MODELING THE IMPACT OF CLIMATE CHANGE ON GROWTH AND YIELD OF TOMATO

By

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(2010-20-114)

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VELLANIKKARA, THRISSUR – 680656

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THESIS

Submitted in partial fulfillment of the requirement

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Kerala Agricultural University, Thrissur

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

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2015

DECLARATION

I hereby declare that the thesis entitled **"Modeling the impact of climate change on growth and yield of tomato"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled**'Modeling the impact of climate change on growth and yield of tomato.'**is arecord of research work done independently by Ms. Safia.M. (2010-20-114) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

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DEDICATED TO MY GRAND FATHER

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ABBREVIATIONS

AR5	Assessment Report 5
AVRDC	Asian Vegetable Research Development Center
CT	Canopy Temperature
CATD	Canopy Air Temperature Difference
CD	Critical Difference
CERES	Crop Estimation through Resource and Environment Synthesis
DSSAT	Decision Support System for Agro technology Transfer
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDD	Growing Degree Days
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
IPCC	Inter government panel on Climate Change
KAU	Kerala Agricultural University
LAI	Leaf area index
NS	Non-significant
OF	Open field
PH	Polyhouse
RS	Rain shelter
RH-I	Morning Relative humidity
RH-II	After noon Relative humidity
RMSE	Root Mean Square error
RCP	Representative Concentration Pathway
STmax	Maximum soil temperature
STmin	Minimum soil temperature

SM	Soil moisture
T_{max}	Maximum temperature
T_{min}	Minimum temperature
UV-B	Ultra Violet radiation
PAR	Photosynthetically Active Radiation

Introduction

1. INTRODUCTION

Tomato is the world's largest vegetable crop. It is one of the most important vegetable crops cultivated for its fleshy fruits and it is considered as important commercial and dietary vegetable crop. The estimated area and production of tomato for India are about 3, 50, 000 hectares and 53, 00, 000 tons respectively. The average productivity of tomato in our country is nearly 15.1 tons per hectare. Its successful production in the tropics is, however, constrained by environmental variations especially under open field conditions. The rising temperatures and carbon dioxide concentration and uncertainty in rainfall associated with climate change may have serious direct and indirect consequences on crop production and hence food security.

According to the Inter-Governmental Panel on Climate Change (IPCC, 2014) there is a general reduction of potential crop yields and a decrease in water availability for agriculture and population in many parts of the developing world. The main drivers of agricultural response to climate change are biophysical effects and socioeconomic factors. There is a biophysical effect on crop production by changing the meteorological variables, including rising temperatures, changing precipitation patterns and increasing levels of CO_2 (Mc Carthy *et al,* 2001). Potentially changing climates will have considerable impact upon horticultural processes and productivity across the globe. Biophysical effects of climate change on agricultural production depend on the regional as well as agricultural system, and the effects vary over time. In fact, the increase of temperature limits crop yield by accelerating the plant development, affecting the floral organs and fruit formation and the functioning of photosynthetic apparatus.

The rate of global warming is expected to continue increasing if no mitigation efforts take place to reduce the carbon intensity of the world economy and the consequent emission of green-house gases (Raupach *et al*., 2007). Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010). Increasing atmospheric greenhouse gas concentrations are expected to induce significant climate change over the next century and beyond, but the impacts on society remain highly uncertain (Chavas, *et al.,* 2009). The agriculture sector is already under pressure for increasing food demand, problems associated with agricultural land and water resource depletion. The issues of climate change make the pressure more acute for the sector.

There is a wide gap between potential and actual yield of tomato and the growth and yield 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. Various models are used in farm decision making, analyzing for strategic planning, making production management decisions, analyzing policies and defining research needs. DSSAT V 4.5 -CROPGRO module for tomato was used to validate the growth, development and yield of tomato as well as predict the future yield under the different scenarios.

Considering all these factors, the present study has been taken up with the following objective,

- Modeling of growth and yield of tomato.
- The impact of climate change based on projected climate change scenarios using DSSAT model.

Review of literature

2. REVIEW OF LITERATURE

The growth and yield of any crop is highly associated with environmental factors. Interactions between crop and weather are the backbone for the productivity and stabilized yield. Climate change alters weather conditions considerably which is sufficiently evident from observations all around the world. Climate change alters weather variables and there by affect the production of tomato. General Circulation Models (GCMs) are very useful in predicting the future climate. Crop weather simulation models with the help of GCMs can estimate the impact of future climate conditions on production of tomato. In this chapter we are going to review the effect of different weather variables on tomato and how the climate change is altering weather and its impact on the production of tomato is being reviewed.

2.1 MORPHOLOGICAL PARAMETERS

2.1.1 Plant height

Plants grown under greenhouse grew more vigorously than in open field. They exhibited greater plant height due to cellular expansion and cell division under shaded condition (El- Aidy *et al*., 1988). Lal *et al,* (1991) reported the highest mean plant height of 98.30 cm in Plant-74 and the lowest mean of 50.09 cm in cultivar Azad Kranti in tomato.

Abou-Hadid *et al,* (1994) reported that tomato plants grown under tunnels in Egypt showed a highly significant plant height in various stages of development against open condition. Arin and Ankara, (2001) reported 643.72 per cent increase in height at the planting time in tomato plants grown under low tunnel than those grown without tunnel in which it was 602.87 per cent.

Tomato crop grown under greenhouse condition attained more plant height of 84.10 cm against 69.03 cm in the open field (Ganesan and Subashini., 2001). Plant height of tomato was found to be higher under polyhouse condition compared to open field condition during both kharif and summer seasons (Anbarasan, 2002). Tomato plants grown under plastic tunnels of any gauge had more plant height compared to uncovered plants (Kumar and Srivastava. 2002).

The tomato plants grown under shade exhibited better growth in terms of plant height and dry matter production compared to those in open field (Thangam *et al*., 2002). Sethi *et al*, (2003) reported that growth of muskmelon inside greenhouse was much higher as compared to open field. It was observed that the average growth rate of inside plants was 4mm per day whereas it was 2mm per day for outside plants.

2.1.2 Leaf Area index

Leaf area index is a major determinant of crop growth rate and temperature is the main determinant of leaf area development (Watson, 1952).

High temperature increased the rate of the leaf initiation and appearance (Milthrope., 1959). De konning, (1988) and Huevelink, (1999) found LAI values as low as 1.5°C or 2.0°C in summer. De kreiji, (1955) reported that in tomato, high humidity in winter or early spring caused low leaf area, which negatively influenced production.

In a work reported by Heuvelink, (1989) day temperature was more important than night temperature in determining leaf area in tomato. At leaf are index of 3, an indeterminate tomato crop intercepts theoretically about 90 per cent of incident light. (Cavero *et al*., 1998).

Scholberg *et al*, (2000) reported that polyhouse tomato had higher leaf are index of 5.94 in both summer and kharif season whereas it was only 4.26 and 4.31 respectively under open field condition at 60 days after transplanting. For optimum light interception and fruit yields of a field grown tomato crop, the LAI should be around 4 to 5. Lower LAI value would reduce light interception and increase yield loss due to sunburn while higher values may delay the onset of fruit production. (Scholberg *et al*., 2000).

Low LAI resulted in reduction of crop photosynthesis and yield (Heuvelink *et al*., 2005). The strong assimilate demand by the growing fruits at higher temperatures reduced leaf growth in greenhouse (Huevelink and Dorais, 2005). The amount of intercepted light is a predominant factor in tomato crop growth and biomass production and depends mainly on leaf area. This relationship can be described as a negative exponential function of leaf area index. Low light levels observed in late autumn (October and November) and changes in crop light interception as influenced by leaf area development may also reduce growth rate (Huevelink and Dorais, 2005).

2.2 PHENOLOGICAL CHARACTERS

2.2.1 Days to flower

Grimstad, (1995) indicated that low temperature delayed flowering. Ho, (1996) observed that under low light conditions, initiation of first inflorescence is delayed in tomato, as more leaves are initiated prior to the inflorescence. In an indeterminate plant, temperature affects floral initiation, floral development, fruit set and fruit growth simultaneously.

Ajithkumar, (1999) found that morning and afternoon relative humidity during the first and second weeks after planting had positive effects on the days to flower. He also reported that it has a negative correlation with bright sunshine hours during first to second week after planting.

Anbarasan, (2002) reported that kharif tomato took 60.71 days and summer tomato took 55.09 days for fifty per cent flowering in open field whereas it was 58.65 days and 59.40 days respectively for polyhouse crop. Vezhavendan, (2003) observed earliest flowering of capsicum in rain shelter compared to open field condition.

ICAR, (2004) observed significant difference with regard to earliness of tomato variety Anagha under rain shelter and open field during summer. But during rainy season, there was a significant difference. Open field crop flowered at 62.17 days after planting whereas under rain shelter with roof ventilation, it was 65.7 days.

2.2.2 Days to harvest

Slack and Calvert, (1978) found a positive correlation in tomato between increasing night temperature and early fruit yield, but final yield was negatively correlated to temperature. Gent, (1988) found that under a day night temperature difference of 9.0°C, greenhouse tomato fruits grew and ripened quickly, resulting in greater yield. Grimstad and frimanslund, (1993) reported 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}. Grimstad, (1993) observed that low temperature resulted in a delayed harvesting of tomato in greenhouse.

Moccia *et al,* (1999) noted that determinate variety Lilliput of tomato exhibited early yield. Open crop of tomato took less number of days to maturity compared to crop under rain shelter (AVRDC, 2000). Study conducted by Arin and

Ankara, (2001) indicated that low tunnels are useful for promoting early harvesting and high total yield when compared with uncovered crop.

Vezhavendan, (2003) noted that capsicum under rain shelter took less number of days to harvest than open crop in both Rabi and Kharif season in Kerala. Early flowering and fruiting were noticed in open field when compared to shade for different genotypes of tomato tried (Thangam *et al.,* 2002). ICAR, (2004) noted that tomato under rain shelter harvested earlier than open crop during Rabi but during rainy season, open field crop was harvested earlier than covered crop.

2.3 YIELD AND YIELD ATTRIBUTES

2.3.1 Fruit setting per centage

Shelby *et al,* (1978) reported that the fruit set could be governed by dominant genes with moderate heritability (broad sense) of 54 per cent. High heritability, GCV and PCV for fruit setting per centage at high. Picken, (1984) reported that warm day and cool night temperature extremes in high tunnel could however interfere with flower development and fruit set. Optimum growth and development of tomato occurs at (or) above 20.0°C (Wolf *et al.,* 1986).

Abdul-Baki, (1991) noted that high temperature induced flower abscission which resulted in reduced fruit set and yield. Same results were reported by Rao and Sreevijayapadma, (1991). Under greenhouse in winter season, the number of fruit set decreased rapidly from the fifth cluster (Bertin and Gary., 1992). Ercan and Vural, (1994) reported that fruit setting ratio were relatively higher with 97.86 per cent in Cairo F1 and 98.08 under greenhouse condition. Temperatures below 10.0°C or above 3.0°C (the exact value depending on the cultivar) are detrimental to one or more of the processes leading to fruit set. Peet *et al,* (1996) reported that tomato fruit set and fruit weight per plant decreased as mean daily temperature increased from 25-29.0°C.

Empty flowers and persistent flowers without fruit set in the 35/20.0°C regime in tomato as observed by Lohar and Peet, (1998). The effect of chronic, mild heat stress on fruit set release of pollen grains, photosynthesis, night respiration were examined under different temperature regimes, 28/22.0°C or 26/22.0°C (optimal temperature), 32/26.0°C using five cultivars. From this study Sato *et al,* (2000) suggested that number of pollen grains produced during photosynthesis and night respiration did not limit fruit set under chronic and mild heat stress.

2.3.2 Fruit weight

Lower sink activity of sweet pepper fruits at low temperature reduces the mean fruit weight (Bakker and Van Uffelen., 1988). Naniwal *et al,* (1992) observed a range of 44.4g in Pusa Ruby to 81.89g in MDT 21 for this trait. A range of 29.86 to 56.6g of fruit weight was observed in a study conducted by Bhardwaj and Thakur, (1994) with 26 genotypes of tomato during summer season.

At higher temperature an almost similar amount of assimilates has to be distributed over a large number of fruits resulting in a lower average fruit weight. Thus the potential fruit weight at 23.0°C is about 40 per cent lower than at 17.0°C (De Konning, 1988).

Joshi *et al,* (1998) recorded an average weight of 61.12g per tomato fruit. Fruit weight of tomato was 38.3g under plastic shelter whereas it was 33.7g in open condition (AVRDC., 2000).

Cucumber under polyhouse gave 239g and all the plants in open field gave poor yield or got killed (Kanthaswamy *et al.,* 2000). Fruits obtained from polyhouse crops gave higher mean of 26.56g as compared to 25.10g in open field during summer. During kharif season, it was 27.74g and 22.19g respectively (Anbarasan., 2002).

ICAR, (2004) recorded average fruit weight of 23.0g during rabi and 39.1g during kharif inside rain shelter in tomato whereas it was 17.5g and 43.1g respectively in open field. Hazarika and Phookan, (2005) found that among different genotypes of tomato tried, cultivar.

2.3.3 Yield per plant

Shelby *et al,* (1978) reported a slight but significant decline in pollen viability from plants subjected to high temperature. During winter in mid hills of Uttar Pradesh, Bhatnagar *et al,* (1990) found that in the open field tomato plants were killed by frost. In greenhouse, a yield of 360 to 507 quintal per hectar was obtained.

Dane *et al,* (1991) observed reduced pollen viability after prolonged period of higher temperatures in the field, which resulted poor fruit yield. Stress during fruiting stage reduces productivity in tomato (Rao and Sreevijayapadma., 1991).

Isshiki, (1994) observed a double yield of tomato in rain shelter than open field. Fontes *et al.,* (1997) recorded average marketable fruit yield of 3.15 kg per plant in plastic tunnel, which was 141 per cent higher than in field grown plants with marketable fruits representing 94 and 71 per cent of total yield. He also noted that the average yield of marketable fruits of two tomato cultivars, Sunny and EF-50 in plastic tunnel was 51 per cent higher than that of field grown plants.

In an experiment with long life type salad tomato cultivars, Gualberto *et al,* (1998) reported that marketable fruit yield was 40 to 45 per cent higher in greenhouse than open field. Rain shelter cultivation of tomato at plastic culture development centre, Thavanur recorded a yield of 5 kg per m^2 in open condition (KAU. 1999)

Arya *et al,* (2000) reported that plastic shelter increased tomato and capsicum production by 169 and 956 per cent without any us of pesticides. Chandra *et al,* (2000) recorded a higher yield of 110.51 t per ha with Pusa Hybrid 2 varieties of tomato inside polyhouse.

A study conducted in TNAU in naturally ventilated polyhouse with insect proof net and open field by Nagalakshmi *et al,* (2000) showed that S-41 under polyhouse was early in flowering and fruit set than open field and yield was double compared to open field. Srivastava, (2000) obtained 60 to 70 per cent higher tomato yield under polyhouse in high rainfall areas of Jorhat, Assam. Dixit *et al, (*2002) found green leafy vegetables under greenhouse structure showed superior yield and yield attributing characters as compared to open field condition.

2.4 EFFECT OF WEATHER PARAMETERS

2.4.1 Air temperature

In Canada, Charles and Harris, (1972) found low fruit set in tomato at 10°C and 12.8°C, which was primarily due to poor pollen viability and germination and to a lesser extent to a high stigma position in the antheridial cone. At 26.7°C, stigma height was the main factor reducing fruit set but low stigma receptivity was an important factor in some selections. Shvebs and Grudev, (1972) revealed that during fruit formation the optimum day and night temperatures were above 16.0°C and l3.0°C respectively. In their study at Russia, a relationship between the sum of mean daily temperature and the duration of flowering was observed.

Friend and Helson, (1976) suggested that high growth rate obtained under a high day temperature was the result of a high rate of net photosynthesis. Nilwik, (1981) observed changes in RGR during seedling stage in response to temperature.

Rudich *et al,* (1977) observed that the higher temperature condition (39°C ± 2.0°C day and 22.0°C ± 2.0°C night) at Israel caused deficient fruit set in tomatoes. The impaired fruit set of Roma VF was found to be associated with pollen viability, style elongation, and lack of formation of the endothecium, which is essential to stamen and pollen thecae opening. Takahashi *et al, (*1977) in a study with the tomato cv. Fukuju-No.2, the highest number of flower buds/plant was obtained from plants receiving high NPK and grown at day/night temperature of 22/12.0°C.

Longuenesse, (1978) grew tomato cv. Montfavet 63.5 in a glass house with a day temperature of 20.0°C and night temperature of 15.0°C or 11.0°C and he reported that, with the lower night temperature, flowering, fruit development and maturity were delayed, but not affect the number of flowers and fruits resulting in higher fruit yield.

A high positive correlation (r =0.9) between the number of seeds/fruit and fruit size at a day temperature of 27.0°C was reported by Rylski, (1979). Kuo *et al, (*1979) observed that the ability to produce viable pollen, ovules, and hormonal activity under high temperature is accounted for differences in fruit setting ability in both heat tolerant and heat-sensitive cultivars.

Papadopoulos and Tiessen, (1981) reported that a low greenhouse air temperature of 19.0°C (day)/14.0°C (night) during the autumn, caused no reduction in yield when compared with the standard 22°C/17°C. An air temperature of 13.0°C/08.0°C during the spring markedly reduced yield compared with 19.0°C/14.0°C. Flowering of Ohio MR-13 in growth chambers was delayed significantly at 24.0°C/08°C compared with 24.0°C/17.0°C but the flowering of Vendor was unaffected. Marketable yield of Vendor was significantly higher at 24°C/08°C than at 24.0°C/17.0°C while that of Ohio MR-13 was unaffected. At a constant day air temperature of 24.0°C, the amount of small fruits decreased as night air temperature was lowered from 14.0°C to 08.0°C. Kleinnendorst and Veen, (1983) noted a decline in NAR below a day temperature of 18.0°C in cucumber.

Khayat *et al,* (1985) opined that the fruit production in the cultivar, Moneymaker was not reduced by interruption of the optimum night temperature regime (18.0°C) by short intervals (2 hrs) of lower temperature. The same treatment increased the yield on the cv. Cherry by 82 per cent compared with a constant night temperature of 18°C. The yield increase in this cultivar was due to a larger number of fruits per plant.

Alberton and Rudich, (1986) reported that the development of the root system differ among tomato cultivars and the day temperature of 26.5°C and night temperature 16-22°C resulted in the heavier root system.

In an experiment with four cultivars Precodor, Vemone, Marmande and Raf, Noto and Malfa, (1986) observed that the shortest number of days from sowing to flowering was noted in plants treated with the lowest temperature and exposed to it for the longest time.

Smeets and Garretsen, (1986) and Heuvelink, (1989) demonstrated that there are changes in RGR during seedling stage in response to temperature. De Koning, (1988) reported a positive effect of increasing night temperature on final fruit yield and fruit size.

In another experiment by Cholette and Lord, (1989) the seeds of the cv. Carmello was sown on 16 January and the plants were grown under night temperatures of 17.0°C, 12.0°C or 7.0°C for 2 months after the 6th leaf had expanded and the first cluster was visible (e.g. 24 February to 15 April). Total and marketable yields were significantly higher on Nutrient Film Technique (NFT) than in soils, but there was no advantage for the early yield. The date on which half of the flowers of the first cluster opened was 2 weeks earlier for the 17.0°C treatment there for the 7.0°C treatment indicating that low night temperature reduced the rate of development.

Heuvelink, (1989) reported that day temperature was more important than night temperatures in determining the fresh and dry weight, plant length, leaf area and RGR of young tomato plants.

He also found that an increased temperature regime reduced plant growth and development, number of leaves and number of trusses. Growth reduction was caused by a lowering in leaf area ratio (LAR). The decrease in LAR at an inversed temperature regime was caused mainly by a decrease in specific leaf area (SLA).

Leaf number, the main component of total leaf area is a function of leaf appearance rate. Temperature is a major limitation to leaf appearance rate in crops (Kiniry *et al.,* 1991).

Young tomato plants were more affected by low temperature than older plants showing reduced net assimilation rates and reduced leaf growth (Voican and Leibig., 1991). Higher temperature in the early stages of growth of tomato promoted leaf expansion (Cockshull., 1992).

Increase in fruit temperature resulted in immediate cracking in ripe fruits or delayed cracking in green fruits (Peet., 1992). Growth of vegetative organs on aubergines and tomato in greenhouse was negatively influenced by highest temperature among 30.3, 32.1 and 34.0 °C. Treatment of higher temperature than day temperature reduced plant height in tomato and cucumber at 21 and 61 days after sowing mainly due to a decrease in internodal length (Abou Habid *et al.,* 1994).

Rao *et al,* (1992) studied the rate of net photosynthesis, growth and dry matter (DM) production in tomato cultivars IIHR 224 and Arka Saurabh that had been grown in the chambers at day/night temperatures of 35.0°C/20.0°C and 35.0°C/27.0°C. Significant cultivar differences were observed at both temperatures. Photosynthesis was lower in both cultivars at a night temperature of 27.0°C. Leaf area and total DM for IIHR 1224 were lower with a night temperature of 27.0°C. When plants were pre hardened by exposure to 40.0°C for 2 hours during the night period at the 3-leaf stage, plants of IIHR 1224 receiving 35.0°C/27.0°C treatment had a higher relative growth rate and net assimilation rate than those receiving 35.0°C/20.0°C.

Pearce *et al,* (1993) found that average fruit size decreased with temperature, being a consequence of increased truss appearance rate and accelerated fruit development.

Fruit weight in capsicum reduced with temperature whereas it increased in aubergines (La-malfa., 1993). Ercan *et al, (*1994) studied the effect of low temperature on fruit set and yield of the tomato cultivars Dario F_1 and Amfora F_1 and established that low temperatures reduced the pollen count and thus reduced fruit set and yield. The minimum temperature below which pollen degeneration in the flower began was 5.0°C for Amphura and 10.0°C for Dario.

Romano *et al,* (1994) found that vegetative growth of plants was affected by low temperature but yield was reduced. Studies conducted by Grimstad, (1995) showed that at low temperature pulse at the beginning of the daily light period was most effective for tomato giving higher plant height. Low temperature reduced leaf number and shoot dry weight. Flowering was delayed resulting in a delayed harvest. Tomato fruit set and fruit weight per plant decreased as mean daily temperatures increased from 25.0 to 29.0°C (Peet *et al.,* 1996).

Rylski and Aloni reported that the temperature and irradiation condition at early stages of flower development are important factors that determine fruit yield and quality. A low night temperature can induce the tomato seedling to produce a higher flower number (Ho., 1996).

Wang-Xiao Xuan, (1996) conducted experiment on 6 tomato cultivars at China and found that germination of seeds and pollen, pollen tube growth, growth of the hypocotyledonary axis and fruit set decreased with decreasing temperatures. Under temperatures of 8.0°C and12.0°C, all the above parameters showed a positive correlation with the cold tolerance of the cultivars. Under low temperature in the field, plant growth, flowering, fruiting, pollination and fertilization were inhibited to different degrees and cold tolerant cultivars performing better than cold sensitive ones

Langton and Cockshull, (1997) reported that extension growth in tomato responded to the absolute day and night temperature rather than to difference between day and night temperatures. The optimum temperature for extension growth was rather higher for day temperature than night temperature. At higher air temperature, fruits matured before sufficient growth had occurred (Wada *et al.,* 1998)

A study conducted at Vellanikkara condition (Ajithkumar, 1999) showed that the maximum temperature range of 30.6-33.7°C and a minimum temperature range of 22.1-24.3°C were found to be optimum for crop growth of tomato. He also reported that the maximum temperature range of 31.6-32.1°C and minimum temperature range of 24.1-24.3°C were optimum for early flowering whereas minimum temperature range of 22.1-23.3°C during sixth and eighth week after planting are optimum for increased yield.

Mean yield per plant in all the genotypes of tomato tried was more reduced under high temperature in the field and glasshouse condition during summer than during kharif (Muthuvel *et al.,* 1999). During summer under polyhouse, number of branches and leaf area index were positively correlated with maximum temperature while RGR was not affected.

Muthuvel *et al.,* (2000) observed smaller fruits in tomato plants grown under glasshouse which may be due to competition among the fruits for assimilates. Anbarasan, (2002) observed larger fruits in tomato under polyhouse during both summer and kharif than crop in the open field.

High temperature may reduce pollen quality, increase floral anomaly and consequently reduced fruit number (Dorais *et al.,* 2001).

2.4.2 Soil temperature

Abdelhafeez, (1971) reported that growth of tomato plants was soil temperature below 20°C and air temperature of 17.0°C.

Saito and Ho, (1971) found that exposure of the plants at 9°C for produced fascinated flowers which might be due to the surplus nutrient the young flower buds just on pre or post differential stage. They remarked that at low temperature vegetative growth is restricted which is due to the supply of more nutrients for flower development.

Hisatomi, (1972) found that an increase in leaf area and stem thickness was markedly enhanced by the higher soil temperature. Fruit number per unit area and total yield, however, were greater at lower soil temperatures. The adverse of high temperature on the yield of winter crop flowering during February was due to the excessive vegetative growth produced.

In a study in tomato cultivar “Extase” grown in containers and soil kept at constant temperatures of 15.0°C, 20.0°C, 25.0°C, 30.0°C and 35.0°C, Stanev and Angelov, (1978) reported that a reduction of soil temperature from 30.0°C to 15.0°C decreased the leaf area by 50 to 70 per cent and an increase in soil temperature to 35.0°C decreased it by 20 to 40 per cent. Net photosynthetic productivity was the highest at 15°C, the peak at 25-30.0°C and decreased by 60-70 per cent at 50.0°C and by 22 to 38 per cent at 35.0°C.

2.4.3 Relative humidity

Bakker and Ufflen, (1988) reported that final yield of tomato was reduced by high humidity at night and had no significant effect by day time humidity. Bakker (1990) observed the effect of humidity on growth and propagation of glasshouse tomatoes, cucumber and sweet pepper. Humidity levels were observed to be 20 to 25 per cent higher as compared to outside conditions. Growth of inside plants was increased by 30 per cent and it took about 30 days and it took about 30 days lesser for the fruits to mature.

Major long term effect of humidity on greenhouse crops is through its effect on leaf area. Leaf expansion is favored by high humidity. There was a small but significant increase in RGR in response to an increase in day time humidity in tomato seedling. The effect of humidity on RGR was attributed to the small increase in NAR (Bakker., 1990).

Shoot length and leaf area increased with increase in RH. Higher RH increased the number of flowers produced and reduced the time for flowering (Gislerod and Mortenson., 1991). Percentage of cracked fruits and crack length were decreased by low humidity and increased with high humidity (Ohta *et al.,* 1991). High humidity inside greenhouse reduced leaf dry weight (Adams and Holder., 1992).

In greenhouse, high humidity is a major concern in connection with fungal and bacterial (Bailey., 1995). Maroto *et al.,* (1995) observed that fruits from plants grown in high humidity had a higher incidence of cracking. High day and night humidity increased blossom end rot from the end of August (Pivot *et al.,* 1998).

Ajithkumar, (1999) reported that at Vellanikkara condition, relative humidity of 70 to 86 per cent and afternoon relative humidity was negatively correlated with yield. Significant positive correlations were obtained between morning relative humidity and plant height and LAI. Evening relative humidity also had a significant positive correlation with above characters (Anbarasan., 2002). Improved vegetative growth under low plastic tunnels may largely be attributed to increased air temperature and relative humidity (Kumar and Srivastava, 2002). Peet *et al,* (1992) reported that fruit weight was most sensitive to high humidity at high temperatures.

2.4.4 Light intensity

Bruggink, (1987) stated that, in tomato, cucumber, and sweet pepper seedlings, relative growth rate is not proportional to variation in light integrals. Bruggink and Heuvelink, (1987) found that leaf area ratio, the ratio between leaf area and total biomass increased with declining light intensity, thus partly compensating for the net assimilating rate.

High light intensity may have a role in increasing cracking. Under high light conditions, fruit soluble solids and fruit growth rates are higher and are sometime associated with increased cracking (Peet, 1992). The area and dry weight of leaves and dry weight of roots and stems were with an irradiance of 14.7 or 8.5 $MJm^{-2}day^{-1}$ than with lower irradiances. Fruit yield was highest in plants receiving full sun and plants failed to fruit at an irradiance of -3.3$MJm^{-2}day^{-1}$ in greenhouse (Mohd Razi and Ali, 1994).

When tomato is grown in glasshouse, the single fruit size and fruit number can be affected by season largely through direct effect of solar radiation on crop photosynthesis and glasshouse air temperature (Cockshull and Ho., 1995).

Shaheen *et al,* (1995) studied different light intensities under polyhouse conditions on tomato. They found that increasing shade level reduced seedling fresh weight and dry weight in both winter and autumn. Highest NAR values were obtained in control treatment. Decreasing the light intensities reduced the values of NAR. A solar radiation flux density of 200 cal cm-2day-1 was considered to be the lowest value for tomato growth (Estefanel *et al.,* 1998).

