Phosphorus, K- Potassium

4.7.1. BIOMETRIC OBSERVATIONS

4.7.1.1. Plant height

Analysis of variance was performed for fortnightly plant height from 15 to 105 days after transplanting and results are presented in Appendix ii.

The effect of date of planting on fortnightly plant height from 15 to 105 days after transplanting is provided in Table 4.11. Significant difference was observed and comparison was made between dates of planting. It was found that on 30, 45, 75, 90 and 105 days after transplanting, plant height was highest for 15th September planting and the corresponding values were 45.4, 54.6, 83, 92.1 and 96.7 cm respectively. On 15 days after transplanting, 15th September (22cm) and 15th October (20.6cm) plantings were on par with respect to plant height, whereas on 60days after transplanting, 15th September (62.7 cm) and 1st october (59.6 cm) plantings were on par. Lowest plant height was recorded for December 1st planting on 30, 45, 75 , 90 and 105 days after transplanting with corresponding heights of 25.5, 33.1,45.1,46.0 and 46.5 cm respectively. But on 15 and 60 days after transplanting, November 15th and December 1st plantings were on par.

The effect of mulch treatments on fortnightly plant height from 15 to 105 days after transplanting is provided in Table 4.12. Except on 15 days after transplanting high significant difference was observed between mulch treatments for plant height. Highest plant height was recorded for black top white bottom polythene mulch and lowest plant height was recorded for control at all fortnight intervals from 30 to 105 days after transplanting.

Interaction between date of planting and mulch treatments was significant (Appendix ii.) with respect to plant height at fortnightly intervals except 30, 90 and 105 days after transplanting. When there was interaction between date of planting and mulch treatments, best mulch for each date of planting was given.

On 15 days after transplanting, there was no significant effect of mulch treatments on plant height for 15th September (D1), 15th October (D3), 1st November (D4) and 1st December (D6) plantings. For 1st October (D2) planting, plant height was lowest for black top white bottom polythene (15.66 cm), whereas control, white top black bottom polythene and straw mulches were on par (Table 4.13(a)).

Table 4.11. Effect of dates of planting on plant height

Date of planting	PLANT HEIGHT (cm)						
	15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	105DAT
D1	22.0^{a}	45.4^{a}	54.6^{a}	62.7^{a}	83.0^{a}	92.1^{a}	96.7^{a}
D2	18.0^{b}	36.2^{b}	50.4^{b}	59.6^{ab}	77.6^{b}	86.5^{b}	88.6^{b}
D3	20.6^{a}	35.3^{bc}	47.4^{c}	58.1^{bc}	73.8^{b}	81.4^{c}	85.1^{b}
D4	13.6^{c}	32.6^{c}	42.8^{d}	55.6^{c}	67.7^{c}	76.1^{d}	78.2^{c}
D5	10.4^{d}	29.2^{d}	36.9^{e}	45.8^{d}	56.3^{d}	58.4^{e}	60.5^{d}
D6	10.3^{d}	25.5^{e}	33.1^{f}	43.3^{d}	45.1^{e}	46.0^{f}	46.5^{e}
CD	1.62	3.30	2.74	3.84	5.27	5.00	4.62

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November , D6 -1st December

Table 4.12. Effect of mulching on plant height

Types of mulch	PLANT HEIGHT (cm)						
	15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	105DAT
M0	15.7	29.4^{c}	39.4^{c}	48.8^{d}	63.0^{c}	69.4^{d}	72.4^{d}
M1	16.0	35.2^{b}	44.6^{b}	55.7^{b}	68.1^{b}	74.6^{b}	76.9^{b}
M2	16.3	37.4^{a}	48.3^{a}	58.4^{a}	71.0^{a}	77.1^{a}	79.6^{a}
M3	15.5	34.3^{b}	44.7^{b}	53.9^{c}	66.9^{b}	72.6^{c}	74.8^{c}
CD	NS	1.52	1.15	1.28	1.49	1.72	1.53

M0- Control M1 - White top black bottom polythene M2 - Black top white bottom polythene
M3- Paddy staw CD – Critical difference DAT – Days after transplanting

For 15th November planting, plant height was high on 15 days after transplanting for black top white bottom and white top black bottom polythene mulches. Plant height was less for straw mulch (9.26 cm) and control (8.50 cm) (Table 4.13(a)).

On 45 days after transplanting, for 15th September (D1) and 15th October (D3) plantings, black top white bottom polythene (57.0 cm) and straw mulch (59.1 cm) were on par. For 1st October (D2) and 15th November (D5) plantings, black top white bottom polythene recorded high and control recorded low plant height. Black top white bottom (47.6 cm) and white top black bottom polythene (45.4 cm) mulches were on par for 1st November planting with respect to plant height. For 1st December planting, black top white bottom polythene (36.5 cm) and white top black bottom polythene (45.4 cm) mulches were on par and recorded high plant height and control recorded low (27.8 cm) plant height (Table 4.13(a)).

On 60 days after transplanting, black top white bottom polythene (64.16 cm) and white top black bottom polythene (65.66cm) mulches were on par and recorded high plant height, whereas straw mulch (61.83 cm) and control (59.16 cm) were on par and recorded low plant height for 15th September (D1) planting. For 1st October (D2) planting, black top white bottom polythene recorded high (64.25 cm) and control recorded low (54.83 cm) plant height. For 15th November (D5) and 1st December (D6) planting, black top white bottom polythene showed highest and control showed lowest plant height. Plant height of mulches were on par with each other, whereas control recorded lowest height during 15th October (D3) and 1st November (D4) planting (Table 4.13(a)).

On 75 days after transplanting 15th September (D1), 1st October (D2), 15th October (D3) planting plant height did not vary between mulches and control. However in 1st November (D4) planting plant height of mulches are on par and control recorded lowest plant height. Black polythene showed highest and control showed lowest plant height during 15th November (D5) and 1st December (D6) planting. Corresponding values were given in Table 4.13 (b).

4.7.1.2. Number of trusses per plant

Analysis of variance was performed for number of trusses per plant and results are presented in Appendix ii.

Table 4.13(a). Interaction effect of date of planting and mulching on plant height

Dates of planting	15DAT					30DAT				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	
D1	22.75^{a}	21.16^{a}	21.41^{a}	22.66^{a}	2.70	43.0	45.3	48.0	45.3	NS
D2	19.33^{a}	17.83^{a}	15.66^{b}	19.50^{a}		32.6	35.9	38.3	37.5	
D3	21.83^{a}	21.08^{a}	20.00^{a}	19.83^{a}		31.5	35.9	37.2	36.6	
D4	12.83^{a}	14.41^{a}	15.00^{a}	12.50^{a}		26.6	35.4	37.6	31.0	
D5	8.50^{b}	11.08^{ab}	13.08^{a}	9.26^{b}		22.3	31.6	34.0	29.1	
D6	9.00^{a}	9.66^{a}	11.25^{a}	11.41^{a}		20.1	27.1	28.5	26.1	
Dates of planting	**45DAT**					**60DAT**				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	CD
D1	49.6^{c}	52.8^{b}	57^{a}	59.1^{a}	2.97	59.16^{c}	65.66^{a}	64.16^{ab}	61.83^{bc}	3.34
D2	44.6^{c}	51.5^{b}	55.5^{a}	50.1^{b}		54.83^{c}	60.66^{b}	64.25^{a}	58.66^{b}	
D3	45.8^{bc}	44.6^{c}	51^{a}	48.3^{ab}		53^{c}	59.58^{ab}	61.25^{a}	58.5^{ab}	
D4	37.1^{c}	45.4^{a}	47.6^{a}	41^{b}		51.16^{c}	55.16^{ab}	58.66^{a}	57.54^{ab}	
D5	31.1^{c}	38.5^{b}	42^{a}	36.1^{b}		38^{c}	47.66^{b}	52.66^{a}	44.66^{b}	
D6	27.8^{c}	34.6^{ab}	36.5^{a}	33.5^{b}		36.33^{c}	45.33b	49.66^{a}	42^{b}	

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 -1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy staw, CD – Critical difference, DAT – Days after transplanting

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Table 4.13(b). Interaction effect of date of planting and mulching on plant height

Dates of planting	75DAT					90DAT				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	
D1	80.66^{b}	82.66^{ab}	83.83^{ab}	85^{a}	3.94	88.6	92.8	92.5	94.5	NS
D2	75.16^{b}	78.83^{ab}	80.83^{a}	75.66^{b}		84.4	86.8	89.5	85.0	
D3	70.16^{c}	74.66^{ab}	76.66^{a}	73.5^{abc}		78.4	82.2	83.8	80.9	
D4	63.33^{c}	67.5^{ab}	70.5^{a}	69.41^{ab}		71.8	76.4	80.8	75.1	
D5	51.16^{c}	58.16^{b}	62.5^{a}	53.33^{c}		53.8	60.1	63.8	55.8	
D6	37.33^{c}	47^{b}	51.83^{a}	44.33^{b}		39.0	49.0	51.8	44.3	

Dates of planting	105 DAT				
	M0	M1	M2	M3	
D1	95.1	97.0	97.1	97.3	NS
D2	86.5	88.8	91.8	87.1	
D3	81.7	86.0	87.8	84.9	
D4	73.8	78.6	82.8	77.5	
D5	57.0	61.3	66.0	57.6	
D6	40.1	49.6	51.8	44.3	

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 -1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy staw, CD – Critical difference, DAT – Days after transplanting

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The effect of date of planting on number of trusses per plant is provided in Table 4.14. Among the dates of planting 15th September (D1), 1st October (D2) and 15th October (D3) plantings were on par with each other and recorded more number of trusses per plant. Less number of trusses per plant was noted in 1st December planting (D6) was on par with 15th November (D5).

The effect of mulch treatments on number of trusses per plant is provided in Table 4.15. Significant difference was not observed between mulch treatments with respect to number of trusses per plant. Interaction between date of planting and mulch treatments was non significant (Appendix ii.) with respect to number of trusses per plant (Table 4.16).

4.7.1.3. Number of fruits per plant

Analysis of variance was performed for number of fruits per plant and results are presented in Appendix ii.

The effect of date of planting on number of fruits per plant is provided in Table 4.14. For number of fruits per plant, 15th September planting (D1) was on par with 1st October (D2), 15th October (D3) and 1st November (D4) and the corresponding values are 33, 30, 32 and 31 respectively. Less number of fruits per plant was noted in 1st December planting (D6) has recorded less number of fruits per plant (24) which was on par with 15th November (D5) (28).

The effect of mulch treatments on number of fruits per plant is provided in Table 4.15. Significant difference was observed between mulch treatments with respect to number of fruits per plant (Table 4.17). Black polythene mulch (M2) has recorded more number of fruits per plant (36) and control (M0) has recorded lowest number of fruits (22).

Interaction between date of planting and mulch treatments was significant (Appendix ii.) with respect to number of fruits per plant. When there was interaction between date of planting and mulch treatments, best mulch for each date of planting was given.

On 15th September (D1) planting the number of fruits per plant does not vary between mulches whereas control recorded the less number of fruits . 105

Table 4.14. Effect of dates of planting on yield parameters

Dates of planting	Yield parameters		
	Yield (kg/plant)	Number of trusses (per plant)	Number of fruits (per plant)
D1	1.22[a]	46.58[ab]	32.58[a]
D2	1.06[b]	43.95[ab]	30.33[a]
D3	1.00[bc]	46.62[a]	32.33[a]
D4	0.93[cd]	40.66[c]	30.75[a]
D5	0.85[d]	23.83[d]	28.16[b]
D6	0.70[e]	21.50[d]	23.75[c]
CD	0.10	3.19	2.85

Table 4.15. Effect of mulching on yield parameters

Types of mulch	Yield parameters		
	Yield (kg/plant)	Number of trusses (per plant)	Number of fruits (per plant)
M0	0.75[c]	35.86	22.38[c]
M1	0.93[b]	37.5	29.77[b]
M2	1.11[a]	37.27	35.88[a]
M3	1.06[a]	38.13	30.55[b]
CD	0.05	NS	1.85

D1 - 15th September
D2- 1st October
D3- 15th October
D4 - 1st November
D5 - 15th November
D6 - 1st December
DAT – Days after transplanting
M1 - White top black bottom polythene
M2 - Black top white bottom polythene
M3- Paddy straw
M0- Control
CD- Critical difference

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During 1st October (D2) planting black top white bottom polythene and white top black bottom polythene were on par with more number of fruits. During 15th October (D3) planting black top white bottom polythene recorded more number of fruits compared to other treatments. During 1st November (D4), 15th November (D5) and 1st December planting (D6) black top white bottom polythene was on par with straw mulch and recorded more number of fruits.

4.7.1.4. Fruit yield per plant

Analysis of variance was performed for fruit yield per plant and results are presented in Appendix ii.

The effect of date of planting on fruit yield per plant is provided in Table 4.14. Significant difference was observed and comparison was made between dates of planting. 15th September planting (D1) recorded maximum fruit yield (1.22 kg) per plant, whereas 1st December planting (D6) has recorded less fruit yield (0.7 kg) per plant.

The effect of mulch treatments on fruit yield per plant is provided in Table 4.15. Significant difference was observed between mulch treatments with respect to number of fruits per plant. Black polythene mulch (M2) has recorded yield of 1.11 kg/plant and was on par with straw mulch (M3)(1.06kg/plant) and control (M0) has recorded lowest yield of 0.75 kg/plant.

Interaction effect between dates of planting and mulch treatments with respect to fruit yield per plant was analysed and provided in Appendix ii. There was a significant difference between dates of planting and mulch treatments with respect to fruit yield per plant (Table 4.18). For significant results interaction effect was studied and best mulch for each date of planting was given.

The results showed that during 15th September (D1) planting the fruit yield does not vary between control and mulches. During 1st October (D2) and 15th December planting mulches are on par and control recorded less yield. During 1st and 15th November planting black polythene was on par with straw mulch and recorded more yield. During 1st December planting (D6) black polythene recorded more yield compared to other mulches and control.

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Table 4.16. Interaction effect between dates of planting and mulches on number of trusses per plant

Dates of planting	M0	M1	M2	M3	
D1	45.16	46.66	47.83	46.66	NS
D2	43.66	43.33	43.50	45.33	
D3	45.00	47.16	45.83	48.50	
D4	37.00	42.16	40.83	42.66	
D5	22.5	23.83	24.16	24.83	
D6	21.83	21.83	21.5	20.83	

Table 4.17. Interaction effect between dates of planting and mulches on fruit yield per plant

Dates of planting	M0	M1	M2	M3	CD
D1	1.23^{a}	1.17^{a}	1.23^{a}	1.27^{a}	0.132
D2	0.77^{b}	1.10^{a}	1.23^{a}	1.17^{a}	
D3	0.73^{b}	1.00^{a}	1.13^{a}	1.13^{a}	
D4	0.70^{c}	0.90^{b}	1.07^{a}	1.07^{a}	
D5	0.60^{c}	0.77^{b}	1.07^{a}	0.97^{a}	
D6	0.47^{c}	0.67^{b}	0.93^{a}	0.77^{b}	

Table 4.18. Interaction effect between dates of planting and mulches on number of fruits per plant

Dates of planting	M0	M1	M2	M3	CD
D1	29.33^{b}	33.00^{a}	36.33^{a}	31.67^{a}	4.682
D2	21.67^{b}	34.33^{a}	39.00^{a}	26.33^{b}	
D3	24.33^{c}	33.33^{b}	38.67^{a}	33.00^{b}	
D4	22.67^{c}	30.00^{b}	36.00^{a}	34.33^{ab}	
D5	19.67^{c}	26.33^{b}	34.67^{a}	32.00^{a}	
D6	16.67^{c}	21.67^{b}	30.67^{a}	26.00^{ab}	

D1 - 15th September
D2- 1st October
D3- 15th October
D4 - 1st November
D5 - 15th November
D6 - 1st December
DAT – Days after transplanting
M1 - White top black bottom polythene
M2 - Black top white bottom polythene
M3- Paddy straw
M0- Control
CD- Critical difference

4.7.1.5. Number of weeds per square meter

Analysis of variance was performed for number of weeds per square meter and results are presented in Appendix ii.

The effect of date of planting on number of weeds per square meter is provided in Table 4.19. Significant difference was not observed between dates of planting.

The effect of mulch treatments on number of weeds per square meter in Table 4.20. Significant difference was observed between mulch treatments with respect to number of weeds per square meter. Black polythene mulch (M2) was on par with white polythene mulch (M1) has recorded significantly lowest number of weeds at thirty (10.4 m^{-2}), sixty (18.8 m^{-2} and 19.7 m^{-2}) and ninty (29.5 m^{-2} and 30 m^{-2}) days after transplanting. Control (M0) had recorded highest weed density of 54.8 m^{-2}, 102.6 m^{-2}, 152.2 m^{-2} at 30, 60 and 90 days after transplanting respectively.

Interaction between dates of planting and mulch treatments with respect to fruit yield per plant was analysed and provided in Appendix ii. There was a significant difference between dates of planting and mulch treatments with respect to fruit yield per plant (Table 4.21). For significant results interaction effect was studied and best mulch for each date of planting was given.

For 30 days after planting interaction effect between dates of planting and mulch treatments was non-significant with respect to number of weeds.

For 60 days after planting, during 15th September planting mulch treatments were on par and recorded less number of weeds compared to control. In all other plantings black top white bottom polythene and white top black bottom polythene were on par and recorded less number of weeds compared to other treatments.

For 90 days after planting, except during 1st December planting in all other plantings black top white bottom polythene and white top black bottom polythene were on par and recorded less number of weeds compared to other treatments.

Table 4.19. Effect of date of planting on number of weeds

Dates of planting	Number of weeds per meter square		
	30DAT	60DAT	90DAT
D1	22.3	43.3	66
D2	26.7	47.3	73.7
D3	25.7	45.3	72.7
D4	23.7	39	67
D5	29.7	60.3	86
D6	22	48.3	73.3
CD	NS	NS	NS

Table 4.20. Effect of mulching on number of weeds

Types of mulch	Number of weeds per meter square		
	30DAT	60DAT	90DAT
M0	54.8^{a}	102.6^{a}	152.2^{a}
M1	10.4^{c}	19.7^{c}	30.0^{c}
M2	10.4^{c}	18.8^{c}	29.5^{c}
M3	24.2^{b}	47.7^{b}	80.6^{b}
CD	4.89	8.36	12.13

D1 - 15th September, D2- 1st October, D3- 15th October, D4 - 1st November, D5 - 15th November, D6 - 1st December

DAT – Days after transplanting, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, M0- Control, CD- Critical difference

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Table 4.21. Interaction effect between dates of planting and mulches on number of weeds

Dates of planting	30DAT					60DAT					90DAT				
	M0	M1	M2	M3		M0	M1	M2	M3	CD	M0	M1	M2	M3	CD
D1	42.7	9.3	13.3	24	NS	90.7^{a}	21.3^{b}	21.3^{b}	40^{b}	21.40	142.7^{a}	30.7^{c}	28^{c}	62.7^{b}	30.46
D2	61.3	10.7	8	26.7		100^{a}	20^{c}	17.3^{c}	52^{b}		150.7^{a}	30.7^{c}	29.3^{c}	84^{b}	
D3	62.7	10.7	6.7	22.7		105.3^{a}	17.3^{c}	12^{c}	46.7^{b}		150.7^{a}	29.3^{c}	24^{c}	86.7^{b}	
D4	45.3	9.3	16	24		70.7^{a}	14.7^{c}	24^{c}	46.7^{b}		117.3^{a}	29.3^{c}	38.7^{c}	82.7^{b}	
D5	62.7	12	12	32		132^{a}	20^{c}	24^{c}	65.3^{b}		178.7^{a}	25.3^{c}	32^{c}	108^{b}	
D6	54.7	10.7	6.7	16		117.3^{a}	25.3^{b}	14.7^{b}	36^{b}		173.3^{a}	34.7^{b}	25.3^{c}	60^{b}	

D1 - 15th September
D2- 1st October
D3- 15th October
D4 - 1st November
D5 - 15th November
D6 - 1st December
DAT – Days after transplanting
M1 - White top black bottom polythene
M2 - Black top white bottom polythene
M3- Paddy straw
M0- Control
CD- Critical difference
NS- Non significant

4.7.2. PHENOLOGICAL OBSERVATIONS

The phenological observations were recorded for every planting. The recorded duration for the completion of each growth stages *viz.* first flowering, fifty percent flowering, first fruiting, fifty percent fruiting, first harvesting, duration of the crop were given in the Table 4.22 and 4.23.

4.7.2.1. Number of days taken for first flowering

Analysis of variance was performed for Number of days taken for first flowering after transplanting and results are presented in Appendix ii.

The effect of date of planting on number of days taken for first flowering after transplanting is provided in Table 4.22. The number of days taken for first flowering was found to be on par and higher for the crops transplanted on 15th September, 1st October and 15th October (28 days), whereas plants transplanted on 1st November, 15th November and 1st December were on par and took 27 days for first flowering

The effect of mulch treatments on number of days taken for first flowering after transplanting is provided in Table 4.23.The number of days taken for first flowering was found to be twenty eight days for the control (without mulch), whereas mulched treatments (white top black bottom polythene, black top white bottom polythene and straw) were on par and took 27 days.

Interaction between dates of planting and mulch treatments with respect to number of days taken for first flowering was analysed and provided in Appendix ii.

For 15th September (D1) and 1st October(D2) planting black polythene (M2) took more number of days (29 and 30days) and control (M0) took less number of days (27 and 26 days) for first flowering. During 15th October (D3) planting, white (M1) and black top white bottom (M2) were on par took 28 days, whereas straw mulch and control were on par and took 27 days for flowering. In 1st November planting, control took more number of days (28 days) and black polythene took 26 days for flowering. White and black polythene mulch were on par and took less number of days (26 days) when compared to control (28 days) during 15th November and 1st December transplanting (Table 4.24)

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4.7.2.2. Number of days taken for fifty percent flowering

Analysis of variance was performed for number of days taken for fifty percent flowering after transplanting and results are presented in Appendix ii.

The effect of date of planting on number of days taken for fifty percent flowering after transplanting is provided in Table 4.22. The number of days taken for fifty percent flowering by 15th September, 1st October transplanted plants were on par and higher (38 days). Less number of days fifty percent flowering (36 days) was taken by 1st December transplanted plants.

The effect of mulch treatments on number of days taken for fifty percent flowering after transplanting is provided in Table 4.23. Control and mulched treatments does not show any significant results on fifty percent flowering.

Interaction effect between dates of planting and mulch treatments with respect to number of days taken for fifty percent flowering was analysed and provided in Appendix ii. The results on effect of dates of planting and mulching on duration for fifty percent flowering showed that during 15th September (D1) and 1st October (D2) planting, control (M0) took less number of days for 50% flowering compared to, mulches. During 15th October (D3) black polythene (M2) took more number of days whereas remaining mulches and control were on par. In 1st November planting, black polythene took less number of days, whereas remaining mulches and control were on par. Control took more days compared to mulches 15th November and 1st December transplanting. Corresponding values are given in Table 4.24

4.7.2.3. Number of days taken for first fruiting

Analysis of variance was performed for number of days taken for first fruiting after transplanting and results are presented in Appendix ii.

The effect of date of planting on number of days taken for first fruiting after transplanting is provided in Table 4.22. The number of days taken for first fruiting was found to be higher (38 days) for the crops transplanted on 15th September, whereas plants transplanted on 1st December took thirty six days for first fruiting.

The effect of mulch treatments on number of days taken for first fruiting after transplanting is provided in Table 4.23. 113

The number of days taken for first flowering was found to be thirty seven days for the control (without mulch), white top black bottom polythene and straw mulch, whereas black top white bottom polythene took thirty six days.

Interaction effect between dates of planting and mulch treatments with respect to number of days taken for first fruiting was analysed and provided in Appendix ii. During 15^{th} September (D1), 1^{st} October (D2) and 15^{th} October (D3) planting, control (M0) took less number of days for first fruiting compared to mulches. During 1^{st} November (D4), 15^{th} November (D5) and 1^{st} December (D6) transplanting control (M0) took more number of days. Corresponding values are given in Table 4.25.

4.7.2.4. Number of days taken for fifty percent fruiting

Analysis of variance was performed for number of days taken for fifty percent fruiting after transplanting and results are presented in Appendix ii.

The effect of date of planting on number of days taken for fifty percent fruiting after transplanting is provided in Table 4.22. The number of days taken for fifty percent fruiting was found to be on par and higher (48 days) for the crops transplanted on 15^{th} September and 1^{st} October, whereas 15^{th} November and 1^{st} December transplanted plants were on par and took forty five days for fifty percent fruiting.

The effect of mulch treatments on number of days taken for fifty percent fruiting after transplanting is provided in Table 4.23. Control and mulched treatments does not show any significant results on fifty percent fruiting.

Interaction effect between dates of planting and mulch treatments with respect to number of days taken for fifty percent fruiting was analysed and provided in Appendix ii. During 15^{th} September (D1), white (M1) and black top white bottom (M2) were on par took 49 and 50 days respectively, whereas straw mulch and control were on par and took 47 days for 50% fruiting. In 1^{st} October (D2), 15^{th} October (D3), 1^{st} November (D4), 15^{th} November (D5) transplanting control (M0) took more number of days and black polythene took less days for 50% fruiting. During 1^{st} December planting there was no significant variations. Corresponding values are given in Table 4.25.

4.7.2.5. Number of days taken for first harvest

Analysis of variance was performed for number of days taken for first harvest after transplanting and results are presented in Appendix ii.

The effect of date of planting on number of days taken for first harvest after transplanting is provided in Table 4.22. The number of days taken for first harvest was found to be on par and higher for the plants transplanted on 15th September and 1st October, whereas 1st December transplants took least number of days for first harvest.

The effect of mulch treatments on number of days taken for first harvest after transplanting is provided in Table 4.23. Control and mulched treatments does not show any significant results on first harvest.

Interaction effect between dates of planting and mulch treatments with respect to number of days taken for first flowering was analysed and provided in Appendix ii. In all the dates of planting, number of days taken for first harvesting by mulched treatments was higher and on par to each other, whereas control (without mulch) took less number of days for first harvesting. Corresponding values are given in Table 4.26.

