CROP WEATHER RELATIONSHIPS IN CAULIFLOWER (*Brassica oleracea* var. *botrytis* L.)

By

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(2010-11-124)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

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2012

DECLARATION

I, **Karthika V. P.** (2010-11-124) hereby declare that this thesis entitled **"Crop weather relationships in cauliflower (*Brassica oleracea* var. *botrytis* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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25/08/2012

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Dedicated to

My Parents and Sisters

ACKNOWLEDGEMENT

Here comes the end of the long journey of M.Sc. research which taught me the lessons of scientific experimentation and moulded me in a way to face and overcome all sorts of difficulties by giving lots of experiences and responsibilities. At this point, I have to remember all those helping-hands behind this task with a great sense of gratitude.

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

*My gratefulness and personal obligation go without any reservation to **Dr. B. Ajithkumar**, Member of my advisory committee and Assistant Professor and Head of the Department of Agricultural Meteorology, for his constant encouragement, creative ideas, extreme patience and expert guidance. I am greatly indebted to him for the immense help extended for the completion of my research programme.*

*I feel great pleasure to express my indebtedness to **Dr. T. Pradeepkumar**, Member of my advisory committee and Associate Professor of the Department of Olericulture, for the valuable advices, ever-willing help and encouragement during my field study and for the relevant suggestions during the preparation of the manuscript.*

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

*I am obliged to **Ms. P. Lincy Davis**, Assistant Professor of the Department of Agricultural Meteorology, for the sustained interest, constant support and timely help extended throughout the course of investigation.*

*I wish to express my heartfelt gratitude to **Dr. George** and **Dr. Sallykutty** of Department of Olericulture and **Dr. Aravindhakshan** and **Dr. Anitha** of Central Nursery for providing me all necessary facilities during the field work.*

*I sincerely express my obligations to **Dr. Jim, Dr. Shoshamma** of Department of Entomology, **Dr. Sally K. Mathew** and **Dr. Beena** of Department of Plant Pathology and **Dr. Prameela** of Department of Agronomy for their timely help and valuable advices at crucial stages of my study.*

*My heartfelt thanks are due to **Dr. Dijee Bastian**, PG Academic Officer, for all sorts of helps rendered throughout the course of study.*

*The helps received from **Mr. Manikantan N.** of Central Research Institute for Dryland Agriculture and **Dr. Mohammed Shamim** of Cropping Systems Resource Management, Modipuram are specially acknowledged.*

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

*With all regards, I acknowledge the whole-hearted co-operation and gracious help rendered by each and every member of the **College of Horticulture** during the period of study.*

I sincerely thank the facilities rendered by the College Library, Computer Club and Central Library.

*I am obliged to **Kerala Agricultural University** for granting me the Junior Research Fellowship.*

*I take this opportunity to thank **Mr. Gangadharan** and **Ms. Leelamani** of my Department for the unconditional help and co-operation provided by them in these two years.*

*I sincerely acknowledge the help and support of **Mr. Gopakumar, Mr. Krishnakumar, Mr. Saju** and all other staffs of the Academy for Climate Change Education and Research and I have to specially thank **Mr. Niyas, Mr. Toufeeque, Ms. Krishnaveni, Ms. Binciya, Ms. Sharon** and other 2010 and 2011 batch students for all sorts of helps rendered by them.*

*I express my sincere thanks to **Mr. Gopi, Mr. Akhil, Mr. Pranav, Ms. Sathi, Ms. Yashodhara, Mr. Bakker** and **Ms. Jasheeda** of Department of Olericulture and **Ms. Shobhana, Mr. Balan** and **Mr. Madhu** for the help rendered during my field studies.*

I am thankful to my seniors and friends in the Indian Agricultural Research Institute, Ms. Rejula, Ms. Manju Mary Paul and Mr. Denny who helped me to collect seeds for the field experiment.

With immense pleasure, I thank my seniors, Ms. Arya Lekshmi, Ms. Somya, Ms. Malu, Ms. Anju, Ms. Anitha, Ms. Amrutha, Ms. Sreeja, Ms. Reeja, Ms. Renisha, Ms. Divya and Ms. Leksmi Prasanna, who had contributed in some way or other towards the completion of this work.

I wholeheartedly thank my friends, Ms. Jyothi, Ms. Renju, Ms. Resmi, Mr. Dhanesh, Ms. Punya, Ms. Yamuna, Ms. Rinu, Ms. Fasila, Ms. Shareefa, Ms. Anchana, Ms. Manjusha, Mr. Najeeb, Ms. Jeethu, Ms. Ayisha, Mr. Adarsh, Mr. Sameer and all other batch-mates for their love, co-operation and help.

I extend my loving gratitude to my juniors, Ms. Neethu Chandran, Ms. Sharanya, Ms. Rosmy, Ms. Nissa, Ms. Airina, and Ms. Nithya for the constant support and indispensable help provided by them.

Words cannot express my soulful gratitude to my beloved seniors, Ms. Jisha and Ms. Nisha who were more than friends to me, for their loving support and inspiring words. Even though they are far away, their encouragement and constant support greatly influenced me during the course of study.

Lastly, I will fail in my duty, if I don't record my heartfelt gratitude to my beloved parents for being the pillars of strength for me. I am forever beholden to my parents, grandmother, sisters, brothers-in-law and nephew, for their boundless affection, support, prayers, blessings and personal sacrifices for me.

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

Above all, I gratefully bow my head before the Almighty, for the blessings showered upon me in completing the thesis successfully.

Karthika V. P.

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Introduction

1. INTRODUCTION

Weather parameters influence all stages of plant growth and thereby affect the crop productivity. Each crop has its own set of optimum and tolerable environmental conditions under which it can grow efficiently. Knowledge about the relationships between crop growth stages and weather parameters is very important to maximize the production and productivity by adjusting the crop management practices. For a plant to be successful in a given region, the sequences of its growth phases must fit in the climate to ensure good growth and adequate production. Agro-climatological knowledge of individual crops and individual locations is thus very essential.

Vegetable crops, the important component of horticulture, assume great significance in providing food and nutritional security. Even though India ranks second in the world production of vegetables (NHB, 2011), the availability of vegetables still continues to be much low below the dietary requirements. There is ample scope to increase the productivity by the development of location and situation specific technologies. But the challenges before us are to produce more from shrinking land and declined water in the scenario of climate change. Extreme variation in varietal performance caused by uncertain seasonal conditions is a serious risk in vegetable farming. So, we have to find out the relationships between the magnitude of yield fluctuations and environmental influences of the crop growing season.

Cauliflower (*Brassica oleracea* var. *botrytis*) belonging to the family brassicaceae is one among the most popular vegetable crops cultivated in India. It is grown for its fleshy immature inflorescence which is known as curd. Cauliflower occupies the pride position among cole crops due to its delicious taste, flavour and nutritive value. It enjoys first position among the different cole crops cultivated all over the world (Saravaiya and Patel, 2005). India is the second largest producer of cauliflower in the world contributing 33% to the global production. It is cultivated in an area of 3.48 lakh hectares with a production of 65.69 lakh tonnes and productivity of 18.9 mt ha^{-1}. The major cauliflower producing states in India are Bihar, Uttar Pradesh, Orissa, West Bengal, Assam, Haryana and Maharashtra (NHB, 2011).

Cauliflower is originated from wild cabbage (*Brassica oleracea* var. *sylvestris*) and its centre of origin is believed to be the Island of Cyprus (Kohli *et al.*, 2008). Cauliflower grows at latitudes varying from 45°S in New Zealand to 65°N in Scandinavian countries. It is grown in all continents of the world, of which Asia is the leading one followed by Europe (Swarup, 2006). Cauliflower was first introduced to India from England in 1822. Within a period of one hundred years, these introduced varieties underwent selection by local growers when seed production was attempted by them in North Indian plains. Selections were made for early maturity and wider adaptability to hot and humid conditions. These types are commonly known as Indian or tropical cauliflowers which are good for early sowing and early harvest (ICAR, 2004).

Cauliflower was considered as a temperate crop when snowball types only were available. With the development of tropical Indian cauliflower, it became possible to cultivate in tropics and throughout the year in North Indian plains (Gopalakrishnan, 2007). Now-a-days, with advances in breeding programme, a number of varieties suitable for different temperature ranges have been developed. This genotypic variation has made cultivation of cauliflower possible over a range of climatic conditions. It is therefore important to choose the appropriate variety with respect to climatic condition to enable curd formation. But compared to other vegetables, hybrids are very popular in cool season crops due to their high yield, uniform maturity, earliness and wider adaptability (Pradeepkumar and George, 2009).

The development of tropical varieties of cauliflower at IARI, New Delhi, enhanced the spreading of its cultivation to non-traditional areas of Karnataka and Tamil Nadu (Pradeepkumar *et al.*, 2002). The hill tracts of Idukki and Wayanad districts of Kerala also offered ample scope for its cultivation. Under Intensive Vegetable Development Programme, cauliflower cultivation was undertaken in Kerala during 1998-99, with a total production of 137 mt, out of which 117 mt was from Wayanad and 20 mt from Idukki (Arya and Prakash, 2002).

The development of tropical hybrids from both public and private sectors, which can grow well under high temperature conditions, provided an opportunity to think about extending the cultivation of cauliflower to the plains of Kerala. Even though cauliflower can be grown in the humid plains of Kerala during the winter season, its cultivation is not yet organized in a way to obtain maximum production and as on today, no attempt was made to quantify the cauliflower-weather relationships in the plains. Hence, studies have to be conducted to determine the optimum planting time for cauliflower in different climatic conditions.

In this context, the present investigation was planned to identify and study the critical weather elements influencing the growth and development of cauliflower and to assess its suitability with regard to growth and yield in the central part of Kerala which is experiencing a humid tropical climate. The study also aimed to determine the optimum planting time under the prevailing climatic conditions.

Review of Literature

2. REVIEW OF LITERATURE

Cauliflower (*Brassica oleracea* var. *botrytis*) is a cool season crop grown for its immature inflorescence called curd which is a rich source of dietary nutrients and antioxidants. Cauliflower is very sensitive to growing conditions and requires more attention than cabbage, broccoli and other close relatives and hence it is regarded as the aristocrat of the cruciferae family. It can be grown in a wide range of climates, but for the transformation from vegetative to curd initiation phase and for the development of curd, it needs distinct climatic conditions. Available literatures on the influence of weather on growth and development of cauliflower are reviewed in this chapter under the following major heads.

2.1. Effect of weather parameters on the growth and yield of cauliflower

2.2. Effect of planting date on the growth and yield of cauliflower

2.3. Tropical cultivation of cauliflower

2.4. Climatic models for cauliflower production

2.5. Weather influence on the incidence of pests

2.6. Weather influence on the incidence of diseases

2.7. Weather influence on the incidence of physiological disorders

2.1. EFFECT OF WEATHER PARAMETERS ON THE GROWTH AND YIELD OF CAULIFLOWER

2.1.1. Effect of temperature

Gill and Singh (1973) reported that maximum and minimum temperatures of 15.4-18.9°C and 4.6-6.8°C, respectively during October, November and December induced good vegetative growth in cauliflower in Kullu Valley. They also reported that temperature fluctuations in the month of February affected the seed yield adversely. Fujime and Hirose (1980) investigated the effects of diurnal variation of temperature on curd formation of cauliflower by growing under low temperature during one part of the day and high temperature during the remaining part of the day and concluded that the stimulus of low temperature given in a certain period of the day will get reduced but not nullified by subsequent high temperature. They also reported that even though the plants are grown at diurnal variation of temperature and have not formed curds, the low temperature effect will accumulate in the plants and they soon form curds when the chilling requirement is satisfied.

Some cauliflower cultivars initiate curd formation at about the same rate whether they are grown under cool or very warm weather conditions. Other cultivars require more than twice as long a time to form curds under high-temperature conditions than under cool or moderate temperatures. The delay or retardation of curd formation is the result of lack of sufficient growing time during which the temperature is below a critical value. This critical temperature appears to vary with different cultivars (Liptay, 1981). Wurr *et al.* (1988) based on experiments conducted at Wellesbourne, reported that cauliflower plants showed maximum rate of vernalization between 5°C and 17°C and at temperatures lower and higher than this range, reduced vernalization rates were observed which resulted in large variation in the mean number of leaves formed at the time of curd initiation which ranged between 22 and 36.7 leaves.

Plant to plant variation within a cauliflower crop in respect of curd initiation date is due to both differences in date on which the juvenile phase ends and differences in temperature experienced subsequently by the individual plants. The duration of the harvest period is determined primarily by the date of juvenility, temperature after the end of the juvenility and temperature during curd growth, possibly all interacting with a genetic component. The final number of leaves also depends on temperature after the juvenile phase (Booij, 1990a). Booij (1990b) reported that curd fresh weight at maturity was reduced by low temperatures before transplanting, especially in the case of plants with a higher number of visible leaves at the time of transplanting.

In an experiment conducted at Netherlands, Booij and Struik (1990) observed that after the juvenile phase, the apical dome diameter of cauliflower plants kept under weak curd-inducing conditions (22°C) increased very slowly compared to those kept under strong curd-inducing conditions (14°C). Chatterjee and Som (1990) reported that average maximum temperature of 26.3°C, minimum temperature of 20.1°C and relative humidity of 88.3-88.6% were effective in stimulating plant growth and curd formation in cauliflower in Pedong, Kalimpong.

The temperature during vegetative growth has a strong influence on the time of curd initiation and, together with variation in the duration of curd growth from initiation to maturity, affects the time taken from transplanting to maturity (Wurr and Fellows, 1990). In the experiment conducted by Wurr *et al.* (1990b) in controlled environment cabinets, it was found that there was a linear relationship between early curd growth and temperature between 8°C to 18°C. Pearson *et al.* (1994) reported that the rate of curd initiation in cauliflower increased up to a mean temperature of 14°C, but declined thereafter. The thermal time required to elapse for curd initiation to occur was 296°C days accumulated above a base temperature of 2.8°C. They found a curvilinear relationship between the logarithm of curd diameter and thermal time for the variety Revito.

Wheeler *et al.* (1995) reported that the period from transplanting to curd initiation and the subsequent growth of the curd is strongly influenced by temperature. Curd weight exhibited a negative linear function with respect to mean temperature. Due to this negative relation and the low temperature requirement for curd initiation, they opined that the crop duration for late transplanted crops will be longer in a warm climate. Warmer temperatures reduced total biomass at the last harvest, due partly to later initiation of curds and reduced curd growth rates. The dry weight reduction was 6 per cent for every 1°C rise in temperature.

Wurr *et al.* (1995) reported that in early sown cauliflower crop, rise in temperature greatly reduced the length of juvenile and curd growth phases but had little effect on vernalization and consequently reduced the overall duration of growth. But for later sown crop, temperature rise reduced the lengths of juvenile and curd growth phases but increased the duration of vernalization because temperatures were beyond its optimum. They also reported that under Wellesbourne conditions, the rate of vernalization is more at 9-9.5°C and is zero below 9°C or above 21°C for the cultivar White Fox. As temperature rises above 9.5°C, the rate of vernalization declines. According to Csizinszky (1996), under warm-humid climatic conditions, seedling growth and planting of green cauliflower should be timed when minimum temperatures fall to less than 21°C.

Wurr *et al.* (1996) reported that in Wellesbourne of UK, increased temperatures (up to 4°C above the ambient temperature) delayed curd initiation in the cauliflower cultivar March by up to 49 days and increased the final number of leaves by 36. Nowbuth (1997) reported that warmer temperatures favoured leaf production in cauliflower up to a maximum after which a decrease was noticed. Leaf production peaked at 22.5°C for the temperate variety Revito and at 25°C for the local Mauritian variety and after that leaf production declined. Curd initiation in Revito occurred at a temperature range of 11-19.5°C compared to the local tropical variety which initiated curd at a higher range of 11-22.5°C. No curd formation was observed at and beyond 22.5°C in Revito and 25°C in the local variety. Warm temperatures also showed an inhibitory effect on the rate of apex diameter expansion.

Olesen and Grevsen (1997) found that the relative leaf area expansion was found to be a linear function of daily mean leaf surface temperature, but at temperatures above 21°C, lower rates are exhibited. Wien and Wurr (1997) reported that high frequency of curd disorders are possible in cauliflower, if they are grown beyond the range of temperature conditions for which they are originally developed. Leaf production and expansion rate increases with temperature up to the end of juvenility, but if the temperature exceeds the range needed for vernalization, curd formation could be delayed or interrupted by further leaf formation and at temperatures lower than the optimum, leaf area development could be curtailed, leading to buttoning or the production of ricey curds.

