EFFECT OF GROWING ENVIRONMENT AND MICROCLIMATE ON PARTHENOCARPIC CUCUMBER

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Effect of growing environment and microclimate on parthenocarpic cucumber"** 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 **"Effect of growing environment and microclimate on parthenocarpic cucumber"** is a record of research work done independently by **Ms. Smitha K. (2014-11-235)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Introduction

1. INTRODUCTION

India is the second largest producer of vegetables in the world. Cucumber *(Cucumis sativus)* is one of the most important cucurbitaceous vegetable crops grown extensively in tropical and sub-tropical parts of the country. It is considered as fourth most important vegetable crop after tomato, cabbage and onion. Cucumber is a thermophilic and frost susceptible crop, growing best at a temperature above 20°C. It is grown for its tender fruits, which are consumed either raw as salad, cooked as vegetable or as pickling cucumber in its immature stage.

In the recent years, due to changing climatic conditions in the country, production and quality of most vegetable crops have been directly and indirectly affected by high temperatures and exposure to elevated levels of carbon dioxide and ozone. Extremely high temperatures can even cause early flower drop in cucumber. Various other climatic factors like humidity, rainfall, light intensity etc. also affect the normal growth and development in cucumber if they are not provided in optimum range during the growing season.

Protected cultivation of vegetables could be used to improve yield quantity and quality (Singh *et al.*, 2012; Ganesan, 2002). The productivity and quality of cucumber grown under open field conditions is generally low. Cucumber under open fields are grown in two seasons; one in summer and second in rainy season. During winter season, it cannot be grown under open field conditions. Keeping in view the abiotic stresses in changing climate under open field, production technology of cucumber has been developed and standardized for cultivation under polyhouse and rain shelter. The yield of cucumber in protected structures can be increased manifold as compared to their open field cultivation.

The demand of fresh salad varieties of cucumber is increasing day by day and growing this crop under protected conditions is becoming a profitable proposition. The production technology of parthenocarpic cucumber has been developed and standardized for its cultivation under polyhouse conditions. The protected cultivation could solve the problem of low productivity during extreme weather conditions.

Therefore, in the present scenario of perpetual demand for vegetables and drastically shrinking land holdings, protected cultivation of vegetable crops suitable for domestic as well as export purposes is the best alternative for using land and other resources more efficiently (Sanwal *et al.*, 2004).

Small and marginal farmers can adopt rain shelter for successful cultivation of vegetables in rainy season. More importantly under rain shelter cultivation around 60 percent increase in crop production was observed even in the offseason and the crops were early in production.

In Kerala the production of vegetables is low during the monsoon period due to heavy rainfall and unfavorable conditions. Cultivation in plastic greenhouse has increased recently in Kerala and presently Kerala is having more than 700 polyhouses. But the modifications in the microclimate are not well known, where microclimatic variation has a major impact on crop performance as extremes affect growth, development and yield of crops (Slingo *et al.*, 2005).Thus the work was aimed to determine the efficacy of greenhouse cultivation compared to open field as well as rain shelter on growth and yield of vegetables.

Till to date, there is not much work available on effect of growing environment and microclimate on parthenocarpic cucumber production. There is an urgent need to assess the cultivation of cucumber under different growing environments to understand the effect of microclimate as well as growing conditions on yield of cucumber. Thus, the investigation was aimed to determine the following objective,

- To study the seasonal and diurnal variations of different weather parameters as well as CO_2 concentration under different growing environments.
- To study the effect of micro climate on growth and development of cucumber under different growing environments.

Review of literature

Crop growth and development are primarily governed by environmental conditions. The success or failure of crops is intimately related to the weather during the crop periods. A sound knowledge of the climatic factors and its interactions with crop is essential for successful agriculture. Cucumber growth, development, productivity and post harvest quality largely depends on the interaction between the plant genetics and the environmental conditions under which they are grown (Rajasekar *et al.,* 2013). Cucumber is grown widely throughout the world in open field and protected environment (Xiaoyu Yang *et al.,* 2012). Green house system is one of the alternative methods for solving problems faced due to climate variability (Akinyoola *et al.,* 2013). Available literature on the effect of different weather variables and microclimate on growth and development of cucumber under different growing environments are reviewed in this chapter.

2.1. MORPHOLOGICAL CHARACTERS

2.1.1. Plant height

Plants exhibit greater height under greenhouse than in open field. This is mainly due to cellular expansion and cell division under shaded condition (El- Aidy *et al.,* 1988). Abou-Hadid *et al.* (1994) reported that tomato plants grown under tunnels showed a significantly higher plant height in various stages of development against open condition in Egypt.

Arin and Ankara (2001) reported that tomato plants grown under low tunnel recorded 643.7 per cent increase in height as compared to plants grown without tunnel (602.8%). According to Anbarasan (2002) plant height of tomato was found to be higher under polyhouse condition compared to open field condition in both summer and kharif seasons.

Rajasekar *et al.* (2013) found that in cucumber the plant height was highest under shade net house compared to open field in both winter and summer seasons due to favorable microclimatic conditions i.e. temperature, relative humidity and light intensity and enhanced photosynthesis and respiration in the shade net house.

Inthichack *et al.* (2014) studied the plant growth and mineral composition in cucumber, melon and water melon grown under four constant day and night temperatures of 25/15°C,22.5/17.5°C,17.5/22.5°C and 15/25°C and they concluded that decreased day temperature results in decreased plant height and relative chlorophyll content of the cucumber.

2.1.2. Leaf area index

Watson (1952) reported that temperature is the major determinant of leaf area development where leaf area index is a main source of crop growth rate due to leaf physiology and increased number of stomata.

Marcelis and Eijer (1993) found that in cucumber total leaf area and leaf weight per plant were greater at 25°C than at 18°C, though the reverse was true for individual leaf area and weight, with increasing light levels from 30 to 100 per cent of full light the number of fruits and leaves per plant as well as the individual leaf area and weight increased while specific leaf area decreased.

Scholberg *et al.* (2000) reported that both summer and kharif seasons polyhouse tomato had higher leaf area index (5.9) whereas it was only 4.2 and 4.3 respectively under open field condition at 60 days after transplanting. For optimum light interception and fruit yields of a field grown tomato crop, the leaf area index should be around 4 to 5. Lower leaf area index value would reduce light interception and increase yield loss due to sunburn while higher values may delay the onset of fruit production.

According to Xiaolei and Zhifeng (2002) to maintain high photosynthetic rates and yield of cucumber a reasonable leaf area index is required. Vines with 13-16 leaves each would have a leaf area index between 3-3.5, which absorb more solar radiation and maintain an optimal assimilation rate and results in a higher yield. Low leaf area index resulted in reduction of crop photosynthesis and yield and the strong assimilate demand by the growing fruits at higher temperatures reduced leaf growth in greenhouse (Huevelink and Dorais, 2005). Continuous lighting for 3 week period reduced leaf area by 20% leaves in cucumber (Pettersen, 2010).

Rajasekar *et al.* (2013) concluded that in cucumber under shade net house number of leaves per plant was more compared to open field due to taller plants, increased number of secondary branches and the beneficial microclimate in the shade net house.

2.2. PHENOLOGICAL CHARACTERS

2.2.1. Days to flower

Nitsch *et al.* (1952) conducted an experiment on the development of sex expression in cucurbit flowers in France and results reported that there is a reduced number of female flowers observed when there is an extended photoperiod (16hours) and when the temperature is 30°C and is decreased. Filgueira (1981) found that increase in the proportion of female flowers in cucumber observed when there is a short photoperiods, low light intensity and low temperature. Short days and low night temperature favored pistillate flower formation and long day and high temperature favored staminate flower formation in cucumber (Ito and Saito, 1957).

Cantliffe (1981) found that when the environmental factors were analyzed independently, there is an increase of female flowers in cucumber observed when the light intensity increased. In glass house cucumber higher flower abortion was observed at lower night temperature (Lint and Heij, 1982).

Uffelen (1982) observed that cucumber with a 25/17°C day/night temperature regime and a 12 hour day length grew faster and flowered earlier than those grown at a constant temperature of 21 °C.

Schapendonk and Brouwer (1984) found that from the time of start of flowering to the next 36 days the dry matter distribution between leaves, stem and roots in cucumber remained constant. Ying and Li (1990) conducted experiments on four cucumber cultivars and found that increased female flower production was noticed at low night temperature.

Nederhoff and Vegter (1993) from an experiment on cucumber with four dates of planting and 3 temperature concluded that the higher temperature regime enhanced early flowering and fruiting of older plants but with younger plants the time of flowering and early yields were little affected by the end of harvest however the temperature regime made difference to yield, fruit number or average fruit weight.

In cucumber supplementary lighting reduced the number of days to the opening of the first flower by 9 days and increased yields by 14 per cent where the yield increases were due to increased number of fruits per plant than increased individual fruit weight (Foti and Cosentino, 1991).

Ho (1996) observed that under low light conditions, initiation of first inflorescence is delayed in tomato. In an indeterminate plant, temperature affects floral initiation, floral development, fruit set and fruit growth simultaneously.

Anbarasan (2002) reported that kharif tomato took 60.7 days and summer tomato took 55 days for fifty per cent flowering in open field whereas it was 58.6 days and 59.4 days respectively for polyhouse crop. Vezhavendan (2003) observed earliest flowering of capsicum in rain shelter compared to open field condition.

High temperature helps flowering and support photoperiodism and for the better growth of cucumber in Nigeria necessary microclimate factors such as temperature and relative humidity should be 28°C and 85%, respectively (Akinyoola *et al.*, 2013).

2.3. YIELD AND YIELD ATTRIBUTES

2.3.1. Fruit setting percentage

Miller and Ries (1958) found that increased length to diameter ratio of pickling cucumber fruits was observed at low temperature (60°F). Plants grown at 70 °F (night temperature) produced more fruits at the 11 hour day than at the 15 hour day while at 60°F (night temperature) plants produced more fruits under long day conditions.

Research findings of Toki (1978) indicated that night temperature should be maintained at 16.0°Cfor 4 hour from 17 to 21 hours in the evening followed by lower temperature of 10.0°C to 12.0°C for the remaining night. This temperature regime increased the cucumber yield by 12 percent as compared with those of the conventional cultivation for night and day temperatures.

Drews (1979) reported that cucumber fruit set and development (cv.Trix) from February to July found that small fruits gained 25- 30g fresh weight per day. Daily growth in length and width varied between 20-30 mm and 2.5- 3.5mm, respectively. Increase in light intensity and air temperature reduced the period of fruit development from 25 to 13 days. Low night air temperature enhanced fruit set whereas high air temperatures at low relative humidity encouraged fruit drop. About 30 per cent of female flowers (135 flowers per plant) developed into marketable fruits.

Slack and Hand (1980) reported that higher temperature induces earlier in cucumber but a high day temperature is more effective than a high night temperature and increasing night temperature up to 23°C results in early fruit yield but there is no significant change when the day temperature increases above 22°C. Schroder and Drews (1982) concluded that in cucumber date of planting generally controlled the earliness of the harvest the total yields however were little affected by the planting date.

The fruiting time of cucumber mainly depends on early temperature condition and reduction of vegetative growth by fruit load in cucumber without any changes on the ratio between weight of shoot and roots (Obshatko and Shabalina, 1984).

Palkin (1987) conducted experiments with the cucumber hybrid and results showed that the temperature requirement in the post transplanting period varied with the growth stage. Up to mass flowering day air temperature of 20-30°C night temperature not below 12°C and soil temperature not below 17°C were required. During flowering and fruiting in natural light, optimal day ,night and ground temperature combinations were 25-27°C ,15-18°C and 17 °C and 25-27°C, 12°C and 25°C respectively.

Comparison of the effect of different temperature regimes on cucumber under glass house showed that rising the average 24 hours temperature by 1°C advanced harvest by 4 days when the rise was due to a higher night temperature. However harvest was advanced by 12 days when the rise was due to an increase in day temperature (Uffelen, 1988).

Bruyn *et al.* (1988) in glass house trials using cucumber planted on 15th July, 24th July,12th and 25th August reported that earlier planting gave the highest total yield (17.6 kg/m^2). Each weeks delay in planting resulted in yield loss of 1.7kg/m^2.

Wawrzyniak (1988) found that the highest yield of short cucumbers (154.0 kg/100m^2) was obtained when the seedlings were planted out during the 1st half of March.

Martinez (1989) from an experiment on cucumber sown in summer (Aug-Oct) and winter (Nov – March) found out that both seasons gave equal yield of 10-11kg/m^2.The length of the growing period increased from 90 days in summer to 150 days in winter.

Staked cucumber cv.Sprint 440 (s) were grown in 4 experiments conducted in the spring (22 March to 13 June), summer (6 June to 9 August) and autumn (23 August to 25 October) of 1985 and spring (14 April to 3 July) of 1987. Irrigation was applied when the soil moisture tension at 6 inches depth reached 30-50 cent bars. The amount of water applied was 32000,16000,4000 and 24000 gal/acre for the four periods respectively, while rainfall from sowing to harvest was 17, 20, 21.5, and 18 inches respectively. Yields were significantly increased by irrigation (Hanna and Adams, 1991).

Tanis (1990) working with cucumber sown on 14 to 21 March found that cumulative yields and average fruit weight were highest with the younger (late sown) plants in which all stem fruits were retained.

Campiothi *et al.* (1991) found that the mean fruit weight and the number of fruits per plant in cucumber were lower in the autumn than in the spring season. Cucumber sown in December and January found that the early and total yield in terms of number of fruits per plant, kg/plant and g/ha were highest with December sowing (Lyutova and Kamontseva, 1992).

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. Grimstad (1995) observed that low temperature resulted in a delayed harvesting of tomato in greenhouse.

Marcelis (1993a) working with cucumber observed that the biomass allocation to the fruits increased with when plants were treated over an extended period (62 days) in short term (4 days) the allocation to the fruits did not increase with increasing irradiance. Isshiki (1994) observed a double yield of tomato in rain shelter than open field.

Kim *et al.* (1994) conducted a experiments on the influence of growth temperature on parthenocarpic fruit set in a late parthenocarpy type cucumber, He observed that a low growing temperature of 15°C resulted in the highest average rate of parthenocarpic fruit set, 78 per cent at all growth stages, at 20°C, 25°C and 30°C rate was below 50 per cent.

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.

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 26.5g as compared to 25.2g in open field during summer. During kharif season, it was 27.7g and 22.2g respectively (Anbarasan, 2002).

Development of cucumber fruits by suppressing growth and the third and fourth lateral branches were noticed at air temperature 30°C and 60% relative humidity where development of lateral branches by suppressing fruit growth was recorded when the air temperature of 25 °C and 40% relative humidity (Nobuo *et al.*, 2011).

Nobuo *et al.*(2011) studied the effect of air temperature on fruiting in cucumber, where air temperature at 25°C and 40% relative humidity results in increased total number of fruits and during low temperature seasons, percentage of marketable fruit was decreased number of fruits developed to maturity in cucumber was significantly more in kharif season compared to summer. During kharif season the seed yield per fruit, seed yield per plant and seed yield per $1000m^2$ were more compared to summer. Growth stages depends on planting date in cucumber, number of days to planting to emergence was highest for the early planting dates and it showed an decreasing trend for the later planting dates where calypso variety taken 64 days to reach fruit harvest for planting date first where it took 40 days for planting date 10 (Wehner and Guner, 2014).

ICAR (2004) recorded in tomato average fruit weight of 23g during Rabi and 39.1g during Kharif inside rain shelter whereas it was 17.5g and 43.1g respectively in open field. Number of fruits, weight, length, diameter and yield of cucumber fruits significantly depends on time of transplanting (Sharma *et al.*, 2006).

Girish *et al.* (2014) found that in cucumber, number of fruits developed to maturity was significantly more in kharif season than summer. Study conducted at Vellanikkara to know the comparison of growing cucumber under both polyhouse and open field condition showed that in polyhouse fruit weight is 13.3% higher than in open field (Rajasekharan and Nandini, 2015).

2.4. EFFECT OF WEATHER PARAMETERS

2.4.1. Air temperature

Miller and Ries (1958) found that there is an increase in the length to diameter ratio of pickling cucumber fruits under low temperature (60°C). Plants grown at 70°F night temperature produced more fruits at the 11 hour day than the 15 hour day while at 50°F night temperature plants produced more fruits under long day conditions. Vooran and Challa (1978) concluded that the date of first harvest was strongly affected by planting date and night temperature in cucumber.

Drews *et al.* (1980) found that low night temperature 16°C resulted in yield increase but the start of yielding was delayed. High temperature 23°C caused earlier bearing but because of earlier planting the total yield was decreased. This was supported by Vooren (1980) and according to him increasing night temperature from

12-20°C delayed maturity in cucumber. At the same time, an increase in day temperature from 20 to 26°C also showed a similar response.

To describe sensitivity of various aspects of cucumber growth to temperature cannot be explained by diurnal temperatures and earliness of fruit production and stem elongation have specific responses to within a day temperature regime (Heij, 1980). There is a marked increase in net assimilation rate due to enrichment with the 25/15°C settings and at 21/19°C treatment relative growth rate responses are showed decreasing rate in cucumber (Dennis, 1980). Air temperature at 20°C day and either 12/7°C night air temperature will promote the cucumber growth and gave higher early yields (Nijs, 1981).

Lint and Heij (1982) reported that cucumber seedlings planted in the green house on 13th or 27th December or 10th or 24th January and grown at 21-27°Cday temperature and 12°C,16°C or 20°C night temperature found that the later planting produced more fruits than early planting. Night temperature had only a slight effect on fruit per stem but there was an optimum near 16°C.

Cucumber leaf unfolding rate responds rapidly to a change in temperature compared to light intensity and air temperature of 20°C days and either 12°C or 7°C nights showed a faster growth and gave higher early yields in cucumber (Schapendonk and Browner, 1984).

Heissner and Drews (1985) in their studies on yield increase in green house cucumber in relation to temperature conditions found that neither planting date nor night temperature (11°C, 14°C, 17°C) affected the total yield but both affected earliness.

Fast growth was observed when alternating high (25°C) and low (15°C) temperatures within the night but the growth of cucumber reduced when the same temperature integral was obtained with alternating nights of 25°C and 15°C (Challa and Brouwer, 1985).

The positive effect of fluctuating temperature as compared to constant average temperature control the rate of growth on a short term also affects the morphological characteristics of the cucumber plant (Challa and Brouwer, 1985).

In cucumber increased fruit number per plant resulted in a more total fruit dry weight but lower dry weights of leaves, stem and roots (Heuvelink and Marcelis, 1989).

In young cucumber crop the growth was mainly dependent on effect of temperature where during maturity stage radiation was the limiting factor for yield determination and air temperature at 18°C is critical for the cucumber fruit production for January and April planting (Krug and Liebig, 1980). Marcelis (1993) conducted an experiment on cucumber cv. corona and found that fruits grown at an average temperature of 17.6°C were only 0.8 cm longer than those grown at 23.6°C. Fruit growth duration was 19.6 days and 11.9 days respectively at lower and higher temperature. At the lower and higher temperatures, it was also observed that fruit dry matter content was 3.3 and 2.9 per cent respectively.

Jeong *et al.* (1991) reported that the rate of cucumber tendril elongation and the rate of free coiling or coiling on contact with the support increased with increasing temperature and decreased when light intensity was reduced by 50 per cent.

Rylski and Aloni (1991) observed that the percentage fruit set at night temperature of 8-10°C was much higher than that at 18-20°C. At the lower temperatures fruits were seedless and deformed whereas at 18-20°C they were well shaped and contained approximately 150 seed/fruits. Due to low temperature premature leaf chlorosis in winter grown cucumber plants may be caused by starch accumulation in the chloroplast as a result of the inhibition of starch and soluble sugar export from the leaf (Schaffer *et al.*, 1991).

Combination of 25/19°C with 0.3Kpa VPD (high humidity) showed an enhanced growth of cucumber (Olympios and Hanan, 1992). Choi *et al.* (1995) opined that a temperature of 22°C resulted in the highest and lowest concentrations of nutrients in the xylem sap. The photosynthesis and transpiration were significantly lower at 12°C than at 22.0°C.or 32.0°C.

Markovsakaya (1994) observed that the optimum day and night temperature range for cucumber seedlings (cv. Alma- Atinskii) was from 28 to 32 °C.Widders *et al.*(1993) found that under high night temperature (24 or 29°C), full sunlight and regular irrigation, expansion growth rates of cucumber fruits as measured by changes in fruit diameters were most rapid.

Reduction in plant height and leaf petiole length without a decrease in plant dry weight was noticed at optimal temperature drop (Sysoeva *et al.*, 1997). Under control regime of air temperature shoot growth can be modified and the sinusoidal regimes of temperature control can increase the cucumber growth (Yoshida *et al.*, 1998).

Among meteorological elements, air temperature is considered as the most important element determining the rate of plant growth and development (Ahmed *et al.*, 2004, Chmielewski *et al.*, 2005). Increase in the air temperature changed the growth stages of cucumber (Kabarczyk, 2009) in Poland condition. In Poland, increase in air temperature contribute acceleration of phenophases of cucumber, for emergence average acceleration of the date amounted to +1.9days/10years,fruit setting +2.1 days/10 years due to increased air temperature there is a shortening of the fructification period and results deteriorate conditions for achieving good yield in cucumber (Kabarczyk, 2009). In Poland reduction in the total yield occurred with a frequency from 40% to above 80% and reduction in the marketable yield occurred with a frequency from 50% to above 70% due to high air temperature (Kabarczyk, 2010). Air temperature at 25.0°C showed a suppressed fruit growth and increased leaf development in cucumber (Nobuo, 2011). An increase by 1°C of average temperature which shortened the stages of the cucumber from -0.6 to - 4.5 days/10years (Kabarczyk, 2012).

Both summer and winter season mean weekly temperature was higher under open field condition compared to shade net house and the lower temperature favors increased plant height, no of branches, internodal length, average fruit weight and yield per plant in the shade net house than in the open field (Rajasekar *et al.*, 2013).

Temperature have significant effect on cucumber growth and development and there is a significant decrease in leaf and stem dry weight of cucumber under negative day and night temperature and 15/25°C was the lowest day and night temperature value plotted (Inthichack *et al.*, 2014).

2.4.2. Soil temperature

Soil temperature ranging from 14 to 22°C results faster growth of cucumber (Nijs, 1981). Cucumber grew faster and gave higher early yields when soil temperature ranges from 14 to 22°C (Schapendonk, 1984). Krug and Liebig (1980) found that soil temperature at 24°C results increased stem growth of one week after planting cucumber and showed a wilting when the soil temperature is below 16°C and showed a long term retardation of stem and leaf growth and fruit production. Wilcox and Pfeiffer (1990) studied the effect of soil temperature on growth of vegetables and result showed that growth of bean, cucumber, egg plant, sweet paper and watermelon was limited when the soil temperature were maintained in the 16.7–18.9°C temperature or lower.

Low soil temperature will inhibit the growth of cucumber (Krug and Liebig, 1980). Kabarczyk (2009) conducted experiment in Poland to study the effect of soil temperature on cucumber yield and he found that when the average soil temperature at the depth of 5cm in the period from sowing to harvesting amounted to ≤17.9°C and ≤17.3°C results at least 5% reduction in the total yield and marketable yield of cucumber respectively.

2.4.3. Relative humidity

High humidity and low ventilation rates in greenhouse results several physiological disorders in cucumber (Bakker, *et al.*, 1987). Hand (1988) reported that the atmospheric humidity being higher inside insulated greenhouse than open field due to restricted air exchange inside the greenhouse.

Andreas (1990) conducted an experiment with cucumber cv.corona sown on 9 January and 23 June 1989 with mean temperature of 20.8 and 21.9°C and mean relative humidity of 72.2 and 71.4 per cent obtained yields of 63 and 23 cucumbers/m^2 respectively.

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. Combination of high temperature and humidity allows higher rate of carbon dioxide injection and then promotes maximum growth of cucumber (Olympios and Hanan, 1992).

Sanden and Veen (1992) from an experiment on cucumber seedlings (cv.corona) grown at air relative humidities of 55, 75 or 95 per cent concluded that relative growth rate increased with increasing air humidity. This was attributed to increasing net assimilation rate and stomatal conductance as air humidity increased from 55 to 75 per cent and to increasing specific leaf area as humidity increased from 75 to 95 per cent. Leaf water potential changed in parallel with changes in the water potential of the root environment.

Adams and Hand (1993) studied the effect of humidity on dry matter, high humidity decreased leaf dry weight in cucumber. Relative humidity in the shade net house was always higher than in the open field (Rajasekar *et al.*, 2013).

Significant variation in weather parameters was observed among the growth situations and growing seasons, under shade net house highest relative humidity of 59.50 and 67.10% was recorded during summer and winter season respectively. Whereas the lowest relative humidity of 52.6% and 56.62% was recorded during summer and winter season under open field condition (Rajasekar *et al.*, 2014).

2.4.4. Light intensity

Light intensity mainly affects during the time prior to planting showed a significant importance to the leaf unfolding rate in the subsequent period from planting until flowering (Schapendonk, 1984).

Reduced light conditions results in significant reduction in photosynthetic capacity in lower leaves (Pettersen, 2010a). Bruggink and Heuvelink (1987) stated that, in tomato, cucumber, and sweet pepper seedlings, relative growth rate is not proportional to variation in light integrals and also they 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.

Supplemental lighting results in increased plant development, leaf chlorophyll, leaf photosynthesis, plant biomass and early marketable yield production in cucumber and due to supplemental lighting there is an increase in biomass allocation to fruit, fruit dry matter content and skin chlorophyll content(XiumingHao, *et al.*, 1994).

Due to reduced light level main stem length, internode length and individual leaf area increased where as main stem diameter and number of leaves per plant decreased in cucumber (Haque *et al.*, 2009).

According to Pettersen *et al.* (2010) cucumber plants grown under 24h/day light had lower chlorophyll index compared to plants grown under 20h/day lighting period. Reduced light condition results in decreased photosynthetic capacity in lower leaves photosynthetic characteristics in cucumber is mainly depended on lighting regime. Intracanopy lighting where 65% of overhead lamps and 35% of lamps mounted vertically along the plant rows results improved distribution of light in the canopy and helps to increase the net photosynthesis and photosynthetic capacity. Due to intracanopy light, yield of cucumber increased by 11% compared to traditional overhead light. Horizontally growing cucumbers showed that there is no decline in photosynthetic capacity when cucumber leaves are growing under good light conditions.

Growth and development of vegetables mainly depends on light among the environmental factors especially in protected conditions (Xiaoyu Yang *et al.*, 2012) Light intensity was higher under open field than in shade net (Rajasekar *et al.*, 2013).

2.4.5. Photosynthetic Active Radiation (PAR)

Haque *et al.* (2009) found that there is a drastic decrease in number of leaves per plant when the PAR is at 50%, there is an increase in SPAR value because of PAR level reduction where chlorophyll synthesis in leaves increased at partial shading conditions at 25% PAR significant yield reduction was noticed and there is no reduction in the dry matter when the light is reduced to 100% PAR to 50% PAR at full sunlight highest yield (15.32 t/ha) produced in cucumber.

According to Dongsheng and Pingping (2013) cucumber leaf net photosynthetic rate was increasing below LSP and decreasing above LSP (LSP was between 1200 and 1400 umolm^{-2}s^{-1}).

Cucumber growth and development was influenced by photosynthetic active radiation where there is a reduction of about 48.2% inside the polyhouse when compared to open field (Rajasekharan and Nandini, 2015).

Study conducted at Chengdu to know the effect of PAR on photosynthesis and a total of 16 cucumber accessions were selected from the core collection to perform the assay.These accessions are from India, Russia, Spain, Germany, America, Japan, as well as provinces of Xinjiang, Guizhou, Fujian, Henan, Shandong, Guangxi, Anhui, Hubei, Sichuan, and Yunnan in China. All the cucumber plants were grown in greenhouse at the same time in spring, 2015. The fifth top leaves of two month old plants were subjected to photosynthesis measurement. They found that photosynthetic responses to PAR of the 16 cucumber species showed significant differences under the light intensity from 400 to 2400 µmol/m^2/s^1. Photosynthesis increased rapidly when PAR increased from 0 to 800 µmol/m^2 s^1 (Zhao *et al.,* 2016).

2.4.6. Ultraviolet radiation

Increased intensities of UV – B irradiation results a significant reduction in the leaf area and dry weight of cucumber and due to increased UV-B irradiation, relative growth rate, net assimilation rate and leaf area ration were reduced (Nouchi, 1993).

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.

2.4.7. Carbon dioxide

Under water stressed condition plants have lower stomatal conductance and carbon dioxide assimilation rates (Abdul, *et al.*, 1993). Cucumber production increased considerably by increasing carbon dioxide concentration between 50 and 1000ppm (Heij and Uffelen, 1984).

Gustafasson and Weick (1991) found that CO_2 uptake by tomato and cucumber crops was directly related to the intensity of solar radiation at 1500 and 2870ppm concentration cause damage to full grown leaves and results reduced growth and production. Cucumber production increased to 18% due to increased carbon dioxide from 200 to ambient level of 340ppm.

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 and Alock (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 C4 crops responded very much less than C3 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 concentrations. 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).

2.4.8. Solar radiation

Cucumber as a thermophilous plant requires proper solar and thermal conditions for its proper growth and development during its average 4 months vegetative season (Krug and Liebig 1980, Marcelis 1993).

Evangelinamedrano (2005) reported that the diurnal canopy transpiration rate was four times higher than at high radiation level compared to low radiation level.

The duration of cucumber development stages were closely dependent on the sunshine hours where an increase by 1 hour of average sunshine duration shortened the stages of cucumber plant from -0.3 to -3.5 days/10 years in Poland. (Kabarczyk, 2012).

2.5. EFFECT OF GROWING ENVIRONMENTS

Chaugale *et al.* (1990) reported that under open field, relative humidity was lower than that of polyhouse where relative humidity fluctuation affects cucumber growth and development.

Net assimilation rates were higher in unshaded plants where under shaded cucumber produced less total dry matter and proportionately put more dry matter into leaves and stems and less into roots and fruits (Smith *et al.*, 1984).

In rain shelter efficient air flow is possible due to effective ventilation system and it maintains natural air mass balance between in and out promotes crop growth (Sharif *et al.*, 2008).

According to XiumingHao (1998) in glasshouse high dry matter production was translated into high fruit dry matter content but not high early marketable yield.

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.

Thangam *et al.* (2002) conducted a study on tomato growth under open and shaded conditions and found that early flowering and fruiting were noticed in open field when compared to shade for different genotypes of tomato tried and also tomato plants grown under shade exhibited better growth in terms of plant height and dry matter production compared to those in open field.

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.

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 plant.

The use of greenhouse in arid region decreases the crop water requirement by reducing evapotranspiration by 65 to 80% compared to outside (Fernades *et al.*, 2003).Protected cultivation of vegetable crops suitable for domestic and export purposes could be a more efficient alternative for land use and other resources (Sanwal *et al.*, 2004).

According to Rahman and Al-Wahaibi (2004) the irrigation water use efficiency was higher in the greenhouse than that of the open field because of the lower water requirements and higher yields of cucumbers. But the total water use efficiency approached that of the field as the rates were maximized, because of the high quantity of water used in evaporative cooling. The average cooling pad water use was found to be 79.1 l m^{-2} day^{-1} of pad area. In the greenhouse, irrigation water use efficiency was highest with 2 mm/day applications (31.3 kg/m^3), whereas in the open field the highest irrigation water use efficiency obtained was only 7.6 kg/m^3 for the 6 mm/day applications.

Interaction between effect of time of transplanting and environment interaction showed a significant increase in number of fruits(12.6), fruit length (18.5cm) and yield (5.38kg/plant) when transplanting was done early under polyhouse (Sonia and Sharma, 2006).

Under rain shelter, day time temperatures rise above ambient and this is suitable for growing warm season crops like tomato at cooler (Kratky, 2006).

An experiment was conducted in a covered polyhouse along with an open field (control) aside the Field Laboratory of the Department of Crop Botany, Bangladesh Agricultural University, Mymensingh during the period from December 2007 to April 2008 to compare the phenological development and production potentials of two tomato varieties viz. BARI Tomato-3 and Ratan under polyhouse and open field conditions. They found that tomato plants grown inside the polyhouse hastened first flowering, first fruiting and first maturity by about 3, 4 and 5 days, respectively as compared to the plants grown in the outside natural condition Polyhouse plants prolonged the duration of fruit harvest by about 9 days. The varietals effect was found to be significant for days required to first maturity and end of fruit harvest but insignificant for days required to first flowering and first fruiting and polyhouse plants had significantly higher number of flower clusters/plant, flowers/cluster, flowers/plant, number of fruit clusters/plant and fruits/cluster than the plants grown in open field (Parvej *et al.*, 2010).

Narayanankutty *et al.* (2013) reported that cucumber varieties grown under greenhouse selected for a low light and low temperature environment of spring and winter season so the warm humid climate of Kerala is well suited for cucumber cultivation.

A study conducted at Vellanikkara showed that both summer and rainy season cucumber had maximum vine length and maximum number of branches under rain shelter compared to open field (Sadanendan, 2013).

The plant height, number of branches, number of leaves per plant, internodal length, leaf area and leaf area index were influenced by growing environment and during winter intermodal length of cucumber was highest under shade net house due to accumulation of photosynthates which triggered early initiation of flowers (Rajasekar *et al.*, 2013).

During summer season cost benefit ratio of cucumber inside the rain shelter was 1:5.15 and in open field it was found that 1:4.8 and during rainy season cost benefit ratio was 1:1.4 and 1:6 under rain shelter and open field respectively (Sadanendan, 2013).

Girish *et al.*(2014) concluded that under polyhouse vine length, number of leaves, fruit weight, fruit length and fruit width of cucumber were significantly higher compared to open field condition and under polyhouse germination percentage seedling length, seedling dry weight were significantly higher in comparison to open field conditions.

Patel and Bhagat (2014) found that under shade net, days to 50% flowering in cucumber was recorded as 29.25, 30.58 and 33.33 with 35.50 and 75% shading respectively where in open field it was found 45.71 which were more compared to shade net. Under polyhouse highest average diameter of the cucumber fruit (4.19cm) was recorded compared to open field (2.31cm).and the average length of cucumber fruit (16.76cm) was noticed under shade net and 7.81cm recorded under open field. Average weight of cucumber fruit under shade net was 170.82g where in open field it was found 82.81g and maximum length of vine at last harvest was 4.37cm, where in open field minimum length of vine (1.65cm) was recorded in cucumber. Under shade net maximum number of cucumber fruits (8.32) was recorded compared to open field (2.30). Maximum yield of fruit per vine (1.42kg) was observed under shade net condition where in open field, it was found 0.19kg in cucumber. Total yield of cucumber under shade net was 8 to 10 times more than open field condition.

Mean air temperature of 40.3°Cto 24.6°C,mean relative humidity of 91.80 to 30.53%,mean sunshine hours 8.04 to 11.04hours,wind speed 1.72 to 6.55km/hr were found to be optimum for higher yield of cucumber under shade net (Patel and Bhagat, 2014).