4.7.2.6. Duration of the crop

Analysis of variance was performed for total duration of the crop and results are presented in Appendix ii.

The effect of date of planting on total duration of the crop is provided in Table 4.22. The total duration of 15th September transplanted plants was high (137 days), whereas total duration of 15th November (116 days) and 1st December (114 days) transplanted plants was on par and less when compared to remaining dates of planting.

The effect of mulch treatments on total duration of the crop is provided in Table 4.23. Significant difference was observed and comparison was made between dates of planting.The duration of plants under black polythene was highest (129days), whereas for control duration was lowest (117 days). Interaction effect between dates of planting and mulch treatments with respect to total duration of the crop was analysed and provided in Appendix ii. Dates of planting and mulches does not show any interaction effect on duaration of the crop (Table 4.26).

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Table 4.22. Effect of dates of planting on phenophases duration

Dates of planting	NUMBER OF DAYS TAKEN FOR PHENOPHASES					
	Days to first flowering	Days to fifty percent flowering	Days to first fruiting	Days to fifty percent fruiting	Days to harvesting	Total Duration
D1	28^{a}	38^{a}	38^{a}	48^{a}	82^{a}	137^{a}
D2	28^{a}	38^{a}	37^{b}	48^{a}	80^{ab}	133^{b}
D3	28^{a}	37^{b}	37^{b}	47^{b}	78^{bc}	130^{c}
D4	27^{b}	37^{b}	37^{b}	46^{c}	76^{c}	121^{d}
D5	27^{b}	37^{b}	37^{b}	45^{d}	66^{d}	116^{e}
D6	27^{b}	36^{c}	36^{c}	45^{d}	57^{e}	114^{e}
CD	0.48	0.54	0.47	0.75	3.62	2

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November , D6 -1st December, CD – Critical difference

Table 4.23. Effect of mulching on phenophases duration

Types of Mulching	NUMBER OF DAYS TAKEN FOR PHENOPHASES					
	Days to first flowering	Days to fifty percent flowering	Days to first fruiting	Days to fifty percent fruiting	Days to harvesting	Total Duration
M0	28^{a}	37	37^{a}	46	73	117^{d}
M1	27^{b}	37	37^{a}	46	73	128^{b}
M2	27^{b}	37	36^{b}	46	73	129^{a}
M3	27^{b}	37	37^{a}	46	73	126^{c}
CD	0.34	NS	0.3	NS	NS	0.78

M0- Control, M1 - White top black bottom polythene , M2 - Black top white bottom polythene, M3 - Paddy straw

CD – Critical difference, NS – Non significant

Table 4.24. Interaction effect between dates of planting and mulches on number days taken for first flowering and fifty percent flowering

Dates of planting	NO OF DAYS TO FIRST FLOWERING					NO OF DAYS TO FIFTY PERCENT FLOWERING				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	CD
D1	27^{c}	28^{b}	29^{a}	28^{b}	0.87	35^{c}	39^{a}	40^{a}	37^{b}	1.21
D2	26^{d}	28^{b}	30^{a}	27^{c}		35^{c}	37^{b}	40^{a}	38^{b}	
D3	27^{b}	28^{a}	28^{a}	27^{b}		36^{b}	37^{b}	40^{a}	36^{b}	
D4	28^{a}	27^{b}	26^{c}	27^{b}		39^{a}	38^{a}	35^{b}	38^{a}	
D5	29^{a}	26^{c}	26^{c}	27^{b}		40^{a}	37^{b}	34^{c}	36^{b}	
D6	28^{a}	26^{c}	26^{c}	27^{b}		38^{a}	35^{b}	35^{b}	35^{b}	

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene M2 - Black top white bottom polythene, M3- Paddy straw, CD – Critical difference,

Table 4.25. Interaction effect between dates of planting and mulches on number days taken for first fruiting and fifty percent fruiting

Dates of planting	NO OF DAYS TO FIRST FRUITING					NO OF DAYS TO FIFTY PERCENT FRUITING				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	CD
D1	37^{b}	38^{a}	38^{a}	38^{a}	0.77	47^{b}	49^{a}	50^{a}	47^{b}	1.70
D2	36^{c}	38^{a}	38^{a}	37^{b}		50^{a}	47^{bc}	46^{c}	48^{b}	
D3	36^{c}	38^{a}	38^{a}	37^{b}		50^{a}	47^{b}	43^{c}	47^{b}	
D4	39^{a}	36^{c}	35^{d}	38^{b}		43^{c}	45^{b}	48^{a}	46^{b}	
D5	38^{a}	36^{c}	36^{c}	37^{b}		44^{c}	45^{bc}	47^{a}	45^{bc}	
D6	38^{a}	36^{c}	34^{d}	37^{b}		45^{a}	45^{a}	44^{a}	45^{a}	

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, CD – Critical difference

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Table 4.26. Interaction effect between dates of planting and mulches on number days taken for first harvesting and total duration

Date of plantings	NO OF DAYS TO FIRST HARVESTING					TOTAL DURATION				
	M0	M1	M2	M3	CD	M0	M1	M2	M3	
D1	129^{b}	139^{a}	140^{a}	139^{a}		79	82	86	82	
D2	125^{b}	135^{a}	137^{a}	135^{a}		79	79	81	80	
D3	121^{b}	134^{a}	134^{a}	132^{a}	2.00	77	78	78	77	NS
D4	111^{c}	124^{ab}	126^{a}	122^{b}		77	76	75	75	
D5	109^{c}	119^{ab}	121^{a}	117^{b}		68	66	64	67	
D6	106^{c}	117^{a}	118^{a}	114^{b}		60	56	55	58	

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, CD – Critical difference, NS –Non- significant

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4.8. HEAT UNITS

The heat units required during the entire crop period was recorded over standard meteorological weeks. The heat units required for the entire crop season was presented in Table 4.27.

4.8.1.1. Weekly accumulated growing degree days (AGDD)

The accumulated growing degree days required for entire period was given in Fig.4.8. The highest and lowest accumulated growing degree days were recorded on 10^{th} and 38^{th} week respectively. The recorded highest and lowest accumulated GDD was 180.3 day °C and 148.6 day °C.

4.8.1.2 Weekly accumulated heliothermal unit (AHTU)

The accumulated heliothermal units required for the entire crop season was presented in Fig. 4.9. The accumulated HTU indicated variations in their entire crop period. The highest (1763.11 day °C h) and lowest (603.1 day °C h) accumulated heliothermal units were recorded on 9^{th} and 42^{th} week, respectively.

4.8.1.3. Weekly accumulated photothermal unit (APTU)

The accumulated photo thermal unit during the entire crop season was given in the Fig. 4.10. Accumulated photo thermal units were recorded highest (2131.04 day °C h) on 10^{th} week and lowest (1642.8 day °C h) on 52^{th} week.

4.8.2. The heat units prevailed during different phenophases

The heat units accumulated during each phenophases were also worked out individually.

4.8.2.1. Heat units required during transplanting to first flowering

The heat units required during transplanting to first flowering stage of tomato crop at different date of transplanting was given in the Table 4.28.

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Table 4.27. Weekly heat units during the crop growing season

Week No.	AGDD	AHTU	APTU
37	159.35	621.15	1928.14
38	148.65	622.65	1785.89
39	153.38	633.87	1827.48
40	154.40	632.80	1826.24
41	155.90	713.95	1830.73
42	150.65	603.13	1755.86
43	150.25	908.31	1736.58
44	160.75	1173.51	1844.04
45	154.08	890.55	1751.94
46	152.50	1019.99	1720.94
47	158.65	1085.96	1774.63
48	155.08	671.59	1719.17
49	153.78	1117.93	1689.30
50	154.10	788.05	1677.44
51	153.35	1392.86	1656.18
52	151.33	1423.83	1642.82
1	170.68	1509.64	1871.15
2	155.73	1145.60	1724.32
3	154.48	1327.62	1725.66
4	158.30	1279.35	1784.41
5	156.28	1413.03	1774.82
6	166.28	1417.68	1905.06
7	168.95	1592.40	1950.23
8	170.18	1743.23	1981.29
9	177.95	1763.11	2086.97
10	180.38	1726.19	2131.04
11	174.55	1046.78	2077.15
12	174.65	1374.70	2095.80
13	153.65	1099.00	1859.17

AGDD - Accumulated growing degree days, AHTU - Accumulated heliothermal unit

APTU - Accumulated photo thermal un

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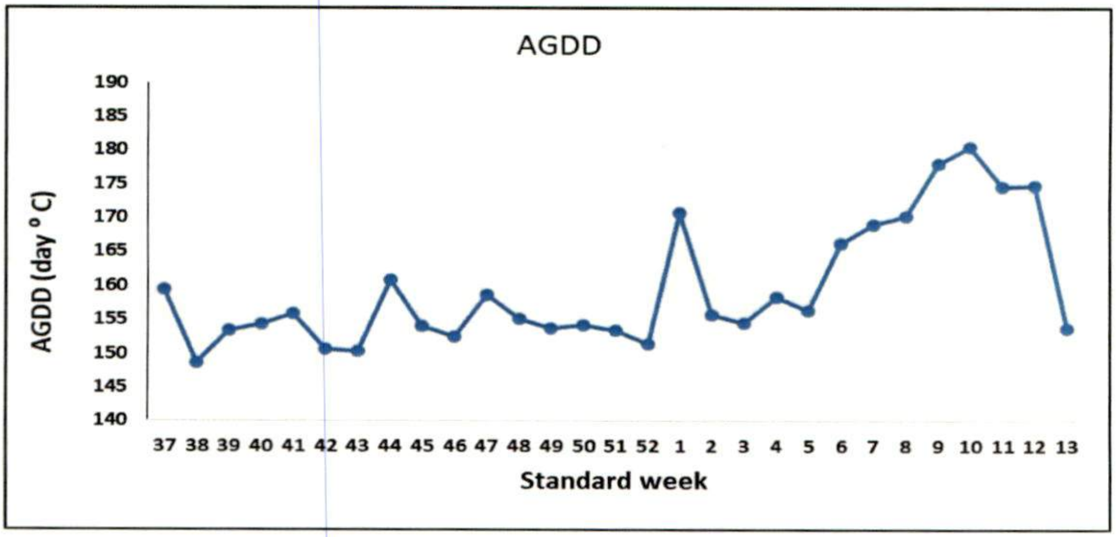

Fig 4.8. Weekly growing degree days (day °C) for entire crop period

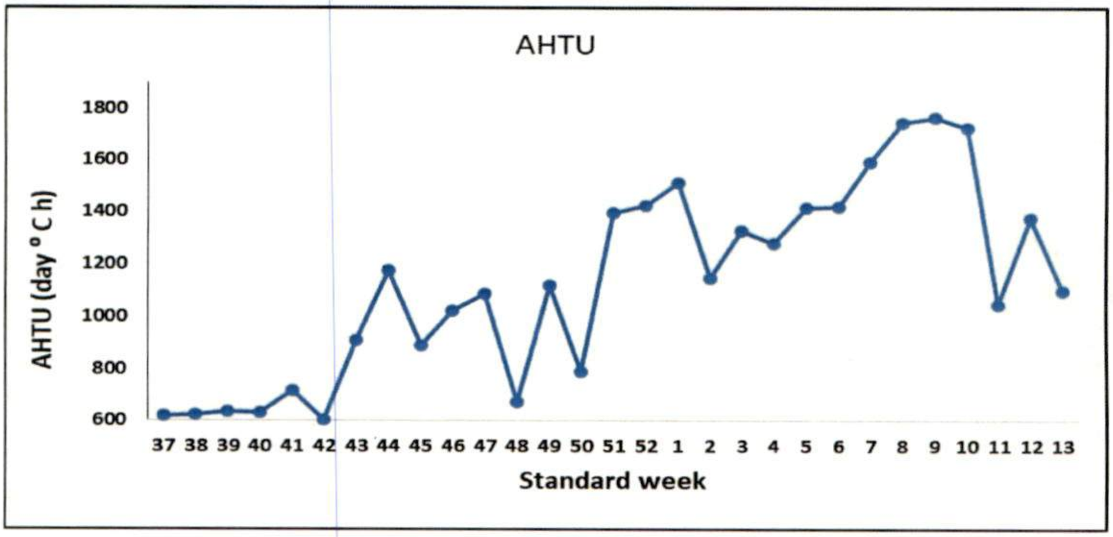

Fig 4.9. Weekly heliothermal units (day °C h) for entire crop period

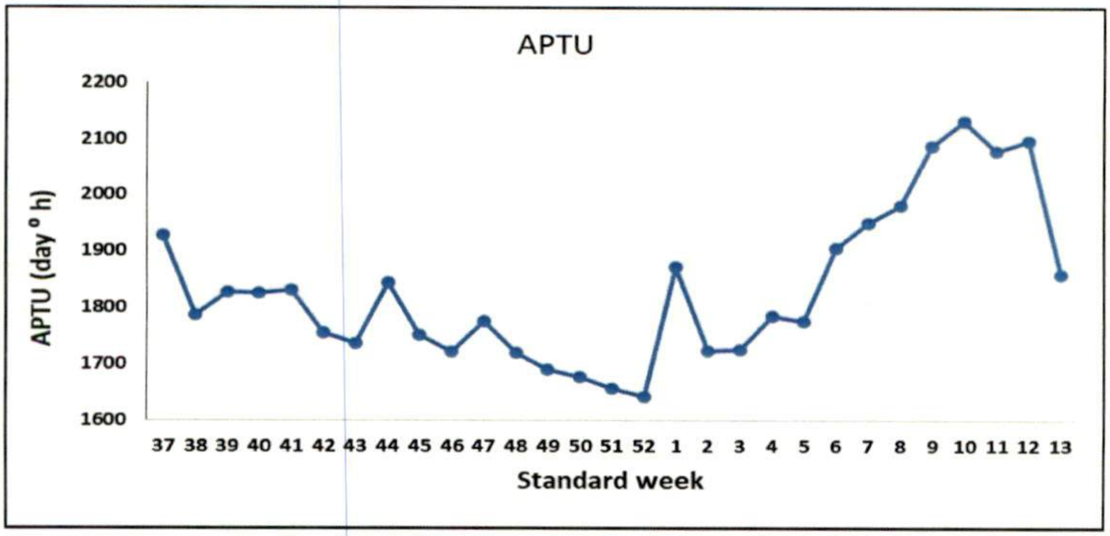

Fig 4.10 Weekly photothermal units (day °C h) for entire crop period

4.8.2.1.1. Accumulated growing degree days (AGDD)

The accumulated growing degree day (GDD) during transplanting to first flowering was recorded highest on fifth date of planting in control, first date of planting in white top black bottom and black top white bottom polythene mulch and fourth date of planting in straw mulch. The recorded value of accumulated GDD was 650.60 day °C 620.08 day °C, 627.4 day ^{0}C and 608.75 day ^{0}C respectively.

4.8.2.1.2. Accumulated heliothermal unit (AHTU)

The late transplanting showed an increase in accumulated heliothermal units for both treatment with mulches and control. The recorded range of HTU for control was highest on sixth date of planting (4673.18 day °C h) and lowest on first date of planting (2631.88 day °C h). The highest accumulated heliothermal unit for white top black bottom, black top white bottom and straw mulch was 4151.54 day °C h , 3958.04 day °C h and 4284.40 day °C h respectively. Lowest Accumulated heliothermal unit for white top black bottom, black top white bottom and straw mulch was 2696.65 day °C h, 2699.58 day °C h and 2732.74 day °C h respectively.

4.8.2.1.3. Accumulated photo thermal units (APTU)

The treatment without mulch (control) recorded highest (7116.31 day °C h) accumulated PTU on fifth date of planting and lowest (6663.17 day °C h) on third date of planting. The highest accumulated PTU for treatment with mulches were 7378.49, 7464.19 and 7162.38 day °C h and lowest were 6416.22, 6204.96 and 6604.26 day °C h respectively.

4.8.2.2. Heat units required during transplanting to fifty percent flowering

The accumulated growing degree days required during transplanting to fifty percent flowering was given in the Table 4.29.

4.8.2.2.1. Accumulated growing degree day (GDD)

Accumulated growing degree day was highest (650.24 day °C) in fifth date of planting in control. Whereas, The recorded highest value of GDD was 9663.16 day °C, 1283.61 day °C and 806.48 day °C for white top black bottom, black top white bottom and straw mulch on second, first and fifth date of planting respectively.

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The lowest value of GDD were 754.27 day °C, 810.77 day °C, 759.9 day °C and 785.5 day °C on first, fourth, fifth and fourth date of planting for control, white top black bottom, black top white bottom and straw mulch respectively.

4.8.2.2.2. Accumulated helio thermal units (HTU)

The accumulated highest heliothermal unit for control, white top black bottom, black top white bottom and straw mulch were 6497.11 day °C h, 6129.45 day °C h, 5882.77 day °C h and 5944.98 day °C h on sixth date of planting. The accumulated HTU was found to be lowest (2953.6, 4220.0, 4157.5 and 3318.4 day °C h) on first date of plantings for control and straw mulch and first date of planting white top black bottom, black top white bottom.

4.8.2.2.3. Accumulated photo thermal units (PTU)

The highest (9663.1, 9562.1, 15219.1 and 9713.0 day °C h) and lowest (8811.2, 8825.6, 8395.6 and 8613.1 day °C h) values of accumulated PTU were recorded on fifth and third date of planting for control, first and fourth date of planting for white top black bottom , first and fifth date of planting for black top white bottom and second and sixth date of planting for straw mulch.

4.8.2.3. Heat units required during transplanting to first fruiting

The accumulated growing degree days required during transplanting to first fruiting was given in the Table 4.30.

4.8.2.3.1 Accumulated growing degree days (GDD)

The accumulated growing degree day (GDD) during transplanting to first fruiting was recorded highest on first date of planting in control, white top black bottom, black top white bottom and straw mulch. The recorded value of accumulated GDD was 1023.2 day °C 1269.0 day °C, 1269.0 day ^{0}C and 1269.0 day ^{0}C respectively.

4.8.2.3.2. Accumulated heliothermal unit (HTU)

The delayed transplanting showed an increase in accumulated heliothermal units for both treatment with mulches and control. The recorded range of HTU for control was highest on sixth date of planting (6396.1 day °C h) and lowest on second date of planting (3404.4 day °C h).

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Table 4.28. Heat units experienced during transplanting to first flowering at different dates of planting

Dates of planting	TYPE OF MULCH					
	M0			M1		
	GDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)	GDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)
D1	597.67	2631.88	7116.31	620.08	2696.65	7378.49
D2	589.65	2810.78	6901.58	604.02	2842.38	7066.79
D3	578.09	3245.72	6663.17	600.63	3433.56	6917.80
D4	632.60	4039.12	7137.47	586.78	3790.91	6628.81
D5	650.24	3917.75	7207.74	577.63	3650.34	6416.22
D6	647.92	4673.18	7057.52	592.20	4151.54	6450.21
Dates of planting	M2			M3		
	GDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)	GDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)
D1	627.40	2699.58	7464.19	605.05	2732.74	7162.38
D2	618.83	2911.03	7237.47	605.53	3081.49	7046.47
D3	622.89	3612.05	7169.41	588.46	3468.53	6735.16
D4	586.72	3819.76	6628.16	608.75	3884.95	6834.24
D5	570.14	3585.98	6334.65	604.35	3996.31	6665.89
D6	569.70	3958.04	6204.96	606.33	4284.40	6604.26

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, AGDD - Accumulated growing degree days, AHTU - Accumulated heliothermal unit APTU - Accumulated photo thermal units

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Table 4.29. Heat units experienced during transplanting to fifty percent flowering at different dates of planting

Dates of planting	TYPE OF MULCH					
	M0			M1		
	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)
D1	754.27	2953.67	8947.12	1059.60	4267.70	12554.77
D2	776.00	3822.62	9053.00	821.83	4220.09	9562.11
D3	768.39	4602.95	8811.22	829.75	5024.66	9498.53
D4	843.47	5321.47	9462.87	785.55	4863.18	8825.69
D5	877.25	5784.51	9663.16	810.77	5178.32	8945.14
D6	860.85	6497.11	9392.91	811.34	6129.45	8848.23
Dates of planting	M2			M3		
	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)
D1	1283.62	5125.10	15219.18	806.48	3318.44	9552.74
D2	848.63	4157.52	9881.02	833.52	4074.61	9713.06
D3	852.31	5152.54	9751.10	829.76	5024.66	9498.54
D4	778.58	4803.20	8748.97	785.55	4863.19	8825.70
D5	759.90	4720.33	8395.70	796.36	5043.50	8789.45
D6	782.83	5882.78	8534.55	789.98	5944.98	8613.20

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, AGDD - Accumulated growing degree days, AHTU - Accumulated heliothermal unit
APTU - Accumulated photo thermal units

The highest Accumulated heliothermal unit for white top black bottom, black top white bottom and straw mulch was 5882.7 day °C h, 5633.4 day °C h , 6298.4 day °C h respectively. Lowest Accumulated heliothermal unit for white top black bottom, black top white bottom and straw mulch was 4264.9 day °C h , 3978.1 day °C h and 3955.7 day °C h respectively.

4.8.2.1.3. Accumulated photo thermal units (APTU)

The treatment without mulch (control) recorded highest (12133.3 day °C h) accumulated PTU on first date of planting and lowest (9030.8 day °C h) on fifth date of planting. The highest accumulated PTU for treatment with mulches were 15050.5 day °C h and lowest were 8534.5, 8216.6 and 9059.1 day °C h respectively.

4.8.2.4. Heat units required during transplanting to fifty percent fruiting

The accumulated growing degree days required during transplanting to fifty percent fruiting was given in the Table 4.31.

4.8.2.4.1. Accumulated growing degree day (AGDD)

Accumulated growing degree day was highest (1092.9 °C) in sixth date of planting in control. Whereas, the recorded highest value of GDD was 1064.2 day °C, 1094.8 day °C and 1048.6 day °C for white top black bottom, black top white bottom and straw mulch on second, first and fifth date of planting respectively. The lowest value of GDD were 934.9 day °C, 979.4 day °C, 950.9 day °C and 990.3 day °C on second date of planting for control and white top black bottom, fifth and fourth date of planting for black top white bottom polythene and straw mulch respectively.

4.8.2.4.2. Accumulated helio thermal units (AHTU)

The accumulated highest heliothermal unit for control, white top black bottom, black top white bottom and straw mulch were 6064.1 day °C h, 7807.4 day °C h, 7685.2 day °C h and 6059.2 day °C h on sixth date of planting. The accumulated HTU was found to be lowest (4444.5, 4650.5, 5293.1 and 4786.2 day °C h) on second of plantings for control, white top black bottom and straw mulch and on first date of planting for black top white bottom and straw mulch respectively.

Table 4.30. Heat units experienced during transplanting to first fruiting at different dates of planting

Dates of planting	TYPE OF MULCH					
	M0			M1		
	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)
D1	1023.27	4089.63	12133.37	1269.07	4984.02	15050.50
D2	784.10	3404.48	9172.11	836.30	4264.94	9727.03
D3	799.45	4585.85	9209.38	807.02	4391.76	9344.51
D4	821.43	5158.49	9220.41	792.52	4923.17	8902.42
D5	818.70	5237.82	9030.82	788.73	4989.98	8707.09
D6	847.02	6396.13	9240.74	782.82	5882.77	8534.54
Dates of planting	M2			M3		
	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)	AGDD (day ^0C)	AHTU (day ^0C h)	APTU (day ^0C h)
D1	1269.07	4984.02	15050.50	1269.07	4984.02	15050.50
D2	818.90	3978.12	9542.06	811.66	3955.70	9459.60
D3	837.32	5077.62	9583.28	807.02	4391.76	9344.51
D4	771.27	4736.04	8668.67	806.77	5045.72	9059.17
D5	766.77	4784.26	8469.94	825.50	5297.66	9104.26
D6	753.83	5633.46	8215.63	832.65	6298.43	9082.71

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 - 1st December M0- Control,
M1 - White top black bottom polythene M2 - Black top white bottom polythene M3- Paddy straw AGDD - Accumulated growing degree days,
AHTU - Accumulated heliothermal unit APTU - Accumulated photo thermal units

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Table 4.31. Heat units experienced during transplanting to fifty percent fruiting at different dates of planting

Dates of planting	TYPE OF MULCH					
	M0			M1		
	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)
D1	1018.31	4728.65	11997.55	1064.26	5077.89	12525.98
D2	934.92	4444.59	10917.52	979.45	4650.53	11429.56
D3	964.15	5857.88	10997.84	1002.55	6059.26	11423.99
D4	997.57	6064.17	11141.81	990.23	6057.56	11061.79
D5	1091.15	7770.75	11990.96	1028.03	7190.23	11301.45
D6	1092.95	8321.35	11975.15	1025.98	7807.46	11225.87
Dates of planting	M2			M3		
	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)
D1	1094.80	5293.17	12874.92	1026.00	4786.28	12085.91
D2	1048.03	5722.92	12124.08	1015.38	5289.10	11781.96
D3	1032.56	6282.96	11757.17	1002.55	6059.26	11423.99
D4	968.18	5917.90	10822.19	990.35	6089.95	11062.41
D5	950.91	6475.52	10460.88	1034.91	7257.00	11376.48
D6	1010.88	7685.28	11057.50	1048.61	7974.08	11478.62

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, AGDD - Accumulated growing degree days, AHTU - Accumulated heliothermal unit
APTU - Accumulated photo thermal units

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4.8.2.4.3. Accumulated photo thermal units (APTU)

The highest (11997.5, 12525.9, 12874.9 and 12085.9 day °C h) and lowest (10917.5, 11061.7, 10460.8and 11062.4day °C h) values of accumulated PTU were recorded on first and second date of planting for control, first and fourth date of planting for white top black bottom and straw mulch and first and fifth black top white bottom mulch.

4.8.2.5. Heat units required during transplanting to harvesting

The accumulated growing degree days required during transplanting to harvesting was given in the Table 4.32.

4.8.2.5.1. Accumulated growing degree days (AGDD)

The accumulated growing degree day (GDD) during transplanting to harvesting was recorded highest on first date of planting in control, white top black bottom, black top white bottom polythene and straw mulch. The recorded value of accumulated GDD was 1746.4 day °C , 1804.1 day °C, 1899.5 day ^{0}C and 1819.1 day ^{0}C respectively.