Ajithkumar, (1999) reported that bright sunshine of 5.2-10.0 hours required for optimum growth of tomato under Vellanikkara condition. He also found that days to first flowering showed a negative correlation with bright sunshine. The accumulated photosynthetically active radiation and sum temperature were significantly correlated with flowering and fruit set (Pek and Helyes., 2004).

2.4.5 Ultraviolet radiation

Battaglia and Brenan, (2000) studied the effects of relatively short term high intensity exposure to UV upon photosynthetic carbon dioxide fixation in cotyledons of cucumber (*Cucumis sativus*) and sunflower (*Helianthus anus*). Treatment with 194 K m^{-2} of UV radiation delivered over 16 hours lead to significantly reduced carbon dioxide fixation rates in cucumber, while sunflower showed no inhibition or slight increase. The concentration of chlorophyll a and chlorophyll b were unchanged in response to UV treatment in cucumber showed statistically significant increase in sunflower. Flavonoids (i.e. methanol extractable UV absorbing compounds) decreased in cucumber and were unchanged in sunflower.

Hao *et al,* (2000) reported that exposure to enhanced UV increased leaf chlorophyll and UV-absorbing compounds but decreased leaf area and root/shoot ratio. Also pre-exposure to enhance UV mitigated O_3 damage to leaf photosynthesis at elevated CO_2.

Hui *et al,* 2004 studied the effects of enhanced UV radiation on hormone changes in vegetative and reproductive tissues of tomato (*Lycopersicon esculentum* Mill.) and their relationships with reproductive characteristics. Two cultivars, Tong Hui (TH) and Xia Guang (XG), were grown in the field for one growing season under ambient (Control), ambient plus 2.54 kJ m^{-2} d^{-1} (T1) or ambient plus 4.25 kJ m^{-2} d^{-1} (T2) of supplemental ultraviolet-B (280–320 nm). The number of open flowers increased significantly in the TH cultivar under T2 while it declined in the XG cultivar under T1. The pollen germination from both cultivars was inhibited by UV treatment, fruit number was enhanced in the TH cultivar at both UV doses and in the XG cultivar at the low dose. On the other hand, seed size (dry weight) was reduced in the XG cultivar by both UV doses and in the TH cultivar at the low UV dose. The final germination rates of seeds from control and UV treated plants of both cultivars showed no significant differences ($p > 0.05$), while germination was delayed in the TH cultivar at both doses of UV and in the XG cultivar only for T2.

In a study conducted by Maharaj *et al,* 2010 to examine the effect of hormic doses of ultraviolet radiation in delaying the senescence of tomato, it was found that the development of color and lycopene as well as the decline in chlorophyll were significantly retarded in response to the treatment with hormic and hyper doses. Treatment with hyper doses however impaired ripening and caused abnormal browning.

Under controlled conditions when young tomato plants were treated with UV radiation for different durations of 10, 30, 60, and 120 minutes, it was found that in 10 and 30 minutes treated plants, leaf colour measured immediately after the irradiation, did not change statistically, whereas the 60 and 120 minutes treatments were characterised by a deep senescence with a general stem and leaf yellowing. The results demonstrate that high UV doses determined irreversible damages, both at physiological and morphological levels that lead plants to death, whereas lower irradiations allowed plants to partially recover their normal physiological status (Castronuovo *et al.*, 2014).

2.4.6 Carbon dioxide

According to Kimball, (1982), crop yields will probably increase by 33 per cent with the doubling of CO_2.

Bhattacharya *et al,* 1985 reported that although CO_2 enrichment caused a significant increase in the total number and weight of seeds as well as pods, it did not affect the ratio of seed dry weight to the total dry weight of above-ground plant parts (harvest index) in cow pea.

Cure, (1986) reported that the net CO_2 exchange rate of crops increased 52% on first exposure to a doubled CO_2 concentration, but was only 29% higher after the plants had acclimatized to the new concentration. For net assimilation rate, the increases were smaller, but fell with time in a similar way. The C_4 crops responded very much less than C_3 crops. The responses of biomass accumulation and yield were similar to that for carbon fixation rate. Yield increased on average 41% for a doubling of CO_2 concentration. The variation in harvest index was small and erratic except for soybean, where it decreased with a doubling of CO_2 concentration. Conductance and transpiration were both inversely related to CO_2 concentration. Transpiration decreased 23% on average for a doubling of CO_2.

The increasing concentration of CO_2 affects the plants directly, causing changes in their chemical composition, physiological processes, production and fitness (Drake et al., 1997).

Percentage decreases in pollen viability, seed-set, seed yield and harvest index due to elevated temperature were greater at elevated CO_2 when compared with ambient CO_2. Elevated CO_2 increased seed yield (26%) at 32/22.0°C, but decreased seed yield (10%) at 36/26.0°C. At high temperatures, elevated CO_2 increased vegetative growth but not seed yield, thus, leading to decreased harvest index.

Prasad *et al.,* Percentage decreases in pollen viability, seed-set, seed yield and harvest index due to elevated temperature were greater at elevated CO_2 when compared with ambient CO_2. Elevated CO_2 increased seed yield (26%) at 32/22.0°C, but decreased seed yield (10%) at 36/26.0°C. At high temperatures, elevated CO_2 increased vegetative growth but not seed yield, thus, leading to decreased harvest index.

2.5. CLIMATE CHANGE

2.5.1. Climate change impact on tomato

Tomato plants that are grown under an inversed temperature regime are also reduced in height, due to shorter internodes (Calvert., 1964). The CROPGRO-Tomato (DSSAT V4.5) simulates tomato (*Lycopersicon esculentum*) growth, development and yield. The model requires calibration for tomato grown in specific environmental conditions before assessing the yield potential of tomato. The model should be a useful tool evaluating the potential yield of tomato under various thermal environments. (Sunil *et al.,* 2006).

Production of tomato (*Lycopersicon esculentum*) is severely affected during the peak of rainy seasons in Southwestern Nigeria leading to a decline in yield and fluctuation of prices. To study and identify the impacts of climate variability on phenological stages and yield components of tomato, Tomato was cultivated in two separate peak rainy seasons (August to October, 2009 and May to July, 2010). Climatic variables including rainfall, relative humidity, maximum temperature, and minimum temperature were evaluated on four different tomato varieties (Roma VFN, Ibadan Local, Beske, UTC) with respect to tomato growth stages and quality of its yield components (Oladitan *et al.,* 2014). A weather model was evaluated to estimate the hourly time temperature and relative humidity inside of a zenithal ventilated type greenhouse, as a function of the weather outside the greenhouse. The study was carried out during the winter of 2008-2009, in a commercial greenhouse with tomato production (Reyes *et al*., 2012). Better growth, development and yield of tomato were achieved under polyhouse due to the higher (optimum) temperature and lower relative humidity during the winter months (December to February) which positively influenced the morpho-phenological and physiological events of tomato plants. (Parvej *et al.,* 2010).

2.7. CROP GROWTH MODELS

2.7.1. DSSAT

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, 1998, 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.

2.7.2. CROPGRO-Tomato

Scholberg and Jones, (2012) conducted a study to update the cardinal temperature parameters of the CROPGROW- 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.

Sunil *et al,* (2006) conducted a study to calibrate and test CROPGRO-TOMATO for tomato growth, development and yield under different thermal environment. The model correctly predicted biomass, leaf area index and total yield. The model estimated the yield with in a mean error of 4.5 per cent.

Materials and Methods

The current investigation was carried out at the Academy of Climate Change Education and Research during 2014-2015 with the objective to study "Modeling the impact of climate change on growth and yield of tomato". In order to achieve the objectives of the present investigation, field experiments were conducted at different dates of planting i.e., 1st and 10th of December, 2014 and 10th and 20th of January 2015. The details of location, climate and soil conditions of the experimental site and methodology for estimation of different parameters and procedure for model validation and calibration are described in this chapter. The materials used and the methods followed are presented below:

3.1 DETAILS OF FIELD EXPERIMENT

3.1.1 Location

The field experiments were conducted during December 2014 to March 2015 under three growing namely, polyhouse, rain shelter and open field at the Central nursery located in the main campus of the Kerala Agricultural University at Vellanikkara, Thrissur district, Kerala. The site is located at 10°31'N and 76°13' E longitude and at an altitude of 22.25 m above MSL.

3.1.2 Climate

The area experiences a typical warm humid climate and receives average annual rainfall of 2663 mm.

3.1.3 Soil

The soil of the experimental site comes under the textural class of sandy clay loam and is acidic in reaction.

3.1.4 Variety

Tomato variety Anagha, (Accession number LE415, Semi determinate) resistant to bacterial wilt released from Kerala Agricultural University was used for the study.

3.2 METHODS

The study was conducted throughout December 2014- March 2015 duration in polyhouse, rain shelter and open field simultaneously in a split plot design with 3 replications. The plot size was 20 m^2 the crop was raised in grow bags of size 16×16 cm placed at 60×60 cm spacing.

Treatments were laid out in split block design with three replications. The package of practices recommendations were followed under non-limiting water conditions. The crops were planted on four different dates (T1, T2, T3 and T4) under three different growing environments (Poly house, Rain Shelter, and Open field) as shown below in Table 1.

Table 1. Dates of Planting of Tomato

Treatments	Dates of Planting
T1	1st December 2014
T2	10th December 2014
T3	10th January 2015
T4	20th January 2015

3.2.1 Cultural operations

3.2.1.1 Nursery management

Nursery was raised in portrays containing rooting medium of perlite, vermicompost and coirpith 1:1:1 and adequate plant protection measures were also taken. Seedlings were transplanted to the experimental site at 20 days after sowing.

3.2.1.2 Preparation of main field and transplanting

The experimental site, polyhouse, rain shelter and open field were cleared thoroughly in order to avoid weeds during growing period. The grow bags were filled with the potting material and were kept at a spacing of 60×60 cm. Vermicompost and pseudomonas were incorporated into the grow bags and 20 days old healthy seedling were transplanted. Irrigation was given immediately after transplanting using a rose can.

3.2.1.3 After cultivation

The experimental site was kept free of weeds throughout the crop growth period by hand weeding.

3.2.1.4 Fertilizers and manure application

Urea, Super phosphate and Muriate of potash were the source material for supplying the nutrients N, P_2O_5 and K_2O respectively. A fertilizer dose of 75:40:25 kg was applied in split doses as per KAU package of practices.

3.2.1.5 Staking and training

Staking and training was practiced using wooden poles and coir.

3.2.1.6 Plant protection

The required plant protection as stated in the KAU package of practices were undertaken as and when required.

3.2.1.7 Harvesting

Fruits were harvested at red ripe stage as indicated by colour change from green to red and fruit parameters were recorded.

3.3 OBSERVATIONS

Three Plants per replication from polyhouse, rain shelter and open field conditions were selected for recording observations. Well-developed fruits were randomly selected from each plant for recording observations.

3.3.1 Morphological characters

3.3.1.1 Plant height (cm)

Plant height was measured at weekly intervals from the very first week until the final crop harvest. This was measured from the collar region of the plant to the tip of the plant.

3.3.1.2 Leaf area index (LAI)

The leaf area index was recorded at weekly intervals using CI 110/120- digital plant canopy imager.

3.3.1.3 Biomass (gm)

Three plants per replication were dried in a hot air oven at 80°C and the dry weight of the samples were recorded using electronic balance and mean value was taken and expressed in grams.

3.3.2 Phenological characters

3.3.2.1 Days to first flower

The number of days taken from transplanting to opening of first flower was recorded and the mean was worked out.

3.3.2.2 Days to first harvest

The number of days from transplanting to first harvest was recorded for three plants per replication and the mean was used for analysis.

3.3.2.3 Days to last harvest

The number of days from transplanting to last harvest was recorded for three plants per replication and the mean was used for analysis.

3.3.3 Yield and yield attributes

3.3.3.1 Per cent of fruit set

The number of fruits formed from the total number of flowers produced from the three plants per replication was recorded and the mean was worked out.

3.3.3.2 Average fruit weight (g)

Total weight of five fruits per replication was observed at each harvest and the mean was calculated.

3.3.3.3 Fruit yield per plant and total yield

Fruit yield per plant was calculated for all the selected plants by adding the yield of individual harvest and expressed in kilograms. The per plant fruit yield was extrapolated to yield obtained in a hectare of land to calculate total yield expressed in tons per hectare.

3.3.4 Weather observations

The weather parameters were recorded using automatic weather station installed inside each growing environment. The UV radiations were recorded using the UV biometer.

Table 2. Weather parameters used in the experiment

S .No.	Weather parameter	Unit
1	Maximum temperature	°C
2	Minimum temperature	°C
3	Rainfall	mm
4	Minimum relative humidity	%
5	Maximum relative humidity	%
6	Solar radiation	($W\ m^{-2}$)
7	UV radiation	($W\ m^{-2}$)
8	PAR	($W\ m^{-2}$)
9	Soil temperatures	°C
10	Minimum soil temperature	%
11	Maximum soil temperature	%
12	Soil moisture	°C
13	Canopy temperature	°C
14	Canopy air temperature difference	°C
15	Carbon dioxide	ppm

3.4 STATISTICAL ANALYSIS

The data recorded from the field experiment was analysed statistically using Analysis of variance technique. Split plot design was used in the analysis of weather and crop data.

Correlation and regression analysis were done between the growth and yield characters with the weekly mean values of maximum temperature, minimum temperature, relative humidity, solar radiation, UV radiation, photosynthetically active radiation (PAR), canopy temperature, canopy air temperature difference (CATD) to determine the effect of weather elements on the growth, yield characters of tomato. Regression equations were worked out from these observations.

The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

3.5 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, 1998; Uehara, 1998; Jones *et al*, 1998) is used for modelling the impact of growth and yield of tomato.

Validation of CROPGRO-tomato requires to develop genetic co-efficient based on the varietal characters of the variety and the details are as follows:

Table 3. Genetic Coefficients for the CROPGRO -Tomato model

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 vpm CO2, and high light (mg CO2/m2-s)
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm2/g)
SIZLF	Maximum size of full leaf (three leaflets) (cm2)
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))

The minimum data set required for the operation and calibration of the CROPGRO–Tomato given below,

3.5.1 Data required

3.5.1.1 Level 1 Data

Weather Data Required (Daily)

1. Minimum and maximum temperature

2. Rainfall

3. Total solar radiation or sunshine hours

Soil Data

1. General site information

2. Soil surface information

3. Soil profile data, for each soil horizon in which roots are likely to grow

Initial Conditions

1. Previous field history

2. Initial soil profiles conditions

3. Surface residues at the start of simulation or at planting

Management Data

1. Planting

2. Input information

3.5.1.2 Level 2 Data

Crop and Soil Response Measurements

1. Treatments

2. Yield and yield components

3. General observations

3.5.1.3 Level 3 Data

1. Growth analysis measurements

2. Soil water content versus depth

3. Soil fertility versus depth

3.5.2 Calibration of CROPGRO–Tomato model

Data obtained from the experiments carried out with tomato cultivars Anagha under four 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 iteratively, 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.

3.5.3 Validation of CROPGRO–Tomato model

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{i=1}^{n}(Pi - Oi)^2}{n}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass) respectively and n is the mean of the observed variables.

3.6 CLIMATE CHANGE SCENARIOS

Impacts of climate change will depend not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios, and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

Table 4. Description of Representative Concentration Pathway (RCP) scenarios (Moss, 2010)

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Climate change data projected by GCMs on daily basis is used for the present study. Daily data of following variables has taken

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the CROPGRO-Tomato model to simulate the impacts of climate change on tomato yields in Kerala.

3.7 GENERAL CIRCULATION MODELS (GCMs) USED

The Ensembled mean data of seventeen models has been used for the years 2030, 2050 and 2080.

Table 5. General Circulation Models used for the study

No	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institut Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	M0IROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-

		Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

Results

The results of the experiment entitled "Modeling the impact of climate change on growth and yield of tomato" are presented in this chapter. The effect of different weather parameters on growth and yield under different growing environment i.e. polyhouse, rain shelter and open field were studied. The crop simulation model DSSAT-developed by IBSNAT was validated for tomato variety "Anagha" and used for studying the impact of climate change based on IPCC projections for the year 2030, 2050 and 2080 under different Representative Concentration Pathways (RCP 2.6, 4.5, 6.0 and 8.5).

4.1 BIOMERIC OBSERVATION

4.1.1 Plant height

The weekly plant height and the maximum plant height attained by the tomato crops planted under different growing environments are given in Table (6 and 7).

Table 6. Weekly Plant height of tomato (cm)

Growing environment	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9
01-Dec-14									
Polyhouse	8.8^{ab}	18.5^{ab}	34.0^{b}	46.3^{c}	62.1^{cd}	80.4^{c}	98.0^{d}	117.2^{b}	138.6^{b}
Rain shelter	10.0^{a}	17.6^{ab}	42.0^{a}	61.9^{b}	79.1^{b}	94.4^{b}	106.7^{bc}	116.8^{b}	123.9^{cd}
Open field	10.1^{a}	16.8^{b}	36.0^{b}	49.7^{c}	60.1^{cd}	67.8^{d}	71.7^{f}	73.2^{d}	74.2^{f}
10-Dec-14									
Polyhouse	9.7^{a}	23.3^{a}	44.3^{a}	67.6^{a}	90.2^{a}	111.9^{a}	134.8^{a}	153.6^{a}	169.4^{a}
Rain shelter	9.4^{ab}	18.2^{ab}	41.4^{a}	62.0^{b}	79.7^{b}	95.2^{b}	109.0^{b}	120.9^{b}	129.2^{c}
Open field	8.2^{b}	17.0^{b}	36.7^{ab}	49.4^{c}	56.4^{d}	58.9^{e}	60.3^{g}	61.2^{e}	61.6^{g}
10-Jan-15									
Polyhouse	8.9^{ab}	20.8^{ab}	41.6^{a}	60.6^{b}	79.0^{b}	95.6^{b}	108.0^{b}	116.8^{b}	126.0^{cd}
Rain shelter	8.4^{ab}	19.7^{ab}	40.7^{a}	58.9^{b}	78.1^{b}	95.4^{b}	104.2^{bc}	113.9^{b}	120.9^{d}
Open field	8.3^{b}	19.2^{ab}	34.8^{b}	42.8^{d}	46.6^{e}	48.8^{f}	50.0^{h}	50.3^{f}	50.4^{h}
20-Jan-15									
Polyhouse	9.7^{a}	20.3^{a}	38.3^{ab}	50.8^{c}	66.9^{c}	79.6^{c}	90.8^{ed}	97.2^{c}	102.4^{e}
Rain shelter	9.0^{ab}	18.9^{ab}	37.7^{b}	51.1^{c}	63.9^{c}	73.0^{d}	85.4^{e}	92.3^{c}	96.7^{e}
Open field	9.9^{a}	19.4^{ab}	34.7^{b}	39.2^{d}	39.7^{f}	39.9^{g}	39.9^{i}	39.9^{g}	39.9^{g}
CD 5%	1.38	3.29	4.36	5.41	6.39	8.42	8.70	8.61	8.14

Table 7. Maximum height (cm)

Date of transplanting	Growing environment	Maximum height
01-Dec-14	Polyhouse	251.7[a]
	Rain shelter	136.1[d]
	Open field	74.9[f]
10-Dec-14	Polyhouse	251.1[a]
	Rain shelter	141.9[c]
	Open field	61.7[g]
10-Jan-15	Polyhouse	152.9[b]
	Rain shelter	129.3[d]
	Open field	50.4[h]
20-Jan-15	Polyhouse	106.4[e]
	Rain shelter	101.6[e]
	Open field	39.9[i]
	CD 5%	7.8

As is evident from the tables, the dates of transplanting and the growing environment had a significant effect on the weekly plant height and the maximum height. Among the different treatments, irrespective of the date of transplanting, the maximum height was recorded by the crops grown inside the polyhouse. Among the crops planted in the polyhouse on 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015, the duration of the exponential growth phase was extended up to 14, 13, 10 and 7 weeks respectively. Similarly, for the crops transplanted in rain shelter on the same dates the duration was eighth weeks for all the crops, whereas the duration did not exceed more than four weeks for the crops transplanted in the open field on the same dates. Highest maximum height was recorded in the crops transplanted inside the polyhouse on 1 December 2014 (251.7 cm) and 10 December 2015 (251.1cm). Where as the least maximum height was observed among the crops transplanted in the open field on 20 January 2015 (39.88 cm).

4.1.2 Leaf area index (LAI) at weekly interval

The weekly LAI were assessed and it was found that the dates of transplanting and growing environment had a significant effect on the maximum LAI obtained Table (8 and 9). It was noted that the highest value of LAI coincided with the flowering and fruiting stages. The highest LAI of 3.8 was recorded in the crop transplanted in the open field on 1 December 2014 and also in the crops transplanted inside the polyhouse and rain shelter on 20 January 2015. The crop inside the polyhouse maintained a higher LAI (>2.5) for a period of 16 weeks whereas crop inside rainshelter and open field maintained for a period of 13 and 16 week respectively. The least values of maximum LAI (3.2) was observed in the crops in the open field transplanted on 20 January 2015.

Table 8. Weekly Leaf Area Index

Growing environment	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9
					01-Dec-14				
Polyhouse	0.91^{ab}	1.66^{a}	2.67^{a}	3.17^{a}	3.14^{ab}	3.31^{a}	3.24^{ab}	2.18^{ab}	3.25^{a}
Rain shelter	0.83^{bc}	1.48^{ab}	1.91^{b}	2.56^{b}	2.93^{bc}	2.47^{b}	2.29^{bc}	3.16^{a}	2.45^{ab}
Open field	0.88^{b}	1.45^{ab}	1.54^{bc}	1.34^{d}	1.48^{e}	1.61^{bc}	1.37^{cd}	1.71^{ab}	1.50^{bc}
					10-Dec-14				
Polyhouse	0.84^{bc}	1.75^{a}	2.18^{ab}	3.08^{a}	3.35^{a}	3.62^{a}	3.57^{a}	2.72^{a}	3.58^{a}
Rain shelter	0.87^{b}	1.99^{a}	1.42^{bc}	1.19^{d}	1.46^{e}	1.83^{bc}	2.20^{a}	2.51^{a}	2.15^{b}
Open field	0.75^{c}	1.29^{ab}	1.24^{c}	1.38^{d}	1.45^{e}	1.52^{c}	1.71^{c}	2.43^{a}	1.42^{c}
					10-Jan-15				
Polyhouse	0.77^{bc}	1.13^{b}	2.58^{a}	3.09^{a}	3.44^{a}	3.53^{a}	3.60^{a}	2.97^{a}	3.52^{a}
Rain shelter	0.81^{bc}	1.24^{ab}	1.65^{bc}	2.35^{bc}	2.65^{c}	2.41^{b}	2.88^{b}	2.65^{a}	1.78^{bc}
Open field	0.79^{bc}	1.58^{a}	1.58^{bc}	1.38^{d}	1.56^{e}	2.07^{b}	1.97^{c}	1.50^{ab}	0.69^{d}
					20-Jan-15				
Polyhouse	1.00^{a}	1.42^{ab}	2.40^{ab}	3.35^{a}	3.35^{a}	3.20^{a}	3.50^{a}	3.05^{a}	3.67^{a}
Rain shelter	1.02^{a}	1.31^{ab}	2.23^{ab}	1.97^{c}	2.20^{d}	3.18^{a}	3.62^{a}	3.17^{a}	3.03^{a}
Open field	0.91^{ab}	1.52^{ab}	2.24^{ab}	1.22^{d}	1.70^{e}	1.41^{c}	1.19^{d}	1.40^{ab}	0.03^{d}
CD	0.11	0.43	0.54	0.36	0.36	0.47	0.62	2.26	0.66

Table 9. Maximum LAI

Date of transplanting	Growing environment	Maximum LAI
01-Dec-14	Polyhouse	3.6^{c}
	Rain shelter	3.5^{c}
	Open field	3.8^{a}
10-Dec-14	Polyhouse	3.7^{ab}
	Rain shelter	3.6^{c}
	Open field	3.6^{c}
10-Jan-15	Polyhouse	3.6^{c}
	Rain shelter	3.7^{ab}
	Open field	3.6^{c}
20-Jan-15	Polyhouse	3.8^{a}
	Rain shelter	3.8^{a}
	Open field	3.2^{d}
	CD 5%	0.159

4.1.3 Biomass at the time of last harvest (t ha^{-1})

The highest biomass at the end of the crop was observed in the crop transplanted inside the polyhouse on 10 January 2015 (2.28 t ha^{-1}) which was statistically on par with crop transplanted inside the polyhouse on 1 December 2014 (2.23 t ha^{-1}). Irrespective of dates of transplanting the highest biomass was recorded inside the polyhouse, followed by crops inside rain shelter. The crop grown under open field condition during 1 December 2014 and 20 January 2015 (1.13 and 1.31 t ha^{-1}) recorded the least biomass are given in Table (10).

Table 10. Biomass at the time of last harvest (t ha^{-1})

Date of transplanting	Growing environment	Biomass at the time of last harvest
01-Dec-14	Polyhouse	1.77^{c}
	Rain shelter	1.49^{e}
	Open field	1.13^{g}
10-Dec-14	Polyhouse	2.23^{a}
	Rain shelter	1.63^{d}
	Open field	1.56^{de}
10-Jan-15	Polyhouse	2.28^{a}
	Rain shelter	2.03^{b}
	Open field	1.19^{g}
20-Jan-15	Polyhouse	2.01^{b}
	Rain shelter	1.90^{bc}
	Open field	1.31^{f}
	CD 5%	0.13

4.2 PHENOLOGICAL OBSERVATIONS

4.2.1 Days to first flowering

The days taken to first flowering were found to be higher and statistically similar for the crops transplanted inside the polyhouse and rain shelter on 1 December 2014 (23 days) and 10 December 2014 (22 and 21 days each respectively). Least number of days to flowering was obtained from the crop planted in open field on10 January and 20 January 2015 (17 days). Irrespective of growing environments dates to first flowering showed a decreasing trend from the 1 December 2014 transplanting to 20 January 2015 transplanting are given in Table 11.

Table 11. Number of days to first flower

Date of transplanting	Growing environment	Days to first flower
01-Dec-14	Polyhouse	23.0[a]
	Rain shelter	20.0[bc]
	Open field	19.0[c]
10-Dec-14	Polyhouse	22.0[ab]
	Rain shelter	21.0[b]
	Open field	19.0[c]
10-Jan-15	Polyhouse	20.0[bc]
	Rain shelter	18.0[cd]
	Open field	17.0[d]
20-Jan-15	Polyhouse	20.0[bc]
	Rain shelter	19.0[c]
	Open field	17.0[d]
	CD 5%	1.967

4.2.2 Days to first harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest (Table 12). In all the dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest. The crops transplanted inside the polyhouse and rain shelter on 1 December 2014 took an extreme 70 days for the first harvest while the open field crop took just 60 days. For the second crop transplanted on 10 December 2014, the number of days taken for first harvest was 65, 61 and 61 days respectively for the polyhouse, rain shelter and open field condition. All the crops transplanted inside the polyhouse, rain shelter and in the open field on 10 January 2015 took 50, 50 and 50 days respectively while it was 46 days for crops inside the polyhouse, rain shelter and open field crop transplanted on 20 January 2015. Irrespective of the growing environment the days taken to first harvest showed a declining trend in the crops transplanted on 1 December 2014 to 20 January 2015.

Table 12. Number of days to first harvest

Date of transplanting	Growing Environment	Days to first harvest
01-Dec-14	Polyhouse	70.0[a]
	Rain shelter	70.0[a]
	Open field	60.0[c]
10-Dec-14	Polyhouse	65.0[b]
	Rain shelter	61.0[c]
	Open field	61.0[c]
10-Jan-15	Polyhouse	50.0[d]
	Rain shelter	50.0[d]
	Open field	50.0[d]
20-Jan-15	Polyhouse	46.0[e]
	Rain shelter	46.0[e]
	Open field	46.0[e]
	CD 5%	1.499

4.2.3 Days to last harvest

The dates of transplanting and the growing environment had a significant effect on the number of days taken for last harvest (Table 13). The crops transplanted inside the polyhouse on 1 December 2014 took the maximum days for the last harvest (114 days) while the crop transplanted on 20 January 2015 in the open field took the least number of days for attaining the last harvest (56 days). A gradual decrease in the number of days to last harvest was evident from the crops transplanted on 1 December 2014 to the crops transplanted on 20 January 2015, irrespective of the growing environment.

Table 13. Days to last harvest

Date of transplanting	Growing environment	Days to last harvest
01-Dec-14	Polyhouse	114.0[a]
	Rain shelter	112.0[a]
	Open field	88.0[e]
10-Dec-14	Polyhouse	107.0[b]
	Rain shelter	101.0[c]
	Open field	95.0[d]
10-Jan-15	Polyhouse	81.0[f]
	Rain shelter	81.7[f]
	Open field	65.0[h]
20-Jan-15	Polyhouse	76.0[g]
	Rain shelter	76.7[g]
	Open field	56.0[i]
	CD 5%	2.188

4.3 YIELD AND YIELD ATTRIBUTES

4.3.1 Per cent fruit set

The percentages of fruit set values are given in the Table 14. The highest percentage of fruit set (61.7 and 50.1 per cent respectively) was observed in the plants transplanted inside the polyhouse on 1 and 10 December 2014. Whereas, the least fruit set percentage was observed in crops planted in the open field on 10 and 20 January 2015. Irrespective of the dates of transplanting the highest and lowest fruit set consistently occurred within the polyhouse and in the plants in the open field respectively.