A study conducted at TNAU on screening vegetables under shade net showed that the temperature recorded during the experiment showed variation between shade net and open field during both summer and winter season. Maximum mean temperature of 34.20°C and 32.8°C minimum temperature of 32.06% and 30.10°Cwas recorded in open field condition during winter and summer seasons and also under different growing environments light intensity showed significant difference where under open field condition highest light intensity (34044.45 and 25867.01 μ mol / m^2) was observed during summer and winter seasons respectively.

In shade net house minimum light intensity of 25867.01 and 18333.74 μ mol / m^2) was observed during summer and winter season (Rajasekar *et al.*, 2014).

Yield character of cucumber was significantly influenced by prevailing weather and more fruit per plant occurred in cucumber under shade net house during summer and winter season. During both summer and winter season, fruit in the shade net house were longer compared to open field condition and shade net grown cucumber had heavier fruit than field cultivation in both seasons. Highest fruit weight was recorded under shade net (Rajasekar *et al.*, 2014).

Study conducted at Vellanikkara to study the growth of cucumber under open field and polyhouse showed that number of harvest in polyhouse is 21.52% more than open field (Rajasekharan and Nandini, 2015).

Materials and methods

3. MATERIALS AND METHODS

The study was conducted at the College of Horticulture, Vellanikkara during 2014-2015 with the objective to study "Effect of growing environment and microclimate on parthenocarpic Cucumber". In order to achieve the objectives of the present investigation, field experiments were conducted at six dates of planting i.e., January 15, January 25 and February 05, 2015 and June 1, June 10 and June 20 2015 in three growing environments i.e., Polyhouse, Rain shelter and Open field. The details of location, climate and soil conditions of the experimental site and methodology for estimation of different parameters 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 at Agricultural Research Station located in Mannuthy, 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

Kafka variety of cucumber which is a parthenocarpic variety with duration of 90-100 days and it matures in 40-45 days and produces long, straight cucumbers with thin, non bitter skins. Fruit size is 29-35 cm long and very uniform and fruits are very stable and uniform. A reliable variety for all-year round growing in greenhouses.

3.2. METHODS

The study was conducted in two seasons in polyhouse, rain shelter and open field simultaneously in a split plot design with 3 replications. The plot size was 20 m^2 and spacing was 1.5 x 0.5m.The package of practices recommendations were followed under non-limiting water conditions. The crops were planted on six different dates (T1, T2, T3, T4, T5 and T6) under three different growing environments.

T1 – January 15

T2 – January 25

T3 – February 05

T4 – June 01

T5 – June 10

T6 – June 20

3.3. CULTURAL OPERATIONS

3.3.1. Nursery management

Nursery was raised in portrays containing rooting medium of compost, perlite and vermicompost 3:1:1 and adequate plant protection measures were also taken. Seedlings were transplanted to the experimental site at 14 days after sowing.

3.3.2. Preparation of main field and transplanting

The experimental site, i.e., polyhouse, rain shelter and open field were cleared thoroughly in order to avoid weeds during growing period. The grow bags were filled with soil, coir pith and manure 2:1:1 ratio. Irrigation was given immediately after transplanting using a rose can.

3.3.3. After cultivation

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

3.3.4. Fertilizers and manure application

Urea, 19:19:19, MAP and Potassium nitrate were the source material for supplying the nutrients N, P_2O_5 and K_2O respectively.

3.3.5. Staking and training

Staking and training was practiced using wooden poles, coir and floricultural net

3.3.6. Plant protection

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

3.3.7. Harvesting

Cucumber crop matures within 40 - 50 days and harvesting starts 45 - 55 days after planting.

3.4. OBSERVATIONS

Three plants per replication from polyhouse, rain shelter and open field conditions were selected for recording observations.

3.4.1. Morphological characters

3.4.1.1. Plant height (cm)

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

3.4.1.2. Leaf area index (LAI)

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

3.4.1.3. Biomass (g)

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.

3.5. PHENOLOGICAL CHARACTERS

3.5.1. Days to first flowering

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

3.5.2. 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.

3.5.3. Days to last harvest

The number of days taken to last harvest from the date of first harvest was counted for three conditions and expressed as days to last harvest.

3.5.4. Number of harvest

Total number of harvest made from three conditions was recorded.

3.6. YIELD AND YIELD ATTRIBUTES

3.6.1. 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.

3.6.2. Average fruit weight (g)

Using fruit yield per plant and fruits per plants average fruit weight were worked out.

$$\text{Average fruit weight} = \frac{\text{Fruit yield per plant}}{\text{Fruits per plant}}$$

3.6.3. Fruit yield per plant and total yield (kg)

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.

3.6.4. Marketable yield (kg)

The diseased, discolored and damaged cucumbers were discarded and uniform size cucumber was selected from three growing environments from each harvest. Marketable yield was calculated from total yield and expressed in kilograms.

3.6.5. Duration of crop

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

3.6.6. 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.Canopy Temperature and Canopy Air Temperature Difference (CATD) was recorded using infrared thermometer. PAR was recorded using CI 110/120- digital plant canopy imager. Carbon dioxide was recorded using CO_2 meter.

Table 1. Weather parameters used in the experiment

Sl.no	Weather parameters	Unit
1	Maximum temperature	°C
2	Minimum temperature	°C
3	Soil temperature	°C
4	Canopy air temperature	°C
5	Canopy air temperature difference	°C
6	Rainfall	mm
7	Relative humidity	%
8	Soil moisture	%
9	Solar radiation	Wm^{-2}
10	UV radiation	mW/cm^{-2}
11	PAR	$\mu mol\ s^{-1}m^{-2}$
12	Carbon dioxide	ppm

3.7. STATISTICAL ANALYSIS

The data recorded from the field experiment was analyzed 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 cucumber. Regression equations were worked out from these observations. The different statistical software like WASP 2.0 and SPSS were used in the study for various statistical analyses.

Plate 1. Automatic weather station

Cucumber obtained from different growing environments

Plate 2a. Rain shelter

Plate 2b Polyhouse

Plate 2c Open field

Results

The results of the experiment entitled "Effect of growing environment and microclimate on parthenocarpic cucumber" are presented in this chapter. The effect of weather parameters on growth and yield under different growing environment i.e. polyhouse, rain shelter and open field were studied.

4.1. WEATHER DURING THE CROP PERIOD

The effect of different weather parameters during crop period under different growing environments in two seasons are presented below (Table 2- 13).

4.1.1. Temperature (°C)

4.1.1.1. Maximum temperature (°C)

The highest value of mean weekly maximum temperature for the crops transplanted on winter season were recorded inside the rain shelter (49.4 °C) while the lowest mean weekly maximum temperature were recorded in the open field condition (36.8 °C). During rainy season highest value of mean weekly maximum temperature was recorded inside the polyhouse (43.2 °C) followed by rain shelter (42.7 °C) and open field (33.0 °C). Regardless of the season the highest mean weekly maximum temperatures were recorded inside the rain shelter whereas the lowest values were obtained in the open field. During winter season maximum temperature showed an increasing trend throughout the growing period but showed a decreasing trend during rainy season (Table 2).

4.4.1.2. Minimum temperature (°C)

From the Table 3 it is clear that crops transplanted in winter season, the highest and lowest values of 26.0 °C and 20.8 °C were recorded under open field and rain shelter, respectively. In rainy season the highest value of mean weekly minimum temperature was recorded inside the polyhouse (25.2 °C) followed by open field (25.0 °C) and rain shelter (24.8 °C). The lowest weekly mean minimum temperature was recorded under open field (23.3°C).

Table.2. Weekly variation of maximum temperature during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	32.6	33.1	33.1	33.8	35.4	35.2	34.7	35.6	34.0	36.0	36.8		
RS	34.7	35.1	36.3	40.4	47.4	45.5	46.6	47.7	44.6	49.1	49.4		
PH	33.9	35.3	37.5	40.1	46.8	45.5	45.6	47.4	46.0	48.5	48.9	47.2	47.5
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	33.0	32.4	30.6	30.7	32.0	30.5	30.8	28.4	29.3	31.2	30.3	30.9	
RS	42.7	41.4	39.1	36.7	37.5	35.4	35.0	32.3	36.8	37.2	34.2	36.6	
PH	43.2	41.6	38.2	36.0	38.1	36.1	35.3	31.3	34.6	36.1	32.1	34.3	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 3. Weekly variation of minimum temperature during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	22.2	23.1	23.8	23.3	23.5	22.3	23.9	24.6	24.9	25.2	26.0		
RS	20.8	23.3	24.6	21.8	22.2	20.5	22.8	23.7	24.1	24.5	25.2		
PH	21.6	24.0	25.1	22.6	23.0	21.4	23.5	24.4	24.7	25.0	25.6	25.7	24.4
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	25.0	24.3	23.7	24.8	23.8	24.3	23.8	23.6	23.3	24.9	24.5	24.4	
RS	24.6	23.9	23.5	24.3	23.6	24.7	24.2	23.8	23.6	24.0	23.8	24.8	
PH	24.9	24.3	23.9	24.6	24.0	25.0	24.4	24.3	24.2	24.5	24.4	25.2	

OF- Open field PH- Polyhouse RS- Rain shelter

The minimum temperature was high in open field conditions during winters where as in rainy season; polyhouse conditions recorded the highest value.

4.4.2. Soil temperature

The maximum and minimum soil temperature experienced during the entire crop growing period is given below on weekly basis.

4.4.2.1. Maximum soil temperature (°C)

The highest value of weekly maximum soil temperature was recorded crop transplanted under open field condition (50.7 °C) followed by polyhouse (47.7 °C) and rain shelter (47.3 °C) where in rainy season highest weekly maximum soil temperature was recorded inside the polyhouse (41.5 °C) followed by rain shelter (40.6 °C) and open field (38.3°C). Winter season the maximum soil temperature showed increasing trend where as during rainy season maximum soil temperature showed decreasing trend (Table 4).

4.4.2.2. Minimum soil temperature (°C)

The highest weekly minimum soil temperatures were observed under open field condition followed by polyhouse and rain shelter both in winter season and rainy seasons. The highest value of minimum soil temperatures were 34.9 °C, 28.5 °C and 34.1 °C under open field, polyhouse and rain shelter respectively during winter season. Whereas during rainy season the highest minimum temperatures were in the tune of 33.6 °C, 28.0 °C and 33.4 °C under open field, polyhouse and rain shelter respectively. The lowest minimum temperature also followed the same trend (Table 5).

4.4.3. Soil moisture (%)

Table 6 showed that highest and lowest value of soil moisture during winter season was recorded inside the polyhouse (42.7%) and open field (40.2%) respectively. The value of soil moisture recorded during rainy season was also high inside the polyhouse (42.6%) followed by rain shelter (41.8%) and open field (40.9%).

Table.4. Weekly variation of maximum soil temperature during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	40.4	44.9	44.8	45.8	44.7	47.9	47.4	50.7	46.9	43.7	47.2		
RS	36.9	40.0	39.4	43.6	38.6	45.9	44.2	47.3	45.3	43.0	44.5		
PH	37.1	40.7	40.1	43.2	39.5	46.2	44.5	47.7	44.8	42.8	43.3	40.7	38.8
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	38.3	38.1	37.0	32.3	30.1	37.8	37.3	31.3	29.4	30.2	29.5	30.3	
RS	40.4	40.5	40.6	32.7	31.0	38.0	39.4	33.4	32.0	35.7	36.2	35.9	
PH	41.3	41.4	41.5	35.5	34.2	38.4	39.9	34.0	36.8	38.5	37.1	38.2	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 5. Weekly variation of minimum soil temperature during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	30.6	31.3	32.0	31.0	32.9	31.8	33.6	34.5	33.8	32.9	34.9		
RS	23.5	27.4	28.5	24.7	25.3	24.1	25.4	26.2	26.6	27.5	27.8		
PH	28.0	32.7	34.1	29.5	30.2	28.8	30.3	31.3	31.8	32.9	33.2	32.8	32.9
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	33.6	32.8	31.7	31.7	32.8	31.5	32.1	31.3	31.0	31.9	31.8	32.4	
RS	28.0	27.8	27.9	27.9	27.2	25.5	25.7	25.6	25.9	26.5	25.8	26.9	
PH	33.4	33.2	33.3	33.3	32.5	30.5	30.7	30.6	30.9	31.7	30.8	32.2	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 6. Weekly variation of soil moisture during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	39.2	39.3	39.8	38.7	40.0	40.0	40.2	40.2	39.9	39.2	39.8		
RS	40.7	40.8	41.0	41.0	40.8	40.8	39.1	41.8	41.9	41.9	41.9		
PH	41.8	41.6	41.6	39.8	41.8	42.7	42.7	42.7	42.7	41.6	37.0	38.1	41.1
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	39.5	40.5	40.5	39.9	38.6	39.5	40.7	40.9	37.4	40.7	40.7	40.6	
RS	39.4	39.7	41.5	41.8	39.6	40.1	41.5	40.1	41.5	41.5	40.6	40.4	
PH	42.5	42.6	38.9	42.3	42.3	41.0	42.3	41.4	41.5	40.2	41.0	41.3	

OF- Open field PH- Polyhouse RS- Rain shelter

4.4.4. Relative humidity (%)

The maximum and minimum relative humidity experienced during the entire crop growing period is given below on weekly basis.

4.4.4.1. Maximum relative humidity (%)

During winter season the highest and lowest value of maximum relative humidity was recorded inside the polyhouse (97.3%) and rain shelter (74.9 %) respectively and during rainy season also polyhouse recorded highest value of maximum relative humidity (98.7%) and lowest value 88.7% was recorded in rain shelter. Irrespective of season the highest and lowest value of maximum relative humidity was recorded inside the polyhouse and rain shelter throughout the crop period (Table 7).

4.4.4.2. Minimum relative humidity (%)

Table 8 showed that highest minimum relative humidity was recorded inside the polyhouse (56.7 %) followed by rain shelter (51.9 %) and open field (48.7 %) during winter season and in rainy season highest value was recorded inside the polyhouse (98.7 %) and lowest value was recorded under rain shelter (87.4 %).

4.4.5. Solar radiation (Wm^{-2})

Highest value of solar radiation in winter season recorded under open field (990 Wm^{-2}) and lowest value recorded inside polyhouse and rain shelter (53 Wm^{-2}). Winter season solar radiation showed increasing trend where in rainy season it showed decreasing trend. Regardless of season the highest and lowest value of solar radiation was recorded under open field and polyhouse and rain shelter respectively (Table 9).

4.4.6. Photosynthetically active radiation ($\mu mol\ s^{-1} m^{-2}$)

The least weekly photosynthetically active radiation for both seasons was 169 $\mu mol\ s^{-1} m^{-2}$ recorded inside the polyhouse whereas, the highest value of 1300 $\mu mol\ s^{-1} m^{-2}$ was observed under open field. In winter season PAR recorded inside

Table. 7. Weekly variation of maximum relative humidity during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	74.9	75.3	70.3	78.4	76.1	73.1	86.3	84.0	79.4	88.8	84.8		
RS	68.9	72.6	68.3	69.0	62.1	59.7	68.1	67.5	66.9	70.9	70.1		
PH	80.2	90.7	84.5	88.6	93.0	93.8	94.9	94.4	95.4	97.3	96.5	96.8	96.2
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	89.3	92.4	95.1	93.3	95.9	94.1	94.7	96.3	95.0	93.9	96.4	94.8	
RS	77.3	81.2	86.4	82.8	87.4	79.9	81.3	86.3	89.1	80.8	86.1	82.4	
PH	97.7	97.8	98.6	98.0	98.7	93.3	94.0	95.0	95.2	90.4	93.0	91.6	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 8. Weekly variation of minimum relative humidity during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	52.8	46.8	51.5	46.5	55.1	48.3	55.3	55.9	52.4	53.0	56.2		
RS	44.7	41.4	44.2	39.5	43.6	29.9	38.7	46.7	44.1	44.2	45.1		
PH	40.9	37.9	39.9	35.7	38.5	26.4	29.5	33.4	23.1	23.0	23.4	23.2	23.1
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	65.4	73.1	75.3	93.3	95.9	70.6	72.0	86.4	71.6	68.9	75.1	72.8	
RS	43.8	44.3	59.6	85.9	87.4	58.4	61.1	73.1	58.6	59.7	71.5	62.4	
PH	56.9	57.0	57.5	89.5	92.3	54.3	54.7	55.3	55.4	55.0	52.3	55.1	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 9. Weekly variation of solar radiation during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	944	891	863	911	934	946	982	974	946	973	990		
RS	53	61	62	72	74	75	62	69	71	75	73		
PH	53	61	62	72	74	75	62	69	71	75	73	67	67
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	907	853	746	657	564	487	187	170	179	190	160	171	
RS	53	42	30	33	48	28	28	26	27	28	27	28	
PH	53	42	30	33	48	28	28	26	27	28	27	28	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 10. Weekly variation of PAR during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	862	884	799	846	987	963	942	1002	1222	1300	1210		
RS	627	646	625	685	698	802	764	753	901	966	936		
PH	348	366	332	387	411	447	505	476	560	575	603	663	624
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	987	1023	894	958	799	922	895	906	895	710	902	853	
RS	569	701	489	794	379	610	573	794	523	373	743	490	
PH	223	311	169	422	189	284	389	423	254	175	336	266	

OF- Open field PH- Polyhouse RS- Rain shelter

the polyhouse and rain shelter was 603µmol $s^{-1}m^{-2}$ and 966µmol $s^{-1}m^{-2}$ respectively and under open field it was 1300µmol $s^{-1}m^{-2}$ and during rainy season PAR inside polyhouse and open field condition was 422 µmol $s^{-1}m^{-2}$ and 1023µmol $s^{-1}m^{-2}$ respectively. Regardless of season the highest mean weekly PAR was recorded under open field whereas the lowest values were obtained inside the polyhouse (Table 10).

4.4.7. Canopy temperature (°C)

From the Table 11 it is clear that the highest weekly canopy temperature was recorded inside the open field (39.1 °C) followed by rain shelter (38.8 °C) and polyhouse (34.2 °C). In rainy season highest value of canopy was recorded in rain shelter (36.4 °C) followed by open field (34.6 °C) and polyhouse (32.4 °C).

4.4.8. Canopy air temperature difference (CATD)

The highest CATD value was recorded inside polyhouse (-3.8) followed by rain shelter (-3.4) and open field (-3.2) in winter season. Where during rainy season the highest value was recorded inside polyhouse (-3.5) and least value was recorded under open field and rain shelter (-2.0). It showed that inside the polyhouse crops are grown well as compared to rain shelter and open field condition (Table 12).

4.4.9. UV radiations ($mWcm^{-2}$)

Highest and lowest value of UV radiation was recorded under open field and polyhouse respectively in both seasons. In winter season highest value of UV radiation recorded was 74.6 $mWcm^{-2}$ recorded under open field and lowest value was 0.7 mW/cm^{-2} recorded inside the polyhouse. Whereas during rainy season highest and lowest value of UV radiation was 73.7 $mWcm^{-2}$ and 2.0 mW/cm^{-2} under open field and polyhouse respectively. Irrespective of season highest value was recorded under open field and lowest value of UV radiation was recorded inside polyhouse (Table 13).

Table. 11. Weekly variation of canopy temperature during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	31.8	39.1	36.2	36.6	32.4	33.4	27.9	28.0	24.7	26.6	26.4		
RS	31.4	38.8	36.1	36.5	31.2	30.3	28.1	26.6	22.8	25.2	27.9		
PH	31.1	34.2	30.0	33.9	31.0	28.3	26.9	25.4	21.6	23.1	25.9	29.5	25.5
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	31.6	32.6	33.4	34.6	34.1	33.7	33.6	34.6	31.7	30.5	29.3	27.9	
RS	31.9	32.9	36.2	36.4	33.8	33.0	31.4	31.9	30.5	28.8	28.4	27.8	
PH	30.6	30.1	31.6	32.4	29.0	30.4	29.9	30.4	30.0	29.1	28.6	26.8	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 12. Weekly variation of canopy air temperature difference during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	-3.2	-3.0	-2.9	-3.0	-2.9	-2.4	-2.1	-2.4	-2.4	-2.7	-2.1		
RS	-3.4	-3.3	-3.0	-2.8	-2.9	-2.6	-2.2	-2.5	-2.7	-2.6	-2.0		
PH	-3.8	-3.7	-3.5	-3.3	-3.3	-3.1	-3.1	-3.0	-3.0	-2.9	-2.9	-2.8	-2.7
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	-3.1	-2.8	-3.1	-2.9	-3.1	-2.8	-2.7	-2.4	-2.2	-2.3	-2.1	-2.0	
RS	-3.0	-2.9	-3.1	-3.0	-3.2	-3.1	-2.6	-2.4	-2.1	-2.2	-2.3	-2.0	
PH	-3.5	-3.3	-3.4	-3.1	-3.4	-3.4	-3.0	-3.1	-2.9	-3.0	-2.9	-2.5	

OF- Open field PH- Polyhouse RS- Rain shelter

Table. 13. Weekly variation of UV radiation during crop period

Winter season													
Week	3	4	5	6	7	8	9	10	11	12	13	14	15
OF	56.4	57.5	58.1	59	62.1	63.3	63.7	64.4	64.7	71	74.6		
RS	8.0	10.8	11.9	12.2	12.3	12.8	13.5	13.8	14.2	15.1	15.1		
PH	0.7	1.6	1.7	1.8	1.8	2	2	2.2	2.2	2.4	3.9	3.3	3.9
Rainy season													
Week	22	23	24	25	26	27	28	29	30	31	32	33	
OF	73.8	72.9	70.4	68.3	67.5	66.8	66.1	66.1	65.2	64.2	62.3	60.2	
RS	13.4	13.2	13.0	13.0	12.7	12.3	11.6	8.1	8.0	7.2	6.8	6.3	
PH	2.9	2.7	2.3	2.7	2.6	2.3	2.3	2.3	2.4	2.3	2.0	2.2	

OF- Open field PH- Polyhouse RS- Rain shelter

4.2. DIURNAL VARIATIONS IN WEATHER PARAMETERS

4.2.1. Temperature

The highest value of air temperature inside the polyhouse (34.7°C), rain shelter (34.2°C), open field (33.4°C) occurring around 15:00,15:00 and 13:00 hours while the lowest value were 20.5°C, 20.9°C and 20.0°C respectively recorded inside polyhouse, rain shelter, open field (Fig.1). During rainy season the highest value of air temperature inside the polyhouse (33.5°C), rain shelter (34.1°C), open field (28.3°C) occurring around 16:00,16:00 and 15:00 hours while the lowest value were 23.7°C, 23.6°C and 23.2°C respectively recorded inside polyhouse, rain shelter, open field (Fig, 2).

4.2.2. Relative humidity

The highest value of relative humidity inside the polyhouse, rain shelter and open field were 93%, 85%, 86% respectively whereas the lowest values were 37%, 50%, 46% correspondingly in the polyhouse, rain shelter and open field and occurred around 15:00,14:00,15:00 respectively (Fig.3). Where during rainy season the highest value of relative humidity inside the polyhouse, rain shelter and open field were 98.9%, 96.2%, 96.1% respectively recorded around 6 am. Whereas the lowest values were 60.7%, 71.4%, 75.4% correspondingly in the polyhouse, rain shelter and open field and occurred around 15:00,16:00,16:00 respectively (Fig 4).

4.2.3. Soil temperature

The highest value of soil temperature recorded in the open field, rain shelter and polyhouse were 34.5°C, 31.3°C, 31.2°C occurred around 13:00 hours. The least value were 22.5°C, 21.7°C, 21.1 °C recorded inside the polyhouse, rain shelter and open field the change in soil temperature in all three growing conditions were showed a same trend throughout the day (Fig. 5). Where from the Fig 6 it is clear that during rainy season the highest value of soil temperature recorded in the open field, rain shelter and polyhouse were 39.6°C, 33.4°C, 34.1°C occurred around 17:00,1600,1600 hours respectively. The least value were 25.2°C, 24.2°C, 23.9 °C recorded inside the polyhouse, rain shelter and