4.8.2.5.2. Accumulated heliothermal unit (AHTU)

The recorded range of HTU for control was highest on fifth date of planting (12164.2 day °C h) and lowest on first date of planting (9384.6 day °C h). The highest Accumulated heliothermal unit for white top black bottom, black top white bottom polythene and straw mulch was 11736.8 day °C h , 11736.8 day °C h and 11926.89 day °C h respectively. Lowest Accumulated heliothermal unit for white top black bottom, black top white bottom polythene and straw mulch was 9617.0 day °C h , 10009.7 day °C h and 9768.0 day °C h respectively.

4.8.2.5.3. Accumulated photo thermal units (APTU)

The treatment without mulch (control) recorded highest (20190.2 day °C h) accumulated PTU on first date of planting and lowest (14654.8 day °C h) on sixth date of planting. The highest accumulated PTU for treatment with mulches were 20827.8, 21873.53 and 20992.8 day °C h and lowest were 13452.1, 13110.9 and 14064.0 day °C h respectively.

Table 4.32. Heat units experienced during transplanting to harvesting at different dates of planting

Dates of planting	TYPE OF MULCH					
	M0			M1		
	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)	AGDD (day ^{0}C)	AHTU (day ^{0}C h)	APTU (day ^{0}C h)
D1	1746.43	9384.62	20190.24	1804.14	9617.01	20827.89
D2	1741.43	9847.26	19853.31	1755.85	9982.09	20009.01
D3	1687.61	11008.93	18893.87	1715.45	11268.44	19197.25
D4	1673.11	11933.02	18524.66	1650.61	11736.85	18274.15
D5	1480.53	12164.23	16309.00	1473.90	10854.22	16234.71
D6	1330.85	12131.46	14654.86	1224.42	11347.49	13452.17
Dates of planting	**M2**			**M3**		
	AGDD (day ^{0}C)	**AHTU (day ^{0}C h)**	**APTU (day ^{0}C h)**	**AGDD (day ^{0}C)**	**AHTU (day ^{0}C h)**	**APTU (day ^{0}C h)**
D1	1899.53	10230.56	21873.53	1819.13	9768.02	20992.80
D2	1798.44	10009.72	20561.08	1757.62	10144.71	19947.86
D3	1722.45	11334.94	19273.55	1701.48	11139.95	19045.01
D4	1650.61	11736.85	18274.15	1673.23	11926.89	18525.19
D5	1400.23	10251.70	15409.64	1473.55	11473.01	16230.88
D6	1194.22	11123.34	13110.91	1278.57	11758.90	14064.06

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, M0- Control, M1 - White top black bottom polythene, M2 - Black top white bottom polythene, M3- Paddy straw, AGDD - Accumulated growing degree days, AHTU - Accumulated heliothermal unit
APTU - Accumulated photo thermal units

4.8.3. INFLUENCE OF HEAT UNITS ON YIELD OF TOMATO

Heat units such as accumulated growing degree days (AGDD), heliothermal units (AHTU) and photo thermal units (APTU) are correlated with yield of tomato crop for different phenophases and the results were presented in the Table 4.33. During the phenophases P1 (transplanting to first flowering), P3 (transplanting to first fruiting) and P5 (transplanting to harvesting), the accumulated growing degree days showed a significantly positive correlation with yield, whereas accumulated photo thermal units during P1, P2, P3, P4 and P5 were showing positive correlation with the yield.

Table 4.33. Influence of heat units on yield of tomato

Phenophases	AGDD	AHTU	APTU
P1	0.233*	-0.552	0.557**
P2	0.198	-0.614	0.296*
P3	0.406**	-0.357	0.455**
P4	-0.054	-0.627	0.311**
P5	0.610**	-0.541	0.632**

Table 4.34. Influence of heat units on duration of phenophases of tomato

Phenophases	AGDD	AHTU	APTU
P1	0.982**	0.057	0.836**
P2	0.498**	0.272*	0.483**
P3	0.369**	0.127	0.375**
P4	0.991**	0.380**	0.857**
P5	0.998**	-0.372	0.994**

*- Significant at 5% level **- Significant at 1% level

4.8.4. Influence of heat units on the duration of different growth stages

Accumulated growing degree days and photothermal units showed significantly positive correlation with duration in phenophase P1, P2, P3, P4 and P5. Heliothermal units during phenophases P2 and P4 showed a significantly positive correlation with the duration and presented in the Table 4.34.

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4. 9. CROP WEATHER RELATIONSHIPS

The correlation between weather elements with yield and yield contributing parameters were worked out for different phenophases of crop growth. Correlation between weather and duration of different phenophases were also worked out.

4. 9. 1. Influence of weather parameters on crop duration

The correlation between weather elements and duration of different phenological stages were presented in the Table 4.35.

4.9.1.1. Transplanting to flowering

The weather parameters had no correlation with duration of transplanting to flowering.

4.9.1.2. Transplanting to fifty percent flowering

The weather parameters had no correlation with duration of transplanting to fifty percent flowering.

4.9.1.3. Transplanting to fruiting

During transplanting to fruiting, the weather parameters like afternoon relative humidity, rainfall and rainy days, had significant positive correlation and maximum temperatures, temperature range, bright sunshine hours showed negative correlation.

4.9.1.4. Transplanting to fifty percent fruiting

Evaporation had significant positive correlation and forenoon and afternoon vapour pressure deficit showed negative correlation during transplanting to fifty percent.

4.9.1.5. Transplanting to harvesting

The duration of transplanting to harvesting was found positively correlated with weather parameters like minimum temperature, forenoon and afternoon vapour pressure deficit, morning and afternoon relative humidity rainfall and rainy days and negatively correlated with maximum temperatures, temperature range, bright sunshine hours, wind speed and evaporation.

Table 4. 35. Correlation between weather and phenophase duration

Crop stages	Tmax	Tmin	Trange	RH I	RH II	VPD I	VPD II	RF	RD	BSS	WS	Epan
P1	-0.207	0.120	-0.177	0.025	0.077	-0.021	-0.014	0.168	0.128	-0.15	0.007	0.007
P2	-0.218	0.076	-0.158	0.026	0.105	-0.014	0.045	0.208	0.200	-0.071	-0.072	-0.039
P3	-0.416**	0.222	-0.339**	0.148	0.243*	0.083	0.142	0.371**	0.328**	-0.262*	-0.175	-0.15
P4	-0.193	-0.110	-0.051	-0.209	-0.135	-0.266*	-0.236*	0.200	0.081	0.101	0.215	0.269*
P5	-0.755**	0.851**	-0.813**	0.885**	0.872**	0.902**	0.893**	0.741**	0.816**	-0.834**	-0.877**	-0.879**

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to flowering, P2- Transplanting to fifty percent flowering, P3- Transplanting to fruiting, P4- Transplanting to fifty percent fruiting, P5- Transplanting to harvesting

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4. 9. 2. Influence of weather during different phenophases on yield parameters

4.9.2.1. Correlation between weather and yield

The weather parameters like minimum temperature, forenoon and afternoon vapour pressure deficit, morning and afternoon relative humidity rainfall and rainy days, had significant positive correlation and maximum temperatures, temperature range, bright sunshine hours, wind speed, evaporation showed negative correlation between yield and weather during all the phenophases (Table 4.36).

4.9.2.2. Correlation between weather and number of fruits

During all the phenophases, the weather parameters like minimum temperature, forenoon and afternoon vapour pressure deficit, morning and afternoon relative humidity rainfall and rainy days, had significant positive correlation and maximum temperatures, temperature range, bright sunshine hours, wind speed, evaporation showed negative correlation between number of fruits and weather (Table 4.37).

4.9.2.3. Correlation between weather and number of trusses

Minimum temperature, forenoon and afternoon vapour pressure deficit, morning and afternoon relative humidity rainfall and rainy days, had significant positive correlation and maximum temperatures, temperature range, bright sunshine hours, wind speed, evaporation showed negative correlation between yield and weather during transplanting to fruiting (Table 4.38).

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Table 4. 36. Correlation between weather and yield

Crop stages	Tmax	Tmin	Trange	RH I	RH II	VPD I	VPD II	RF	RD	BSS	WS	Epan
P1	-0.568**	0.685**	-0.630**	0.649**	0.649**	0.632**	0.633**	0.681**	0.694**	-0.652**	-0.623**	-0.599**
P2	-0.610**	0.679**	-0.675**	0.696**	0.696**	0.666**	0.670**	0.680**	0.704**	-0.711**	-0.665**	-0.674**
P3	-0.626**	0.679**	-0.681**	0.689**	0.695**	0.657**	0.666**	0.675**	0.689**	-0.704**	-0.659**	-0.665**
P4	-0.636**	0.701**	-0.687**	0.677**	0.691**	0.661**	0.666**	0.664**	0.688**	-0.692**	-0.651**	-0.647**
P5	-0.680**	0.674**	-0.682**	0.693**	0.686**	0.690**	0.684**	0.662**	0.683**	-0.673**	-0.676**	-0.674**

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to flowering P2- Transplanting to 50% flowering P3- Transplanting to fruiting P4- Transplanting to 50% fruiting
P5- Transplanting to harvesting

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Table 4. 37. Correlation between weather and number of fruits

Crop stage	Tmax	Tmin	Trange	RH I	RH II	VPD I	VPDII	RF	RD	BSS	WS	Epan
P1	-0.226	0.365**	-0.288*	0.397**	0.373**	0.420**	0.424**	0.348**	0.419**	-0.329**	-0.429**	-0.406**
P2	-0.238*	0.397**	-0.329**	0.459**	0.409**	0.476**	0.453**	0.339**	0.385**	-0.394**	-0.439**	-0.459**
P3	-0.261*	0.394**	-0.339**	0.444**	0.406**	0.460**	0.444**	0.330**	0.365**	-0.394**	-0.429**	-0.447**
P4	-0.342**	0.350**	-0.349**	0.393**	0.379**	0.404**	0.393**	0.315**	0.344**	-0.343**	-0.365**	-0.370**
P5	-0.342**	0.350**	-0.349**	0.393**	0.379**	0.404**	0.393**	0.315**	0.344**	-0.343**	-0.365**	-0.370**

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to flowering P2- Transplanting to 50% flowering P3- Transplanting to fruiting P4- Transplanting to 50% fruiting P5- Transplanting to harvesting

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Table 4. 38. Correlation between weather and number of trusses

Crop stage	Tmax	Tmin	Trange	RH I	RH II	VPD I	VPD II	RF	RD	BSS	WS	Epan
P1	-0.637**	0.792**	-0.716**	0.714**	0.812**	0.721**	0.822**	0.749**	0.893**	-0.733**	-0.850**	-0.778**
P2	-0.623**	0.802**	-0.742**	0.841**	0.844**	0.843**	0.869**	0.729**	0.827**	-0.752**	-0.903**	-0.865**
P3	-0.628**	0.802**	-0.743**	0.839**	0.842**	0.842**	0.868**	0.726**	0.823**	-0.750**	-0.903**	-0.865**
P4	-0.629**	0.855**	-0.759**	0.911**	0.890**	0.908**	0.916**	0.706**	0.816**	-0.866**	-0.941**	-0.932**
P5	-0.746**	0.804**	-0.783**	0.842**	0.840**	0.857**	0.860**	0.691**	0.769**	-0.789**	-0.836**	-0.842**

*- Significant at 5% level **- Significant at 1% level

P1- Transplanting to flowering P2- Transplanting to 50% flowering P3- Transplanting to fruiting P4- Transplanting to 50% fruiting
P5- Transplanting to harvesting

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4.10 INCIDENCE OF PEST AND DISEASES

During the crop period, incidence of pests and diseases were comparatively less. The incidence of pests was more in early planting crops compared to delayed plantings. The pest noticed in the field during the crop season was tobacco caterpillar (*Spodoptera litura*). Disease noticed in the field was tomato spotted wilt virus (Table 4.39).

Table 4.39. Pest and disease observed during different dates of planting

Dates of planting	Pest	Disease
15th September	✓	✓
1st October	✓	✓
15th December	✓	✓
1st November	X	✓
15th November	X	✓
1st December	X	✓

4.11. CALIBRATION OF GENETIC COEFFICIENTS

The tomato crop with Six dates of transplanting (15th September, 1st October, 15th December, 1st November, 15th November and 1st December) has been raised for calibrating genetic coeffients for Anagha variety. The model used was DSSAT CROPGO- Tomato model. The Genetic coefficients for the variety Anagha were developed and presented in the Table 4.40.

4.11.1. Predicted v/s Observed fruit yield

In variety Anagha , observed fruit yield of tomato varied from 2976 (D6) to 5128 kg dm ha^{-1} (D1) for different planting dates. The model overestimated the fruit yield in all date of plantings except D1 and D2. Error percent of CROPGRO – Tomato simulated fruit yield from those corresponding observed ones during the crop season was presented in Table 4.41.

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Plate 4.1. Incidence of tobacco caterpillar (*Spodoptera litura*)

Plate 4.2. Incidence of tomato spotted wilt virus

Table 4.40. Genetic coefficients of Tomato

Genetic coefficients	Values
CSDL	12.33
PPSEN	0
EM-FL	34
FL-SH	1
FL-SD	19
SD-PM	50
FL-LF	50
LFMAX	3.8
SLAVR	80
SIZLF	100
XFRT	0.4
WTPSD	0.008
SFDUR	44
SDPDV	300
PODUR	36.5
THRSH	9.2
SDPRO	0.3
SDLIP	0

Table 4.41. Observed and predicted fruit yield

Dates of planting	Observed	Predicted	RMSE	MAPE
D1	5128	4077	1051	20.50
D2	4426	4223	203	4.59
D3	4146	4210	64	1.54
D4	3832	4441	609	15.89
D5	3509	4184	675	19.24
D6	2976	4625	1649	55.41
Average	4002.833	4293.333	708.5	19.52

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, RMSE- Root mean square, MAPE – Mean absolute percent error

4.11.2. Predicted v/s Observed leaf area index

In variety Anagha , observed leaf area index of tomato varied from 2.81cm^{-2} (D6) to 3.12 cm^{-2} (D1) for different planting dates. The model estimated leaf area index was low in all the dates of planting. Error percent of CROPGRO – Tomato simulated leaf area index from those corresponding observed ones during the crop season was presented in Table 4.42.

Table 4.42. Observed and Predicted leaf area index

Dates of planting	Observed	Predicted	RMSE	MAPE
D1	3.12	2.34	0.78	25
D2	3.09	2.47	0.62	20.06
D3	3.16	2.45	0.71	22.47
D4	2.97	2.53	0.44	14.81
D5	2.81	2.55	0.26	9.25
D6	2.81	2.64	0.17	6.05
Average	2.99	2.50	0.50	16.27

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, RMSE- Root mean square, MAPE – Mean absolute percent error

4.11.3. Predicted v/s Observed phenological development

In order to get accurate simulation of crop growth and yield, the accurate simulation of phasic development of the crop was crucial. Thus, evaluation of the phasic development was the most important and the first step in any study aimed at assessment of the performance of a simulation crop model. The results obtained from the field observation showed that, phenological observation for both the varieties with respect to different planting dates were found to be different.

4.11.3.1. Days to anthesis

A comparison between the model simulated and the field observed duration for anthesis was presented in Table 4.43. The results showed that, the observed duration of anthesis varied from 27 (D4, D5, D6) to 28 (D1, D2, D3) days. Days to anthesis as simulated by model were found to be under estimated in D1, D2 and D3. It was overestimated in D6.

4.11.3.2. Days to fruit initiation

A comparison between the model simulated and the field observed duration for fruit initiation was presented in Table 4.44. The results showed that, the observed duration of fruit initiation varied from 36 (D6) to 38 (D1) days. Days to fruit initiation as simulated by model were found to be overestimated in all the dates of planting except D1.

Table 4.43. Observed and predicted anthesis days

Dates of planting	Observed	Predicted	RMSE	MAPE
D1	28	26	2	7.14
D2	28	27	0	3.57
D3	28	27	0	3.57
D4	27	27	0	0.00
D5	27	27	0	0.00
D6	27	28	1	3.70
Average	27.5	27	0.5	2.99

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, RMSE- Root mean square, MAPE – Mean absolute percent error

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Table 4.44. Observed and predicted fruit initiation days

Dates of planting	Observed	Predicted	RMSE	MAPE
D1	38	38	0	0.00
D2	37	38	1	2.70
D3	37	38	1	2.70
D4	37	39	2	5.41
D5	37	39	2	5.41
D6	36	40	4	11.11
Average	37	38.6	1.6	4.55

D1 - 15th September , D2- 1st October , D3- 15th October , D4 - 1st November , D5 - 15th November, D6 - 1st December, RMSE- Root mean square, MAPE – Mean absolute percent error

4.11.4. Model performance

Root Mean Square Error (RMSE) and D-stat index for yield and phenophases is given in Table 4.45.

Table 4.45. RMSE and D-stat index for yield and phenophases

Variable Name	RMSE	D-Stat.
Anthesis day	3.367	0.37
LAI maximum	0.546	0.26
1st fruit day	5.492	0.355
Fruit yield (kg dm ha $^{-1}$)	884.648	0.149

RMSE - Root Mean Square Error, LAI – Leaf area index

Discussion

5. DISCUSSION

The present study was taken up with a view to calibrate their genetic coefficient for Anagha variety of tomato using DSSAT CROPGRO tomato model and to study the micrometeorological aspects under different growing environment. The results of the experiments details are discussed below.

5.1. WEATHER PARAMETERS

5.1.1. Weather parameters experienced during transplanting to flowering

The weather parameters maximum temperature, minimum temperature, temperature range, forenoon relative humidity, afternoon relative humidity, rainfall, rainy days, forenoon vapour pressure deficit, afternoon vapour pressure deficit, wind speed, bright sunshine hours and evaporation experienced by the crop during transplanting to flowering is given in the Table 5.1(a), 5.1(b) and 5.1(c).

Highest maximum temperature was recorded during fourth date of planting with control (32.93 ^{0}C), whereas first date of planting with control recorded lowest (31.08 ^{0}C) maximum temperature during transplanting to flowering. Minimum temperature was highest (22.67 ^{0}C) during first date of planting with black top white bottom and white top black bottom polythene, whereas last date of planting with control (21.21^{0}C) recorded lowest minimum temperature. The Highest temperature range was recorded during fourth date of planting with black top white bottom mulch (11.29 ^{0}C), whereas first date of planting with control recorded lowest temperature range (8.42 ^{0}C). Forenoon relative humidity was highest (94 %) during first date of planting with black top white bottom mulch, whereas sixth date of planting with control recorded lowest (78 %) forenoon relative humidity (Table 5.1(a)).

The highest afternoon relative humidity was recorded during second date of planting with control (72 %), whereas sixth date of planting with control recorded lowest forenoon relative humidity (49 %). Highest rainfall of 338.1 mm and 13 rainy days was obtained for first date of planting with black top white bottom mulch, whereas rainfall for delayed dates of planting was nil. Highest forenoon vapour pressure deficit of 22.75 mm Hg was obtained for first date of planting with white top

Table 5.1(a). Weather parameters experienced during transplanting to flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Maximum temperature (^{0} C)						
M0	31.08	31.32	31.86	32.93	32.72	32.47
M1	31.10	31.32	31.90	32.92	32.82	32.51
M2	31.11	31.35	31.94	32.92	32.81	32.47
M3	31.09	31.32	31.87	32.92	32.78	32.50
Minimum temperature (^{0} C)						
M0	22.65	22.35	22.04	21.72	21.61	21.21
M1	22.67	22.34	22.05	21.64	21.61	21.35
M2	22.67	22.33	22.03	21.64	21.62	21.35
M3	22.66	22.34	22.05	21.67	21.63	21.33
Temperature range (^{0} C)						
M0	8.42	8.97	9.82	11.21	11.11	11.25
M1	8.44	8.98	9.85	11.28	11.21	11.16
M2	8.44	9.01	9.91	11.29	11.19	11.12
M3	8.43	8.98	9.83	11.24	11.15	11.17
Forenoon relative humidity (%)						
M0	94	94	88	87	89	78
M1	94	94	88	88	88	80
M2	94	94	89	88	88	80
M3	94	94	88	88	89	80

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.1(b). Weather parameters experienced during transplanting to flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon relative humidity (%)						
M0	71	72	66	58	59	49
M1	71	72	66	58	58	51
M2	71	71	65	58	58	52
M3	71	72	66	58	58	51
Rainfall (mm)						
M0	334.1	170.9	139.7	58.3	26.1	0
M1	338.1	178.3	139.7	58.3	26.1	0
M2	339.7	182	139.7	58.3	26.1	0
M3	335.3	178.3	139.7	58.3	26.1	0
Rainy days (day)						
M0	11	9	8	5	2	0
M1	12	10	8	5	2	0
M2	13	10	8	5	2	0
M3	12	10	8	5	2	0
Forenoon vapour pressure deficit (mm Hg)						
M0	22.74	22.37	21.34	21.35	21.46	18.35
M1	22.75	22.34	21.36	21.44	21.42	18.79
M2	22.75	22.31	21.38	21.40	21.42	18.92
M3	22.74	22.34	21.34	21.38	21.43	18.69

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.1(c). Weather parameters experienced during transplanting to flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon vapour pressure deficit (mm Hg)						
M0	22.41	22.68	22.03	20.43	20.55	17.18
M1	22.48	22.67	21.88	20.50	20.41	17.73
M2	22.51	22.63	21.79	20.47	20.44	17.93
M3	22.43	22.67	21.98	20.45	20.48	17.59
Wind speed (km h^{-1})						
M0	0.42	0.10	1.01	1.65	2.18	5.13
M1	0.41	0.13	0.99	1.55	2.37	4.82
M2	0.40	0.15	0.99	1.54	2.39	4.79
M3	0.42	0.13	1.00	1.58	2.30	4.93
Bright sunshine hours (h)						
M0	4.36	4.70	5.52	6.37	6.00	7.19
M1	4.31	4.64	5.63	6.45	6.30	6.98
M2	4.26	4.64	5.71	6.49	6.27	6.92
M3	4.36	4.64	5.55	6.38	6.27	7.04
Evaporation (mm)						
M0	2.50	2.30	2.60	2.89	2.77	3.82
M1	2.49	2.29	2.61	2.88	2.91	3.63
M2	2.48	2.29	2.63	2.88	2.91	3.57
M3	2.50	2.29	2.60	2.88	2.87	3.68

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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black bottom polythene and black top white bottom mulch, whereas lowest vapour pressure deficit was recorded during last date of planting with control (Table 5.1(b)).

Afternoon vapour pressure deficit was highest (22.51 mm Hg) for first date of planting with black top white bottom mulch, whereas lowest vapour pressure deficit was recorded during last date of planting with control. Highest wind speed of 5.13 km h^{-1} was recorded during last date of planting with control, whereas lowest wind speed of 0.40 km h^{-1} was recorded during first date of planting with black top white bottom mulch. Highest bright sunshine hours of 7.19 h was recorded during last date of planting with control, whereas lowest bright sunshine hours of 4.26 h was recorded during first date of planting with black top white bottom mulch. Highest evaporation of 3.82 (mm) was recorded during last date of planting with control, whereas lowest evaporation of 2.48 (mm) was recorded during first date of planting with black top white bottom mulch (Table 5.1(c)).

During transplanting to flowering stage, highest maximum temperature, high wind speed, bright sunshine hours and evaporation was noticed in last date of planting, which were found to cause negative impact on flowering(Table 4.1) . Hence during last date of planting number of flowers and fruits were found to be less. This is in agreement with results obtained by Nduwimana and Wei (2017).

5.1.2. Weather parameters experienced during first flowering to fifty percent flowering

Highest maximum temperature (33.18 ^{0}C) was recorded during third date of planting with black top white bottom mulch , whereas first date of planting with control recorded lowest (30.81^{0}C) maximum temperature. Highest minimum temperature was recorded during first date of planting with straw mulch (22.35^{0}C , whereas last date of planting with control recorded lowest minimum temperature (19.72^{0}C). Highest temperature range (13.29^{0}C) was recorded during sixth date of planting with straw mulch, whereas first date of planting with control recorded lowest temperature range (8.55^{0}C). The highest forenoon relative humidity was recorded during first date of planting with control and straw mulch (95%), whereas sixth date of planting with control recorded lowest forenoon relative humidity (71%) (Table 5.2(a)).

Table 5.2(a). Weather parameters experienced during first flowering to fifty percent flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Maximum temperature (^{0} C)						
M0	30.81	32.29	32.86	32.18	32.46	32.76
M1	31.00	32.48	33.13	32.13	32.41	32.86
M2	31.22	32.64	33.18	32.11	32.49	33.01
M3	31.01	32.47	33.12	32.06	32.30	32.92
Minimum temperature (^{0} C)						
M0	22.26	22.37	21.07	21.71	21.48	19.72
M1	22.26	22.24	21.28	22.12	21.41	19.78
M2	22.04	22.23	21.24	22.21	21.40	19.91
M3	22.35	22.24	21.30	22.13	21.43	19.58
Temperature range (^{0} C)						
M0	8.55	9.91	11.79	10.46	10.98	13.04
M1	8.74	10.25	11.85	10.02	11.00	13.08
M2	9.18	10.41	11.94	9.90	11.09	13.10
M3	8.66	10.23	11.82	9.94	10.87	13.29
Forenoon relative humidity (%)						
M0	95	84	93	86	72	71
M1	95	83	93	84	79	71
M2	94	82	93	83	82	73
M3	95	82	93	84	78	73

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.2(b). Weather parameters experienced during first flowering to fifty percent flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon relative humidity (%)						
M0	80	61	56	61	45	39
M1	78	62	57	60	51	38
M2	75	61	57	60	53	38
M3	79	62	56	60	51	38
Rainfall (mm)						
M0	67.50	80.13	0.00	0.00	0.00	0.00
M1	67.50	57.23	13.87	0.00	0.00	0.00
M2	66.30	40.80	22.20	0.00	0.00	0.00
M3	67.90	57.23	13.87	0.00	0.00	0.00
Rainy days (day)						
M0	6	4	0	0	0	0
M1	6	4	1	0	0	0
M2	5	4	2	0	0	0
M3	6	4	1	0	0	0
Forenoon vapour pressure deficit (mm Hg)						
M0	22.21	20.90	22.58	20.69	16.96	15.20
M1	22.38	20.78	22.58	20.47	18.68	15.43
M2	22.14	20.70	22.65	20.34	19.39	15.98
M3	22.44	20.75	22.55	20.50	18.51	15.72

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.2(c). Weather parameters experienced during first flowering to fifty percent flowering

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon vapour pressure deficit (mm Hg)						
M0	23.27	21.46	19.95	20.48	15.90	13.86
M1	23.37	21.57	20.53	20.20	17.68	13.66
M2	23.01	21.37	20.72	20.12	18.37	13.85
M3	23.50	21.51	20.44	20.25	17.71	13.80
Wind speed (km h^{-1})						
M0	0.09	1.32	0.64	3.90	7.05	4.76
M1	0.09	1.71	0.74	4.48	4.66	5.23
M2	0.09	1.92	0.81	4.64	4.03	5.15
M3	0.09	1.76	0.74	4.75	5.02	5.11
Bright sunshine hours (h)						
M0	2.59	6.21	7.14	6.05	7.77	8.66
M1	3.44	5.94	7.06	5.14	6.71	8.99
M2	4.17	5.91	6.82	5.06	6.12	9.06
M3	3.37	5.82	7.08	5.19	6.20	9.06
Evaporation (mm)						
M0	2.09	3.04	2.61	3.08	4.51	4.13
M1	2.04	2.98	2.71	3.14	3.50	4.44
M2	2.14	2.91	2.74	3.18	3.20	4.46
M3	2.11	2.95	2.71	3.20	3.50	4.40

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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The highest afternoon relative humidity was recorded during first date of planting with control (80 %), whereas sixth date of planting with white top black bottom mulch recorded lowest forenoon relative humidity (38 %).