According to Nowbuth and Pearson (1998), warmer temperatures cause decreased production of leaves. The final number of leaves was less when the temperature was 25-30°C. Wurr and Fellows (1998) conducted an experiment in winter cauliflower to study the leaf production and curd initiation in response to temperature. In this experiment, they used perforated polythene and non-woven fleece to cover the crops in order to raise the temperature by 1.6°C and 1.1°C respectively, compared to that of open planted crops. They reported that the time to curd initiation extended up to 93 days in the cauliflower selection 'December/January' and up to 57 days in the selection 'March'. They also reported that winter cauliflower vernalize most effectively between 10 and 16°C with an optimum rate of vernalization at about 14°C.

According to Hazra and Som (1999), when the early high temperature tolerant cultivars are grown late in the low temperature conditions, quick transformation to curding without proper vegetative development takes place resulting in the production of small button-like curds and in more low temperature condition, direct formation of typical green buds takes place. They also reported that the optimum soil temperature range for germination of cauliflower seed is 10-30°C. The minimum, maximum and optimum temperatures for germination are 4.4°C, 37.8°C and 25°C respectively.

Olesen and Grevsen (2000) used a base temperature of 1.9°C for describing the ageing of leaf area and leaf mass, whereas root mass is handled with a base temperature of 0°C to describe the ageing of roots. According to Uzun and Peksen (2000), base temperature for thermal time calculations for both from planting to curd initiation and from curd initiation to harvest in cauliflower is 2.8°C in Turkey. Depending on the cultivars, plants required 600 to 1600°C days to initiate curd. Curd weight decreased with increased thermal time up to 1200°C days and increased after this point up to 1600°C days. They revealed based on their study that lower the thermal time required by the plants for vegetative growth, the earlier they mature. They also concluded that temperatures during vegetative growth of the cauliflower plants should be higher than those of curd growth for obtaining higher yield.

Wurr and Fellows (2000) reported that under UK conditions, the optimum temperature for curd induction of all maturity groups of cauliflower varied between 9°C and 14°C. They also reported that the early summer crops took shorter period from planting to curd initiation whereas the winter cauliflower took the longest period. According to Chatterjee and Kabir (2002), young cauliflower seedlings of early cultivars cease growth at temperatures slightly above 0°C in temperate regions. The optimum temperature for the growth of young plant is around 23°C at first which later drops to 17-20°C. The tropical cultivars show growth even at 32°C. However, at high temperatures than that required for curding, the plant remains vegetative and continues to form new foliage. Even when the plants become generative, more leaves are usually formed at higher temperatures than at lower temperatures. In the study conducted by Pradeepkumar *et al.* (2002) at Wayanad district of Kerala, it was observed that the early planted crops (5^{th} October) yielded highest curd weight with shorter crop duration which was attributed by the low maximum and minimum temperatures experienced by the crop.

Guo *et al.* (2004) reported that in Netherlands, the most effective temperature for the induction of inflorescence in the cold-requiring cultivar cv. '60 day' was 10°C and at 25°C, flowering did not occur. He also reported that temperature along with its duration affected flowering and inflorescence development. Ajithkumar (2005) based on the experiment conducted at Anand, Gujarat, reported that the maximum, minimum and mean temperatures were negatively and significantly correlated with number of days during the curd induction phase and curd maturity phase.

Warland *et al.* (2006) reported that in southern Ontario, hot weather during the month of August reduced the quality of cauliflower curds. About 10% reduction in yield was occurred when the temperature reached 30°C or more during the growing season. Ajithkumar and Savani (2007) reported that in Anand, Gujarat, for the completion of crop growth of cauliflower cultivar Snowball 16, the average values of accumulated growing degree days, heliothermal units and photothermal units were found to be 2173.5°C days, 20555°C day hours and 23308.4°C day hours respectively.

According to Gopalakrishnan (2007), yield of cauliflower varies with varieties and temperature. At temperatures above 25°C, curds will be small, loose or yellow. At this temperature, maximum yield in early varieties is only 10 t ha^{-1}. Yield in same cultivar will increase to 12-15 t ha^{-1} at 20-25°C. Rahman *et al.* (2007a) conducted an experiment in UK to study the relationship between temperature and growth and development of cauliflower after curd initiation and observed that the cauliflower curds increased in size and shape with increase in mean growing temperatures after curd initiation up to an optimum and declined thereafter. The optimum temperature for curd growth was 21-22°C which was higher than that required for growth of vegetative components (19°C) except for stem length. They reported that the growth and development of cauliflower after curd initiation could be resolved into linear or curvilinear function of effective temperatures calculated with optimum temperature of

19-23°C. They also suggested that future warmer climates will be beneficial for winter cauliflower production rather than summer production.

Singh (2007) opined that early maturing cauliflower varieties thrive best where temperature varies between 20°C to 25°C in September to October and 5°C to 10°C in December to January. The optimum monthly temperature for curd formation is 15-22°C, with an average maximum temperature of 25°C and average minimum of 8°C. High temperature during curd maturation promotes defective curds and deteriorates quality of curds. According to Kohli *et al.* (2008), cauliflower plants changeover to curding phase from 5°C to nearly 28-30°C, depending on the variety. Cauliflower can tolerate temperature as low as 4°C and as high as 38°C, however, it cannot withstand so low or high temperature as cabbage does. Hot and dry weather is not at all suited for its cultivation. If temperature remains higher than that required for curding in specific varieties, the plant will remain vegetative without forming any curd and continue to form new foliage. Temperature should not fluctuate too much during the curd initiation and development phase otherwise, the curd quality will deteriorate.

Singh (2008) reported that cauliflower grew best in cool to warm conditions (15-25°C) with high humidity. Though some varieties can grow at temperatures above 30°C, most varieties are very sensitive to higher temperature. Delayed curd initiation in cauliflower occurred due to increased temperature. According to Koike *et al.* (2009), most of the cauliflower growing areas in California have a day-time temperature of 17-29°C and the night-time temperature varies between 3°C and 12°C. At temperatures of 27°C and above, cauliflower tends to have small jacket leaves, small curds and solar yellowing. Cauliflower varieties are very responsive to temperature, so they require specific temperature for their curd initiation and development. Varieties are classified into different maturity groups based on temperature requirements as extra early (20-27°C), early (20-25°C), medium (16-20°C), mid-late (12-16°C) and late (10-16°C) groups (Singh and Nath, 2011).

Suseela and Rangaswami (2011) reported that under greenhouse conditions, higher temperature showed an inhibitory effect on plant spread, but it increased plant height. They also found that the plant spread and plant height in the open field was significantly lower than the crop planted in the greenhouse. Cauliflower gave better yield when maximum and average temperatures during vegetative and curd initiation stages inside the greenhouse were less than 30.5°C and 28.5°C respectively during winter season and less than 33°C and 30°C during summer season. When maximum and average temperatures exceeded 33.5°C and 30.5°C respectively, crop showed abnormal vegetative growth and resulted in low yield. Suseela (2012) reported that during summer season vegetative growth of cauliflower was less compared to the winter season crop.

2.1.2. Effect of solar radiation

Wheeler *et al.* (1995) reported that Radiation conversion coefficient in cauliflower is found to be higher at elevated CO_2 levels and it increased by 42% at 531 µmol mol^{-1} CO_2 concentration but decreased slightly with increase in temperature. Olesen and Grevsen (1997) reported that radiation conversion coefficient appeared to be largely unaffected by temperatures above 14°C, but it declined with increase in irradiance. They also reported that in high irradiance treatments, reductions in leaf area expansion rate and dry matter production rate were observed in cauliflower and broccoli.

In an experiment conducted at Lombok, Indonesia to determine whether tropical cauliflower cv. Milky was able to produce curds in the high, non-inducing temperatures of the lowland tropics, Jaya *et al.* (2002) observed that the high temperature and irradiance during the curd growth phase resulted in poor quality curds. Rahman *et al.* (2007a), based on their experiment done at UK reported that leaf area, stem length, fresh and dry weights of leaf and stem at four weeks after curd initiation were significantly higher in high incident radiation conditions during summer than in the low incident radiation conditions during winter. Curd growth parameters like curd length, diameter, fresh and dry weights were also significantly higher in the high incident radiation conditions compared to low incident radiation conditions. But the curd dry matter accumulation was more efficient under low radiation levels compared to high radiation levels.

Rahman *et al.* (2007b) found out a clear positive linear relationship between the accumulated incident radiation integral and logarithm of plant dry weight. Similar relationship was also observed in curd dry matter accumulation. Radiation conversion coefficients for both plant and curd of cauliflower were observed to be higher under lower incident radiation levels than higher radiation levels. Thus they indicated that the rate of increase per unit incident radiation integral is greater under lower radiation conditions. Masarirambi *et al.* (2011) reported that direct exposure to sunlight resulted in the development of yellow pigments on curds. Curds left uncovered will discolour due to activation of peroxidise enzyme by sunlight and curd will loosen in the sun's heat.

2.1.3. Effect of humidity

Sharma and Parashar (1982) reported that cooler and wet weather helped plant growth and development in respect of yield parameters resulting in increased production compared to higher temperature with absolutely no rainfall resulting in lower yield of cauliflower. Chatterjee and Kabir (2002) reported that high relative humidity induced riciness in some cultivars of cauliflower.

Nathoo (2003) conducted a study to understand the comparative performance of four summer cauliflower varieties with local cultivar at Mauritius under humid and super-humid conditions and it was found that the marketable yield at humid zone was significantly higher than super-humid zone for all the varieties. The two varieties White Contessa and Splendor when planted during winter recorded the lowest yield in super-humid region because of the prevailing low temperature in this region which initiated premature flowering in these varieties. Cauliflower performed better at the humid region in terms of curd circumference and compactness. Ajithkumar (2005) based on the experiment conducted at Anand, Gujarat, reported that the number of days taken for the completion of juvenile phase showed significant negative correlation with forenoon relative humidity.

2.1.4. Effect of light

In a pre-transplanting light treatment experiment, Khan and Holliday (1968) observed that increasing natural daylight from 8 to 12 hours suppressed the leaf number as well as the dry matter yield of the curd per plant. Wheeler *et al.* (1995) observed the canopy light extinction coefficient of cauliflower as 0.4 which may be associated with a slightly erect leaf inclination. According to Olesen and Grevsen (1997), canopy light extinction coefficient is 0.55 for cauliflower and 0.45 for broccoli. The lower extinction coefficient in broccoli compared to cauliflower was because of the presence of more erect leaves and there was no significant influence of irradiance was detected.

Phuwiwat (2000) carried out a study in Thailand to determine the growth and yield of nethouse grown cauliflower under three shade levels and reported that cauliflower plants exhibited adaptation to the reduced light by increasing plant height, leaf area per plant and the leaf chlorophyll content. Alt *et al.* (2001) reported that shaded cauliflower plants had higher stem to leaf ratios than non-shaded plants. According to Ismail and Ann (2004), shading of plants significantly reduced vegetative growth and curd size of cauliflower, but colour of shaded curd was whiter than that of non-shaded curd.

Rahman *et al.* (2007a) reported that growth and development of cauliflower after curd initiation declined with increasing shade levels. Leaf area and leaf dry weight were reduced progressively with increasing shade levels both during autumn and summer plantings and these reductions were found to be consistent throughout the growing period after curd initiation. Curd growth also followed the same pattern. Decrease in stem dry weight was found to be twice under higher incident radiation integral during summer than that under low radiation integral during autumn.

According to Singh (2007), cauliflower is very exacting in photoperiod requirements and the early varieties require short day conditions. Capuno *et al.* (2009) reported that plants grown under rain-shelter were taller than open-field planted crop. Protected plants were subjected to a relatively reduced light which resulted in an increase in the plant height in search of light.

2.2. EFFECT OF PLANTING DATE ON THE GROWTH AND YIELD OF CAULIFLOWER

According to Howe and Waters (1982), maturity in cauliflower varies with the time of the year. In west-central Florida, fall plantings take the longest to mature followed by winter and spring which take progressively shorter periods to mature. In an experiment conducted with 8 planting dates between 1st May and 15th July by Booij (1987), it was observed that there was a correlation between the number of days from transplanting to harvesting and the date of curd initiation. He reported that late curd initiation resulted in late harvest.

When six cultivars of cauliflower were transplanted on 11th June, 2nd May, 24th May and 24th June in Aarslev, Denmark, Grevsen (1990) observed that the period between transplanting and curd initiation showed more variation than that from curd initiation to harvest. Patil *et al.* (1995) revealed that under Poona conditions, appropriate time for cauliflower sowing and transplanting in terms of higher yield are first week of August and first week of September respectively.

According to Gill and Sharma (1996), sowing times depend on the varieties and the agroclimatic conditions prevailing in a particular region. In North-Indian plains, early cauliflowers are sown from May end to mid-July, mid types from July to August end and snowball types from September to October. In the hills, sowing of snowball types is done by August end or September beginning and mid-types are sown from April to July. At high altitudes (more than 2000m above MSL), snowball is sown in April. In Kullu valley and Saproon valley, the most optimum time of transplanting cauliflower is the first fortnight of October.

In a study done at Jorhat, Assam, it was observed that sowing of cauliflower on 15th July gave the maximum curd weight (78.48 q ha^{-1}) which significantly declined with each delay in sowing time (30th July and 14th August). The early sown crops resulted in longer duration and produced taller plants with more number of leaves, higher plant spread, more leaf size index and lowest percentage of abnormal curds than late sown crops (Gautam *et al.*, 1998).

At North Lakhimpur of Assam, an experiment was carried out with nine cultivars planted on three dates at 10 days interval *viz.,* 3 early (1^{st}, 11^{th} and 21^{st} September), 3 mid-season (11^{th}, 21^{st} and 31^{st} October) and 3 late (15^{th} and 25^{th} November and 5^{th} December) and observed that planting time exhibited a significant effect on days to curd formation, curd size, curd weight and yield. With gradual delay in planting in early and mid-season cultivars, rise in yield was registered and for late cultivars, mid planting date was found to be superior. The highest yields in early, mid and late cultivars were obtained from the 21^{st} September, 31^{st} October and 25^{th} November plantings respectively (Dutta, 1999).

In a study done at Pedong, Kalimpong, Chatterjee and Som (1990) observed that sowing of cauliflower seeds in August-January was suitable for cauliflower curd production, but the maximum gross and net weights as well as size of the curd were more in the crop transplanted in the month of September. Sphehia and Korla (2000) reported that in Hisar, cauliflower planted on 5^{th} October gave the highest yield of cauliflower whereas 5^{th} November planting resulted in the production of unmarketable curds.

Uzun and Peksen (2000) reported that in Samsun of Turkey, thermal time elapsing from planting to curd initiation and leaf number per plant declined with delay in planting time. In the first planting on 1^{st} July, vegetative growth was enhanced by the effect of low mean temperatures compared to other planting times, namely 15^{th} July and 1^{st} August. Curd weight was also highest in the 1^{st} July planting because of the higher vegetative growth of the plants. It was also found that increasing temperatures during the second and third planting times caused the plants to have shorter vegetative growth periods.

At RARS, Ambalavayal, Kerala, located at an altitude of 974m above MSL which experiences a mild subtropical climate during October to February, a study was undertaken to investigate the performance of different cauliflower cultivars through sequential planting starting from October. Early (5^{th} October) planting induced production of more number of leaves and short stalks. The gross and net weight and total yield were recorded to be highest in the early planting, whereas, late planting resulted in lower yield. The days to maturity was 66 for the variety PES-1 when planted on 5th October and the duration increased to 68 and 77.5 days, when planting date delayed to 25th October and 16th November respectively. The same trend was also found in all the varieties tested. The study revealed that even 20 days interval in planting is critical for this temperature sensitive crop and early planting is ideal for realizing potential yields in the high range regions of Kerala (Pradeepkumar *et al.*, 2002).

Srivastava *et al.* (2002) conducted an experiment in Uttaranchal during rainy season and obtained the highest yield (194.6 q ha^{-1}) from the 10th August planted crop. They also reported that delay in planting date from 26th July to 25th August resulted in increase in plant height and decrease in number of leaves.

When semi-early cultivars of cauliflower were tested under Southeast Spain conditions, Fernandez *et al.* (2003) observed that November planting of cv. Tenere took the longest time for curd initiation (77 days), while the shortest was in the February plantings of cv. Fargo and Kimball (33 days). The duration of the cultivation cycle exceeded 100 days in first and second crops because of the lower than usual winter temperatures during the cultivation period, with a mean value of 11°C. In subsequent plantings, the cycle gradually shortened as the weather improved and the last planting in March took only 70 days, but it yielded the lowest curd weight.