Table 14. Percentage fruit set

Date of transplanting	Growing environment	Percentage fruit set
01-Dec-14	Polyhouse	61.7[a]
	Rain shelter	43.0[c]
	Open field	26.9[e]
10-Dec-14	Polyhouse	50.1[b]
	Rain shelter	34.6[d]
	Open field	24.0[ef]
10-Jan-15	Polyhouse	25.4[ef]
	Rain shelter	23.7[ef]
	Open field	20.1[ef]
20-Jan-15	Polyhouse	26.1[e]
	Rain shelter	26.0[e]
	Open field	20.0[f]
	CD 5%	5.378

4.3.2 Fruit yield per plant (kg)

The dates of transplanting and growing environment had a significant effect on the fruit yield obtained from a single plant (Table 15). The highest fruit yield per plant was recorded from the crops planted inside the polyhouse on 1 and 10 December 2014 (4.5 kg per plant). The per plant yield obtained from the crops transplanted on 1 and 10 December 2014 inside the polyhouse and rain shelter were statistically similar. A decrease in plant yield was observed with delay in planting. The least values were recorded in the crops transplanted in the open field on 20 January 2015 (0.3 kg per plant).

Table 15. Fruit yield per plant (kg)

Date of transplanting	Growing environment	Fruit yield per plant
01-Dec-14	Polyhouse	4.5^{a}
	Rain shelter	3.8^{b}
	Open field	2.9^{bc}
10-Dec-14	Polyhouse	4.5^{a}
	Rain shelter	2.7^{bc}
	Open field	2.3^{c}
10-Jan-15	polyhouse	3.3^{b}
	Rain shelter	2.9^{bc}
	Open field	1.5^{d}
20-Jan-15	Polyhouse	2.9^{bc}
	Rain shelter	2.7^{bc}
	Open field	0.3^{e}
	CD 5%	0.794

4.3.3 Average fruit weight (g)

The highest average fruit weight was recorded in the crop inside rain shelter transplanted on 10 January 2015 (58.0g), 20 January 2015 (56.0g) and 10 December 2014 (52.0g) followed by fruit obtained from the 10 December 2014, 10 January 2015 and 20 January 2015 crop inside polyhouse. The lowest fruit weight was obtained consistent in the open field except for the crop transplanted on 1 December 2014 are given in Table (16).

4.3.4. Total yield (t ha^{-1})

The total yield in tons per hectare was found to be significantly influenced by the date of transplanting and the growing environment (Table 16). The maximum yield of 111.5 tons per hectare and 111.2 tons per hectare were obtained from the crops transplanted inside the polyhouse on 1 and 10 December 2014 respectively. The yields from the crops transplanted inside the polyhouse on 1 and 10 December 2014 and the yield from the crops transplanted inside the rain shelter on 1 December 2014 were statistically similar. Regardless of the dates of transplanting the yields from the crops inside the polyhouse were consistently highest followed by the crops inside the rain shelter and open field. The lowest yields were obtained from the crops in the open field transplanted on 20 January 2015.

Table 16. Average fruit weight and Total yield

Date of transplanting	Growing environment	Average fruit weight (g)	Total yield (t ha^{-1})
01-Dec-14	Polyhouse	36^{c}	111.5^{a}
	Rain shelter	48^{ab}	92.4^{a}
	Open field	50^{ab}	73.2^{ab}
10-Dec-14	Polyhouse	39^{bc}	111.2^{a}
	Rain shelter	52^{a}	71.2^{b}
	Open field	35^{c}	57.5^{bc}
10-Jan-15	Polyhouse	46^{ab}	82^{ab}
	Rain shelter	58^{a}	68.5^{b}
	Open field	13^{d}	38.4^{c}
20-Jan-15	Polyhouse	44^{b}	73^{ab}
	Rain shelter	56^{a}	66.7^{b}
	Open field	13^{d}	7.5^{d}
	CD 5%	6.1	19.831

4.4 WEATHER DURING THE CROP PERIOD

4.4.1 Temperature (°C)

The highest value of mean weekly minimum temperatures for the crops transplanted on 1 and 10 December 2014 were recorded inside the polyhouse (29.0°C) during week 14 and 15 following transplantation while the lowest mean weekly temperatures were recorded in the open field condition during the week seven and eight subsequent of the same date of transplanting (21.7°C). For the crops transplanted on 10 and 20 January 2015, the highest value of mean weekly minimum temperature (30.6°C) were recorded inside the polyhouse during week 12 and 13 following transplantation while the lowest mean weekly temperatures were recorded in the open field condition during the second (21.7°C) and sixth week subsequent of transplanting (24.4°C). Regardless of the dates of transplanting the highest mean weekly minimum temperatures were recorded inside the polyhouse whereas the lowest weekly minimum temperatures were recorded in the open field condition (Fig. 1).

The highest value of 41.0°C mean weekly maximum temperature was recorded inside the rain shelter during all the growing season whereas the least value of 33.7°C was recorded for the first and second season crops planted on 1 and 10 December 2014 respectively in the open field. The lowest maximum weekly temperature values for the third and fourth season crops transplanted in open field on 10 and 20 January 2015 were 34.5 °C and 37.5 °C respectively. Regardless of the date of transplanting the highest mean weekly maximum temperatures were recorded inside the rain shelter whereas the lowest values were obtained in the open field. All throughout the growing period both weekly minimum and maximum temperatures showed an increasing trend (Fig. 2).

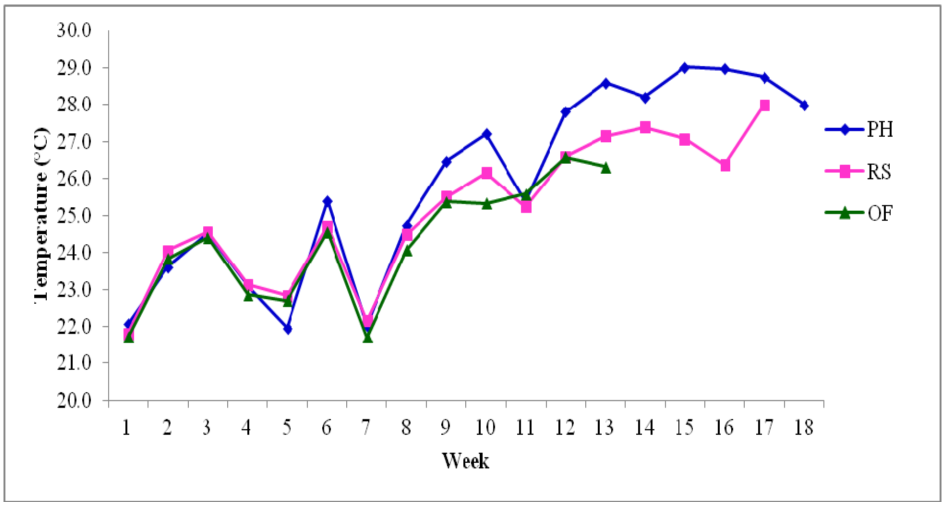

Fig 1. Weekly variation in minimum temperature

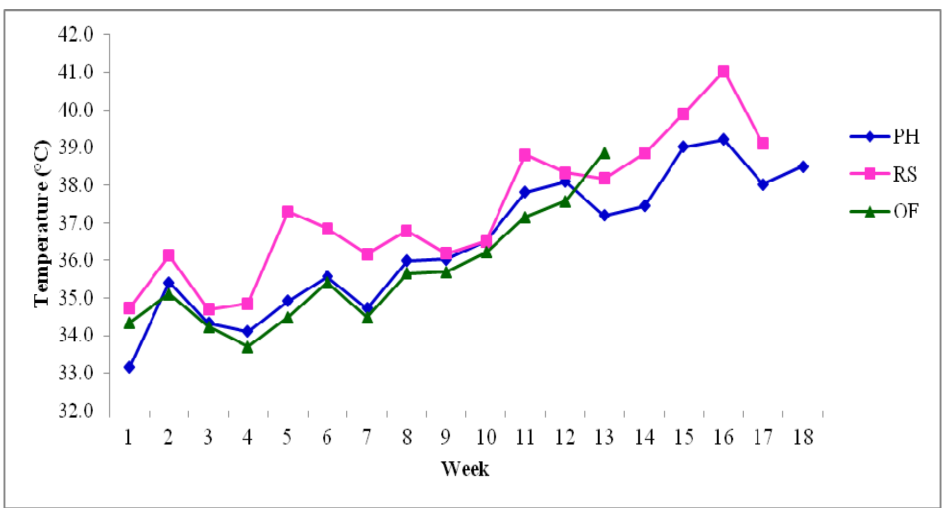

Fig 2. Weekly variation in maximum temperature

4.4.2 Relative humidity (%)

For the crops transplanted on 1 and 10 December 2014 the highest value of 57.6% and 59% weekly minimum relative humidity were recorded in the open field during the second and first week following transplanting whereas it was 49% for the crops planted in open field on 10 and 20 January 2015 (week 9 and 7 following transplanting). The lowest values of weekly minimum relative humidity 25.1% for the different growing season (1 and 10 December 2014, 1 and 10 January 2015) were recorded in the polyhouse. Regardless of the dates of transplanting the highest and the lowest values weekly minimum relative humidity were consistently recorded in the open field and polyhouse respectively (Fig. 3).

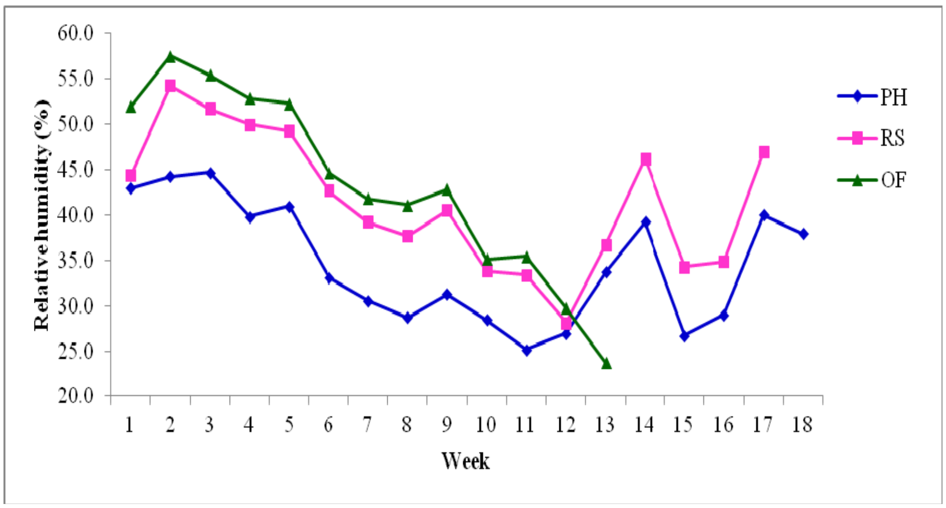

Fig 3. Weekly variation in minimum relative humidity

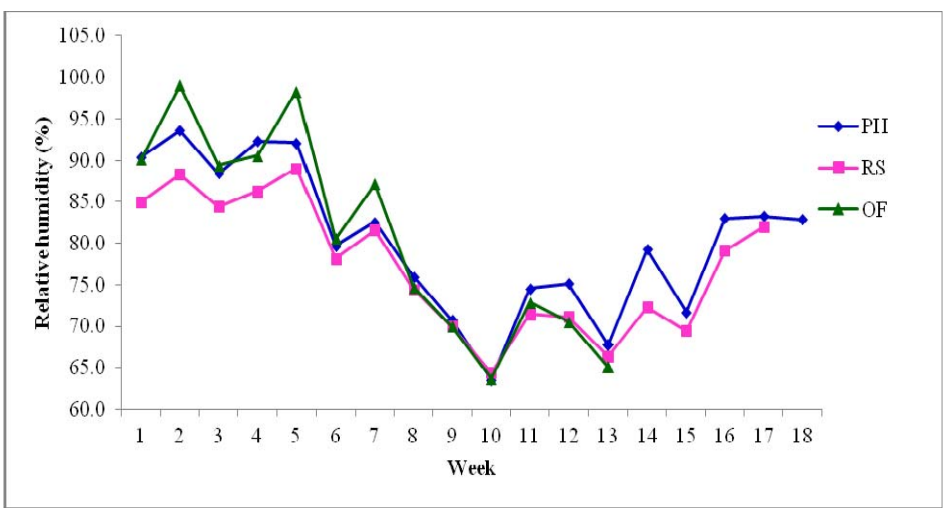

Fig 4. Weekly variation in maximum relative humidity

For the crops transplanted on 1 and 10 December 2014 the highest value of 98.3% weekly maximum relative humidity were recorded in the open field during the second and first week following transplantation whereas it was 87.1% and 83.4% respectively for the crops planted in open field on 10 and 20 January 2015 in the week 2 and 9 following transplanting. In general both the maximum and minimum weekly relative humidity showed a decreasing trend regardless of the dates of transplanting (Fig. 4).

4.4.3 Soil temperature (°C)

The highest minimum soil temperature (28.5°C) for the entire growing season was recorded in the open field condition while the lowest minimum soil temperature for the first and second crop was recorded inside the rain shelter (21.8°C). The lowest minimum soil temperature (21.8°C and 22.6°C) during the third and fourth crop season was recorded in the open field and inside the polyhouse. The highest maximum soil temperatures of 55.7°C and 62.6 °C were during the 10 and 20 January planted crops the open field. Overall the minimum and maximum had an increasing trend all throughout the four growing period regardless of the dates of transplanting (Fig. 5 and 6).

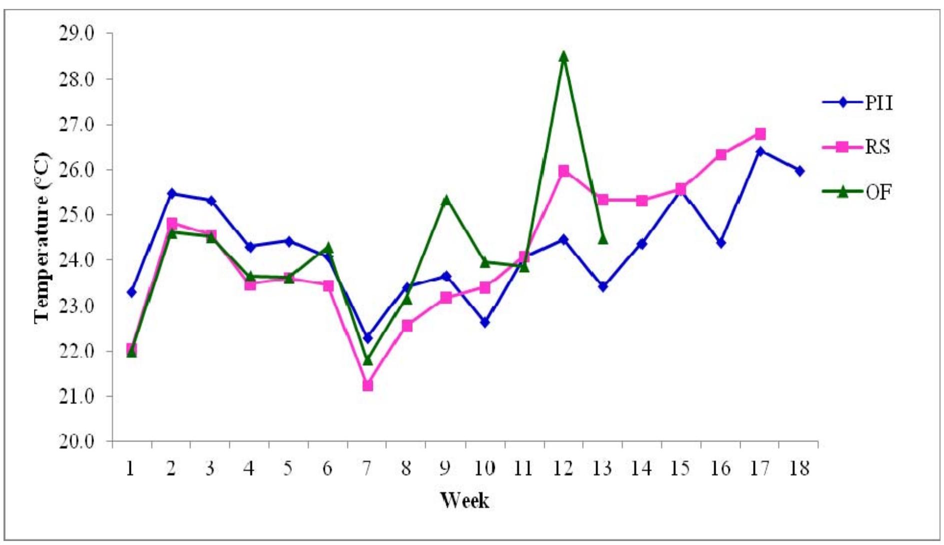

Fig 5. Weekly variation in minimum soil temperature

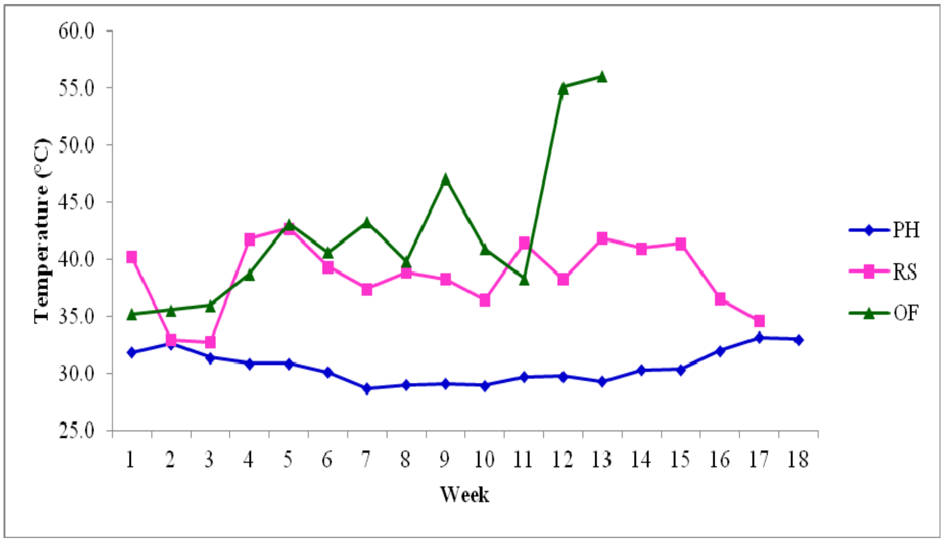

Fig 6. Weekly variation in maximum soil temperature

4.4.4 Soil moisture (%)

The highest and lowest values (40.4% and 19.4% respectively) of average soil moisture during the 01 December 2014 and 10 December 2014 growing season was recorded in the open field and the rain shelter, whereas for the 10 January 2015 and the 20 January 2015 crop the highest and lowest values were 34.6% and 19.4% recorded inside the polyhouse and rain shelter respectively (Fig. 7).

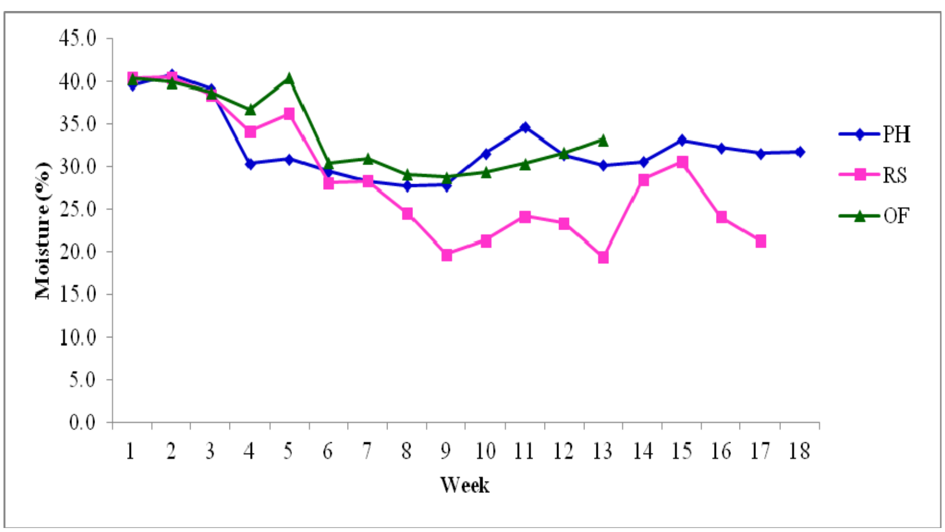

Fig 7. Weekly variation in soil moisture

4.4.5 UV radiations (Wm^{-2})

The lowest values of UV radiation were observed for crops planted on 1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015 were recorded inside the polyhouse (1.5, 3.6, 1.8 and 1.5 Wm^{-2} respectively) while the highest value were recorded in the open field condition (74.6, 83.3, 76.5, 83.3 Wm^{-2}).

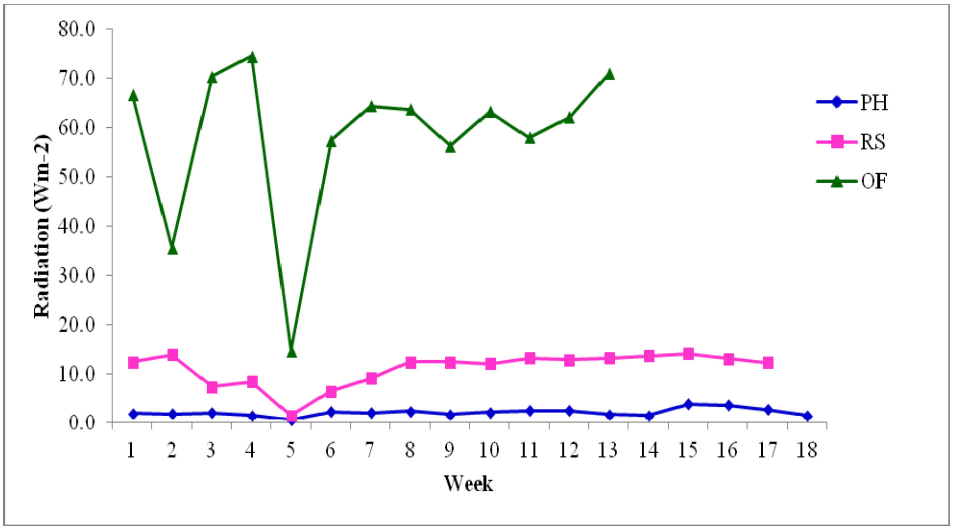

Fig 8. Weekly variation in UV radiation

The UV radiation in the open field condition showed an increasing trend from December 2014 to March 2015 while it was more or less the same inside the polyhouse and rain shelter throughout the entire growing period (Fig.8).

4.4.6 Canopy temperature (°C)

The highest weekly canopy temperature for the crops transplanted on 1 December 2014 was recorded inside the rain shelter (40.4 °C) whereas the least value 24.8 °C was recorded in the open field. For the crop transplanted on 10 December 2014, the highest value of canopy temperature (43.3°C) was recorded inside the rain shelter and the least value (25.8°C) was recorded inside the polyhouse. During the third crop transplanted on 10 January 2015 season both the highest and the lowest values were obtained inside the polyhouse (40.5°C and 25.3°C) while for the fourth crop transplanted on 20 January 2015 the highest value of 37.2°C and lowest value of 27.9°C were recorded in the rain shelter and polyhouse respectively (Fig. 9).

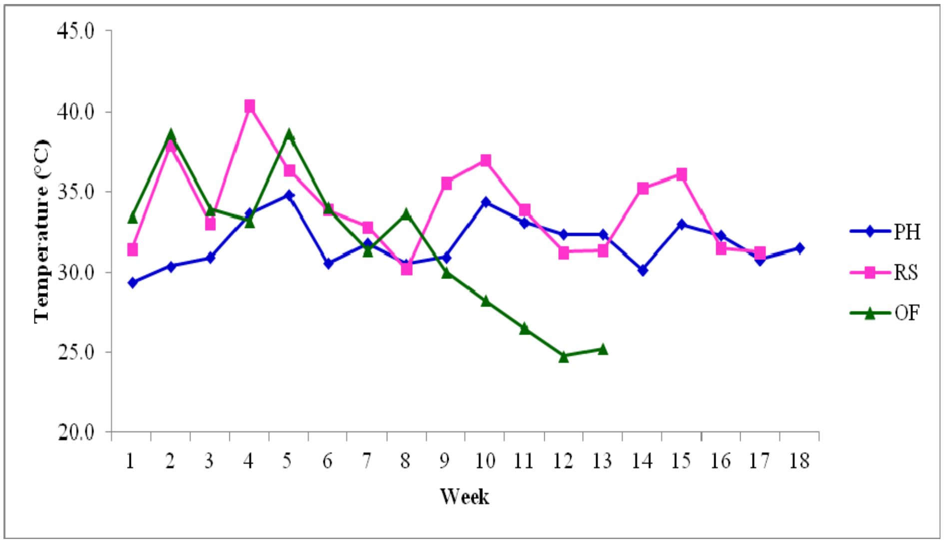

Fig 9. Weekly variation in canopy temperature

4.4.7 Canopy air temperature difference (CATD)

The highest weekly canopy air temperature difference for the crops transplanted on 10 December 2014 was recorded in the open field (2.9°C) whereas the least value were recorded on crop inside polyhouse (-4.9°C). For the second season crop the both highest and lowest value of CATD (2.6°C and -5.0°C) was recorded in the open field. During the third crop season the highest value of CATD (1.7°C) was recorded in the open field and the least value (-5.0°C) was recorded inside the polyhouse. While for the fourth crop season the highest value of 1.0°C and lowest value of -3.8°C were recorded in the open field and polyhouse respectively (Fig. 10).

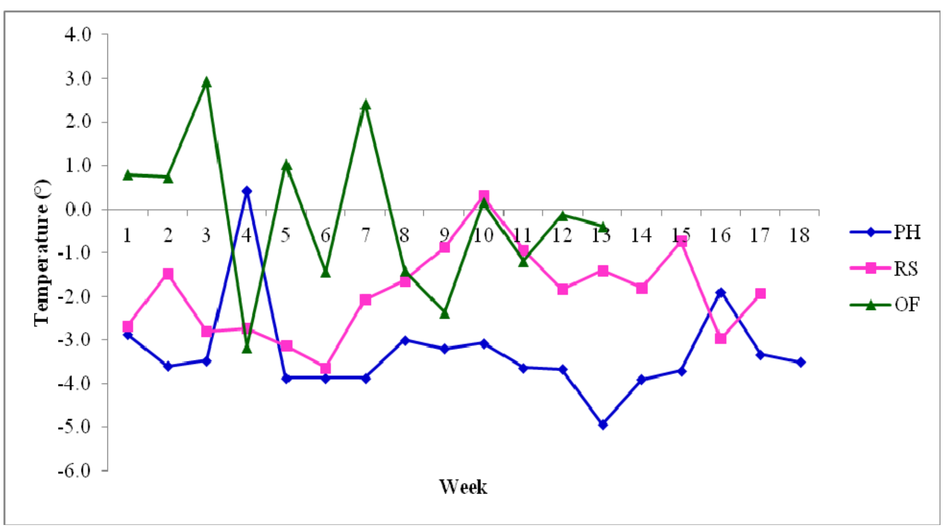

Fig 10. Weekly variation in canopy air temperature difference

4.4.8 Photosynthetically active radiation (PAR)

The least weekly photosynthetically active radiation for all the four growing period was recorded inside the polyhouse and rain shelter (103.88 Wm^{-2}) whereas, the highest value was observed (1321 Wm^{-2}) for the crop transplanted on 1 December 2014. The crops planted in the open field on 10 December 2014, 10 January and 20 January, 2015 recorded PAR of 1300 Wm^{-2} (Fig. 11).

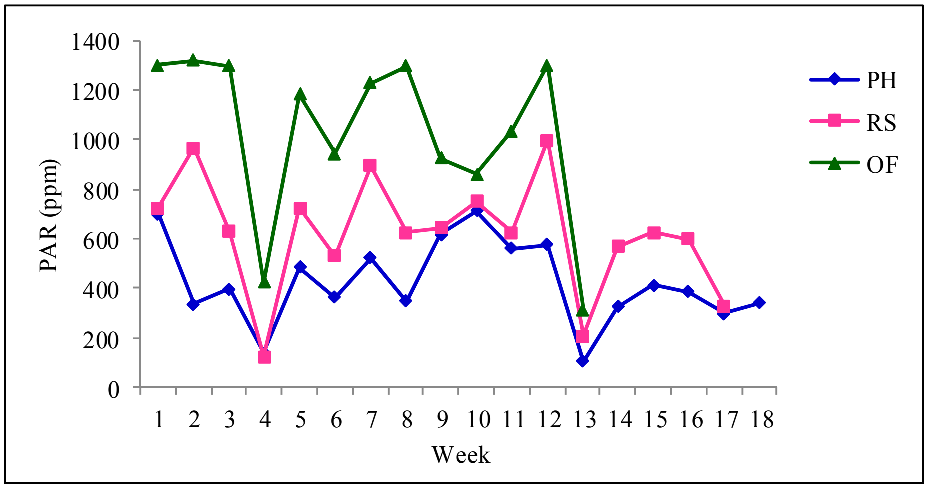

Fig 11. Weekly variation in photosynthetically active radiation

4.4.8 Solar radiation (Wm^{-2})

The highest solar radiation for the crop transplanted in open filed on 1 and 10 December 2014, 1 and 10 January 2015 were 705, 716.6, 712.9 and 712.8 Wm^{-2} respectively whereas in the rain shelter and poly house it was 203, 201.2, 243.4 and 243.5 Wm^{-2} respectively for the same dates of transplanting (Fig. 12).