Highest rainfall of 80.13 mm was obtained during second date of planting with control, whereas last dates of planting does not receive rainfall. The number of rainy days were higher during first date of planting. Highest forenoon vapour pressure deficit of 22.65 mm Hg was obtained for third date of planting with black top white bottom polythene mulch, whereas lowest vapour pressure deficit (15.20 mm Hg) was recorded during last date of planting with control (Table 5.2(b)).

Highest afternoon vapour pressure deficit of 23.50 mm Hg was obtained for first date of planting with straw mulch, whereas lowest vapour pressure deficit of 13.66 mm Hg was recorded during last date of planting with white top black bottom polythene mulch. Highest wind speed of 7.05 km h^{-1} was recorded during fifth date of planting with control, whereas lowest wind speed of 0.09 km h^{-1} was recorded during first date of planting in case of all the mulch treatments. Highest bright sunshine hours of 9.06 h was recorded during last date of planting with black top white bottom polythene and straw mulch, whereas lowest bright sunshine hours of 2.59 h was recorded during first date of planting with control. Highest evaporation of 4.51mm was recorded during fifth date of planting with control, whereas lowest evaporation of 2.04 mm was recorded during first date of planting with white top black bottom mulch (Table 5.2(c)).

5.1.3. Weather parameters experienced during first fruiting to fifty percent fruiting

Highest maximum temperature (33.44 ^{0}C) was recorded during third date of planting with control, whereas first date of planting with control recorded lowest maximum temperature (31.92 ^{0}C). Highest minimum temperature (22.06 ^{0}C) was recorded during third date of planting with black top white bottom polythene mulch , whereas fifth date of planting with control recorded lowest minimum temperature (20.14 ^{0}C). Highest temperature range was recorded during fifth date of planting with control (12.79 ^{0}C) , whereas first date of planting with control (10 ^{0}C) recorded lowest temperature range. The highest forenoon relative humidity (92 %) was recorded during

Table 5.3(a). Weather parameters experienced during first fruiting to fifty percent fruiting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Maximum temperature (^{0} C)						
M0	31.92	32.24	33.44	32.70	32.94	33.18
M1	32.25	32.69	33.35	32.71	32.71	32.96
M2	32.36	32.63	33.04	32.71	32.66	32.94
M3	32.03	32.47	33.35	32.67	32.86	33.16
Minimum temperature (^{0} C)						
M0	21.93	21.65	21.69	21.26	20.14	21.41
M1	21.94	21.38	21.87	21.08	20.87	21.18
M2	21.99	21.15	22.06	21.09	21.29	21.10
M3	21.84	21.23	21.87	21.21	20.78	21.33
Temperature range (^{0} C)						
M0	10.00	10.59	11.75	11.43	12.79	11.77
M1	10.32	11.31	11.48	11.63	11.83	11.79
M2	10.37	11.47	10.97	11.63	11.37	11.84
M3	10.19	11.24	11.48	11.46	12.08	11.84
Forenoon relative humidity (%)						
M0	90	86	89	90	72	69
M1	89	89	87	90	68	70
M2	88	91	86	92	68	70
M3	90	89	87	90	70	71

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.3(b). Weather parameters experienced during first fruiting to fifty percent fruiting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon relative humidity (%)						
M0	64	60	55	59	38	36
M1	62	56	55	59	38	38
M2	61	57	56	60	40	38
M3	62	58	55	59	38	38
Rainfall (mm)						
M0	36.34	3.50	26.10	0.00	0.00	0.00
M1	21.14	0.00	26.10	0.00	0.00	0.00
M2	30.47	0.00	13.30	0.00	0.00	0.00
M3	19.72	1.40	26.10	0.00	0.00	0.00
Rainy days (day)						
M0	1	1	2	0	0	0
M1	1	0	2	0	0	0
M2	2	0	1	0	0	0
M3	1	0	2	0	0	0
Forenoon vapour pressure deficit (mm Hg)						
M0	21.61	20.94	20.99	21.15	16.01	15.45
M1	21.38	20.94	20.85	21.16	15.55	15.57
M2	21.24	22.05	20.55	21.48	15.93	15.70
M3	21.42	21.57	20.85	21.12	15.69	15.93

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.3(c). Weather parameters experienced during first fruiting to fifty percent fruiting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon vapour pressure deficit (mm Hg)						
M0	22.16	20.41	20.30	20.27	13.95	12.98
M1	21.94	19.65	20.12	20.26	13.79	13.27
M2	21.70	19.90	20.02	20.48	14.46	13.44
M3	21.91	20.02	20.12	20.29	13.48	13.33
Wind speed (km h^{-1})						
M0	0.45	2.06	1.78	0.99	6.37	6.51
M1	0.72	1.40	2.03	0.98	7.38	6.36
M2	0.78	1.13	2.82	0.77	7.71	6.15
M3	0.56	1.46	2.03	1.17	7.06	6.34
Bright sunshine hours (h)						
M0	6.47	5.66	6.39	5.36	9.31	7.75
M1	6.73	6.59	6.13	6.04	9.21	7.99
M2	6.76	6.64	6.26	6.28	9.22	8.03
M3	6.58	6.26	6.13	5.93	8.74	7.79
Evaporation (mm)						
M0	2.49	2.74	3.08	2.28	4.84	4.75
M1	2.67	2.68	3.09	2.34	5.11	4.58
M2	2.76	2.59	3.25	2.27	5.08	4.51
M3	2.57	2.64	3.09	2.36	4.97	4.66

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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fourth date of planting with black top white bottom mulch, whereas sixth date of planting with control recorded lowest forenoon relative humidity (69 %) (Table 5.3 (a)).

During flowering to fifty percent flowering stage, highest maximum temperature, high wind speed, bright sunshine hours and evaporation was noticed in last date of planting, which were found to cause negative impact on flowering(Table 4.1) . Hence during last date of planting number of flowers and fruits were found to be less. This is in agreement with results obtained by Nduwimana and Wei (2017).

The highest afternoon relative humidity (64 %) was recorded during first date of planting with control, whereas sixth date of planting with control recorded lowest forenoon relative humidity (36 %). Highest rainfall of 36.24 mm was obtained during first date of planting with control, whereas during last dates of planting rainfall was nill. The number of rainy days was high for third date of planting. Highest forenoon vapour pressure deficit of 22.05 mm Hg was obtained for second date of planting with black top white bottom polythene mulch, whereas lowest vapour pressure deficit (15.45 mm Hg) was recorded during last date of planting with control (Table 5.3(b)).

Highest afternoon vapour pressure deficit of 22.16 mm Hg was obtained for first date of planting with control, whereas lowest vapour pressure deficit (12.98 mm Hg) was recorded during last date of planting with control. Highest wind speed of 7.71 km h^{-1} was recorded during last date of planting with black top white bottom mulch, whereas lowest wind speed of 0.45 km h^{-1} was recorded during first date of planting with control. Highest bright sunshine hours of 9.31 h was recorded during fifth date of planting with control, whereas lowest bright sunshine hours of 5.36 h was recorded during fourth date of planting with control. Highest evaporation of 5.11 (mm) was recorded during fifth date of planting with white top black bottom polythene mulch , whereas lowest evaporation of 2.49 (mm) was recorded during first date of planting with control (Table 5.3(c)).

The highest maximum temperature was noticed in last three dates of planting High wind speed, bright sunshine hours and evaporation was more in last date of planting. Because of elevated temperature and high evaporation the rate of fruit development was less in last date of planting. Similar results was obtained from the study of Adams *et al.,* 2001.

5.1.4. Weather parameters experienced during fifty percent fruiting to harvesting

Highest maximum temperature (33.55 ^{0}C) was recorded during sixth date of planting with control, whereas second date of planting with white top black bottom polythene mulch recorded lowest maximum temperature (32.21 ^{0}C). Highest minimum temperature (21.77 ^{0}C) was recorded during first date of planting with straw mulch, whereas fifth date of planting with black top white bottom recorded lowest minimum temperature (20.51^{0}C). Highest temperature range was recorded during sixth date of planting with black top white bottom polythene (12.63^{0}C) , whereas first date of planting with white top black bottom polythene mulch (10.82 ^{0}C) recorded lowest temperature range . The highest forenoon relative humidity (87 %) was recorded during first date of planting with black top white bottom mulch, whereas sixth date of planting with control recorded lowest forenoon relative humidity (65%) (Table 5.4(a)).

The highest afternoon relative humidity (59 %) was recorded during first date of planting with straw mulch, whereas sixth date of planting with black top white bottom mulch recorded lowest forenoon relative humidity (35 %). Highest rainfall of 59.50 mm was obtained for first date of planting with control, whereas rainfall during last dates of planting was nill. The number of rainy days during first date of planting was 5 under control, white top black bottom and straw mulch. Highest forenoon vapour pressure deficit of 21.24 mm Hg was obtained for first date of planting with control, whereas lowest vapour pressure deficit was recorded during last date of planting with control (Table 5.4(b)).

Highest afternoon vapour pressure deficit of 20.55 mm Hg was obtained for first date of planting with control, whereas lowest vapour pressure deficit was recorded during last date of planting with control (13.17 mm Hg). Highest wind speed of 6.50 km h^{-1} was recorded during fourth date of planting with white top black bottom mulch, whereas lowest wind speed of 1.80 km h^{-1} was recorded during first date of planting with control. Highest bright sunshine hours of 8.63 h was recorded during last date of planting with black top white bottom polythene, whereas lowest bright sunshine hours of 6.13 h was recorded during first date of planting with white top black bottom

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Table 5.4(a). Weather parameters experienced during fifty percent fruiting to harvesting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Maximum temperature (^{0} C)						
M0	32.89	32.73	32.46	32.85	33.02	33.55
M1	32.69	32.21	32.45	32.72	33.08	33.32
M2	32.67	32.69	32.46	32.72	33.01	33.35
M3	32.75	32.64	32.57	32.90	33.09	33.43
Minimum temperature (^{0} C)						
M0	21.75	21.47	21.39	20.83	20.99	21.01
M1	21.74	21.39	21.16	20.84	20.68	20.87
M2	21.67	21.61	21.13	20.85	20.51	20.72
M3	21.77	21.37	21.12	20.79	20.68	21.07
Temperature range (^{0} C)						
M0	11.14	11.26	11.07	12.02	12.04	12.53
M1	10.95	10.82	11.28	11.88	12.40	12.45
M2	11.00	11.07	11.33	11.86	12.50	12.63
M3	10.97	11.27	11.45	12.11	12.41	12.37
Forenoon relative humidity (%)						
M0	87	87	79	71	69	65
M1	87	73	78	71	71	69
M2	87	85	78	72	72	68
M3	87	84	76	70	71	66

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.4(b). Weather parameters experienced during fifty percent fruiting to harvesting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon relative humidity (%)						
M0	58	57	51	40	37	36
M1	58	48	50	40	38	38
M2	58	56	50	41	38	35
M3	59	54	47	39	38	37
Rainfall (mm)						
M0	59.50	26.10	0.00	0.00	0.00	0.00
M1	58.30	8.70	0.00	0.00	0.00	0.00
M2	29.58	26.10	0.00	0.00	0.00	0.00
M3	59.10	17.40	0.00	0.00	0.00	0.00
Rainy days (day)						
M0	5	2	0	0	0	0
M1	5	1	0	0	0	0
M2	3	2	0	0	0	0
M3	5	1	0	0	0	0
Forenoon vapour pressure deficit (mm Hg)						
M0	21.61	20.94	20.99	21.15	16.01	15.45
M1	21.38	20.94	20.85	21.16	15.55	15.57
M2	21.24	22.05	20.55	21.48	15.93	15.70
M3	21.42	21.57	20.85	21.12	15.69	15.93

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

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Table 5.4(c). Weather parameters experienced during fifty percent fruiting to harvesting

Type of mulch	Dates of planting					
	D1	D2	D3	D4	D5	D6
Afternoon vapour pressure deficit (mm Hg)						
M0	20.55	19.92	17.53	14.14	13.29	13.17
M1	20.40	16.72	17.19	14.36	13.52	13.67
M2	20.40	19.56	17.17	14.48	13.59	12.88
M3	20.53	18.96	16.27	13.86	13.51	13.38
Wind speed (km h^{-1})						
M0	1.80	2.64	5.08	6.48	6.09	5.40
M1	2.21	5.70	5.23	6.50	5.59	5.87
M2	2.21	3.28	5.21	6.33	5.76	6.41
M3	2.20	3.68	5.63	6.25	5.71	5.65
Bright sunshine hours (h)						
M0	6.42	6.20	7.10	8.56	8.15	8.13
M1	6.13	8.28	7.29	8.54	8.20	8.40
M2	6.13	6.40	7.32	8.34	8.46	8.63
M3	6.28	6.63	7.69	8.46	8.25	8.25
Evaporation (mm)						
M0	2.92	2.96	3.81	4.66	4.61	4.31
M1	2.96	4.16	3.88	4.61	4.43	4.48
M2	2.88	3.14	3.88	4.54	4.54	4.74
M3	2.96	3.30	4.14	4.59	4.46	4.41

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November
D6 -1st December M0- Control M1 - White top black bottom polythene
M2 - Black top white bottom polythene M3 - Paddy straw

polythene and black top white bottom mulch. Highest evaporation of 4.66 (mm) was recorded during fourth date of planting with control, whereas lowest evaporation of 2.88 (mm) was recorded during first date of planting with black top white bottom mulch (Table 5.4(c)).

The highest maximum temperature was noticed in last three dates of planting High wind speed, bright sunshine hours and evaporation was more in last date of planting. Elevated temperature and high evaporation might have impaired fruit set in tomato due to elongation of style, and poor pollen production which led to poor fruit set and lower fruit yield. The results are similar to the findings of Adams *et al.* (2001), Islam *et al.* (2010) and Singh *et al.* (2015).

.2. MICROMETEOROLOGICAL PARAMETERS

5.2.1. Effect of date of planting and mulching on soil temperature

In present study, the soil temperature during both forenoon and afternoon showed increasing trend as the transplanting was delayed (Fig. 5.1 and 5.2). The highest soil temperature was recorded under black top white polythene mulch, followed by white top black bottom polythene and straw mulch during both forenoon and afternoon. The lowest soil temperature was recorded in control (Fig 5.3 and 5.4). Black plastic mulches are more effective in increasing soil temperature due to a greater net radiation under the mulch compared to bare soil.

This observation is in agreement with the properties of black bodies as good heat emitters as well as good heat absorbers. Black plastic mulches raise soil temperatures so that mineralization of nutrients takes place. Hence it results in increased plant growth and higher yields compared to bare ground. These results are supported with the findings of Lamont (1999), Singh *et al*. (2009), Rajablariani *et al.* (2012) and Anderson *et al*. (2012)

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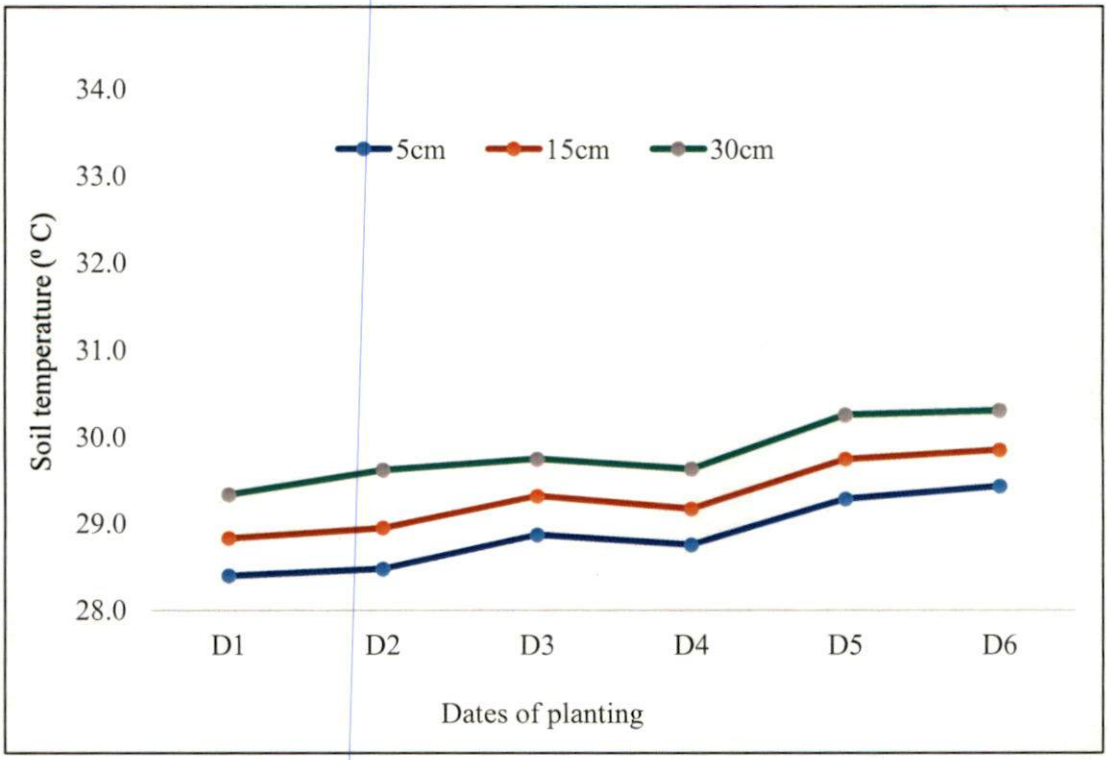

Fig. 5.1 Effect of date of planting on forenoon soil temperature (^{0} C)

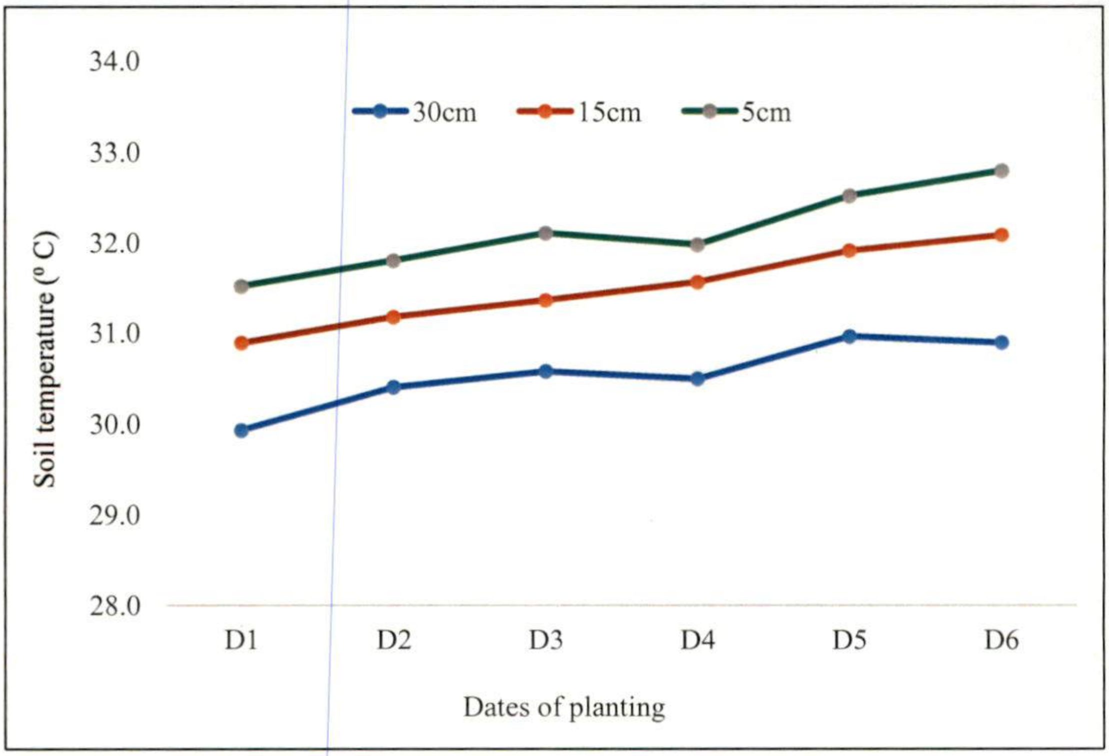

Fig. 5.2 Effect of date of planting on afternoon soil temperature (^{0} C)

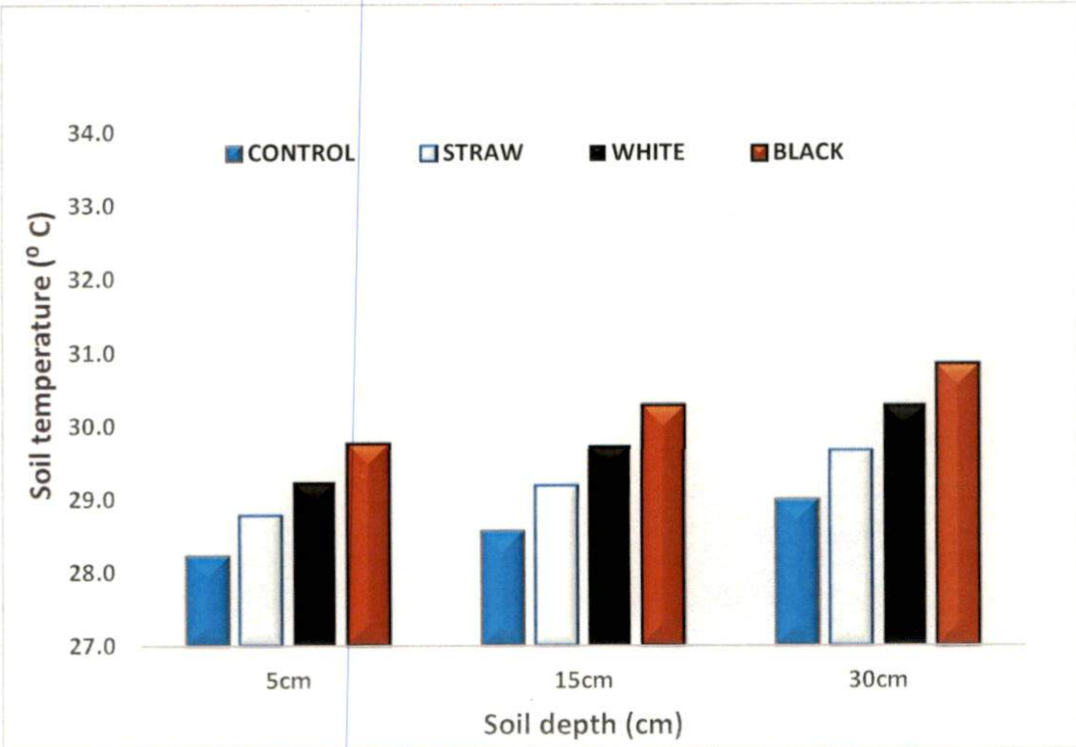

Fig. 5.3 Effect of mulching on forenoon soil temperature

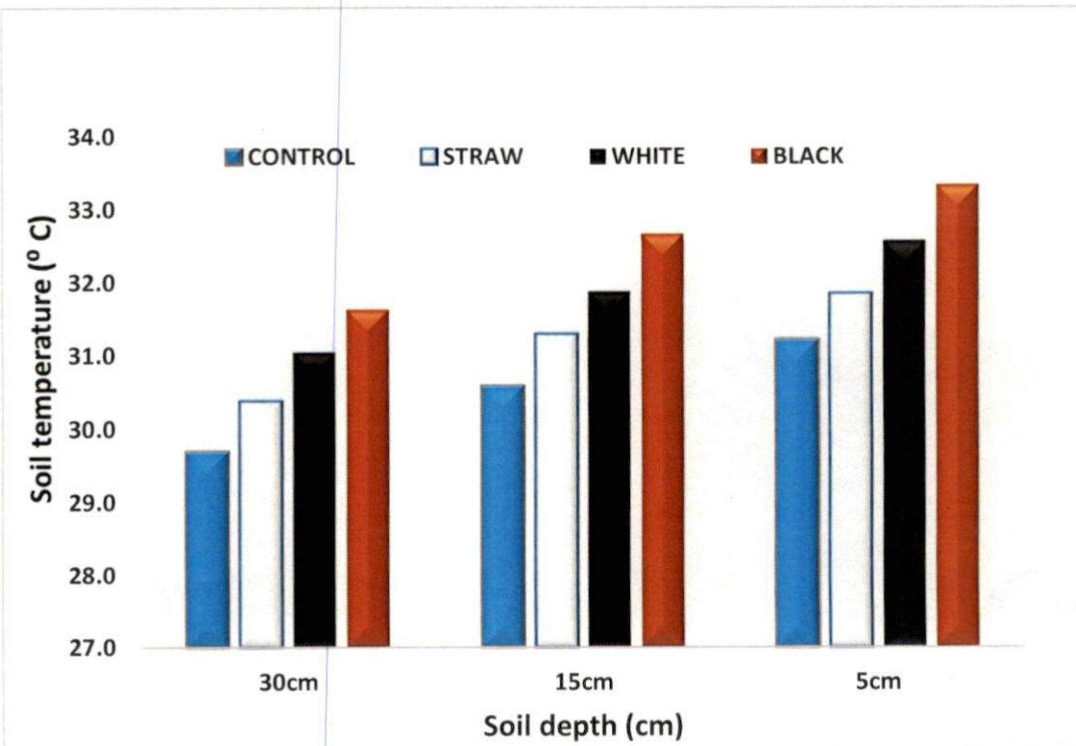

Fig. 5.4 Effect of mulching on afternoon soil temperature

5.2.2. Effect of date of planting and mulching on soil moisture

In present study, the soil moisture showed decreasing trend as the date of planting delayed (Fig. 5.5). Among the mulch treatments black top white polythene mulch retained highest soil moisture, followed by straw mulch and white top black bottom polythene. The lowest soil moisture was recorded in control (Fig. 5.6). The increased moisture content in black polythene and other mulches might be due to adequate soil cover provided by the mulches. This prevented contact between the soil and dry air, which reduced the evaporation. Also, mulches reduce impact of raindrops and splash, thereby preventing soil compaction, reducing surface run-off and increasing water infiltration. All these combined to increase the soil moisture content and reduce moisture depletion. Higher soil moisture content increases root proliferation and thus enhances availability of nutrients to crop roots. Similar findings have been reported by Moolchand (2010), Ashrafuzzaman *et al*. (2011).