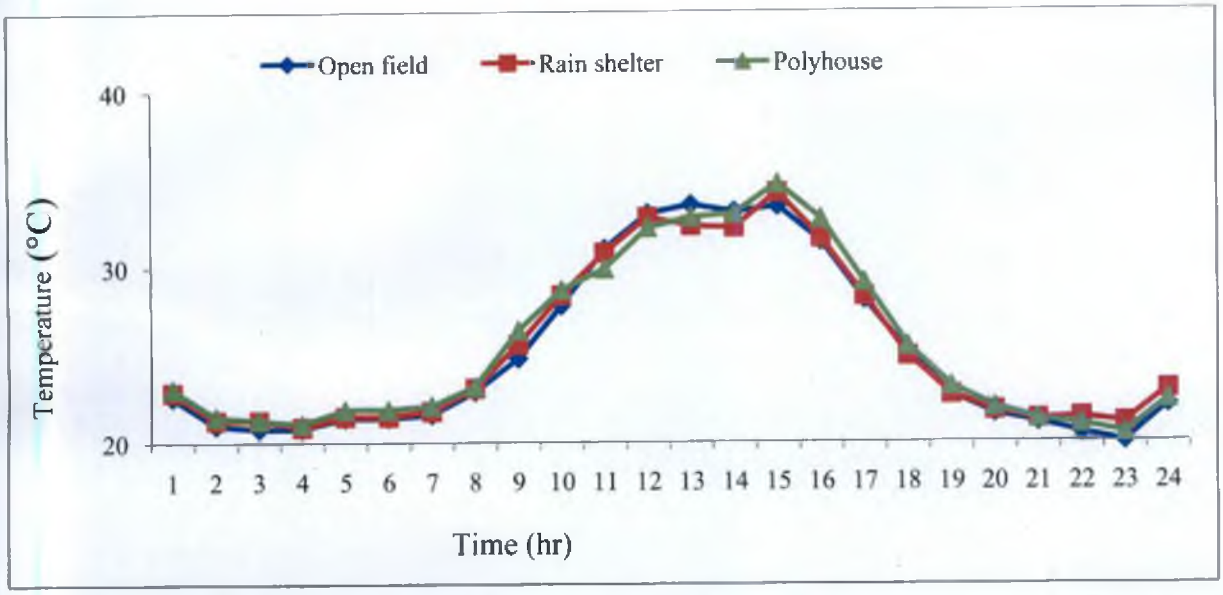

Fig.1. Diurnal variation of temperature during winter season

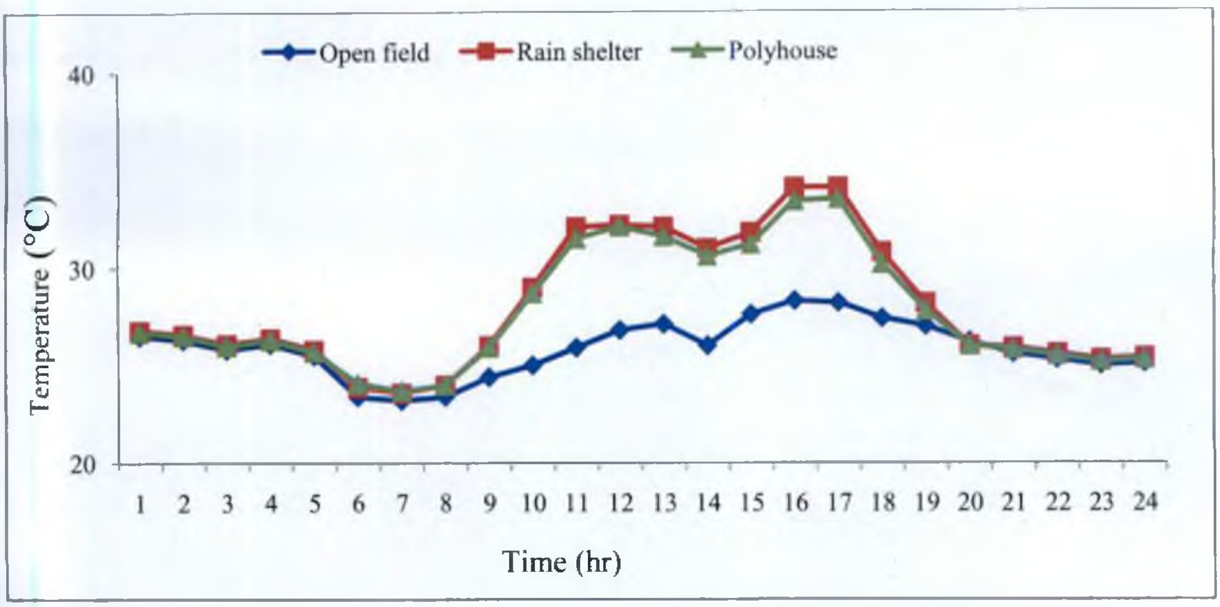

Fig.2. Diurnal variation of temperature during rainy season

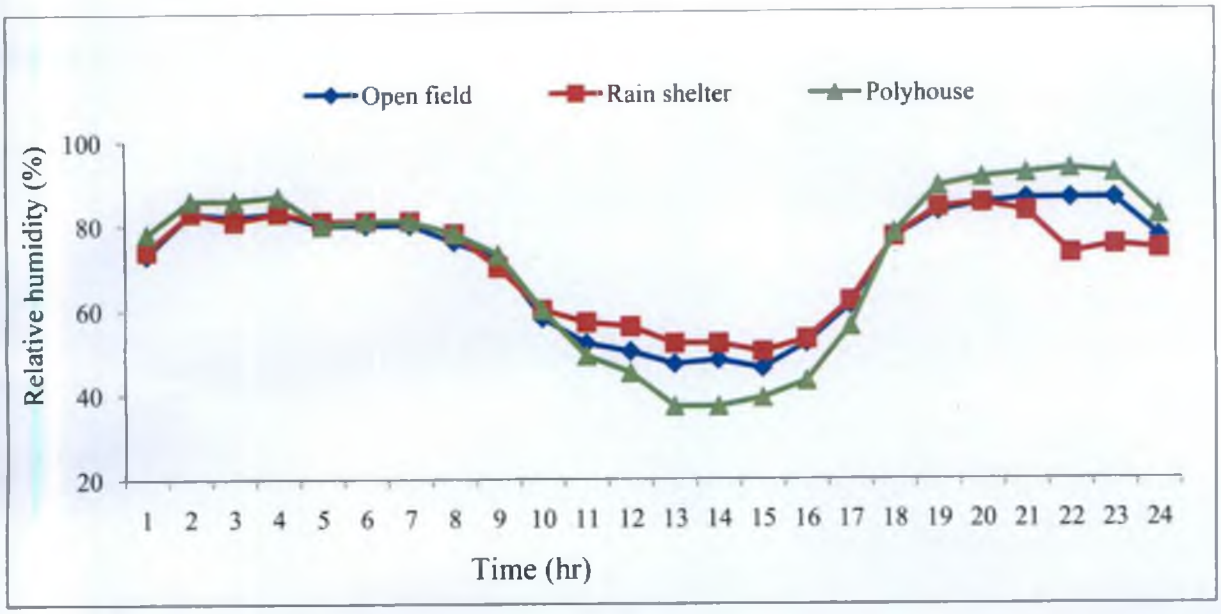

Fig.3. Diurnal variation of relative humidity during winter season

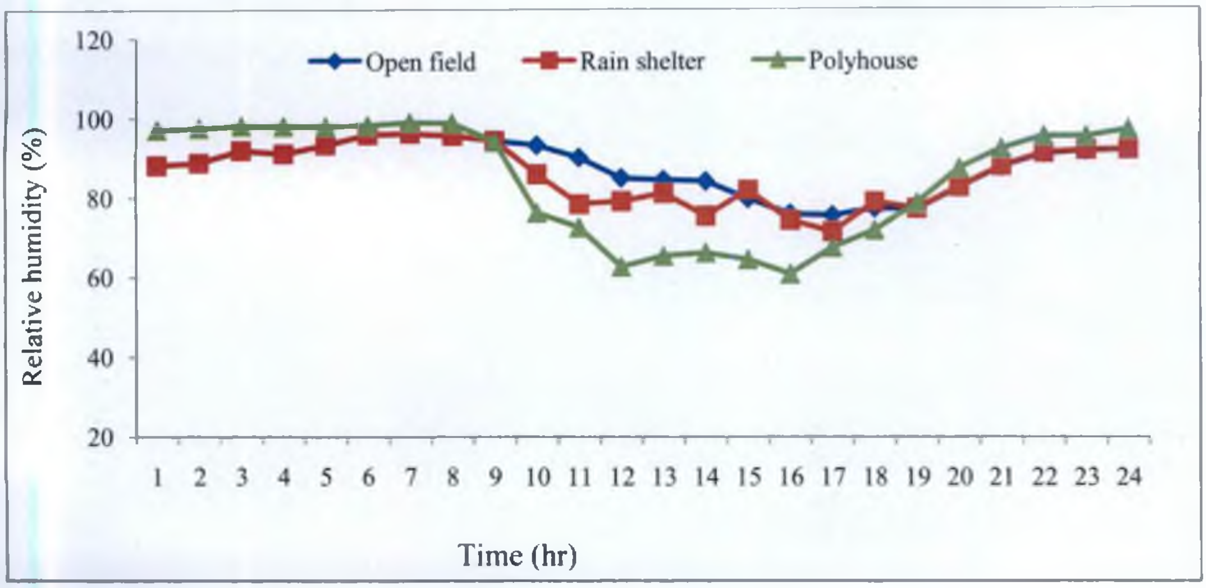

Fig.4. Diurnal variation of relative humidity during rainy season

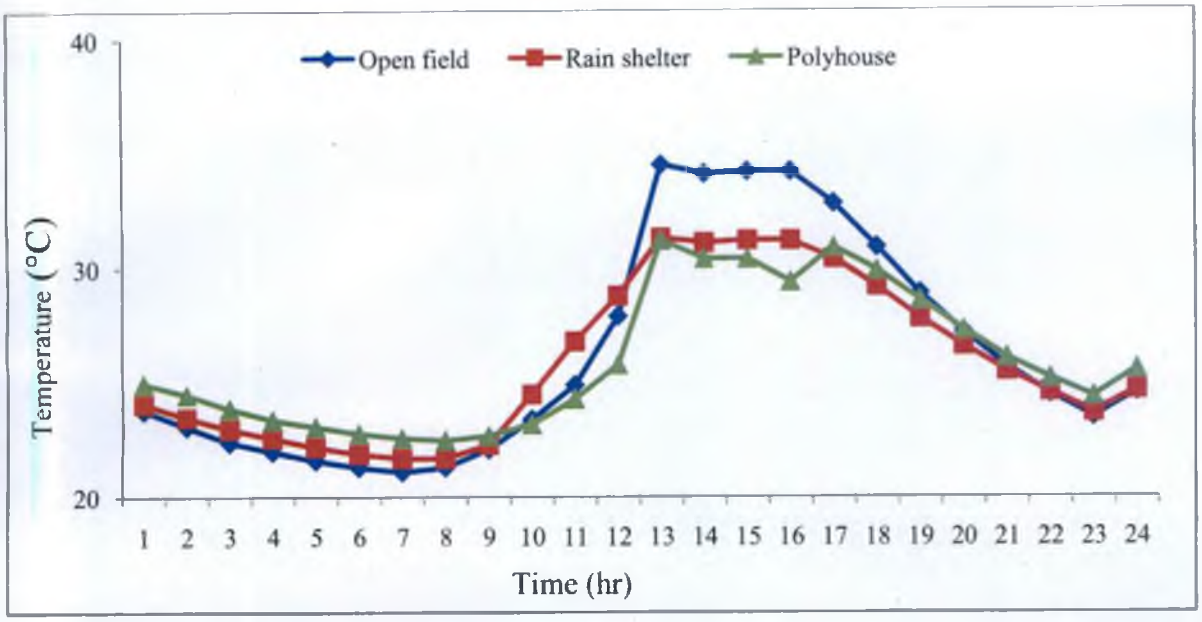

Fig.5. Diurnal variation of soil temperature during winter season

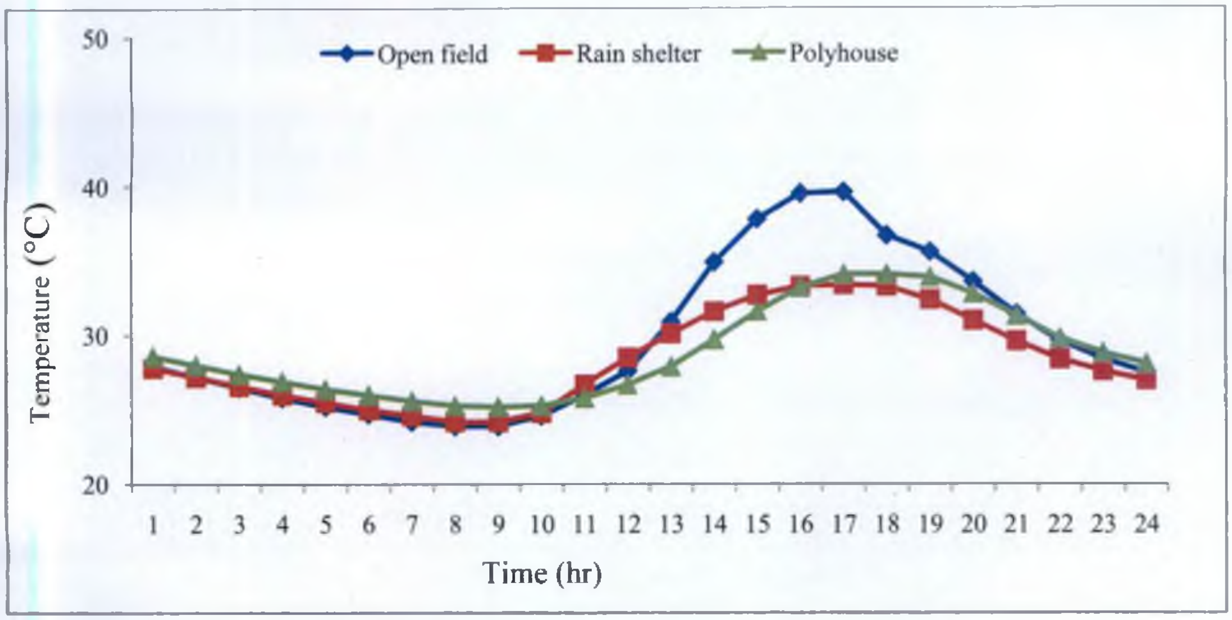

Fig.6. Diurnal variation of soil temperature during rainy season

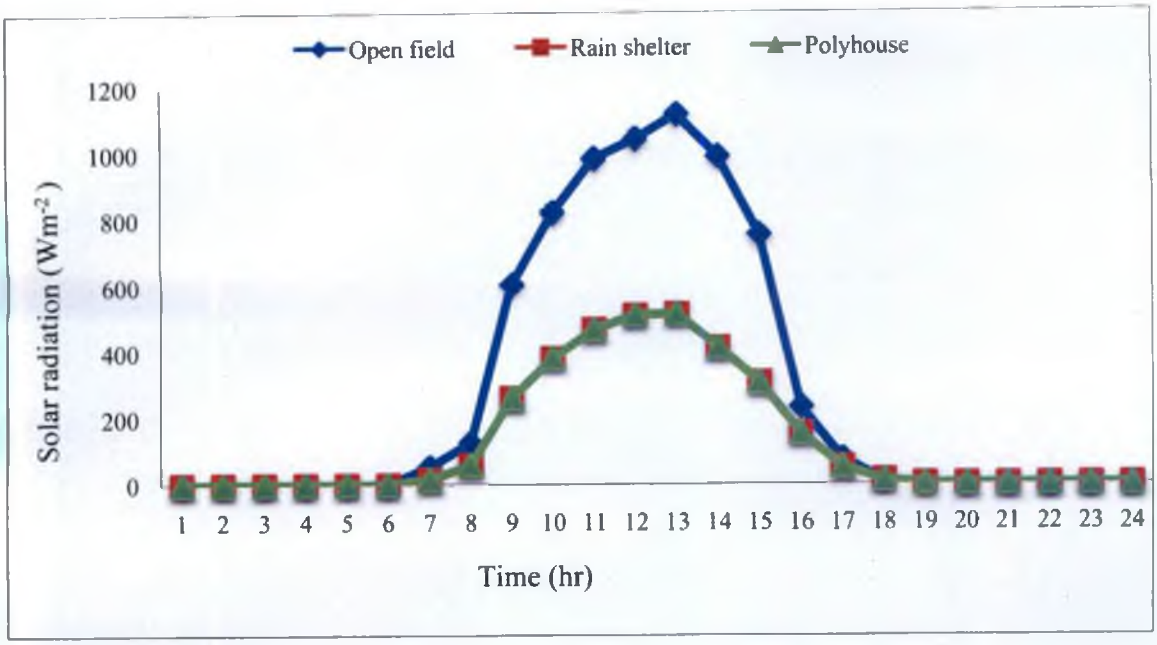

Fig.7. Diurnal variation of solar radiation during winter season

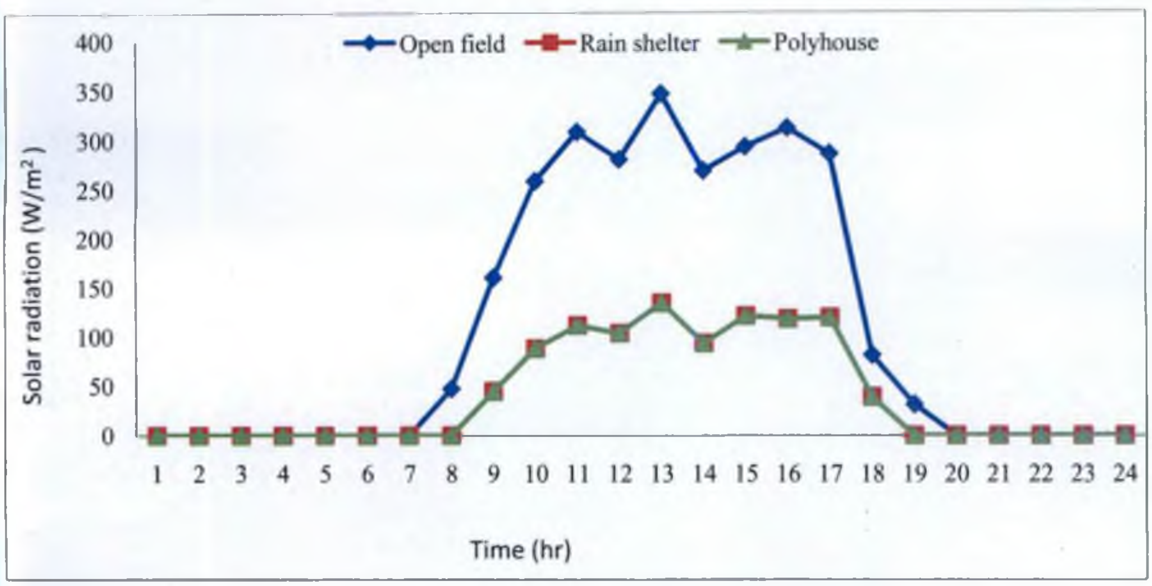

Fig.8. Diurnal variation of solar radiation during rainy season

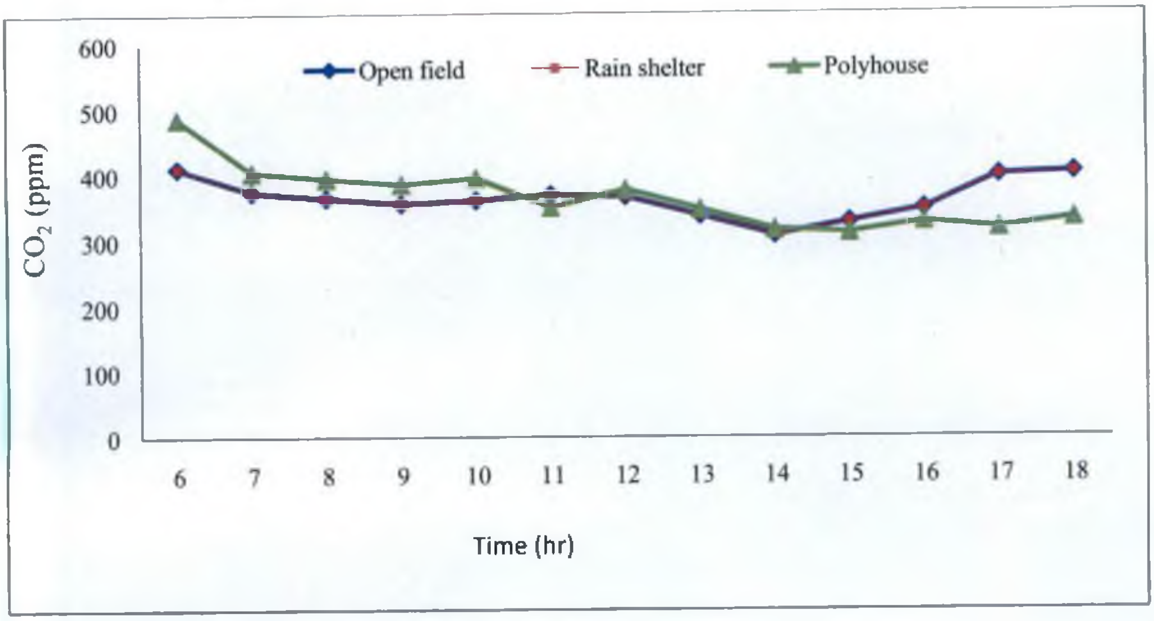

Fig.9. Diurnal variation of CO_2 during crop season

open field. The changes in soil temperature in all three growing conditions were showed a same trend throughout the day.

4.2.4. Solar radiation

In summer season highest amount of solar radiation was recorded in the open field. The amount of solar radiation increased from 9 hours in all three growing conditions. Highest amount of solar radiation was recorded under open field around 13.00.The peak values were recorded under open field and protected environments have drastic difference. The peak value recorded under open field was 1117 Wm^{-2} .Where in case of protected environments it was only 514 Wm^{-2} (Fig. 7). Where highest amount of solar radiation was recorded in the open field. Highest amount of solar radiation was recorded under open field around 12.00. The peak value recorded under open field, polyhouse and rain shelter was 345.3Wm^{-2} 116.9Wm^{-2} and 113.9Wm^{-2}. Solar radiation recorded during rainy season showed a fluctuating trend throughout the cropping period (Fig. 8).

4.2.5. Carbon dioxide

The highest values of CO_2 inside the polyhouse (486ppm) and in the open field (410ppm) were recorded in the morning hours at 6:00 am whereas the least values of CO_2 inside the polyhouse (310ppm) and in open field (306ppm) was recorded around 15:00 and 14:00 hours respectively (Fig. 9).

4.3. BIOMERIC OBSERVATIONS

4.3.1. Plant height

The weekly plant height and the maximum plant height attained by the cucumber crops planted under different growing environments and six dates of planting are given in Table 14 and 15. It was found that the date 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 crop grown inside the polyhouse.

Inside the polyhouse the duration of the exponential growth phase was extended up to 13, 12, 10, 13, 11 and 10 weeks for the crop transplanted on January 15, 25, February 5, June 1, 10 and 20 respectively. Similarly, for the crop transplanted in rain shelter and open field on the same dates the duration was 9, 9, 8, 12, 11, and 10 respectively. Highest maximum height was recorded in the crop transplanted inside the polyhouse on 1 June 2015 (278.7cm). Whereas the least maximum height was observed among the crop transplanted in the open field on 05 February 2015 (113.3 cm).

4.3.2. Leaf area index (LAI) at weekly interval

The weekly leaf area index and the maximum leaf area attained by the crop planted on different dates under three growing environments are presented in Table 16 and 17. From the tables it can be clearly observed that the dates of transplanting and growing environment had a significant effect on the maximum LAI obtained. The highest LAI was recorded by the crop transplanted inside the polyhouse (2.72) on 25 January 2015. The lowest maximum LAI (1.88) was observed by the crop under the open field conditions transplanted on 15 January 2015.

4.3.3. Biomass at the time of last harvest

Biomass at the time of last harvest under different growing environments and six dates of transplanting are presented below (Table 18). The highest biomass at the time of harvest was observed in the crop transplanted inside the polyhouse (1.4 t ha^{-1}) on 25 January 2015 and lowest was 0.95 t ha^{-1} when planted under open field conditions on 20 June 2015. Irrespective of dates of transplanting the highest biomass was recorded inside the polyhouse, followed by crop inside rain shelter. The crop grown under open field condition recorded the least biomass.

Table 14. Effect of micro climate on weekly plant height of cucumber (cm)

Growing environments	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
15-01-2015								
Polyhouse	13.2	31.6	64.3	94.7	122.7	137.0	158.0	183.7
`Rain shelter	13.4	33.6	72.7	100.0	125.0	139.7	149.0	165.0
Open field	12.3	20.3	37.7	57.0	76.0	101.0	119.7	135.3
25-01-2015								
Polyhouse	11.5	22.0	49.7	73.7	95.3	132.7	149.7	166.7
Rain shelter	9.7	23.3	52.7	84.0	103.3	113.3	140.0	161.7
Open field	12.2	21.0	45.0	65.3	86.3	104.3	127.7	143.7
05-02-2015								
Polyhouse	9.6	26.6	54.0	81.0	107.7	135.7	162.3	187.7
Rain shelter	9.5	26	59.3	92.7	115.0	131.0	155.7	178.7
Open field	10.2	20.3	45.3	65.3	87.3	107.3	128.0	158.7
01-06-2015								
Polyhouse	6.3	10.8	30.0	63.0	126.0	164.0	192.3	230.7
Rain shelter	6.3	10.4	28.0	63.0	114.3	142.0	164.0	190.7
Open field	6.3	9.8	25.7	56.3	111.3	140.3	161.7	178.7
10-06-2015								
Polyhouse	6.3	11.5	33.0	66.3	104.3	132.0	156.0	176.7
Rain shelter	6.2	11.6	33.7	64.7	86.0	124.3	143.0	156.7
Open field	6.4	9.5	25.7	48.0	60.0	80.0	109.0	129.7
20-06-2015								
Polyhouse	6.2	10.6	33.3	65.7	111.7	133.3	154.3	182.0
Rain shelter	6.1	10.4	29.3	56.0	86.7	127.3	146.7	172.3
Open field	6.2	9.9	25.0	36.7	56.0	80.0	120.0	145.6
CD 5%	1.2	6.7	9.4	12.7	12.7	9.9	12.2	15.2

Table 15. Effect of micro climate on maximum plant height (cm)

Date of Transplanting	Growing Environment	Maximum height
15 January 2015	Polyhouse	246.3
	Rain Shelter	154.0
	Open field	126.0
25 January 2015	Polyhouse	221.7
	Rain Shelter	142.0
	Open field	130.3
05 February 2015	Polyhouse	213.0
	Rain Shelter	135.0
	Open field	113.3
01 June 2015	Polyhouse	278.7
	Rain Shelter	236.0
	Open field	219.3
10 June 2015	Polyhouse	199.7
	Rain Shelter	170.7
	Open field	145.7
20 June 2015	Polyhouse	185.7
	Rain Shelter	176.7
	Open field	145.7
	CD 5%	12.1

Table16. Effect of micro climate on weekly leaf area index

Growing Environment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
15-01-2015								
Polyhouse	0.46	0.74	0.92	1.30	1.53	1.66	1.93	1.99
Rain Shelter	0.61	0.76	0.99	1.03	1.26	1.60	2.31	1.98
Open field	0.53	0.63	0.80	0.89	1.10	1.33	1.88	1.74
25-01-2015								
Polyhouse	0.41	0.66	0.90	1.18	1.43	1.69	1.86	2.08
Rain Shelter	0.46	0.66	0.90	1.10	1.35	1.59	2.46	2.25
Open field	0.46	0.64	0.85	1.02	1.24	1.44	1.85	1.79
05-02-2015								
Polyhouse	0.51	0.76	0.87	1.27	1.51	1.79	2.07	2.35
Rain Shelter	0.45	0.70	1.02	0.95	1.24	2.08	1.76	1.46
Open field	0.41	0.68	0.90	1.14	1.35	2.13	1.92	1.61
01-06-2015								
Polyhouse	0.41	0.53	0.70	0.84	1.05	1.20	1.63	2.05
Rain Shelter	0.39	0.61	0.65	0.86	1.05	1.37	1.62	1.91
Open field	0.38	0.55	0.60	0.73	0.85	0.99	1.27	1.53
10-06-2015								
Polyhouse	0.50	0.69	0.92	1.23	1.55	1.85	2.04	2.23
Rain Shelter	0.53	0.69	0.90	1.13	1.37	1.64	1.89	2.12
Open field	0.44	0.52	0.72	0.93	1.16	1.41	1.68	1.93
20-06-2015								
Polyhouse	0.40	0.43	0.83	1.09	1.44	1.80	2.37	2.59
Rain Shelter	0.36	0.49	0.48	0.80	1.16	1.40	1.79	2.33
Open field	0.33	0.41	0.69	0.93	1.27	1.40	1.71	1.89
CD 5%	0.08	0.12	0.10	0.16	0.19	0.23	0.21	0.29

Table 17. Effect of micro climate on maximum leaf area index

Date of Transplanting	Growing Environment	Maximum leaf area index
15 January 2015	Polyhouse	2.69
	Rain Shelter	2.30
	Open field	1.88
25 January 2015	Polyhouse	2.72
	Rain Shelter	2.46
	Open field	2.06
05 February 2015	Polyhouse	2.50
	Rain Shelter	2.08
	Open field	2.14
01 June 2015	Polyhouse	2.61
	Rain Shelter	2.28
	Open field	2.08
10 June 2015	Polyhouse	2.66
	Rain Shelter	2.51
	Open field	2.34
20 June 2015	Polyhouse	2.62
	Rain Shelter	2.44
	Open field	2.26
	CD 5%	0.28

Table 18. Effect of micro climate on biomass at the time of last harvest (t ha^{-1})

Date of Transplanting	Growing Environment	Biomass at the time of last harvest (t ha^{-1})
15 January 2015	Polyhouse	1.40
	Rain Shelter	1.15
	Open field	1.10
25 January 2015	Polyhouse	1.18
	Rain Shelter	1.09
	Open field	0.99
05 February 2015	Polyhouse	1.31
	Rain Shelter	1.13
	Open field	0.98
01 June 2015	Polyhouse	1.35
	Rain Shelter	1.07
	Open field	1.07
10 June 2015	Polyhouse	1.36
	Rain Shelter	1.22
	Open field	0.96
20 June 2015	Polyhouse	1.29
	Rain Shelter	1.14
	Open field	0.95
	CD 5%	0.18

4.4. PHENOLOGICAL OBSERVATIONS

The days taken by the crop to attain various phenological stages i.e., first flowering, first harvest and last harvest planted under different growing environment and planting dates are presented in Table 19.

4.4.1. Days to first flowering

The date of transplanting and growing environment had a significant effect on the number of days taken for appearance of the first flower (Table 19). The crop planted in the open field took more number of days for flowering (27 days) crop transplanted on 15 January 2015 and 20 June 2015 and the crop inside the polyhouse took the least number of days to flower (19.0) when transplanted on 10 June 2015. In all the dates of transplanting, crop inside the polyhouse condition took least number of days to first flowering. Crops transplanted on 20 June 2015 inside the polyhouse and rain shelter took 23 days to first flowering.

4.4.2. Days to first harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest (Table19). The crops transplanted under the open field conditions on 25 January and 5 February 2015 took an extreme 39 and 40 days respectively for the first harvest while the crop planted on 25 January 2015 and 10 June 2015 inside the polyhouse took least number of days (29.0). But for the crop planted on 20 June 2015, under rain shelter took least number of days to first harvest (35) as compare crop inside polyhouse (37) and open field (38). Whereas in the remaining five date of transplanting polyhouse grown crop took least number of days to first harvest.

4.4.3. 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 19). The crop transplanted inside the polyhouse on 15 January 2015 took the maximum days for the last harvest (64 days) while the crop transplanted on 5 February 2015 and 20 June 2015 in the rain shelter and open field took the least number of days for attaining the last harvest (17days) respectively. Irrespective of the growing environment the days taken to last harvest showed a declining trend in the crop transplanted from the first transplanting to last transplanting.

4.5. YIELD AND YIELD ATTRIBUTES

Analysis of variance (ANOVA) was performed on yield and the various yield attributes and is presented below (Table 20).

4.5.1. Fruit yield per plant (kg)

Table 20 showed that the dates of transplanting and growing environments had a significant effect on the fruit yield obtained from a single plant. Highest fruit yield per plant was recorded by the crop planted inside the polyhouse (6.60) on 1 June 2015. Whereas crop transplanted under open field (0.30) recorded the minimum fruit yield when planted on 05 February 2015. The crop planted inside the polyhouse recorded 5.5, 5.3 and 5.4 kg when planted on 15, 25 January and 05 February respectively. Whereas crop transplanted under rain shelter and open field showed a much decreases fruit yield per plant as compare to polyhouse conditions. It is interesting to notice that the fruit yield under rain shelter and open field plantings are better during the rainy season.

4.5.2. Average fruit weight (g)

Average fruit weight values are given in the Table 20. Crop transplanted on 1 June 2015 inside the polyhouse showed a highest average fruit weight (166.4) where lowest average fruit weight (150) was recorded under open field conditions when planted on 05 February 2015. The average fruit weight of polyhouse grown crop was around 165 and for the crops under rain shelter was 161 except when transplanted on 1 June 2015 (164). Whereas the crops under open field conditions showed a least average fruit weight as compare to crop transplanted inside the polyhouse and rain shelter.

Table 19. Effect of micro climate on days taken to first flowering, first harvest and last harvest

Date of Transplanting	Growing Environment	First flowering	First harvest	Last harvest
15 January 2015	Polyhouse	19.66	34.60	64.00
	Rain Shelter	25.00	40.00	19.00
	Open field	27.00	38.00	21.00
25 January 2015	Polyhouse	20.00	29.00	57.00
	Rain Shelter	24.00	37.00	18.00
	Open field	22.00	39.00	20.00
05 February2015	Polyhouse	21.00	33.00	43.00
	Rain Shelter	23.00	38.00	17.00
	Open field	25.00	40.00	18.00
01 June 2015	Polyhouse	21.00	30.60	49.00
	Rain Shelter	22.00	35.60	37.00
	Open field	25.00	36.00	32.00
10 June 2015	Polyhouse	19.00	29.00	41.00
	Rain Shelter	21.00	36.00	31.00
	Open field	23.00	37.60	21.00
20 June 2015	Polyhouse	23.00	37.00	24.00
	Rain Shelter	23.00	35.00	23.00
	Open field	27.00	38.00	17.00
	CD 5%	0.23	1.53	1.47

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Table 20. Effect of micro climate on fruit yield per plant, number of fruits per plant and average fruit weight

Date of Transplanting	Growing Environment	Fruit yield per plant (kg)	Number of fruits per plant	Average fruit weight (g)
15 January 2015	Polyhouse	5.50	33.33	166.00
	Rain Shelter	0.43	2.66	161.10
	Open field	0.37	2.33	155.60
25 January 2015	Polyhouse	5.30	32.00	165.60
	Rain Shelter	0.43	2.66	161.10
	Open field	0.37	2.33	155.60
05 February 2015	Polyhouse	5.40	32.33	166.00
	Rain Shelter	0.43	2.66	161.10
	Open field	0.30	2.00	150.00
01 June 2015	Polyhouse	6.60	39.66	166.40
	Rain Shelter	1.86	11.33	164.40
	Open field	0.70	4.33	162.20
10 June 2015	Polyhouse	4.40	26.33	165.80
	Rain Shelter	1.73	10.66	162.20
	Open field	0.80	5.00	160.00
20 June 2015	Polyhouse	2.30	14.00	164.20
	Rain Shelter	1.00	6.33	156.50
	Open field	0.53	3.33	161.10
	CD 5%	0.56	3.26	10.07

4.5.3. Per cent fruit set

From the Table 21 it is clear that the highest percentage fruit set was recorded inside the polyhouse crop (60.7) planted on 15 January 2015 and the lowest percentage fruit set (16.6) was recorded under rain shelter conditions during the winter season. During rainy season also highest percentage fruit set was recorded inside the polyhouse (63.2) crop followed by crop transplanted under rain shelter (33.8).

4.5.4. Number of harvests

Analysis of variance (ANOVA) was performed and the result for number of harvests is presented in Table 22. The number of harvest ware found to be higher and statistically significant for the crop transplanted inside the polyhouse and crop transplanted under open field took least number of harvests. Irrespective of the growing environments number of harvest showed a decreasing trend in the crop transplanted under both winter and rainy season.

4.5.5. Crop duration

Crop duration of cucumber planted on different dates under three growing environments are presented in Table 23. The duration of the crop found to be significantly influenced by the growing environments and dates of transplanting. Crop grown inside the polyhouse took more number of days to complete the crop cycle as compare to crops transplanted under rain shelter and open field. The duration of the crop was showed a decreasing trend from first transplanting to last transplanting in each growing environments.

Table 21. Effect of micro climate on per cent fruit set

Date of Transplanting	Growing Environment	Percent fruit set
15 January 2015	Polyhouse	60.7
	Rain Shelter	21.7
	Open field	23.3
25 January 2015	Polyhouse	54.8
	Rain Shelter	16.6
	Open field	21.1
05 February 2015	Polyhouse	55.1
	Rain Shelter	16.6
	Open field	26.2
01 June 2015	Polyhouse	63.2
	Rain Shelter	33.8
	Open field	24.9
10 June 2015	Polyhouse	53.0
	Rain Shelter	31.0
	Open field	22.0
20 June 2015	Polyhouse	40.5
	Rain Shelter	22.8
	Open field	16.4
	CD 5%	5.3

Table 22. Effect of micro climate on number of harvest

Date of Transplanting	Growing Environment	Number of harvest
15 January 2015	Polyhouse	15.00
	Rain Shelter	8.00
	Open field	6.70
25 January 2015	Polyhouse	13.00
	Rain Shelter	6.30
	Open field	5.30
05 February 2015	Polyhouse	10.00
	Rain Shelter	5.00
	Open field	4.30
01 June 2015	Polyhouse	23.00
	Rain Shelter	15.70
	Open field	13.00
10 June 2015	Polyhouse	20.00
	Rain Shelter	17.00
	Open field	12.00
20 June 2015	Polyhouse	12.00
	Rain Shelter	9.00
	Open field	9.00
	CD 5%	0.57

Table 23. Effect of micro climate on duration of the crop

Date of Transplanting	Growing Environment	Duration
15 January 2015	Polyhouse	109.0
	Rain Shelter	71.0
	Open field	72.0
25 January 2015	Polyhouse	98.0
	Rain Shelter	68.0
	Open field	67.3
05 February 2015	Polyhouse	88.0
	Rain Shelter	67.7
	Open field	69.0
01 June 2015	Polyhouse	92.0
	Rain Shelter	84.0
	Open field	80.0
10 June 2015	Polyhouse	82.0
	Rain Shelter	81.0
	Open field	70.0
20 June 2015	Polyhouse	74.0
	Rain Shelter	71.0
	Open field	68.0
	CD 5%	1.8

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

Total yield and marketable yield of cucumber in polyhouse, rain shelter and open field condition under six dates of transplanting are presented below (Table 24).

The total yield in tons per hectare was found to be significantly influenced by the date of transplanting and the growing environment. The maximum yield of 89.10 tons per hectare was obtained from the crop transplanted inside the polyhouse on 1 June 2015. The yields from the crop transplanted under the rain shelter and open fields statistically similar during the winter season whereas yields were significantly different during the rainy season. Regardless of the dates of transplanting the yields from the crop inside the polyhouse were consistently higher followed by the crop inside the rain shelter and open field. The lowest yields (4.05 t ha^{-1}) were obtained from the crop in the open field transplanted on 05 February 2015. During rainy season except first transplanting the yield obtained inside the polyhouse was decreased due to pest attack.

4.5.7. Marketable yield (t ha^{-1})

The dates of transplanting and growing environments had a significant effect on marketable yield of cucumber. Highest marketable yield was recorded inside the polyhouse crop (96.2%) on 10 June 2015 and the lowest marketable yield was recorded under open field condition (31.3%) on 20 June 2015. The yield loss was minimum on crop transplanted on 25 January 2015 in three growing environments.

Table 24. Effect of micro climate on total yield and marketable yield (t ha^{-1})

Date of Transplanting	Growing Environment	Total yield (t ha^{-1})	Marketable yield (t ha^{-1})
15 January 2015	Polyhouse	74.70	71.10
	Rain Shelter	5.85	4.95
	Open field	4.95	3.15
25 January 2015	Polyhouse	71.55	66.60
	Rain Shelter	5.85	4.95
	Open field	4.95	4.05
05 February 2015	Polyhouse	72.45	68.85
	Rain Shelter	5.85	4.05
	Open field	4.05	3.15
01 June 2015	Polyhouse	89.10	83.70
	Rain Shelter	25.20	21.60
	Open field	9.45	7.20
10 June 2015	Polyhouse	58.95	56.70
	Rain Shelter	23.40	18.00
	Open field	10.80	6.30
20 June 2015	Polyhouse	48.05	26.55
	Rain Shelter	13.5	10.35
	Open field	7.20	2.25
	CD 5%	7.52	7.52

4.6. CROP WEATHER RELATIONSHIPS

4.6.1. Biometric Observation

4.6.1.1. Maximum plant height

The correlation between maximum plant height and different weather parameters was found out and is presented below. The correlation between plant height and different weather parameters was found out and is presented in the Table (25 and 26) for all the six dates of transplanting. It showed solar radiation (-0.511, -0.523, -0.571, -0.580) UV radiation (-0.586, -0.581, -0.565, -0.586) and PAR (-0.611, 0.636, -0.395, -0.532) exhibited strong significant negative correlation during vegetative, flowering, fruiting and harvesting stage respectively. Whereas maximum (0.563, 0.582, 0.555, 0.530) and minimum relative humidity (0.333, 0.583, 0.523, 0.552) showed a significant positive correlation during the four growth stages. The influence of maximum temperature on plant height showed positive correlation only during the first week (0.295) after planting. Minimum temperature showed positive correlation during first week (0.400) and third week (0.306) corresponding to vegetative stage (0.388). Whereas maximum soil temperature showed negative correlation during flowering stage (-0.508), harvesting stage (-0.468) and fourth, fifth and eighth week (-0.418, -0.535 and -0.395) respectively. Canopy temperature (-0.317, -0.291) showed negative correlation during flowering, fruiting stage and fourth week (-0.342) where it showed positive correlation during harvesting stage (0.500), seventh and eighth week (0.451, 0.591). In case of CATD seventh and eighth week (-0.530, -0.580) showed negative correlation. Minimum soil temperature and maximum temperature exhibited non-significant effect on plant height.

4.6.1.2. Maximum leaf area index

The correlation between maximum leaf area index and different weather parameters was found out and is presented below (Table 27 and 28). The weekly leaf area index showed a significant negative correlation between solar radiation (-0.738, -0.737,-0.688 and -0.679) and UV radiation (-0.743,-0.762, -0.776 and -0.758) during all stages where it showed a significantly negative correlation between maximum soil temperature in vegetative (-0.319), flowering(-0.401) and harvesting (-0.455) stage whereas soil moisture (0.808, 0.700, 0.594, 0.324), minimum temperature (0.616, 0.366, 0.330, 0.306), maximum relative humidity (0.539, 0.455, 0.473, 0.412) and minimum relative humidity (0.422, 0.344, 0.470, 0.413) showed a significantly positive correlation during four stages. Minimum soil temperature was the only parameter which showed non-significant effect on leaf area index. Maximum temperature is significant only during fourth week (0.400) and flowering stage (0.363). Where CT showed a negative correlation during fourth, fifth and sixth week (-0.536, -0.536 and -0.320) and flowering (-0.607) and fruiting (-0.346) stage respectively whereas CATD showed a negative correlation during fourth (-0.405), seventh (-0.558), eighth week (-0.543), vegetative (0.652) and flowering (0.461) stage respectively.

4.6.1.3. Biomass at the time of last harvest

The correlation between biomass at the time of last harvest and different weather parameters was found out and is presented in the Table (29 and 30) for all the six dates of transplanting. Maximum (0.456, 0.476, 0.327, 0.309) and minimum temperature (0.692, 0.648, 0.378, 0.508), soil moisture (0.871, 0.645, 0.758, 0.321) showed strong positive correlation during vegetative, flowering, fruiting and harvesting stage. Where PAR (-0.842,-0.735, -0.739, -0.867), UV radiation (-0.817, -0.810, -0.807, -0.815) exhibited negative correlation with biomass at the time of last harvest during all four growth stages. Maximum and minimum soil temperature and minimum relative humidity showed non-significant effect on biomass. Maximum relative humidity was positively significant during vegetative stage (0.351) and first and second week (0.402 and 0.318) respectively. Canopy temperature showed a negative correlation during flowering stage (-0.558), second week (-0.310), fourth week (-0.534) and fifth week (-0.441) respectively. Whereas CATD (0.549, 0.693, 0.378) showed a positive correlation during vegetative, flowering and fruiting stage and first, fifth, seventh and eighth week (0.301, 0.459, 0.444 and 0.496) respectively.