According to Nathoo (2003), there are three distinct cropping seasons for cauliflower production in Mauritius. These are the early season (January-April), the mid season (May-August) and the late season (September-December). The most popular variety cv. Local which is open-pollinated grows well in a temperature range of 15-25°C, but no production is possible during the summer months (October-March). Thapa and Pati (2003) conducted a study in Mohanpur, West Bengal and found that transplanting on 5th September resulted in more number of leaves and plant height, curd weight per plant, curd size and curd yield compared to planting on 20th august, 20th September and 5th October.

Ajithkumar (2005) conducted a study on cauliflower with three dates of planting at Anand, Gujarat and observed that the 1st November planted crop resulted in more curd yield and biomass compared to the crops planted on 15th November and 1st

December. BingLiang *et al.* (2005) conducted a study in Beijing, China to investigate the plant growth under five different dates of sowing *viz.*, 25th May, 5th, 20th and 30th June and 15th July and revealed that the leaf length and width of the biggest leaf and plant height increased significantly during curd initiation with each delay in sowing date, but the number of leaves decreased.

Cebula *et al.* (2005) reported that in Krakow, Poland, the planting time for the late and early cultivars of cauliflower were second half of June and first half of July respectively. Jana and Mukhopadhyay (2006) conducted an experiment at Cooch Behar, West Bengal with three dates of sowings and reported that sowing on 15th August gave the highest curd yield which later decreased with each delay in sowing time.

According to Sharma *et al.* (2006a), transplanting of cauliflower seedlings should not be delayed beyond first week of June in dry temperate zone of western Himalaya. They reported that transplanting of Pusa Snowball K1 on June 2nd gave significantly higher yield and out-yielded the other combinations of transplanting dates and varieties in the dry temperate zone of western Himalaya. Early transplanting (18th May) resulted in low yield due to the prevailing low temperatures which restrict the growth during the early stages. In the case of late transplanted crop, gradual increase in temperature was observed which proportionately reduced the vegetative growth.

Swarup (2006) reported that in southern (Karnataka, Tamil Nadu and Andhra Pradesh) and western India (Maharashtra and Gujarat), early and mid-season maturing cultivars can be sown during December-February and late season snowball types in September-October. However, the appropriate time of sowing may vary according to location, climate, cultivar and local practices.

Ajithkumar and Savani (2007) based on their two year investigations conducted in Anand, Gujarat, on the cultivar Snowball 16 reported that the number of days taken by the crop for completion of each phenophase varied with the date of planting. The number of days taken for harvest was higher in the crop planted in 1st November in both years of study (104 and 112 days respectively) and consistently decreased with subsequent plantings. The days taken to harvest were much lower in case of 30th November in both the years of study (89 and 87.9 days respectively). The crop planted on November 1st recorded the highest yield than the delayed plantings.

According to Din *et al.* (2007), June is the suitable month for the sowing of cauliflower in Juglote, Gilgit of Pakistan and the most appropriate sowing date is 16th June in terms of curd weight and fresh plant weight compared to other sowing dates *viz.,* 1st June, 1st July, 16th July and 31st July. According to Joseph and Markose (2007), cauliflower is grown both in hills and plains from 11°N to 35°N during July to March in northern plains and from March to November in hills in India.

In an experiment conducted at PAU, Ludhiana, Kaur *et al.* (2007) observed significantly higher curd yield (196.9 q ha^{-1}) in the earlier planting on 15th November and lowest yield in the delayed planting on 5th November (108.1 q ha^{-1}). In the study conducted at Karnal, Haryana, Selvakumar *et al.* (2007) observed that the curd diameter and the number of days required to reach different phenophases in cauliflower got reduced as the date of sowing delayed from 20th July to 20th August.

Ara *et al.* (2009) reported that all the vegetative growth parameters like plant height, number of leaves, whole plant weight, marketable curd weight and per hectare yield were influenced significantly by the date of planting. They inferred from the study done at Bangladesh that irrespective of the lines, cauliflower should be planted in the month of August for better performance. Plant height and number of leaves per plant were maximum at earlier planting on 1st May and then decreased gradually with subsequent delay in planting, but marketable curd weight and whole plant weight were found to be highest in the late planting on 1st August.

According to Fritz *et al.* (2009), in Minnesota, early maturing varieties of cole crops are more sensitive to low temperature damage than those maturing later. So, the initial planting date seldom goes earlier than mid-April. Fall season plantings should be made in early July, since the end of the season in Minnesota is approximately early November. The various cauliflower growing tracts and seasons in California were described by Koike *et al.* (2009). According to them, cauliflower is transplanted and harvested virtually year-round in the central and south coast of California. In the San

Joaquin Valley, planting begins in mid-July and in the southern deserts, planting begins in August and continues until early December.

2.3. TROPICAL CULTIVATION OF CAULIFLOWER

Pradeepkumar *et al.* (2002) revealed that synthetic cultivars belonging to the early maturing type of tropical cauliflower perform well under high range conditions of Kerala and they identified PES-1 as superior variety among all the varieties used under different planting dates. The highly significant interaction between varieties and dates of planting signifies the need for selecting suitable genotypes and season for cultivation for realizing potential yields.

Pradeepkumar and George (2009) reported that tropical hybrids of cauliflower can now be grown successfully in the prevailing agroclimatic conditions of Kerala plains and it came up well during October-March. Pusa Deepali and Pusa Early Synthetic are potential varieties suitable for Kerala plains. F1 hybrids of cauliflower like Greeshma, Atisheeghra and Basant from private entrepreneurs are also found to yield good quality curds.

In a study done by Elavarasan (2011) in hills and plains of Kerala using early maturing cauliflower varieties, the yield obtained was found to be very low in plains compared to hills. The curd weight ranged between 610g and 800g in hills whereas it was in the range of 34-82g in plains. The crop took 83.88 to 93.16 days to reach maturity in hilly region, but the harvest maturity delayed by 39-45 days in plains by taking 128.16 to 132.16 days.

Singh and Nath (2011) reported that in India, there are two separate groups of cauliflowers *viz.,* tropical annual Indian cauliflower and temperate annuals commonly known as snowball types. Development of Indian cauliflower helped to extend cauliflower cultivation from temperate countries to tropics and subtropics. Genes for tolerance to high temperature and rainfall of Indian cauliflower were also utilized for developing improved varieties in other countries also.

2.4. CLIMATIC MODELS FOR CAULIFLOWER PRODUCTION

A model for the prediction of harvest in cauliflower was developed by Grevsen (1990) based on the multi-linear regression relationship between accumulated day degrees > 5°C from planting to harvest and the effect of cultivar, planting day number and its square and this model accounted for 84% of the variation in observed accumulated day degrees > 5°C. Wurr *et al.* (1990b) developed a model using a quadratic relationship between the logarithm of curd diameter and accumulated day degrees to predict when curds of any specified size will be produced, using a base temperature of 0°C.

A model describing the effect of temperature on vernalization rate by linear relationships was developed by Wurr *et al.* (1993) using four cardinal temperatures to predict the time of curd initiation. Pearson *et al.* (1994) developed a model which accurately predicts the effects of temperature on cauliflower. This model could be used for the prediction of maturity dates without the need of field sampling and for crop scheduling. The model predicted the time to curd initiation without considering a juvenile phase.

Grevsen and Olesen (1994) developed a model of cauliflower development during the juvenile and the curd induction phase. They described the duration of the juvenile phase by a temperature sum starting from transplanting, using a base temperature of 0°C. The duration of the curd induction phase in the model was described by using the linear response to temperature which was symmetrical below and above an optimal temperature.

Kage and Stutzel (1999) derived an empirical model to predict development and dry matter partitioning in cauliflower using the data of field experiments which was a combination of an empirical relationship between temperature sum and leaf number. It described the dry matter partitioning between leaf and stem and the allocation of dry matter to the curd.

Olesen and Grevsen (2000) developed a simulation model of climatic effects on plant productivity and variability in cauliflower which could be used for predicting time of crop maturity and for designing of schedules for crop planting. The model could also be used for evaluating effects of climate variability and climate change on cauliflower production.

A simulation model was proposed by Reeves *et al.* (2001) to predict changes in apex development during the curd induction phase of winter cauliflower. The induction function implied very little apex expansion below 4°C and above 17°C for the selection 'March' and below 8°C and above 17°C for the selection 'December/January'.

2.5. WEATHER INFLUENCE ON THE INCIDENCE OF PESTS

According to Gill and Sharma (1996), Diamondback moth (*Plutella xylostella*) is one of the most serious pests of cole crops grown under comparatively high temperature conditions. Rao *et al.* (2003) reported that the larval populations of DBM and tobacco caterpillar (*Spodoptera litura*) were negatively correlated with maximum and minimum temperatures in the first cropping season (20^{th} November - 21^{st} January) in Bapatla of Andhra Pradesh. According to Lingappa *et al.* (2004), even though DBM is noticed throughout the year in India, its incidence is more during February to September.

Jankowska (2005) reported that in Poland, the highest infestation of DBM during 1993-1996 was observed in mid-July and in 1997, it occurred in the beginning of August. He also reported that heavy rains are important factors in decreasing the number of DBM caterpillars on vegetables. Varalakshmi *et al.* (2006) reported that the larval population of DBM and Spodoptera on cauliflower showed non-significant positive correlation with maximum temperature, significant negative correlation with minimum temperature, significant positive correlation with morning relative humidity and non-significant negative correlation with evening relative humidity.

Study done at Allahabad Agricultural University on Sultana variety of cabbage showed that the population of DBM commenced from second fortnight of February and gradually increased and reached the peak level during the second fortnight of March and thereafter declined and recorded the lowest population during second week of April. There was a significant positive correlation between DBM and maximum and minimum temperatures. Relative humidity and rainfall showed non-significant negative correlation whereas, wind velocity and sunshine hours showed non-significant positive correlation. Maximum temperature of 33-38.3°C, minimum temperature of 15.5-20.7°C and relative humidity of 45-60% were supposed to be congenial for the incidence of DBM (Wagle *et al.*, 2006).

According to Oke (2008), cool windy weather reduces the activity of DBM adult and females often die before they lay all their eggs. Heavy rainfall can wash off small larvae and reduce numbers by more than half. Ahmad *et al.* (2009) reported that an outbreak of DBM was occurred on cauliflower in the agroclimatic conditions of Aligarh, Utter Pradesh in 2006, during the dry period of September to first fortnight of October. The initial infestation occurred at temperature of 20.4-31.3°C with relative humidity of 69.9-90.3% and total rainfall of 70.2 mm. A significant increase in the density of DBM was recorded after 10th August and then in the first fortnight of September when temperature was 20.2-31.8°C with relative humidity of 57.4-83.9%. An outbreak situation was noted in the second fortnight of September when temperature fluctuated between 18.6°C and 35.6°C with 64.10-78.30% relative humidity.

Golizadeh *et al.* (2009) reported that DBM could develop and reproduce in a broad temperature range (10-30°C) and it will not survive at 35°C. He also reported that cauliflower is a better host for DBM compared to cabbage. Ahmad and Ansari (2010) reported that rain and maximum humidity were unfavourable for the DBM population.

Patait *et al.* (2008) reported that pest incidences were dependant on weather and during rainy season populations of *Crocidolomia binotalis* (leaf webber), DBM and *Trichoplusia ni* (cabbage semilooper) were influenced positively by forenoon relative humidity and negatively by minimum temperature, but the populations of *Hellula undalis* (cabbage borer) and *Spodoptera litura* (tobacco caterpillar) were affected positively by the action of minimum temperature and rainy days and negatively by forenoon relative humidity and rainfall. During winter season, the populations of leaf webber and DBM were affected positively by the action of afternoon relative humidity and maximum temperature and negatively by the action of forenoon relative humidity and minimum temperature. The forenoon relative humidity showed positive and maximum temperature showed negative effect on the population of cabbage borer. The population of tobacco caterpillar was influenced positively by forenoon relative humidity and negatively by minimum temperature and afternoon relative humidity.

In a study conducted at Peshawar, Younas *et al.* (2004) observed the infestation of cabbage aphid (*Brevicoryne brassicae*) on cauliflower during the last week of October which increased gradually and remained at the peak population from first week to mid of November. The population declined as the crop progressed towards maturity during the end of December when the onset of cold weather occurred. Siddiqui *et al.* (2009) based on the study conducted at Pakistan reported that temperature played an important role in the population build up of aphids. The attack of aphids were more in the months of December and January when the mean temperature was low (9.6-13.1°C) with high relative humidity (70.1-76.6%).

In a study done at Modinagar, Yadav (2010) observed that aphids (*Myzus persicae*) appeared on cauliflower in the last week of December. Though, the potential increase rate remained low till the end of January, it reached the peak value rapidly during the first week of March and thereafter it declined. In a study done at Imphal, Manipur, it was observed that the population of the aphid in cauliflower is negatively correlated with temperature, relative humidity and rainfall whereas, sunshine hours and wind speed correlated positively (Bilashini and Singh, 2011).

2.6. WEATHER INFLUENCE ON THE INCIDENCE OF DISEASES

Chakrabarty and Shyam (1989) conducted an experiment at Saproon valley, Solan, Himachal Pradesh to study the different meteorological factors affecting curd rot of cauliflower caused by *Fusarium equiseti*. The disease started appearing during the month of February and became conspicuous by the end of March. They opined that temperature had a profound influence on the disease development and the maximum development of disease took place between 15°C and 20°C and temperature, relative humidity and rainfall were positively correlated with the disease. Shyam *et al.* (1994) reported that in Himachal Pradesh, curd rot symptoms appeared in the end of February at mature curd stage and continued till the end of April.

Gill and Sharma (1996) reported that black rot caused by the bacteria *Xanthomonas campestris* pv. *campestris* was found to be the serious bacterial disease of cole crops, particularly destructive in tropical and moderately warm temperate areas. Hazra and Som (1999) revealed that black rot disease was very much prevalent in all parts of the temperate and subtropical zones of the country where rainfall or dew is plenty and average temperature lies between 15°C and 22°C.

According to Verma (2002), incidence and development of black rot of cauliflower is strongly and positively influenced by temperature. Temperature of 25-35°C and relative humidity of 95.6-100% were found to be optimum for the disease incidence and development. Singh (2007) reported that the optimum temperature for the occurrence of black rot disease is 26.5-30°C and the disease incidence is favoured by frequent rains.

In a study done at Thrissur, Kerala by Prasanna (2011), it was observed that the incidence of black rot was positively correlated with the maximum temperature and sunshine hours experienced 9 days prior to the disease incidence whereas, climatic factors up to 8 day prior to the incidence of black rot were not found to be significant. There was an increase in disease incidence with increase in temperature and sunshine hours. The disease incidence was found to be more during warm temperature and high humidity periods which resulted in maximum yield reduction. She also reported that among the 16 varieties screened, Basant was found to be the most susceptible one to black rot.

Singh (2007) reported that the incidence of bacterial soft rot disease caused by the bacteria *Erwinia caratovora* was favoured by high humidity. Capuno *et al.* (2009) reported that 100% bacterial soft rot infection occurred in cauliflower due to heavy rains, when planted in open condition, whereas disease was absent in the plants grown under rain-shelter.

According to Sharma *et al.* (2006b), the disease index of alternaria leaf spot was highest (greater than 30%) in the November and February months, when the temperature was 20-28°C. According to Ahuja *et al.* (2010), alternaria leaf spot appears in August in Haryana conditions. Infected leaves show black spot with concentric rings. It is a most common fungal disease observed during rainy season and the spores of the fungus are spread mainly by wind and splashes of rain.

Sharma *et al.* (2006b) reported that the maximum disease index of downy mildew (50-60%) was observed during December-February in cauliflower when the temperature ranged between 15°C and 22°C and the *Sclerotinia* stalk rot index was observed to be more (greater than 30%) during February-March at temperature 18-22°C. Saxena and Singh (1984) reported that in Agra district of Uttar Pradesh, fusarium wilt occurred during the period of late September-October in the seedling beds as well as in fields after the transplantation of seedlings. The temperature ranged from 28°C to 32°C during this period with high humidity. It was observed that the incidence of disease decreased with decrease in atmospheric and soil temperatures.

2.7. WEATHER INFLUENCE ON THE INCIDENCE OF PHYSIOLOGICAL DISORDERS

According to Hazra and Som (1999), among cole crops, physiological disorders are mostly found in cauliflower because of its sensitivity to varying environments. Wien and Wurr (1997) reported that higher or lower temperatures than the optimum needed for curd initiation during early curd development could lead to the formation of structures that represent either a partial reversion to the vegetative state or to a more complete reproductive structure. The adaptation of tropical cauliflower cultivars to high temperatures implied that they would rarely encounter heat sufficient to cause the development of leafy curds. At the other extreme, cauliflower cultivars that require a cold period for curd formation would form ricey curds only infrequently.