5.3. SOIL PARAMETERS

5.3.1. Effect of date of planting and mulching on soil pH and organic carbon

The analysis of soil pH and organic carbon showed that, the soil samples taken after the harvest of the crop recorded high pH and more organic carbon compared to initial samples (Fig. 5.7 and 5.8). The soil pH and organic carbon does not vary between the dates of planting, whereas among the mulch treatments paddy straw mulch recorded higher pH and organic carbon. This might be due to addition of organic matter by decomposition of straw and release of bases . The result was supported by findings of Borthakur and Bhattacharya (1992), Tukey and Schoff (1963) and Broschat (2007)

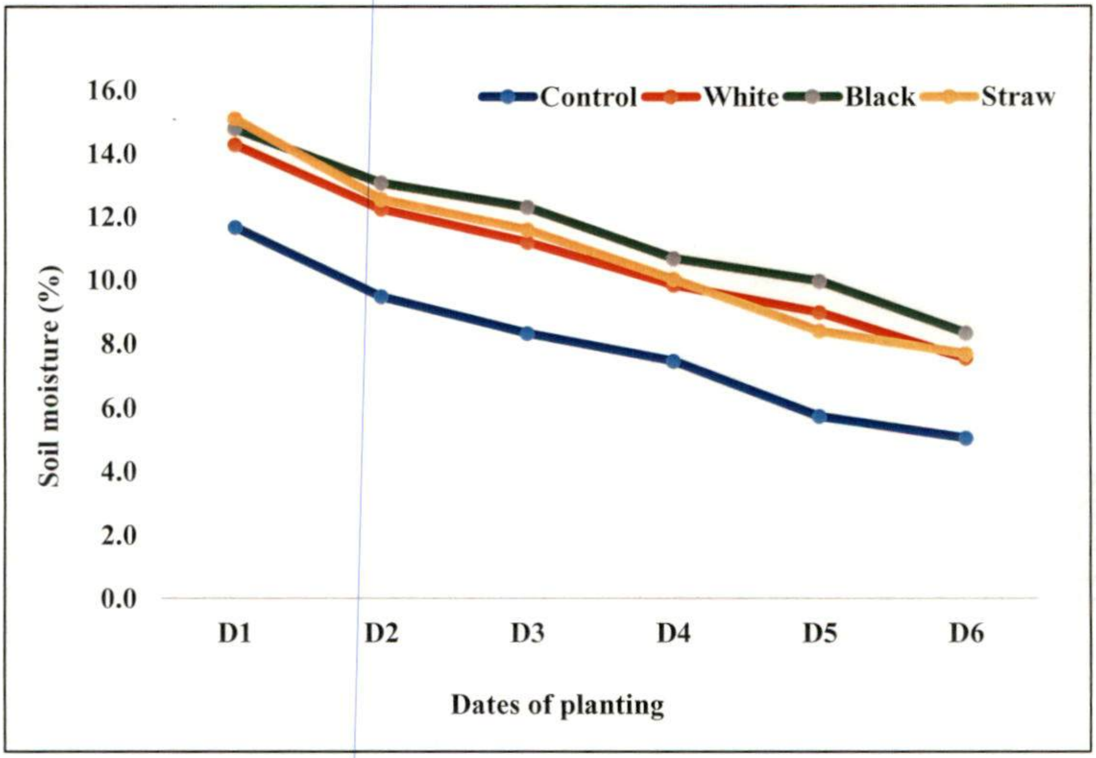

Fig. 5.5 Effect of date of planting on soil moisture

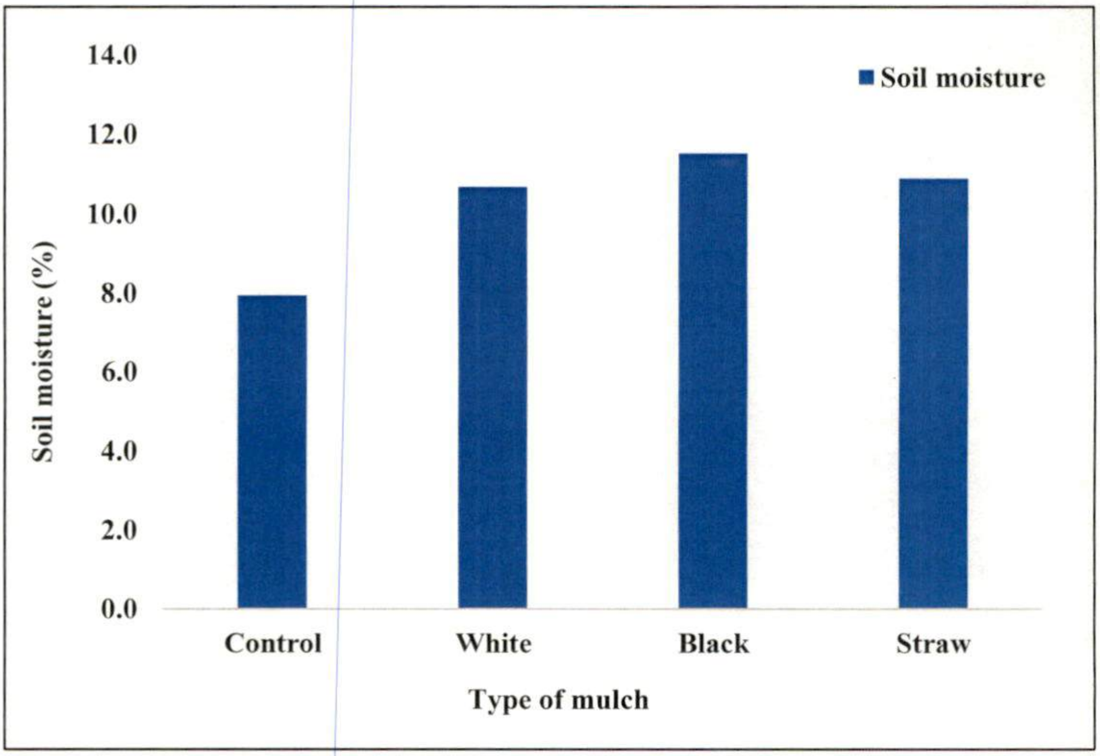

Fig. 5.6 Effect of mulching on soil moisture

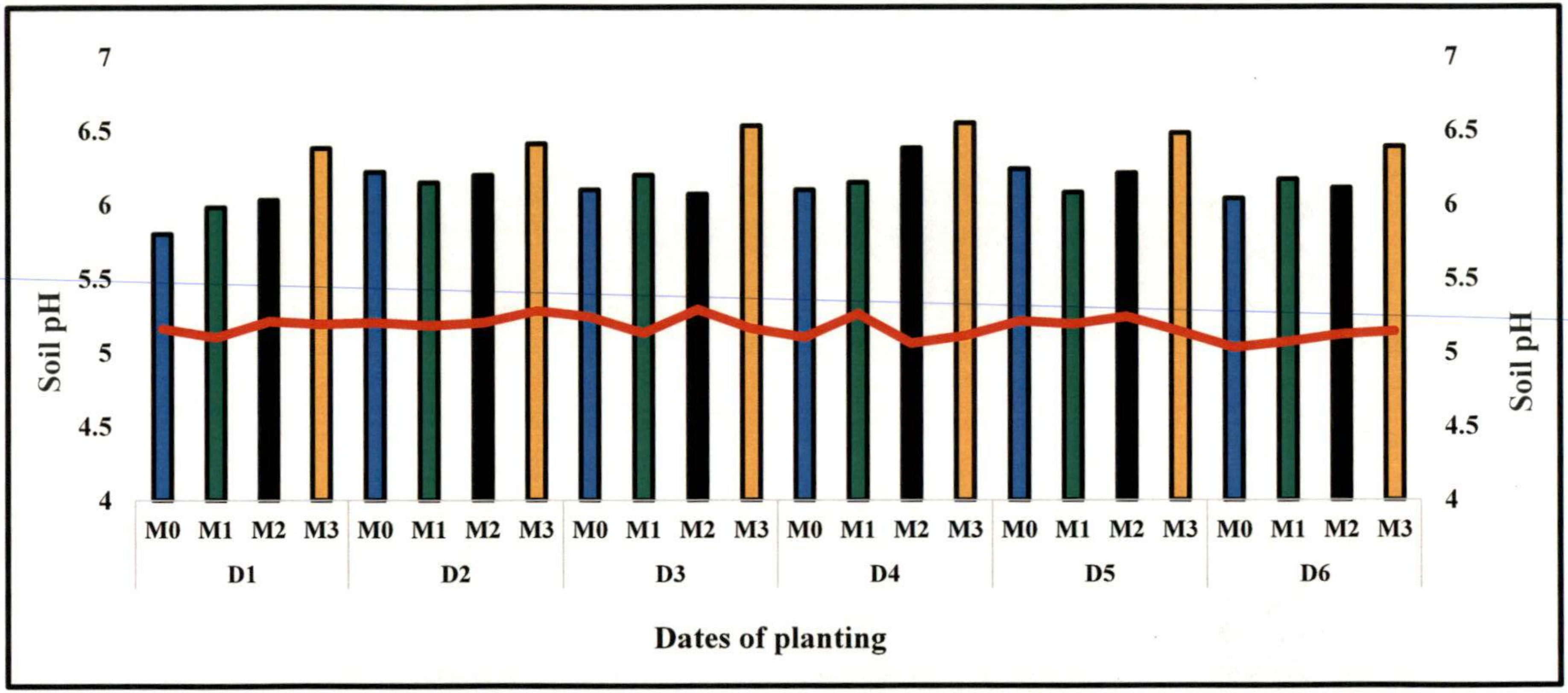

Fig. 5.7. Effect of date of planting and mulching on soil pH

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw

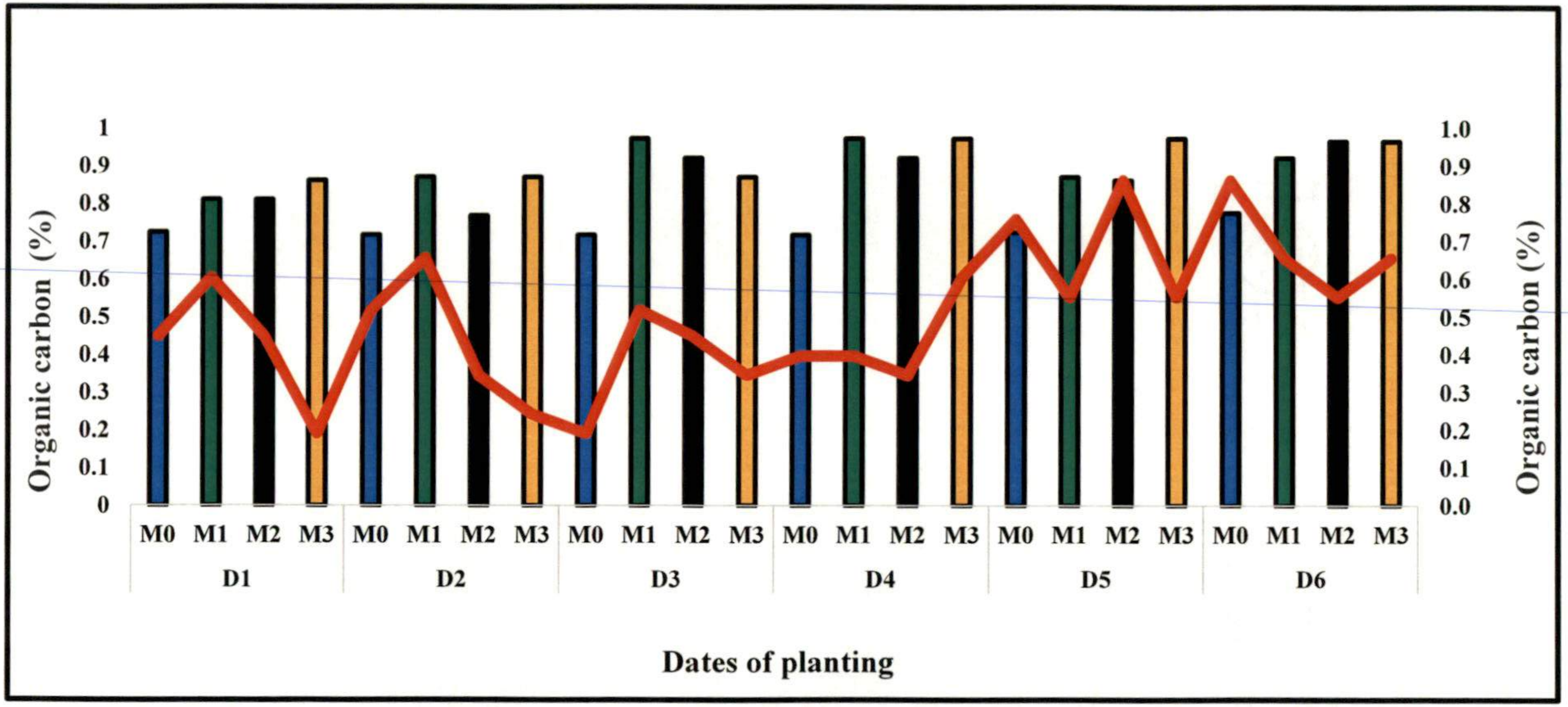

Fig. 5.8. Effect of date of planting and mulching on organic carbon

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw

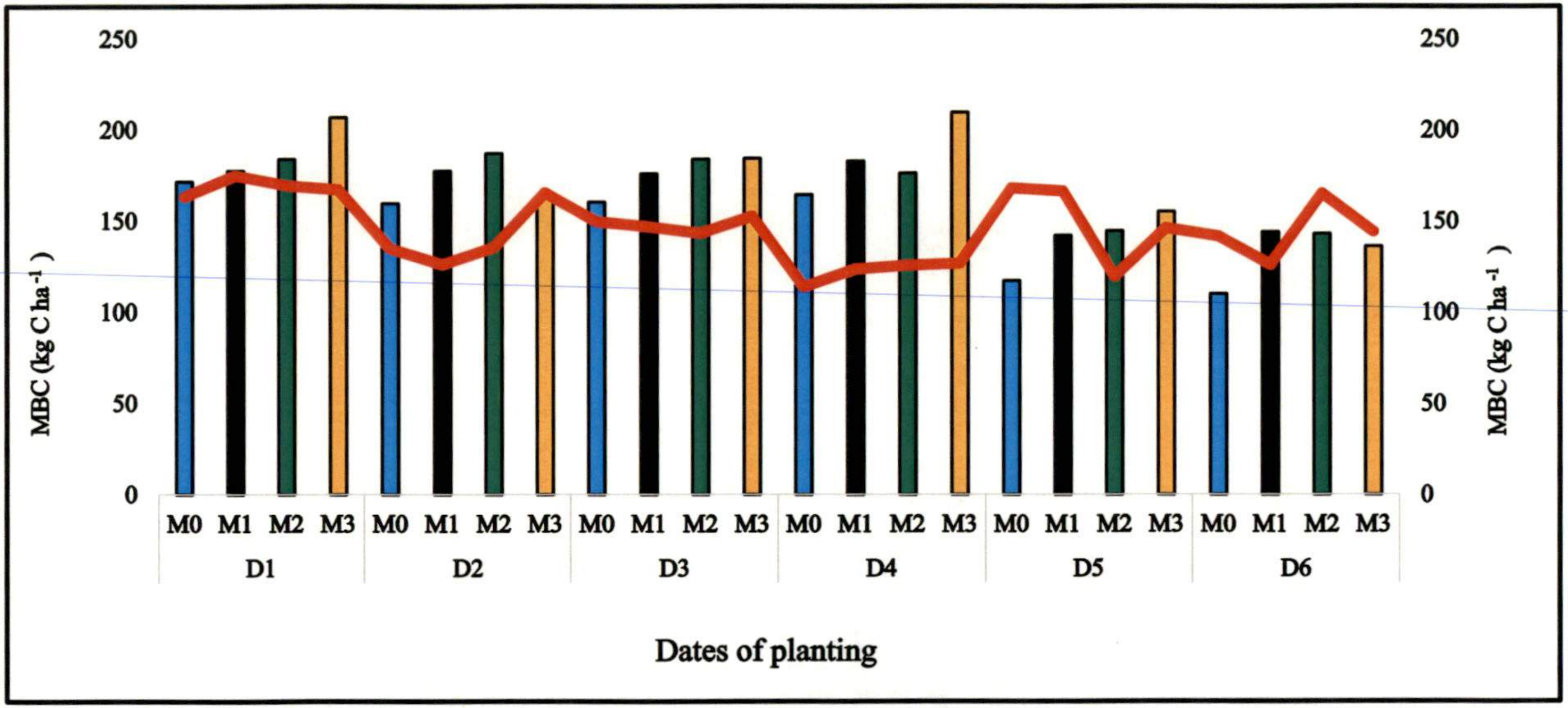

Fig. 5.9. Effect of date of planting and mulching on microbial biomass carbon

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw MBC – microbial biomass carbon

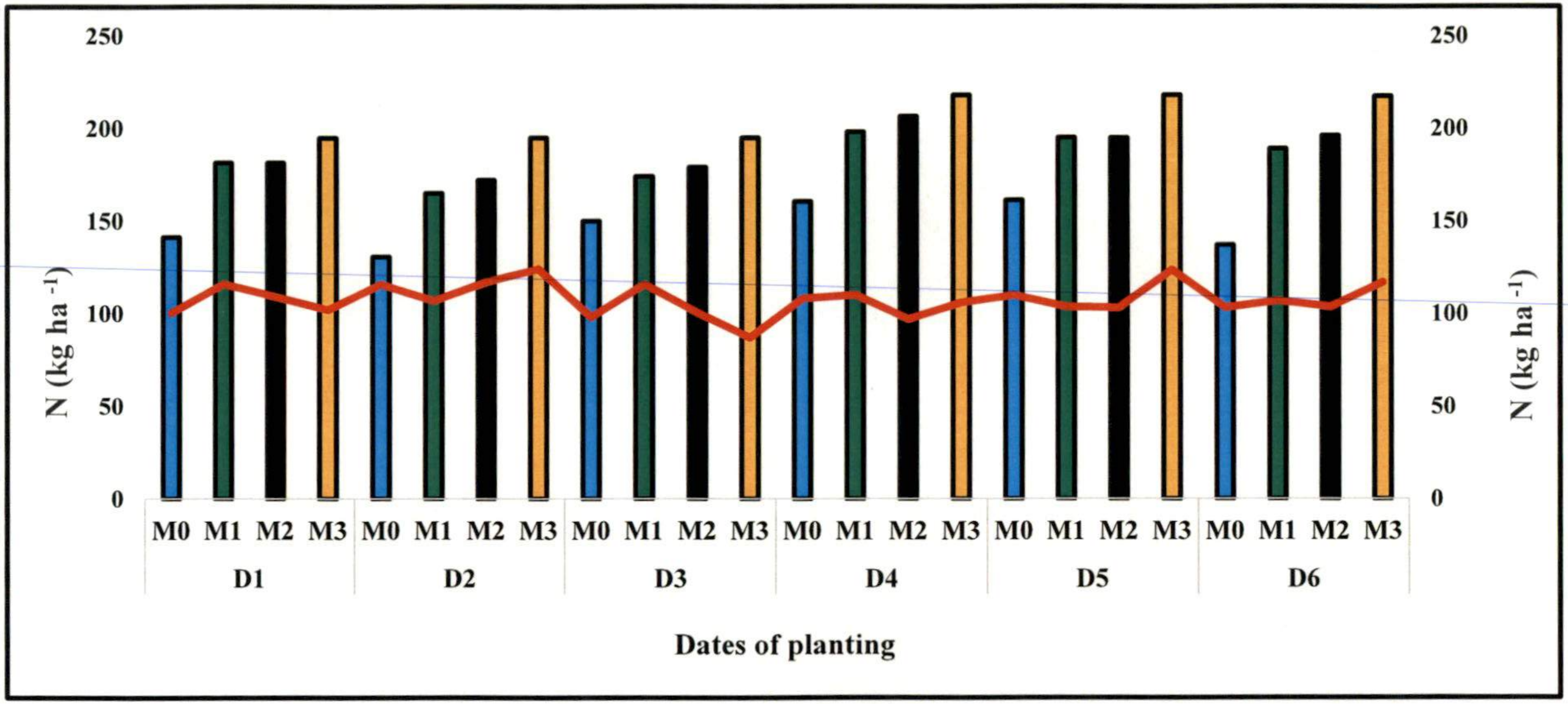

Fig. 5.10. Effect of date of planting and mulching on available nitrogen

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw N – Available nitrogen

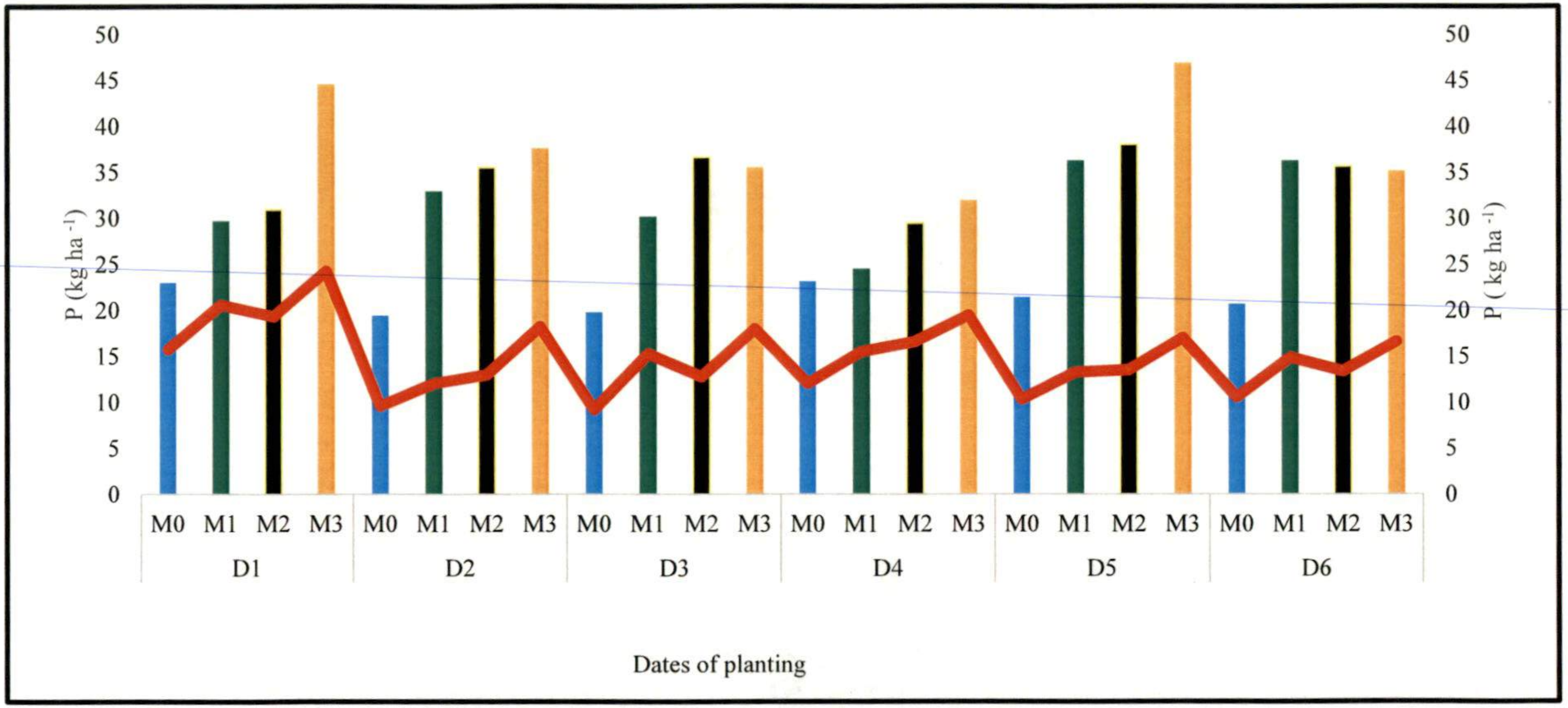

Fig. 5.11. Effect of date of planting and mulching on available phosphorus

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw P – Available phosphorus

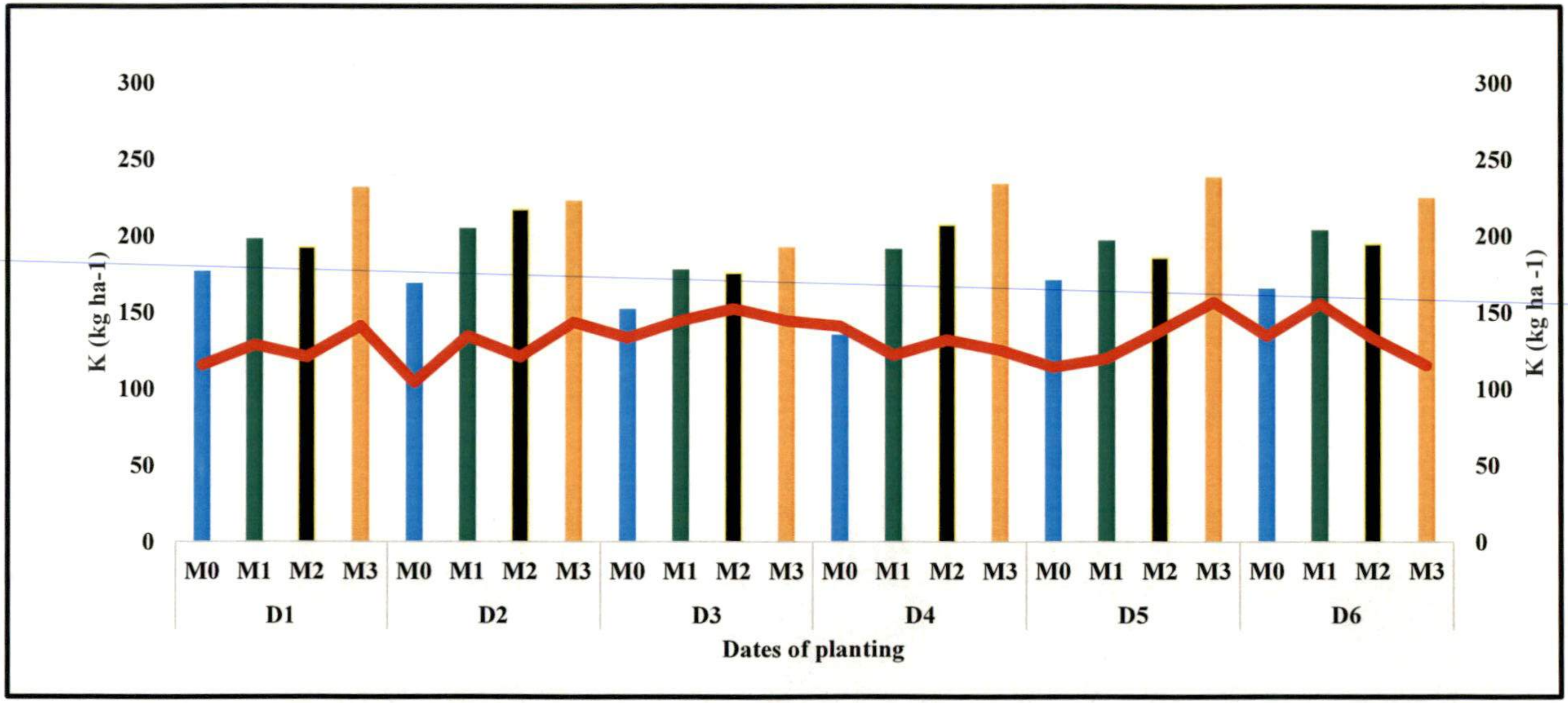

Fig. 5.12. Effect of date of planting and mulching on available potassium

D1 - 15[th] September D2- 1[st] October D3- 15[th] October D4 - 1[st] November D5 - 15[th] November D6 -1[st] December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw K – Available potassium