Table 25. Correlation between plant height and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.295*	0.245	0.141	0.128	0.225	0.044	0.032	-0.055
Tmin	0.400*	0.289	0.306*	0.281	0.148	0.184	0.081	-0.058
STmin	0.222	0.321*	0.270	0.112	0.020	-0.069	-0.074	-0.130
STmax	-0.144	-0.104	-0.222	-0.418**	-0.535**	-0.252	-0.196	-0.395*
SM	0.490**	0.482**	0.238	0.558**	0.360*	0.430**	0.640**	0.216
RH-I	0.581**	0.450**	0.572**	0.546**	0.611**	0.553**	0.441**	0.594**
RH -II	0.265	0.244	0.395*	0.533**	0.610**	0.524**	0.437**	0.586**
SR	-0.507**	0.496**	-0.511**	-0.483**	-0.552**	-0.571**	-0.574**	-0.578**
CT	-0.102	0.098	-0.206	-0.342*	-0.202	-0.252	0.451**	0.591**
CATD	-0.218	-0.070	-0.119	-0.149	0.277	-0.062	-0.531**	-0.580**
UV	-0.531**	0.611**	-0.573**	-0.570**	-0.590**	-0.565**	-0.589**	-0.582**
PAR	-0.656**	-0.571**	-0.323*	-0.514**	-0.511**	-0.395*	-0.401*	-0.320*

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

Table 26. Correlation between plant height and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.259	0.195	0.041	0.024
Tmin	0.388*	0.219	0.184	0.062
STmax	-0.198	-0.528**	-0.275	-0.468**
STmin	0.286	0.067	-0.070	-0.028
SM	0.614**	0.542**	0.424**	0.178
RH1	0.563**	0.582**	0.555**	0.530**
RH2	0.333*	0.583**	0.523**	0.552**
SR	-0.511**	-0.523**	-0.571**	-0.580**
CT	-0.169	-0.317*	-0.291*	0.500**
CATD	0.488**	0.705**	0.323*	-0.352*
PAR	-0.611**	-0.636**	-0.395*	-0.532**
UV	-0.586**	-0.581**	-0.565**	-0.586**

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

Table 27. Correlation between leaf area index and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.201	0.151	0.245	0.400*	0.221	0.238	0.183	0.211
Tmin	0.544**	0.548**	0.513**	0.415**	0.283	0.326*	0.297*	0.159
STmin	0.135	0.281	0.103	-0.086	-0.208	-0.217	-0.217	-0.228
STmax	-0.286	-0.327*	-0.322*	-0.391*	-0.314*	-0.331*	-0.347*	-0.340*
SM	0.755**	0.527**	0.383*	0.628**	0.594**	0.576**	0.532**	0.300*
RH-I	0.621**	0.462**	0.443**	0.466**	0.422**	0.477**	0.343*	0.387*
RH -II	0.401*	0.393*	0.392*	0.341*	0.313*	0.470**	0.378*	0.301*
SR	-0.731**	-0.739**	-0.718**	-0.745**	-0.714**	-0.688**	-0.686**	-0.682**
CT	0.233	0.225	-0.190	-0.536**	-0.536**	-0.320*	0.069	0.227
CATD	0.099	0.118	-0.240	-0.405*	0.233	-0.116	-0.558**	-0.543**
UV	-0.731**	-0.655**	-0.775**	-0.766**	-0.758**	-0.776**	-0.755**	-0.759**
PAR	-0.824**	-0.708**	-0.467**	-0.703**	-0.623**	-0.460**	-0.661**	-0.693**

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

Table 28. Correlation between leaf area index and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	-0.743**	-0.762**	-0.776**	-0.758**
Tmin	0.249	0.363*	0.216	0.218
STmax	0.616**	0.366*	0.331*	0.307*
STmin	-0.319*	-0.401*	-0.264	-0.457**
SM	0.202	-0.134	-0.222	-0.137
RH1	0.808**	0.700**	0.595**	0.325*
RH2	0.539**	0.455**	0.473**	0.412**
SR	0.422**	0.344*	0.470**	0.413**
CT	-0.738**	-0.737**	-0.688**	-0.679**
CATD	0.097	-0.607**	-0.346*	0.148
PAR	0.652**	0.461**	0.200	-0.147
UV	-0.788**	-0.819**	-0.460**	-0.787**

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

Table 29. Correlation between biomass at the time of last harvest and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.447**	0.429**	0.266	0.460**	0.369*	0.349*	0.276	0.321*
Tmin	0.521**	0.590**	0.678**	0.598**	0.627**	0.374*	0.477**	0.395*
STmin	-0.015	0.190	0.139	-0.051	-0.103	-0.170	-0.104	-0.090
STmax	-0.063	-0.093	-0.208	-0.182	-0.218	-0.057	-0.216	-0.217
SM	0.697**	0.576**	0.523**	0.510**	0.626**	0.744**	0.462**	0.342*
RH-I	0.402*	0.318*	0.268	0.274	0.284	0.292*	0.272	0.272
RH -II	0.144	0.139	0.244	0.197	0.174	0.224	0.219	0.196
SR	-0.721**	-0.659**	-0.639**	-0.566**	-0.525**	-0.494**	-0.489**	-0.487**
CT	-0.130	0.310*	-0.181	-0.534**	-0.441**	-0.272	0.152	0.261
CATD	-0.301*	-0.125	0.166	-0.092	0.459**	0.021	-0.444**	-0.496**
UV	-0.776**	-0.828**	-0.788**	-0.805**	-0.814**	-0.807**	-0.817**	-0.811**
PAR	-0.820**	-0.710**	-0.604**	-0.799**	-0.416**	-0.739**	-0.803**	-0.800**

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

Table 30. Correlation between biomass at the time of last harvest and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.456**	0.476**	0.327*	0.309*
Tmin	0.692**	0.648**	0.378*	0.508**
STmax	-0.074	-0.239	0.046	-0.323*
STmin	0.130	-0.062	-0.174	-0.039
SM	0.871**	0.645**	0.758**	0.321*
RH1	0.351*	0.288	0.288	0.272
RH2	0.180	0.199	0.225	0.265
SR	-0.682**	-0.551**	-0.494**	-0.490**
CT	-0.034	-0.558**	-0.282	0.198
CATD	0.549**	0.693**	0.378*	-0.101
PAR	-0.842**	-0.735**	-0.739**	-0.867**
UV	-0.817**	-0.810**	-0.807**	-0.815**

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

4.6.2. Phenological Observations

Correlation between weather and phenological observations like days to first flowering, days to first harvest and days to last harvest were done and presented below.

4.6.2.1. Days to first flowering

Table 31 showed that UV radiation, solar radiation, minimum temperature and PAR showed significant negative correlation whereas maximum temperature, soil moisture, maximum and minimum relative humidity exhibited positive correlation with days taken to first flowering. Among the weather parameters maximum soil temperature and CT showed non-significant effect on days to first flowering. CATD showed a positive correlation with days to first flowering during fourth, (0.355).

4.6.2.2. Days to first harvest

Days to first harvest had a negative correlation with minimum temperature, UV radiation, PAR and minimum soil temperature. While maximum temperature (0.301) exhibited positive correlation during vegetative stage and third and fourth week respectively. Minimum temperature (-0.484, -0.315, -0.430) showed negative correlation during vegetative, flowering and fruiting stage respectively. Maximum soil temperature showed a positive correlation during flowering (0.314) and harvesting stage (0.368) and fourth week (0.463). Maximum soil temperature had positive correlation with days to first harvest and during flowering stage except maximum temperature and minimum soil temperature all other weather parameters were showed significant correlation (Table 32 and 33).

4.6.2.3. Days to last harvest

UV radiation, PAR, solar radiation and CATD showed negative correlation and maximum and minimum temperature, minimum soil temperature, soil moisture, maximum and minimum relative humidity and CT showed positive correlation with days taken for last harvest. Where maximum soil temperature showed non-significant effect on days to last harvest. Table 32 showed that PAR (-0.499, -0.619, -0.502 and -0.600), UV radiation (-0.552, -0.547, -0.541, -0.553) and solar radiation (-0.422, - 0.373, -0.372, -0.375) exhibited negative correlation throughout the growing stages while maximum relative humidity (0.369, 0.528, 0.556, 0.573) showed positive correlation during entire growing stages with days to last harvest. Whereas minimum relative humidity exhibited positive correlation during flowering (0.322), fruiting (0.358) and harvesting stage(0.402) and fourth week to eighth week (0.327, 0.314, 0.359, 0.322 and 0.343) respectively. Canopy temperature exhibited positive correlation during harvesting stage (0.414) and seventh and eighth week (0.355 and 0.396). CATD showed positive correlation during vegetative stage (0.524), flowering stage (0.559) and fifth week (0.443) and negative correlation during harvesting stage (-0.447) and seventh and eighth week (-0.538, 0.647) respectively. Maximum temperature was positively correlated with days taken for last harvest during flowering stage (0.362) and fourth and fifth week (0.343, 0.375).Whereas minimum temperature showed a positive correlation during vegetative stage (0.436) and first to third week (0.347, 0.415 and 0.344) respectively (Table 34 and 35).

Table 31. Correlation between first flowering and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5
Tmax	0.379*	0.330*	0.368*	0.472**	0.340*
Tmin	-0.579**	-0.520**	-0.394*	-0.460**	-0.379*
STmin	-0.206	-0.055	0.176	0.346*	0.058
STmax	-0.076	-0.176	-0.093	-0.001	0.119
SM	0.543**	0.428**	0.400*	0.408*	0.470**
RH-I	0.373*	0.142	0.289	0.423**	0.308*
RH -II	0.010	0.035	0.268	0.324*	0.132
SR	0.617**	0.539**	0.477**	0.493**	0.455**
CT	-0.268	-0.067	0.236	0.276	0.253
CATD	0.054	-0.058	0.174	0.355*	-0.197
UV	-0.735**	-0.546**	-0.694**	-0.677**	-0.668**
PAR	-0.792**	-0.462**	-0.497**	-0.554**	-0.727**

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

Table 32. Correlation between first harvest and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	-0.232	-0.222	0.399*	0.310*	-0.169	-0.099	-0.082	-0.084
Tmin	-0.595**	-0.424**	-0.212	-0.404*	-0.222	-0.436**	-0.323*	-0.157
STmin	-0.351*	-0.382*	-0.139	-0.183	-0.007	-0.047	-0.039	-0.015
STmax	-0.104	-0.017	0.100	0.463**	0.160	0.122	0.135	0.292*
SM	0.577**	0.185	0.167	0.583**	0.490**	0.547**	0.714**	0.237
RH-I	0.459**	0.285	0.480**	0.527**	0.501**	0.510**	0.405*	0.523**
RH -II	0.222	0.148	0.344*	0.420**	0.364*	0.423**	0.398*	0.404*
SR	0.474**	0.459**	0.449**	0.424**	0.428**	0.424**	0.417**	0.420**
CT	-0.335*	0.200	0.132	0.299*	0.288	0.231	-0.415**	-0.356*
CATD	-0.136	0.077	0.250	0.211	-0.082	0.315*	0.554**	0.437**
UV	-0.525**	-0.551**	-0.534**	-0.553**	-0.551**	-0.555**	-0.557**	-0.547**
PAR	-0.576**	-0.474**	-0.439**	-0.544**	-0.611**	-0.316*	-0.482**	-0.524**

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

Table 33. Correlation between first harvest and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.301*	-0.223	-0.110	-0.096
Tmin	-0.484**	-0.315*	-0.430**	-0.284
STmax	0.056	0.314*	0.210	0.368*
STmin	-0.287	-0.084	-0.049	-0.094
SM	-0.511**	-0.640**	-0.515**	-0.162
RH1	-0.427**	-0.514**	-0.516**	-0.468**
RH2	-0.276	-0.394*	-0.421**	-0.438**
SR	0.466**	0.432**	0.424**	0.421**
CT	0.058	0.333*	0.307*	-0.378*
CATD	-0.664**	-0.447**	-0.123	0.140
PAR	0.588**	0.720**	0.316*	0.628**
UV	0.551**	0.553**	0.555**	0.553**

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

Table 34. Correlation between last harvest and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.098	0.064	0.212	0.343*	0.375*	0.236	0.212	0.219
Tmin	0.347*	0.415**	0.344*	0.270	0.176	0.166	0.210	0.152
STmin	0.211	0.466**	0.365*	0.188	0.111	0.054	0.089	0.110
STmax	0.052	0.153	-0.057	-0.194	-0.148	0.087	0.050	-0.052
SM	0.435**	0.453**	0.276	0.390*	0.512**	0.622**	0.688**	0.273
RH-I	0.453**	0.211	0.388*	0.512**	0.543**	0.551**	0.521**	0.583**
RH -II	0.059	-0.026	0.212	0.327*	0.314*	0.359*	0.322*	0.343*
SR	-0.443**	-0.409**	-0.397*	-0.363*	-0.373*	-0.372*	-0.372*	-0.373*
CT	0.128	0.255	-0.263	-0.267	-0.187	-0.088	0.355*	0.396*
CATD	-0.159	0.060	0.030	-0.186	0.443**	-0.035	-0.538**	-0.647**
UV	-0.523**	-0.553**	-0.539**	-0.542**	-0.550**	-0.541**	-0.555**	-0.549**
PAR	-0.595**	-0.387*	-0.278	-0.492**	-0.506**	-0.502**	-0.439**	-0.492**

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

Table 35. Correlation between last harvest and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.126	0.362*	0.242	0.248
Tmin	0.436**	0.226	0.163	0.291
STmax	0.020	-0.176	0.048	-0.167
STmin	0.348*	0.143	0.056	0.203
SM	0.615**	0.529**	0.593**	0.010
RH1	0.369*	0.528**	0.556**	0.573**
RH2	0.100	0.322*	0.358*	0.402*
SR	-0.422**	-0.373*	-0.372*	-0.375*
CT	-0.002	-0.262	-0.135	0.414**
CATD	0.524**	0.559**	0.220	-0.447**
PAR	-0.499**	-0.619**	-0.502**	-0.600**
UV	-0.552**	-0.547**	-0.541**	-0.553**

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

4.6.3. Yield and yield attributes

The correlation analysis between weather parameters and yield attributes were done and the results are presented below.

4.6.3.1. Percentage fruit set

From the Table 36 and 37 it is clear that maximum and minimum air temperature, minimum soil temperature, soil moisture, morning and evening relative humidity showed a positive correlation whereas solar radiation(-0.455, -0.370,-0.333, -0.330), UV (-0.608,-0.610, -0.608, -0.613) and PAR (-0.701,-0.752, -0.616, -0.776) showed a negative correlation with percentage fruit set throughout the growing stages. While maximum soil temperature exhibited non-significant effect on percent fruit set and minimum soil temperature showed positive correlation only during first week to fourth week (0.328, 0.542, 0.432 and 0.323) later it showed a non-significant effect. From stage wise analysis except maximum soil temperature all weather parameters showed a significant correlation with percent fruit set. Where minimum temperature (0.569, 0.499, 0.404, 0.446) and maximum relative humidity (0.500, 0.596, 0.580, 0.614) showed a positive correlation with percent fruit set during vegetative, flowering, fruiting and harvesting stage respectively. Maximum temperature exhibited positive correlation during flowering stage (0.334) and fifth week (0.304). Canopy temperature showed a negative correlation during flowering stage (-0.494) and fourth and fifth week (-0.474, -0.389) where it showed positive correlation during harvesting stage (0.435) and seventh and eighth week (-0.407 and -0.389).

Table 36. Correlation between percent fruit set and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.229	0.229	0.227	0.293*	0.304*	0.177	0.149	0.161
Tmin	0.510**	0.502**	0.457**	0.509**	0.447**	0.403*	0.418**	0.322*
STmin	0.328*	0.542**	0.432**	0.323*	0.252	0.170	0.202	0.222
STmax	0.096	0.102	-0.046	-0.187	-0.165	0.009	-0.060	-0.140
SM	0.544**	0.529**	0.298*	0.578**	0.641**	0.674**	0.556**	0.144
RH-I	0.546**	0.375*	0.495**	0.586**	0.591**	0.580**	0.591**	0.598**
RH -II	0.178	0.110	0.299*	0.374*	0.359*	0.437**	0.399*	0.400*
SR	-0.486**	-0.440**	-0.419**	-0.383*	-0.348*	-0.333*	-0.329*	-0.329*
CT	0.017	0.249	-0.256	-0.474**	-0.389*	-0.204	0.407**	0.462**
CATD	-0.216	-0.144	-0.072	-0.207	0.353*	-0.011	-0.442**	-0.527**
UV	-0.587**	-0.586**	-0.602**	-0.609**	-0.611**	-0.608**	-0.609**	-0.614**
PAR	-0.701**	-0.554**	-0.520**	-0.681**	-0.542**	-0.616**	-0.620**	-0.678**

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

Table 37. Correlation between percent fruit set and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.268	0.334*	0.167	0.172
Tmin	0.569**	0.499**	0.404*	0.446**
STmax	0.101	-0.199	0.057	-0.260
STmin	0.462**	0.296*	0.169	0.295*
SM	0.681**	0.703**	0.672**	-0.016
RH1	0.500**	0.596**	0.580**	0.614**
RH2	0.212	0.378*	0.437**	0.475**
SR	-0.455**	-0.370*	-0.333*	-0.330*
CT	-0.058	-0.494**	-0.251	0.435**
CATD	0.560**	0.650**	0.229	-0.280
PAR	-0.701**	-0.752**	-0.616**	-0.776**
UV	-0.608**	-0.610**	-0.608**	-0.613**

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

4.6.3.2. Crop duration

The duration of the crop showed a significant positive correlation with soil moisture, morning and evening relative humidity and CT and it was negatively correlated with solar radiation (-0.419, -0.370,-0.371, -0.373), UV(-0.541, -0.536, -0.519, -0.563) and PAR (-0.458, -0.561, -0.519, -0.563). Minimum soil temperature (0.403) and minimum temperature (0.304) was showed positive correlation only during vegetative stage and second and third week (0.424 and 0.350). Where maximum soil temperature was showed a non-significant effect on crop duration. Air and soil temperature and soil moisture showed non-significant effect and maximum temperature, soil moisture, maximum humidity and CATD showed a positive correlation during flowering stage and solar radiation and PAR showed negative correlation (Table 38 and 39).

4.6.3.3. Number of harvest

UV radiation (-0.450, -0.454, 0.454, -0.456), solar radiation (-0.444, -0.538, -0.584, -0.591) and maximum soil temperature (-0.398, -0.771, -0.502, -0.752) exhibited negative correlation during vegetative, flowering, fruiting and harvesting stage respectively. Maximum relative humidity (0.760, 0.718, 0.638, 0.616) and minimum relative humidity (0.625, 0.811, 0.759, 0.776) showed a positive correlation during all the four stages. Canopy temperature showed negative correlation during fruiting stage (-0.446) and sixth week (-0.376) and positive correlation during eighth week (0.446). CATD exhibited positive correlation during vegetative stage (0.492), flowering stage (0.575) and second, third, four, seven and eighth week (-0.338, -0.400, - 0.406, -0.602 and -0.630). Minimum temperature during the vegetative stage (0.303) and first week (0.405) showed a positive correlation whereas maximum temperature exhibited during fruiting stage (-0.314), harvesting stage (-0.322) and first, sixth, seventh and eighth week (-0.312, -0.312, -0.364 and -0.334) showed a negative correlation with number of harvest (Table 40 and 41).

Table 38. Correlation between crop duration and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.081	0.047	0.180	0.346*	0.406**	0.267	0.241	0.245
Tmin	0.277	0.390*	0.354*	0.230	0.168	0.096	0.169	0.139
STmin	0.139	0.424**	0.350*	0.136	0.087	0.008	0.050	0.084
STmax	0.013	0.147	-0.054	-0.137	-0.155	0.109	0.066	-0.009
SM	0.384*	0.495**	0.298*	0.322*	0.496**	0.597**	0.644**	0.295*
RH-I	0.408*	0.183	0.339*	0.463**	0.510**	0.499**	0.494**	0.554**
RH -II	0.019	-0.059	0.169	0.283	0.288	0.307*	0.272	0.304*
SR	-0.438**	-0.406*	-0.398*	-0.360*	-0.371*	-0.371*	-0.372*	-0.371*
CT	0.063	0.335*	-0.256	-0.256	-0.148	-0.064	0.303*	0.378*
CATD	-0.221	0.077	0.098	-0.160	0.499**	0.041	-0.519**	-0.668**
UV	-0.501**	-0.554**	-0.528**	-0.529**	-0.542**	-0.528**	-0.544**	-0.540**
PAR	-0.563**	-0.347*	-0.247	-0.475**	-0.432**	-0.519**	-0.423**	-0.454**

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

Table 39. Correlation between crop duration and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.103	0.385*	0.272	0.279
Tmin	0.403*	0.202	0.093	0.270
STmax	0.010	-0.153	0.082	-0.130
STmin	0.304*	0.106	0.009	0.173
SM	0.615**	0.477**	0.571**	0.013
RH1	0.326*	0.486**	0.503**	0.541**
RH2	0.056	0.287	0.306*	0.361*
SR	-0.419**	-0.370*	-0.371*	-0.373*
CT	0.019	-0.235	-0.101	0.386*
CATD	0.461**	0.561**	0.242	-0.477**
PAR	-0.458**	-0.561**	-0.519**	-0.563**
UV	-0.541**	-0.536**	-0.528**	-0.543**

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

Table 40. Correlation between number of harvest and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.312*	0.159	-0.059	-0.077	-0.130	-0.312*	-0.364*	-0.334*
Tmin	0.405*	0.089	0.279	0.225	0.251	0.218	-0.094	-0.293*
STmin	0.386*	0.359*	0.381*	0.235	0.082	-0.021	-0.100	-0.164
STmax	-0.194	-0.124	-0.604**	-0.767**	-0.647**	-0.463**	-0.559**	-0.688**
SM	0.514**	0.303*	0.250	0.417**	0.186	0.365*	0.475**	0.155
RH-I	0.739**	0.680**	0.754**	0.728**	0.693**	0.636**	0.584**	0.676**
RH -II	0.459**	0.471**	0.764**	0.840**	0.744**	0.760**	0.772**	0.747**
SR	-0.414**	-0.445**	-0.461**	-0.497**	-0.569**	-0.584**	-0.587**	-0.592**
CT	-0.241	0.162	0.095	-0.207	-0.239	-0.376*	0.255	0.446**
CATD	-0.277	-0.338*	-0.400*	-0.406*	-0.008	-0.240	-0.602**	-0.630**
UV	-0.397*	-0.451**	-0.466**	-0.437**	-0.470**	-0.454**	-0.463**	-0.447**
PAR	-0.689**	-0.538**	-0.388*	-0.544**	-0.401*	-0.136	-0.340*	-0.398*

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

Table 41. Correlation between number of harvest and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.163	-0.101	-0.314*	-0.322*
Tmin	0.303*	0.252	0.218	-0.160
STmax	-0.398*	-0.771**	-0.502**	-0.752**
STmin	0.403*	0.162	-0.022	-0.060
SM	0.537**	0.357*	0.364*	0.220
RH1	0.760**	0.718**	0.638**	0.616**
RH2	0.625**	0.811**	0.759**	0.776**
SR	-0.444**	-0.538**	-0.584**	-0.591**
CT	0.053	-0.251	-0.446**	0.177
CATD	0.492**	0.575**	0.284	-0.177
PAR	-0.638**	-0.579**	-0.136	-0.462**
UV	-0.450**	-0.454**	-0.454**	-0.456**

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

4.6.3.4. Fruit yield per plant

Fruit yield per plant showed non-significant effect on maximum soil temperature where minimum soil temperature was exhibited positive correlation during vegetative stage, second and third week (0.472 and 0.357) and later it showed non significance. Maximum and minimum temperature, maximum and minimum relative humidity, soil moisture showed positive correlation and UV radiation, PAR and solar radiation showed negative correlation. Minimum temperature (0.530, 0.453, 0.409, 0.445), morning relative humidity (0.491, 0.574, 0.586, 0.586) and PAR (-0.711, -0.776, -0.580, -0.768), UV radiation (-0.635, -0.642, -0.642, -0.642) and solar radiation (-0.519, -0.462, -0.420, -0.416) exhibited positive and negative correlation during all growth stages respectively. Canopy temperature during flowering stage (-0.538), and fifth, seventh and eighth week (-0.342, -0.508, -0.434) exhibited negative correlation where harvesting stage (0.504), seventh and eighth week (0.467 and 0.526) showed a positive correlation with fruit yield per plant. Where CATD exhibited a positive correlation during vegetative stage (0.558), flowering stage (0.649). Maximum temperature during vegetative stage (0.313), flowering stage (0.384) and third, fourth and fifth week (0.322, 0.356 and 0.363) showed a positive correlation with fruit yield per plant (Table 43).

4.6.3.5. Total yield

Table 44 and 45 showed that total yield showed positive correlation with minimum temperature (0.530, 0.453, 0.409, 0.445) and maximum relative humidity (0.491, 0.574, 0.586, 0.586) during vegetative, flowering, fruiting and harvesting stage respectively. Whereas maximum soil temperature exhibited non-significance. Solar radiation, UV radiation and PAR showed negative correlation with total yield. Solar radiation (-0.519, -0.462, -0.420, -0.416), PAR (-0.711, -0.776, -0.580, -0.768), UV radiation (-0.635, -0.642, -0.642, -0.642) were showed negative correlation during all growth stages. Flowering stage except soil temperature all weather parameters exhibited significant effect. Minimum soil temperature showed a positive correlation with total yield during vegetative stage (0.385) and second and third week (0.472, 0.357).

Table 42. Correlation between fruit yield per plant and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.255	0.255	0.322*	0.356*	0.363*	0.228	0.216	0.215
Tmin	0.492**	0.487**	0.383*	0.483**	0.390*	0.411**	0.416**	0.323*
STmin	0.277	0.472**	0.357*	0.255	0.179	0.109	0.151	0.161
STmax	0.103	0.069	-0.021	-0.212	-0.166	0.014	-0.030	-0.135
SM	0.580**	0.546**	0.260	0.583**	0.715**	0.652**	0.664**	0.150
RH-I	0.548**	0.367*	0.485**	0.568**	0.572**	0.583**	0.546**	0.581**
RH -II	0.185	0.122	0.284	0.349*	0.341*	0.419**	0.365*	0.372*
SR	-0.531**	-0.512**	-0.494**	-0.474**	-0.437**	-0.420**	-0.416**	-0.415**
CT	0.085	0.141	-0.342*	-0.508**	-0.434**	-0.200	0.467**	0.526**
CATD	-0.146	-0.122	-0.065	-0.200	0.337*	-0.028	-0.494**	-0.520**
UV	-0.617**	-0.605**	-0.632**	-0.642**	-0.640**	-0.642**	-0.640**	-0.642**
PAR	-0.717**	-0.572**	-0.512**	-0.673**	-0.584**	-0.580**	-0.610**	-0.668**

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

Table 43. Correlation between fruit yield per plant and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.313*	0.384*	0.224	0.233
Tmin	0.530**	0.453**	0.409*	0.445**
STmax	0.069	-0.205	0.024	-0.249
STmin	0.385*	0.219	0.108	0.241
SM	0.707**	0.753**	0.640**	0.057
RH1	0.491**	0.574**	0.586**	0.586**
RH2	0.218	0.352*	0.418*	0.443**
SR	-0.519**	-0.462**	-0.420*	-0.416**
CT	-0.161	-0.538**	-0.249	0.504**
CATD	0.558**	0.649**	0.212	-0.254
PAR	-0.711**	-0.776**	-0.580**	-0.768**
UV	-0.635**	-0.642**	-0.642**	-0.642**

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

Table 44. Correlation between total yield and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	0.255	0.255	0.322*	0.356*	0.363*	0.228	0.216	0.215
Tmin	0.492**	0.487**	0.383*	0.483**	0.390*	0.411**	0.416**	0.323*
STmin	0.277	0.472**	0.357*	0.255	0.179	0.109	0.151	0.161
STmax	0.103	0.069	-0.021	-0.212	-0.166	0.014	-0.030	-0.135
SM	0.580**	0.546**	0.260	0.583**	0.715**	0.652**	0.664**	0.150
RH-I	0.548**	0.367*	0.485**	0.568**	0.572**	0.583**	0.546**	0.581**
RH -II	0.185	0.122	0.284	0.349*	0.341*	0.419**	0.365*	0.372*
SR	-0.531**	-0.512**	-0.494**	-0.474**	-0.437**	-0.420**	-0.416**	-0.415**
CT	0.085	0.141	-0.342*	-0.508**	-0.434**	-0.200	0.467**	0.526**
CATD	-0.146	-0.122	-0.065	-0.200	-0.337*	-0.028	-0.494**	-0.520**
UV	-0.617**	-0.605**	-0.632**	-0.642**	-0.640**	-0.642**	-0.640**	-0.642**
PAR	-0.717**	-0.572**	-0.512**	-0.673**	-0.584**	-0.580**	-0.610**	-0.668**

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

Table 45. Correlation between total yield and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	0.313*	0.384*	0.224	0.233
Tmin	0.530**	0.453**	0.409*	0.445**
STmax	0.069	-0.205	0.024	-0.249
STmin	0.385*	0.219	0.108	0.241
SM	0.707**	0.753**	0.640**	0.057
RH1	0.491**	0.574**	0.586**	0.586**
RH2	0.218	0.352*	0.418**	0.443**
SR	-0.519**	-0.462**	-0.420**	-0.416**
CT	-0.161	-0.538**	-0.249	0.504**
CATD	-0.558**	-0.649**	-0.212	-0.254
PAR	-0.711**	-0.776**	-0.580**	-0.768**
UV	-0.635**	-0.642**	-0.642**	-0.642**

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

4.6.3.6. Average fruit weight

Solar radiation, UV radiation, maximum and minimum relative humidity exhibited non-significance. In flowering stage except CATD (0.398) all weather parameters showed non-significance. Maximum temperature was negatively correlated with average fruit weight during vegetative stage (-0.365), second week (-0.397) and third week (-0.390) and minimum temperature (-0.432, -0.336) exhibited negative correlation during fruiting, harvesting stage and third, sixth, seventh and eighth week (0.413,-0.426,-0.374,-0.359) respectively. Harvesting stage except minimum temperature (-0.336) and CATD (-0.379) all other weather parameters were showed non-significance (Table 46 and 47).

Table 46. Correlation between average fruit weight and different weather parameters during different growth stages

	Vegetative stage	Flowering stage	Fruiting stage	Harvesting stage
Tmax	-0.365*	-0.177	-0.230	-0.208
Tmin	0.214	-0.165	-0.432**	-0.336*
STmax	-0.174	-0.290	-0.122	-0.036
STmin	0.132	-0.009	-0.169	-0.106
SM	-0.139	-0.141	-0.267	-0.050
RH1	0.037	-0.045	-0.052	-0.006
RH2	0.043	0.125	0.052	0.127
SR	0.048	0.132	0.113	0.109
CT	0.268	-0.080	-0.219	-0.081
CATD	0.119	0.398*	0.072	-0.379*
PAR	0.137	0.209	-0.169	0.164
UV	0.011	0.049	0.071	0.026

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

Table 47.Correlation between average fruit weight and different weather parameters during weeks after planting

	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Tmax	-0.092	-0.397*	-0.390*	-0.177	-0.064	-0.257	-0.244	-0.231
Tmin	-0.049	0.129	0.413**	-0.070	-0.219	-0.426**	-0.374*	-0.359*
STmin	-0.012	0.156	0.326*	0.068	-0.041	-0.174	-0.160	-0.129
STmax	-0.247	0.337*	-0.219	-0.203	-0.361*	0.021	0.105	-0.011
SM	-0.118	-0.149	-0.124	0.027	-0.323*	-0.231	-0.076	0.312
RH-I	0.059	0.022	0.049	-0.083	0.013	-0.059	-0.002	0.069
RH -II	-0.062	0.004	0.115	0.120	0.151	0.055	0.127	0.194
SR	0.049	0.055	0.037	0.137	0.128	0.113	0.108	0.114
CT	-0.169	0.388*	0.143	-0.002	-0.157	-0.265	-0.011	0.063
CATD	-0.057	0.127	0.129	0.213	0.369*	0.146	-0.025	-0.181
UV	0.024	-0.034	0.037	0.055	0.042	0.071	0.028	0.025
PAR	0.020	-0.088	0.407*	0.238	0.109	-0.169	0.281	0.335*

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

4.7. MULTIPLE REGRESSION MODELS DEVELOPED

Correlation matrices (Tables 24 to 38) were developed for cucumber by using pooled data of six 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. LAI, days to different phenological stages and yield were estimated using multiple regression models.

4.7.1. Leaf area index

Leaf area index = 5.648**-0.001PAR2**-0.102Tmin3** (R^2 = 0.81)

PAR2 = PAR from flowering stage

Tmin3 = Minimum temperature from fruiting stage

From the regression equation it is clear that PAR during the flowering stage and minimum temperature during fruiting stage have significant influence on leaf area index.

4.7.2. Days to last harvest

Days to last harvest = -84.17**+1.117RH4**+1.338Tmax2**+10.678** CATD3** (R^2=0.76)

RH4 = Relative humidity from harvesting stage

Tmax2 = Maximum temperature from flowering stage

CATD3 = CATD from fruiting stage

From the regression equation it is clear that among the weather parameters relative humidity during harvesting stage, maximum temperature during flowering stage and canopy air temperature difference during fruiting stage have significant effect on days taken for last harvest.

4.7.3. Total yield

Total yield = -12.158**-0.052PAR2**+1.202RH3**- 0.050 PAR3** (R^2 = 0.82)

PAR2 = PAR from flowering stage

RH3 = Relative humidity from fruiting stage

PAR3 = PAR from fruiting stage

Total yield was significantly depended on PAR during flowering and fruiting stage, relative humidity during fruiting stage.

4.7.4. Duration

Duration = 17.393**-1.746UV4**-1.428RH4**-0.669RH1**+1.488UV3** ($R^2 = 0.85$)

UV4= UV radiation from harvesting stage

RH4= Relative humidity from harvesting stage

RH1 = Relative humidity from vegetative stage

UV3 = UV radiation from fruiting stage

The duration of the crop was significantly depended on UV radiation during the fruiting and harvesting stage and relative humidity during the vegetative and harvesting stage.

Discussion

The present study was taken up with a view to study the effect of growing environments and microclimate on growth and yield of cucumber and crop weather relationships in cucumber under different growing environment. The results presented in the previous chapter are discussed here under.

5.1. WEATHER DURING THE CROP PERIOD

5.1.1. Temperature (°C)

The highest maximum temperature was recorded during winter season inside the rain shelter and polyhouse was 49.4°C and 48.9°Crespectively. Whereas the lowest value was obtained in the open field (36.8°C). The highest and lowest maximum temperature was recorded inside the polyhouse (43.2°C) and open field (32°C) during rainy season. Maximum temperature showed an increasing trend throughout the growing period. For the crop transplanted on winter season the highest and lowest value of minimum temperature 26.0°C and 25.2°C were recorded under open field and rain shelter respectively. Rainy season the highest value of mean weekly minimum temperature was recorded inside the polyhouse (25.2°C) followed by open field (25.0°C) and rain shelter (24.8°C). The diurnal variation in the temperature under three growing environments showed the highest value of air temperature inside the polyhouse followed by rain shelter and open field. High temperature inside the rain shelter and polyhouse is mainly due to physical properties of covering material which traps the long wave radiation.Air temperature is the main environmental component influencing vegetative growth, flowering, fruit setting, fruit development, fruit ripening, and fruit quality of crop. The average 24-h temperature is believed to be responsible for the growth rate of the crop-the higher the average air temperature the faster the growth. The outside air mass receives direct radiation, which heated the air in multiple magnitude, as compared to the inside air mass which receives a large portion of diffuse radiation. It creates an unbalanced thermo-potential between the outside and inside environment. When outside temperature increased at a faster rate, it resulted in a temperature difference and caused the heat to flow into the internal environment (inflow). Between 1000 h and 1500 h, the outside environment became a heat source and the inside environment as a heat sink until an isothermal occurred (1500 h) with a value around 34 °C. At this point, the process of heat built-up was continuing, and caused the increase in inside temperature. This environmental pattern showed that the heat flow changed at about 1500 h, where the inside air temperature was higher than outside and took ≥ 18 hours from 1600 h to about 1000 h the next morning. This phenomenon occurs due to the heat that is retained in the structure and dissipated by the crops during respiration at night. At night the breakdown of sugar through respiration is taking place and plants dissipate heat and CO_2 into the internal environment, which contributes to the higher values of temperature inside the protected structures as compared to open field condition. This view was supported by Hirama*et al.* (2003), Dhandare*et al.* (2008). Pandey *et al.* (2005) found a difference of 6 to 7°C in polyhouse was more when compared to open field which favors crop productivity where in this study maximum temperature difference between polyhouse and open field was 9 to 11°C and the temperature difference between polyhouse and rain shelter was around 2 to 2.2°C. Minimum temperature recorded inside the rain shelter was less as compared to polyhouse and open field during both the seasons. This is mainly due to the structure of rain shelter where efficient air flow is possible due to effective ventilation system and incoming solar radiation was less due to covering material and also the sides of rain shelter allows the energy transfer. Where during rainy season the value of minimum temperature recorded inside the rain shelter was less as compared to winter season due to moisture effect. This was supported by Sharif *et al.* (2008).