According to Grevsen *et al.* (2003), temperature is responsible for bracting and riciness, which result in quality degradation. Riciness is a kind of strong vernalization reaction on flower induction at low temperature, whereas, bracting is a type of de-vernalization where small cauline leaves develop and penetrate the curd surface as a result of high temperature. In an experiment conducted at Aarslev, Denmark, it was observed that the risk of bracting increased considerably when temperature just after curd initiation went above 18°C and high temperature followed by drop in temperature before curd initiation and then again low temperatures in the following period gave a high risk of riciness defects.

Hazra and Som (1999) reported that the prevalence of high temperature than the optimum for a particular variety during curd development causes leafiness. Kohli *et al.* (2008) reported that under unfavourable weather conditions, especially during warm cloudy nights, cauliflower curds may become loose due to elongation of individual pedicels and velvety or granular in appearance. According to Bhat (2009), premature initiation of floral buds on curd giving a velvety appearance which is characterized as riciness may result from any temperature higher or lower than optimum required for a particular variety.

According to Kohli *et al.* (2008), cauliflower curd surface sometimes shows pink tinge due to exposure to high light intensity, which leads to the formation of anthocyanin pigment, especially when the temperature is extremely low. According to Bhat (2009), the check of vegetative growth followed by suitable temperature for transformation to curding may induce buttoning which is the development of small heads while the plants are small.

Materials and Methods

3. MATERIALS AND METHODS

The present experiment on "Crop weather relationships in cauliflower (*Brassica oleracea* var. *botrytis* L.)" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2010-11 and 2011-12.

3.1. EXPERIMENTAL SITE

3.1.1. Location

The experimental site is located at 10°31' N latitude and 76°13' E longitude with an altitude of 25 m above MSL in the central zone of Kerala.

3.1.2. Soil

The experimental location has a deep well drained sandy loam soil which is acidic in reaction.

3.1.3. Climate

The area experiences a typical warm humid tropical climate. The average annual rainfall is 2800 mm which is spread in 111 rainy days. The area is benefitted both by southwest and northeast monsoons. The contribution of southwest monsoon to the annual rainfall is about 68% with 80 rainy days, followed by 16% during post-monsoon with 18 rainy days, 14% during summer with 12 days and two per cent during winter with only one rainy day.

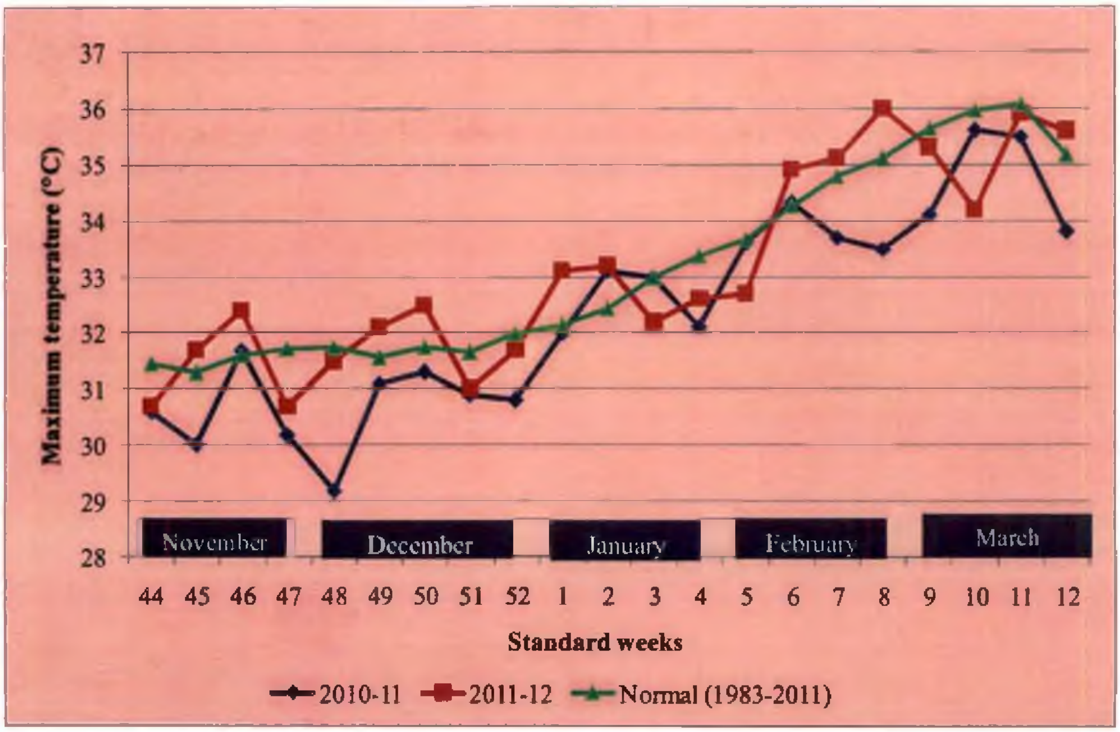
The annual mean, maximum and minimum temperatures of the location are 27.8°C, 32.2°C and 23.3°C respectively. The mean temperature ranges from 26.0°C in July to 30.2°C in April. The mean maximum temperature ranges between 29.0°C in July and 36.1°C in March and the mean minimum temperature varies from 22.2°C in January to 25.1°C in April. The average annual sunshine is 6.7 hrs day^{-1} with the maximum (9.3 hrs day^{-1}) in February and the minimum (3.0 hrs day^{-1}) in July. The mean annual relative humidity is 73% with forenoon relative humidity of 86% and afternoon relative humidity of 60% and the average annual wind speed is in the order of 5-6 km hr^{-1}. From the middle of November to the middle of February, strong

Table 3.1. Weekly weather parameters during the experimental period in 2010-11

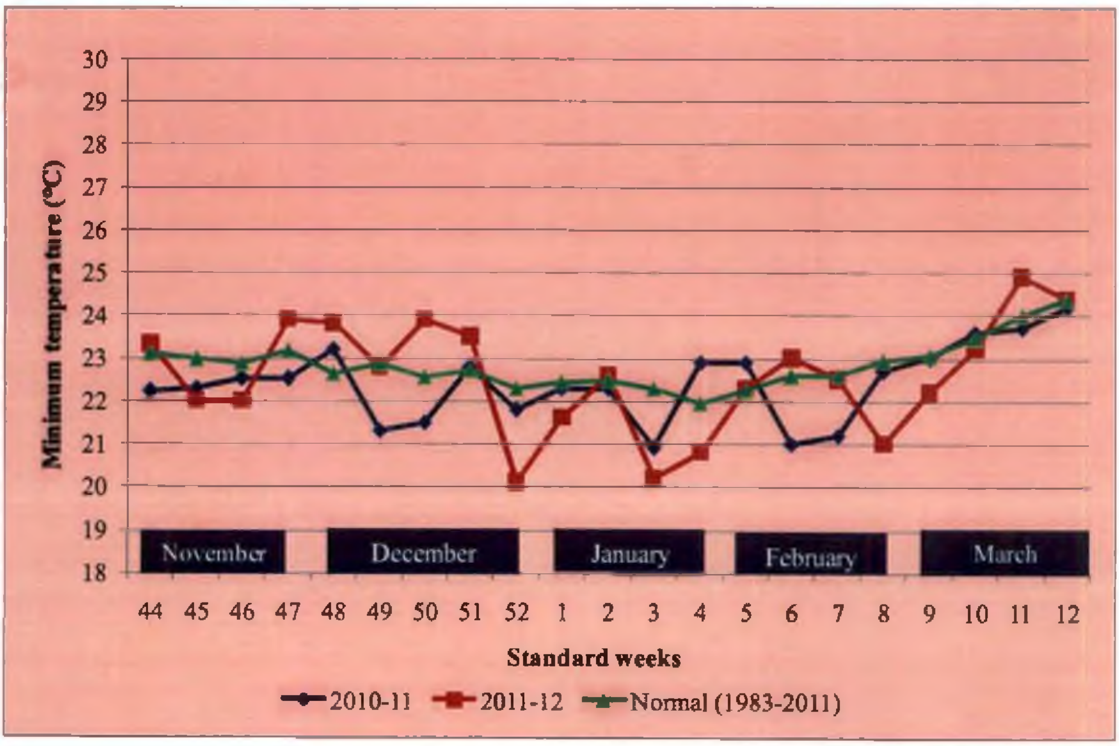
Week No.	Tmax (°C)	Tmin (°C)	RH I (%)	RH II (%)	VP I (mm Hg)	VP II (mm Hg)	RF (mm)	RD	BSS (hrs)	WS (km hr^{-1})
44	30.6	22.2	95.0	70.6	21.7	22.7	147.7	5.0	4.3	2.7
45	30.0	22.3	95.7	73.1	21.8	21.9	141.3	4.0	3.7	2.0
46	31.7	22.5	92.4	67.0	22.0	22.4	35.3	2.0	6.1	2.7
47	30.2	22.5	91.3	70.7	20.9	21.3	58.9	2.0	2.8	3.6
48	29.2	23.2	83.1	70.6	19.6	19.6	10.9	1.0	2.1	6.5
49	31.1	21.3	89.3	58.6	18.9	19.0	0.0	0.0	4.4	2.7
50	31.3	21.5	91.0	59.4	19.1	19.3	19.0	2.0	6.9	3.0
51	30.9	22.8	77.0	54.9	17.2	18.9	2.4	0.0	9.1	7.9
52	30.8	21.8	75.6	51.3	15.9	16.8	0.0	0.0	7.6	6.0
1	32.0	22.3	83.6	50.7	17.9	17.2	0.0	0.0	7.4	4.2
2	33.1	22.3	85.1	42.0	18.3	15.4	0.0	0.0	6.2	3.8
3	33.0	20.9	73.0	36.0	15.3	13.2	0.0	0.0	9.8	6.1
4	32.1	22.9	67.1	37.7	14.9	13.1	0.0	0.0	9.8	9.5
5	33.6	22.9	61.3	28.9	14.2	10.9	0.0	0.0	9.5	8.6
6	34.3	21.0	67.6	27.3	14.5	10.8	0.0	0.0	9.6	6.0
7	33.7	21.2	74.6	34.7	15.1	13.1	0.0	0.0	9.8	4.8
8	33.5	22.7	89.6	52.3	19.7	19.2	65.9	2.0	6.4	3.6
9	34.1	23.0	73.3	35.6	16.6	13.7	11.6	1.0	9.0	5.5
10	35.6	23.6	91.6	39.1	21.2	16.4	0.0	0.0	9.3	3.7
11	35.5	23.7	84.0	32.7	19.8	13.7	10.0	2.0	9.6	5.2
12	33.8	24.2	88.3	54.1	21.6	20.9	0.0	0.0	7.8	3.3

Table 3.2. Weekly weather parameters during the experimental period in 2011-12

Week No.	Tmax (°C)	Tmin (°C)	RH I (%)	RH II (%)	VP I (mm Hg)	VP II (mm Hg)	RF (mm)	RD	BSS (hrs)	WS (km hr^{-1})
44	30.7	23.3	89.6	68.9	21.2	22.1	192.8	3.0	2.8	2.9
45	31.7	22.0	84.4	54.1	18.8	18.6	34.2	3.0	7.3	3.2
46	32.4	22.0	79.6	47.6	19.0	17.3	0.0	0.0	9.3	4.7
47	30.7	23.9	62.6	54.0	15.5	17.1	3.5	1.0	6.8	9.2
48	31.5	23.8	87.4	63.9	20.6	21.1	11.9	2.0	3.8	3.4
49	32.1	22.8	81.7	51.4	19.2	18.0	0.0	0.0	8.5	4.4
50	32.5	23.9	72.6	46.1	17.8	16.4	0.0	0.0	8.9	8.0
51	31.0	23.5	61.7	43.9	14.4	14.2	0.0	0.0	6.1	9.8
52	31.7	20.1	80.9	49.8	16.5	16.9	2.4	0.0	6.4	4.4
1	33.1	21.6	84.1	43.9	17.7	16.4	0.0	0.0	9.8	5.5
2	33.2	22.6	81.3	43.9	17.6	16.3	0.0	0.0	9.6	6.0
3	32.2	20.2	71.0	38.1	14.3	13.3	0.0	0.0	9.1	5.5
4	32.6	20.8	66.6	34.0	13.9	12.2	0.0	0.0	9.8	8.0
5	32.7	22.3	66.4	38.6	14.7	14.0	0.0	0.0	9.3	8.9
6	34.9	23.0	78.4	41.3	18.4	16.8	0.0	0.0	8.9	4.6
7	35.1	22.5	83.1	38.3	18.6	15.1	0.0	0.0	8.9	4.7
8	36.0	21.0	74.3	21.6	15.2	9.3	0.0	0.0	8.8	4.9
9	35.3	22.2	78.1	39.5	17.3	16.1	0.0	0.0	9.0	3.9
10	34.2	23.2	89.3	50.1	22.1	18.8	0.0	0.0	7.3	3.4
11	35.9	24.9	84.6	48.9	21.9	19.8	2.5	1.0	7.8	4.0
12	35.6	24.4	82.9	45.0	22.2	18.9	0.0	0.0	8.0	3.2