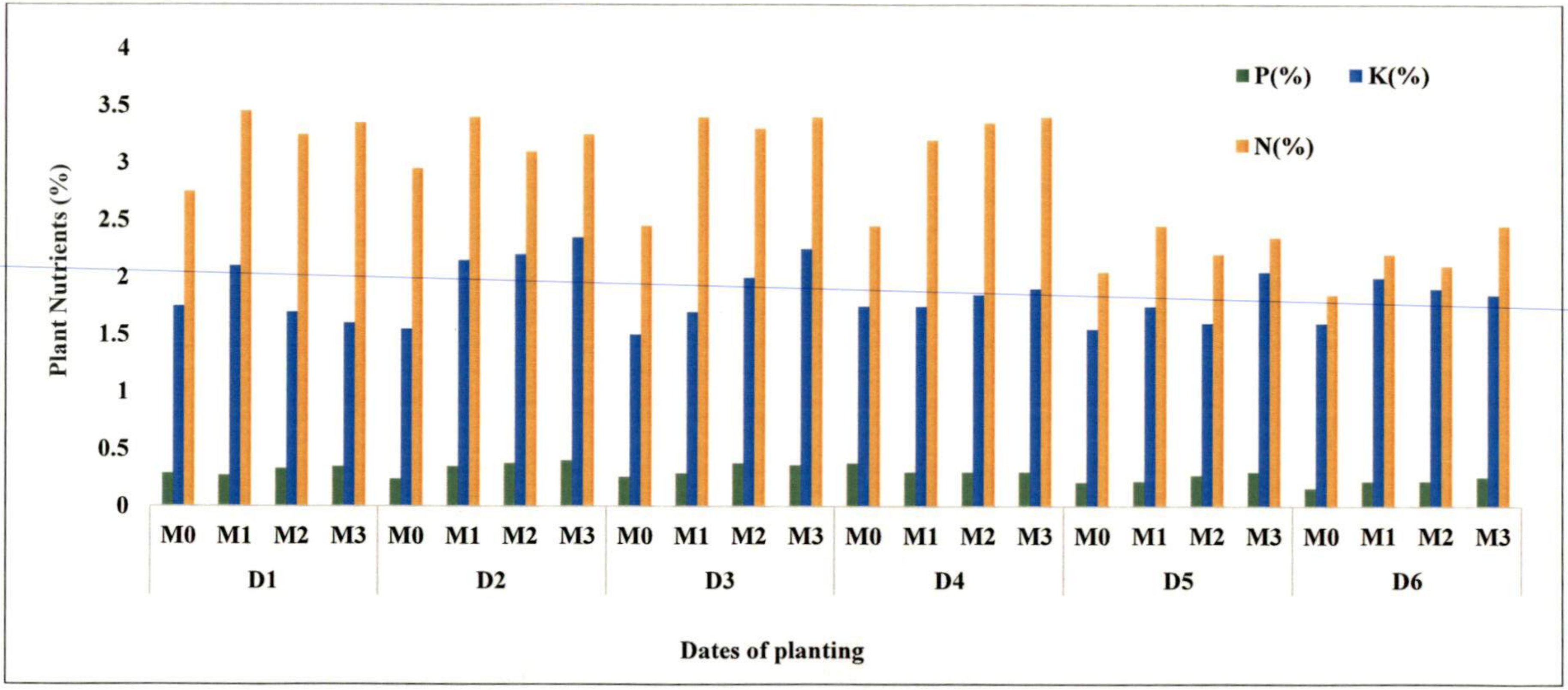

Fig. 5.13. Effect of date of planting and mulching on plant nutrients

D1 - 15th September D2- 1st October D3- 15th October D4 - 1st November D5 - 15th November D6 -1st December M0- Control

M1 - White top black bottom polythene M2 - Black top white bottom polythene M3 - Paddy straw N – nitrogen P – phosphorus K - potassium

5.3.2. Effect of date of planting and mulching on soil microbial biomass carbon

From the Table 4.9(a) and Figure 5.9. it is clear that soil microbial biomass carbon content was more in early dates of planting, as the soil moisture decreased microbial biomass carbon content also decreased in. Among the mulches and control, mulches had highest microbial biomass content. This might be due to availability of more soil moisture in mulches, which increased the microbial population. Supported by findings on Vasconcelos (2015).

5.3.3. Effect of date of planting and mulching on N, P and K

The analysis of available nitrogen, phosphorus and potassium showed that, the soil samples taken after the harvest of the crop recorded high soil nutrients compared to initial samples (Fig. 5.10, 5.11 and 5.12). The available soil nutrients (N, P and K) was does not vary between the dates of planting, whereas mulched recorded more soil nutrients compared to control. The increased availability of available nitrogen and phosphorus in polythene mulched plot might be due to the optimum soil temperature, optimum soil moisture levels, increased mineralization, reduction in nutrients leaching and lower uptake of nutrients by weeds . The results are close to findings of Singh *et al.* (2009) and More *et al.* (2014).

The increased availability of available potassium in paddy straw mulched plot might be due to addition of potassium to the soil which is present in the straw (Table 5.54). Tan *et al.* (2007) stated that the level of potassium in the straw comprised approximately 80 percent of that in the whole plant, most of which was returned to the soil, thereby increasing the K content.

5.4. PLANT PARAMETERS

5.4.1. Uptake of N, P and K nutrients by tomato

In the present investigation, it is clear that the uptake of nutrients was increased due to the addition of mulches (Table 4.10 and Fig. 5.13). This might be due to sufficient soil moisture, optimum soil temperature, reduction in nutrients leaching, nutrient utilization and reduction in the weeds competition. Similar results are obtained by Famoso and Bautista (1983) and Wein and Minotti (1987).

5.5. BIOMETRIC PARAMETERS

5.5.1. Plant height

In present study, the plant height decreased as the transplanting was delayed (Table 4.10). The highest plant height was recorded during 15th September planting and lowest during 1st December planting. From the correlation analysis, it was identified that maximum temperature, temperature range, bright sunshine hours, wind speed and evaporation had negative effect on plant height (Table 5.5(a)). While minimum temperature, relative humidity, vapour pressure deficit, rainfall and rainy days showed positive effect (Table 5.5(b)). Due to availability of longer growing period and soil moisture, and sufficient utilization of nutrients from the soil and leads to vigorous growth of the plants. The results are similar to findings of Singh *et al.* (2015) in tomato.

Table 5.5(a). Correlation coefficients between weather parameters and plant height

Tmax	DTR	BSS	WS	Epan
-0.841**	-0.879**	-0.886**	-0.919**	-0.920**

Table 5.5(b). Correlation coefficients between weather parameters and plant height

Tmin	RH I	RH II	VPD I	VPD II	RF	RD
0.898**	0.935**	0.923**	0.946**	0.938**	0.803**	0.869**

The highest plant height was recorded under black polythene mulch and followed by white polythene and straw mulch which were found to be on par (Table 4.11). The lowest plant height was observed under control (bare soil). Due to the extended retention of moisture by mulches which resulted in higher growth of plant compared to control (bare soil) . The results of present study was supported from the findings of Chakraborty and Sadhu (1994) and Hudu *et al.* (2002).

5.5.2. Yield parameters

The number of trusses per plant, number of fruits per plant, fruit yield per plant were influenced by different planting dates and mulching materials (Table 4.13 and 4.14).

The early transplanted crops produced the maximum number of trusses per plant, number of fruits per plant and fruit yield per plant as compared to late planted crop, which might be due to the availability of long period for vegetative growth and reproduction in early planted crop. In late transplanted crop, the temperature at flowering stage exceeded the optimum which might have impaired fruit set in tomato due to elongation of style, and poor pollen production which led to poor fruit set and lower fruit yield. The results are similar to the findings of Islam *et al.* (2010) and Singh *et al.* (2015).

Sufficient soil moisture, nutrient utilization and reduction in the weeds competition might be reason for more yield under mulches. The effect of mulching material on yield parameters in this present study is in agreement with Rashid *et al.* (2010), Kumar *et al.* (2012) and Bhujbal *et al.* (2015) in tomato. Represented graphically in Fig 5.1 to Fig 5.6

5.5.3. Number of weeds

The results on number of weeds showed that polythene mulches has recorded significantly lowest number of weeds and control has recorded highest number of weeds.

As polythene mulch act as physical barrier and prevents light to enter the soil, which is required for germination and nourishment of weed seeds, the number of weeds was found to be minimum. The higher number of weeds in control may be attributed to the open soil surface available to weeds for free growth. Similar results were also obtained by Ngouajio *et al.* (2008) and Schonbeck (1999).