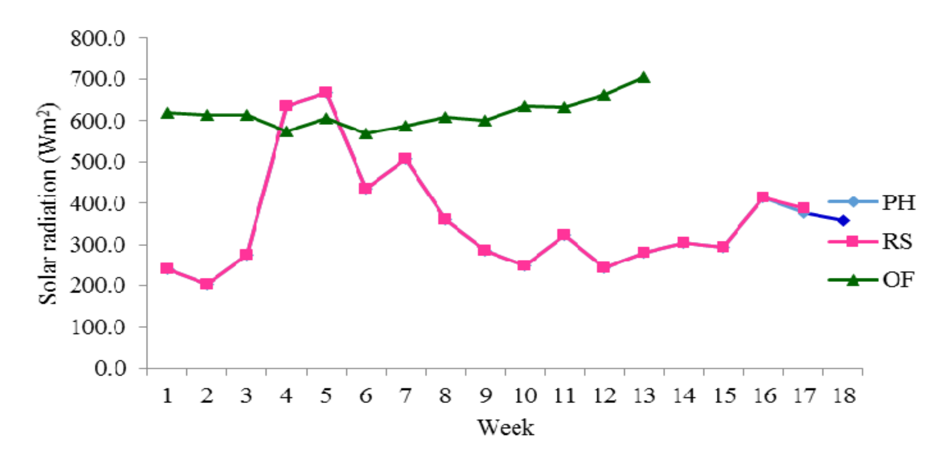

Fig 12. Weekly variation in Solar radiation

4.5 CROP WEATHER RELATIONSHIPS

4.5.1 Biometric Observation

4.5.1.1 Maximum height

The weekly height showed a significant negatively correlation between maximum soil temperature (-0.66, -0.601, -0.785, -0.83), UV radiation (-0.78, -0.731, -0.781, -0.751), CATD (-0.692, -0.687, -0.807, -0.81) and PAR (-0.8, -0.874, -0.596, -0.626) during vegetative, flowering, fruiting and harvesting stages respectively. Solar radiation (-0.591, -0.558, -0.769) had a negative correlation during vegetative, fruiting and harvesting stage. Whereas maximum relative humidity (-0.594, -0.738) and minimum soil temperature (-0.551 and -0.735) showed a significantly negative correlation during fruiting and harvesting stage respectively, Canopy temperature during first, sixth week (-0.555, -0.536) and vegetative stage (-0.363) also showed a negatively significance.

Positive correlations were obtained with minimum relative humidity during first, third, fourth, eighth week (0.356, 0.434, 0.365, 0.375) and vegetative, flowering stage (0.375 and 0.384) respectively. Minimum soil temperature during first, second, third week (0.377, 0.353, and 0.5) and vegetative stage (0.564) showed a negative correlation with plant height (Table 17 and 18).

Table 17. Correlation between height and different weather parameters during weeks after planting

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.788	-0.705	NS	NS	NS	-0.350	-0.484	-0.686	-0.839
T_{min}	NS	NS	NS	-0.411	NS	NS	NS	NS	NS
T_{max}	-0.365	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	0.356	NS	0.434	0.365	NS	NS	NS	0.379	NS
RH-II	NS	NS	NS	NS	NS	-0.521	-0.574	-0.581	-0.596
ST_{min}	0.377	0.353	0.500	NS	NS	NS	-0.469	-0.539	-0.691
ST_{max}	-0.557	-0.632	-0.603	-0.612	-0.697	-0.734	-0.791	-0.764	-0.806
SM	0.353	NS	NS	NS	NS	NS	-0.538	-0.393	NS
UV	-0.750	-0.758	-0.681	-0.768	-0.613	-0.770	-0.774	-0.778	-0.781
CT	-0.555	NS	NS	NS	NS	-0.536	NS	NS	NS
CATD	-0.782	NS	-0.721	-0.387	-0.709	-0.736	-0.823	-0.400	-0.600
PAR	-0.645	-0.645	-0.767	-0.754	-0.811	-0.397	-0.477	NS	-0.431

Table 18. Correlation between height and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.591	NS	-0.558	-0.769
T_{min}	NS	-0.387	NS	NS
T_{max}	NS	NS	NS	NS
RH-I	0.375	0.384	NS	NS
RH-II	NS	NS	-0.597	-0.738
ST_{min}	0.564	NS	-0.551	-0.735
ST_{max}	-0.660	-0.601	-0.785	-0.830
SM	NS	NS	NS	NS
UV	-0.780	-0.731	-0.781	-0.751
CT	-0.363	NS	NS	NS
CATD	-0.692	-0.687	-0.805	-0.810
PAR	-0.800	-0.874	-0.596	-0.626

5.5.1.2 Maximum LAI

The leaf area index showed a negatively correlation with Solar radiation (-0.621, -0.561, -0.697, -0.552), UV radiation (-0.639, -0.651, -0.642, -0.401), CATD (-0.583, -0.465, -0.362, -0.461) during vegetative, flowering, fruiting and harvesting stage. Whereas maximum soil temperature (-0.473, -0.606, -0.539) showed a significant negative correlation during vegetative, fruiting and harvesting stage and minimum relative humidity showed negative correlation during flowering (-0.401) and fruiting stages (-0.458). Soil moisture during fruiting stage (-0.434), week 6 (-0.402) and week7 (-0.423) also had a negative correlation with LAI. The only parameter influenced the LAI positively was the canopy temperature during eighth week (0.408) after planting (Table 19 and 20).

Table 19. Correlation between LAI and different weather parameters during weeks after planting

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.478	-0.511	-0.474	-0.467	-0.641	-0.665	-0.677	-0.660	-0.459
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	-0.376	NS	-0.355	NS	-0.373	NS	-0.429	-0.442
ST_{min}	NS	NS	-0.402	NS	NS	NS	NS	NS	NS
ST_{max}	-0.418	-0.514	-0.412	NS	-0.691	-0.429	-0.546	-0.589	-0.530
SM	NS	NS	NS	NS	NS	-0.402	-0.423	NS	NS
UV	-0.575	-0.567	-0.699	-0.612	-0.535	-0.643	-0.620	-0.593	-0.611
CT	NS	NS	NS	NS	NS	-0.405	NS	0.408	NS
CATD	-0.481	-0.508	-0.462	-0.367	-0.410	NS	-0.451	NS	NS
PAR	-0.423	NS	NS	NS	-0.403	NS	NS	NS	NS

Table 20. Correlation between LAI and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.621	-0.561	-0.697	-0.552
T_{min}	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	NS
RH-II	NS	-0.401	-0.458	NS
ST_{min}	NS	NS	NS	NS
ST_{max}	-0.473	NS	-0.606	-0.539
SM	NS	NS	-0.434	NS
UV	-0.639	-0.651	-0.642	-0.401
CT	NS	NS	NS	NS
CATD	-0.583	-0.465	-0.362	-0.461
PAR	NS	NS	NS	NS

4.5.1.3 Biomass at the time of last harvest (t ha^{-1})

The correlation between biomass at the time of last harvest and different weather parameters was found out and is presented in the Table (21 and 22) for all the four dates of transplanting. It showed strong negatively significant correlation with solar radiation (-0.863, -0.701, -0.850, -0.722), maximum relative humidity (-0.588, -0.666, -0.743, -0.458), maximum soil temperature (-0.701, -0.627, -0.726, -0.821), UV radiation (-0.806, -0.723, -0.782, -0.781), CATD (-0.785, -0.694, -0.621, -0.674), PAR (-0.827, -0.505, -0.761, -0.696) throughout vegetative, flowering, fruiting and harvesting stage respectively. Soil moisture had negative correlation during vegetative (-0.406) and flowering (-0.469) and canopy temperature also showed negatively correlation during fruiting stage (-0.382).

Biomass exhibited a positively correlation with minimum temperature (0.422, 0.473, 0.694) throughout vegetative, fruiting and harvesting stage. Maximum temperature had positive correlation during fruiting (0.387) and harvesting stage (0.403). Minimum relative humidity also had positive correlation during harvesting stage (0.722).

Table 21. Correlation between biomass at the time of last harvest and different weather parameters (tons ha^{-1})

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.525	-0.519	-0.476	-0.554	-0.765	-0.734	-0.861	-0.823	-0.679
Tmin	0.451	NS	NS	NS	0.490	NS	0.427	0.497	0.362
Tmax	NS	NS	NS	0.351	NS	NS	0.393	NS	NS
RH-I	NS	-0.353	NS	NS	NS	NS	NS	NS	NS
RH-II	-0.438	-0.621	-0.620	-0.610	-0.600	NS	NS	-0.656	-0.669
STmin	0.416	NS	NS	NS	NS	NS	NS	NS	-0.369
STmax	-0.679	-0.611	-0.648	-0.637	-0.761	-0.616	-0.744	-0.634	-0.850
ASM	NS	NS	-0.448	-0.403	-0.490	NS	NS	NS	NS
UV	-0.776	-0.756	-0.766	-0.778	-0.433	-0.801	-0.815	-0.820	-0.800
CT	NS	NS	0.354	NS	-0.551	-0.484	NS	NS	-0.387
CAT	-0.765	-0.447	-0.698	-0.455	-0.637	-0.485	-0.748	NS	-0.424
PAR	-0.840	-0.632	-0.786	NS	-0.640	-0.506	-0.674	-0.562	-0.721

Table 22. Correlation between biomass at the time of last harvest and different weather parameters (tons ha^{-1})

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.863	-0.701	-0.850	-0.722
Tmin	0.422	NS	0.473	0.694
Tmax	NS	NS	0.387	0.403
RH-I	NS	NS	NS	0.722
RH-II	-0.588	-0.666	-0.743	-0.458
STmin	NS	NS	NS	NS
STmax	-0.701	-0.627	-0.726	-0.821
ASM	-0.406	-0.469	NS	NS
UV	-0.806	-0.723	-0.782	-0.781
CT	NS	NS	-0.382	NS
CAT	-0.785	-0.694	-0.621	-0.674
PAR	-0.827	-0.505	-0.761	-0.696

4.5.2 Phenological Observation

4.5.2.1 Days to first flowering

Days to first flowering varied significantly for all the four dates of transplanting and the growing environment. The number of days to first flowering had positive correlation with maximum relative humidity during vegetative and flowering stage (0.619, 0.593). Whereas soil moisture had significant positive correlation during first, second, third week and vegetative stage (0.629, 0.617, 0.494 and 0.537).

Minimum soil temperature showed positive correlation during second, third and vegetative stage (0.406, 0.525, 0.501) respectively.

Days to first flowering had negative correlation with maximum temperature (-0.558, -0.646), minimum temperature (-0.515, -0.454), UV radiation (-0.489, -0.489), CATD (-0.479, -0.401) and PAR (-0.488, -0.680) during vegetative and flowering stage. Solar radiation exhibited negative correlation during the first week, second week and vegetative stage (-0.646, -0.536 and-0.350) (Table 23).

Table 23. Correlation between days to first flowering and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Vegetative stage	Flowering stage
SR	-0.646	-0.536	NS	0.415	NS	-0.350	NS
T_{min}	-0.467	NS	-0.402	-0.633	-0.563	-0.558	-0.646
T_{max}	-0.571	NS	-0.570	-0.454	-0.466	-0.515	-0.454
RH-I	0.544	0.555	0.646	0.587	0.513	0.619	0.593
RH-II	NS	NS	0.360	NS	0.382	NS	NS
ST_{min}	NS	0.406	0.525	NS	-0.501	0.542	NS
ST_{max}	-0.366	-0.542	NS	NS	-0.488	-0.428	NS
SM	0.629	0.617	0.494	NS	NS	0.537	NS
UV	-0.429	-0.454	-0.497	-0.476	-0.538	-0.489	-0.489
CT	-0.370	NS	NS	NS	NS	NS	NS
CATD	-0.483	NS	-0.413	NS	-0.419	-0.479	-0.401
PAR	NS	-0.488	-0.365	-0.712	-0.577	-0.488	-0.680

4.5.2.2 Days to first harvest

Days to first harvest had a positive correlation with maximum relative humidity (0.879, 0.896, and 0.670) throughout the vegetative, flowering and fruiting stage, minmum relative humidity (0.678 and 0.686) and soil moisture (0.821 and 0.505) during vegetative and flowering stages, canopy temperature (0.587 and 0.567) during flowering and harvesting stage, minimum soil temperature (0.644) during vegetative stage and solar radiation (0.636) during flowering stage.

Days to first harvest exhibited a strong negative correlation with minimum temperature (-0.839, -0.912, -0.858, -0.474), maximum temperature (-0.7410, -0.667, -0.758, -0.379) throughout vegetative, flowering, fruiting and harvesting stage, minimum soil temperature (-0.761, -0.731) and canopy air temperature difference (-0.353, -0.409) during fruiting and harvesting stage, minimum relative humidity

(-0.427) and maximum relative humidity (-0.453) during harvesting stage and PAR (-0.514) during flowering stage (Table 24 and 25).

Table 24. Correlation between days to first harvest and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.468	-0.350	NS	0.675	0.547	NS	NS	NS	-0.446
T_{min}	-0.774	NS	-0.636	-0.856	-0.859	-0.677	-0.899	-0.819	-0.617
T_{max}	-0.773	NS	-0.862	-0.738	-0.627	-0.706	-0.782	-0.777	-0.798
RH-I	0.796	0.778	0.875	0.844	0.757	0.806	0.573	0.626	-0.795
RH-II	0.616	0.655	0.739	0.685	0.757	NS	-0.364	NS	NS
ST_{min}	NS	0.623	0.782	NS	-0.476	-0.489	-0.779	-0.697	-0.763
ST_{max}	NS	-0.398	NS	NS	NS	NS	-0.415	-0.358	NS
SM	0.889	0.864	0.757	0.467	0.409	NS	-0.539	-0.691	-0.358
UV	NS	NS	NS	NS	NS	NS	NS	NS	NS
CT	NS	NS	NS	0.538	0.362	NS	NS	NS	NS
CATD	NS	NS	NS	NS	NS	-0.538	NS	NS	NS

Table 25. Correlation between days to first harvest and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	NS	0.636	NS	NS
T_{min}	-0.839	-0.912	-0.858	-0.474
T_{max}	-0.740	-0.667	-0.758	-0.379
RH-I	0.879	0.896	0.670	-0.453
RH-II	0.678	0.686	NS	-0.427
ST_{min}	0.644	NS	-0.761	-0.731
ST_{max}	NS	NS	NS	NS
SM	0.821	0.505	NS	NS
UV	NS	NS	NS	NS
CT	NS	0.587	NS	0.567
CATD	NS	NS	-0.353	-0.409
PAR	NS	-0.514	NS	NS

4.5.2.3 Days to last harvest

Days to last harvest was worked out for each treatment and its correlation with the various weather parameters are provided in the Table (26 and 27). The days to last harvest showed significant negative correlations with UV radiation (-0.526, -0.456, -0.547, -0.409), canopy air temperature difference (-0.428, -0.433, -0.565, -0.642) throughout vegetative, flowering, fruiting and harvesting stage, minimum temperature

(-0.632, -0.796, -0.697) and maximum temperature (-0.547, -0.468, -0.572) during vegetative, flowering, fruiting stage, maximum soil temperature (-0.422, -0.575, -0.595) during vegetative, flowering and fruiting stage, PAR during vegetative (-0.510) and flowering stage (-0.677), minimum soil temperature fruiting (-0.848) and harvesting stage (-0.872), solar radiation (-0.586) and morning relative humidity (-0.560) during harvesting stage.

Days to last harvest exhibited a significant positive correlation with maximum relative humidity (0.777, 0.805, and 0.612) throughout vegetative flowering and fruiting stage, early minimum relative humidity during vegetative (0.507) and flowering stage (0.484), canopy air temperature during flowering (0.565) and harvesting stage (0.615), Minimum soil temperature (0.589) and soil moisture (0.653) during vegetative stage.

Table 26. Correlation between days to last harvest and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.686	-0.587	NS	0.413	NS	NS	NS	-0.469	-0.702
T_{min}	-0.630	NS	-0.486	-0.795	-0.687	-0.613	-0.750	-0.674	-0.566
T_{max}	-0.586	NS	-0.729	-0.527	-0.449	-0.584	-0.606	-0.617	-0.645
RH-I	0.762	0.612	0.779	0.781	0.679	0.738	0.527	0.600	-0.727
RH-II	0.496	0.473	0.556	0.486	0.582	NS	-0.372	NS	-0.388
ST_{min}	NS	0.531	0.633	NS	-0.549	-0.481	-0.848	-0.753	-0.880
ST_{max}	-0.352	-0.641	NS	NS	-0.421	-0.372	-0.678	-0.590	-0.586
SM	0.755	0.697	0.589	0.356	NS	NS	-0.729	-0.735	-0.466
UV	-0.390	-0.495	-0.640	-0.482	-0.471	-0.557	-0.560	-0.521	-0.570
CT	NS	NS	NS	0.518	NS	NS	NS	NS	NS
CATD	-0.462	NS	-0.378	NS	-0.400	-0.661	-0.428	-0.444	NS
PAR	NS	-0.510	-0.398	-0.808	-0.479	NS	NS	NS	NS

Table 27. Correlation between days to last harvest and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	NS	NS	NS	-0.586
T_{min}	-0.632	-0.796	-0.697	NS
T_{max}	-0.547	-0.468	-0.572	NS
RH-I	0.777	0.805	0.612	NS
RH-II	0.507	0.484	NS	-0.560
ST_{min}	0.589	NS	-0.848	-0.872
ST_{max}	-0.422	NS	-0.575	-0.595
SM	0.653	NS	NS	NS
UV	-0.526	-0.456	-0.547	-0.409
CT	NS	0.565	NS	0.615
CATD	-0.428	-0.433	-0.565	-0.642
PAR	-0.511	-0.678	NS	NS

4.5.3 Yield and yield attributes

4.5.3.1 Percentage fruit set

The percent of fruit set occurred had significant negative correlation with the minimum temperature (-0.535, -0.7, -0.471), maximum temperature (-0.509, -0.425, -0.468), maximum soil temperature (-0.450, -0.390, -0.581), UV radiation (-0.554, -0.517, -0.563), CATD (-0.567, -0.476, -0.638), PAR (-0.577, -0.820, -0.356) throughout vegetative, flowering, fruiting stages respectively. Whereas solar radiation (-0.484) and canopy temperature (-0.371) had a significant negative correlation during vegetative stage. Minimum soil temperature had negatively significance during fruiting stage (-0.592). Minimum relative humidity showed negatively significance during seventh week (-0.46) and eighth week (-0.407).

It had a positively correlation with maximum relative humidity throughout vegetative (0.572), flowering (0.647) and fruiting stage (0.448). Minimum soil temperature (0.676) and soil moisture (0.48) had positively significance during vegetative stage. Solar radiation also had negatively significance during flowering stage (0.372) (Table 28 and 29).

Table 28. Correlation between percentage fruit set and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8
SR	-0.718	-0.651	NS	0.432	NS	NS	NS	-0.418
T_{min}	-0.577	NS	NS	-0.614	-0.602	NS	-0.607	-0.481
T_{max}	-0.631	NS	-0.536	-0.462	-0.407	-0.463	-0.553	-0.465
RH-I	0.548	0.471	0.582	0.574	0.569	0.469	0.473	0.622
RH-II	NS	NS	NS	NS	NS	NS	-0.460	-0.407
ST_{min}	NS	0.587	0.733	NS	NS	NS	-0.598	-0.551
ST_{max}	NS	-0.477	-0.441	-0.423	-0.435	-0.545	-0.618	-0.575
SM	0.594	0.586	0.474	NS	NS	NS	-0.512	-0.481
UV	-0.514	-0.545	-0.493	-0.544	-0.464	-0.563	-0.560	-0.553
CT	-0.540	NS	NS	NS	NS	NS	NS	NS
CATD	-0.559	NS	-0.564	NS	-0.562	-0.609	-0.564	-0.368
PAR	NS	-0.500	-0.557	-0.807	-0.636	NS	NS	NS

Table 29. Correlation between percentage fruit set and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage
SR	-0.484	0.372	NS
T_{min}	-0.535	-0.700	-0.471
T_{max}	-0.509	-0.425	-0.468
RH-I	0.572	0.647	0.448
RH-II	NS	NS	NS
ST_{min}	0.676	NS	-0.592
ST_{max}	-0.450	-0.390	-0.581
SM	0.480	NS	NS
UV	-0.554	-0.517	-0.563
CT	-0.371	NS	NS
CATD	-0.567	-0.476	-0.638
PAR	-0.577	-0.820	-0.356

4.5.3.2 Total Fruit yield

The correlation between total yield and different weather parameters was found out and is presented in the Table (30 and 31) for all the four dates of transplanting. It showed strong significant negative correlation with maximum temperature (-0.708,

-0.477, -0.806, 0.776), UV radiation (-0.711, -0.638, -0.721, -0.551), CATD

(-0.507, -0.623, -0.714, -0.684), PAR (-0.582, -0.765, -0.423, -0.426) throughout vegetative, flowering, fruiting and harvesting stage respectively. Whereas solar radiation showed a significant negative correlation during vegetative (-0.499), fruiting (-0.363) and harvesting stage (-0.648). Maximum temperature showed negative correlation during vegetative (-0.363), flowering (-0.363), and fruiting stage (-0.367). Minimum soil temperature had negative correlation during fruiting (-0.706) and harvesting stage (-0.852). Also minimum relative humidity showed negative correlation during harvesting stage (-0.675).

It had a positive correlation with maximum relative humidity throughout vegetative (0.498), flowering (0.480) and fruiting (0.497) and canopy temperature showed significant positive correlation during harvesting stage (0.494) (Table 39 and 40).

Table 30. Correlation between total yield / fruit yield per plant and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.604	-0.576	-0.387	NS	NS	-0.438	-0.449	-0.614	-0.704
T_{min}	-0.358	NS	NA	-0.475	-0.380	NA	-0.434	NS	NS
T_{max}	-0.407	NS	-0.440	-0.390	NS	-0.351	-0.373	NS	-0.396
RH-I	0.462	0.432	0.519	0.469	0.469	0.467	0.495	0.463	-0.402
RH-II	NS	NS	NS	NS	NS	NS	-0.489	-0.408	-0.438
ST_{min}	NS	NS	0.443	NS	-0.553	NS	-0.633	-0.677	-0.738
ST_{max}	-0.524	-0.752	-0.704	-0.492	-0.724	-0.615	-0.835	-0.814	-0.725
SM	0.398	0.369	NS	NS	NS	NS	-0.470	NS	NS
UV	-0.582	-0.759	-0.698	-0.659	-0.677	-0.709	-0.709	-0.678	-0.721
CT	NS	NS	NS	NS	NS	-0.561	NS	NS	NS
CATD	-0.553	NS	-0.446	-0.476	-0.609	-0.707	-0.533	-0.413	-0.500

Table 31. Correlation between total yield / fruit yield per plant and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.499	NS	-0.515	-0.648
T_{min}	NS	-0.435	NA	0.083
T_{max}	-0.363	-0.363	-0.367	NS
RH-I	0.498	0.480	0.497	NS
RH-II	NS	NS	NS	-0.675
ST_{min}	NS	NS	-0.706	-0.852
ST_{max}	-0.708	-0.477	-0.806	-0.776
SM	NS	NS	NS	NS
UV	-0.711	-0.638	-0.721	-0.551
CT	NS	NS	NS	0.494
CATD	-0.507	-0.623	-0.714	-0.684
PAR	-0.582	-0.765	-0.423	-0.426

4.5.9 Average Fruit weight

Average fruit weight showed a significant negatively correlation with solar radiation (-0.726, -0.537, -0.743, -0.65), UV radiation (-0.608, -0.478, -0.622, -0.454), CATD (-0.446, -0.510, -0.502, -0.485) throughout vegetative, flowering, fruiting and harvesting stage respectively. Maximum soil temperature during vegetative (-0.418), fruiting (-0.421) and harvesting stage (-0.616) also had negatively significance with average fruit weight. Minimum soil temperature (-0.396, -0.566) and soil moisture (-0.592, -0.692) showed negatively significance during fruiting and harvesting stage. Minimum relative humidity also had negatively correlation during harvesting stage (-0.372). The only parameter influenced the average fruit weight positively was the canopy temperature throughout second, third, eighth week, vegetative and harvesting stage (0.517, 0.461, 0.394, 0.524 and 0.365 respectively) (Table 32 and 33).

Table 32. Correlation between average fruit weight and different weather parameters

	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9
SR	-0.484	-0.524	-0.492	-0.457	-0.602	-0.721	-0.737	-0.736	-0.613
T_{min}	NS	NS	NS	NS	NS	NS	NS	NS	-0.370
T_{max}	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-I	NS	NS	NS	NS	NS	NS	NS	NS	NS
RH-II	NS	NS	NS	NS	NS	NS	NS	NS	-0.352
ST_{min}	NS	NS	NS	-0.511	NS	0.063	-0.542	-0.418	NS
ST_{max}	-0.455	-0.574	NS	NS	-0.388	NS	-0.545	-0.489	-0.572
SM	NS	NS	NS	NS	NS	-0.544	-0.586	-0.395	-0.621
UV	-0.497	-0.652	-0.582	-0.565	-0.511	-0.617	-0.641	-0.626	-0.684
CT	NS	0.517	0.461	NS	NS	NS	NS	0.394	NS
CATD	-0.451	-0.413	NS	-0.658	NS	-0.502	NS	-0.480	-0.351
PAR	-0.470	NS	-0.353	-0.503	NS	NS	NS	NS	NS

Table 33. Correlation between average fruit weight and different weather parameters

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
SR	-0.726	-0.537	-0.743	-0.650
T_{min}	NS	NS	NS	NS
T_{max}	NS	NS	NS	NS
RH-I	NS	NS	NS	NS
RH-II	NS	NS	NS	-0.372
ST_{min}	NS	NS	-0.396	-0.566
ST_{max}	-0.418	NS	-0.421	-0.616
SM	NS	NS	-0.592	-0.692
UV	-0.608	-0.479	-0.622	-0.454
CT	0.524	NS	NS	0.365
CATD	-0.446	-0.510	-0.502	-0.485
PAR	-0.398	-0.383	NS	NS

4.6 DIURNAL VARIATIONS IN WEATHER PARAMETERS

4.6.1 Temperature

The highest value of air temperature inside the poly house (35.3°C), rain shelter (34.9°C), open field (34.9°C) occurring around 17:00, 15:00 and 16:00 hours respectively while the lowest value were 22.4°C, 22.6°C and 22.5°C respectively recorded inside polyhouse, rain shelter, open field (Fig, 13).

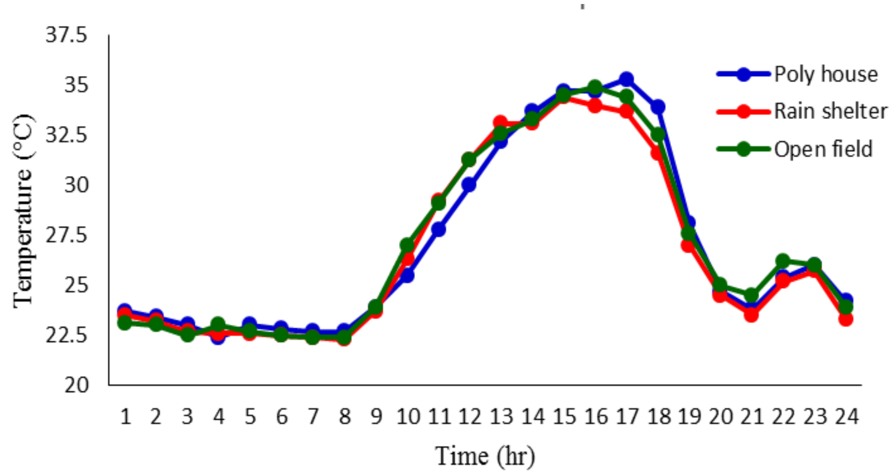

Fig 13. Diurnal variation in temperature

4.6.2 Relative humidity

The highest value of relative humidity inside the polyhouse, rain shelter and open field were 94%, 89%, 100% respectively whereas the lowest values were 32%, 43%, 47% correspondingly in the polyhouse, rain shelter and open field and occurred around 16:00,15:00,15:00 respectively (Fig. 14).

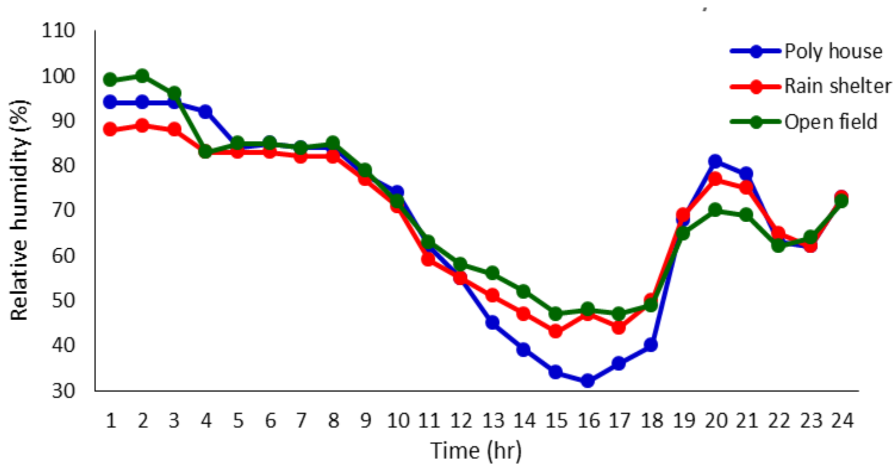

Fig 14. Diurnal variation in relative humidity

4.6.3. Solar radiation

The amount of solar radiation increased from around 09.00 hours in all the three growing environment. The peak value recorded in the open field and protected environment differed drastically. In open field condition the radiation reached up to 1048 Wm^{-2} whereas inside polyhouse and rain shelter it was below 400 Wm^{-2}. It is interesting to note that there was not much fluctuation within the protected environments compared to open field condition. The range of solar radiation the open field was almost around 0-1048 Wm^{-2} whereas under polyhouse and rain shelter it was 0-337 Wm^{-2} (Fig. 15).