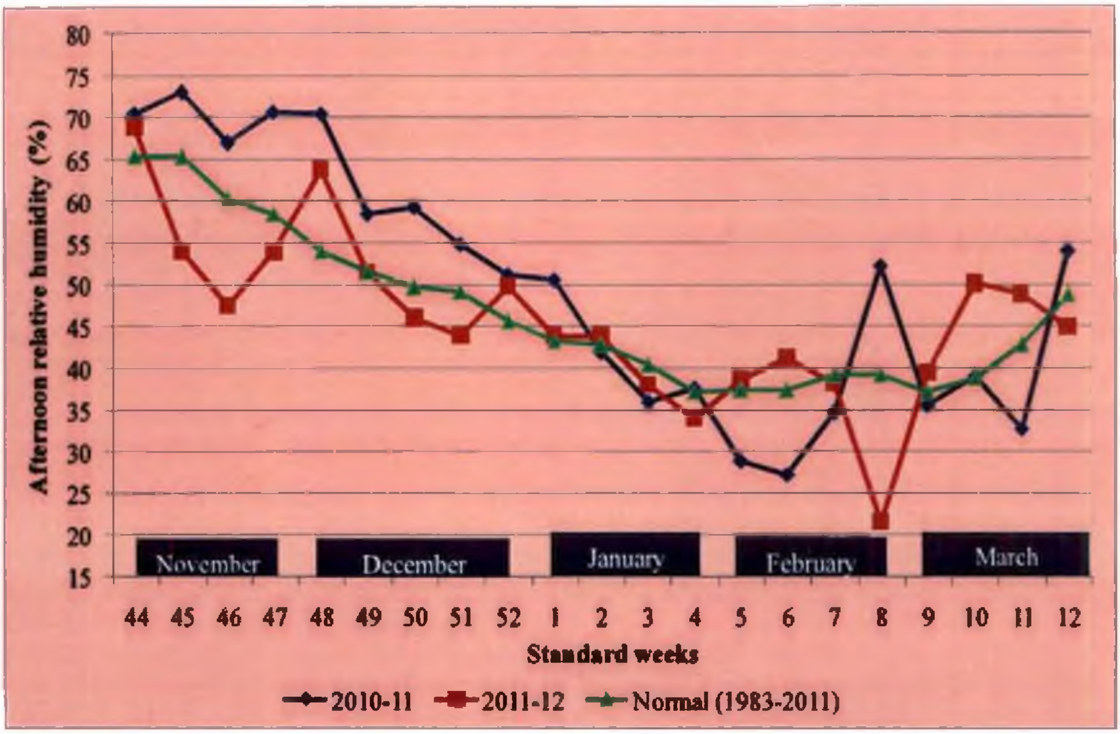


(a) Maximum temperature

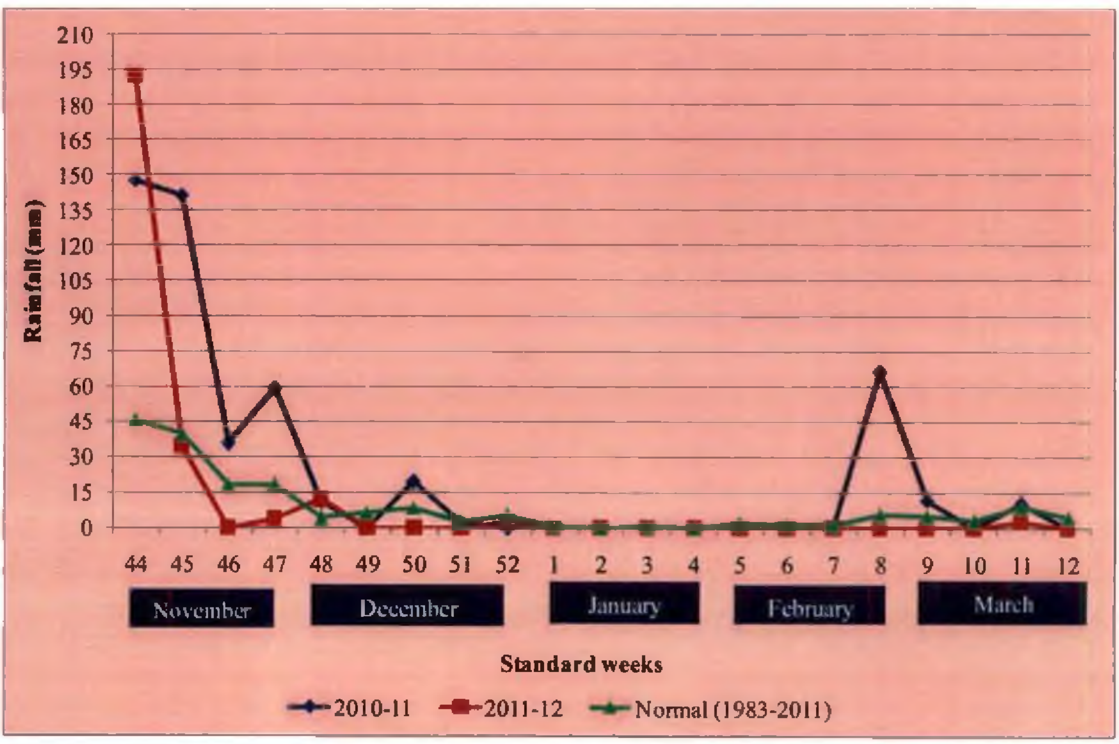


(b) Minimum temperature

Fig. 3.1. Weekly weather parameters during the experiment

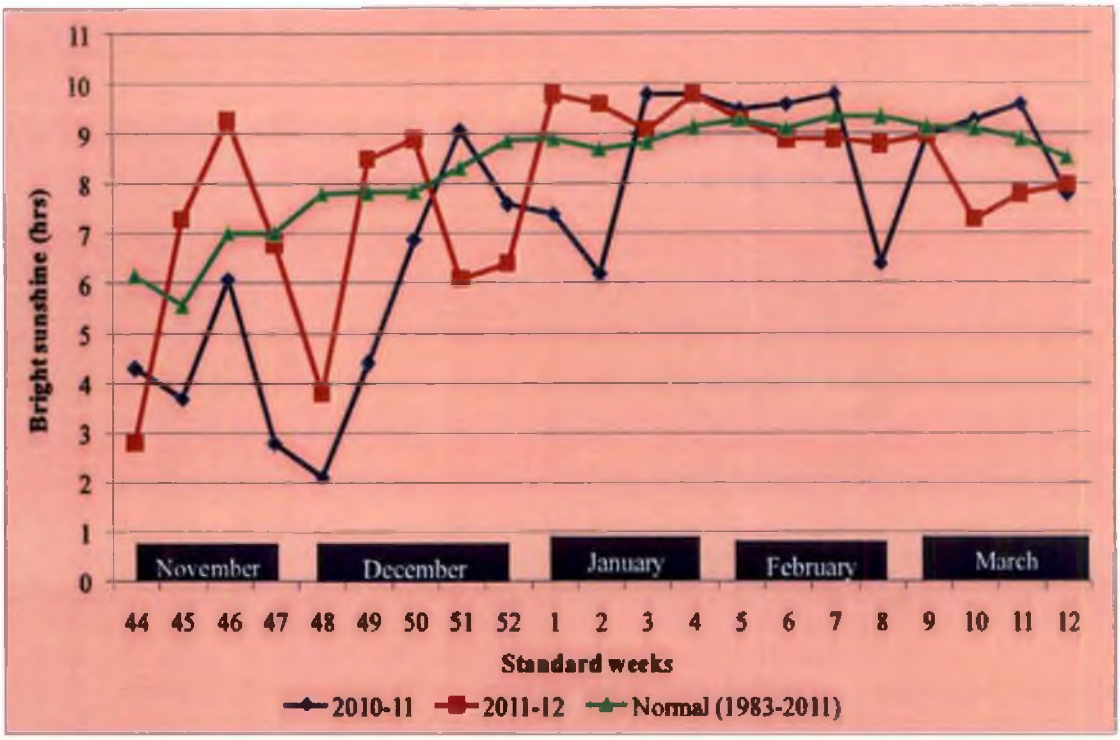


(c) Afternoon relative humidity

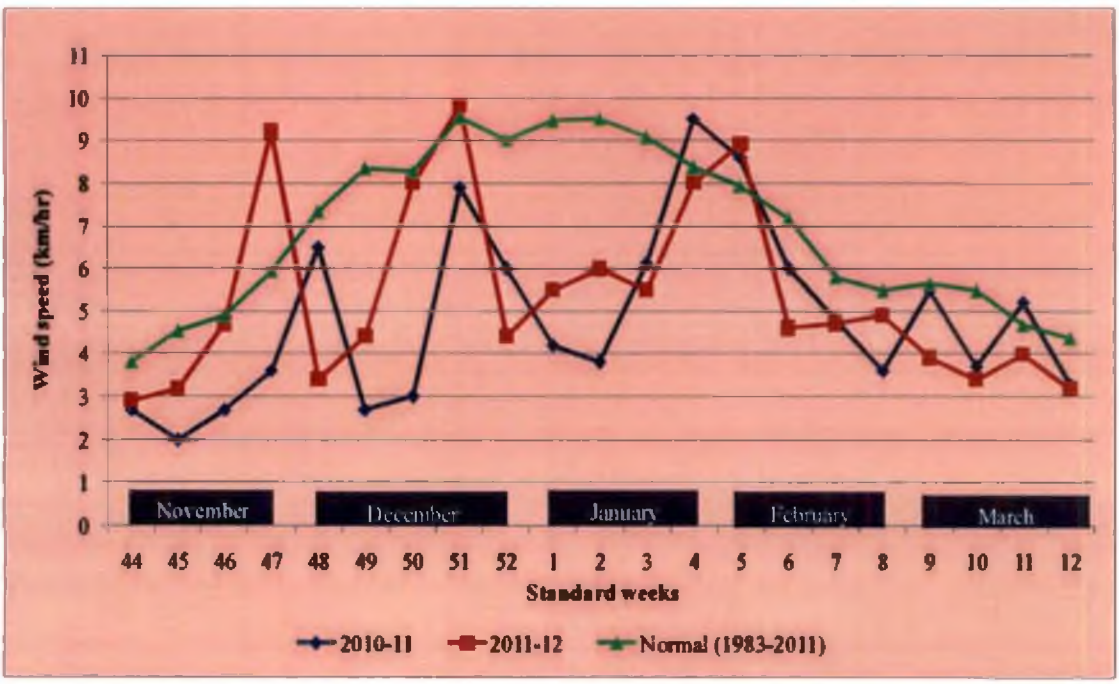


(d) Rainfall

Fig. 3.1. Weekly weather parameters during the experiment (contd.)



(e) Bright sunshine hours



(f) Wind speed

Fig. 3.1. Weekly weather parameters during the experiment (contd.)

easterly dry wind is experienced due to Palakkad gap. This unique feature is observed only in the central zone of Kerala and the crops that are grown in this zone need special attention against strong wind during this period.

The details of the weekly weather parameters during the experimental periods in both years are presented in Table 3.1 and 3.2 and also illustrated in Fig. 3.1.

3.1.4. Season of experiment

The experiment was conducted from October to March in 2010-11 and 2011-12.

3.2. EXPERIMENTAL MATERIALS AND METHODS

3.2.1. Variety

Two hybrids of cauliflower *viz.,* Basant and Pusa Kartik Sankar, which were considered to be suitable for high temperature conditions, were selected for the experiment.

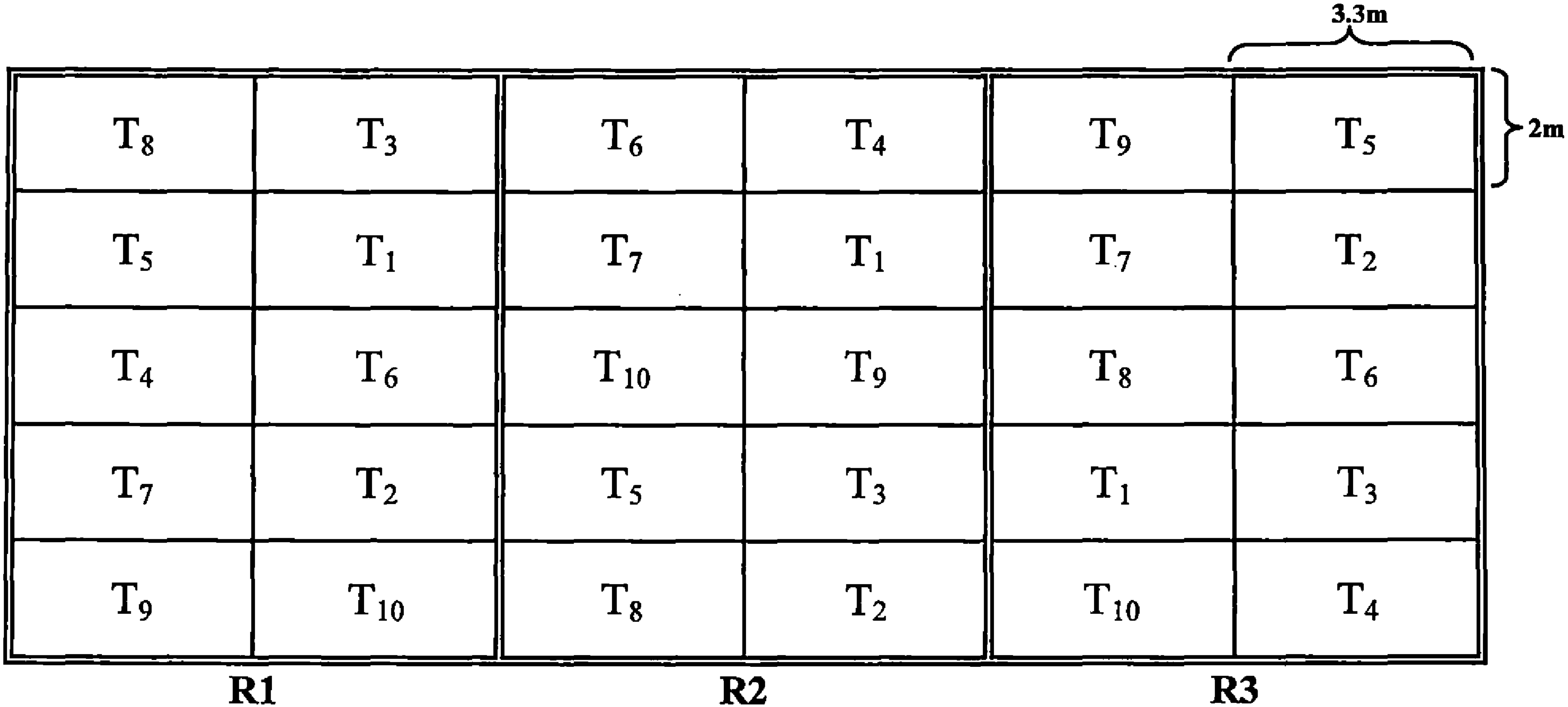
Basant (NS 245) is an early maturing F1 hybrid developed by Namdhari Seeds Private Limited, Bangalore. The plants exhibit open type habit with white coloured semi-dome curds (Singh and Nath, 2011). Pusa Kartik Sankar (DCH 541) is an early maturing hybrid developed at IARI, New Delhi, which produces medium sized white curds (Singh *et al.*, 2009).

3.2.2. Design and layout

The experiment was laid out in Randomized Block Design (RBD) with three replications (Fig. 3.2). There were 30 plots in the field with a plot size of 3.3 x 2.0 sq. m, each accommodating 21 plants with a spacing of 60 cm x 45 cm.

3.2.3. Treatments

The treatments included five planting times at an interval of 15 days starting from 1st November to 1st January with two varieties, *viz.,* Basant and Pusa Kartik Sankar. The different treatments are described in the following table (Table 3.3).



T_1 – 1st November planting + Basant
T_2 – 1st November planting + Pusa Kartik Sankar
T_3 – 15th November planting + Basant
T_4 – 15th November planting + Pusa Kartik Sankar
T_5 – 1st December 1st planting + Basant
T_6 – 1st December planting + Pusa Kartik Sankar
T_7 – 15th December planting + Basant
T_8 – 15th December planting + Pusa Kartik Sankar
T_9 – 1st January planting + Basant
T_{10} – 1st January planting + Pusa Kartik Sankar

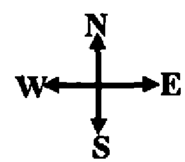


Fig. 3.2. Layout of the field experiment

Table 3.3. Treatments used in the experiment

Treatment	Planting time	Variety
T_1	1st November	Basant
T_2	1st November	Pusa Kartik Sankar
T_3	15th November	Basant
T_4	15th November	Pusa Kartik Sankar
T_5	1st December	Basant
T_6	1st December	Pusa Kartik Sankar
T_7	15th December	Basant
T_8	15th December	Pusa Kartik Sankar
T_9	1st January	Basant
T_{10}	1st January	Pusa Kartik Sankar

3.3. CROP MANAGEMENT

3.3.1. Nursery management

Seeds of cauliflower were sown in plug trays with 98 cavities. The rooting medium was prepared by mixing vermicompost and top soil. Adequate irrigation, drainage and plant protection measures were taken as and when required. The age of the seedling was one month at the time of transplanting (Plate 3.1).

3.3.2. Land preparation and planting

The experimental area was cleared off weeds and stubbles and ploughed well and plots were prepared as per the layout. Furrows were taken 60 cm apart in each plot and planting was done in furrows at a spacing of 45 cm (KAU, 2007). The general view of the field during the experimental period is given in Plate 3.2.

3.3.3. Application of manures and fertilizers

FYM at the rate of 25 t ha^{-1} was incorporated into the field at the time of land preparation. Fertilizers like urea, rajphos and muriate of potash were used in order to supply the required quantities of nutrients (150:100:125 N: P_2O_5: K_2O kg ha^{-1}). Full dose of P_2O_5 and half dose of N and K_2O were applied as basal and the remaining N and K_2O were applied one month after transplanting. Earthing up was done along with the application of second dose of fertilizers (KAU, 2007).

Plate 3.1. Seedlings raised in plug trays

Plate 3.2. General view of the field

3.3.4. Aftercultivation

Until the crop establishment, daily irrigation was provided. Thereafter, irrigation was given in alternate days. The plots were hand-weeded regularly to reduce the crop-weed competition. During the periods of study, crop experienced stresses from different pests and diseases, so plant protection measures like biological, cultural and chemical methods were followed as per requirements.

3.3.5. Harvesting

Cauliflower curds were harvested at vegetable maturity stage based on curd compactness, size and colour.

3.4. OBSERVATIONS

3.4.1. Plant observations

Five plants were selected from each plot for taking plant observations.

3.4.1.1. Plant height

Height of the plant was measured from the ground level to the terminal bud at weekly intervals after transplanting and expressed in centimetres.

3.4.1.2. Number of leaves

Number of fully emerged leaves was recorded at weekly intervals after transplanting.

3.4.2. Plant biomass

One plant from each plot was uprooted at 15, 30 and 45 DAT and at final maturity. The various plant parts like leaves, stem, root and curd were separated and weighed to record the fresh weight. Thereafter the samples were first sundried and then transferred to a hot air oven at 80°C to dry to a constant weight. Biomass was recorded in grams per plant.

3.4.3. Chronological observations

3.4.3.1. Date of sowing

The seeds were sown at an interval of 15 days starting from 1st October to 1st December and the date of sowing of each treatment was noted.

3.4.3.2. Date of transplanting

The transplanting of seedlings were done one month after sowing, starting from 1st November to 1st January and the date of transplanting of each treatment was noted.

3.4.3.3. Date of curd initiation

The day on which the curd was visible at the apex of the plant in 50% of the plants in a plot was taken as the date of curd initiation.

3.4.3.4. Date of harvest

The day on which 50% of the plants in each plot reached harvest maturity was regarded as the date of harvest for that plot.

3.4.4. Duration of different growth stages

3.4.4.1. Duration from transplanting to curd initiation

The number of days from transplanting to the external appearance of curd was counted as duration from transplanting to curd initiation.