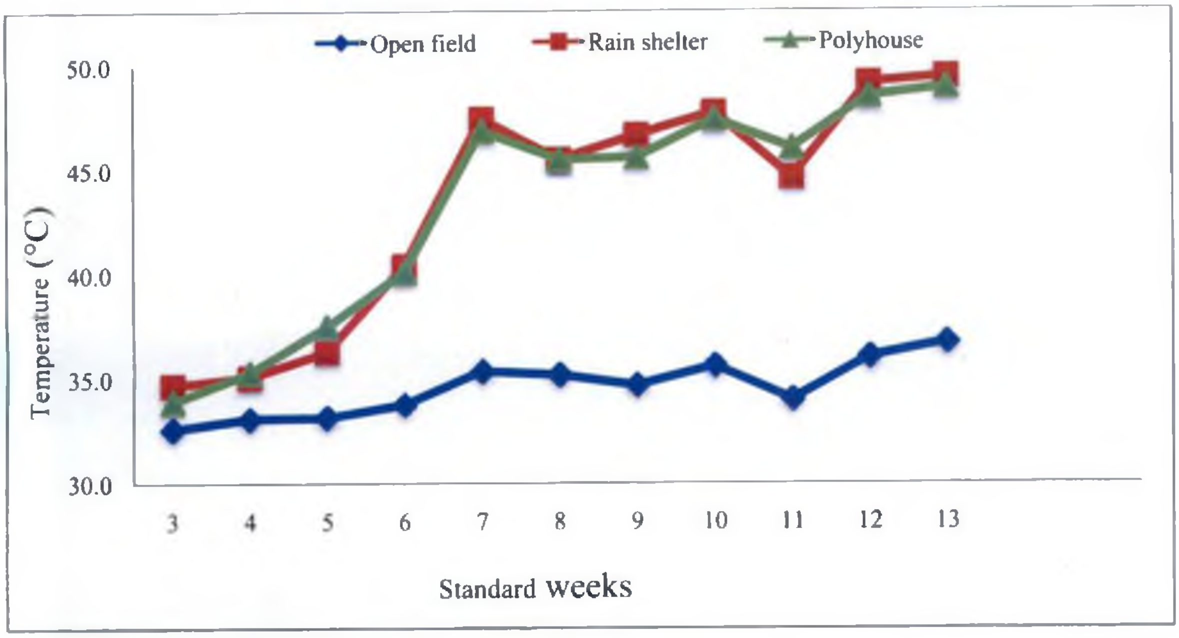

Fig 10. Weekly variation of maximum temperature during winter season

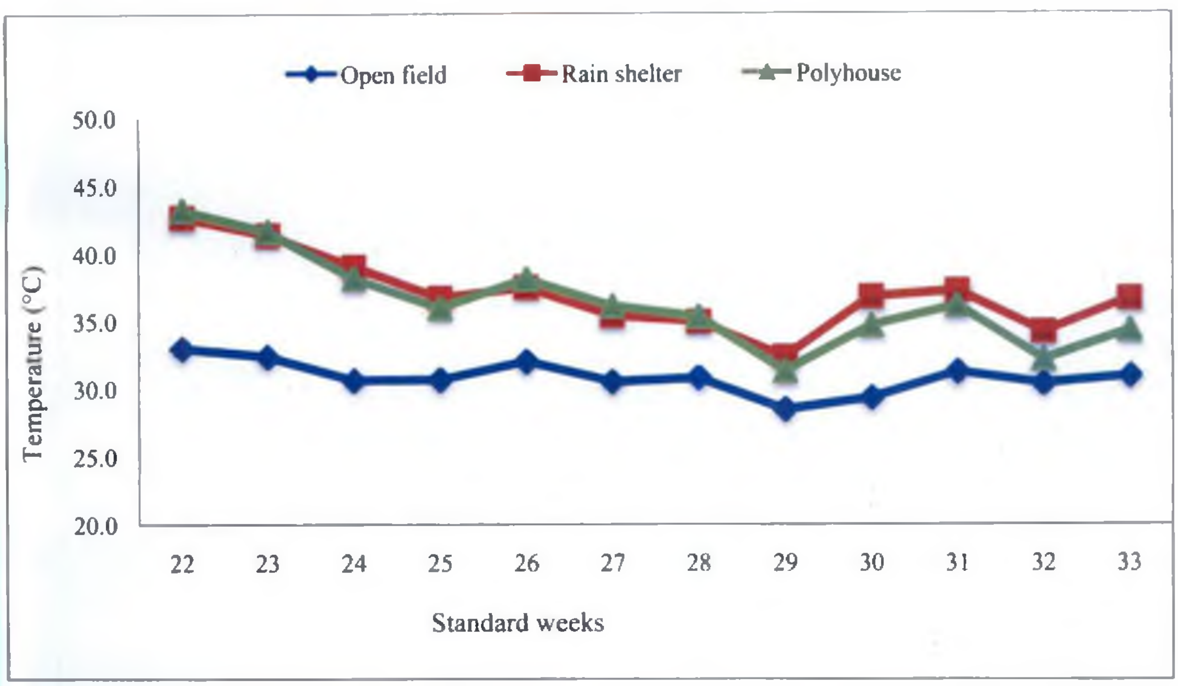

Fig 11. Weekly variation of maximum temperature during rainy season

5.1.2. Soil temperature

Weekly variation of minimum soil temperature under open field condition recorded highest value (34.9°C) when compare to polyhouse (34.1°C) and rain shelter (28.5°C) in winter season and during rainy season highest value of minimum soil temperature was recorded under open field (33.6°C) and lowest value was recorded in rain shelter (28.0°C). The more water a soil has, the slower it will heat up because water needs to absorb lots of energy to increase its temperature. The biological processes for nutrient transformations and nutrient availability are controlled by soil temperature and soil moisture. Soil temperature has a profound influence on seed germination, root and shoot growth, and nutrient uptake and crop growth. Diurnal variation of soil temperature was recorded and the highest value of soil temperature recorded in the open field, rain shelter and polyhouse were occurred around 13:00 hours.The time of the peak temperature of the soil reaches earlier than the air temperature due to the lag of the air temperature.This was also reported by Dhandare*et al.* (2008). Soil temperature fluctuates annually and daily affected mainly by variations in air temperature and solar radiation. Soil is a good absorber of heat. During day time incoming short wave radiation is absorbed by soil and soil temperature heats up, where inside polyhouse soil temperature recorded was less due to less solar radiation absorption and convective loss of energy was less inside the polyhouse due to closed environment. In case of rain shelter the absorption of incoming short wave radiation was less and the convective loss of energy was high as compared to polyhouse. So mixing of air take place and results in decreased soil temperature as compared to open field. During rainy season due to less solar radiation the maximum soil temperature was recorded inside the polyhouse compared to open field. This finding was supported by Liebig (1985), Habtamu*et al.* (2015).

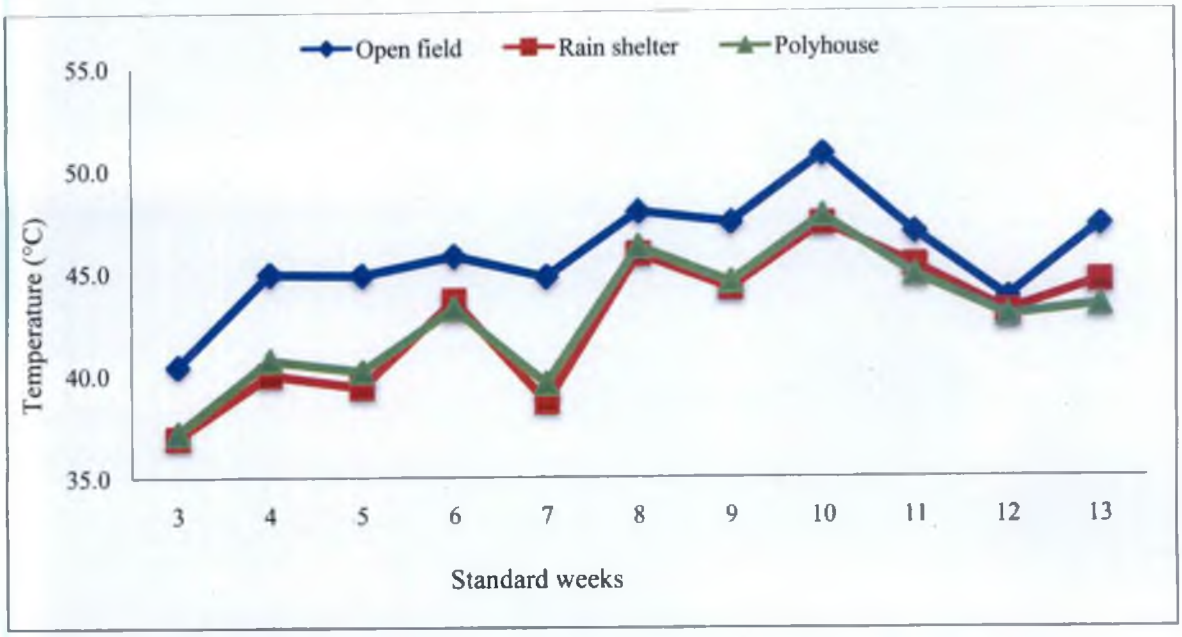

Fig 14. Weekly variation of maximum soil temperature during winter season

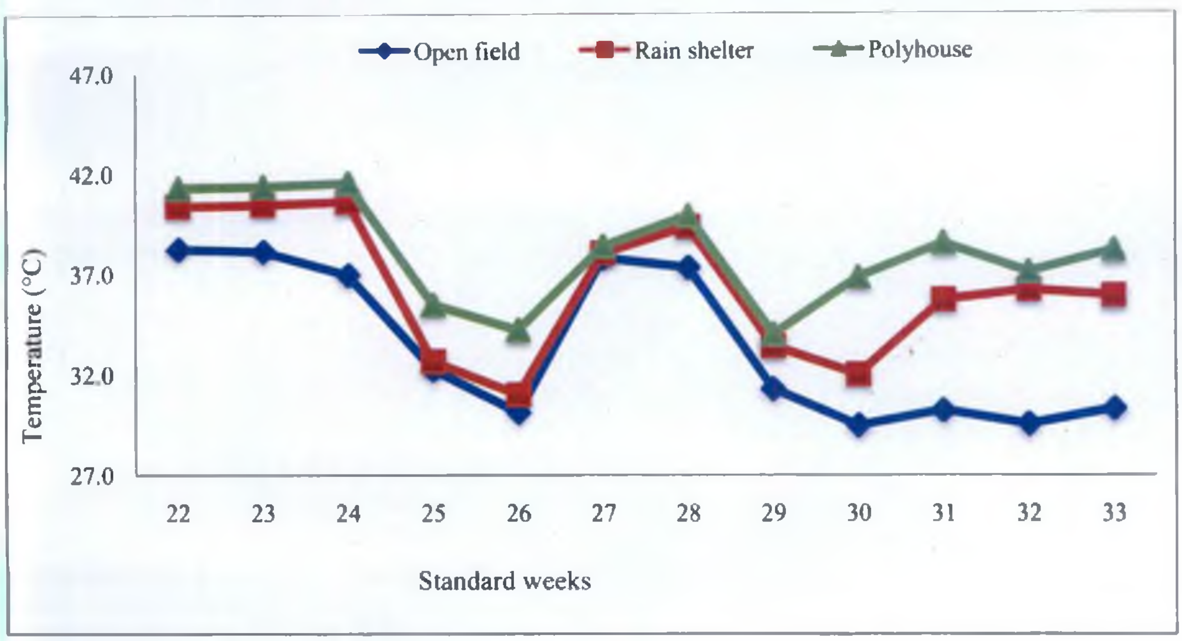

Fig 15. Weekly variation of maximum soil temperature during rainy season

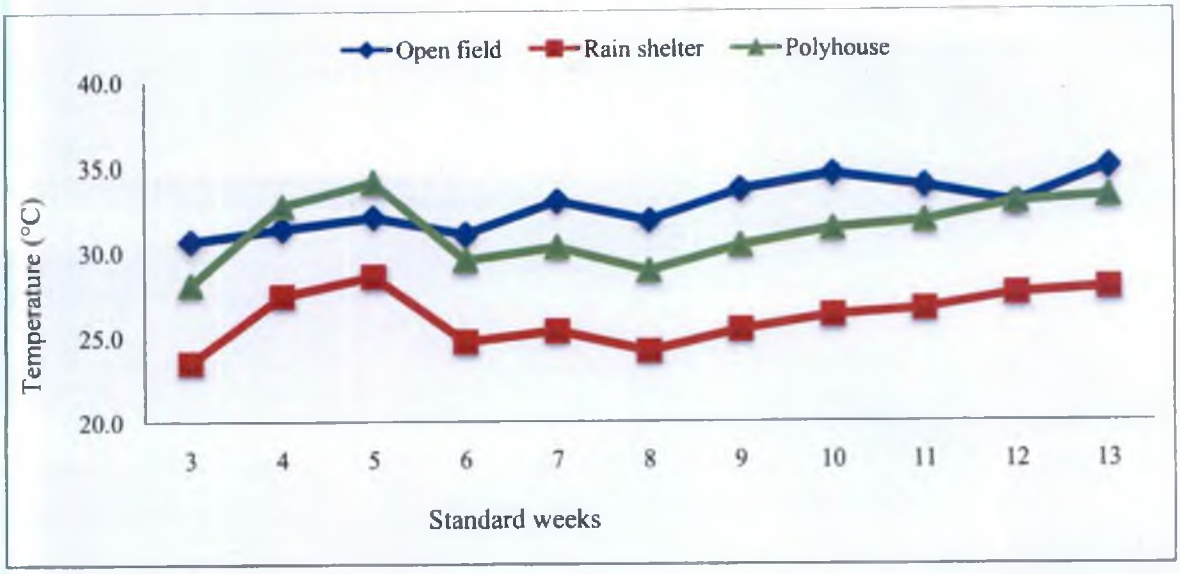

Fig 16. Weekly variation of minimum soil temperature during winter season

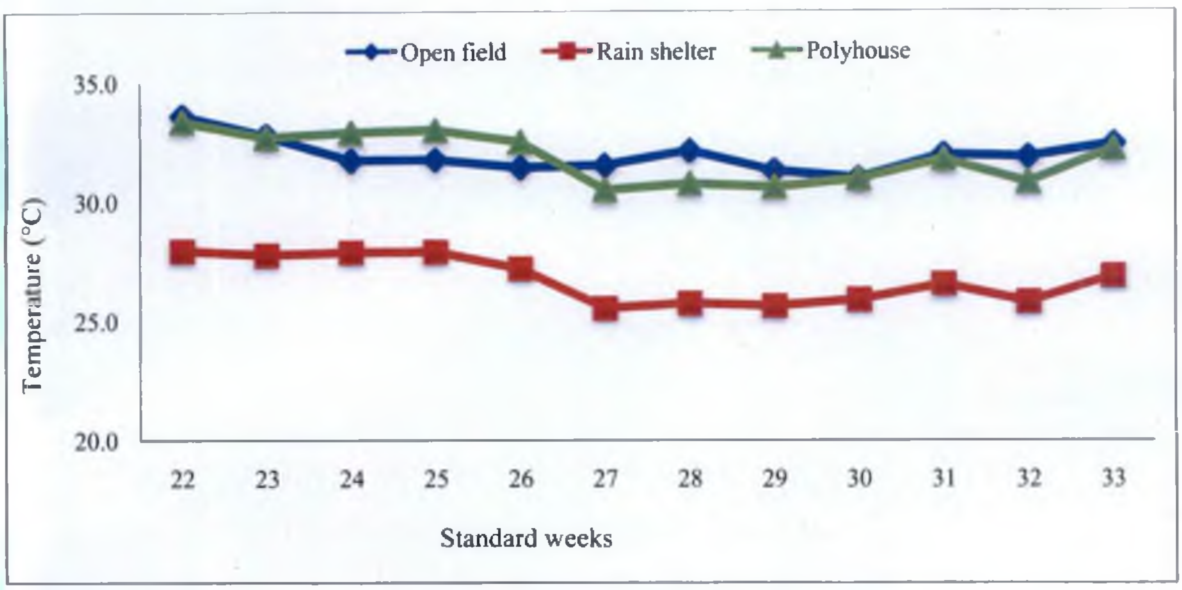

Fig 17. Weekly variation of minimum soil temperature during rainy season

5.1.3. Soil moisture (%)

Highest and lowest value of soil moisture during winter season was recorded inside the polyhouse (42.7%) and open field (40.2%) respectively. Highest value of soil moisture recorded during rainy season was also inside the polyhouse (42.6%) followed by rain shelter (41.8%) and open field (40.9%).overall soil moisture exhibited showed a fluctuating trend during entire crop season.

The thermal diffusivity of the soil is the ratio of the thermal conductivity of the soil to the volumetric heat capacity of the soil. The conductivity and volumetric heat capacity increase with water content so the diffusivity is also dependent upon soil water content. The thermal diffusivity increases with water content at low water contents and then gradually decreases with increasing water contents at high water contents.Light, temperature, humidity, and wind-control the rate of water loss by transpiration and evaporation. Where water use rates are high, crops will deplete the available soil moisture more rapidly, and growth may be more affected, by increasing soil moisture stress. Plant growth is probably dependent upon plant turgor or plant moisture stress, whose relation to soil moisture stress for different rates of transpiration needs to be explored. This was also reported by Hagan (1955). In this study the soil moisture showed fluctuating trend throughout the crop period.

5.1.4. Relative humidity (%)

Highest and lowest value of maximum relative humidity was recorded inside the polyhouse (97.3%) and rain shelter (74.9 %) respectively and during rainy season also polyhouse recorded highest value of maximum relative humidity (98.7%) and lowest value 88.7% was recorded in rain shelter. Highest value of minimum relative humidity was recorded inside the polyhouse (56.7 %) followed by rain shelter (51.9 %) and open field (48.7 %) during winter season and in rainy season highest value was recorded inside the poly house (98.7 %) and lowest value was recorded under rain shelter (87.4 %).The atmospheric humidity being higher inside polyhousethan open field due to restricted air exchange inside the poly house. This result was in accordance with the

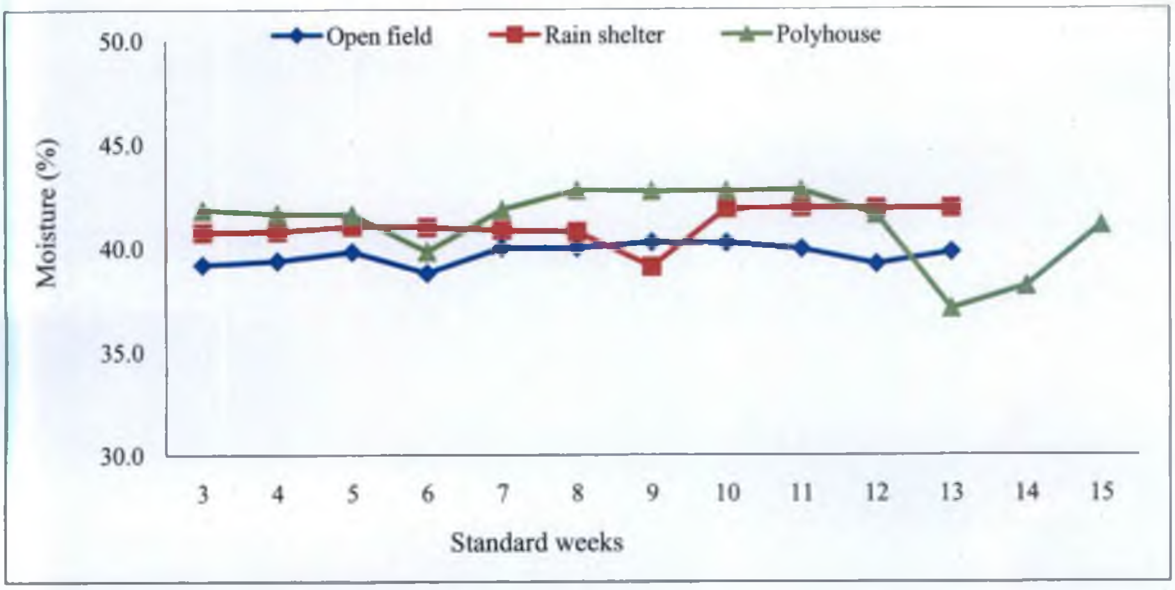

Fig .18. Weekly variation of soil moisture during winter season

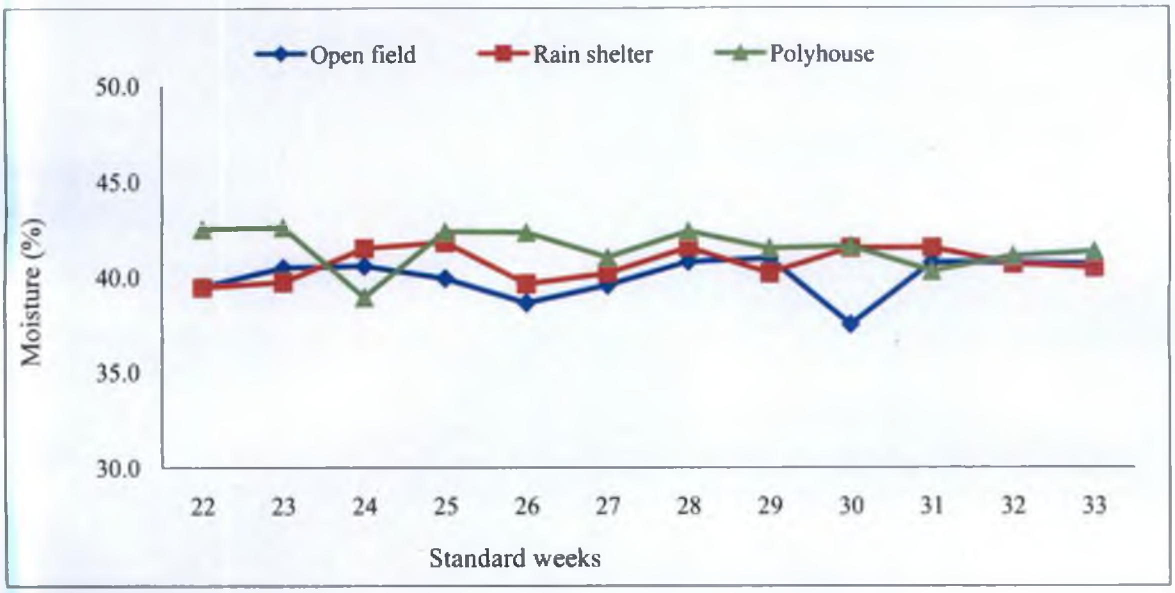

Fig .19. Weekly variation of soil moisture during rainy season

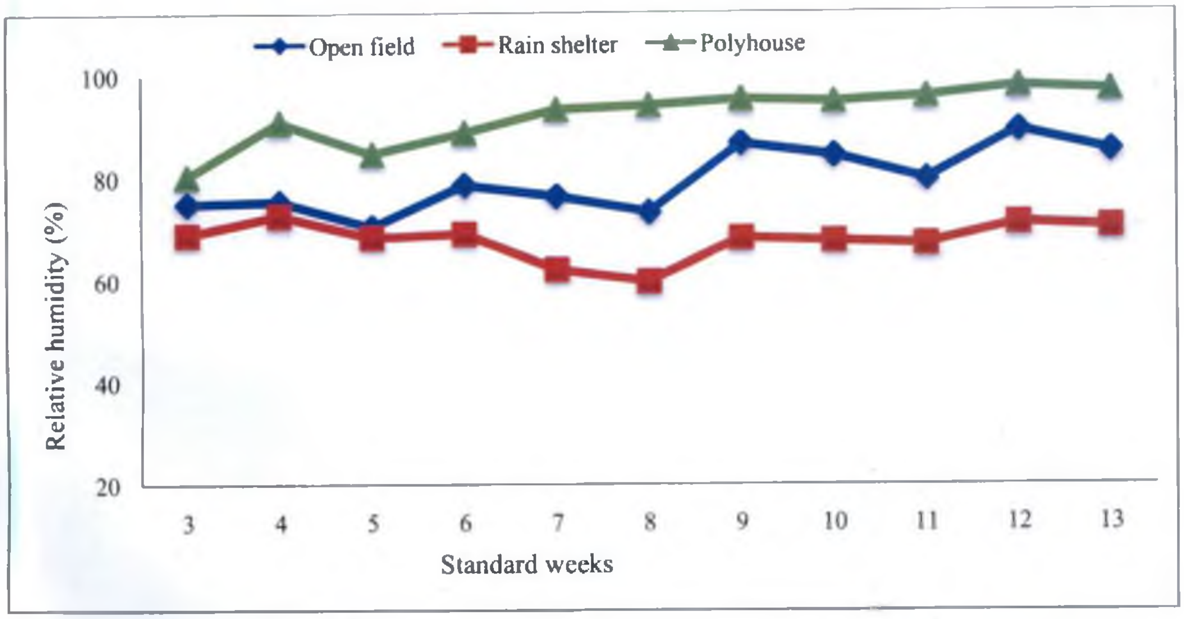

Fig 20. Weekly variation of maximum relative humidity during winter season

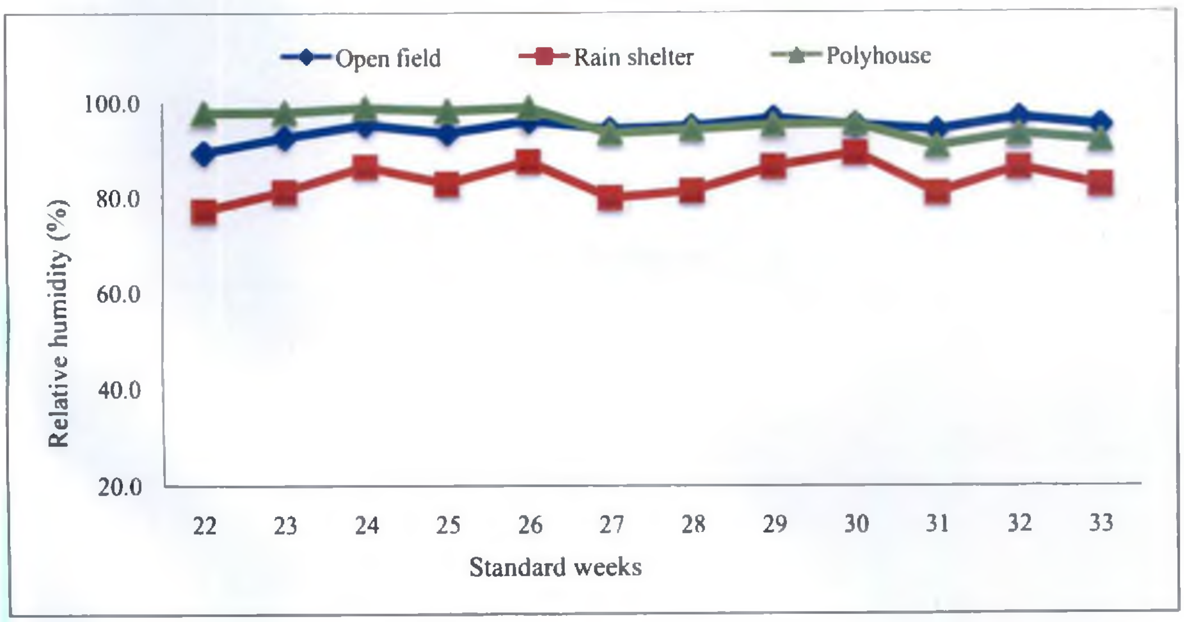

Fig 21. Weekly variation of maximum relative humidity during rainy season

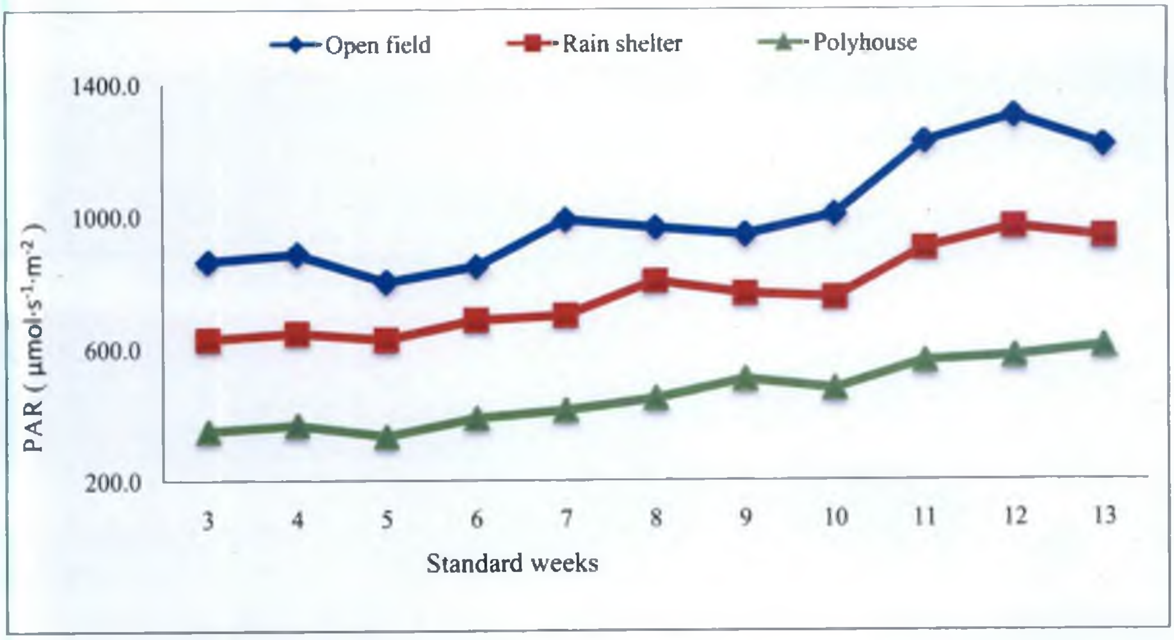

Fig .26. Weekly variation of PAR during winter season

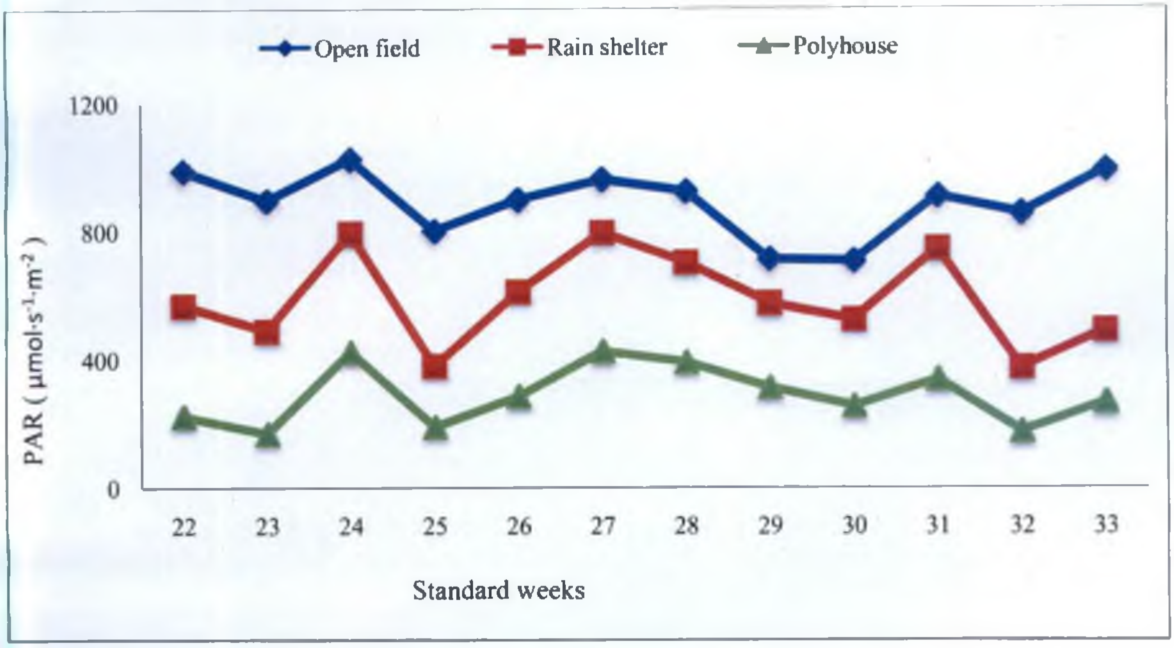

Fig .27. Weekly variation of PAR during rainy season

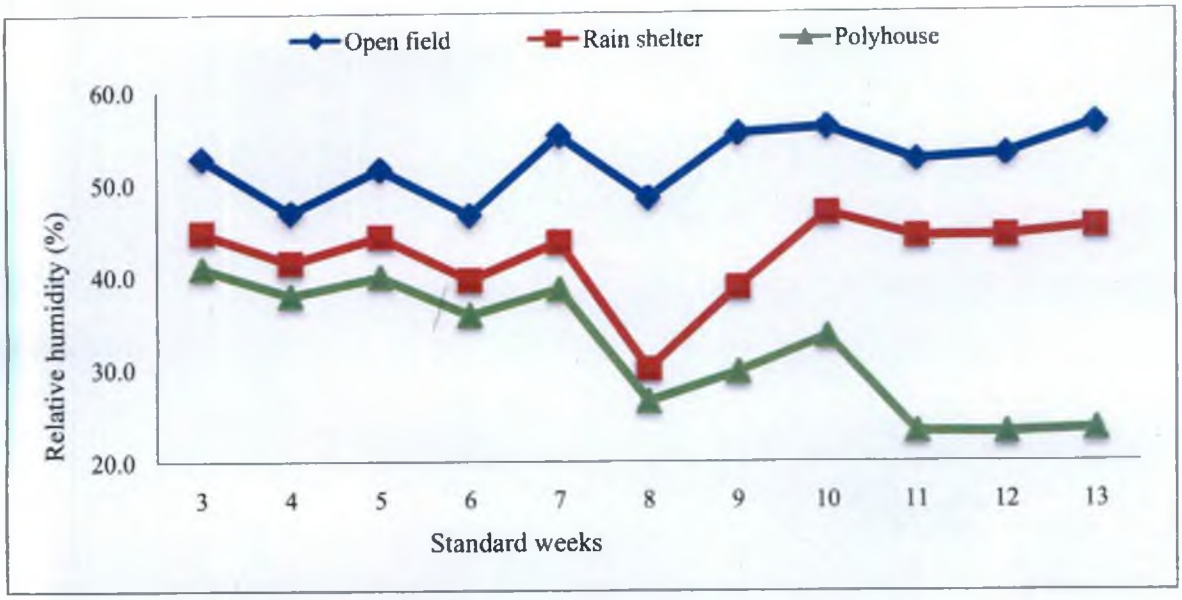

Fig.22. Weekly variation of minimum relative humidity during winter season

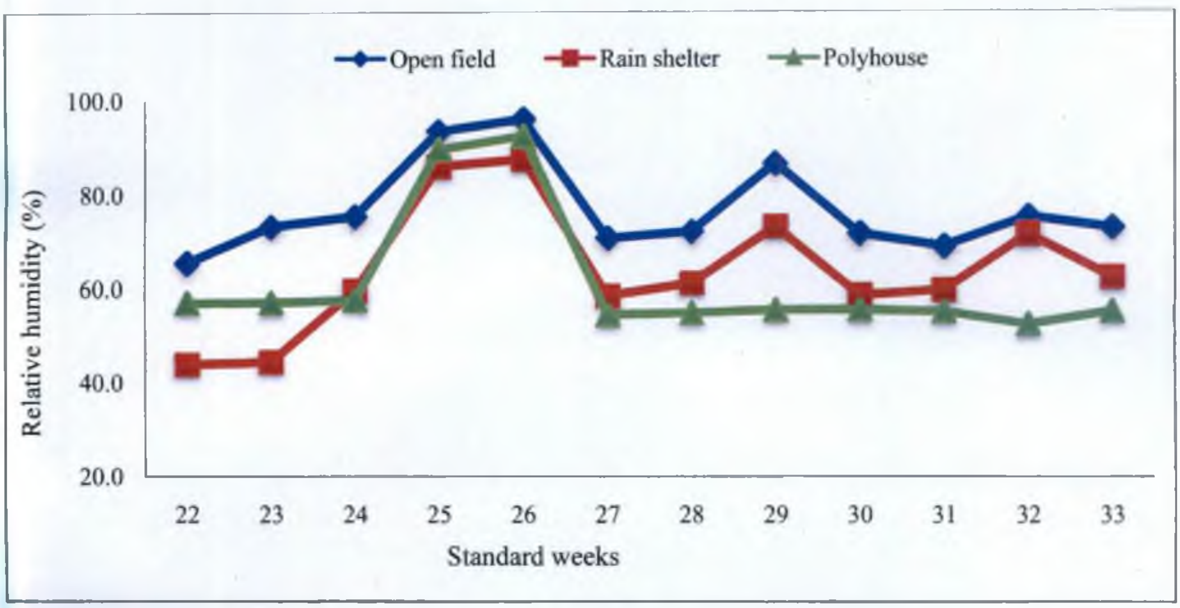

Fig .23 Weekly variation of minimum relative humidity during rainy season findings of Bakker (1984), Hand (1988).The highest value of relative humidity inside the polyhouse, rain shelter and open field were 93%, 85%, 86% respectively whereas the lowest values were 37%, 50%, 46% correspondingly in the polyhouse, rain shelter and open field and occurred around 15:00,14:00,15:00 respectively.The minimum value of relative humidity in the polyhouse was common in initial stage because of its inverse function with higher air temperature. This was in conformity with findings of Nimje and Shyam (1993). Minimum relative humidity was observed in poly house during afternoon for the entire crop period.In poly house conditions, the morning relative humidity was maximum.The variation in the relative humidity with time in poly house may be due to the increase in temperature. Higher humidity was observed inside the poly house during morning hours and gradually decreased in the afternoon because of increase in temperature. Moreover, relative humidity inside the poly house was found to be high at early morning hours. The possible reason for this might be that the poly house was filled with the vegetation and plants were well watered, the ground surface of the greenhouse was always wet. During night, certain quantum of water from soil gets evaporated. Since poly house was covered with ultra violet stabilized sheet and also due to absence of solar radiation, the escape of water vapour from the poly house to outside was comparatively less during night. Besides, at early morning, when sun starts shining, there will be more transpiration from the leaves. Both these factors together caused higher relativehumidity inside the poly house. Since in this study, poly houses was naturally ventilated, this effect does not prolong for longer period, but it occurred hardly for an hour after sunrise. This was in agreement with the studies conducted by Umesh*etal*. (2011).