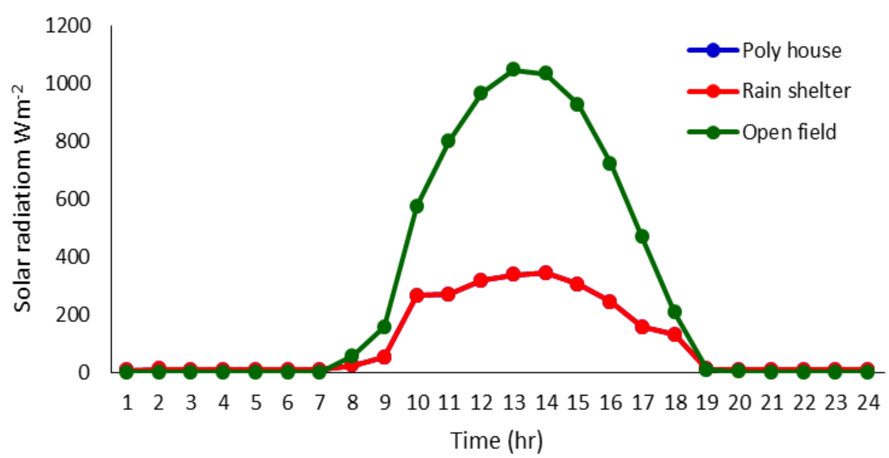

Fig. 15. Diurnal variation in solar radiation

4.6.4 UV radiation

The highest UV-B was recorded in the open field environment followed by rain shelter and polyhouse. The intensity of UV radiation increased from around

07:00 hours in the open field and reached the maximum (129 Wm^{-2}) around 12:00 hours. Where under rain shelter the UV radiation started to increase around 09:00 and reached the peak around 14:00 hours (17.75Wm^{-2}). The lowest intensity of UV radiation was recorded inside the polyhouse 13.35 Wm^{-2} (14:00 hours) (Fig. 16).

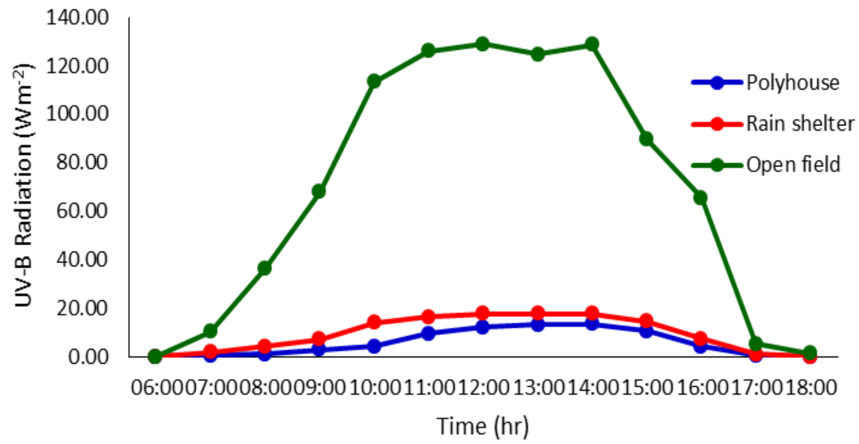

Fig 16. Diurnal variation in UV radiation

4.6.5 Soil temperature

The highest value of soil temperature recorded in the open field, rain shelter and polyhouse were 38.3°C, 32.6°C, 32.2°C occurred around 17:00 hours. The polyhouse, rain shelter and open field having extreme difference in their highest value. The least value were 23.7 °C, 23.0°C, 22.6 °C recorded inside the polyhouse, rain shelter and open field (Fig. 17).

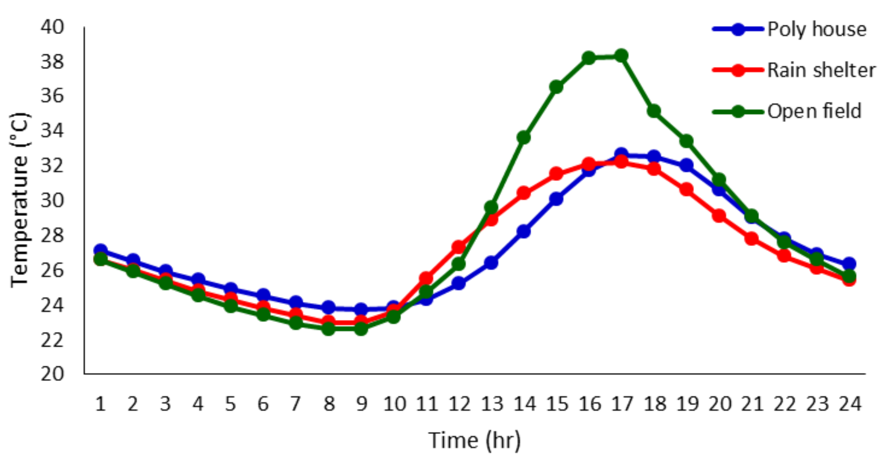

Fig 17. Diurnal variation in soil temperature

4.6.6 Soil moisture

Least soil moisture was recorded during the early morning hours in all the growing environment and it peak to the maximum by early evening hours, the maximum soil moisture inside the polyhouse is 41.1% whereas it was 40.7% in rain shelter and open field, minimum soil moisture inside polyhouse was 40.4% and it was 40.1% in rain shelter and open field (Fig. 18).

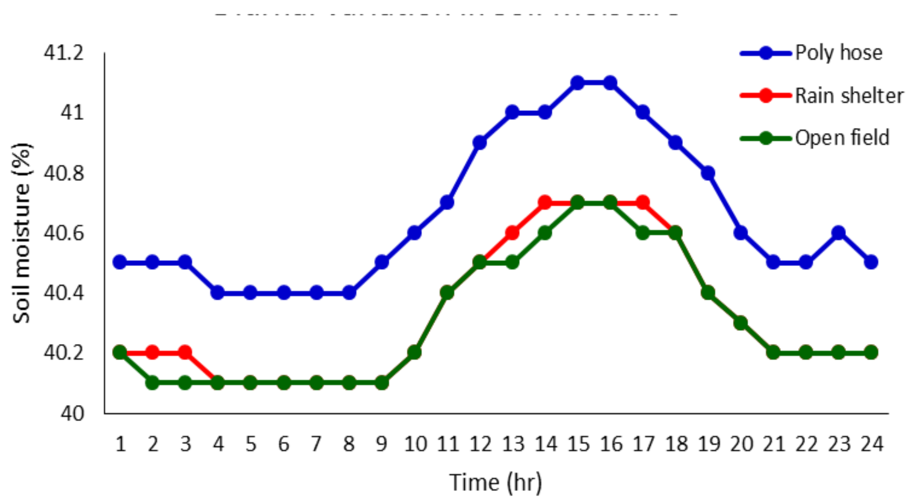

Fig 18. Diurnal variation in soil moisture

4.7 MULTIPLE REGRESSION MODELS DEVELOPED

Correlation matrices (Tables 17 to 33) were developed for tomato by using pooled data of four dates of planting and three growing environments. From the table it can be said that morphological, phenological and yield are highly correlated with weather parameters. Maximum plant height, Biomass, LAI, days to different phenological stages and yield were estimated using multiple regression models.

4.7.1 Morphological observation

4.7.1.1 Maximum height

Maximum height = 116.5–1.412 $UV_{(fru)}$ + 3.25 $RH\text{-}I_{(veg)}$ -5.97 $RH\text{-}I_{(fru)}$ ($R^2 = 0.85$)

Where, $RH\text{-}I_{(veg)}$ = Maximum relative humidity from vegetative stage (%)

$RH\text{-}I_{(fru)}$ = Maximum relative humidity from fruiting stage (%)

$UV_{(fru)}$ = UV radiation from fruiting stage (Wm^{-2})

4.7.1.2 Leaf area index

Leaf area index = 6.79 – 0.002 UV_2 - 0.08 ST_{min3} - 0.01 SM_5+ 0.01 SM_6 ($R^2 = 0.73$)

Where, SM_5 = Soil moisture from fifth week (%)

SM_6 = Soil moisture from sixth week (%)

ST_{min3} = Minimum soil temperature from third week (°C)

UV_2 = UV radiation from second week (Wm^{-2})

4.7.1.3 Biomass

Biomass = 4.071 – 0.002 $SR_{(veg)}$ – 0.04 $RH\text{-}II_{(fru)}$ + 0.004 $UV_{(flw)}$

Where, $SR_{(veg)}$ = Solar radiation from vegetative stage

$RH\text{-}II_{(fru)}$ = Minimum relative humidity from fruiting stage

$UV_{(flw)}$ = UV from flowering stage

4.7.2 Phenological Observation

4.7.2.1 Days to first flowering

Days to first flowering = 3.44 + 1.45 $ST_{min\,(veg)}$ -0.32 CT_3 - 0.2 CT_1 (R^2= 0.70)

Where, CT_1= Canopy temperature from first week (°C)

CT_3= Canopy temperature from third week (°C)

$ST_{min\,(veg)}$ = Minimum soil temperature from vegetative stage (°C)

4.7.2.2 Days to first harvest

Days to first harvest = 204.361- 6.02 $T_{min\,(flw)}$ (R^2= 0.83)

Where, $T_{min\,(flw)}$ = Minimum air temperature from flowering stage (°C)

4.7.2.3 Days to last harvest

Days to last harvest = 659.1 - 8.31 ST_{min9} - 11.7T_{min8} - 1.4 $RH\text{-}II_{(flw)}$ (R^2=0.98)

Where, T_{min8} = Minimum air temperature from eighth week (°C)

$RH\text{-}II_{(flw)}$ = Minimum Relative humidity from flowering stage (%)

ST_{min9} = Minimum soil temperature from ninth week (°C)

4.7.3 Yield and yield attributes

4.7.3.1 Per cent fruit set

Fruit set = 62.491–0.04 $PAR_{(flw)}$–1.9 $T_{min(flw)}$+ 5.25 $ST_{min(veg)}$–2.3 $T_{max(veg)}$

(R^2= 0.94)

Where, $T_{max\,(veg)}$ = Minimum temperature from flowering stage (°C)

$T_{min\,(flw)}$ = Minimum temperature from flowering stage (°C)

$PAR_{(flw)}$ = Photosynthetically active radiation from flowering stage (Wm^{-2})

$ST_{min\ (veg)}$ = Minimum soil temperature from vegetative stage (°C)

4.7.3.3 Total fruit yield

Total fruit yield = 634.94 - 22.5 $ST_{min\ (harv)}$ -0.7UV $_{(flw)}$ + 0.08 SR $_{(harv)}$ (R^2 = 0.80)

Where, $ST_{min\ (harv)}$ = Minimum soil temperature from harvesting stage (°C)

SR $_{(harv)}$ = Solar radiation from harvesting stage (Wm^{-2})

$UV_{(flw)}$ = UV radiation from flowering stage (Wm^{-2})

4.8 DSSAT MODEL VALIDATION

Four dates of transplanting (1 December 2014, 10 December 2014, 10 January 2015 and 20 January 2015) has been raised for validating CROPGRO-Tomato (DSSAT 4.5). The variety used for the study was Anagha. The Genetic coefficients for the variety Anagha were developed and presented in the Table (34).

Table 34. Genetic coefficients of Tomato

Parameter	Value
CSDL	12.33
PPSEN	0
EM-FL	24.8
FL-SH	0
FL-SD	32
SD-PM	50
FL-LF	50
LFMAX	18.6
SLAVR	350
SIZLF	990
XFRT	4.55
WTPSD	0.004
SFDUR	44
SDPDV	300
PODUR	36.5
THRSH	9.2
SDPRO	0.3
SDLIP	0

The observed and simulated yields of tomato using DSSAT 4.5 model for the open field crops was very accurate (Fig 19).

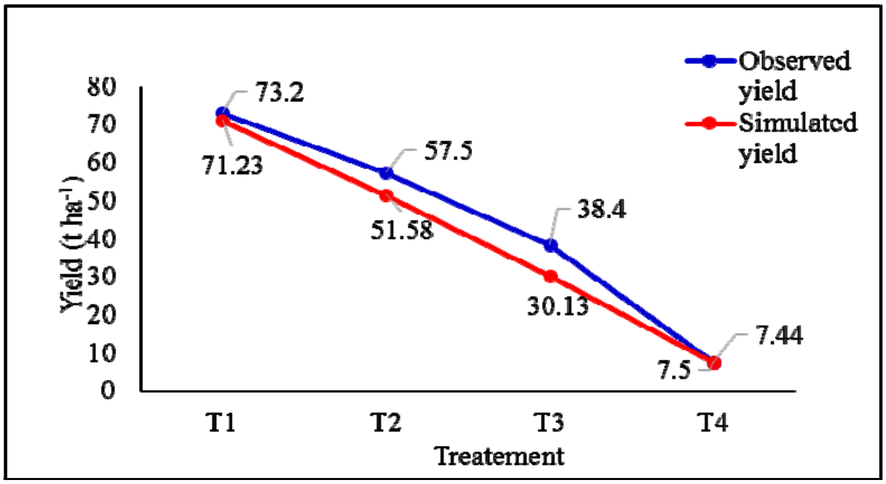

Fig 19. Observed and simulated yields of tomato using DSSAT model

Maximum yield observed was 73.2 t ha^{-1} during the crop transplanted on 01 December 2014. Lowest yield observed was 7.5 tha^{-1} on crop transplanted on 20 January 2015. RMSE for tomato prediction is 1.56 kg and R^2 value is (Table 35).

Table 35. RMSE and R^2 for DSSAT prediction

Model	RMSE	R^2
CROPGRO-Tomato	1.56	0.99

4.9 CLIMATE CHANGE IMPACT ON TOMATO

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model-DSSAT and predicted the future yield for the years 2030, 2050 and 2080. The climate data for the years 2030, 2050 and 2080 under different RCPs has been presented in the fig. (20 to 31)

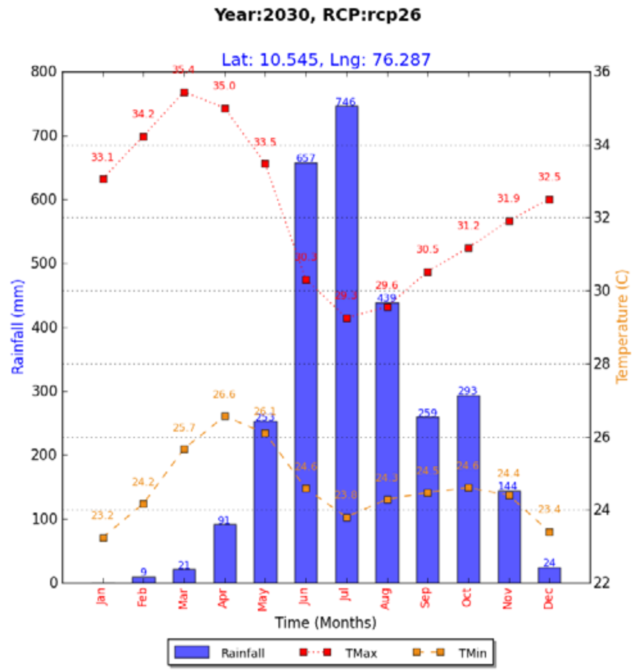

Fig 20. Climate of Vellanikkara in 2030s under RCP 2.6

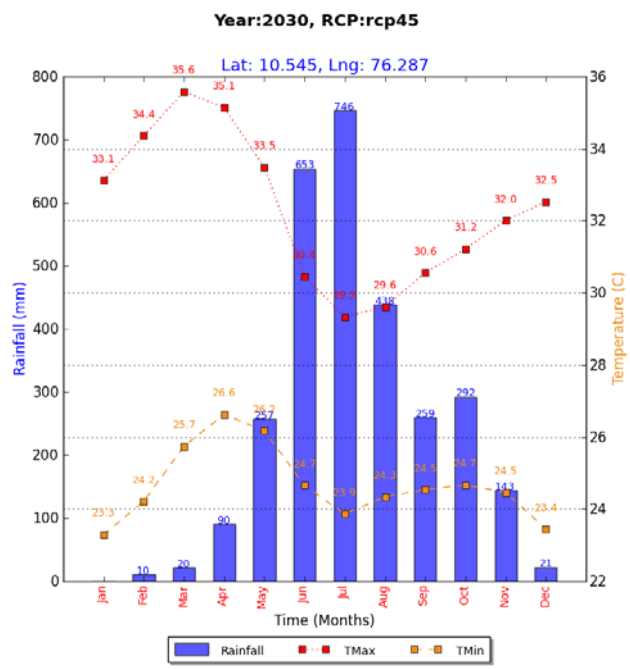

Fig 21. Climate of Vellanikkara in 2030s under RCP 4.5

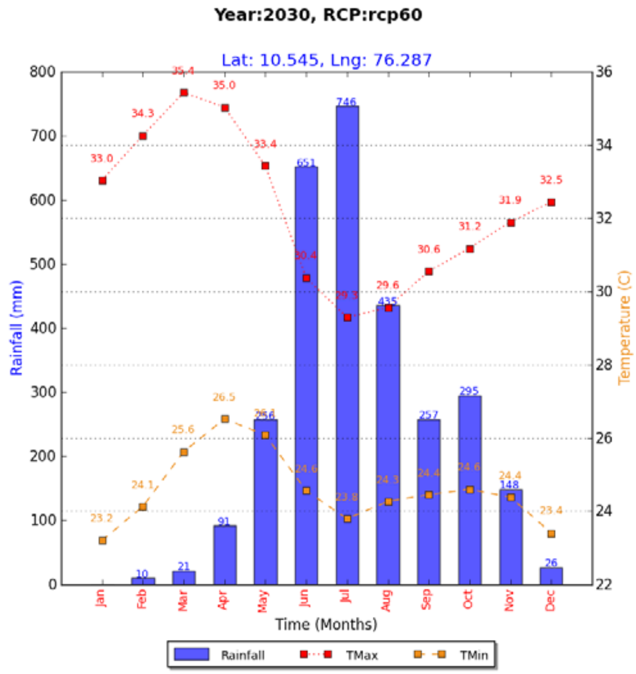

Fig 22. Climate of Vellanikkara in 2030s under RCP 6.0

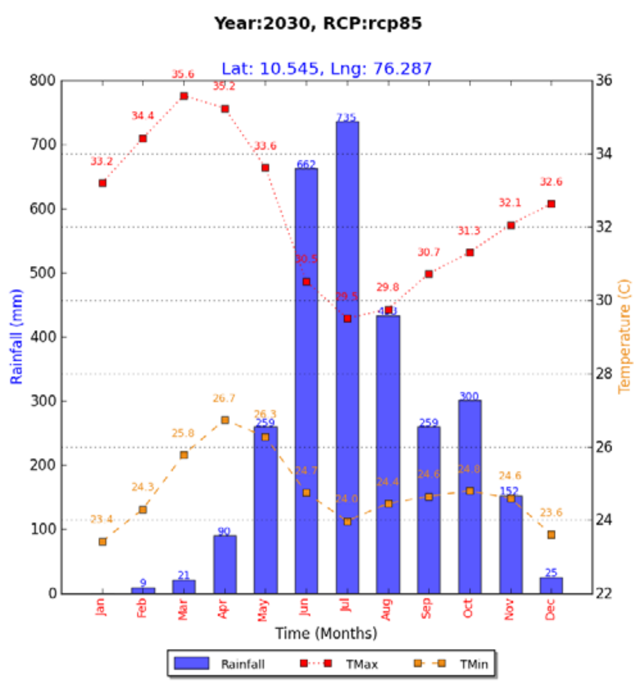

Fig 23. Climate of Vellanikkara in 2030s under RCP 8.5

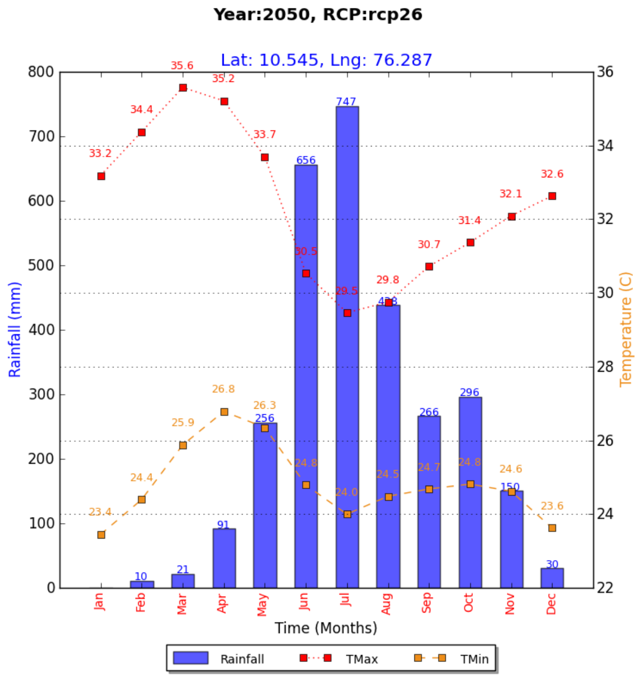

Fig 24. Climate of Vellanikkara in 2050s under RCP 2.6

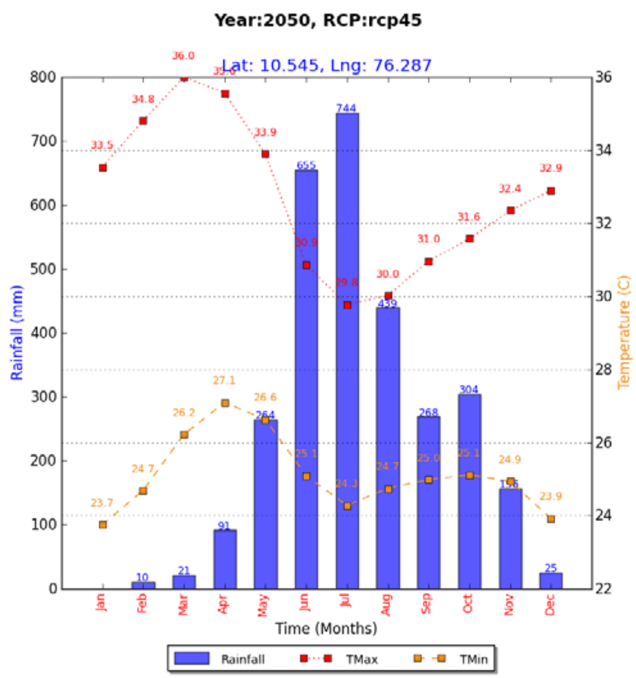

Fig 25. Climate of Vellanikkara in 2050s under RCP 4.5

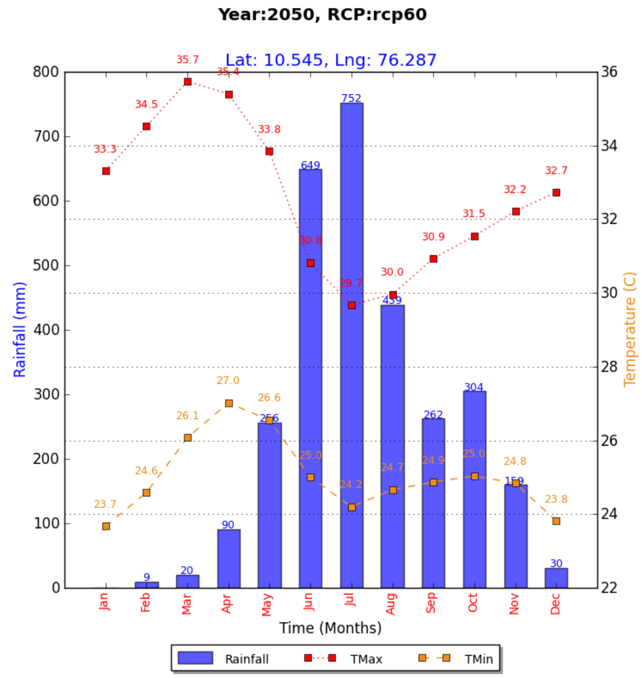

Fig 26. Climate of Vellanikkara in 2050s under RCP 6.0

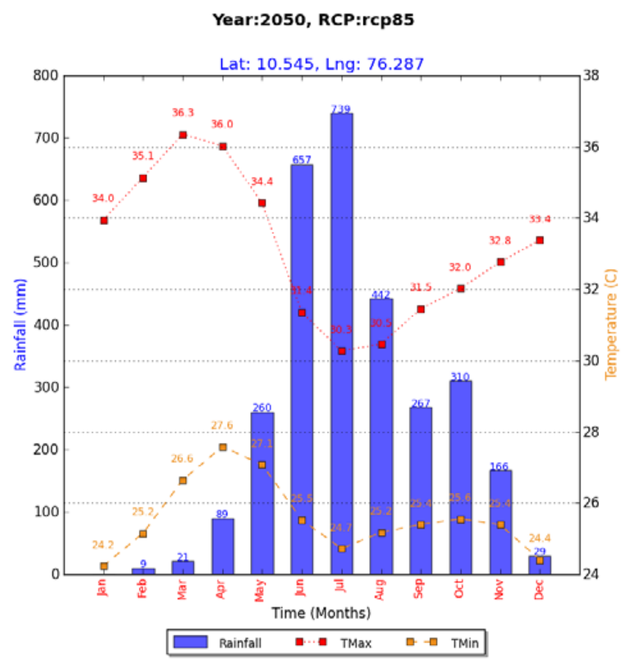

Fig 27. Climate of Vellanikkara in 2050s under RCP 8.5

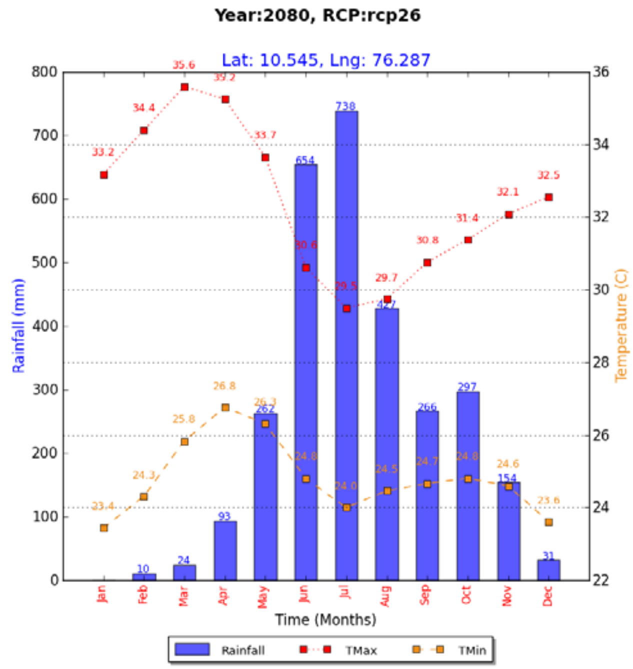

Fig 28. Climate of Vellanikkara in 2080s under RCP 2.6

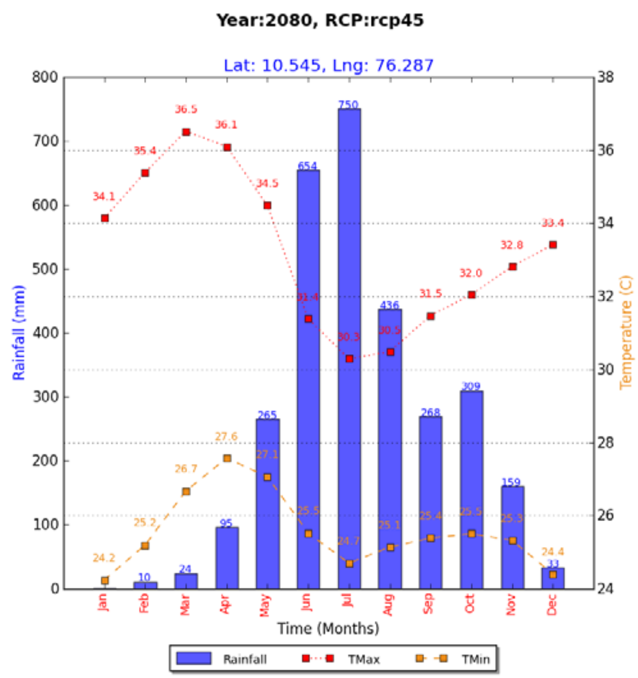

Fig 29. Climate of Vellanikkara in 2080s under RCP 4.5

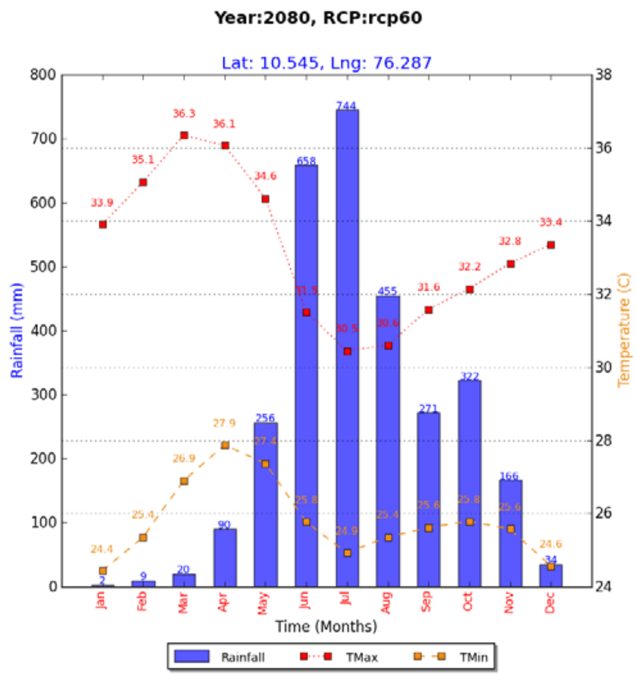

Fig 30. Climate of Vellanikkara in 2080s under RCP 6.0

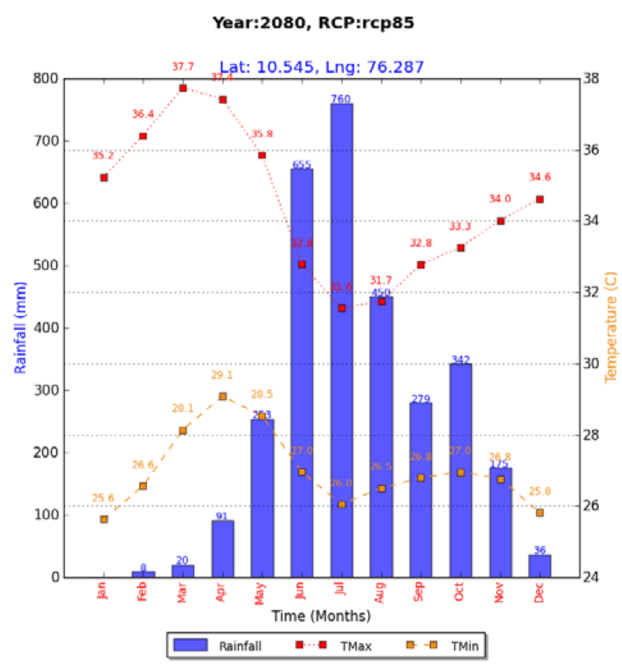

Fig 31. Climate of Vellanikkara in 2080s under RCP 8.5

4.9.1 RCP 2.6

Table 36. Per cent change in the yield (t ha^{-1})

Date of transplanting	Present yield (t ha^{-1})	Percentage reduction in yield (t ha^{-1})		
		2030	2050	2080
01-Dec-14	73.2	60.7 (28.8)	62.7 (27.31)	63.1 (26.99)
10-Dec-14	57.5	50.4 (28.5)	67.4 (18.76)	67 (18.97)
01-Jan-15	38.4	31.3 (26.4)	52.5 (18.25)	56.9 (16.56)
10-Jan-15	7.5	5.3 (7.1)	39.3 (4.55)	48.8 (3.84)

(Values in parenthesis shows the yield in tons per hectare)

As per the RCP 2.6 projections the yield for the years 2030, 2050 and 2080 will be significantly reduced compared to the present yields obtained. For the crops planted on 1 December 2014 the yield reduction was 60.7 percent, 62.7 percent and 63.1 per cent respectively for the years 2030, 2050 and 2080. For the second date of transplanting on 10 December the yield reduction was in the tune of 50.4, 67.4 and 67 percent respectively for the years 2030, 2050 and 2080. For the crops planted on 1 January 2015 the yield reduction was 31.3 per cent, 52.5 percent and 56.9 per cent respectively for the years 2030, 2050 and 2080 whereas it was 5.3 percent, 39.3 percent and 48.8 percent for 20 January 2015 (Table 36).