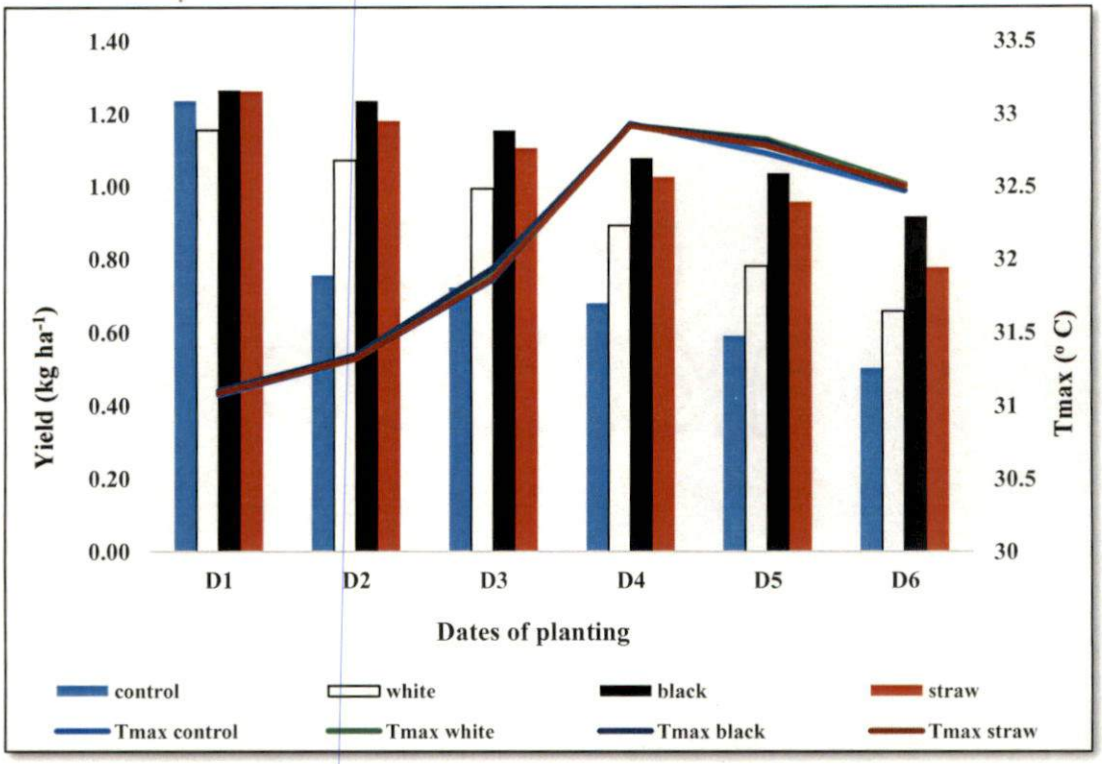

Fig 5.14 Effect of maximum temperature on yield

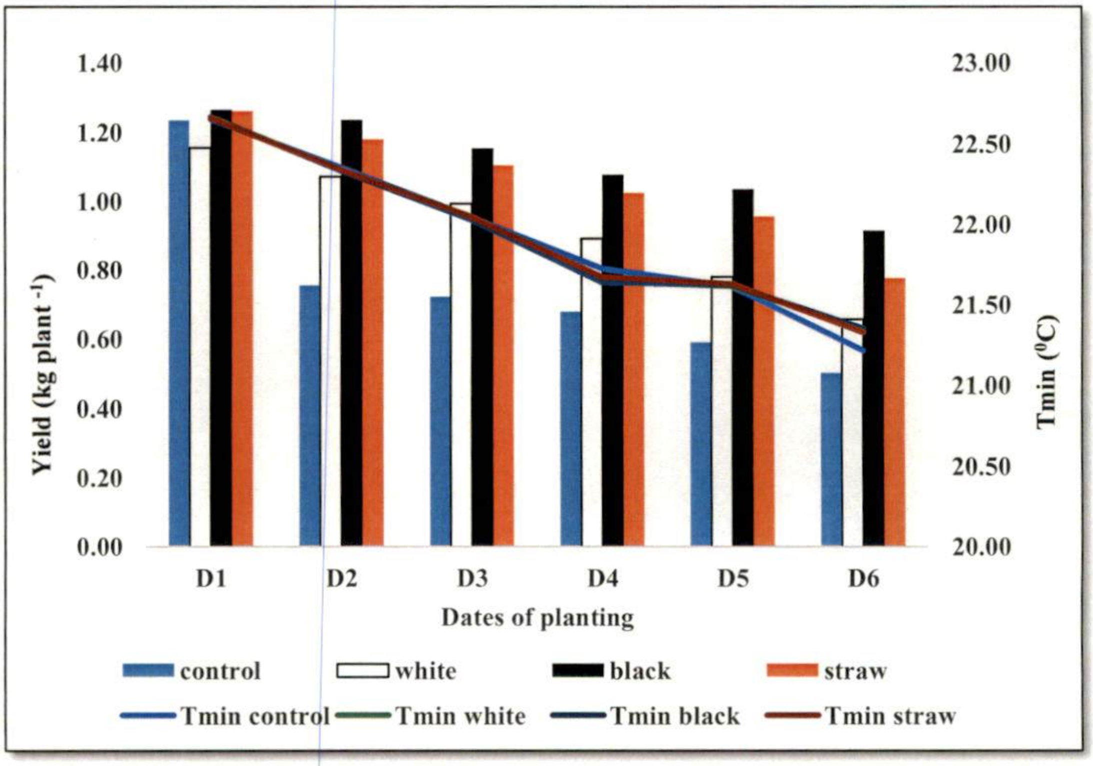

Fig 5.15 Effect of minimum temperature on yield

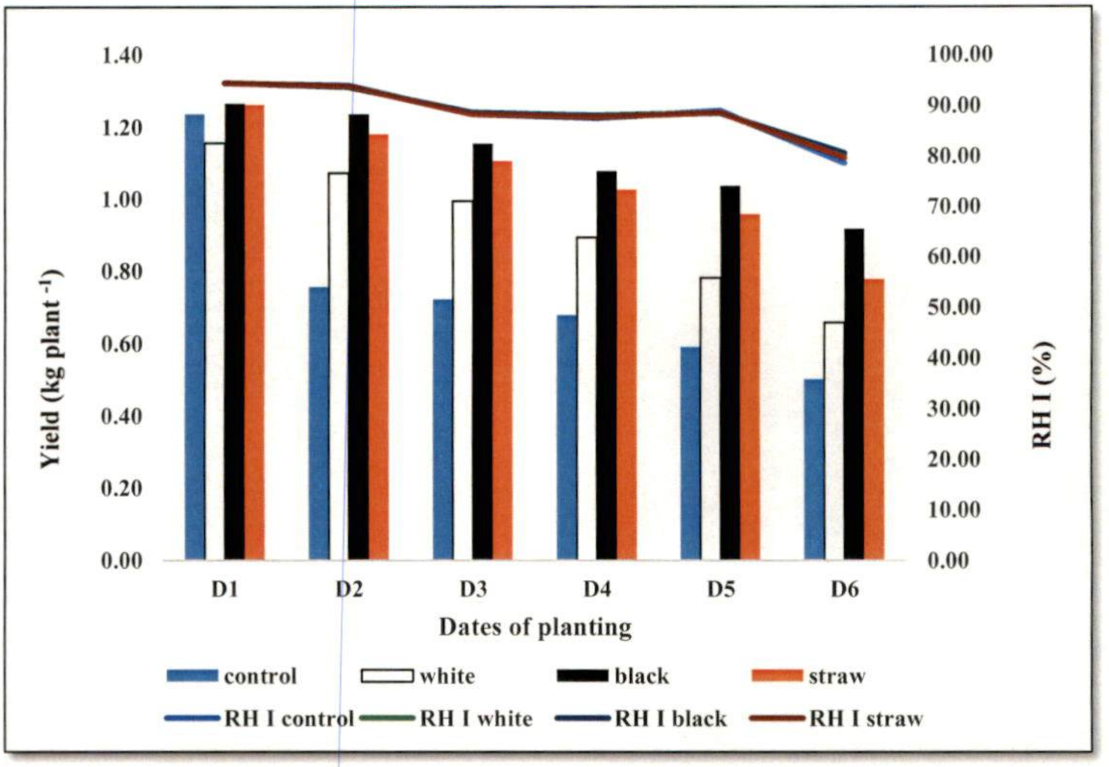

Fig 5.16 Effect of forenoon relative humidity on yield

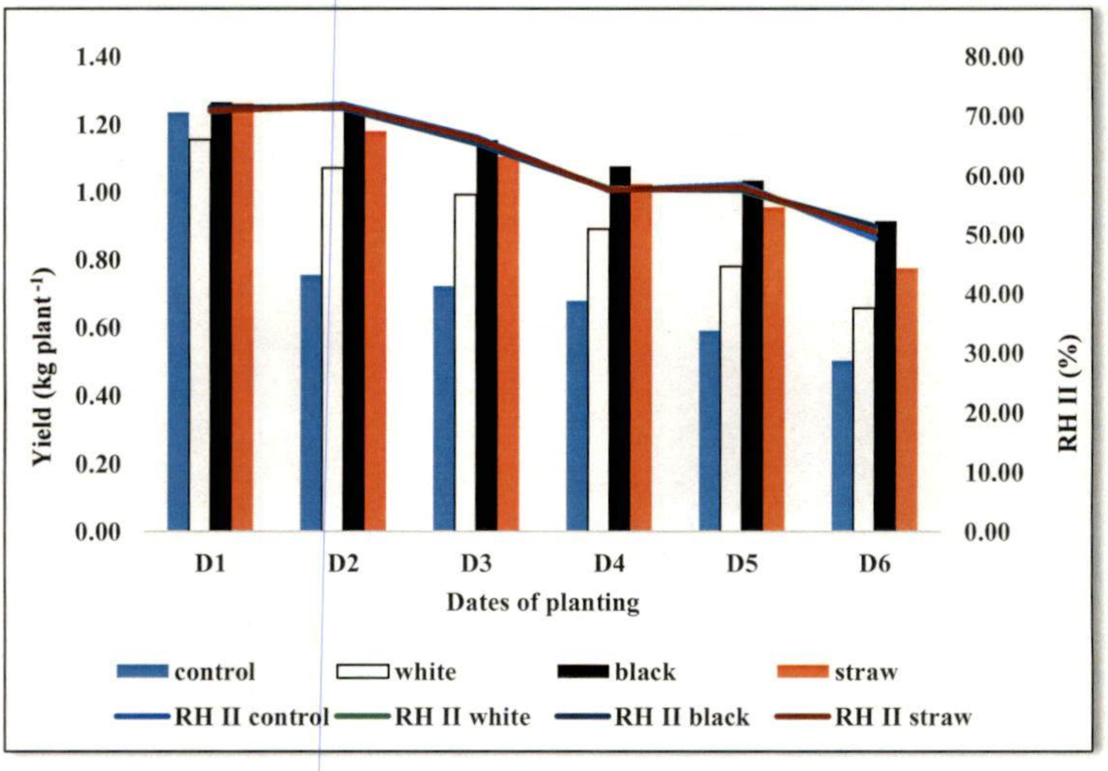

Fig 5.17 Effect of afternoon relative humidity on yield

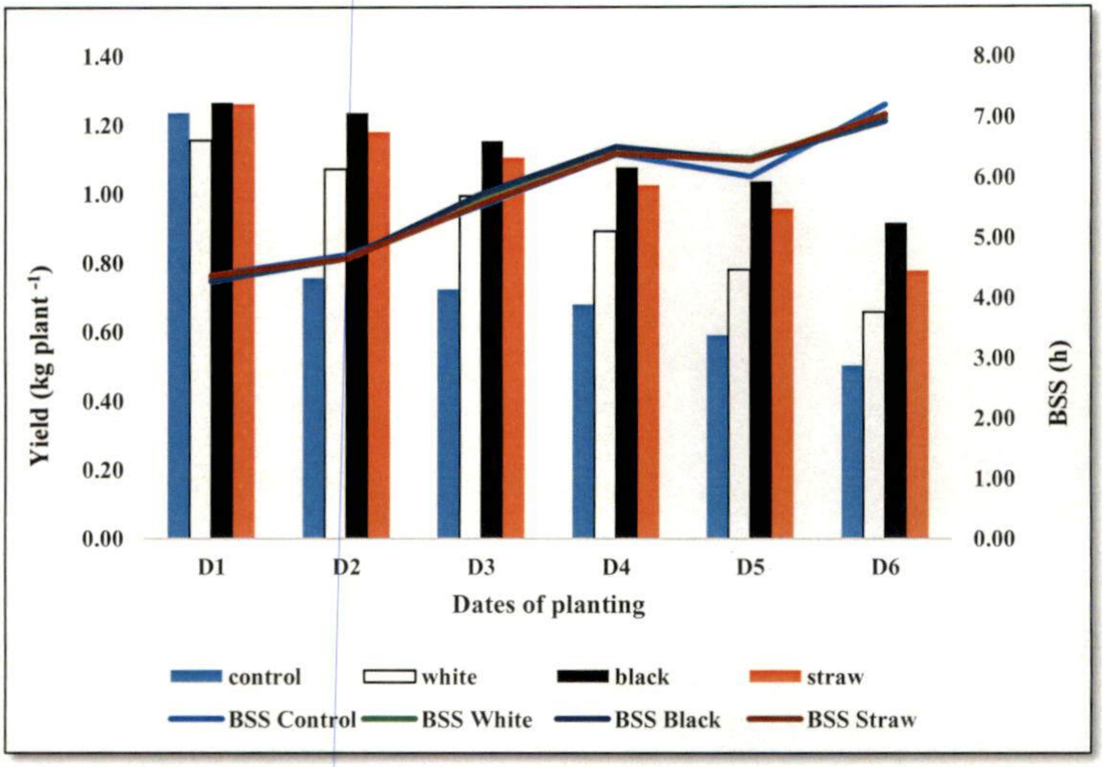

Fig 5.18 Effect of bright sunshine hours on yield

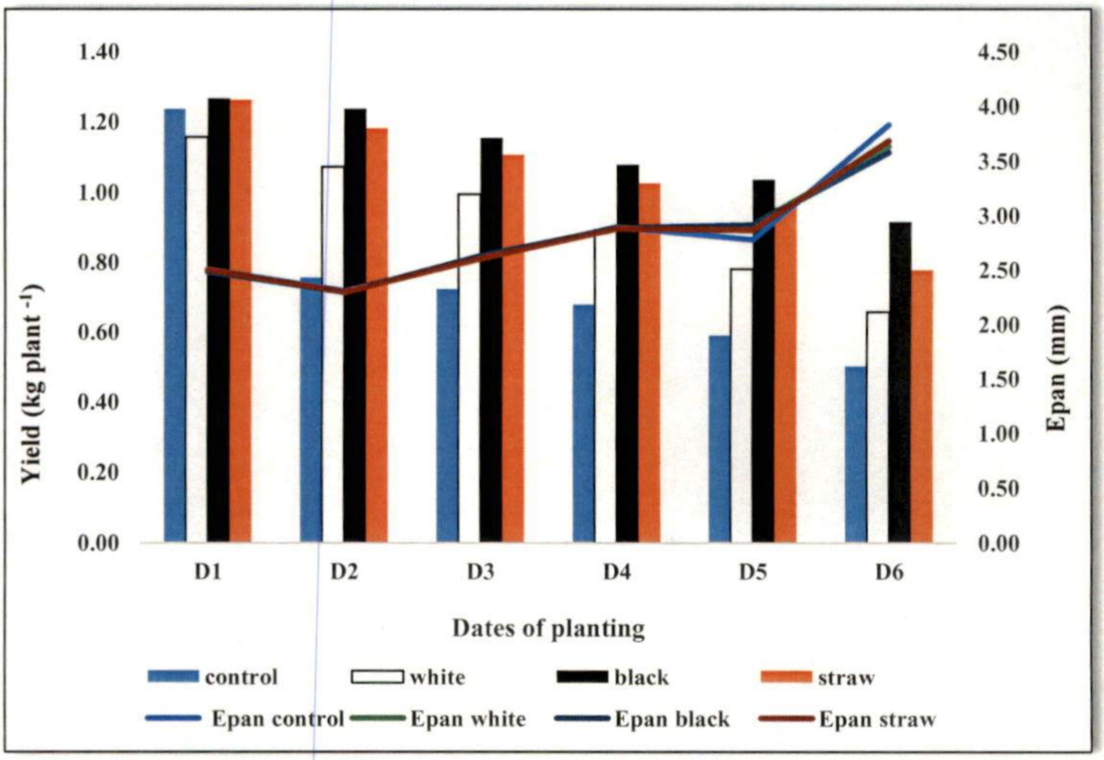

Fig 5.19 Effect of evaporation on yield

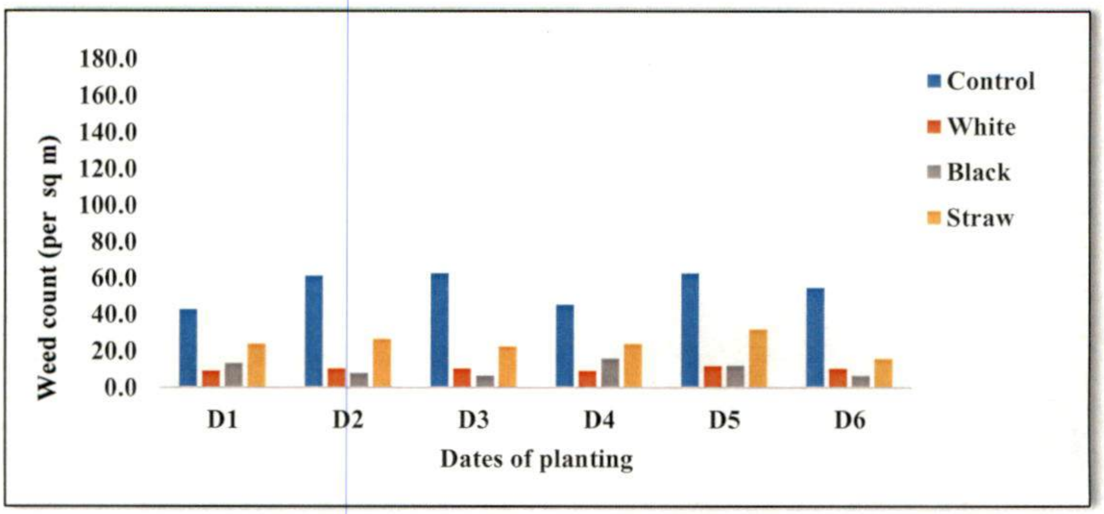

Fig. 5.20. Effect of date of planting and mulching on number of weeds at 30 days after transplanting

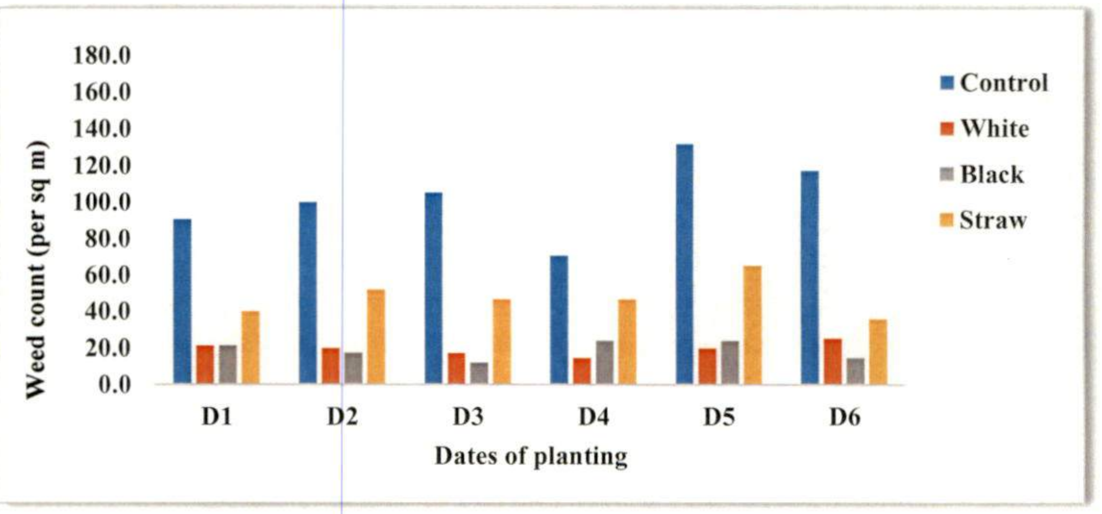

Fig. 5.21. Effect of date of planting and mulching on number of weeds at 60 days

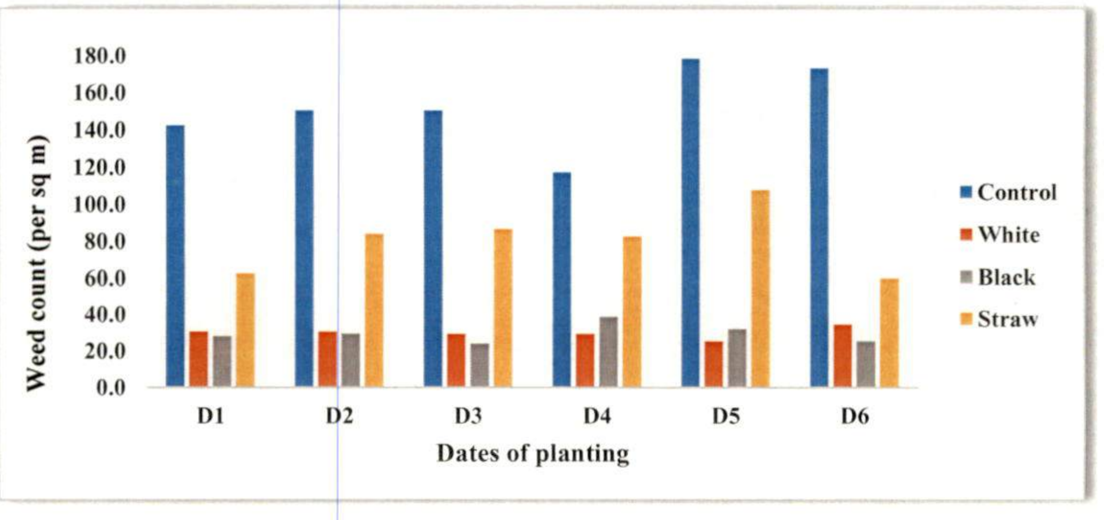

Fig. 5.22. Effect of date of planting and mulching on number of weeds at 90 days after transplanting

5.6. PHENOLOGICAL PARAMETERS

The days taken for different phenophases, flowering, fruiting, harvesting was significantly influenced by dates of transplanting and mulching. The results showed that days for different phenophases decreases for delayed plantings.

From the correlation analysis, it was identified that maximum temperature, bright sunshine hours, high wind speed and evaporation had negative effect on days to fruit setting and harvesting. Hence there was a gradual decrease in days taken for phenophases with the delay in date of transplanting. While minimum temperature, relative humidity, vapour pressure deficit, rainfall and rainy days during this period shows positive influence on the number of days taken for the phenophases. The result was supported by the findings of Samnotra *et al.* (1998).

Influence of mulches on phenophases of tomato showed that black polythene mulch recorded significantly maximum harvest duration , minimum number of days to first flowering, minimum number of days to first fruiting, while no mulch recorded minimum harvest duration, maximum number of days to first flowering, maximum number of days to first fruiting in tomato. The reason for early flowering and fruiting might be due to high temperature under black polythene mulch and extended duration was contributed by the retained high soil moisture. This results was similar to findings of Singh *et al.* (2014), Tegen *et al.* (2014), Bhujbal *et al.* (2015). Represented graphically in Fig. 5.7, 5.8 and 5.9

5.7. EFFECT OF HEAT UNITS ON YIELD AND PHENOLOGY

5.7.1 Fruit yield

The fruit yield was influenced by accumulated growing degree days, heliothermal units and photothermal units. The highest recorded accumulated growing degree days, heliothermal units and photothermal units was during 1st December planting. Lower fruit yield was observed in delayed dates of planting, due to higher accumulation of GDD, HTU and PTU during transplanting to flowering in delayed dates of planting. This result was in agreement with Sunil *et* al. (2005).

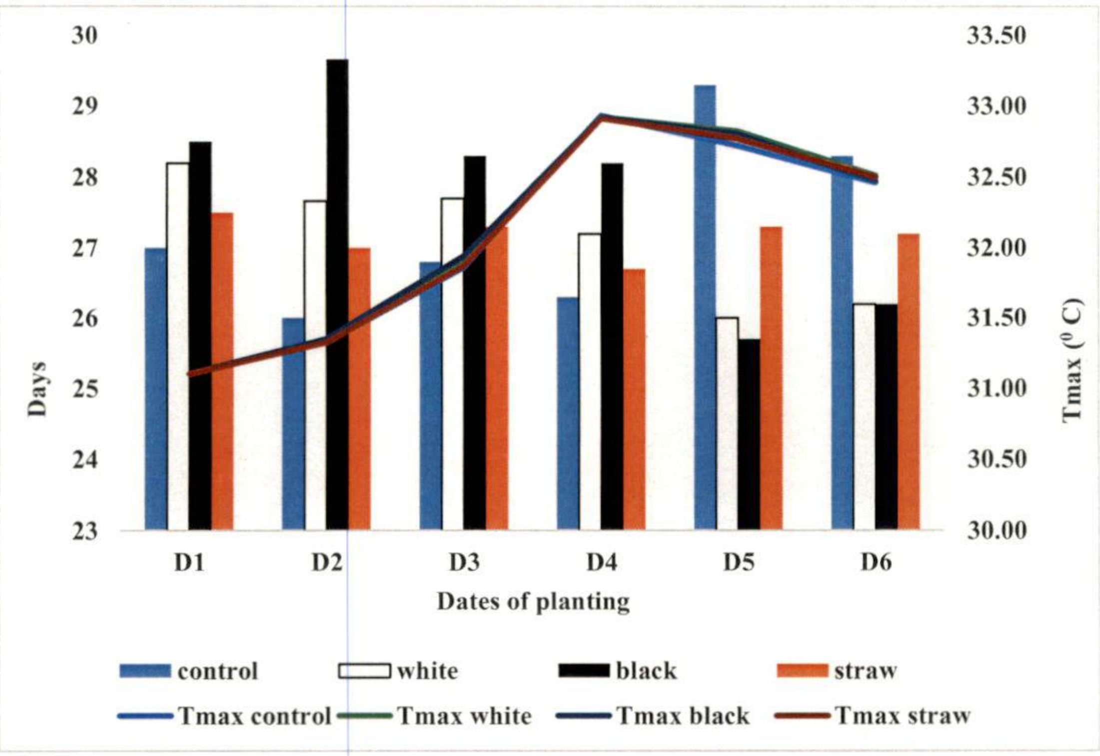

Fig. 5.23. Effect of maximum temperature on duration for flowering

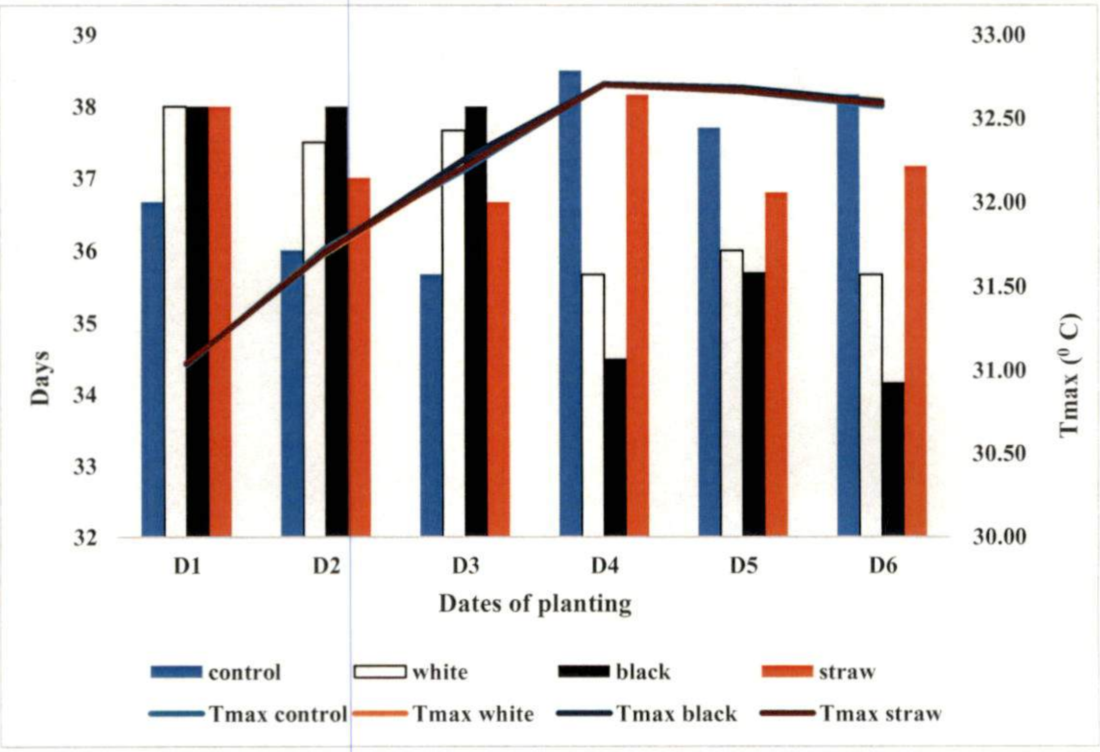

Fig. 5.24. Effect of maximum temperature on duration for fruiting

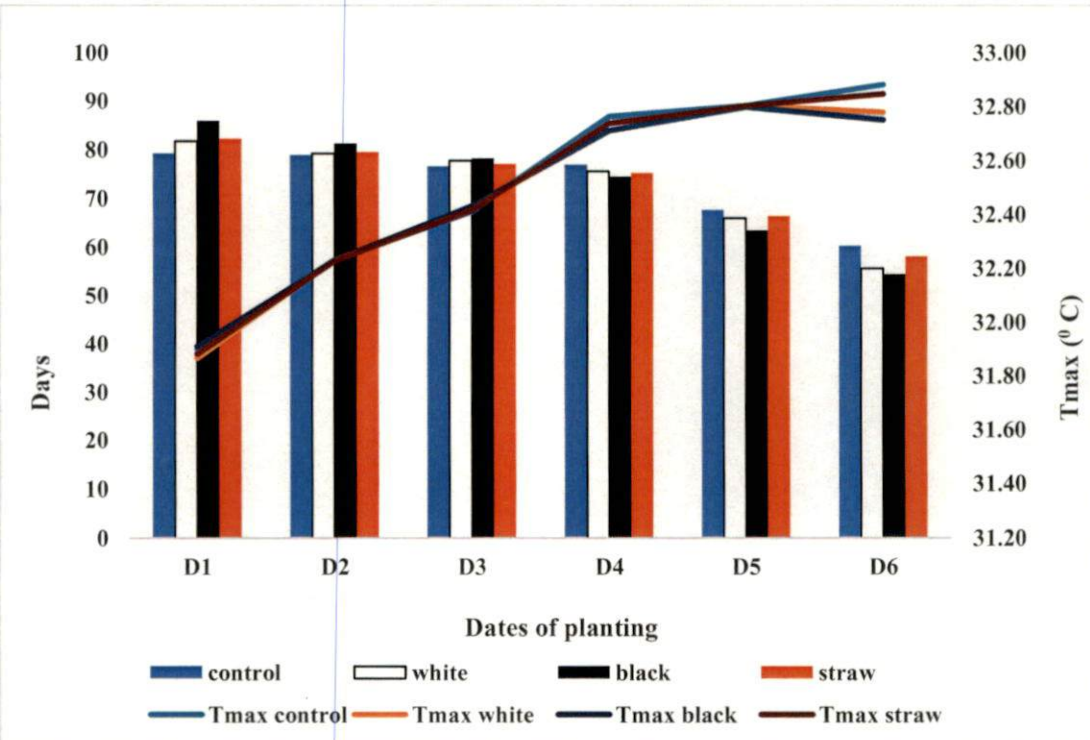

Fig. 5.25. Effect of maximum temperature on duration for harvesting

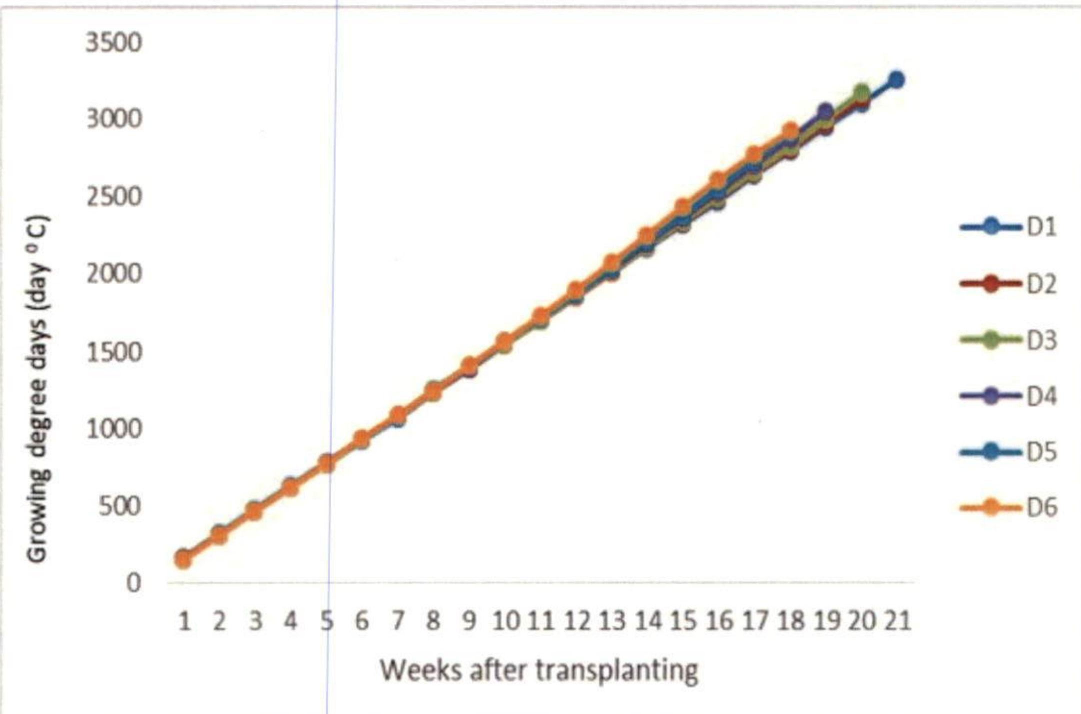

Fig. 5.26. Growing Degree days during different dates of planting

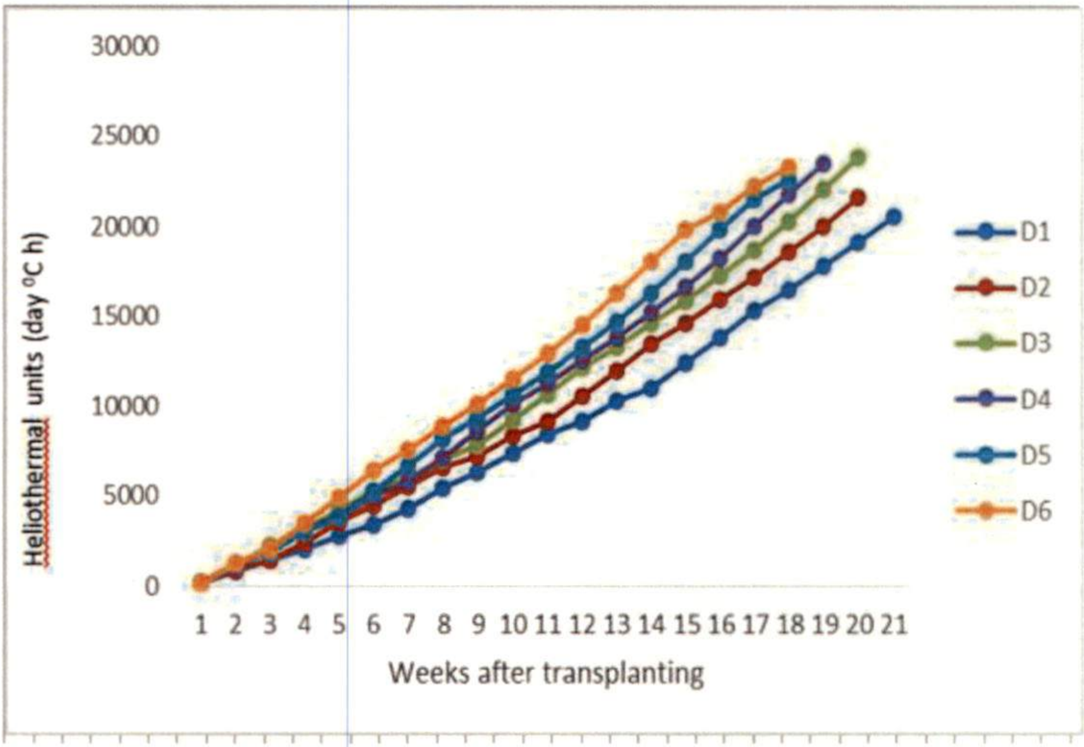

Fig. 5.27. Heliothermal units during different dates of planting

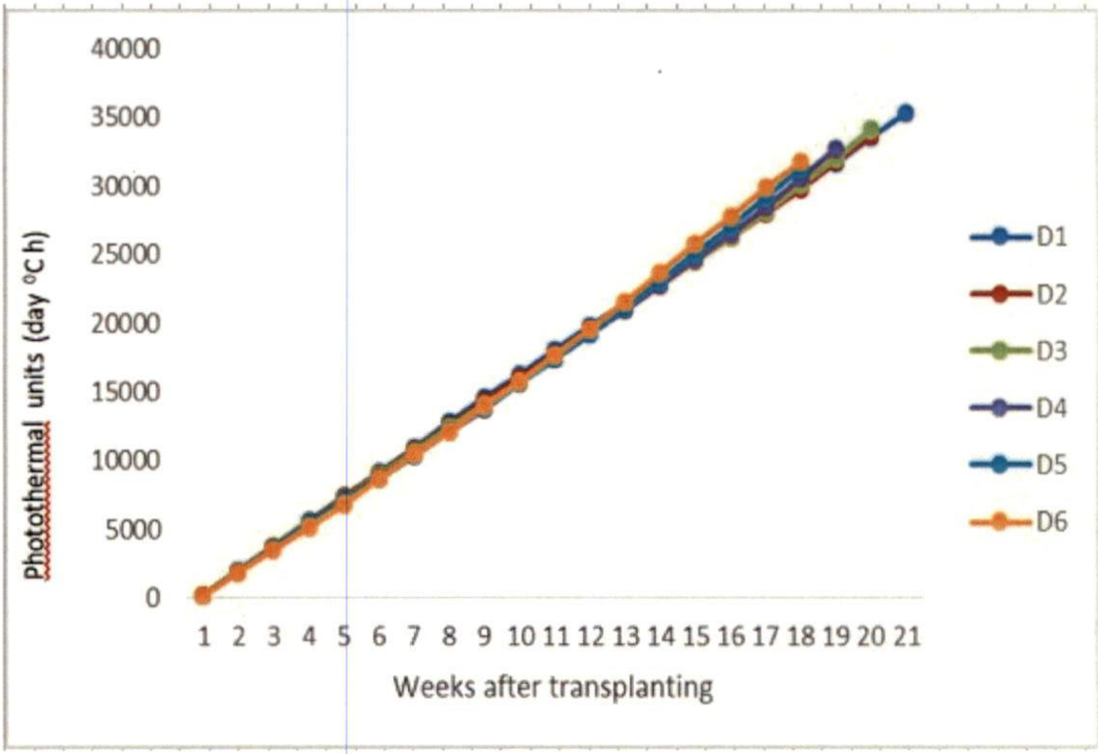

Fig. 5.28. Photothermal units during different dates of planting

5.7.2. Phenology

The duration of phenophases was influenced by accumulated growing degree days, heliothermal units and photothermal units. The highest recorded accumulated growing degree days, heliothermal units and photothermal units was during 1st December planting. Less duration for attaining maturity was observed due to higher accumulation of GDD, HTU and PTU during transplanting to flowering in delayed dates of planting. This result was in agreement with Sunil and Sarma (2005).