3.4.4.2. Duration from curd initiation to harvest

The number of days from curd initiation to the harvest maturity was noted for each experimental plot and taken as the duration from curd initiation to harvest.

3.4.4.3. Duration from transplanting to harvest (crop duration)

The total number of days taken from transplanting to final harvest was regarded as the duration of the crop.

3.4.5. Curd weight

Weight of curd was determined after removing the surrounding leaves and expressed as grams per plant.

3.4.6. Monitoring of pests and diseases

The occurrence of pests and diseases were observed and recorded at weekly intervals.

3.4.7. Weather observations

The daily weather data on maximum and minimum temperatures, forenoon and afternoon relative humidity, rainfall and number of rainy days, bright sunshine hours, wind speed and vapour pressure for the entire crop duration were collected from the Principal Agromet Station of the College of Horticulture, Vellanikkara. The different weather parameters used in the study are described in Table 3.4.

Table 3.4. Weather parameters used in the experiment

Sl. No.	Weather parameter	Unit
1	Maximum temperature	°C
2	Minimum temperature	°C
3	Mean temperature	°C
4	Diurnal Temperature Range	°C
5	Forenoon relative humidity	%
6	Afternoon relative humidity	%
7	Forenoon vapour pressure deficit	mm Hg
8	Afternoon vapour pressure deficit	mm Hg
9	Rainfall	mm
10	Rainy days	-
11	Bright sunshine	hrs
12	Solar radiation	MJ m^{-2}
13	Wind speed	Km hr^{-1}

The mean temperature and diurnal temperature range (DTR) were calculated using the maximum and minimum temperatures. Solar radiation was estimated from bright sunshine hours using DSSAT version 4.5 (Hoogenboom *et al.*, 2009). Forenoon and afternoon vapour pressure deficits (VPD) were calculated using the following equation.

$$VPD = e_s - e_a$$

Where, e_s and e_a are the saturation and actual vapour pressures respectively and e_s was calculated as

$$e_s = \frac{e_a}{RH} \times 100$$

Where, RH is the relative humidity.

3.5. HEAT UNITS

3.5.1. Growing Degree Days (GDD)

The growing degree days were worked out for different crop growth stages and correlated with the various growth and yield characteristics. The following formula was used for the calculation, with a base temperature of 4.4°C (Delahaut and Newenhouse, 1997) and expressed in °C days.

$$GDD = \sum_{i=1}^{n} \left(\frac{T_{max} + T_{min}}{2}\right) - T_{base}$$

Where, T_{max}, T_{min} and T_{base} are maximum, minimum and base temperatures respectively and 'n' is the period from the start to end of a particular growth stage.

3.5.2. Heliothermal Units (HTU)

The heliothermal units were calculated for different crop growth stages and correlated with the various growth and yield characteristics. The following formula was used for the calculation of heliothermal units and expressed in °C day hrs.

$$HTU = \sum_{i=1}^{n} GDD \times SSH$$

Where, SSH is the number of actual bright sunshine hours.

3.5.3. Photothermal Units (PTU)

The photothermal units were also worked out to study the effect of maximum possible sunshine hours on the crop. The photothermal units were calculated using the following formula and expressed in °C day hrs.

$$PTU = \sum_{i=1}^{n} GDD \times L$$

Where, L is the maximum possible sunshine hours.

3.6. STATISTICAL ANALYSIS

Analysis of variance of the field observations were carried out for the two years separately as factorial experiments in Randomized Block Design (RBD) to understand the significance of dates, varieties and date x variety interactions. When the main and interaction effects were found to be significant, Duncan's Multiple Range Test was done for making logical comparisons among them.

The pooled analysis was performed for plant height and number of leaves at the time of harvest and for the duration from transplanting to curd initiation, curd initiation to harvest and transplanting to harvest. For the above characters, analysis was done pooled over the two years to test the significance of year x treatment interactions. This was tested against pooled error over the years. When the error variances in the two years were homogeneous, unweighted analysis was performed and with heterogeneous error variances, weighted analysis was performed as per Panse and Sukhatme (1978). When the year x treatment interaction was found to be significant, for testing the significance of years and treatments, interaction mean square was used. When treatments showed significance, treatment sum of square was further split into sum of squares due to dates, varieties and date x variety interactions and their significances were tested against the year x treatment interaction mean square.

Correlation analysis was carried out to study the influence of weather on cauliflower crop. For this, weekly weather variables prior to critical growth stages were worked out and then correlated with important crop growth and yield characters.

Correlation between various heat units and the duration of corresponding growth stages were also worked out.

Multiple linear regression analysis was performed to predict the curd yield of cauliflower based on different weather parameters. For this, weather parameters during transplanting to curd initiation period was used and the appropriate regression equation was selected based on stepwise regression procedure.

The different software packages like Microsoft-excel, SPSS-16 and MSTAT-C were used in the study, for various statistical analyses.

Results

4. RESULTS

The results obtained from the studies on "Crop weather relationships in cauliflower (*Brassica oleracea* var. *botrytis* L.)" are presented below.

4.1. CHRONOLOGICAL OBSERVATIONS OF CROP GROWTH AND DEVELOPMENT

The seeds of both varieties were sown five times at an interval of 15 days starting from 1st October to 1st December. Correspondingly, the seedlings were transplanted when they were one month old, starting from 1st November to 1st January. In both the years, there were variations among the treatments in reaching the different stages of growth. The chronological data along with the duration of each particular growth stage is presented in the Table 4.1. The different developmental stages of cauliflower crop are given in Plate 4.1.

4.2. WEATHER CONDITIONS EXPERIENCED BY THE CROP

The weather conditions experienced by the crop during the different growth stages of cauliflower in the different times of planting in 2010-11 and 2011-12 are presented below.

4.2.1. Weather during transplanting to curd initiation

The various weather parameters experienced by the crop during the transplanting to curd initiation phase in both the years are presented in Table 4.2.

4.2.1.1. Surface air temperature, relative humidity and vapour pressure deficit

In both years of study, from transplanting to curd initiation, 1st November planted crop experienced the lowest maximum temperature (30.6°C and 31.6°C, respectively in 2010-11 and 2011-12) which progressively increased in each planting time and reached the highest in the 1st January planting (33.2°C and 33.7°C, respectively in 2010-11 and 2011-12). The minimum temperature was low (22.0°C) during 2010-11 in 1st December and 1st January plantings. During 2011-12, it was low in 15th December and 1st January plantings (21.8°C). The minimum temperature was

Table 4.1. Chronological observations of crop growth and development

Treatment	Date of sowing		Date of planting		Date of curd initiation		Date of harvest	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
T_1	Oct 1	Oct 1	Nov 1	Nov 1	Dec 23 (52)	Dec 21 (50)	Jan 11 (71)	Jan 7 (67)
T_2	Oct 1	Oct 1	Nov 1	Nov 1	Dec 20 (49)	Dec 24 (53)	Jan 8 (68)	Jan 9 (69)
T_3	Oct 15	Oct 15	Nov 15	Nov 15	Dec 29 (44)	Jan 15 (61)	Jan 13 (59)	Feb 1 (78)
T_4	Oct 15	Oct 15	Nov 15	Nov 15	Dec 27 (42)	Jan 15 (61)	Jan 13 (59)	Feb 2 (79)
T_5	Nov 1	Nov 1	Dec 1	Dec 1	Jan 26 (56)	Jan 22 (52)	Feb 20 (81)	Feb11 (72)
T_6	Nov 1	Nov 1	Dec 1	Dec 1	Jan 29 (59)	Jan 23 (53)	Feb 22 (83)	Feb 13 (74)
T_7	Nov 15	Nov 15	Dec 15	Dec 15	Feb 6 (53)	Feb 11 (58)	Feb 28 (75)	Feb 29 (76)
T_8	Nov 15	Nov 15	Dec 15	Dec 15	Feb 4 (51)	Feb 10 (57)	Feb 28 (75)	Feb 28 (75)
T_9	Dec 1	Dec 1	Jan 1	Jan 1	Feb 27 (57)	Feb 25 (55)	Mar 18 (76)	Mar 14 (72)
T_{10}	Dec 15	Dec 15	Jan 1	Jan 1	Feb 25 (55)	Feb 26 (56)	Mar 17 (75)	Mar 14 (72)

T_1 - 1st November planting + Basant

T_2 - 1st November planting + Pusa Kartik Sankar

T_3 – 15th November planting + Basant

T_4 – 15th November planting + Pusa Kartik Sankar

T_5 - 1st December planting + Basant

T_6 - 1st December planting + Pusa Kartik Sankar

T_7 – 15th December planting + Basant

T_8 – 15th December planting + Pusa Kartik Sankar

T_9 - 1st January planting + Basant

T_{10} - 1st January planting + Pusa Kartik Sankar

Values in parenthesis represent the mean number of days taken to reach that particular growth stage after planting

(a) After field planting

(b) 15 DAT

(c) 30 DAT

(d) 45 DAT

(e) Curd initiation

(f) Curd development

(g) Curd maturation

Plate 4.1. Growth and developmental stages of cauliflower

Table 4.2. Weather conditions experienced by the crop from transplanting to curd initiation in different times of planting

Weather variable	Time of planting														
	1st November			15th November			1st December			15th December			1st January		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Tmax	30.6	31.6	31.1	30.7	32.0	31.4	31.7	32.3	32.0	32.1	32.6	32.4	33.2	33.7	33.5
Tmin	22.3	23.1	22.7	22.1	22.7	22.4	22.0	22.1	22.1	22.3	21.8	22.1	22.0	21.8	21.9
Tmean	26.5	27.4	27.0	26.4	27.3	26.9	26.8	27.2	27.0	27.2	27.2	27.2	27.6	27.7	27.7
DTR	8.3	8.5	8.4	8.5	9.3	8.9	9.7	10.1	9.9	9.9	10.8	10.4	11.1	11.9	11.5
RH I	89.7	77.4	83.6	85.7	76.5	81.1	80.6	76.7	78.7	75.1	73.6	74.4	75.3	75.8	75.6
RH II	65.9	53.3	59.6	62.1	49.1	55.6	49.9	45.9	47.9	43.8	41.8	42.8	38.7	37.7	38.2
VPD I	2.4	5.4	3.9	3.2	5.5	4.4	4.2	5.3	4.8	5.5	5.8	5.7	5.4	5.2	5.3
VPD II	11.1	16.1	13.6	12.3	17.9	15.1	17.3	19.2	18.3	19.9	21.0	20.5	22.7	24.0	23.4
RF	306.1	240.0	273.1	126.5	17.8	72.2	24.5	2.4	13.5	21.4	2.4	11.9	71.7	0.0	35.9
RD	13.0	9.0	11.0	7.0	3.0	5.0	2.0	0.0	1.0	2.0	0.0	1.0	2.5	0.0	1.3
BSS	4.8	6.9	5.9	5.4	7.6	6.5	7.4	8.2	7.8	8.4	8.6	8.5	8.5	9.3	8.9
SR	14.3	17.1	15.7	15.1	18.0	16.6	17.8	18.8	18.3	19.2	19.5	19.4	19.4	20.3	19.9
WS	3.8	5.7	4.8	4.7	6.3	5.5	5.3	6.0	5.7	6.5	6.7	6.6	5.8	6.0	5.9

high (22.3°C) in 1st November and 15th December plantings in 2010-11 and 1st November planting (23.1°C) in 2011-12.

The mean temperature ranged between 26.4°C in 15th November and 27.6°C in 1st January plantings during 2010-11 and between 27.2°C (1st December and 15th December plantings) and 27.7°C (1st January planting) during 2011-12. The diurnal temperature range (DTR) exhibited the same pattern as that of maximum temperature where it increased for each delay in the planting time from 1st November (8.3°C and 8.5°C, respectively in 2010-11 and 2011-12) to 1st January (11.1°C and 11.9°C, respectively in 2010-11 and 2011-12).

The forenoon and afternoon relative humidity were progressively decreasing with each delay in the planting time and it ranged between 75.3% and 89.7% in forenoon and between 38.7% and 65.9% in afternoon in 2010-11. The relative humidity ranged from 75.8% to 77.4% in forenoon and 37.7% to 53.3% in afternoon in 2011-12. The forenoon vapour pressure deficit (VPD) increased with delay in planting time in 2010-11 and it ranged from 2.4 mm Hg to 5.4 mm Hg whereas, it was observed to be fluctuating in 2011-12. The afternoon VPD was found to be increasing with delay in planting time and it ranged from 11.1 mm Hg to 22.7 mm Hg in 2010-11 and from 16.1 mm Hg to 24 mm Hg in 2011-12.

The study revealed that maximum and mean temperatures, DTR and VPD experienced by the plants were more in the second year compared to the first year experiment in all the planting times. The minimum temperature was also more in the second year except in the 15th December planting. But in the case of relative humidity, it was high in the first year for all planting times.

4.2.1.2. Rainfall and rainy days

The crops under different planting times experienced rainfall during transplanting to curd initiation phase in both the years except in the 1st January planting of 2011-12. The total amount of rainfall was observed to be decreasing in both the years from 1st November to 1st January except in the 1st January planting of 2010-11 (71.7 mm). In the first year, the plants under 1st November planting received a total rainfall of 306.1 mm which became 21.4 mm in 15th December planting. In

2011-12, the total rainfall experienced by the 1st November planted crop was 240.0 mm which decreased to 2.4 mm in 1st December and 15th December plantings and later became rainless in January 1st planting.

In 2010-11, the crops under different planting times experienced 2-13 rainy days with the maximum in 1st November and the minimum in 1st December and 15th December planted crops whereas, in 2011-12, the number of rainy days decreased to 0-9 with the maximum in 1st November and the minimum in 1st January planted crop as in the case of total rainfall.

4.2.1.3. Sunshine hours and solar radiation

The bright sunshine hours (BSS) varied from 4.8 to 8.5 in 2010-11 and 6.9 to 9.3 in 2011-12 for each delay in planting and the solar radiation ranged between 14.3 MJ m^{-2} and 19.4 MJ m^{-2} in 2010-11 and between 17.1 MJ m^{-2} and 20.3 MJ m^{-2} in 2011-12 for the corresponding planting times. Both bright sunshine hours and solar radiation showed an increasing trend from transplanting to curd initiation in both the years, for each delay in planting and compared to first year, the sunshine hours and solar radiation experienced by the crop was more in second year.

4.2.1.4. Wind speed

The wind speed was also more in second year than first year for all planting times. Wind speed was observed to be increasing from 1st November planting (3.8 km hr^{-1}) to 15th December planting (6.5 km hr^{-1}) and later on it decreased in 1st January planting (5.8 km hr^{-1}) in 2010-11, but the wind speed was fluctuating in 2011-12 and it was low in the 1st November planting (5.7 km hr^{-1}) and high in 15th December planting (6.7 km hr^{-1}) followed by 15th November planting (6.3 km hr^{-1}).

4.2.2. Weather during curd initiation to harvest

The various weather parameters experienced by the crop during the curd initiation to harvest phase in 2010-11 and 2011-12 are presented in Table 4.3.

Table 4.3. Weather conditions experienced by the crop from curd initiation to harvest in different times of planting

Weather variable	Time of planting														
	1st November			15th November			1st December			15th December			1st January		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Tmax	31.5	32.2	31.9	32.2	32.4	32.3	33.7	33.4	33.6	33.8	35.6	34.7	35.1	35.0	35.1
Tmin	22.2	21.1	21.7	22.7	20.7	21.7	21.8	22.1	22.0	21.8	21.9	21.9	23.4	22.8	23.1
Tmean	26.8	26.7	26.8	27.5	26.6	27.1	27.8	27.7	27.8	27.8	28.8	28.3	29.2	28.9	29.1
DTR	9.3	11.2	10.3	9.5	11.7	10.6	12.0	11.3	11.7	11.9	13.8	12.9	11.7	12.3	12.0
RH I	79.9	80.6	80.3	83.7	68.8	76.3	69.8	70.7	70.3	78.8	75.1	77.0	83.8	82.2	83.0
RH II	51.4	46.5	49.0	50.3	36.9	43.6	32.9	37.9	35.4	39.5	29.3	34.4	36.3	42.5	39.4
VPD I	4.3	4.3	4.3	3.6	6.5	5.1	6.7	6.5	6.6	4.5	5.4	5.0	3.7	4.2	4.0
VPD II	16.5	19.3	17.9	17.4	22.5	20.0	25.7	23.3	24.5	23.3	30.1	26.7	26.9	23.7	25.3
RF	1.2	2.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	77.5	0.0	38.8	15.8	2.5	9.2
RD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	1.5	2.5	1.0	1.8
BSS	7.6	7.9	7.8	6.7	9.3	8.0	9.5	9.3	9.4	8.4	9.0	8.7	9.4	8.3	8.9
SR	18.2	18.5	18.4	16.8	20.7	18.8	20.6	20.4	20.5	19.1	20.1	19.6	20.3	18.9	19.6
WS	5.3	5.3	5.3	4.4	6.8	5.6	6.4	7.1	6.8	4.7	4.9	4.8	4.7	3.9	4.3

4.2.2.1. Surface air temperature, relative humidity and vapour pressure deficit

The average maximum temperature from curd initiation to harvest ranged from 31.5°C to 35.1°C in 2010-11 and from 32.2°C to 35.6°C in 2011-12 which was higher than that experienced during transplanting to curd initiation. The minimum temperature was 21.8-23.4°C in first year and 20.7-22.8°C in second year for the different planting times and the mean temperature varied between 26.8°C and 29.2°C in 2010-11 and between 26.6°C and 28.9°C in 2011-12. The DTR was also found to be more in second year where, it ranged from 11.2°C to 13.8°C compared to 2010-11 (9.3-12.0°C). The lowest DTR was in 1st November planting in both the years. The DTR was high in 1st December planting in 2010-11 and in 15th December planting in 2011-12.