4.9.2 RCP 4.5

Table 37. Percent change in the yield (t ha^{-1})

Date of transplanting	Present yield (tha-1)	Percentage reduction in yield (t ha-1)		
		2030	2050	2080
01-Dec-14	73.2	62 (27.8)	61.8 (27.98)	62.6 (27.38)
10-Dec-14	57.5	71.3 (16.8)	64 (20.71)	66.7 (19.15)
10-Jan-15	38.4	52.8(18.12)	45.5 (20.94)	58.5 (15.94)
20-Jan-15	7.5	36.7 (4.75)	39.7 (4.52)	57.3 (3.2)

(Values in parenthesis shows the yield in tons per hectare)

As per the RCP 4.5 projections the yield for the years 2030, 2050 and 2080 will be significantly reduced compared to the present yields obtained. For the crops planted on 1 December 2014 the yield reduction was 62 percent, 61.8 percent and 62.6 per cent respectively for the years 2030, 2050 and 2080. For the second date of transplanting on 10 December 2014 the yield reduction was in the tune of 71.3, 64 and 66.7 percent respectively for the years 2030, 2050 and 2080. For the crops planted on 10st January 2015 the yield reduction was 52.8 per cent, 45.5 percent and 58.5 per cent respectively for the years 2030, 2050 and 2080 whereas it was 36.7 percent, 39.7 percent and 57.3 percent for the 20 January 2015 (Table 37).

4.9.3 RCP 6.0

Table 38. Per cent change in the yield (t ha^{-1})

Date of transplanting	Present yield (t ha^{-1})	Percentage reduction in yield (t ha-1)		
		2030	2050	2080
01-Dec-14	73.2	66.1 (24.8)	64.5 (25.99)	59.4 (29.7)
10-Dec-14	57.5	70.3 (17.08)	69.5 (17.54)	64.1 (20.63)
10-Jan-15	38.4	56.6 (16.68)	54.2 (17.58)	57.2 (16.43)
20-Jan-15	7.5	44.4 (4.17)	44.4 (4.17)	57.5 (3.19)

(Values in parenthesis shows the yield in tons per hectare)

As per the RCP 6.0 projections the yield for the years 2030, 2050 and 2080 will be significantly reduced compared to the present yields obtained. For the crops planted on 1 December 2014 the yield reduction was 66.1 percent, 64.5 percent and 59.4 percent respectively for the years 2030, 2050 and 2080. For the second date of transplanting on 10 December the yield reduction was in the tune of 70.3, 69.5 and 64.1 percent respectively for the years 2030, 2050 and 2080. For the crops planted on 10st January 2015 the yield reduction was 56.6 percent, 54.2 percent and 57.2 per cent respectively for the years 2030, 2050 and 2080 whereas it was 36.7 percent, 44.4 percent and 44.4 and 57.5 percent for the 20 January 2015 (Table 38).

4.9.4 RCP 8.5

Table 39. Per cent change in the yield (t ha^{-1})

Dates of transplanting	Present yield (t ha^{-1})	Percentage reduction in yield (t ha^{-1})		
		2030	2050	2080
01-Dec-14	73.2	64 (26.34)	63 (27.62)	41.1 (43.11)
10-Dec-14	57.5	67.3 (18.81)	66.1 (19.51)	55.2 (25.76)
10-Jan-15	38.4	52.6 (18.2)	52 (18.45)	82.4 (6.76)
20-Jan-15	7.5	38.5 (4.61)	50 (3.75)	86.9 (0.98)

(Values in parenthesis shows the yield in tons per hectare)

As per the RCP 8.5 projections the yield for the years 2030, 2050 and 2080 will be significantly reduced compared to the present yields obtained. For the crops planted on 1 December 2014 the yield reduction was 64 percent, 63 percent and 41.1 per cent respectively for the years 2030, 2050 and 2080. For the second date of transplanting on 10 December the yield reduction was in the tune of 67.3, 66.1 and 55.2 percent respectively for the years 2030, 2050 and 2080. For the crops planted on 1 January 2015 the yield reduction was 52.6 percent, 52 percent and 82.4 per cent respectively for the years 2030, 2050 and 2080 whereas it was 38.5 percent, 50 percent and 86.9 percent for 20 January 2015 (Table 39).

Discussion

This experiment were taken up to study the crop weather relationships in tomato under different growing environment, validating the DSSAT model and to predict the impact of climate change on the tomato production by 2030, 2050 and 2080. The results presented in the previous chapter are discussed here under.

5.1 MORPHOLOGICAL PARAMETERS

5.1.1 Plant height

The effect of dates of planting and growing environment had a significant effect on plant height (Fig 32 to 35). The crop planted inside the polyhouse recorded highest plant height in all the dates of planting. It can be also noticed that the plant height reduced considerably in the January planted crops irrespective of growing environment. The plant height was significantly less for the crops grown under open field conditions which experienced high amount of photosynthetically active radiation (above 400 Wm^{-2}) and Ultra violet radiation (Wm^{-2}). So it can be inferred from the study that high solar radiation in terms of PAR and UV had an inverse relationship with the vegetative vigour of tomato. Lower light intensities within the rain shelter and polyhouse retard the destruction of auxin (IAA) and thus promote cell division and cell expansion in the apical portion and hence plants have greater heights. Similar results have been noted by El-Aidy *et al.* (1988), and Abou Habid *et al* (1994).

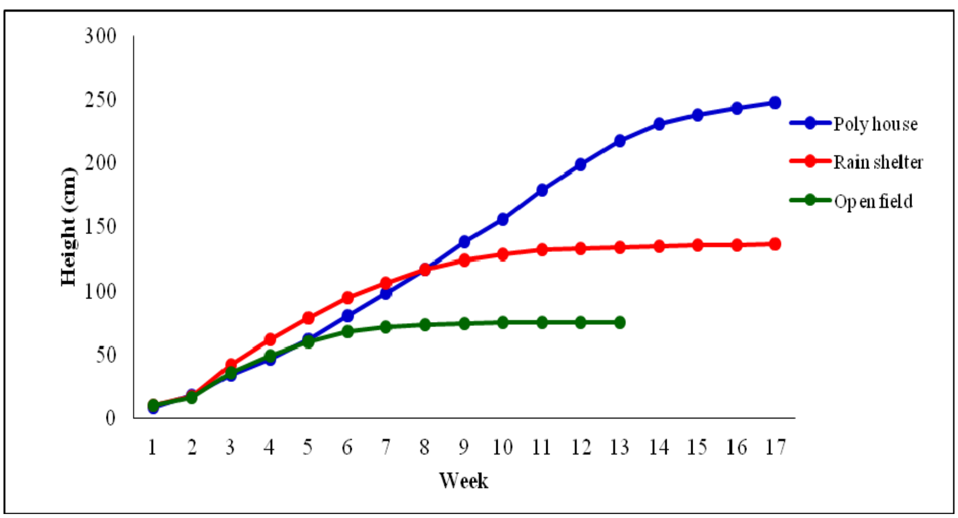

Fig 32.Weekly variation in plant height, Date of transplanting 01 December 2014

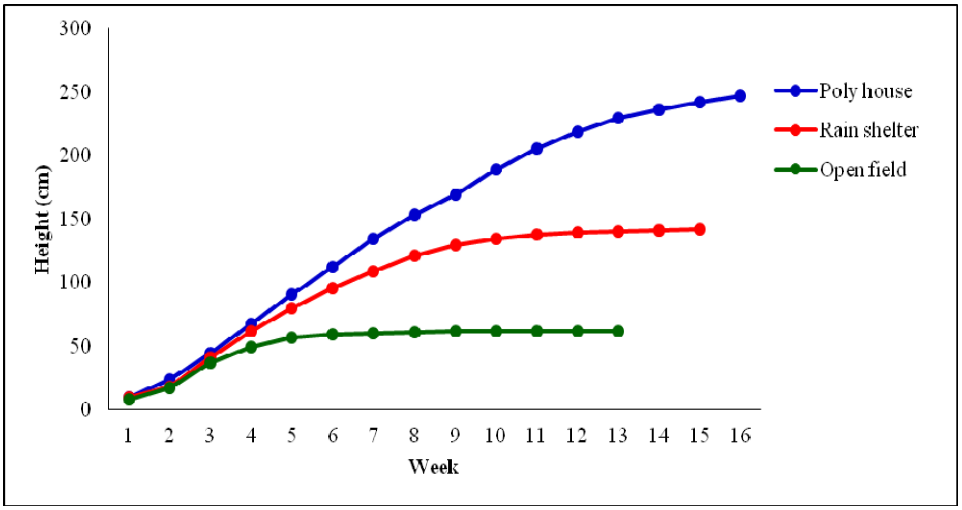

Fig 33.Weekly variation in plant height, Date of transplanting 10 December 2014

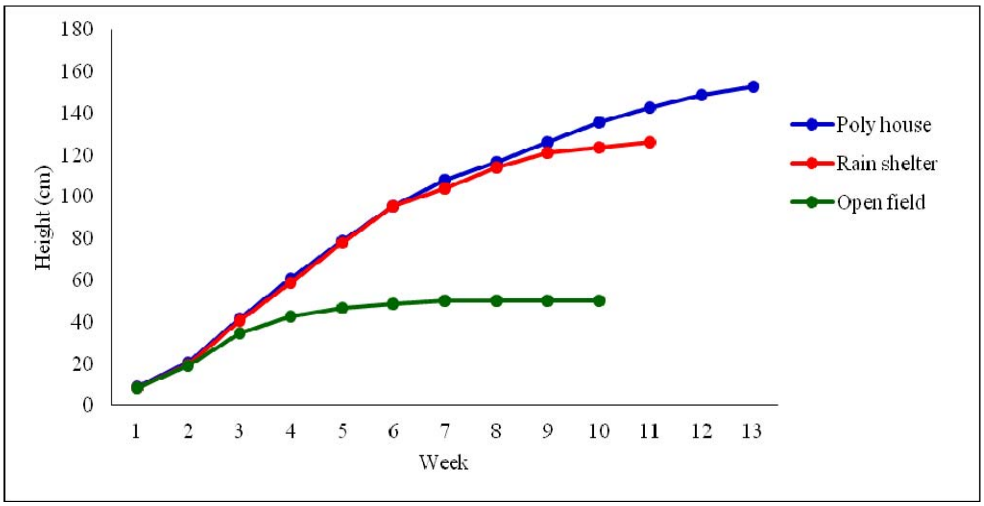

Fig 34. Weekly variation in plant height, Date of transplanting 10 January 2015

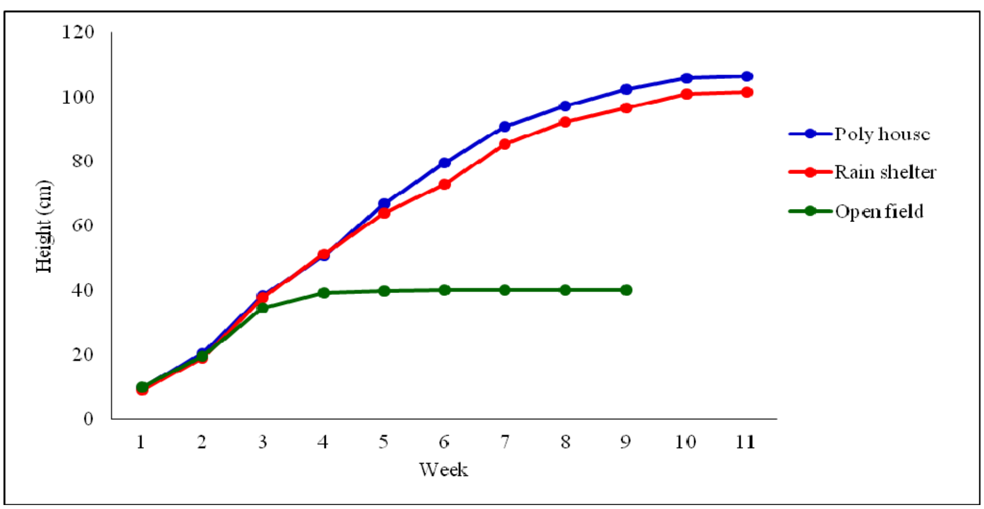

Fig 35. Weekly variation in plant height, Date of transplanting 20 January 2015

5.1.2 Leaf area index

LAI was significantly influenced by the growing environment and dates of transplanting (Fig 36 to 39). The maximum LAI value of 3.8 was observed among the crops transplanted in the open field on 1 December 2014 and in the crops transplanted inside the rain shelter and polyhouse on 20 January 2015. Crops grown inside the polyhouse and rain shelter yielded maximum LAI values. The maximum values of LAI were obtained during the flowering and fruiting stage.

LAI showed a significant negative correlation with solar radiation, minimum relative humidity, minimum and maximum soil temperature, average soil moisture, UV-B radiation, canopy temperature and canopy air temperature difference. The LAI of the crops in the protected structures were consistently higher and prolonged, thus exhibiting more vegetative vigour when compared to the crops in the open field.

The higher LAI in the crops under the rain shelter and polyhouse may be due to lower solar radiation within the rainshelter and polyhouse. Lower solar radiations throughout the different growth stages promote leaf expansion which is needed for better light interception. Similar results were reported by Watson (1952), Milthorpe (1959) and Cockshull (1992).

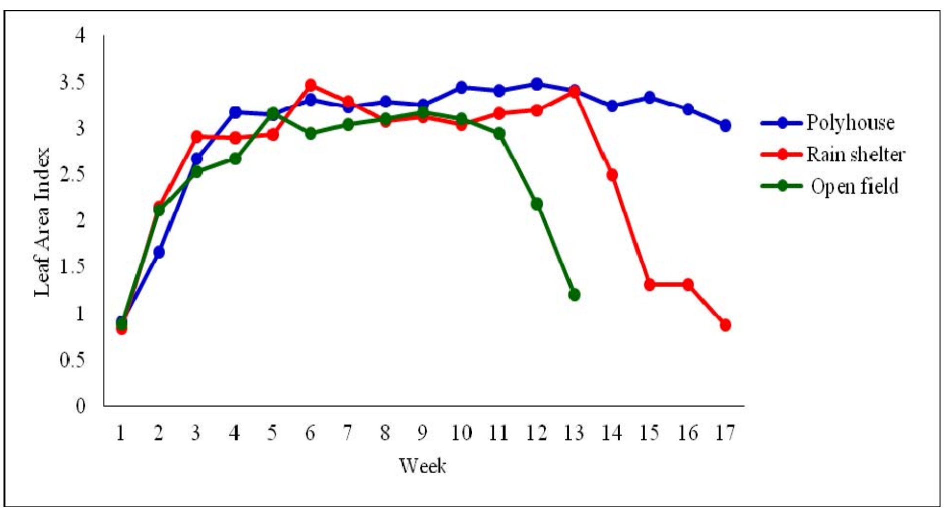

Fig 36.Weekly variation in LAI, Date of transplanting 01 December 2014

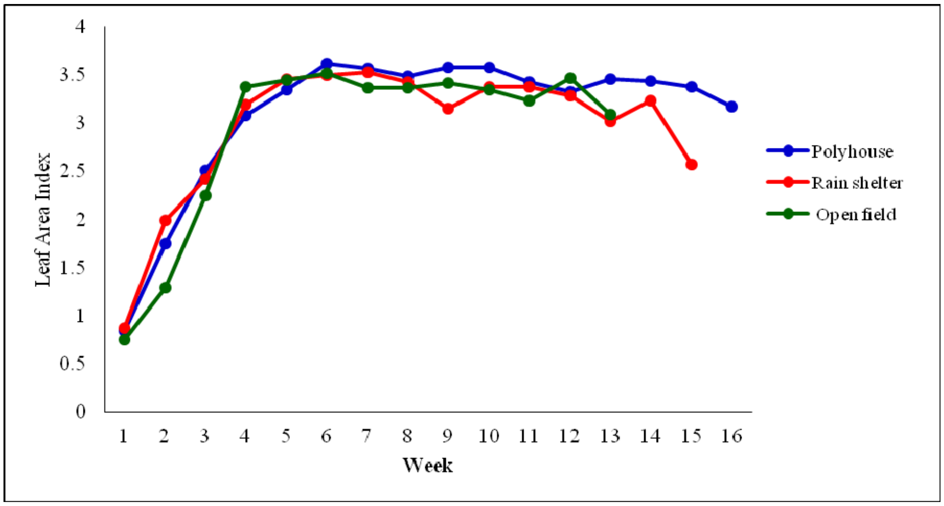

Fig 37.Weekly variation in LAI, Date of transplanting 10 December 2014

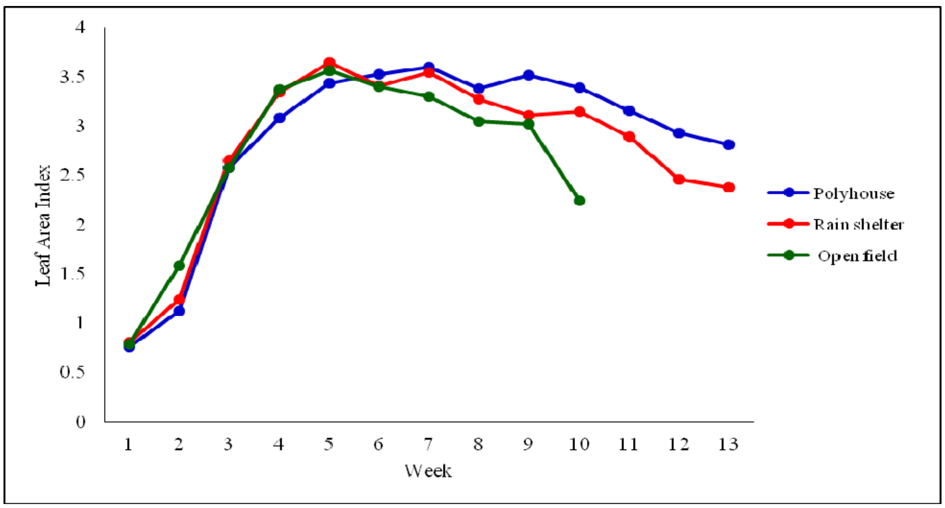

Fig 38.Weekly variation in LAI, Date of transplanting 10 January 2015

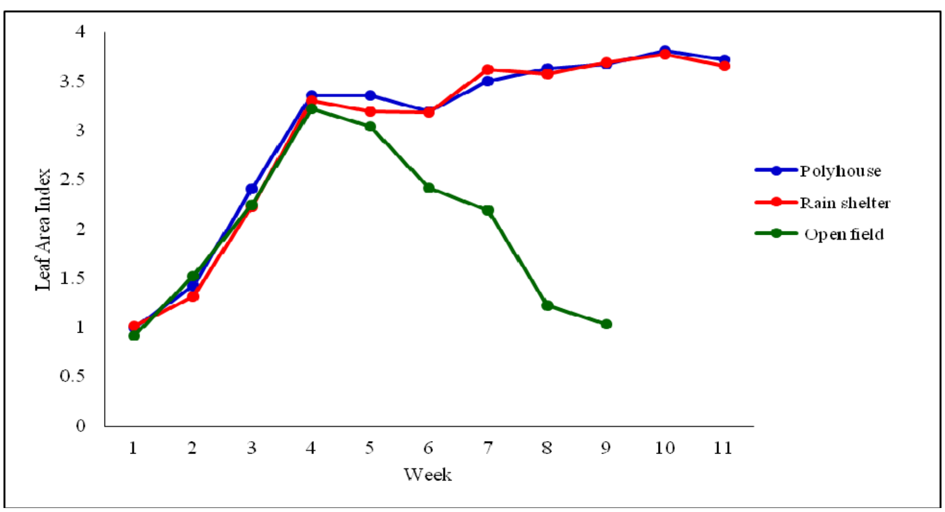

Fig 39.Weekly variation in LAI, Date of transplanting 20 January 2015

5.1.3 Biomass at the time of last harvest

The dates of transplanting and the growing environment had significant influence on the total biomass computed at the end of the crop. Invariably, the greatest biomass was recorded in the crops transplanted inside the polyhouse irrespective of the dates of transplanting. There was a declining trend in the total biomass produced with the delay in transplanting, irrespective of the growing environment (Fig 40).

The total biomass showed strong significant negative correlation with solar radiation, minimum relative humidity, maximum soil temperature, UV-B radiation, CATD, PAR, soil moisture and canopy temperature.

Biomass exhibited a positive correlation with minimum temperature, maximum temperature and maximum relative humidity.

Lower solar radiation within the polyhouse and rainshelter was the crucial factor that influenced greater height and LAI in the crops transplanted within these structures. The greater vegetative vigour was the main reason for the increased biomass production when compared to the crops in the open field. With the delay in transplanting the temperatures increased and the humidity regimes showed a declining trend and hence there was a decrease in the biomass produced in the crops transplanted in the month of January. This is in confirmation with the reports of Heuvelink *et al* (1989) and Ajithkumar (1999)

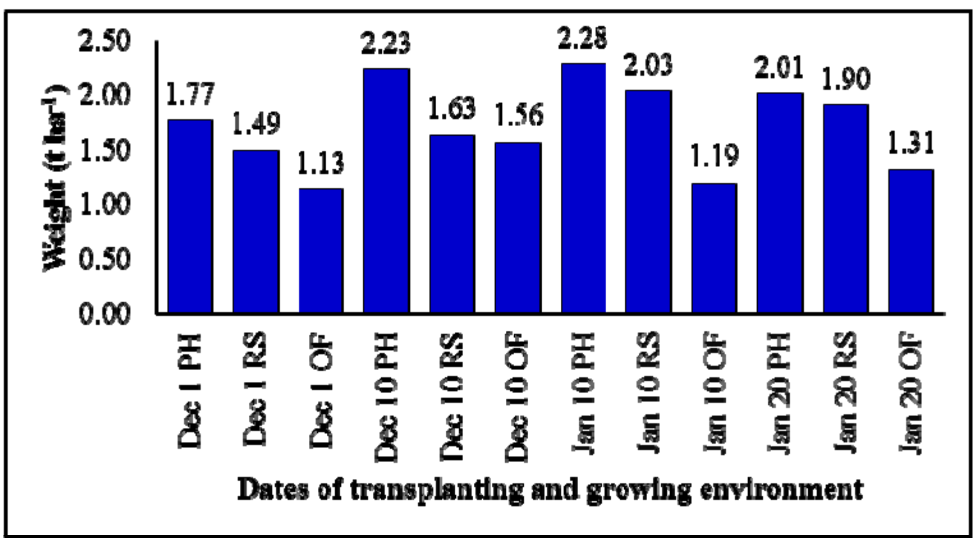

Fig 40. Biomass at the time of last harvest (tons ha^{-1})

The total biomass computed at the end of the crop was found to be significantly decreased with an increase of solar radiation above 400 Wm^{-2}, lower minimum temperatures i.e. below 26°C, higher early morning humidity above 35 percent, higher maximum soil temperatures above 35°C, increased UV-B radiation above 40 Wm^{-2} and canopy air temperature difference above -1.5°.

5.2 PHENOLOGICAL CHARACTERS

5.2.1 Days to first flowering

The days to first flower was significantly influenced by date of transplanting and the growing environment. The crops planted in the open field transplanted on 20 January 2015 took the least number of days to flower. The days to first flower was found to be highest (23 days) in the plants transplanted inside the polyhouse on 1 December 2014. It was found that as the dates of transplanting shifted from December to January, the days taken to first flower invariably reduced in all the crops regardless of the growing environment. The days taken to first flower was significantly less in the crops planted in the open field (Fig 41).

It had significant positive correlations were seen with maximum relative humidity, minimum soil temperatures and soil moisture. Negative correlations with photosynthetically active radiations, maximum and minimum temperatures, canopy air temperature difference and UV-B radiation.

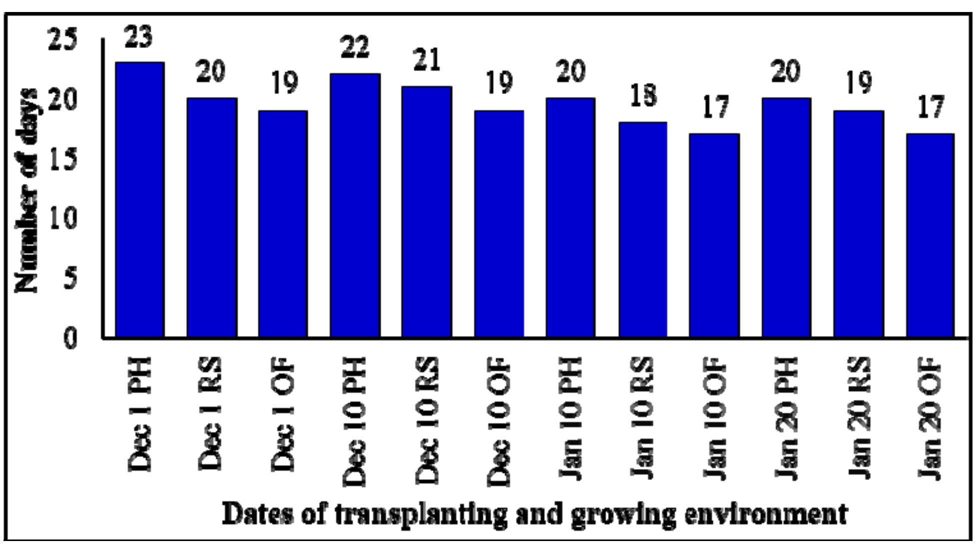

Fig 41. Days to first flowering

In tomato temperature is the major factor that affects floral initiation and its affect is closely associated with light condition. The optimum temperature for floral initiation was found to be below 24°C and solar radiation below 600 Wm^{-2}. This is in confirmation with the findings of Grimstad (1995) and Ho (1996).