5.8. CROGRO - TOMATO SIMULATION MODEL

Models help farmers to make decisions in agricultural planning by prediction of rice yields at various stages of crop growth, based on weather variables. In recent years it is gaining more importance for forecasting the yields and responding to the various weather aberrations by implementation of different management practices.

The performance of the CROGRO – Tomato was tested and evaluated using the calibrated genetic coefficient for both the varieties with their respective planting dates. The results of simulation studies in respect of the effect of planting dates on important parameters of crop growth, development and yield of rice were compared with the observed values from the field experiment. The model could predict the phenophases more accurately. The Predicted yield under different planting dates reasonably closed to the observed values.

Two statistics were used to evaluate the model performances. (i) Root Mean Square Error (RMSE) and (ii) D-stat index. Willmott (1982) stated that the D-stat index value should approach unity and the RMSE approach zero for good performance of the model.

5.8.1. Fruit yield

Predicted yield in Anagha variety of tomato also was in good agreement with observed yield with an RMSE of 884 kg ha^{-1} and D–stat index of 0.149, indicating good performance of the model. The relatively higher variation in observed and simulated yield during delayed planting was attributed to solar radiation. The variable performance of the model was probably due to combination of deficiencies in model

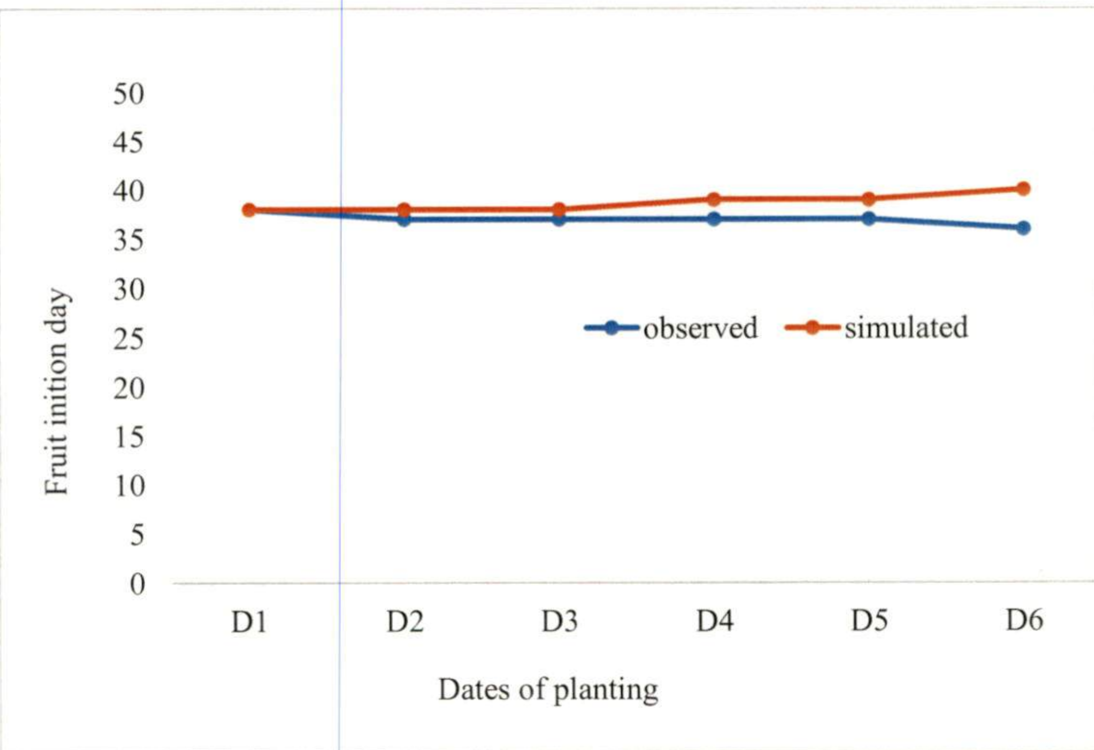

Fig. 5.29. Simulated and observed fruit initiation day

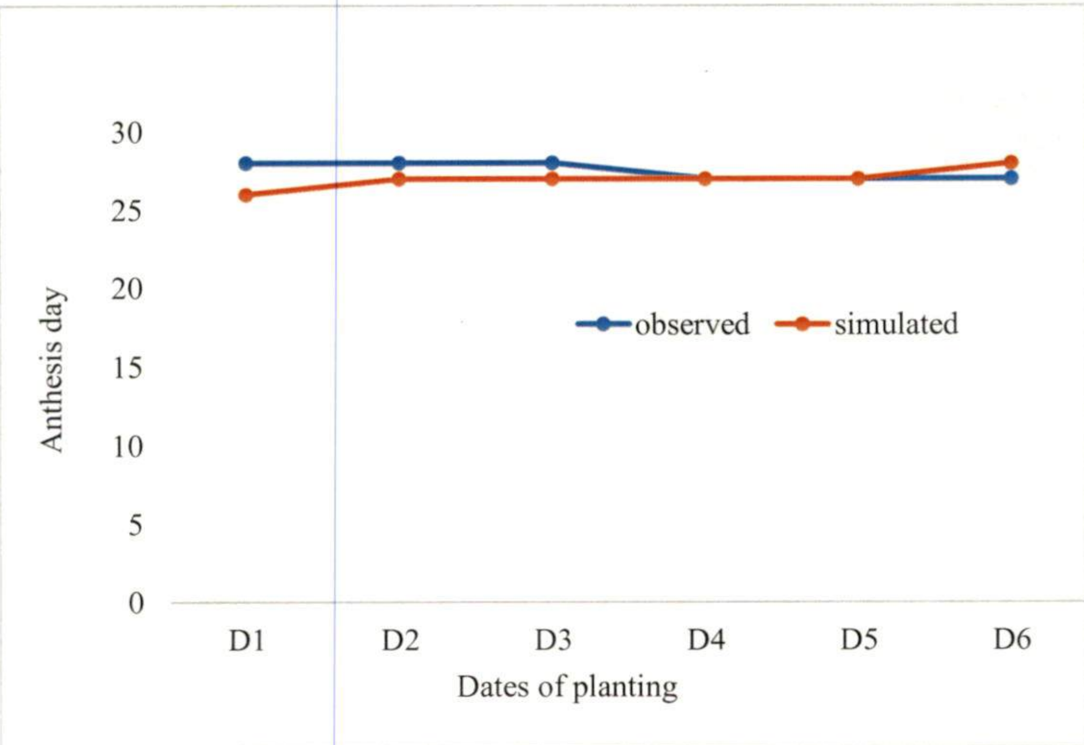

Fig. 5.30. simulated and observed anthesis day

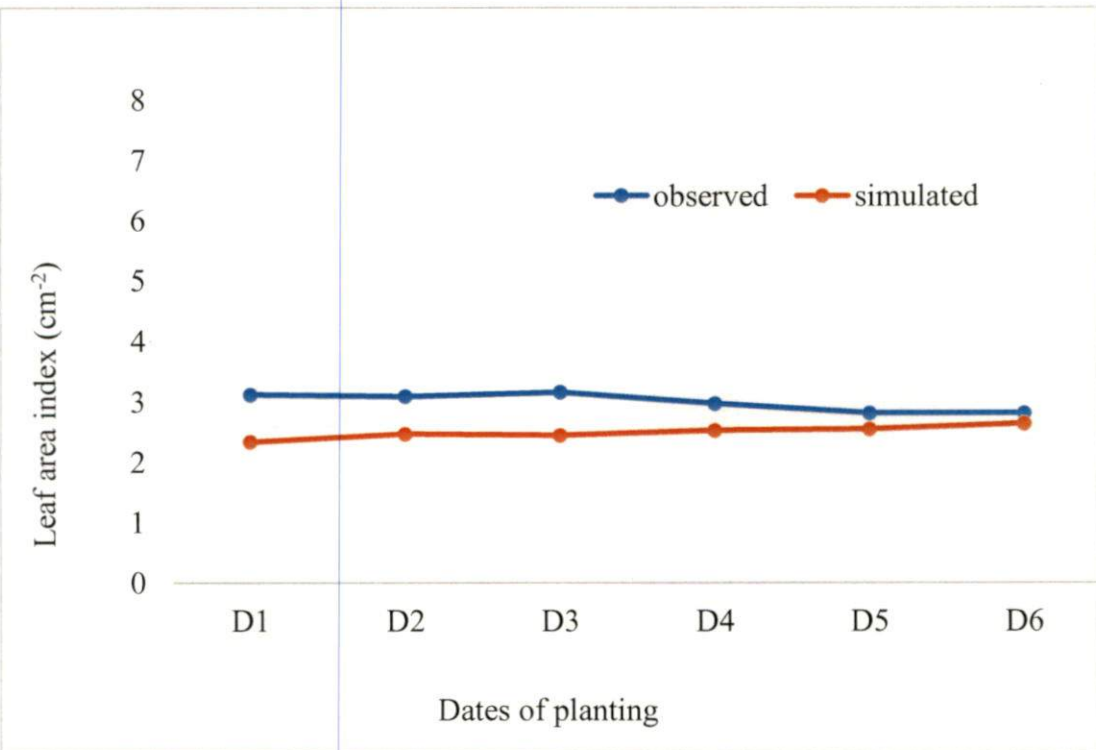

Fig. 5.31. Simulated and observed leaf area index day

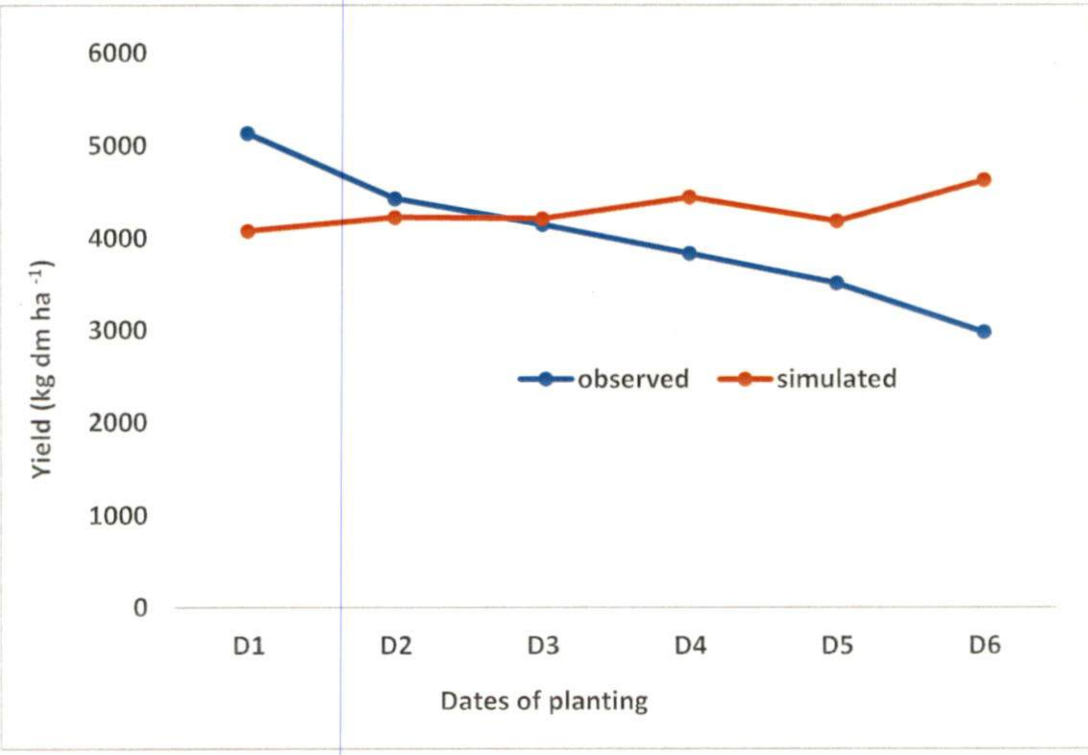

Fig. 5.32. Simulated and Observed yield

inputs, experimental observations, and inclusion of non-modeled factors such as (disease and pests) in model validation and insufficient capture of model processes.

5.8.2. Simulation of phenology

5.8.2.1. Fruit initiation day

The results showed that, conformity between observed and simulated fruit initiation day with root mean square value (RMSE) and D-stat index value of 5.4 and 0.3 respectively.

5.8.2.2. Anthesis day

There was reasonably a good agreement between observed and simulated anthesis day . The root mean square value (RMSE) and D-stat index for simulation of phenology are 3.36 and 0.37 respectively.

5.8.3. Leaf area index

There was reasonably a good agreement between actual and simulated leaf area index, an RMSE of 0.54 and D-stat index of 0.26 was obtained.

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Summary

6. SUMMARY

The study "Crop weather simulation model in tomato (*Solanum lycopersicum* L.)" was conducted at Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2017–18. The study was carried out to calibrate the genetic coefficients for tomato using DSSAT CROPGRO-Tomato model and to evaluate the micrometeorological aspects of tomato under different growing environments

Observations such as weather, micrometeorological, soil nutrients, plant nutrients, biometric and phenological data were recorded at the different stages of development of the crop. Crop weather relationship was studied. The CROPGRO model was calibrated for Anagha variety of tomato. The results obtained from the study are summarized as follows.

Weather parameters showed variations throughout the crop period. The environmental conditions were favourable for early planted crops whereas delayed planted crops experienced more heat stress and deficit soil moisture. The weather parameters *viz*., maximum temperature, temperature range, wind speed, bright sunshine hours and evaporation found to cause negative impact on growth and yield of tomato. The minimum temperature, forenoon and afternoon relative humidity, rainfall, rainy days, forenoon and afternoon vapour pressure deficit found to be positive impact on growth and yield of tomato.

The correlation between weather and phenophases duration showed that, during transplanting to first flowering and fifty percent flowering weather does not have influence on phenophases. During transplanting to first fruiting with increase in the maximum temperature, temperature range and bright sunshine hours there was a decline in the transplanting to first fruiting duration, whereas increased afternoon relative humidity, increased the transplanting to first fruiting duration. During transplanting to fifty percent fruiting with increase in the forenoon and afternoon vapour pressure deficit there was a decline in the transplanting to fifty percent fruiting duration, , whereas increased evaporation, increased the transplanting to fifty percent fruiting duration. During transplanting to harvesting with increase in the maximum temperature, temperature range, wind speed, bright sunshine hours and evaporation there was decline in the transplanting to harvesting duration, whereas with increase in the minimum temperature, forenoon and afternoon relative humidity, rainfall, rainy days, forenoon and afternoon vapour pressure deficit duration of transplanting to harvesting increased.

Soil temperature showed increasing trend towards last plantings. Mulches were more effective in increasing soil temperature due to greater net radiation. Soil under black top white bottom polythene recorded highest temperature, followed by white top black bottom polythene and straw mulch. Lowest soil temperature was recorded for control.

Soil moisture declined towards last dates of planting. Mulches were more efficient in retaining the soil moisture throughout the crop period. Soil under black top white bottom polythene recorded highest moisture, followed by white top black bottom polythene and straw mulch. Lowest soil moisture was recorded for control. The increased moisture content in mulches was due to adequate soil cover provided by the mulches.

Due to the optimum soil temperature, optimum soil moisture levels, reduction in nutrients leaching and lower uptake of nutrients by weeds, the soil and plant nutrients were found to be more under mulches compared to control. Among the mulches straw mulch recorded the highest soil and plant nutrients, followed by black top white bottom and white top black bottom polythene.

Due to availability of longer growing period and soil moisture, and sufficient utilization of nutrients from the soil which leads to vigorous growth, the plant height was more in early date of plantings. Among the mulches black top white bottom mulch recorded highest plant height followed by white top black bottom polythene and straw mulch. Plants under control recorded less plant height due to less nutrient availability, heat and moisture stress.

The yield parameters number of trusses per plant, number of fruits per plant and fruit yield per plant were influenced by different planting dates and mulching materials. The early transplanted crops recorded more number of trusses per plant, number of fruits per plant and fruit yield per plant as compared to late planted crop. Due to the extended retention of moisture by mulches and sufficient utilization of nutrients from the soil the yield parameters were high for the plants under black top 192 white bottom mulch, followed by white top black bottom polythene and straw mulch. Due to high evaporation, weeds competition and soil moisture stress yield parameters found to be less in control.

As polythene mulch act as physical barrier and prevents light to enter the soil, which is required for germination and nourishment of weed seeds, the number of weeds was found to be minimum in mulched plots. The higher number of weeds in control may be attributed to the open soil surface available to weeds for free growth.

Duration taken for each phenophase was found to be different for each dates of planting and mulches. Phenophases duration decreased with increase in the temperature, hence the total duration was found to be more for early dates of planting, which experienced the less heat stress compared to last dates of planting. The minimum temperature, high relative humidity, vapour pressure deficit and rainfall was found to be positive influence on phenophases, whereas maximum temperature, temperature range, wind speed, bright sunshine hours and evaporation found to be negative influence on phenophases.

The fruit yield and duration of phenophases were influenced by accumulated growing degree days, heliothermal units and photothermal units. The highest recorded accumulated growing degree days, heliothermal units and photothermal units was during 1st December planting. Hence lower fruit yield and less duration for attaining maturity was observed in last dates of planting.

From the investigation on micromteorological aspects of tomato under different growing environments it can be concluded that, there is an influence of mulches on the growth, development and yield of tomato especially during dry conditions. The study revealed that yield of black top white bottom polythene mulch was found to be on par with plants under straw mulch. Since straw mulch was found equally efficient in increasing the yield like plastic mulches and by considering the green protocol, use of plastic mulches can be reduced and organic mulches can be encouraged to enhance the growth and yield of tomato.

Simulated anthesis day and fruit initiation day showed satisfactory agreement with observed values with an RMSE (root mean square error) 2.88 and 4.7 and D-stat index of 0.2 and 0.35 respectively indicating good performance of the model. Model

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overestimated the yield compared observed yield with an RMSE (root mean square error) 884.64 and D-stat index of 0.1. Simulated leaf area index showed satisfactory agreement with observed values with an RMSE (root mean square error) 0.5 and D-stat index of 0.26 indicating good performance of the model.

From the study on calibration of genetic coefficients of tomato using DSSAT CROPGRO model it can be concluded that, crop simulation models are efficient in simulating the growth and yield of tomato. The calibrated genetic coefficients can be used to predict growth and yield of tomato of any location by using the standard input files for weather and soil condition as well as crop management.

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Appendix

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

Trange : Diurnal temperature range

RH I : Forenoon relative humidity

RH II : Afternoon relative humidity

VPD I : Forenoon vapour pressure deficit

VPD II : Afternoon vapour pressure deficit

RF : Rainfall

RD : Rainy days

WS : Wind speed

BSS : Bright sunshine hours

Epan : Pan evaporation

Treatments

D1 : First date of planting

D2 : Second date of planting

D3 : Third date of planting

D4 : Fourth date of planting

D5 : Fifth date of planting

D6 : Sixth date of planting

M0 : Control (without mulch)

M1 : White top black bottom polythene

M2 : Black top white bottom polythene

M3 : Straw mulch

Heat units

AGDD : Accumulated rowing degree days

AHTU : Accumulated helio thermal unit

APTU : Accumulated photo thermal unit

Units

kg ha^{-1} : kilogram per hectare

kg dm^{-1} ha^{-1} : kilogram drymatter per hectare

kg C ha^{-1} : kilogram carbon hectare

kg : kilogram

% : percent

km h^{-1} : kilometre per hour

mm : millimetre

^{0}C : degree celsius

°C day h : degree celsius hour

Others

DAT - Days after transplanting

LAI –Leaf area index

MBC – Microbial biomass carbon

(ii) Appendix II

Anova of different plant growth characters

Plant height at 15 days interval after transplanting

Source of Variation	DF	Mean sum of squares						
		15DAT	30DAT	45DAT	60DAT	75DAT	90DAT	105DAT
Dates of planting (A)	5	312.28**	559.71**	807.22**	739.66**	2421.74**	3754.75**	4281.75**
Error(a)	10	3.07	13.00	8.861	17.41	32.73	29.5	25.24
Types of mulch (B)	3	1.73^{NS}	205.30**	241.18**	300.14**	201.01**	190.66**	167.9**
Interaction A X B	15	6.72**	7.42^{NS}	13.22**	9.83**	13.988**	11.20^{NS}	9.46^{NS}
Error(b)	36	2.48	5.04	2.875	3.56	4.874	6.44	5.08

Biometric parameters

Source of Variation	DF	Mean sum of squares					
		No of trusses	No of fruits	yield	Number of weeds		
					30DAT	60DAT	90DAT
Dates of planting (A)	5	1583.34**	130.78**	0.38**	102.93^{NS}	622.62^{NS}	611.02^{NS}
Error(a)	10	12.02	9.61	0.01	149.20	322.089	285.55
Types of mulch (B)	3	16.62^{NS}	554.9**	0.46**	7906.0**	27782.14**	60427.8**
Interaction A X B	15	3.97^{NS}	20.95**	0.02**	89.89^{NS}	387.83*	634.96*
Error(b)	36	7.83	7.43	0.006	51.926	151.778	319.55

Phenological parameters

Source of Variation	DF	Mean sum of squares					
		1st flowering	50% flowering	1st fruiting	50% fruiting	Harvesting	Duration
Dates of planting (A)	5	1.39*	5.31**	2.83**	25.42**	1110.15**	1070.42**
Error(a)	10	0.27	0.34	0.26	0.66	15.44	5.14
Types of mulch (B)	3	0.92*	1.19^{NS}	2.95**	0.12^{NS}	1.24^{NS}	578.71**
Interaction A X B	15	4.44**	12.47**	5.35**	10.93**	11.83**	2.13^{NS}
Error(b)	36	0.26	0.51	0.20	1.00	1.22	1.32

ABSTRACT

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CROP WEATHER SIMULATION MODEL IN TOMATO
(*Solanum lycopersicum* L.)

By

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(2016-11-119)

ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL METEOROLOGY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

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2018

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is known as protective food because of its special nutritive value and wide spread production. Planting time is one of the most important factors among the various cultural practices followed for the production of tomato that greatly influence its growth and yield. Weather parameters play an important role in the growth and yield of tomato. The crop is sensitive to both low and high temperatures. Moisture stress is one of the major problems for the cultivation of tomato, which affects the production adversely. Hence much attention has to be paid on the use of soil cover.

The present investigation "Crop weather simulation model in tomato (*Solanum lycopersicum* L.) " was carried out in the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2017-18, to calibrate the genetic coefficients for tomato using DSSAT CROPGRO-Tomato model and to evaluate the micrometeorological aspects of tomato under different growing environments. The field experiment was conducted at the STCR plot, College of Horticulture, Vellanikkara during September (2017) to March (2018). Split plot design was adopted with six dates of planting *viz*., 15th September, 1st October , 15th October, 1st November, 15th November and 1st December as the main plot treatments and three types of mulches *viz*., black top white bottom, white top black bottom polythene, straw mulch and control as the sub plot treatments. The number of replications for the experiment was three.

The daily weather parameters like maximum and minimum temperatures, forenoon and afternoon relative humidity, bright sunshine hours, pan evaporation, wind speed, rainfall and number of rainy days were recorded during the entire crop growing period, to determine the crop weather relationship.

The daily soil temperature determined during the crop growing period showed increasing trend towards the late plantings, whereas weekly soil moisture showed decreasing trend towards late plantings. Black top white bottom polythene retained highest soil temperature and soil moisture.

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Soil pH, organic carbon and microbial biomass carbon were found to be lowest in control when compared to mulched plots. The analysis of available nitrogen, phosphorus and potassium showed that, the soil samples taken after the harvest of the crop recorded high soil nutrients compared to initial samples. The available soil nutrients (N, P and K) was does not vary between the dates of planting, whereas mulched recorded more soil nutrients compared to control. The increased availability of available nitrogen and phosphorus in polythene mulched plot due to the optimum soil temperature, optimum soil moisture levels, increased mineralization, reduction in nutrients leaching and lower uptake of nutrients by weeds. The increased availability of available potassium in paddy straw mulched plot might be due to addition of potassium to the soil which is present in the straw.

In the present investigation, it is clear that the uptake of plant nutrients (N, P, K) was increased due to the addition of mulches, due to sufficient soil moisture, optimum soil temperature, reduction in nutrients leaching, nutrient utilization and reduction in the weeds competition.

The maximum height of the plants was found to be highest during 15th September and lowest during 1st December planting. Plant height was high in the mulched plots when compared to the control.

The number of trusses per plant for first three plantings were found to be high, whereas it was low in last two plantings. The number of fruits per plant was high in first four plantings and was lowest in last planting. The plants under black top white bottom polythene recorded highest and control recorded lowest number of fruits per plant. The mean yield of 15th September planting was highest and lowest was recorded in control. Yield was high in plants with black top white bottom polythene and straw mulch and were on par. Low number of weeds were recorded in mulched plots, compared to control. The analysis of correlation between weather and yield parameters showed that with increase in the minimum temperature, relative humidity, rainfall and rainy days, yield increased whereas, with increase in the maximum temperature, wind speed, bright sunshine hours and evaporation the yield decreased.

Number of days taken for different phenophases *viz.,* first flowering, fifty percent flowering, first fruiting, fifty percent fruiting, harvesting and total duration decreased towards last planting. The duration of the plants with mulches showed long duration compared to control. The correlation between weather and phenophases was significant.

The fruit yield and duration of phenophases were influenced by accumulated growing degree days, heliothermal units and photothermal units. The highest recorded accumulated growing degree days, heliothermal units and photothermal units was during 1st December planting. Hence lower fruit yield and less duration for attaining maturity was observed in last dates of planting.

The crop genetic coefficients that influence the occurrence of developmental stages in the CROGRO – Tomato model were calibrated, to achieve the best possible agreement between the simulated and observed values. Predicted yield, phenology and leaf area under different planting dates were reasonably close to the observed values.

Thus, the study revealed that there is an influence of mulches on the growth and yield of tomato especially in dry conditions. By modifying the micrometeorological conditions, the yield of the tomato can be enhanced during off season. Crop simulation models are efficient in simulating the growth and yield of tomato.