The maximum temperature was found to be increasing with each delay in planting time both in 2010-11 and 2011-12, except in the 1st January planting of 2011-12 and the maximum temperature was more in second year for all planting times. But the minimum and mean temperatures were more in the first year except in 1st December and 15th December plantings in the case of minimum temperature and 15th December planting in the case of mean temperature.

The forenoon relative humidity was high in the first year for all the plantings, except 1st November and 1st December plantings and it ranged from 69.8% to 83.8% in 2010-11 and 68.8% to 82.2% in the second year. The afternoon relative humidity was also more in first year, except in 1st December and 1st January plantings and it ranged from 32.9% to 51.4% in 2010-11 and 29.3% to 46.5% in 2011-12. The forenoon VPD ranged from 3.6 mm Hg to 6.7 mm Hg and from 4.2 mm Hg to 6.5 mm Hg, in 2010-11 and 2011-12 respectively and the afternoon VPD ranged from 16.5 mm Hg to 26.9 mm Hg in 2010-11 and from 19.3 mm Hg to 30.1 mm Hg in 2011-12.

4.2.2.2. Rainfall and rainy days

In 2010-11, there were no rainy days observed until 15th December planting, where 77.5 mm rainfall was received in 3 days followed by 15.8 mm rainfall in 2.5 days. Rainfall was virtually nil in the second year for all the plantings except in 1st January which received 2.5 mm rainfall (1 rainy day).

4.2.2.3. Sunshine hours and solar radiation

The 1st December planting experienced more BSS hours in 2010-11 (9.5 hrs) followed by 1st January planting (9.4 hrs) and the BSS was less in 15th November planting (6.7 hrs). In 2011-12, BSS was more in 15th November and 1st December plantings (9.3 hrs) and less in 1st November planting (7.9 hrs). Solar radiation was also found to be more in 1st December planting (20.6 MJ m^{-2}) in 2010-11 and in 15th November planting (20.7 MJ m^{-2}) in 2011-12 and it was less in 15th November planting (16.8 MJ m^{-2}) in 2010-11 and in 1st November planting (18.5 MJ m^{-2}) in 2011-12.

4.2.2.4. Wind speed

The wind speed was 4.4-6.4 km hr^{-1}in 2010-11 and 3.9-7.1 km hr^{-1} in 2011-12. The highest wind speed was observed in 1st December planting in both the years and the lowest in 15th November planting in 2010-11 and 1st January planting in 2011-12.

4.2.3. Weather during transplanting to harvest

The various weather parameters experienced by the crop during the transplanting to harvest period (life period of crop) in 2010-11 and 2011-12 are presented in Table 4.4.

4.2.3.1. Surface air temperature, relative humidity and vapour pressure deficit

The average maximum temperature experienced by the 1st November planted crop during its life time was 30.9°C in 2010-11 and 31.8°C in 2011-12 which gradually increased and reached 33.7°C and 34.0°C in 1st January planted crop, in 2010-11 and 2011-12 respectively. In 2010-11, the lowest mean temperature was observed in 1st November planting (26.6°C) whereas in 2011-12, both 1st November and 15th November plantings recorded the lowest mean temperature (27.2°C). The highest mean temperature was in 1st January planted crop in both the years (28°C). The minimum temperature was high in 1st January planting (22.4°C) in 2010-11 and 1st November planting (22.6°C) in 2011-12 and it was low in 1st December planting (21.9°C) in 2010-11 and 15th December planting (21.8°C) in 2011-12. The DTR ranged between 8.6 °C and 11.3°C in 2010-11 and between 9.2°C and 12°C in

Table 4.4. Weather conditions experienced by the crop from transplanting to harvest in different times of planting

Weather variable	Time of planting														
	1st November			15th November			1st December			15th December			1st January		
	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean	2010-11	2011-12	Mean
Tmax	30.9	31.8	31.4	31.1	32.1	31.6	32.3	32.6	32.5	32.6	33.3	33.0	33.7	34.0	33.9
Tmin	22.3	22.6	22.5	22.3	22.3	22.3	21.9	22.1	22.0	22.1	21.8	22.0	22.4	22.0	22.2
Tmean	26.6	27.2	26.9	26.7	27.2	27.0	27.1	27.3	27.2	27.4	27.5	27.5	28.0	28.0	28.0
DTR	8.6	9.2	8.9	8.8	9.8	9.3	10.4	10.5	10.5	10.5	11.5	11.0	11.3	12.0	11.7
RH I	87.0	78.1	82.6	85.2	74.8	80.0	77.3	75.0	76.2	76.2	73.9	75.1	77.5	77.4	77.5
RH II	61.9	51.7	56.8	58.9	46.4	52.7	44.8	43.6	44.2	42.5	38.8	40.7	38.1	38.8	38.5
VPD I	2.9	5.1	4.0	3.3	5.7	4.5	4.9	5.6	5.3	5.2	5.7	5.5	4.9	5.0	5.0
VPD II	12.5	16.8	14.7	13.7	18.9	16.3	19.8	20.4	20.1	20.9	23.2	22.1	23.8	23.9	23.9
RF	307.3	242.4	274.9	126.5	17.8	72.2	24.5	2.4	13.5	98.9	2.4	50.7	87.5	2.5	45.0
RD	13.0	9.0	11.0	7.0	3.0	5.0	2.0	0.0	1.0	5.0	0.0	2.5	5.0	1.0	3.0
BSS	5.6	7.1	6.4	5.7	8.0	6.9	8.0	8.5	8.3	8.4	8.7	8.6	8.8	9.0	8.9
SR	15.3	17.4	16.4	15.6	18.6	17.1	18.6	19.3	19.0	19.2	19.6	19.4	19.6	20.0	19.8
WS	4.2	5.6	4.9	4.6	6.4	5.5	5.7	6.3	6.0	6.0	6.3	6.2	5.5	5.5	5.5

2011-12. The study revealed that the maximum and mean temperatures and DTR were observed to be more in the second year in all the planting times and these were found to be increasing with each delay in planting time.

The forenoon and afternoon relative humidity were found to be decreasing with each delay in planting time except in the case of forenoon relative humidity of 1st January planting in both the years. Relative humidity was observed to be more in the first year in all the planting times, except in the afternoon relative humidity of st January planting. The forenoon relative humidity was 76.2-87.0% in 2010-11 and 73.9-78.1% in 2011-12 for the different planting times and the corresponding afternoon relative humidity was 38.1-61.9% in 2010-11 and 38.8-51.7% in 2011-12. The forenoon and afternoon VPD were observed to be highest in the second year in all the planting times. Forenoon VPD ranged between 2.9 mm Hg (1st November planting) and 5.2 mm Hg (1st December planting) in 2010-11 and between 5.1 mm Hg (1st November planting) and 5.7 mm Hg (15th November planting) in 2011-12.

4.2.3.2. Rainfall and rainy days

In first year, crops under all planting times received rainfall with at least 2 rainy days during the entire crop duration. The 1st November planted crop received the highest amount of rainfall (307.3 mm in 2010-11 and 242.4 mm in 2011-12). The lowest rainfall experienced in 2010-11 was 24.5 mm in 1st December planting. The 1st December and 15th December planted crops in 2011-12 experienced not even a single rainy day during their crop life. The number of rainy days was 2-13 in 2010-11 and 0-9 in 2011-12 with the highest being observed in 1st November planting.

4.2.3.3. Sunshine hours and solar radiation

The bright sunshine hours varied from 5.6 to 8.8 in 2010-11 and 7.1 to 9 in 2011-12 for each delay in planting and the solar radiation ranged between 15.3 MJ m^{-2} and 19.6 MJ m^{-2} in first year and between 17.4 MJ m^{-2} and 20 MJ m^{-2} in second year for the corresponding planting times. Both bright sunshine hours and solar radiation showed an increasing trend during the entire crop duration in both the years for each delay in planting and compared to first year, the sunshine hours and solar radiation experienced by the crop was more in second year for all planting times.

4.2.3.4. Wind speed

Wind speed was observed to be increasing from 1st November planting (4.2 km hr^{-1}) to 15th December planting (6 km hr^{-1}) and later on it decreased in 1st January planting (5.5 km hr^{-1}) in 2010-11, but in 2011-12, the wind speed was fluctuating and it was low in the 1st January planting (5.5 km hr^{-1}) and high in the 15th November planting (6.4 km hr^{-1}). The wind speed was more in second year than first year for all planting times.

4.3. PLANT CHARACTERS

4.3.1. Weekly plant height

Analysis of variance was performed for weekly plant height (up to seven weeks after transplanting) for 2010-11 and 2011-12 experiments and the results are presented in Appendix II-page ii. The time of planting of cauliflower showed high significant influence on weekly plant height in both the years. The varieties differed significantly only in first two weeks after transplanting in 2011-12 and no significant difference was observed in any week of 2010-11 planting. Time of planting x variety interaction was non-significant for plant height.

The mean weekly plant height with respect to time of plating was compared for the two years and is presented in Table 4.5. During 2010-11, for all the weeks compared, the plant height was found to be on par and high in the 15th November and 1st December planted crops except in the second week. In the second week, 15th November planted crop recorded the highest plant height. During 2011-12, the plant height was high in the 15th November and 1st January planted crops in the first two weeks, 1st and 15th November and 1st January plantings in the third week and 1st and 15th November planted crops in the fourth week. In fifth and sixth weeks, 1st November planted crops had the highest plant height and in the seventh week, plant height was high in the 1st November (8.7 cm) and 1st December planted crops (8 cm). The mean weekly plant heights of the two varieties in both the years are given in Table 4.6.

Table 4.5. Mean weekly plant height (cm) with respect to time of planting in different years

Year	Time of planting	Weeks after transplanting						
		1	2	3	4	5	6	7
2010-11	1st November	2.8b	3.5c	3.7c	4.1c	4.5c	5.7b	6.7b
	15th November	5.0a	5.9a	6.0a	6.3a	6.7a	7.9a	9.1a
	1st December	4.8a	5.2b	5.5a	6.2a	6.8a	7.3a	9.2a
	15th December	3.5b	3.7c	4.0bc	4.4bc	5.6b	6.1b	6.8b
	1st January	3.5b	3.9c	4.5b	5.0b	5.4b	6.2b	7.1b
	SE of mean	0.2	0.2	0.2	0.2	0.2	0.3	0.4
2011-12	1st November	2.8b	3.8b	4.5ab	5.6a	6.7a	8.2a	8.7a
	15th November	3.8a	4.3a	4.7a	5.3ab	5.7b	6.5bc	7.2bc
	1st December	2.9b	3.3c	3.9bc	4.5bc	5.8b	7.1b	8.0ab
	15th December	2.8b	3.0c	3.5c	4.0c	4.6c	5.1d	5.7d
	1st January	3.8a	4.1ab	4.4ab	4.7bc	5.0bc	6.0cd	6.5cd
	SE of mean	0.1	0.1	0.2	0.2	0.3	0.3	0.4

Table 4.6. Mean weekly plant height (cm) for the two varieties in different years

Year	Time of planting	Weeks after transplanting						
		1	2	3	4	5	6	7
2010-11	Basant	3.8	4.3	4.7	5.1	5.7	6.5	7.7
	Pusa Kartik Sankar	4.0	4.6	4.7	5.2	5.8	6.8	7.8
	SE of mean	0.2	0.1	0.1	0.1	02	0.2	0.3
2011-12	Basant	3.3a	3.8a	4.3	4.8	5.5	6.5	7.2
	Pusa Kartik Sankar	3.1b	3.6b	4.1	4.8	5.6	6.7	7.3
	SE of mean	0.1	0.1	0.1	0.2	0.2	0.2	0.2

Means with same alphabets as superscripts do not differ significantly

4.3.2. Plant height at the time of harvest

The different times of planting exhibited high significant influence on the plant height at the time of harvest, but the varietal and interaction effects were found to be non-significant in both the years (Appendix II-page iv). In the pooled analysis, no significant difference for the plant height at the time of harvest was observed among the different planting times, varieties and planting time x variety interactions (Appendix III). Comparison of the mean plant height at the time of harvest in both the years is provided in Table 4.7.

Mean plant height showed similarity for 1st December to 1st January plantings in 2010-11 and it was significantly low for 15th November planting (10.2 cm). In 2011-12, highest plant height was recorded in 1st November planting (14.8 cm) and lowest in 15th December planting (10 cm) at the time of harvest. When pooled over years, the plant height varied between 11.2 cm and 13.5 cm.

4.3.3. Weekly number of leaves

Analysis of variance was performed for weekly number of leaves (up to seven weeks after transplanting) for 2010-11 and 2011-12 experiments and the results are presented in Appendix II-page iii.

The mean number of leaves for different planting times in different weeks is given in Table 4.8. In 2010-11, time of planting showed no significant effect on leaf production during the initial weeks, whereas the varietal effect was observed to be significant. But as the crop growth advanced, the effect of planting time on the leaf production became significant and the effect of varieties became non-significant. There was an average of 3.8-4.4 leaves per plant at the time of transplanting which became 20.5 leaves in the 7th week in 15th November planting.