5.1.5. Solar radiation (Wm^{-2})

Highest value of solar radiation in winter season recorded under open field (989.7 Wm^{-2}) and lowest value recorded inside polyhouse and rain shelter (53.3 Wm^{-2}). Regardless of seasons highest and lowest value of solar radiation was recorded under open field and polyhouse and rain shelter respectively. Highest amount of solar radiation was recorded in the open field. The amount of solar radiation increased from 9 hours in all three growing conditions. Highest amount of solar radiation was recorded under open field around13.00.The peak values were recorded under open field and protected environments have drastic difference. The peak value recorded under open field was 1117 Wm^{-2} .Where in case of protected environments it was only 514 Wm^{-2}Light is a prerequisite of plant growth. Plant matter is produced by the process of photosynthesis, which takes place only when light is absorbed by the chlorophyll (green pigment) in the green parts of the plant, mostly in the leaves. The results revealed that the light intensity inside the poly house was found to be much lower than in open field. Further, it was also observed that during morning and evening hours, there was low light intensity. These results are in accordance with those of Albright (1990) who observed that the light intensity was less in poly house.This is mainly due to the polyhouse covering material usually diffuses light which reaches the plant canopy varies with location and prevailing climatic conditions. This diffused light transmission in a polyhouse is reported as advantageous for light penetration. Diffused light penetrated deeper into the canopy and the middle leaves intercepted more light which caused an increase in photosynthesis leading to higher fruit production and also resulted into the reduced evapotranspiration. Wind speed in the polyhouse as expected, was nil. The advantages of low wind speed include low evapotranspiration rate that means lower water requirements this result was in accordance with the findings of Hemming and Reinders (2007), Li *et al.* (2014) ,(Abou-Hadid*et al.*, 1994).

5.1.6. Photosynthetically active radiation (PAR)

The least weekly photosynthetically active radiation for both seasons was recorded inside the polyhouse and rain shelter whereas, the highest value was observed under open field.So increased PAR caused a stressful environment which reduced most of the morphological and biochemical characters of crop under open field where as inside polyhouse due to covering material and its physical properties which cause reduced PAR inside the polyhouse which favored morphological character of the crop. These results were supported by Rajasekharanand Nandini(2014).

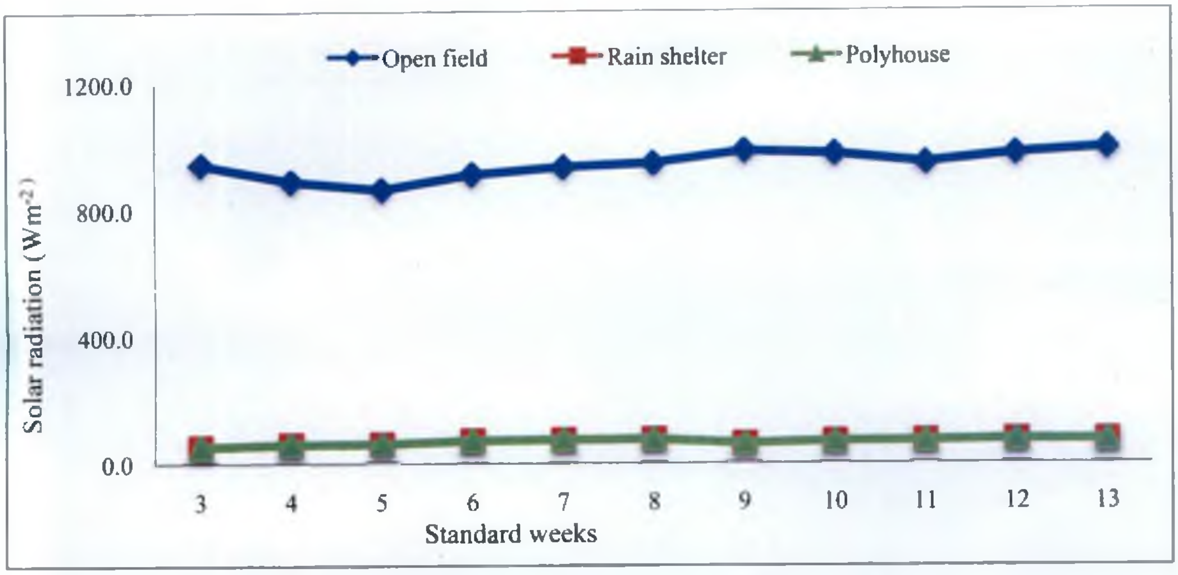

Fig .24 Weekly variation of solar radiation during winter season

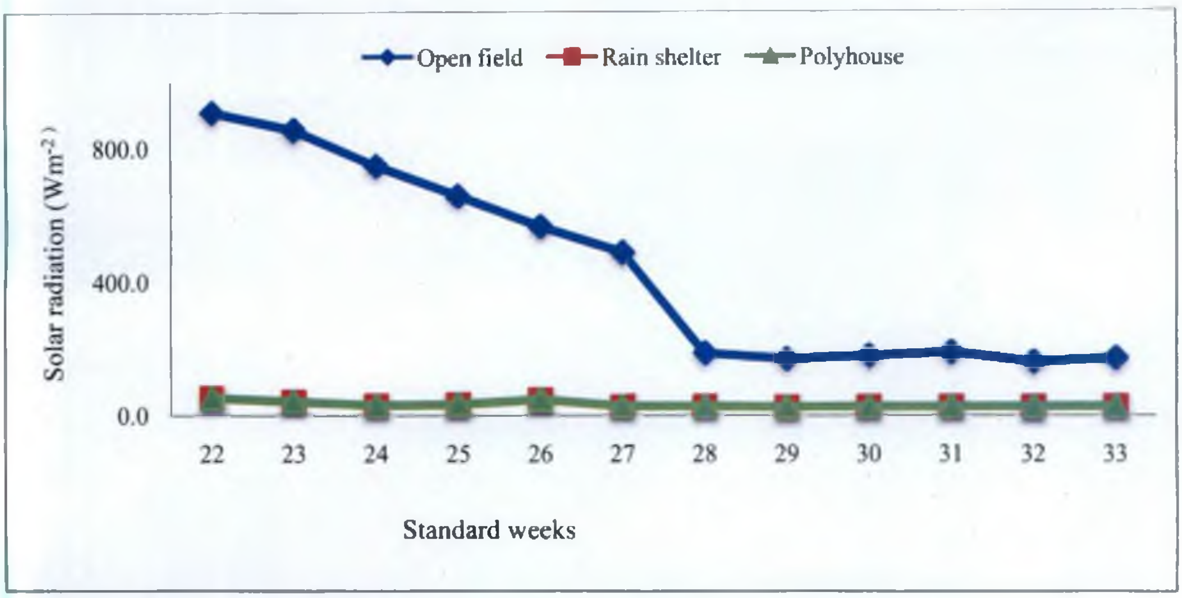

Fig .25 Weekly variation of solar radiation during rainy season

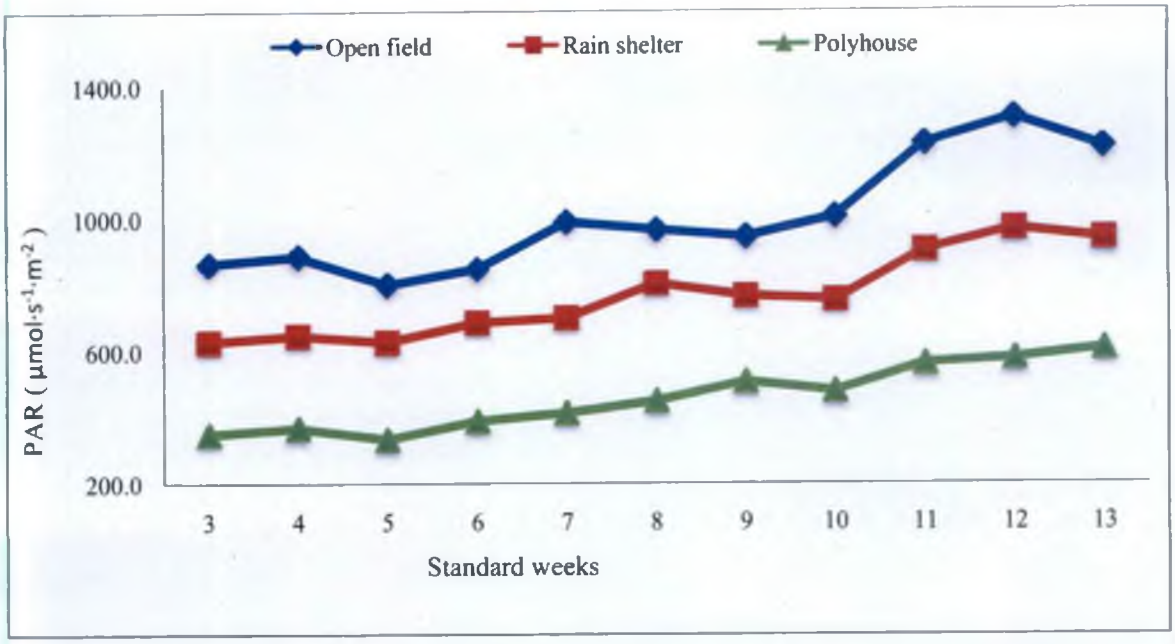

Fig .26. Weekly variation of PAR during winter season

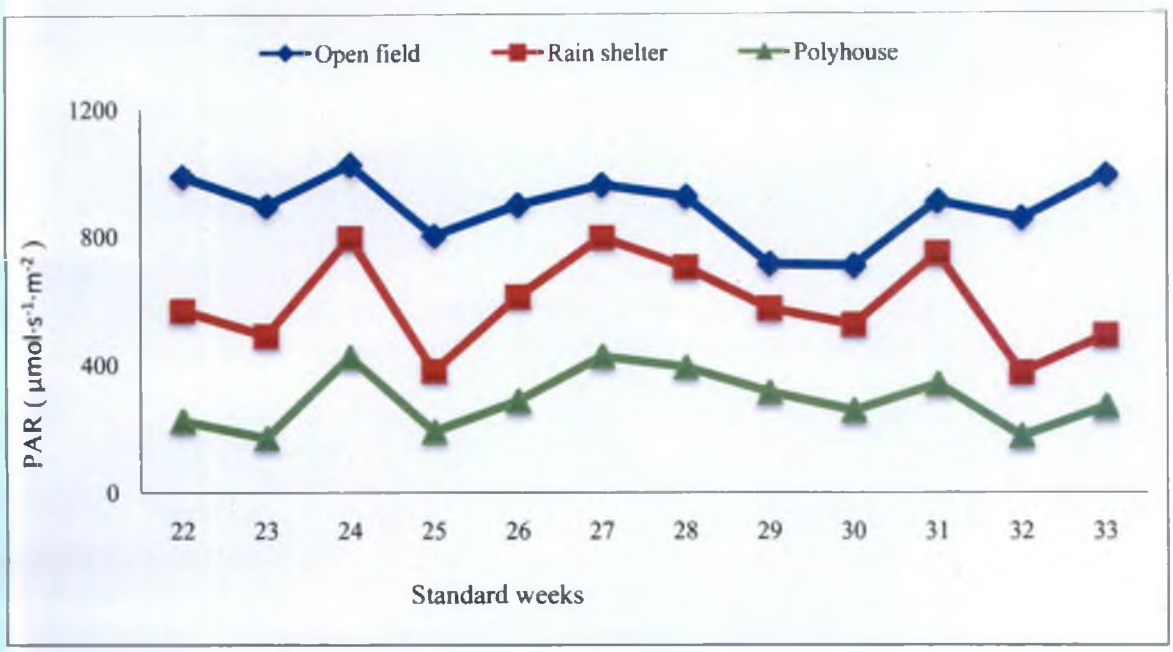

Fig .27. Weekly variation of PAR during rainy season

5.1.7. Canopy temperature(°C) and Canopy air temperature difference(CATD)

The highest weekly canopy temperature was recorded inside the polyhouse (39.1°C) whereas the least value 36.8°C was recorded in the open field during winterseason. In rainy season highest value of canopy temperature was recorded in rain shelter (36.4°C) followed by polyhouse (36.0°C) and open field (35.7°C).

The highest CATD value was recorded inside polyhouse (-3.8) followed by open field (-3.7) and rain shelter (-3.4) in winter season. Where during rainy season the highest value was recorded inside polyhouse (-3.6) and least value was recorded under open field (-3.5).Canopy temperature is often used to indicate vegetative water status and is used in models for estimating transpiration rates and sensible heat transport from vegetation. Canopy temperature increases when solar radiation is absorbed, but is cooled when that energy is used for evaporating water (latent energy or transpiration) rather than heating plant surfaces. Canopy temperature commonly follows a diurnal curve, with daytime temperatures rising due to increases in solar radiation and temperature. A water stressed plant will reduce transpiration and will typically have a higher temperature than the non-stressed crop.So from this study it was clear that inside polyhouse crops are under grown well as compared to open field condition. This was in concurrence with the findings of Dejonge*et al.* (2015), Rajasekharanand Nandini(2014).

5.1.8. UV radiations (Wm^{-2})

Highest and lowest value of UV radiation was recorded under open field and polyhouse in both seasons. Where UV radiation is available in the shorter wavelength range less than 400nm and a large quantity of it is harmful to crop growth. UV radiation was higher under open field. This is due to covering sheet provided in the protected structures. This was also reported by Shahak*et al.* (2008) and Rajasekharanand Nandini(2014).

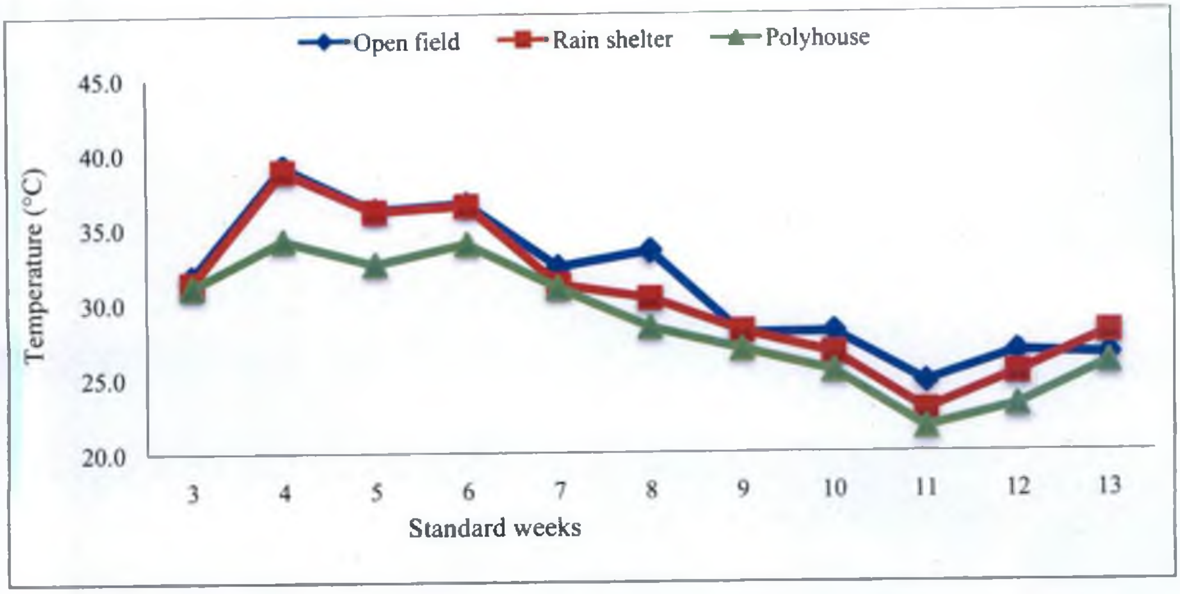

Fig .28. Weekly variation of canopy temperature during winter season

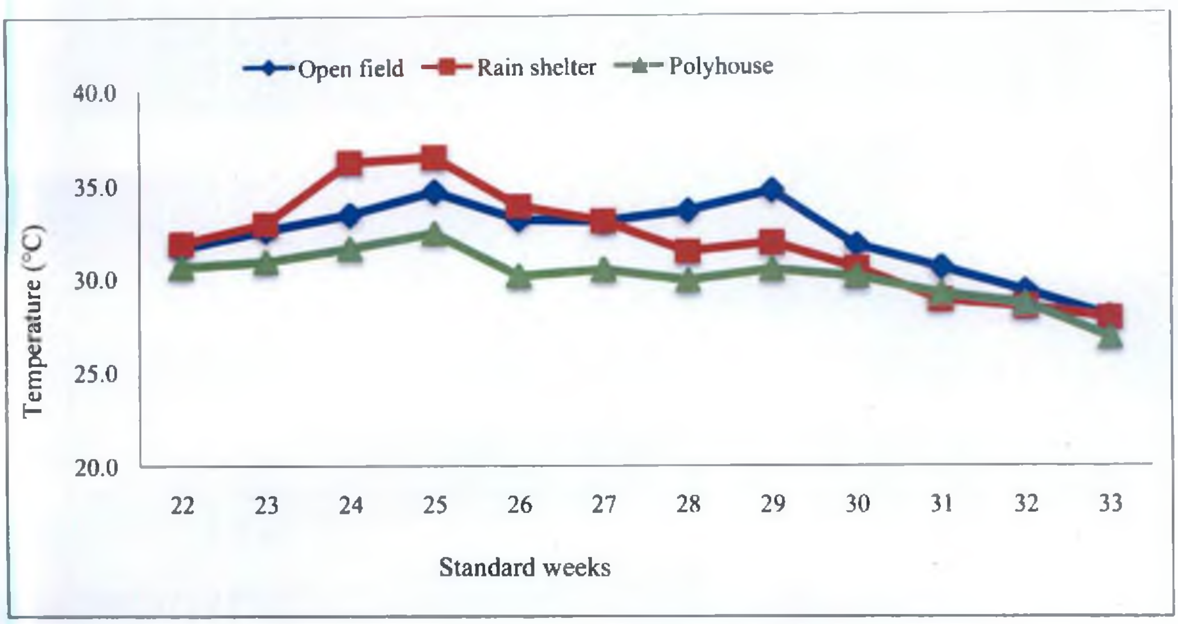

Fig .29. Weekly variation of canopy temperature during rainy season

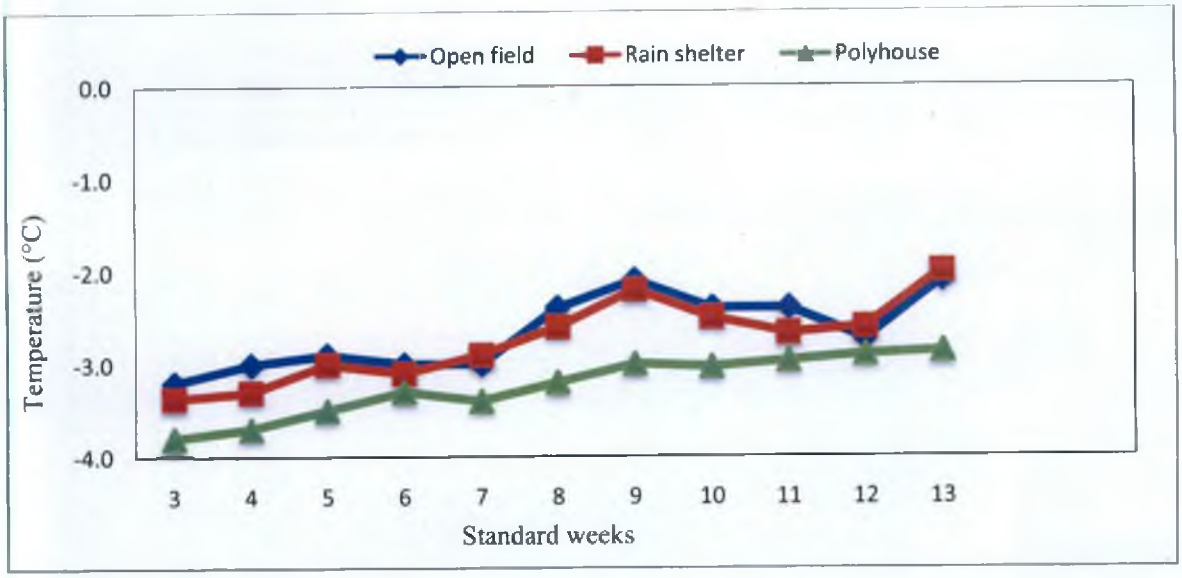

Fig .30. Weekly variation of canopy air temperature difference during winter season

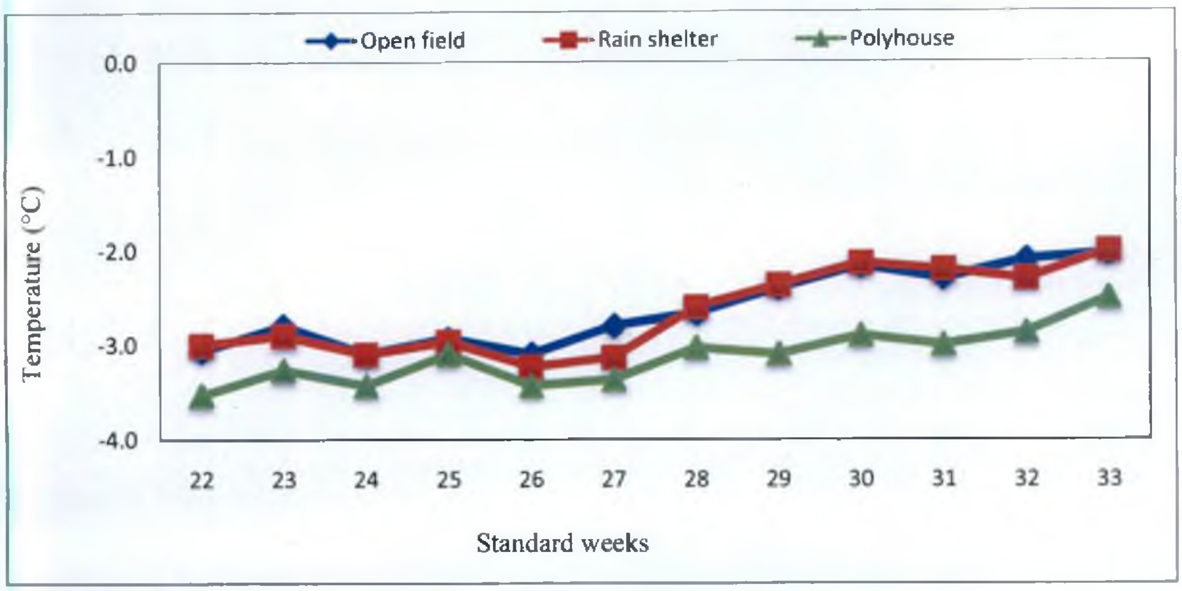

Fig .31. Weekly variation of canopy air temperature difference during rainy season