5.2.2 Days to first harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest. In all the dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest. The days taken for the fruits to mature reduced as the delay in transplanting occurred, regardless of the growing environment (Fig 42).

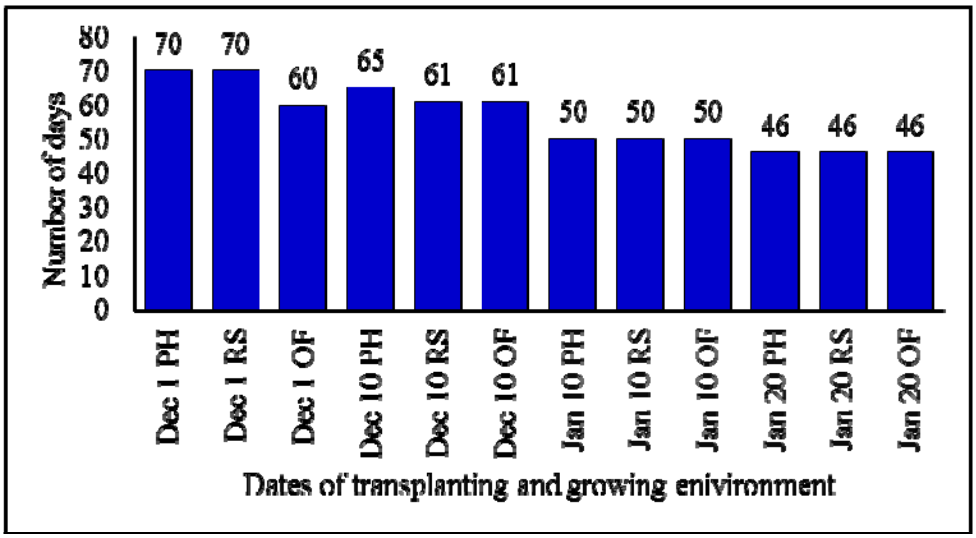

Fig 42.Days to first harvest

The minimum and maximum temperature and the maximum relative humidity were the crucial factors which determined the days taken to first harvest. Higher temperatures hasten the fruit maturity. Within the polyhouse and rain shelter although the temperatures were high but the days taken for first harvest were also higher. This is due to the reason that the minimum and maximum relative humidity were lower within the polyhouse and rainshelter during the harvesting stage and it negatively influenced the otherwise possible hastened maturing of fruits and delayed the first harvest. These are in confirmation with the findings of Slack and Calvert (1978), Gent (1988), Grimstad and Frimanslund (1993), Thangam *et al* (2002).

5.2.3 Days to last harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest (Fig 43). In all the dates of transplanting, crops inside the polyhouse condition took more number of days to first harvest. Days to last harvest was reduced by high solar radiation above 250 W m^{-2} during the first, second, eighth and ninth week and during the harvesting stage, minimum temperature greater than 26°C during the vegetative, flowering, fruiting stage, lower minimum relative humidity during the harvesting stage, maximum soil temperature above 30°C during the vegetative, fruiting and harvesting stage, UV-B radiation above 40 W m^{-2} and canopy air temperature difference above -1 during the vegetative, flowering, fruiting and harvesting stage. This is in consonance with the reports of Grimstad (1993), Moccia *et al* (1999), AVRDC (2000).

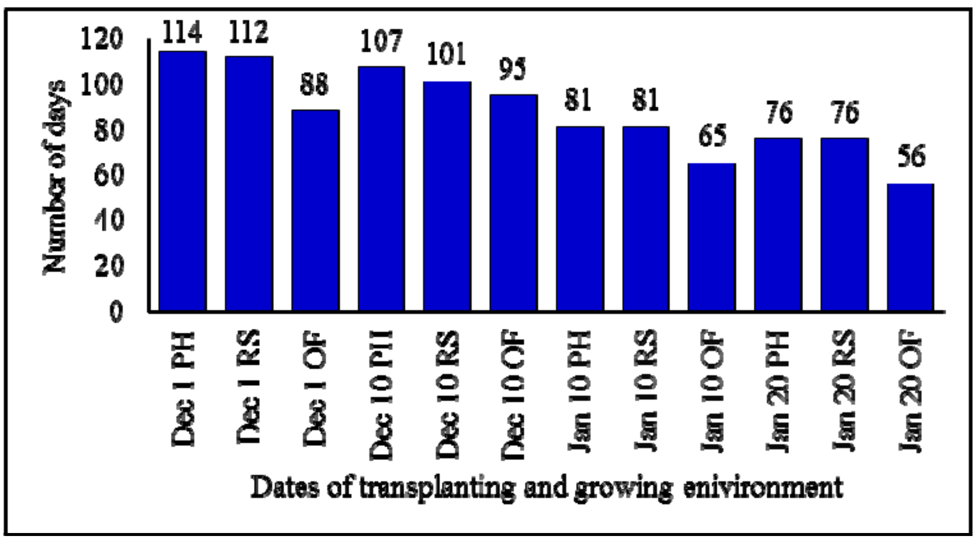

Fig 43. Days to last harvest

5.3 YIELD AND YIELD ATTRIBUTES

5.3.1 Percentage fruit set

The highest percentage of fruit set 61.7 percent was observed in the plants transplanted inside the polyhouse on 1 and 10 December 2014. Whereas, the least fruit set percentage was observed in crops planted in the open field on 10 and 20 January 2015 (Fig 44).

The per cent of fruit set occurred had significant positive correlations with the average solar radiation during the flowering stage, maximum relative humidity and minimum soil temperature. Similarly, it had significant negative correlation with the average solar radiation, minimum temperature, maximum temperature, minimum relative humidity, minimum soil temperature, maximum soil temperature, UV-b radiation, PAR and canopy air temperature difference.

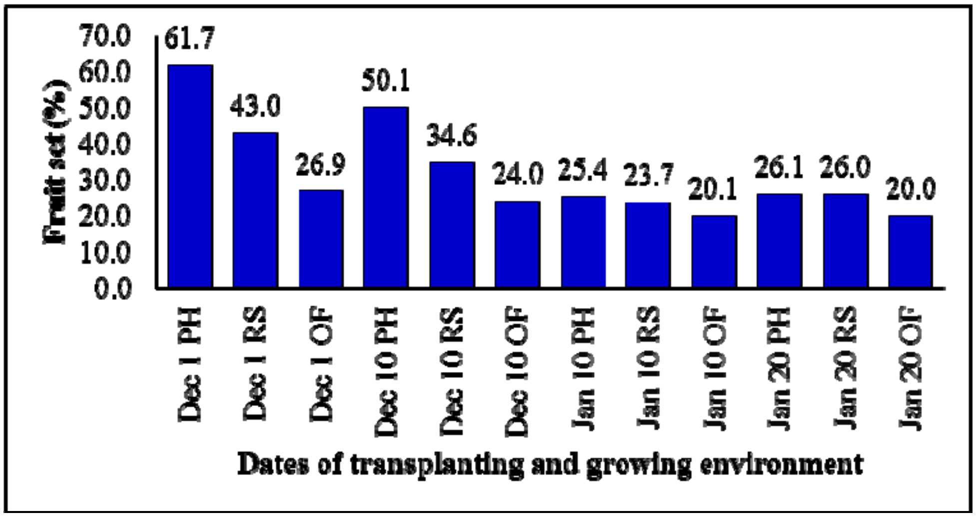

Fig 44. Percentage fruit set (%)

Irrespective of the dates of transplanting the highest and lowest fruit set consistently occurred within the polyhouse and in the plants in the open field respectively. The percentage of fruit set dropped drastically regardless of the growing environment as the dates of transplanting delayed. The failure of fruit set at high may be contributed to the increased minimum and maximum temperatures which resulted in style elongation, flower abortion, flower drop, production of empty flowers and persistent flowers. The same results were reported by many workers like Rao and Sreevijayapadma (1991), Bertin and Gary (1992), Lohar and Peet (1996).

5.3.2 Average fruit weight

The highest average fruit weight was recorded in the crop inside rain shelter transplanted on 20 January 2015 (0.59), 10 January 2015 (0.56) and 10 December 2014 (0.53) followed by fruit obtained from the crop transplanted on 10 December

2014, 10 January 2015 and 20 January 2015 inside polyhouse. The lowest fruit weight was consistently obtained in the open field except for the first season (Fig 45).

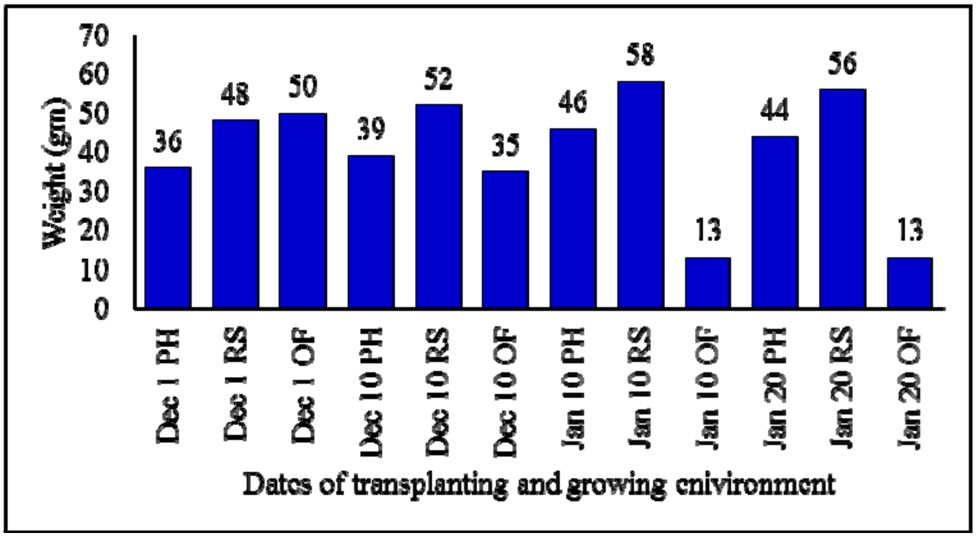

Fig 45. Average fruit weight (gm)

Average fruit weight had significant negative correlations with solar radiation, low minimum relative humidity, low minimum soil temperature, low maximum soil temperature, low UV and CATD and low PAR. It had significant positive correlations with canopy temperature. This is in consonance with the reporting of Bakker and Van Uffelen (1988), De Koning (1994), AVRDC (2000).

5.3.3 Fruit yield per plant and total yield

The total yield in tons per hectare was found significantly influenced by the date of transplanting and the growing environment. The maximum yield of 111.5 tons per hectare and 111.2 tons per hectare were obtained from the crops transplanted inside the polyhouse on 1 and 10 December 2014 respectively. The yields from the crops transplanted inside the polyhouse on 1 and 10 December 2014 and the yield from the crops transplanted inside the rain shelter on 1 December 2014 were statistically similar. Regardless of the dates of transplanting the yields from the crops inside the polyhouse were consistently highest followed by the crops inside the rain shelter and open field. The lowest yields were obtained from the crops in the open field transplanted on 20 January 2015. The total yield obtained showed a declining trend with the delayed transplanting regardless of the growing environment (Fig 46 and 47).

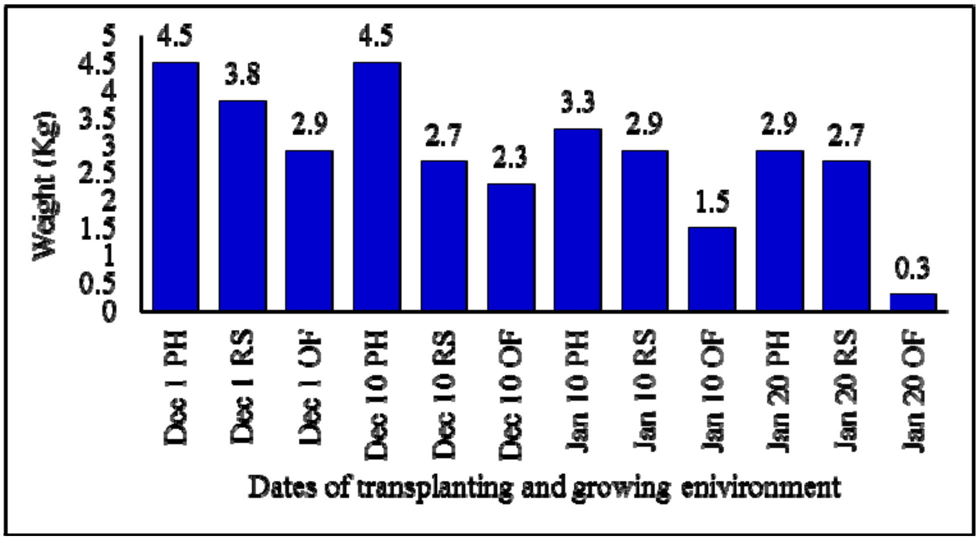

Fig 46. Fruit yield per plant (kg)

The total yield obtained had a significant negative correlation with the average solar radiation, minimum air temperature, maximum air temperature, minimum soil temperature, maximum soil temperature, UV-B radiation, canopy air temperature difference, minimum relative humidity and PAR.

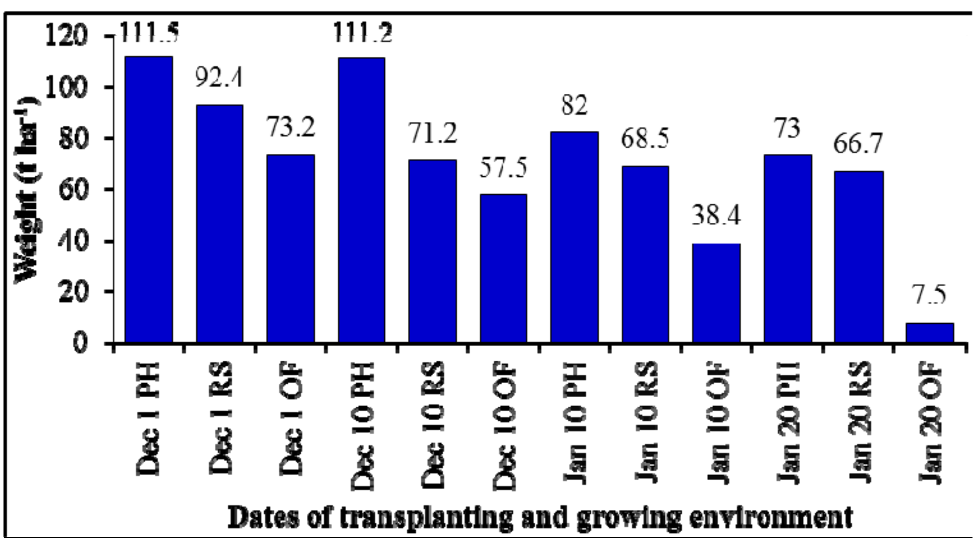

Fig 47.Total yield (t ha^{-1})

The total yield had significant positive correlations with maximum relative humidity, minimum soil temperature during the vegetative stage.

Lower fruit yield per plant and total yield with delay in transplanting is due to lower leaf area index in the crops which had delayed transplanting which resulted in lower light interception and photosynthate assimilation and hence lesser dry matter allocation. Lower fruit set percentage owing to increased mean temperatures and reduced humidity regimes resulting floral abnormalities, flower abortions, production of persistent and empty flowers. This is at par with the findings of Papadopoulos and Tiessen (1981), Khayat *et al* (1985), De Konning (1988), Heuvelink (1989), Muthuvel *et al* (1999).

Greenhouses being framed structures create a barrier between the plant microclimate and ambient climate, and in a way manipulate the surrounding environment congenial enough for the crops to thrive better. Within a greenhouse, it is possible to create a microclimate which is better suited for the development of crop than the outside environment, thus giving better production and uniform quality.

Greenhouse environment has a profound effect on several environment parameters particularly temperature, light, Carbon dioxide and humidity. The plant response to specific environmental parameter is related to the yield and quality.

Air temperature is the main environmental component influencing the vegetative growth, flower initiation, fruit setting, fruit development, fruit ripening and fruit quality. The humidity regime within the greenhouse was optimum for the flower initiation and fruit set and maintaining higher LAI values.

Even though, the light intensities were comparatively very less inside the polyhouse, this was the major substantiating reason for greater vegetative vigour of the plants, both in terms of height and leaf area index. Lower light intensities delayed auxin destruction and promoted cell division and expansion.

Higher LAI values, higher CO_2 content which ensured relatively higher net photosynthesis rates and higher photosynthate formations and assimilation, higher percentage fruit set, optimum soil temperature and moisture altogether resulted in high yield in tomato.

5.4 CLIMATE CHANGE IMPACT ON TOMATO PRODUCTION

5.4.1 2030

Higher temperature and increasing CO_2 levels significantly affected the yields obtained during the different scenarios (Fig 48). Under the RCP 2.6 scenario yield was highest as it had the optimum 33.8°C and 430 ppm. During RCP 4.5 an increasing CO_2 concentration of 434 ppm was the major culprit for reduction as the temperature for the period remained 33.8°C.

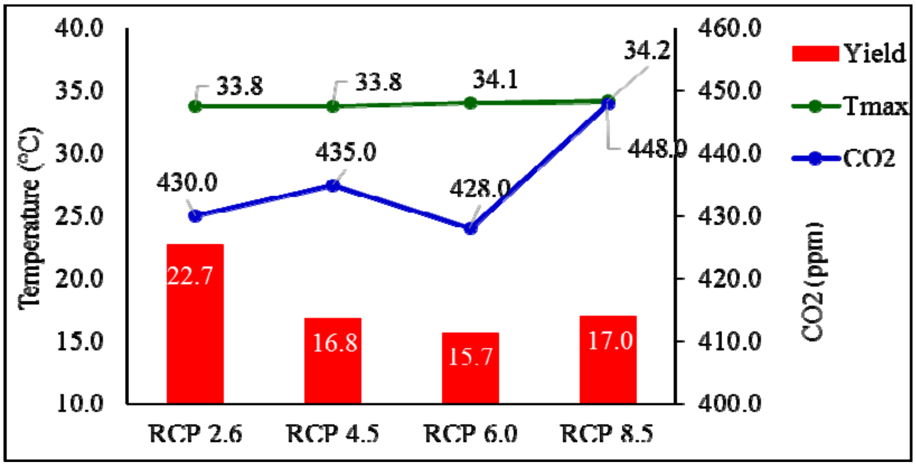

Fig 48. Impact of elevated temperature and CO_2 on tomato yield during 2030

During RCP 6.0 decrease in yield was augmented by a reduced CO_2 content and decrease in temperature. Whereas in RCP 8.5 the increased CO_2 at 448 ppm reduced the yield reduction compared with RCP 6.0. These are in confirmation with the findings of Lin *et al* (2005), Rao and Sreevijayapadma, (1991)

5.4.2 2050

During RCP 2.6 scenario the yield was 17.2 tons ha^{-1}, the temperature and CO_2 concentration during this period was 34.2°C and 442.7 ppm (Fig 49). During RCP 4.5 an increased CO_2 ppm led to an increase in yield of 18.5 tons ha^{-1}. The temperature had negligible effect and the increase in yield is more attributed to CO_2 fertilization. During RCP 6.0 the yield decrease to 16.3 tones ha $^{-1}$ due a decrease in CO_2 concentration which was 477.7 ppm.

During RCP 8.5 a higher CO_2 concentration may augmented the yield but it could not get to the maximum as the positive effects of CO_2 fertilization was diminished by an increase in temperature to 35.1°C This is at par with the findings of Muthuvel *et al.*, (1999).

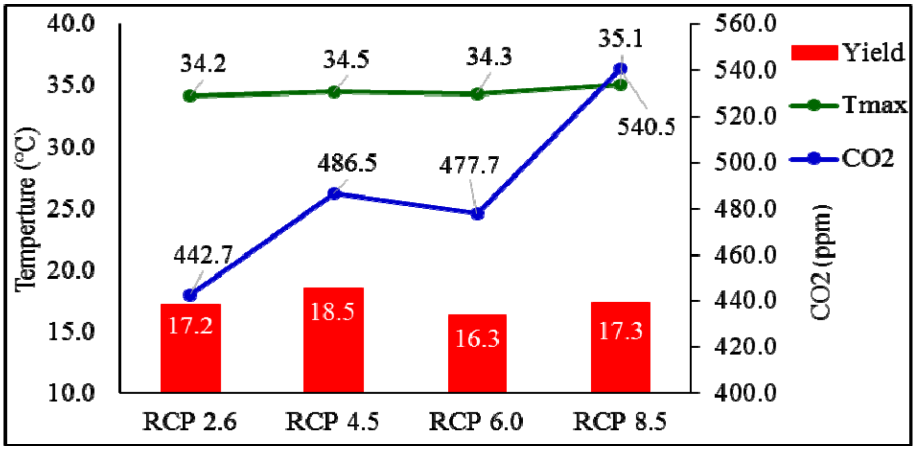

Fig 49. Impact of elevated temperature and CO_2 on tomato yield during 2050

5.4.3 2080

During RCP 2.6 the yield is predicted to be 16.6 tons ha^{-1}. The temperature and CO_2 during this period is predicted to be 34.1 and 431.6 ppm (Fig 50). RCP 4.5 witnessed a decrease in yield owing to a reduction in CO_2 and an increase in maximum temperature by 1°C. An in increase yield was observe as CO_2 increased to 394.3 ppm despite an increase of temperature at a rate of 0.4°C. During RCP 8.5 the yield climbed to 19.2 tons ha^{-1} but the increase was not so large, the major reason being increase in temperature by 1.2°C, which overcame the CO_2 fertilization effect. This is in consonance with the reporting of Prasad *et al,* (2006).

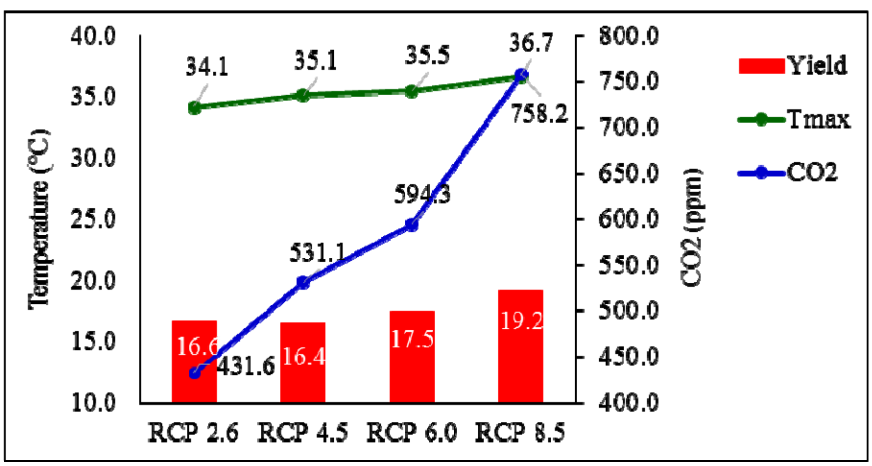

Fig 50. Impact of elevated temperature and CO_2 on tomato yield during 2080

Summary

An experiment was conducted at Central nursery Vellanikkara to Study the effect of various weather parameters on growth and development of tomato and modeling the impact of climate change on growth and development of tomato using DSSAT 4.5 model. The observations on morphological, phenological and yield attributes were recorded at different stages of development of the crop. The observations on weather factors were recorded daily to workout crop weather relationship. DSSAT model was validated and impact of climate change on tomato production was studied.

The salient findings are summarized as follows:

1. The date of transplanting and growing environment had a significant effect on the morphological, phenological and yield parameters of tomato.
2. Then greatest plant height was obtained for the crop planted inside the polyhouse (251.7cm) on 01 December 2014.
3. The maximum biomass accumulation (2.23 t ha^{-1}) was recorded inside the polyhouse by the crops transplanted on10 December 2014 and 10 January 2015.
4. The crop transplanted inside polyhouse on 01 December 2014 took the longest duration of 114 days.
5. Maximum LAI was recorded in the crop transplanted inside the polyhouse, rain shelter (20 January 2015) and open field (10 December 2014).
6. The crop planted inside the polyhouse maintained a higher LAI for longer period of time compared to rain shelter and open field.
7. Highest yield 111.5 t ha^{-1} in the crop transplant inside polyhouse on 01 December 2014. The delay in transplanting resulted reduced fruit in tomato.
8. The highest average fruit weight (53 gm) was recorded when crops are transplanted on 10 January 2015
9. The Per cent fruit set was highest in crops transplanted on 01 December 2014 inside polyhouse.
10. DSSAT model was validated and gave good RMSE values. It can also be used for studying the impact of climate change on growth and yield of tomato.

11. The results also showed that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO_2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in temperature.
12. The yield of tomato (Anagha) will be reduced considerably due to climate change.

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MODELING THE IMPACT OF CLIMATE CHANGE ON GROWTH AND YIELD OF TOMATO

By

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ABSTRACT OF THE THESIS

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Abstract of the thesis

Tomato is the world's largest vegetable crop. It is one of the most important vegetable crops cultivated for its fleshy fruits and it is considered as important commercial and dietary vegetable crop. The average productivity of tomato in our country is nearly 158q per hectare. Its successful production in the tropics is, however, constrained by environmental variations especially under open field conditions. The rising temperatures and carbon dioxide concentration and uncertainty in rainfall associated with climate change may have serious direct and indirect consequences on crop production and hence food security.

Objective of the study were Modeling of growth and yield of tomato and the impact of climate change based on projected climate change scenarios using DSSAT 4.5 model and the impact of climate change will be studied based on projected climatic scenarios (RCP.2.6, 4.5, 6.0 and 8.5). The field was designed as spilt plot under 3 growing situations (S_1-poly house, S_2-rain shelter, S_3-Open condition) at Central Nursery, Vellanikkara. The date of planting was on 2014 December 1st, 10th, 2015 January 10th and 20th. The variety chosen was Anagha.

The date of transplanting and growing environment had a significant effect on the various morphological, Phenological and yield parameters. Then greatest height was obtained by polyhouse (251.7cm) on 01 December 2014.The greatest biomass accumulation (2.23 t ha^{-1}) inside the polyhouse on 10 December 2014 and 10 January 2015. The crop transplanted in polyhouse on 01 December 2014 had the longest duration of 114 days. Maximum LAI was recorded in the crop transplanted inside the polyhouse, rain shelter (20 January 2015) and open field (10 December 2014). Highest yield 111.5 t ha^{-1} in the crop transplant inside polyhouse on 01 December 2014.

DSSAT model was validated and gave good RMSE values. The results also showed that the effect of minimum temperature would drastically reduce the yield. The increasing atmospheric CO2 concentration is likely to have some positive effect on yield, but the effect is not significant compared to the negative impact of rise in

temperature. The yield of tomato (Anagha) will be reduced considerably due to climate change.