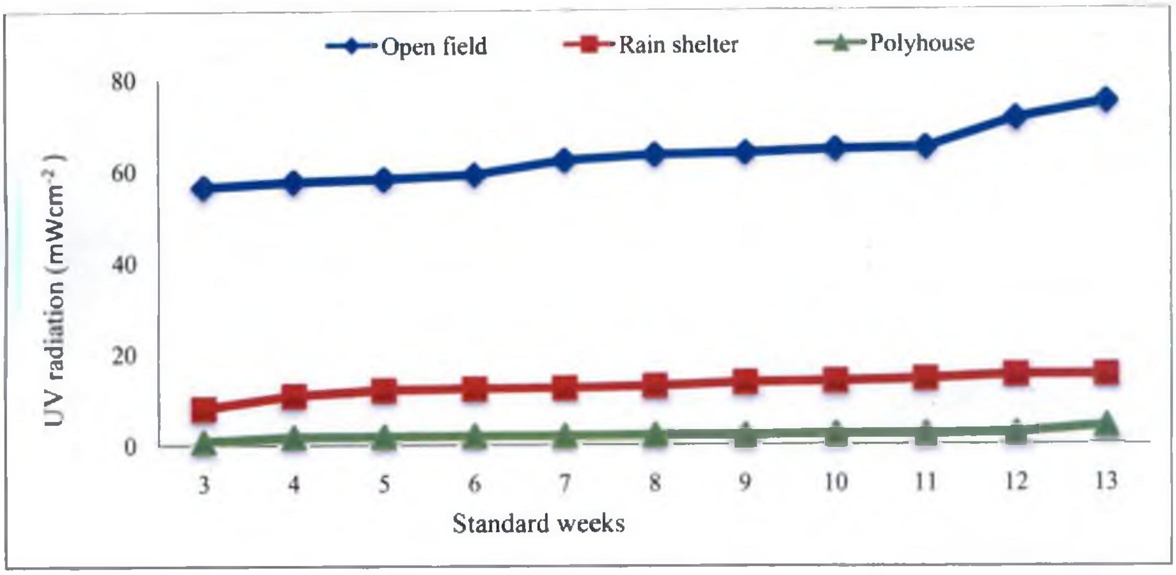

Fig .32. Weekly variation of UV radiation during winter season

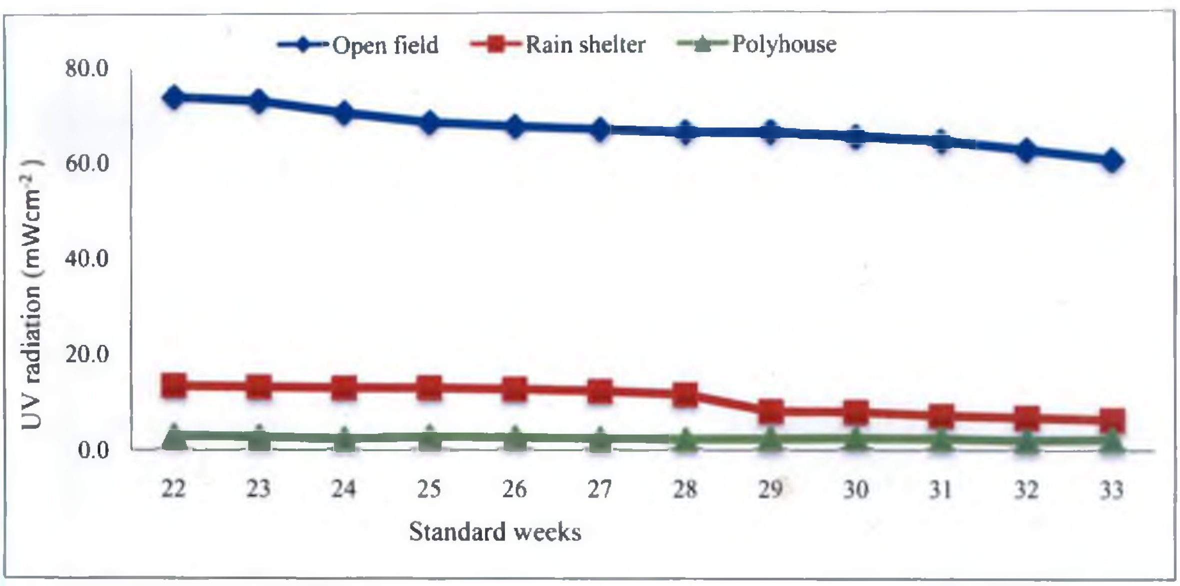

Fig .33. Weekly variation of UV radiation during rainy season

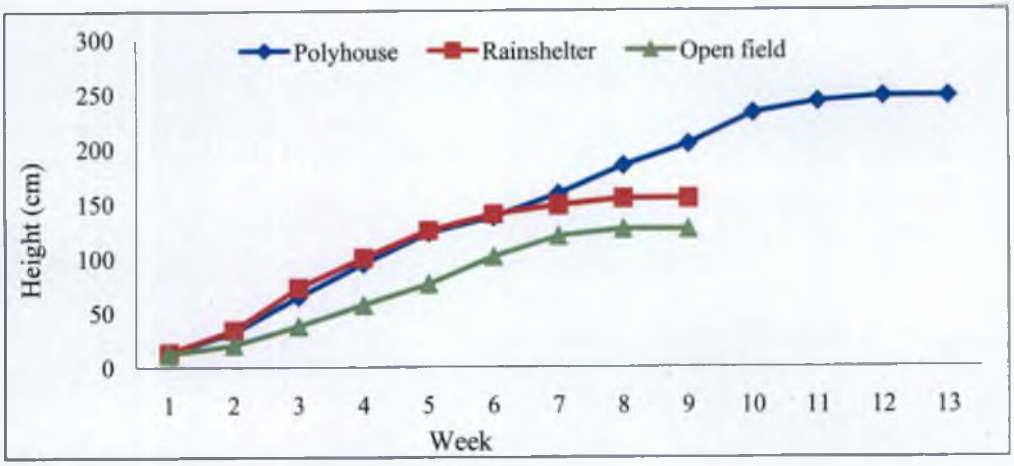

Fig 34.Weekly variation in plant height, Date of transplanting 15 January 2015

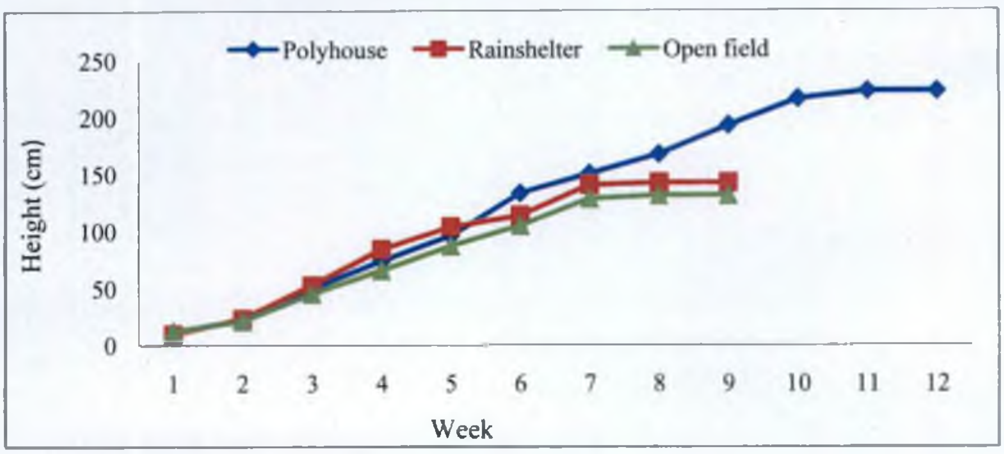

Fig 35.Weekly variation in plant height, Date of transplanting 25 January 2015

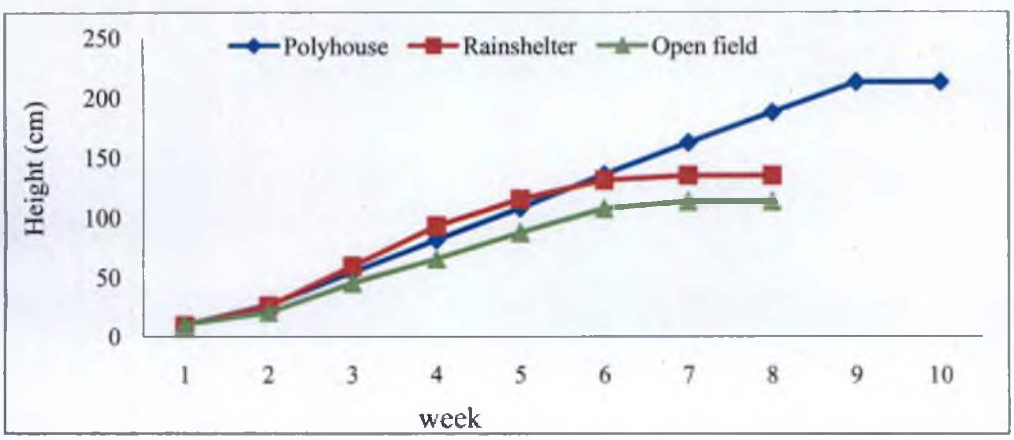

Fig 36.Weekly variation in plant height, Date of transplanting 05 February 2015

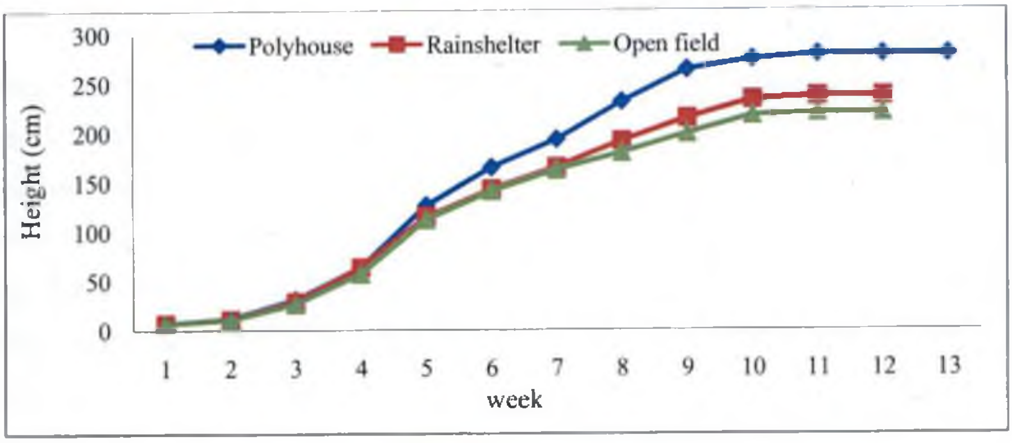

Fig 37.Weekly variation in plant height, Date of transplanting 01 June 2015

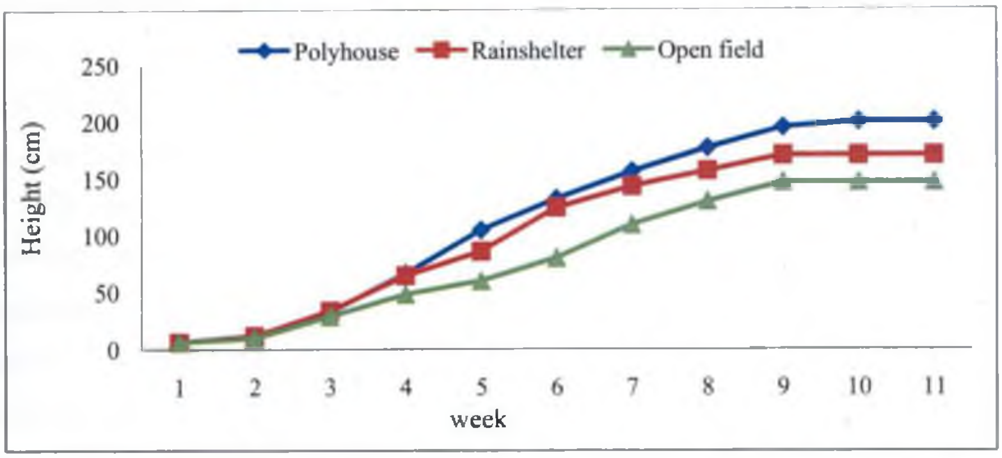

Fig 38.Weekly variation in plant height, Date of transplanting 10 June 2015

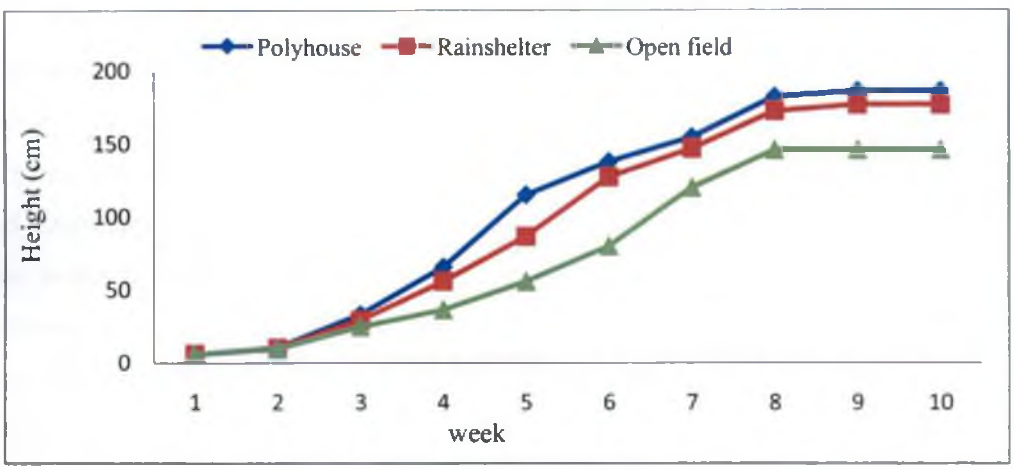

Fig 39.Weekly variation in plant height, Date of transplanting 20 June 2015

High CO_2 was recorded in early morning and it leads to high utilization of solar radiation and helps to increase the photosynthetic rate inside the polyhouse as compared to open field. This was concurrence with the findings of Rajasekar*et al.* (2013).In polyhouse due to closed environment air and water exchange was restricted so the relative humidity inside the polyhouse was more as compared to open field and rain shelter due to high relative humidity the evaporation from the soil also restricted it leads to high soil moisture inside the polyhouse.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 cucumber. Where CO_2,Soil moisture and relative humidityshowed a significant positive correlation with plant height. Kittas*et al.* (2006) also are in the opinion that plants grown at reduced UV level grow taller compared to those grown at high UV levels.

5.2.2. Leaf area index

The date of transplanting and the growing environment had a significant effect on the leaf area index (Fig 36 to 41). The highest LAI was recorded in the crop transplanted inside the poly house (2.72) on 25 January 2015 (2.72). The least values of maximum LAI (1.88) was observed in the crop under the open field conditions transplanted on 15 January 2015.The maximum values of LAI were obtained during the flowering and fruiting stage.

The weekly leaf area index showed a significant negative correlation with solar radiation and UV radiation during all stages whereas soil moisture, relative humidity showed a significantly positive correlation during four stages. 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 polyhousedue to lower solar radiation within the polyhouse and rain shelter. Lower solar radiations throughout the different growth stages promote leaf expansion which is needed for better light interception this was in agreement with findings of Watson (1952), Milthorpe (1959) and Cockshull (1992). And also increased intensities of UV radiation results a significant reduction in the leaf

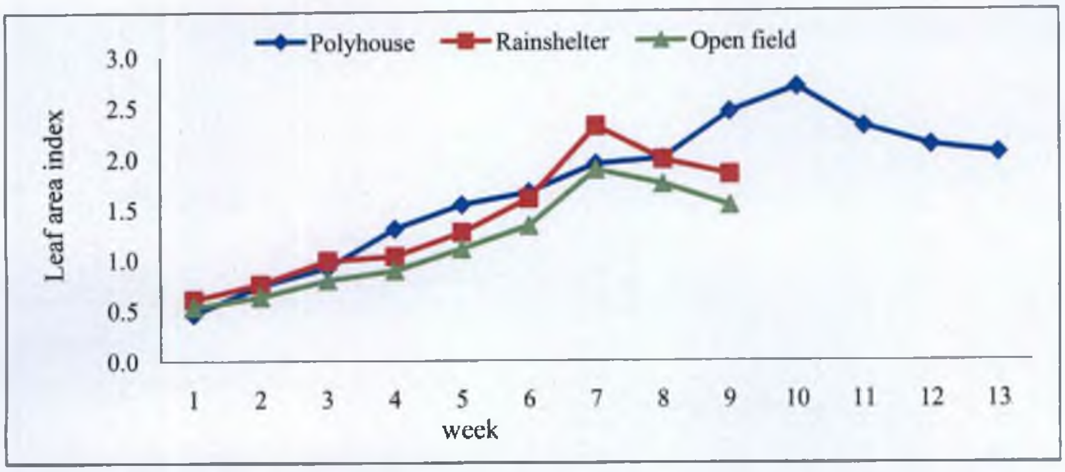

Fig 40.Weekly variation in leaf area index, Date of transplanting 15 January 2015

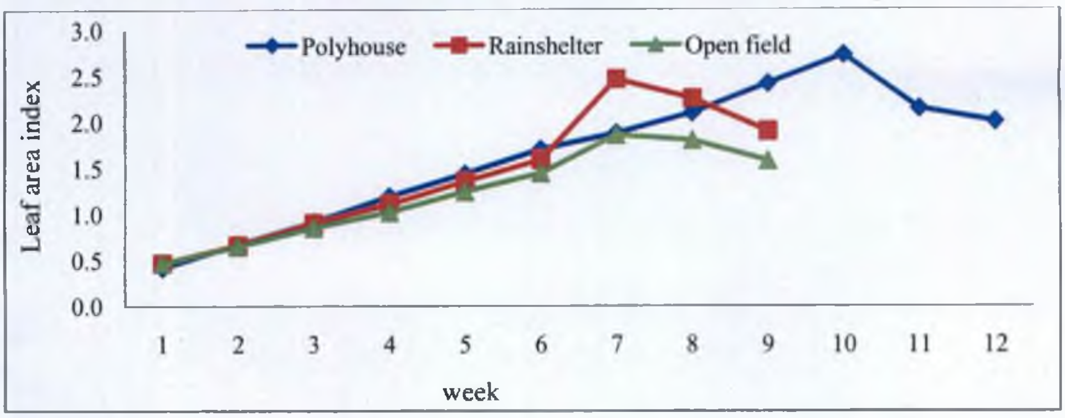

Fig 41.Weekly variation in leaf area index, Date of transplanting 25 January 2015

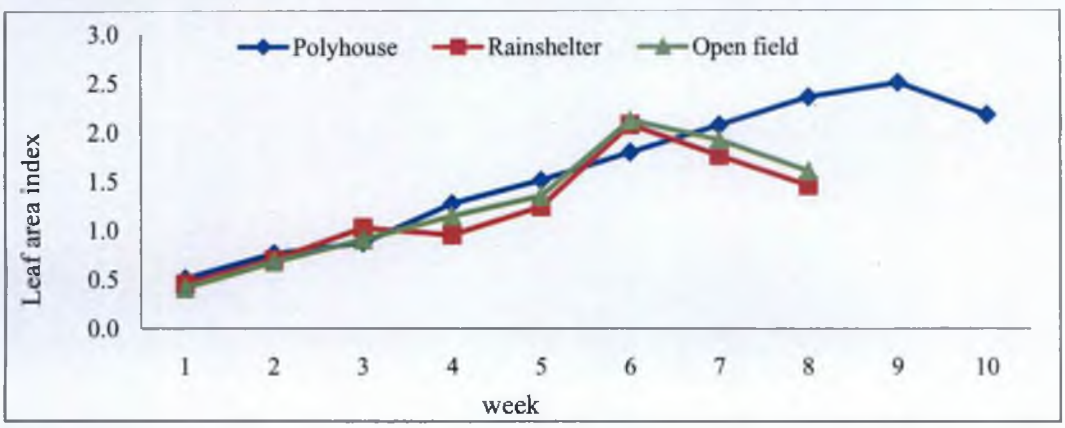

Fig 42.Weekly variation in leaf area index, Date of transplanting 05 February 2015

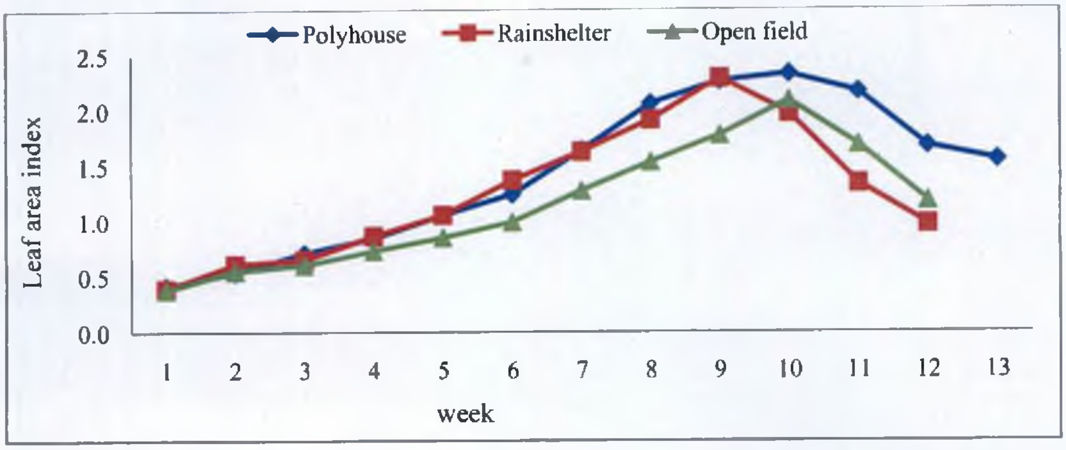

Fig 43.Weekly variation in leaf area index, Date of transplanting 01 June 2015

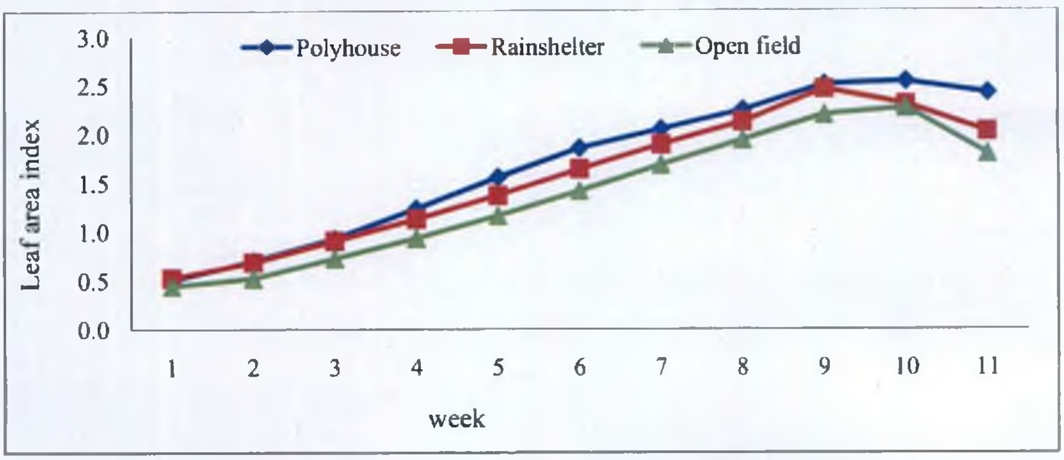

Fig 44.Weekly variation in leaf area index, Date of transplanting 10 June 2015

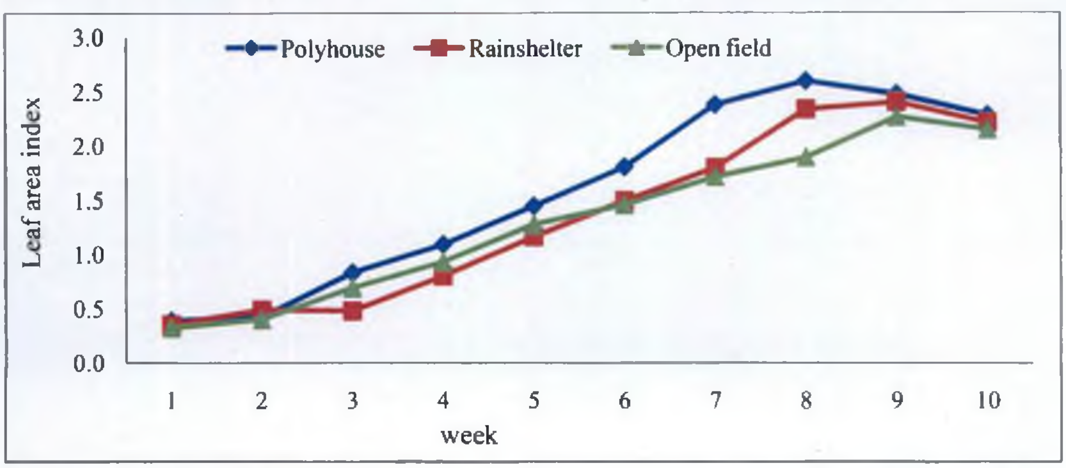

Fig 45.Weekly variation in leaf area index, Date of transplanting 20 June 2015

area and dry weight of cucumber and due to increased UVradiation, relative growth rate, net assimilation rate and leaf area ration were reduced this was in agreement with the findings of Nouchi (1993). Co_2 enrichment inside the polyhouse also contributes to higher leaf area this was in conformity with the findings of Mavrogiano*et al.* (1999).

Rate of leaf initiation and expansion of its area, and net photosynthesis rate decreased with decreasing temperature. Similar findings were reported by (Huang *et al.*, 2002; Van der Ploeg and Heuvelink, 2005).CO_2 enrichment decreases the oxygen inhibition of photosynthesis and increase the net photosynthesis in plants. This is the basis for increased leaf area caused by CO_2 this was in conformity with the findings of (Mortensen, 1987).

5.2.3. Biomass at the time of last harvest

The total biomass at time of last harvest was significantly influenced by the growing environment and dates of transplanting (Fig.42). Irrespective of the dates of transplanting the greatest biomass was recorded in the crops transplanted inside the polyhouse. Regardless of the growing environments total biomass computed at the end of crop showed a decreasing trend with the delay in transplanting. The highest biomass at the end of the crop was observed in the crop transplanted inside the polyhouse(1.4 t ha^{-1}) on 25 January 2015. The crop grown under open field condition recorded the least biomass. Maximum and minimum temperature, soil moisture and morning relative humidity showed positive correlation and PAR,UV radiation, CT,CATD and solar radiation exhibited negative correlation with biomass at the time of last harvest. Lower solar radiation within the polyhouse was the important factor that influenced greater height and LAI in the crops transplanted within the structure and this leads to the greater vegetative vigour and increased biomass production when compared to the crops in the open field. This is in confirmation with the report of Heuvelink (1989).

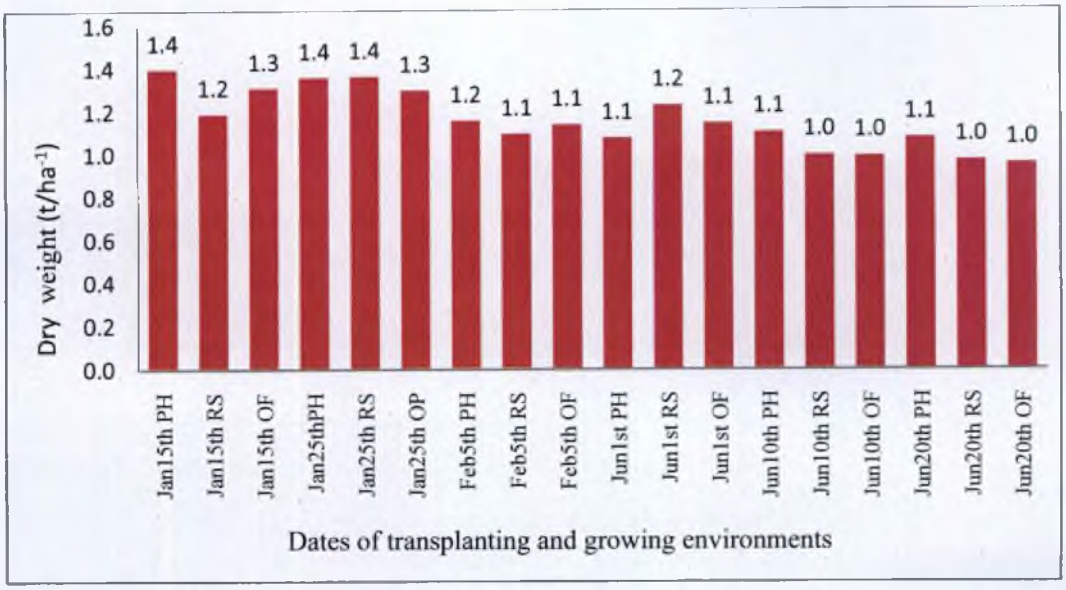

Fig 46. Biomass at the time of last harvest (t/ha^{-1})

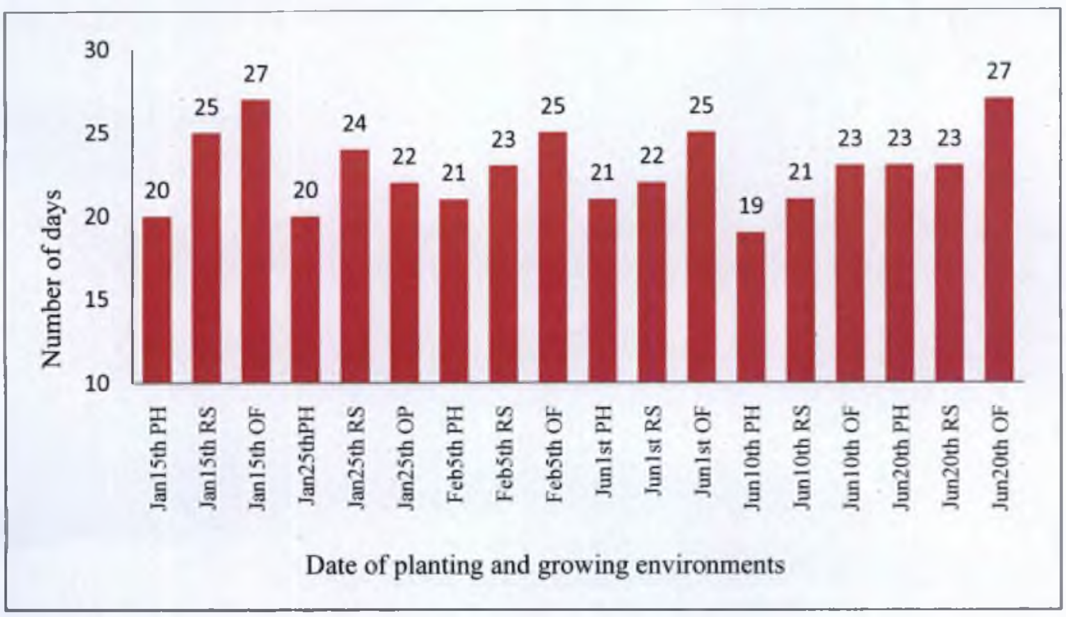

Fig 47. Number of days to first flowering

5.3. PHENOLOGICAL CHARACTERS

5.3.1. Days to first flowering

The date of transplanting and growing environment had a significant effect on the number of days taken for appearance of the first flower(Fig 43). The days to first flower was found to be highest (27 days) in the plants transplanted under open field on15 January 2015 and 20 June 2015. The crop planted inside the poly house on 10 June 2015 took the least number of days to flower (19). In all the dates of transplanting, crops inside the polyhouse condition took least number of days to first flowering.UV radiation, solar radiation and PAR showed significant negative correlation whereas maximum temperature, soil moisture, morning and evening relative humidity exhibited positive correlation with days taken to first flowering.Highest plant height and leaf area index leads to increased number of internodes and results in early flowering inside the polyhouse.Polyhouse climate influenced the crops to open flower and mature of fruits earlier than open field due to the advancement of required heat unit or thermal time of the crops grown inside the polyhouse. This was also reported by (Nagalakshmi*et al.*, 2001; Cheema *et al.*, 2004; Kang and Sidhu, 2005) (Awal and Ikeda, 2003a).

5.3.2. Days to first harvest

The dates of transplanting and growing environment had a significant effect on the days to first harvest (Fig. 44). The crop transplanted under the open field conditions on 25 January and 5 February 2015 took an extreme 39 and 40 days respectively for the first harvest while the crop planted on 25January 2015 and 10 June 2015 inside the polyhouse took least number of days (29.0). Days to first harvest had a positive correlation with temperature, soil moisture, morning and evening relative humidity and CT WhilePAR, UV radiation and maximum soil temperature had negative correlation. This was in conformity with findings of Pravej*et al.* (2010) and Bakker (1990) where experiment conducted in tomato crop reported early flowering, fruit setting and harvest under polyhouse condition when compared to open field and growth of inside plants was increased by 30 per cent and it took lesser days for the fruits to mature. Study

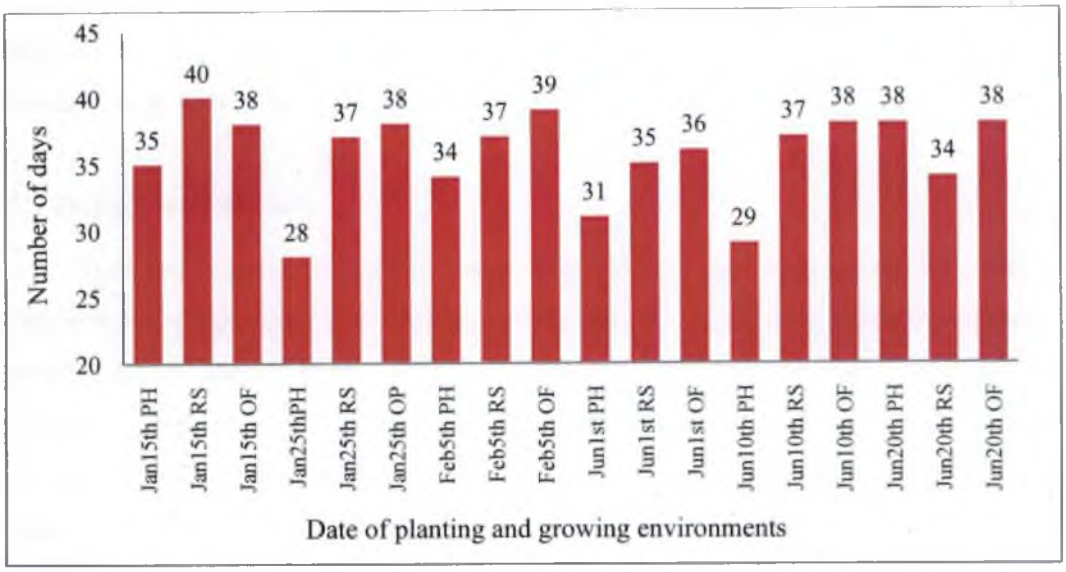

Fig 48. Number of days to first harvest

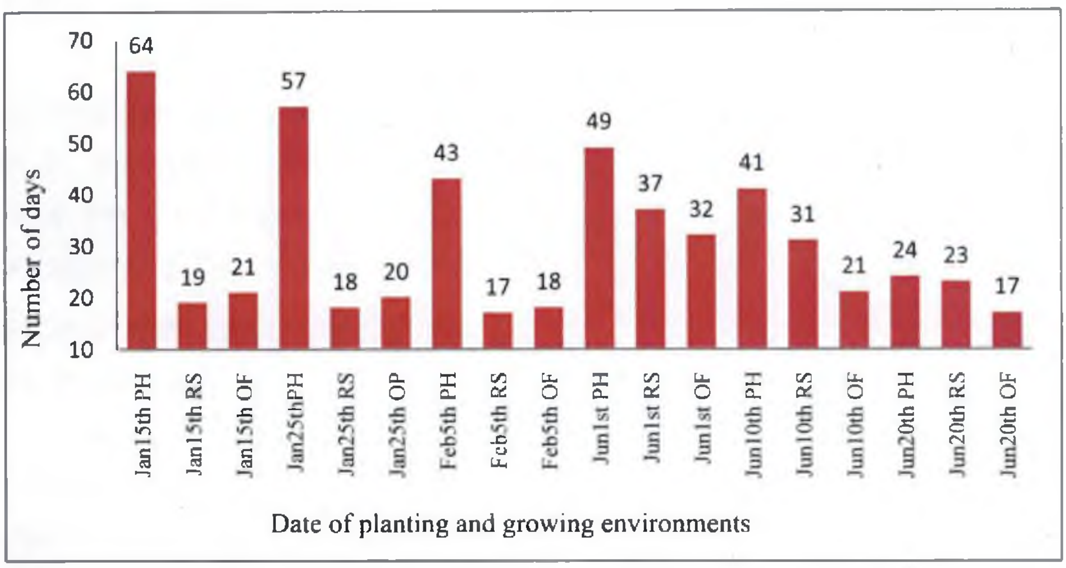

Fig 49. Number of days to last harvest

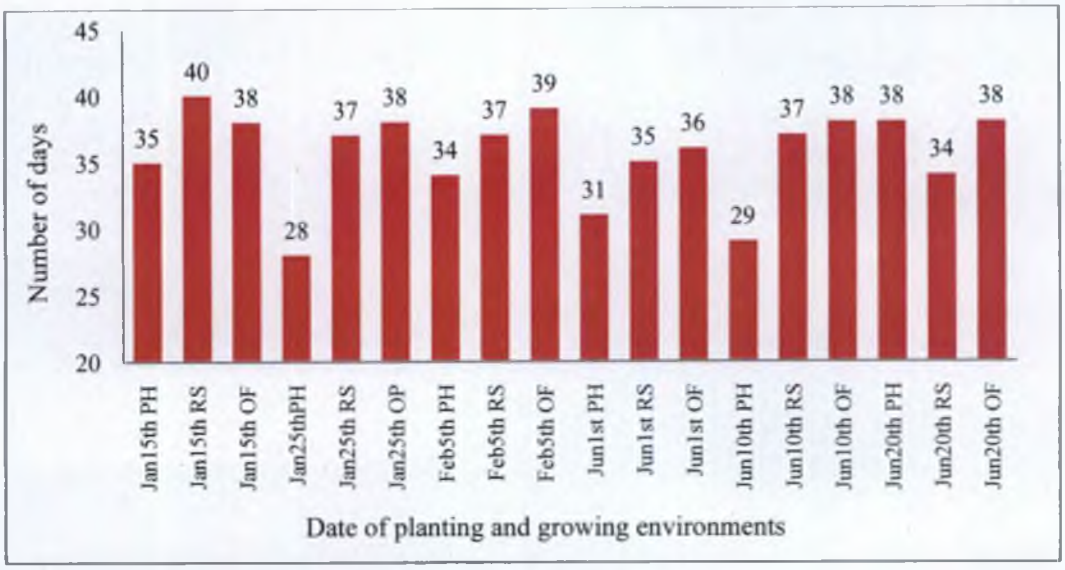

Fig 48. Number of days to first harvest

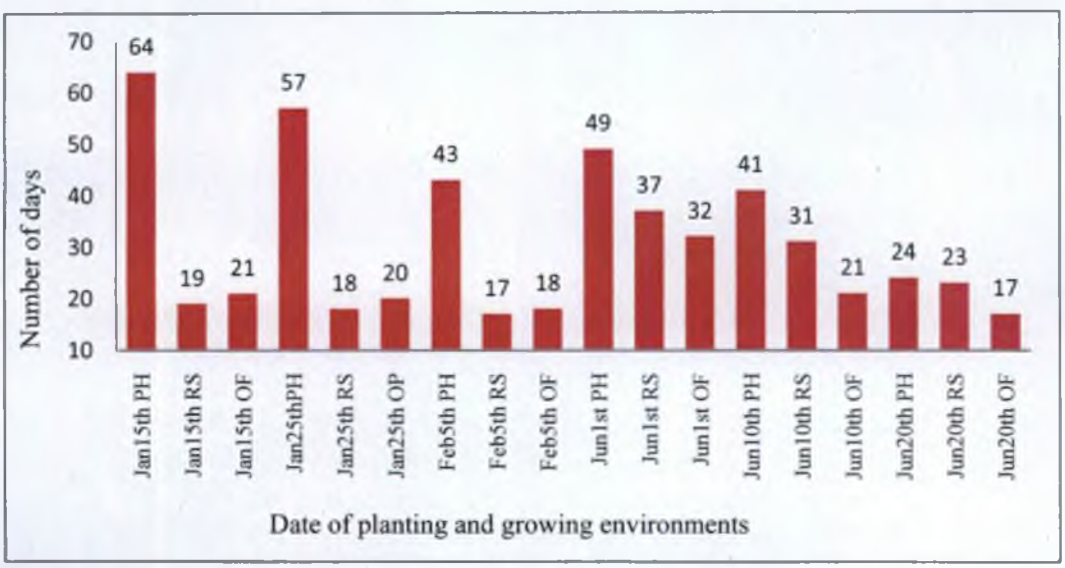

Fig 49. Number of days to last harvest

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.

5.3.3. 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 (Fig. 45). The crop transplanted inside the polyhouse on 10 January 2015 took the maximum days for the last harvest (64 days) while the crop transplanted on 5 February 2015 and 20 June 2015 in the rain shelter and open field took the least number of days for attaining the last harvest (17days).UV radiation, PAR, solar radiation and CATD showed negative correlation and maximum and minimum temperature, minimum soil temperature, soil moisture, morning and evening relative humidity and CAT showed positive correlation with days taken for last harvest.

In this study polyhouse crops took more days to last harvest when compared to crop transplanted under open field and rain shelter. This is due to high photosynthetic rate and carboxylation efficiency of the polyhouse grown crop during later stages of growth. This is also related to low light intensity and PAR in the polyhouse. This view was supported by Rajasekharanand Nandini(2014).

5.4. YIELD AND YIELD ATTRIBUTES

5.4.1. Percentage fruit set

The highest percentage fruit set was recorded inside the poly house crop (60.7) on 1 June 2015 and the least percentage fruit set was recorded under rain shelter (16.6) in first season where in second season highest percentage fruit set was recorded inside the poly house (63.2) crop followed by crop transplanted under rain shelter (33.8). Maximum and minimum air temperature, minimum soil temperature, soil moisture, maximum and minimum relative humidity showed a positive correlation where as solar radiation, CT, CATD, UV and PAR showed a negative correlation with percentage fruit set.