Appendices

APPENDICIES

Date	SR	Tmin	Tmax	RHI	RHII	STmin	STmax	SM
01-12-14	1208	24.8	32.9	76	44	24.6	33.8	40.3
02-12-14	1208	22.7	32.9	86	80	22.1	22.7	40.3
03-12-14	987	20.8	36.7	97	45	20.4	43.6	40.4
04-12-14	1059	22.2	34.7	100	45	22.5	38.5	40.4
05-12-14	1117	20	33.4	85	50	21.1	34.6	40.4
06-12-14	1016	19.6	34.5	90	46	20.8	36.2	40.4
07-12-14	988	21.9	35.3	97	54	22.6	37.3	40.4
08-12-14	1035	23.2	35.7	99	54	24.1	36	40.4
09-12-14	970	23.8	35.9	99	54	25.1	36.8	40.5
10-12-14	1133	24.4	33.6	99	62	25.3	33.8	40.4
11-12-14	892	24.2	32.9	98	66	24.5	32.3	40.4
12-12-14	1054	23.6	35.3	99	58	24.4	35.4	40.4
13-12-14	1072	24.3	36	99	54	24.6	36.7	38.5
14-12-14	1099	23.3	36.3	100	55	24.3	38	39.1
15-12-14	1041	24.7	36.2	98	50	25.4	38.1	39.2
16-12-14	1028	22.8	36.1	100	49	24.1	38.6	40.4
17-12-14	1016	24.9	35.5	81	52	25	38.5	40.5
18-12-14	1013	25.6	31.3	85	64	24.6	29.6	40.4
19-12-14	909	25.6	33.4	86	60	24.6	33.9	39.1
20-12-14	988	24.5	32.1	81	61	24	32.7	36.1
21-12-14	1005	22.8	35	95	52	24	40.7	35.3
22-12-14	936	22.4	34.1	96	51	23.4	53.5	28.5
23-12-14	987	22.9	35.2	93	53	23.4	36.3	32.4
24-12-14	1033	23.8	34.9	85	52	23.8	53.1	36.2
25-12-14	998	23.4	35.1	93	52	24	34.9	39.3
26-12-14	853	21.9	30.8	97	58	24	30.3	40.3
27-12-14	1116	21.8	33.1	84	48	23.5	32.4	40.4
28-12-14	735	23.8	32.7	86	56	23.5	30.7	40.4
29-12-14	1018	22.4	36.8	95	49	23.8	34.8	40.5
30-12-14	929	24.5	34	98	59	23.8	33.3	40.5
31-12-14	935	24.4	33	99	66	25.6	40.1	40.4
01-01-15	1085	22.4	33.5	99	60	25.6	48.8	40.4
02-01-15	1009	22.4	34.8	99	35	21.9	56.9	40.4
03-01-15	1083	21.2	33.9	99	50	21.9	34.8	40.4
04-01-15	1047	21.6	35.4	99	47	22.8	53.2	40.4
05-01-15	1016	21.4	35.8	98	50	23.4	33.9	38.8

06-01-15	990	21.8	36.2	99	41	23.4	48.3	35.9
07-01-15	1061	26	35.5	70	46	26.5	46.7	27.1
08-01-15	902	26	33.8	86	56	26.5	33.3	25.6
09-01-15	915	26	35.6	81	50	24.5	35.2	25.9
10-01-15	972	26.1	36	73	41	24.1	53.8	30.2
11-01-15	1046	24.6	35	57	29	21.7	33.2	29.9
12-01-15	1010	24.3	33.5	65	37	21.7	32.4	29.7
13-01-15	1016	23.1	33.8	70	39	22.5	47.6	38.1
14-01-15	970	21.2	34.3	93	42	22.7	44.5	30.5
15-01-15	948	20.5	34.3	95	43	20.7	51	27.2
16-01-15	983	20.2	35.1	96	39	20.5	45.2	29.1
17-01-15	973	21	35.2	97	47	22.3	46.3	31.6
18-01-15	956	21.7	35.2	94	46	22.3	36.2	30.7
19-01-15	944	22.3	35.1	91	46	21.4	37.9	26.3
20-01-15	945	22.4	35.5	87	39	21.5	37.3	29.6
21-01-15	920	25.3	35	55	41	22.5	39.3	29.3
22-01-15	994	24.8	35.6	70	34	23.7	39.5	28.8
23-01-15	1041	25.3	35	75	43	24.5	42.1	25.7
24-01-15	1027	23.8	36.2	70	46	24.3	38	34.3
25-01-15	1026	24.6	37.1	75	39	24.3	44.7	29.8
26-01-15	1050	24.7	35.9	69	38	25	48.9	29.8
27-01-15	1028	25.1	35.4	65	39	28.8	49.3	29.0
28-01-15	1021	25.7	36.3	70	45	25	55.8	29.8
29-01-15	1005	25.5	35.7	75	47	26.9	53	28.3
30-01-15	985	26.1	35.2	72	51	24.5	35.6	28.3
31-01-15	994	25.7	35.7	72	39	24.5	37.7	28.9
01-02-15	1031	24.8	35.6	67	41	22.8	49.6	27.4
02-02-15	1059	26.9	36.1	63	37	24.6	34.1	27.6
03-02-15	1107	25.3	35.7	63	38	21.2	37.5	33.7
04-02-15	1223	27.4	35.6	61	36	25	46.2	35.1
05-02-15	878	22.8	34.2	68	37	25.5	43.6	29.4
06-02-15	1044	25.5	37.5	59	27	23.6	52.5	28.1
07-02-15	1034	24.9	37.2	60	35	25	35.5	24.7
08-02-15	1033	24.5	37.2	72	36	22.9	37.1	27.0
09-02-15	1088	24.5	37.8	76	28	24.4	34.8	30.4
10-02-15	1094	24.8	36.1	72	35	22.3	33.9	34.4
11-02-15	1049	24.8	36.9	72	37	22.3	35.4	27.2
12-02-15	1047	24.8	37.6	70	37	24.3	36.9	27.5
13-02-15	1031	24.8	36.4	73	40	24.3	38	28.6
14-02-15	1077	27.7	37.8	82	41	24.3	37.5	33.0
15-02-15	1030	27.7	37.5	65	30	25.2	51.8	31.6

16-02-15	1087	27.1	38.1	73	25	29	57.3	27.4
17-02-15	1069	27.1	37.4	78	30	29	55.9	31.5
18-02-15	1066	26.6	35.5	69	46	32.7	52.3	34.5
19-02-15	1151	26.6	37.2	83	38	28.6	56.7	33.1
20-02-15	1133	25.8	38.5	68	21	27.5	55.1	33.8
21-02-15	1141	26.6	37.7	63	27	26.6	52.6	31.2
22-02-15	1160	26.3	38.6	60	21	26.2	55.9	30.1
23-02-15	1154	26.7	39.2	45	21	23.3	60	37.9
24-02-15	1165	26	39	46	19	22.1	51.5	30.9
25-02-15	1113	26.3	38.4	57	31	24	56.8	30.8
26-02-15	1075	27.8	34.7	76	52	25	35.5	29.7
27-02-15	1086	27.8	36.1	85	53	25	35.4	35.8
28-02-15	1066	27.6	36.4	74	48	25.8	36.9	30.6
01-03-15	1221	28.1	36.6	73	48	26.5	38.3	29.5
02-03-15	1206	28.1	35.6	80	59	29.5	52.5	35.2
03-03-15	1203	24.2	35.6	77	51	25.4	53.8	33.8
04-03-15	1104	24.2	36.9	69	45	25.4	59.5	31.2
05-03-15	1178	28.1	38.8	68	48	27.4	56.8	38.0
06-03-15	1241	28.1	38.4	65	42	20.3	56.2	31.6
07-03-15	1111	29	37.5	77	50	30.3	56.4	31.0
08-03-15	1189	28.5	38.3	73	48	28.2	60.8	32.9
09-03-15	1227	27.2	37.6	87	40	29.8	61.9	32.8
10-03-15	1113	29	38.6	69	36	29.6	60.6	33.8
11-03-15	1186	27.9	39.3	62	28	28.1	65.3	36.6
12-03-15	1184	21.6	38.8	65	36	26.2	63.6	30.1
13-03-15	1170	29.1	39.2	62	33	28.4	64.5	30.3
14-03-15	1262	28.4	38.6	71	39	28.2	60.6	33.7
15-03-15	1241	29.5	38.1	79	44	29.5	61.4	32.1
16-03-15	1239	27.6	39.6	93	44	29.4	57.5	31.6
17-03-15	1228	30.3	37.4	83	50	30.6	50	31.7
18-03-15	1191	30.2	38.4	78	47	30.2	51.9	32.3
19-03-15	1216	30.2	38.7	82	49	24.7	56	31.7
20-03-15	1204	29.7	40.4	85	28	30.4	43.1	28.5
21-03-15	1184	29.7	41.4	77	21	27.9	43.5	27.4
22-03-15	1137	21.8	42.2	86	26	19.2	42.7	31.6
23-03-15	1146	28.2	37.9	86	50	27.1	39.6	30.9
24-03-15	1123	24.9	37.2	82	50	27.6	39.4	28.0
25-03-15	977	29.2	37.9	84	50	28.3	39.9	26.5
26-03-15	1148	29	40.6	83	28	27.9	41.4	30.1
27-03-15	1171	28.3	41.4	75	22	26.9	43	26.9
28-03-15	1145	28.3	41	78	27	26.9	43.9	23.4

29-03-15	1157	27.5	41.1	73	31	27.4	43.9	26.5
30-03-15	1227	29.9	40	83	44	29	41.5	30.2
31-03-15	1045	29.4	38.6	79	56	28.2	39.3	30.3
01-04-15	1045	29.4	38.6	87	54	28.1	39.3	27.9

Daily weather data (Open field)

Date	SR	Tmin	Tmax	RHI	RHII	STmin	STmax	SM
01-12-14	631	24.4	31.4	73	44	22.1	50.8	40.35
02-12-14	631	22.5	31.4	84	44	22.5	50.8	40.35
03-12-14	311	20.9	38.9	88	42	20.9	51.5	40.35
04-12-14	344	22.4	35.3	89	43	23	32.2	40.4
05-12-14	375	20.5	34.7	87	46	21.6	31.5	40.4
06-12-14	350	19.9	34.8	87	43	21.3	32.1	40.35
07-12-14	342	22.1	36.7	87	49	23	32.9	40.4
08-12-14	353	23.4	37.3	88	51	24.2	33.5	40.5
09-12-14	346	24.1	36.9	89	50	25.1	33.6	40.5
10-12-14	386	24.7	34.9	88	60	25.3	31.8	40.45
11-12-14	322	24.3	33.5	88	63	24.8	31.4	40.4
12-12-14	331	23.8	36.1	88	54	24.7	32.9	40.45
13-12-14	355	24.5	37.1	88	51	25.1	33.6	40.45
14-12-14	384	23.6	37.1	89	51	24.6	33.9	40.5
15-12-14	357	25	37.2	87	47	25.5	33.8	40.5
16-12-14	354	23.3	36.8	89	46	24.4	33.5	40.45
17-12-14	342	24.8	36.3	81	47	25.4	33.7	40.5
18-12-14	352	25.7	29.9	83	60	24.9	28.4	40.4
19-12-14	328	25.7	32.8	83	57	24.6	30.4	40.45
20-12-14	1166	24.4	31.8	81	58	24.2	30.1	35.4
21-12-14	574	23.1	38.1	87	47	23	39.6	31.35
22-12-14	1345	23	35.6	87	48	23.6	48	38.2
23-12-14	1483	23.3	36.9	87	50	23.5	36.4	32.5
24-12-14	1245	23.8	36.1	85	50	23.9	50.2	36.65
25-12-14	1241	23.6	37.2	87	48	24	35.5	35.1
26-12-14	1076	22.2	30.9	88	56	23.4	43.8	34.85
27-12-14	1355	22.2	34.3	85	45	22.4	32	32.05
28-12-14	791	23.8	32.9	85	53	23.6	46.9	29.4
29-12-14	1488	22.6	39.4	87	43	23.3	38.7	34.15
30-12-14	730	24.7	37	89	55	25.1	44.4	32.85

31-12-14	1461	24.6	35.3	89	61	25	41.9	37.45
01-01-15	884	23	34.8	89	59	24.6	37.3	34.15
02-01-15	1463	20.9	38.7	90	33	21.9	48.7	41.15
03-01-15	1460	21.7	36.9	89	49	22.4	36	34.2
04-01-15	1455	22.3	38.9	90	45	23	52.1	39.6
05-01-15	1446	22	36.9	89	47	23.1	33.1	36.15
06-01-15	980	22.1	36.8	89	41	23.1	54.4	29.9
07-01-15	363	26	38.4	72	41	23.9	45.7	28.65
08-01-15	722	26	36.7	83	54	23.9	30.6	29.3
09-01-15	335	26.1	37.3	82	46	24.1	32.2	26.5
10-01-15	1505	26	36.7	74	40	24	49.6	23.95
11-01-15	383	24.8	35.1	58	30	22.1	30	21.85
12-01-15	373	24.2	34.9	64	37	21.4	29.1	30
13-01-15	954	23.1	34.5	72	38	20.5	29.6	31.5
14-01-15	433	22	37.1	86	38	20.2	34	25.85
15-01-15	1121	21.2	36.7	87	40	21.1	50.1	26.4
16-01-15	1402	20.8	36.7	87	37	20.9	31.7	31.15
17-01-15	1037	21.4	37.3	88	43	22.3	52.8	23.5
18-01-15	1415	22.4	36	87	42	22.4	34.5	29.3
19-01-15	742	22.6	34.9	85	41	22.1	51.7	28.7
20-01-15	1167	22.8	36.7	85	37	22.1	36.3	24.95
21-01-15	758	25.4	36.2	56	39	22.1	51.8	26.3
22-01-15	368	24.8	37.4	69	31	22.5	30.1	23
23-01-15	365	25.6	38.3	77	39	22.8	39.4	21.9
24-01-15	885	25.1	37	74	41	23.2	31	26.5
25-01-15	409	25.1	37	75	36	23.2	31.9	20.75
26-01-15	385	24.9	35.5	69	35	22.7	43.1	18.85
27-01-15	607	25.3	36.2	66	37	22.7	31	18.75
28-01-15	352	25.7	37.1	71	43	22.2	32.1	18.25
29-01-15	344	25.4	36.9	74	46	23.7	47.2	23.1
30-01-15	608	26.3	35.5	72	47	24.2	31.4	20
31-01-15	336	26.1	35.8	71	38	23	30.4	19.6
01-02-15	1006	24.8	36.3	67	38	23.8	52.8	19.5
02-02-15	483	26.7	35	65	36	23.8	30.8	20.1
03-02-15	390	26.4	36.2	62	36	23.8	30.9	24
04-02-15	843	27.2	35.9	61	34	24	31.4	20.5
05-02-15	301	27.5	34.6	68	36	24.1	29.7	19.65

06-02-15	339	25.7	37.3	62	27	22.6	47.2	22.45
07-02-15	340	25.1	37.8	61	35	22.7	31.7	20.3
08-02-15	348	24.5	38.7	72	33	22.9	53.4	22.65
09-02-15	385	24.5	38.2	71	27	24.1	31.3	25.95
10-02-15	347	24.8	37.6	71	33	22.5	30.5	30.75
11-02-15	359	24.8	37.8	71	35	22.5	49.7	21.85
12-02-15	486	22.3	38.8	69	36	23	34.2	25.85
13-02-15	334	26.9	39.2	72	37	23	33.8	24.45
14-02-15	845	25.4	41	81	39	26.8	52.9	20.85
15-02-15	1311	28	39	65	27	26.8	57.9	19.65
16-02-15	373	26.8	38.3	74	24	26	34.4	20.8
17-02-15	342	26.8	38.7	78	29	26	43.1	23.1
18-02-15	669	28.8	37.3	69	43	27.8	33.4	29.1
19-02-15	367	26.8	40.3	82	35	26.3	35.6	23.65
20-02-15	375	25.5	38.3	70	21	25.4	50.2	24.4
21-02-15	383	26	37.4	64	25	25.5	34.8	23.2
22-02-15	384	25.5	38	61	20	25	36.7	19.4
23-02-15	630	26.4	38.9	48	20	24.6	56.2	24
24-02-15	368	25.5	39.6	49	19	24.4	37.3	17.45
25-02-15	370	27	40	64	28	25.4	54.1	18.85
26-02-15	657	27.9	36.5	74	47	27.2	31.6	15.65
27-02-15	356	27.9	37.1	83	50	26	30.6	20.3
28-02-15	374	27.4	37.6	74	46	24.9	51.8	18.9
01-03-15	690	27.9	37.5	73	47	24.9	31.4	20.55
02-03-15	415	27.9	36.9	78	55	25.5	31.9	26.1
03-03-15	1028	25.1	37.6	74	48	25.1	48.8	26.6
04-03-15	365	25.1	38.2	69	41	25.1	32	25.65
05-03-15	377	27.2	40.3	67	43	24.6	44	32.35
06-03-15	858	27.2	39.4	66	43	24.6	56.5	29.8
07-03-15	371	29	40	77	49	26.4	31.9	27.55
08-03-15	405	30.2	39.5	75	45	26	41.8	31.4
09-03-15	1046	27.7	40.2	84	37	26	54.8	32.25
10-03-15	488	28.8	39.7	70	33	26	33.4	33.05
11-03-15	417	27.3	39.6	62	26	25	33.5	33.7
12-03-15	416	21.7	38.9	63	32	24.8	47.6	26.7
13-03-15	468	26.8	41.3	63	32	25.3	34.2	28.85
14-03-15	435	28.2	39.6	70	39	25.9	32.7	29.65

15-03-15	414	29	40	74	41	26.1	53.6	29.8
16-03-15	745	27.8	40.4	85	42	26.3	36.6	26.5
17-03-15	766	29.4	39.1	79	47	27.5	34.1	26.75
18-03-15	755	29.1	40.6	77	43	26.9	35.3	25.25
19-03-15	760	19.8	40.9	78	45	26.9	35.9	23.35
20-03-15	763	29	42.4	79	25	27.2	37.9	23.05
21-03-15	733	28.9	42.1	74	19	27.3	38.4	21.65
22-03-15	709	20.6	41.7	82	23	22.3	37.5	22.05
23-03-15	682	28	39.1	82	47	26.8	34.6	21.25
24-03-15	710	25.7	38.1	82	49	24.1	35.6	19.35
25-03-15	615	29.2	38.6	81	49	27.8	36.7	18.45
26-03-15	709	28.7	42.1	81	26	27.6	38.4	18.85
27-03-15	759	28.1	41.9	74	22	26.8	38.9	19.2
28-03-15	713	28.1	42.4	77	26	26.8	39	23.6
29-03-15	725	28.7	43.7	75	27	27.2	38.7	19.8
30-03-15	768	29.9	42.3	80	42	28.3	38.4	20.5
31-03-15	626	29.8	40.1	77	51	27.7	35.4	20.45
01-04-15	626	29.8	40.1	78	51	27.7	35.4	20.45

Daily weather data (Rain shelter)

Date	SR	Tmin	Tmax	RHI	RHII	STmin	STmax	SM
01-12-14	631.0	25.0	32.6	78.0	44.0	24.6	35.4	40.6
02-12-14	631.0	22.7	23.5	88.0	84.0	24.3	24.5	40.6
03-12-14	311.0	21.1	36.9	94.0	34.0	22.5	34.1	32.8
04-12-14	344.0	22.2	34.9	94.0	32.0	23.7	32.6	40.8
05-12-14	375.0	20.9	34.2	93.0	35.0	22.5	31.2	40.7
06-12-14	350.0	20.0	34.6	93.0	34.0	22.0	31.8	40.7
07-12-14	342.0	22.6	35.5	93.0	38.0	23.6	33.3	40.8
08-12-14	353.0	22.9	36.4	94.0	41.0	24.9	33.3	40.8
09-12-14	346.0	23.5	36.1	94.0	41.0	25.6	33.9	40.8
10-12-14	386.0	24.1	34.5	94.0	50.0	26.0	31.9	40.8
11-12-14	322.0	24.2	33.0	93.0	55.0	25.5	30.1	40.8
12-12-14	331.0	23.4	35.5	94.0	45.0	25.3	32.5	40.8
13-12-14	355.0	24.2	36.1	93.0	38.0	25.8	32.8	40.8
14-12-14	384.0	23.0	36.3	93.0	40.0	25.3	33.7	40.8
15-12-14	357.0	24.4	36.3	93.0	37.0	26.1	33.4	40.9
16-12-14	354.0	22.8	36.1	93.0	37.0	25.3	33.6	40.8
17-12-14	342.0	25.3	35.5	86.0	40.0	26.1	33.0	40.8
18-12-14	352.0	25.7	31.0	84.0	62.0	25.6	27.7	40.8

19-12-14	328.0	25.7	33.3	85.0	50.0	25.3	29.6	40.8
20-12-14	1166.0	24.9	32.3	86.0	50.0	25.1	29.4	40.7
21-12-14	574.0	23.0	35.8	92.0	37.0	23.8	32.9	29.0
22-12-14	1345.0	22.4	35.0	93.0	38.0	24.5	32.2	32.3
23-12-14	1483.0	23.0	35.9	93.0	39.0	24.4	31.6	28.9
24-12-14	1245.0	24.2	35.1	93.0	37.0	24.7	32.5	32.4
25-12-14	1241.0	23.6	35.5	92.0	37.0	24.9	31.7	32.4
26-12-14	1076.0	22.6	30.9	93.0	49.0	24.3	28.2	28.9
27-12-14	1355.0	22.0	33.4	91.0	35.0	23.2	30.1	28.4
28-12-14	791.0	23.9	32.9	91.0	44.0	24.2	29.8	29.4
29-12-14	1488.0	22.0	37.1	93.0	36.0	24.0	31.8	31.0
30-12-14	730.0	24.2	34.4	93.0	44.0	25.6	32.0	29.5
31-12-14	1461.0	24.0	33.1	92.0	54.0	25.7	30.7	30.6
01-01-15	884.0	21.9	33.4	92.0	51.0	25.4	30.1	29.0
02-01-15	1463.0	19.4	35.7	93.0	30.0	22.9	30.7	31.7
03-01-15	1460.0	20.8	34.9	92.0	39.0	23.4	30.2	31.7
04-01-15	1455.0	21.4	35.8	90.0	33.0	24.0	30.8	32.8
05-01-15	1446.0	21.3	35.8	91.0	37.0	24.0	30.5	28.3
06-01-15	980.0	21.6	36.0	90.0	30.0	24.0	30.1	28.7
07-01-15	363.0	27.3	35.9	74.0	33.0	24.1	30.5	32.0
08-01-15	722.0	27.3	34.4	88.0	43.0	24.1	29.9	31.3
09-01-15	335.0	27.1	35.7	83.0	37.0	24.8	30.5	28.7
10-01-15	1505.0	27.5	35.8	75.0	30.0	24.6	30.5	29.7
11-01-15	383.0	25.7	35.4	57.0	22.0	23.0	28.9	27.6
12-01-15	373.0	25.0	33.9	65.0	29.0	22.2	28.0	31.8
13-01-15	954.0	24.2	34.0	70.0	27.0	21.5	27.5	35.0
14-01-15	433.0	21.4	34.4	89.0	30.0	21.0	28.8	26.2
15-01-15	1121.0	20.6	34.3	89.0	32.0	22.4	28.6	29.7
16-01-15	1402.0	20.1	35.6	88.0	29.0	22.2	29.0	24.7
17-01-15	1037.0	21.0	35.5	89.0	34.0	23.2	29.3	25.3
18-01-15	1415.0	21.9	35.4	88.0	33.0	23.6	29.5	25.6
19-01-15	742.0	22.3	35.6	88.0	31.0	23.2	28.7	25.3
20-01-15	1167.0	22.6	35.7	88.0	28.0	23.3	29.1	27.1
21-01-15	758.0	26.2	35.2	55.0	30.0	23.1	28.1	27.9
22-01-15	368.0	25.5	36.4	71.0	23.0	23.4	28.8	28.0
23-01-15	365.0	27.1	35.9	78.0	29.0	23.3	29.2	26.0
24-01-15	885.0	27.2	36.2	77.0	31.0	23.8	29.5	33.2
25-01-15	409.0	22.3	36.9	75.0	29.0	23.8	29.6	26.8
26-01-15	385.0	25.7	35.6	68.0	28.0	23.5	28.9	24.8
27-01-15	607.0	26.3	35.8	67.0	28.0	23.6	29.0	24.4
28-01-15	352.0	27.2	36.3	73.0	31.0	23.0	29.2	25.9
29-01-15	344.0	26.1	36.4	75.0	34.0	24.0	29.4	29.8
30-01-15	608.0	27.3	35.5	73.0	38.0	24.2	29.5	29.4
31-01-15	336.0	26.7	36.1	71.0	30.0	23.9	28.8	29.0

01-02-15	1006.0	26.0	36.5	68.0	30.0	23.4	28.8	31.5
02-02-15	483.0	28.0	35.5	64.0	33.0	23.4	28.4	31.4
03-02-15	390.0	27.7	36.1	63.0	28.0	23.4	28.5	28.5
04-02-15	843.0	28.5	36.4	61.0	30.0	24.0	29.5	32.2
05-02-15	301.0	28.5	35.1	67.0	33.0	24.4	28.2	31.7
06-02-15	339.0	26.6	37.7	59.0	23.0	16.6	28.7	32.3
07-02-15	340.0	25.9	37.2	59.0	26.0	23.3	29.3	32.0
08-02-15	348.0	25.3	37.5	72.0	26.0	23.4	29.9	32.9
09-02-15	385.0	25.3	37.7	76.0	20.0	24.0	29.1	36.8
10-02-15	347.0	25.7	36.4	72.0	25.0	23.0	28.9	36.8
11-02-15	359.0	25.7	37.4	71.0	25.0	23.0	29.3	31.3
12-02-15	486.0	21.2	38.2	71.0	26.0	24.3	29.6	35.6
13-02-15	334.0	23.4	37.8	74.0	28.0	24.3	30.1	36.4
14-02-15	845.0	26.3	38.4	85.0	30.0	24.3	30.7	32.8
15-02-15	1311.0	30.0	38.8	73.0	22.0	25.6	30.2	32.5
16-02-15	373.0	29.8	38.7	82.0	18.0	25.0	30.1	30.5
17-02-15	342.0	23.7	38.2	84.0	23.0	25.0	29.9	31.5
18-02-15	669.0	31.0	35.9	72.0	36.0	25.2	30.3	33.4
19-02-15	367.0	27.2	38.7	87.0	33.0	25.0	30.6	33.2
20-02-15	375.0	27.2	38.4	71.0	33.0	24.5	29.5	32.2
21-02-15	383.0	27.9	37.9	67.0	23.0	23.6	28.8	29.7
22-02-15	384.0	27.9	38.8	63.0	23.0	23.0	29.2	29.3
23-02-15	630.0	28.5	38.5	51.0	23.0	21.7	28.9	33.2
24-02-15	368.0	27.8	39.4	49.0	23.0	21.9	28.9	28.2
25-02-15	370.0	28.2	38.8	49.0	24.0	22.4	29.9	29.5
26-02-15	657.0	29.3	35.1	82.0	42.0	23.7	28.4	28.4
27-02-15	356.0	28.1	36.2	85.0	44.0	24.9	29.1	32.5
28-02-15	374.0	28.8	36.0	79.0	39.0	24.7	29.6	29.6
01-03-15	690.0	29.5	36.3	80.0	41.0	24.7	30.1	29.8
02-03-15	415.0	28.5	35.6	83.0	50.0	24.7	30.0	32.0
03-03-15	1028.0	28.2	36.6	80.0	41.0	24.9	30.3	30.4
04-03-15	365.0	19.6	36.8	79.0	37.0	19.8	30.2	29.9
05-03-15	377.0	29.8	38.6	80.0	36.0	24.7	30.5	30.7
06-03-15	858.0	29.8	39.4	72.0	33.0	24.7	30.8	31.3
07-03-15	371.0	30.2	37.4	80.0	41.0	26.1	30.3	29.4
08-03-15	405.0	31.4	37.7	81.0	37.0	25.8	30.0	30.4
09-03-15	1046.0	28.5	37.8	84.0	32.0	25.9	31.4	32.6
10-03-15	488.0	30.4	39.3	72.0	27.0	26.0	30.5	34.0
11-03-15	417.0	29.3	39.7	64.0	19.0	25.0	29.9	36.9
12-03-15	416.0	23.8	39.0	67.0	25.0	24.9	30.1	30.5
13-03-15	468.0	30.6	39.6	69.0	24.0	25.4	31.1	30.5
14-03-15	435.0	29.2	39.0	73.0	28.0	25.8	29.8	34.1
15-03-15	414.0	31.3	38.7	73.0	32.0	25.9	29.6	33.2
16-03-15	745.0	27.7	39.4	85.0	31.0	25.9	31.5	31.7

17-03-15	766.0	31.3	37.4	78.0	39.0	26.4	30.7	32.3
18-03-15	755.0	31.4	37.8	85.0	37.0	26.5	32.2	32.6
19-03-15	760.0	19.2	37.9	84.0	38.0	16.9	31.9	32.3
20-03-15	763.0	31.0	39.8	84.0	20.0	26.7	32.6	31.9
21-03-15	733.0	31.1	41.0	81.0	20.0	26.8	33.1	31.8
22-03-15	709.0	31.1	41.2	84.0	18.0	21.6	32.1	33.4
23-03-15	682.0	29.1	37.4	83.0	44.0	26.7	32.4	32.2
24-03-15	710.0	25.7	36.9	84.0	45.0	23.8	32.8	31.4
25-03-15	615.0	30.2	36.9	83.0	47.0	27.8	33.4	31.4
26-03-15	709.0	30.0	40.9	83.0	24.0	27.4	34.2	31.3
27-03-15	759.0	29.5	40.9	77.0	19.0	26.9	34.8	33.4
28-03-15	713.0	29.5	40.8	80.0	20.0	26.9	35.9	26.7
29-03-15	725.0	30.7	40.7	81.0	24.0	27.2	35.5	21.1
30-03-15	768.0	30.9	38.9	84.0	44.0	28.2	35.4	25.5
31-03-15	626.0	30.6	38.3	83.0	48.0	27.5	33.5	22.1
01-04-15	124.0	30.3	38.3	75.0	48.0	27.5	33.5	22.1

Daily weather data (polyhouse)