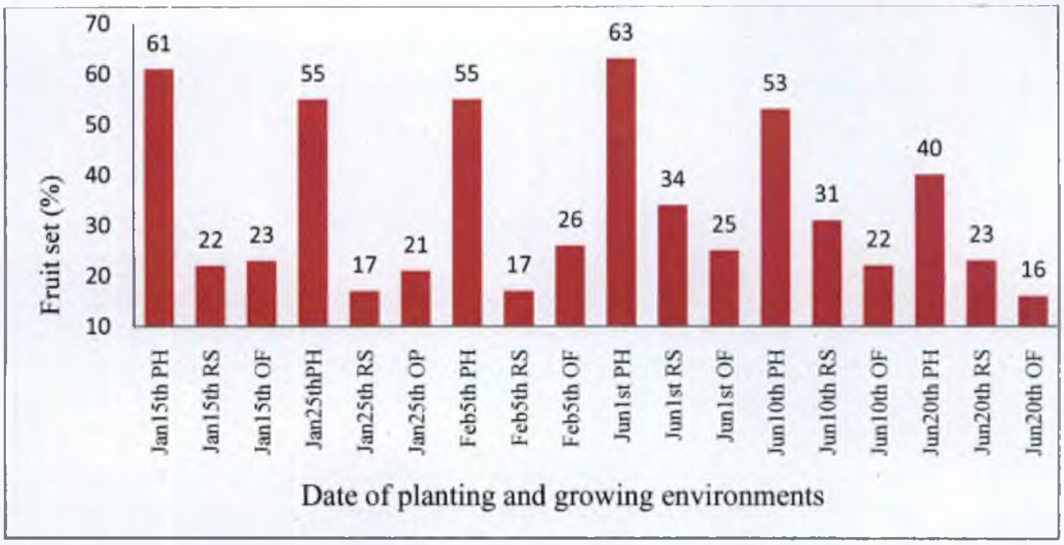

Fig.50 Percentage fruit set

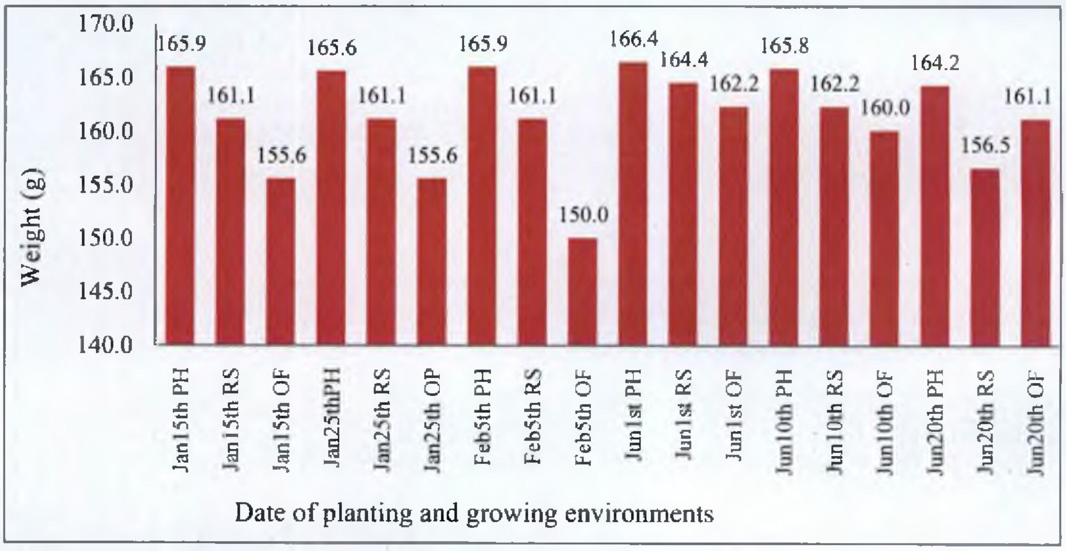

Fig 51. Average fruit weight (g)

Irrespective of the dates of transplanting the highest and lowest fruit set consistently occurred within the polyhouse and the plants in the open field respectively (Fig. 45). 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.* (2000).

5.4.2. Average fruit weight

Crop transplanted inside the poly house showed a highest average fruit weight (166.4) on 1 June 2015 where lowest average fruit weight was recorded under open field (150). In each transplanting average fruit weight of poly house crop was around 165 and the crop transplanted under rain shelter was 161 except crop transplanted on 1 June 2015 (164). Where crop under open field showed a least average fruit weight as compare to crop transplanted inside the poly house and rain shelter (Fig 46). This is due to more of assimilates produced in source region and their efficient partition to sinks, as portioning efficiency is decided by sink strength which was in conformity with the findings of Marcelis (1993). And also maximum temperature and minimum temperature were negatively correlated with average fruit weight during vegetative and fruiting stage respectively.

5.4.3. Fruit yield per plant

The dates of transplanting and growing environments had a significant effect on the fruit yield obtained from a single plant (Fig.47). Highest fruit yield per plant was recorded inside the poly house crop (6.60) on 1 June 2015.Whereas crop transplanted under rain shelter and open field recorded same yield (0.43 and 0.37) on 5 January 2015 and 25 June 2015 respectively. Maximum and minimum temperature, maximum and minimum relative humidity, soil moisture showed positive correlation and UV radiation, PAR and solar radiation showed negative correlation.

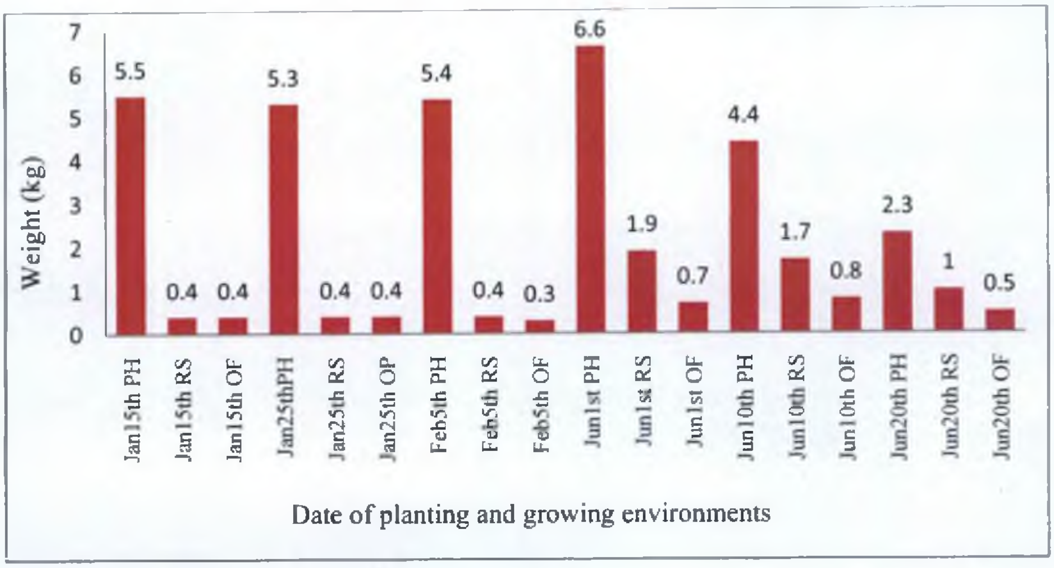

Fig 52. Fruit yield per plant (kg)

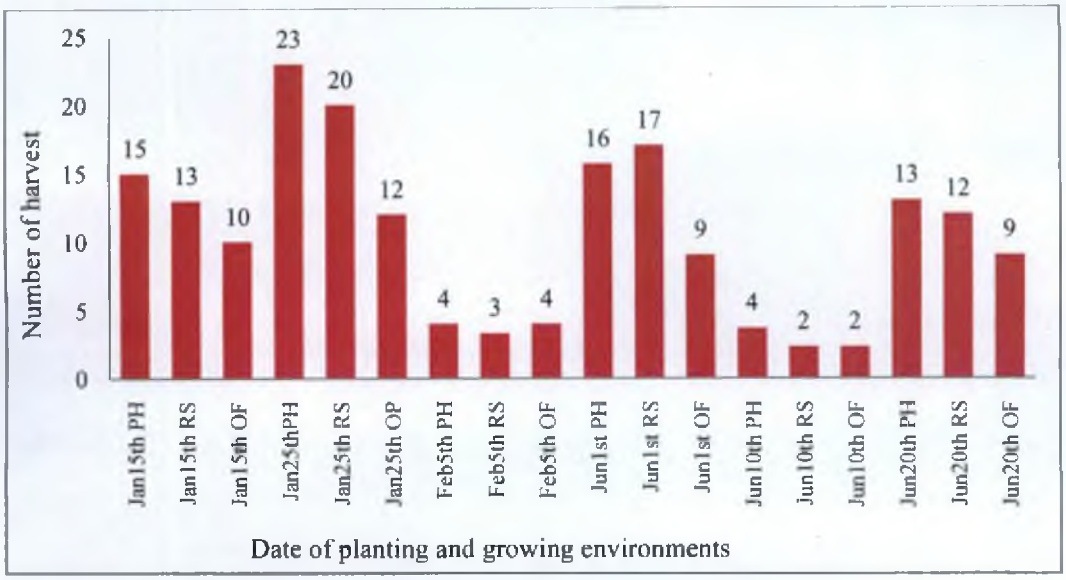

Fig 53.Number of harvest

Irrespective of date of transplanting highest fruit yield per plant was recorded inside the polyhouse as compared to open field and rain shelter. This is due to more number of internodes and there by more number of flowers per axil of polyhouse. This is also being associated with high leaf area index and plant height observed in polyhouse. This results were concurrence with the findings of Kanthaswamy*et al.* (2000),Gaikwad and Dumbre (2001),Nagalakshmi*et al.* (2001) Srivastava *et al.* (2002), Ganesan, (2002a, b, c), Mishra *et al.* (2003) and Kang and Sidhu (2005).The reduction in per plant yield under open field and rain shelter is associated with less vegetative growth and lesser canopy area. This result was in accordance with the findings of Rajasekharan (2014).

5.4.3. Number of harvest

The number of harvest was found to be higher and statistically significant for the crop transplanted inside the poly house and crop transplanted under open field took least number of harvests (Fig. 48). PAR, UV radiation, CATD, solar radiation and maximum soil temperature showed negative correlation with number of harvest.Where relative humidity, soil moisture and minimum soil temperature exhibited positive correlation with number of harvest. This is due to high photosynthetic rate and carboxylation efficiency of the polyhouse grown crop during later stages of growth. This is also related to low light intensity and PAR in the polyhouse. This view was supported by Rajasekharan and Nandini (2014) andVezhavendan (2003).Early maturity is one of the important aspects for harvesting of fruit earlier. Total fruit bearing period was also prolonged under polyhouse. For that reason total number of fruit harvests was more in polyhouse than open field. Similar result was reported by (Pandey *et al.*, 2005).

5.4.4.Crop duration

The duration of the crop found to be significantly influenced by the growing environments and dates of transplanting.Where in each transplanting poly house crop recorded highest days to complete the crop cycle as compare to crop transplanted under rain shelter and open field (Fig.49). The duration of the crop showed a significant positive correlation with soil moisture, relative humidity and CT and it was negatively

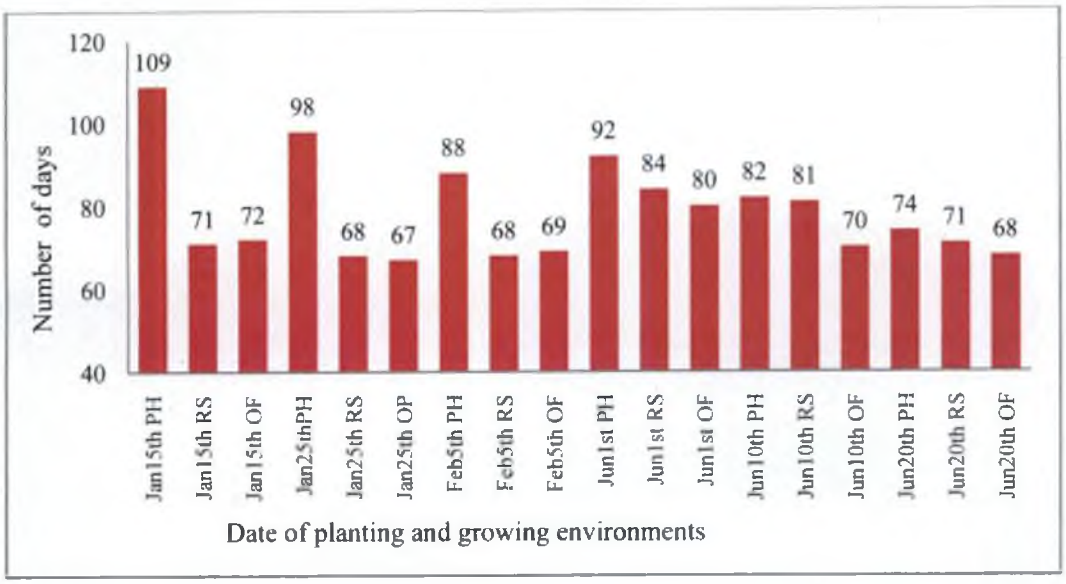

Fig 54. Duartion of the crop

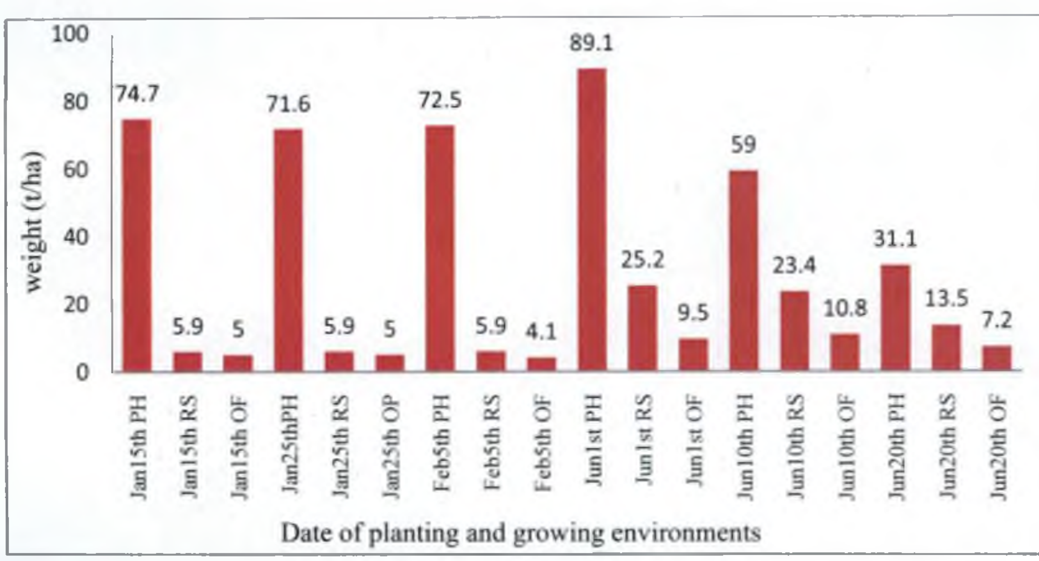

Fig 55.Total yield (t ha^{-1})

correlated with solar radiation, CATD, UV and PAR. Due to cucumber crop bears equal distribution of fruits all along the stem *i.e.*, at each node, hence every leaf in a node supplies photo assimilates to fruits. This demands optimum PAR and light supply at each layer of leaves. In tomato it was reported that poly house plants prolong duration of fruit harvest by about nine days (Parvej*et al.*, 2010).

5.4.5.Total yield

The total yield in tons per hectare was found to be significantly influenced by the date of transplanting and the growing environment. The maximum yield of 89.10 tons/hectare was obtained from the crop transplanted inside the polyhouse on 1June 2015. The yields from the crop transplanted under the rain shelter on 10 and 20 January 2015 and 5 February 2015 were statistically similar. Regardless of the dates of transplanting the yields from the crop inside the polyhouse were consistently highest followed by the crop inside the rain shelter and open field (Fig.50). This is due to more vegetative growth, leaf area index, number of nodes and diffused light at the time of flowering and fruit development. Higher number of fruits per plant and fruit weight also contributes to more yield per plant. More number of fruits per plant and fruit yield per plant ultimately contributed to more fruit yield per hectare in cucumber. Similar findings were also reported by Anjanappa*et al.* (2012), Pant *et al.* (2001), and Mohomedin*et al.* (1991). Lawlor (1995) reported that crop yield is more related to leaf area and photo assimilates distribution than photosynthesis. Solar radiation, UV radiation and PAR showed negative correlation with total yield.

5.4.6.Marketable yield

The dates of transplanting and growing environments had a significant effect on marketable yield of cucumber. Highest marketable yield was recorded inside the poly house crop (96.2%) on 10 June 2015 and the lowest marketable yield was recorded under open field condition (31.3%) on 20 June 2015 (Fig. 51).This is due to the absence of uniform size may be associated with poor assimilate partitioning under open field grown crop. This was in conformity with the findings of Drews (1980), Sood and Sharma (2006) and Singh *et al.* (2012).

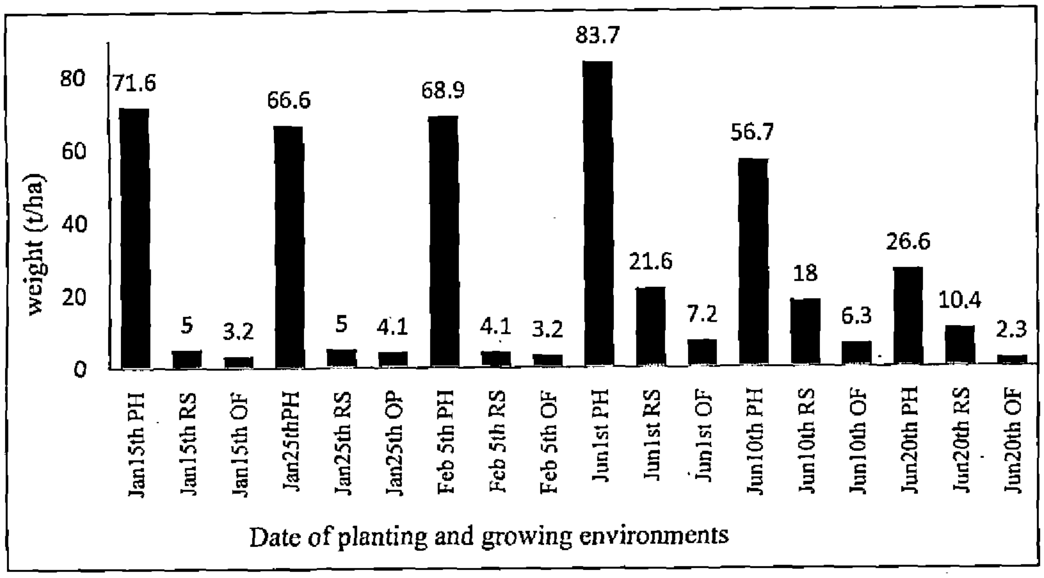

Fig 56.Marketable yield (t ha^{-1})

Summary

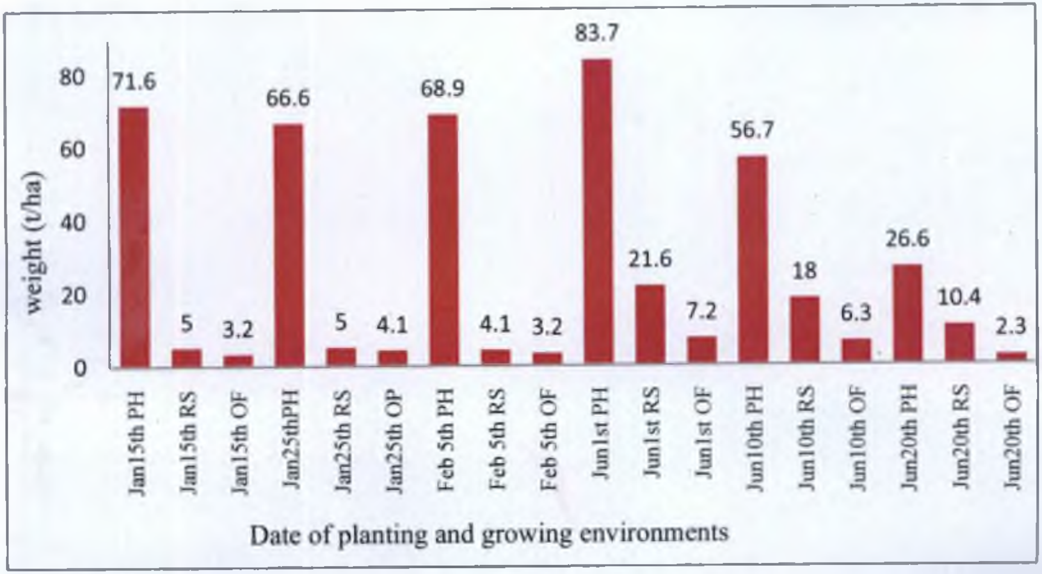

Fig 56.Marketable yield (t ha^{-1})

Summary

6. SUMMARY

An experiment was conducted at the Agricultural research station, Mannuthy during 2014-2015 to study the effect of growing environment and microclimate on cucumber. 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.

The salient findings are summarized as follows:

i. The date of transplanting and growing environment had a significant effect on the morphological, phenological and yield parameters of cucumber.

ii. The highest and lowest plant height was obtained for the crop planted inside the polyhouse (291 cm) and open field (105 cm) respectively.

iii. Maximum LAI was recorded in the crop transplanted inside the polyhouse on 1 June 2015 and on 10 January 2015 (2.82) and the least values of maximum LAI (1.66) was observed in the crop under the open field conditions transplanted on 20 January 2015.

iv. The highest biomass at the end of the crop was observed in the crop transplanted inside the polyhouse (1.4 t ha^{-1}) on 25 January 2015.

v. Polyhouse crops took longest duration of 109 days.

vi. Total yield was highest in the crops transplanted inside the polyhouse (89.1 t ha^{-1}).

vii. Average fruit weight, percentage fruit set and fruit yield per plant was also more in polyhouse as compared to rain shelter and open field.

viii. Phenological observations i.e. polyhouse crops took least days to first flowering (19 days) and first harvest (29days).

ix. Carbon dioxide concentration is more inside the poly house as compared to open field and peak value recorded in the morning hours at 6:00 am whereas the least values of CO_2 was recorded around 15:00 and 14:00 hours respectively.

x. Diurnal variation of temperature, relative humidity and soil temperature was same in three growing environments upto 9 am.

xi. PAR recorded inside the polyhouse was 100 to 700 umolm^{-2}s^{-1} compared to rain shelter (200 to 900 umolm^{-2}s^{-1}) and open field (300 to 1300 umolm^{-2}s^{-1}).

xii. The lowest canopy temperature and CATD was recorded inside the polyhouse

xiii. Higher solar radiation, PAR and UV radiation showed significant negative correlation with crop growth, yield and yield attributing characters.

The protected structure helps to attain maximum yield per unit area as well as maximum quality. The polyhouse structure will cause a change in climatic conditions as compared to open field where inside the polyhouse radiation and air velocity are reduced, temperature and water vapour pressure increased and fluctuations in carbon dioxide concentration are much higher. Each of these changes will cause impact on the crop growth and production. Rain shelter is also one of the protected structure used for the crop production. It mainly protects the crops from rain and the side of the rain shelter was open and allows natural ventilation. But the yield obtained from polyhouse and rain shelter has wide difference. Even though it protects the crops from rain and it also reduces direct solar radiation, UV radiation the yield was less as compared to polyhouse. So the microclimate modifications inside the polyhouse have significant effect on crop yield and quality. Where polyhouse structure favors the morphological, phenological and yield characters of the crop.

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Appendices

Appendix 1

Abbreviations and units used

CATD	- Canopy Air Temperature Difference
CD	- Critical Difference
CT	- Canopy Temperature
KAU	- Kerala Agricultural University
LAI	- Leaf area index
OF	- Open field
PAR	- Photosynthetically Active Radiation
PH	- Polyhouse
RH-I	- Maximum Relative humidity
RH-II	- Minimum Relative humidity
RS	- Rain shelter
SM	- Soil moisture
SR	- Solar radiation
STmax	- Maximum soil temperature
STmin	- Minimum soil temperature
Tmax	- Maximum temperature
Tmin	- Minimum temperature
°C	- Degree Celsius
%	- Per cent
nm	- Nano meter
cm	- Centimetre
cm^2	- Square centimetres
$\mu mol m^{-2} S^{-1}$	- micro mol per meter square per second
Fig.	- Figure

Appendix II

ANOVA of different plant growth characters of 2015 experiment

Plant height at different weeks after planting

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.391	0.196	-	-
Main	2	1.571	0.786	0.696	0.550
Error (a)	4	4.514	1.129	-	-
Sub	5	388.675	77.735	140.138	0.000
Main x Sub	10	11.277	1.128	2.033	0.065
Error (b)	30	16.641	0.555	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	21.539	10.770	-	-
Main	2	185.378	92.689	6.484	0.056
Error (a)	4	57.182	14.295	-	-
Sub	5	3023.128	604.626	36.816	0.000
Main x Sub	10	216.806	21.681	1.320	0.265
Error (b)	30	492.692	16.423	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	41.593	20.796	-	-
Main	2	1341.148	670.574	11.935	0.021
Error (a)	4	224.741	56.185	-	-
Sub	5	8080.148	1616.030	50.518	0.000
Main x Sub	10	1230.185	123.019	3.846	0.002
Error (b)	30	959.667	31.989	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	49.593	24.796	-	-
Main	2	5161.815	2580.907	30.597	0.004
Error (a)	4	337.407	84.352	-	-
Sub	5	7023.481	1404.696	24.030	0.000
Main x Sub	10	1801.519	180.152	3.082	0.008
Error (b)	30	1753.667	58.456	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	107.111	53.556	-	-
Main	2	10209.778	5104.889	34.938	0.003
Error (a)	4	584.444	146.111	-	-
Sub	5	8002.611	1600.522	27.504	0.000
Main x Sub	10	4043.111	404.311	6.948	0.000
Error (b)	30	1745.778	58.193	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	81.926	40.963	-	-
Main	2	13250.037	6625.019	33.293	0.003
Error (a)	4	795.963	198.991	-	-
Sub	5	8277.481	1655.496	47.086	0.000
Main x Sub	10	3086.407	308.641	8.778	0.000
Error (b)	30	1054.778	35.159	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	133.778	66.889	-	-
Main	2	10958.111	5479.056	28.669	0.004
Error (a)	4	764.444	191.111	-	-
Sub	5	8195.056	1639.011	30.697	0.000
Main x Sub	10	1402.333	140.233	2.626	0.020
Error (b)	30	1601.778	53.393	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	254.333	127.167	-	-
Main	2	13964.778	6982.389	31.245	0.004
Error (a)	4	893.889	223.472	-	-
Sub	5	12711.333	2542.267	30.453	0.000
Main x Sub	10	1710.556	171.056	2.049	0.063
Error (b)	30	2504.444	83.481	-	-
Total	53	-	-	-	-

Leaf area index at different weeks after planting

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.007	0.003	-	-
Main	2	0.015	0.008	2.715	0.180
Error (a)	4	0.011	0.003	-	-
Sub	5	0.175	0.035	13.859	0.000
Main x Sub	10	0.054	0.005	2.161	0.050
Error (b)	30	0.076	0.003	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.015	0.007	-	-
Main	2	0.066	0.033	6.146	0.060
Error (a)	4	0.021	0.005	-	-
Sub	5	0.466	0.093	19.368	0.000
Main x Sub	10	0.055	0.005	1.133	0.371
Error (b)	30	0.144	0.005	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.028	0.014	-	-
Main	2	0.091	0.045	6.049	0.062
Error (a)	4	0.030	0.007	-	-
Sub	5	0.667	0.133	41.290	0.000
Main x Sub	10	0.284	0.028	8.781	0.000
Error (b)	30	0.097	0.003	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.020	0.010	-	-
Main	2	0.465	0.232	51.968	0.001
Error (a)	4	0.018	0.004	-	-
Sub	5	0.670	0.134	13.777	0.000
Main x Sub	10	0.293	0.029	3.013	0.009
Error (b)	30	0.292	0.010	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.006	0.003	-	-
Main	2	0.636	0.318	33.183	0.003
Error (a)	4	0.038	0.010	-	-
Sub	5	0.943	0.189	14.084	0.000
Main x Sub	10	0.257	0.026	1.915	0.083
Error (b)	30	0.402	0.013	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.017	0.008	-	-
Main	2	0.819	0.410	28.336	0.004
Error (a)	4	0.058	0.014	-	-
Sub	5	1.196	0.239	12.819	0.000
Main x Sub	10	0.363	0.036	1.946	0.078
Error (b)	30	0.560	0.019	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.071	0.036	-	-
Main	2	1.254	0.627	65.570	0.001
Error (a)	4	0.038	0.010	-	-
Sub	5	1.175	0.235	14.330	0.000
Main x Sub	10	0.585	0.058	3.567	0.003
Error (b)	30	0.492	0.016	-	-
Total	53	-	-	-	-

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.256	0.128	-	-
Main	2	1.422	0.711	54.674	0.001
Error (a)	4	0.052	0.013	-	-
Sub	5	1.255	0.251	8.471	0.000
Main x Sub	10	0.497	0.050	1.677	0.133
Error (b)	30	0.889	0.030	-	-
Total	53	-	-	-	-

Analysis of Percentage fruit setting

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	28.566	14.283	-	-
Main	2	11935.319	5967.660	927.717	0.000
Error (a)	4	25.731	6.433	-	-
Sub	5	1018.318	203.664	20.316	0.000
Main x Sub	10	882.408	88.241	8.802	0.000
Error (b)	30	300.737	10.025	-	-
Total	53	-	-	-	-

Analysis of fruit yield per plant

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.704	0.352	-	-
Main	2	210.063	105.031	726.209	0.000
Error (a)	4	0.579	0.145	-	-
Sub	5	14.676	2.935	26.278	0.000
Main x Sub	10	24.831	2.483	22.229	0.000
Error (b)	30	3.351	0.112	-	-
Total	53	-	-	-	-

Analysis of fruits per plant

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	23.815	11.907	-	-
Main	2	7555.593	3777.796	787.649	0.000
Error (a)	4	19.185	4.796	-	-
Sub	5	519.259	103.852	27.250	0.000
Main x Sub	10	901.741	90.174	23.661	0.000
Error (b)	30	114.333	3.811	-	-
Total	53	-	-	-	-

Analysis of number of harvest

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.704	0.352	-	-
Main	2	713.481	356.741	1328.552	0.000
Error (a)	4	1.074	0.269	-	-
Sub	5	1187.870	237.574	2004.531	0.000
Main x Sub	10	118.741	11.874	100.187	0.000
Error (b)	30	3.556	0.119	-	-
Total	53	-	-	-	-

Analysis of average fruit weight

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	47.267	23.633	-	-
Main	2	612.456	306.228	8.054	0.040
Error (a)	4	152.087	38.022	-	-
Sub	5	155.739	31.148	0.854	0.523
Main x Sub	10	268.319	26.832	0.736	0.685
Error (b)	30	1093.547	36.452	-	-
Total	53	-	-	-	-

Analysis of duration

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	3.000	1.500	-	-
Main	2	3990.778	1995.389	3591.700	0.000
Error (a)	4	2.222	0.556	-	-
Sub	5	1326.889	265.378	220.468	0.000
Main x Sub	10	1984.333	198.433	164.852	0.000
Error (b)	30	36.111	1.204	-	-
Total	53	-	-	-	-

Analysis of total yield

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	128.250	64.125	-	-
Main	2	38283.908	19141.954	726.209	0.000
Error (a)	4	105.435	26.359	-	-
Sub	5	2674.789	534.958	26.278	0.000
Main x Sub	10	4525.402	452.540	22.229	0.000
Error (b)	30	610.740	20.358	-	-
Total	53	-	-	-	-

Analysis of marketable yield

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	117.720	58.860	-	-
Main	2	36327.960	18163.980	642.234	0.000
Error (a)	4	113.130	28.282	-	-
Sub	5	2716.200	543.240	26.667	0.000
Main x Sub	10	3907.980	390.798	19.184	0.000
Error (b)	30	611.145	20.371	-	-
Total	53	-	-	-	-

Analysis of biomass at the time of last harvest

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.009	0.005	-	-
Main	2	0.852	0.426	51.506	0.001
Error (a)	4	0.033	0.008	-	-
Sub	5	0.089	0.018	1.406	0.250
Main x Sub	10	0.092	0.009	0.724	0.696
Error (b)	30	0.380	0.013	-	-
Total	53	-	-	-	-

Analysis of first flowering

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	0.037	0.019	-	-
Main	2	161.370	80.685	4357.000	0.000
Error (a)	4	0.074	0.019	-	-
Sub	5	67.259	13.452	726.400	0.000
Main x Sub	10	54.852	5.485	296.200	0.000
Error (b)	30	0.556	0.019	-	-
Total	53	-	-	-	-

Analysis of First harvest

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	4.593	2.296	-	-
Main	2	350.037	175.019	945.100	0.000
Error (a)	4	0.741	0.185	-	-
Sub	5	101.204	20.241	23.969	0.000
Main x Sub	10	133.963	13.396	15.864	0.000
Error (b)	30	25.333	0.844	-	-
Total	53	-	-	-	-

Analysis of last harvest

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F cal	F prob
Replications	2	1.333	0.667	-	-
Main	2	6691.000	3345.500	1180.765	0.000
Error (a)	4	11.333	2.833	-	-
Sub	5	1810.000	362.000	465.429	0.000
Main x Sub	10	2527.000	252.700	324.900	0.000
Error (b)	30	23.333	0.778	-	-
Total	53	-	-	-	-

EFFECT OF GROWING ENVIRONMENT AND MICROCLIMATE ON PARTHENOCARPIC CUCUMBER

By

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ABSTRACT OF THE THESIS

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Abstract

An investigation was carried out in Department of Agricultural Meteorology, College of Horticulture, Vellanikkara during 2015-16 to determine the the effect of growing environments and microclimate on growth and yield of cucumber and crop weather relationships in cucumber under different growing environment. The study was conducted in polyhouse, rain shelter and open field simultaneously at Agricultural Research Station, Mannuthy in a split plot design with 3 replications with six dates of planting i.e., 15 January, 25 January, 5 February, 1 June, 10 June and 20 June 2015.

The observations on morphological, phenological and yield attributes like plant height, leaf area index, biomass at the time of last harvest, days to first flowering and harvest, days to last harvest, percentage fruit setting, fruit yield per plant, average fruit weight, total yield, number of harvest and crop duration were recorded at different stages of development of the crop. The weather parameters like temperature, relative humidity, solar radiation, soil temperature and soil moisture were recorded using automatic weather station installed inside each growing environment. The UV radiation and carbon dioxide concentration were recorded using the UV biometer and CO_2 meter respectively. Canopy temperature and Canopy Air Temperature Difference (CATD) was recorded using infrared thermometer. PAR was recorded using digital plant canopy imager.

The date of transplanting and growing environment had a significant effect on the morphological, phenological and yield parameters of cucumber. The highest and lowest plant height was obtained for the crop planted inside the polyhouse and open field respectively. Maximum LAI was recorded in the crop transplanted inside the polyhouse on 1 June 2015 and on 10 January 2015 and the least values of maximum LAI was observed in the crop under the open field conditions transplanted on 20 January 2015.The highest biomass at the end of the crop was observed in the crop transplanted inside the polyhouse on 25 January 2015. Polyhouse crops took least days to first flowering and first harvest. Total yield was highest in the crops transplanted

inside the polyhouse and average fruit weight, percentage fruit set and fruit yield per plant was also more in polyhouse as compared to rain shelter and open field.

To determine the critical weather elements affecting the crop growth, correlation analysis was done and it was observed that higher solar radiation, PAR and UV radiation showed significant negative correlation with crop growth, yield and yield attributing characters. Carbon dioxide concentration in the morning time (6 AM) is more inside the poly house as compared to open field and rain shelter. Multiple linear regression models were fitted, to predict the duration of crop, days to first flowering, days to last harvest, leaf area index and total yield based on weather variables.

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 resulted in high yield in cucumber.

So within a polyhouse, 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.