In 2011-12 for all the weeks compared, weekly number of leaves showed high significant difference with respect to time of planting. Among different planting times, 1st November planting recorded the maximum number of leaves which was on par with 1st January planting in the initial weeks after transplanting. In the 7th week, 1st November planted crop recorded 17.9 leaves whereas, 15th December planted crop

Table 4.7. Mean plant height (cm) at the time of harvest with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12			Pooled		
	V1	V2	Mean[1]	V1	V2	Mean[1]	V1	V2	Mean[1]
1st November	12.6	11.8	12.2^{b}	15.3	14.3	14.8^{a}	13.9	13.0	13.5
15th November	10.5	9.8	10.2^{c}	12.3	12.3	12.3^{b}	11.4	11.0	11.2
1st December	13.7	14.3	14.0^{a}	12.4	13.3	12.9^{b}	13.0	13.8	13.4
15th December	13.5	12.4	12.9^{ab}	9.2	10.8	10.0^{c}	11.3	11.6	11.5
1st January	12.5	13.4.	12.9^{ab}	11.8	11.7	11.8^{b}	12.2	12.5	12.3
Mean[2]	12.6	12.3		12.2	12.5		12.4	12.4	
SE of mean	0.3		0.4	0.3		0.4	0.2		0.3

Table 4.8. Mean weekly number of leaves with respect to time of planting in different years

Year	Time of planting	Weeks after transplanting						
		1	2	3	4	5	6	7
2010-11	1st November	3.8	4.5	5.7^{c}	7.6	8.7^{c}	12.0^{bc}	14.4^{bc}
	15th November	4.4	4.5	6.1^{bc}	8.8	10.3^{bc}	15.2^{a}	20.5^{a}
	1st December	4.4	5.1	6.5^{ab}	7.7	10.2^{bc}	13.2^{ab}	17.2^{b}
	15th December	4.0	4.8	6.3^{abc}	8.1	10.9^{a}	13.5^{ab}	16.0^{b}
	1st January	3.8	4.6	6.8^{a}	8.0	9.1^{c}	10.3^{c}	12.3^{c}
	SE of mean	0.2	0.2	0.2	0.3	0.5	0.7	1.0
2011-12	1st November	4.8^{a}	6.0^{a}	6.9^{a}	9.5^{a}	12.2^{a}	15.1^{a}	17.9^{a}
	15th November	3.6^{b}	5.1^{b}	6.2^{bc}	7.2^{c}	8.6^{c}	10.8^{bc}	14.4^{b}
	1st December	2.8^{c}	4.0^{c}	5.7^{cd}	7.4^{bc}	9.9^{b}	12.3^{b}	15.7^{b}
	15th December	2.3^{c}	3.5^{c}	5.3^{d}	6.6^{c}	8.5^{c}	10.3^{c}	12.1^{c}
	1st January	4.4^{a}	5.8^{a}	6.6^{ab}	8.3^{b}	10.0^{b}	12.3^{b}	14.6^{b}
	SE of mean	0.2	0.1	0.2	0.3	0.4	0.6	0.6

Means with same alphabets as superscripts do not differ significantly

V1- Basant V2- Pusa Kartik Sankar Mean[1] – Mean value for the planting time Mean[2] – Mean value for the variety

Table 4.9. Mean weekly number of leaves for the two varieties in different years

Year	Time of planting	Weeks after transplanting						
		1	2	3	4	5	6	7
2010-11	Basant	3.9^{b}	4.4^{b}	5.9^{b}	7.6^{b}	9.3	12.6	16.3
	Pusa Kartik Sankar	4.3^{a}	5.0^{a}	6.7^{a}	8.5^{a}	10.3	13.0	15.9
	SE of mean	0.1	0.1	0.1	0.2	0.3	0.4	0.6
2011-12	Basant	3.8^{a}	5.2^{a}	6.4^{a}	8.1	10.0	12.4	15.3
	Pusa Kartik Sankar	3.4^{b}	4.6^{b}	5.8^{b}	7.5	9.6	11.9	14.6
	SE of mean	0.1	0.1	0.1	0.2	0.3	0.4	0.4

Table 4.10. Mean number of leaves at the time of harvest with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12			Pooled		
	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]
1st November	30.2	31.4	30.8^{ab}	30.8	28.7	29.7^{a}	30.5	30.0	30.3
15th November	27.5	24.5	26.0^{c}	24.3	25.2	24.8^{b}	25.9	24.8	25.4
1st December	33.8	33.3	33.5^{a}	27.0	28.7	27.8^{a}	30.4	31.0	30.7
15th December	29.9	29.3	29.6^{b}	23.4	24.8	24.1^{b}	26.6	27.0	26.8
1st January	23.7	24.1	23.9^{c}	27.5	27.7	27.6^{a}	25.6	25.9	25.7
Mean[2]	29.0	28.5		26.6	27.0		27.8	27.7	
SE of mean	0.6		0.9	0.6		0.9	0.4		0.7

Means with same alphabets as superscripts do not differ significantly

V1- Basant   V2- Pusa Kartik Sankar   Mean[1] – Mean value for the planting time   Mean[2] – Mean value for the variety

recorded only 12.1 leaves. The number of leaves varied significantly among varieties in the initial weeks in both the years and it was more in Pusa Kartik Sankar in 2010-11 and in Basant in 2011-12 (Table 4.9).

4.3.4. Number of leaves at the time of harvest

The time of planting showed high significant influence on final number of leaves in both the years and the effect of variety and time of planting x variety interactions were observed to be non-significant (Appendix II-page iv). Even though, number of leaves at the time of harvest varied for different planting times in both the years, there were no significant difference was observed in the pooled analysis (Appendix III). The mean number of leaves at the time of harvest is presented in Table 4.10.

In 2010-11, the highest number of leaves at the time of harvest was recorded in the 1st December planting (33.5 leaves) followed by 1st November (30.8 leaves) planting and the least number was observed in the 1st January planting (23.9 leaves) and 15th November planting (26 leaves). In 2011-12, the production of leaves was less compared to 2010-11 experiment and recorded the maximum in the 1st November (29.7 leaves), 1st December (27.8 leaves) and 1st January (27.6 leaves) planted crops. When pooled over years, the number of leaves varied between 25.4 and 30.7.

4.4. WHOLE PLANT WEIGHT

4.4.1. Plant fresh and dry weights at 15 DAT, 30 DAT and 45 DAT

High significant influence of time of planting on plant fresh weight was observed in both the years in all the intervals considered except at 30 DAT in 2010-11. The varietal effect was significant at 15 DAT in both the years and at 30 DAT in 2010-11 (Appendix II-page v). The plant fresh and dry weights during the various time intervals for the different times of planting and varieties are given in Table 4.11 and 4.12.

The whole plant fresh weight was observed to be higher in the 1st December and 15th November plantings at 15 DAT in 2010-11 and in 1st December planting in 2011-12. At 30 DAT, no significant difference among the times of planting was

Table 4.11. Mean plant weight (g) at 15 DAT, 30 DAT and 45 DAT with respect to time of planting in different years

Year	Time of planting	Plant fresh weight			Plant dry weight		
		15 DAT	30 DAT	45DAT	15 DAT	30 DAT	45DAT
2010-11	1st November	3.2[b]	24.2	149.5[ab]	0.7[b]	3.4	30.2[a]
	15th November	4.6[a]	25.3	179.1[a]	0.7[b]	3.8	30.8[a]
	1st December	5.1[a]	25.3	89.0[c]	1.1[a]	4.0	16.2[c]
	15th December	2.9[b]	25.5	105.5[bc]	0.5[bc]	4.1	22.1[ab]
	1st January	2.2[b]	21.6	98.0[bc]	0.4[c]	4.0	21.2[ab]
	SE of mean	0.4	2.2	17.5	0.1	0.3	3.5
2011-12	1st November	1.4[d]	36.5[a]	171.6[a]	0.6[c]	5.5[a]	29.2[a]
	15th November	1.7[c]	34.3[a]	162.9[a]	0.8[bc]	5.2[a]	29.0[a]
	1st December	2.9[a]	26.3[b]	116.7[b]	1.3[a]	4.1[bc]	20.2[b]
	15th December	2.4[b]	27.8[b]	103.8[c]	1.1[abc]	4.4[b]	22.5[b]
	1st January	2.4[b]	23.3[c]	95.1[c]	1.1[ab]	3.8[c]	19.5[b]
	SE of mean	0.1	0.9	4.2	0.1	0.2	1.1

Table 4.12. Mean plant weight (g) at 15 DAT, 30 DAT and 45 DAT with respect to varieties in different years

Year	Time of planting	Plant fresh weight			Plant dry weight		
		15 DAT	30 DAT	45DAT	15 DAT	30 DAT	45DAT
2010-11	Basant	4.2[a]	27.4[a]	135.6	0.8[a]	4.3[a]	25.4
	Pusa Kartik Sankar	3.0[b]	21.4[b]	112.8	0.6[b]	3.4[b]	22.8
	SE of mean	0.3	1.4	11.1	0.0	0.2	2.2
2011-12	Basant	2.3[a]	30.2	132.0	1.1	4.6	24.2
	Pusa Kartik Sankar	2.0[b]	29.1	128.0	0.9	4.6	24.0
	SE of mean	0.1	0.5	2.7	0.1	0.1	0.7

Means with same alphabets as superscripts do not differ significantly observed in 2010-11 but in 2011-12, fresh weight was observed to be higher in the 1st November (36.5g) and 15th November (34.3g) plantings. At 45 DAT also, 1st November and 15th November plantings were found to be superior in terms of total plant weight. The effect of time of planting and variety on plant dry weight followed the same relationship as that of plant fresh weight in both the years except at 15 DAT in 2011-12, where 1st December, 15th December and 1st January plantings were became on par.

With respect to varieties, Basant recorded the highest plant fresh weight at 15DAT in both the years and at 30 DAT in 2010-11, but at 45 DAT, both varieties were observed to be similar. Varietal effect on plant dry weight was found to be significant in 2010-11 at 15 DAT and 30 DAT. In both of these time intervals, Basant recorded more dry weight.

4.4.2. Plant fresh and dry weights at the time of harvest

The plant fresh and dry weights at maturity showed significant difference with respect to time of planting and variety, except for the dry weight in 2011-12. The interaction effect was also significant in 2010-11 for both fresh and dry weights (Appendix II-page v). The mean plant fresh and dry weights recorded at the time of harvest were given in Table 4.13 and 4.14.

The plant fresh and dry weights were found to be less in 2010-11 because of the incidence of the devastating bacterial disease of cauliflower called black rot, which caused curd yield reduction and resulted in reduced whole plant weight at the time of harvest. The 1st November planted crop recorded the highest plant fresh and dry weights at the time of harvest (1332.2g and 177.7g, respectively) in 2011-12 and the least plant weight was observed in 1st January planted crop (343g and 53g, respectively). A comparison between the growth habit of 1st November and 1st January planted crops is given in Plate 4.2.

Table 4.13. Mean plant fresh weight (g) at the time of harvest with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12		
	V1	V2	**Mean[1]**	V1	V2	**Mean[1]**
1st November	890.0[a]	735.3[b]	812.7[a]	1397.0	1268.0	1332.2[a]
15th November	755.8[b]	846.4[a]	801.1[a]	979.7	822.7	901.2[b]
1st December	743.2[b]	667.6[b]	705.4[b]	759.7	697.3	728.5[c]
15th December	514.6[c]	402.6[d]	458.6[c]	559.7	511.3	535.5[d]
1st January	274.9[e]	269.1[e]	272.0[c]	359.0	327.0	343.0[e]
Mean[2]	635.7[a]	584.2[b]		810.9	725.2	
SE of mean	13.3		21.1	20.5		32.4

Table 4.14. Mean plant dry weight (g) at the time of harvest with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12		
	V1	V2	**Mean[1]**	V1	V2	**Mean[1]**
1st November	103.1[a]	87.2[b]	95.2[ab]	193.9	161.5	177.7[a]
15th November	92.2[ab]	104.1[a]	98.1[a]	140.2	112.3	126.2[b]
1st December	90.8[b]	87.6[b]	89.2[b]	102.9	97.9	100.4[c]
15th December	61.9[c]	54.0[cd]	58.0[c]	77.3	75.4	76.3[d]
1st January	46.3[d]	43.3[d]	44.8[d]	58.3	47.7	53.0[e]
Mean[2]	78.9	75.2		114.5[a]	98.9[b]	
SE of mean	1.8		2.8	3.5		5.5

Means with same alphabets as superscripts do not differ significantly

V1- Basant V2- Pusa Kartik Sankar Mean[1] – Mean value for the planting time Mean[2] – Mean value for the variety

4.5. DURATION OF DIFFERENT GROWTH STAGES

4.5.1. Duration from transplanting to curd initiation

The times of planting exhibited high significant influence on the duration from transplanting to curd initiation in both the years and the varietal and time of planting x variety interaction effects were found to be significant in 2010-11 (Appendix II-page iv). In the pooled analysis, the duration from transplanting to curd initiation became non-significant with respect to the time of planting (Appendix III). The mean number of days taken to complete this growth stage is given in Table 4.15.

In 2010-11, 15th November planting took the least number of days (43.3 days) whereas, 1st December planting recorded the maximum number of days to reach curd initiation (57.7 days). But in 2011-12, this growth stage was observed to be lengthy for the 15th November planting (61 days) whereas, 1st November planted crop took the minimum number of days (51.3 days) which was on par with 1st December planted crop (52.8 days). When pooled over years, the duration of this growth stage ranged between 50.9 days and 55.6 days.

The interaction between time of planting and variety showed significant influence in 2010-11, and the lowest duration was observed in the 15th November planted Pusa Kartik Sankar (42.3 days) and the highest was observed when the same variety planted on 1st December (59.3 days).

4.5.2. Duration from curd initiation to harvest

The duration from curd initiation to harvest showed high significant difference with respect to the time of planting in both the years whereas, the varietal effect was non-significant. The interaction between time of planting and variety was also found to be significant in 2010-11 (Appendix II-page iv). In pooled analysis also, time of planting and the interaction between time of planting and variety showed significant influences on the duration from curd initiation to harvest (Appendix III). The mean number of days taken to complete this growth stage is given in Table 4.16.

The duration of this growth stage was found to be more in the 1st December planted crop in both the years (24.3 days in 2010-11 and 20.5 days in 2011-12). In

Table 4.15. Mean duration from transplanting to curd initiation (days) with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12			Pooled		
	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]
1st November	51.7[e]	49.3[f]	50.5[d]	49.7	53.0	51.3[d]	50.7	51.2	50.9
15th November	44.3[g]	42.3[h]	43.3[e]	61.3	60.7	61.0[a]	52.8	51.5	52.2
1st December	56.0[bc]	59.3[a]	57.7[a]	52.3	53.3	52.8[d]	54.2	56.3	55.3
15th December	53.3[de]	51.3[e]	52.3[c]	57.7	57.0	57.3[b]	55.5	54.2	54.8
1st January	57.3[b]	54.7[cd]	56.0[b]	54.7	55.7	55.2[c]	56.0	55.2	55.6
Mean[2]	52.5[a]	51.4[b]		55.1	55.9		53.8	53.7	
SE of mean	0.3		0.5	0.3		0.5	0.2		0.3

Table 4.16. Mean duration from curd initiation to harvest (days) with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12			Pooled		
	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]	V1	V2	**Mean**[1]
1st November	19.3[c]	18.7[c]	19.0[c]	17.0	16.0	16.5[d]	18.2	17.3	17.8[bc]
15th November	14.7[e]	16.7[d]	15.7[d]	17.0	18.3	17.7[bc]	15.8	17.5	16.7[c]
1st December	25.0[a]	23.7[a]	24.3[a]	20.3	20.7	20.5[a]	22.7	22.2	22.4[a]
15th December	21.7[b]	23.7[a]	22.7[b]	18.3	18.3	18.3[b]	20.0	21.0	20.5[ab]
1st January	18.7[c]	20.3[bc]	19.5[c]	17.7	16.7	17.2[cd]	18.2	18.5	18.3[bc]
Mean[2]	19.9	20.6		18.1	18.0		19.0	19.3	
SE of mean	0.3		0.4	0.2		0.3	0.2		0.3

Means with same alphabets as superscripts do not differ significantly

V1- Basant V2- Pusa Kartik Sankar Mean[1] – Mean value for the planting time Mean[2] – Mean value for the variety

2010-11, the duration was observed to be less in 15th November planted crop (15.7 days) and in 2011-12, the duration was less in 1st November planted crop (16.5 days) followed by 1st January (17.2 days) planted crop which were on par. In the pooled analysis, it was observed that the 15th November planting took the least number of days (16.7 days) to reach harvest maturity after curd initiation which was on par with 1st November and 1st January plantings and the longest duration was observed in the 1st December planting (22.4 days) which was on par with 15th December planting (20.5 days).

The duration from curd initiation to harvest became significant for the interaction between time of planting and variety in 2010-11 and the lowest duration was observed in the 15th November planted Basant (14.7 days) and highest in the 15th December planted Pusa Kartik Sankar and 1st December plantings of both varieties which were on par.

4.5.3. Duration from transplanting to harvest (crop duration)

The time of planting showed high significant influence with respect to the duration from transplanting to harvest in both the years and the varietal effect was found to be significant in 2011-12. The interaction between time of planting and variety also showed significant influence in 2010-11 and 2011-12 (Appendix II-page iv). In the pooled analysis, no significant difference was noticed for the crop duration with respect to time of planting and variety (Appendix III). The mean number of days taken to complete this growth stage is given in Table 4.17.

In 2010-11, the 15th November planting was early in completing its crop life and took only 59 days to reach harvest stage followed by the 1st November planting (69.5 days) whereas in 2011-12, 1st November planting was observed to be early (67.8 days) than other planting times. The maximum number of days to reach maturity was taken by the 1st December planted crop (82 days) in 2010-11 and 15th November planted crop (78.7 days) in 2011-12. When pooled over years, the crop duration ranged between 68.7 days and 77.7 days.

The interaction between time of planting and variety showed significant influence in both the years. In 2010-11, both varieties exhibited least crop duration

Table 4.17. Mean duration from transplanting to harvest (days) with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12			Pooled		
	V1	V2	**Mean[1]**	V1	V2	**Mean[1]**	V1	V2	**Mean[1]**
1st November	71.0^{d}	68.0^{e}	69.5^{c}	66.7^{f}	69.0^{e}	67.8^{e}	68.8	68.5	68.7
15th November	59.0^{f}	59.0^{f}	59.0^{d}	78.3^{a}	79.0^{a}	78.7^{a}	68.7	69.0	68.8
1st December	81.0^{b}	83.0^{a}	82.0^{a}	72.7^{d}	74.0^{c}	73.3^{c}	76.8	78.5	77.7
15th December	75.0^{c}	75.0^{c}	75.0^{b}	76.0^{b}	75.3^{b}	75.7^{b}	75.5	75.2	75.3
1st January	76.0^{c}	75.0^{c}	75.5^{b}	72.3^{d}	72.3^{d}	72.3^{d}	74.2	73.7	73.9
Mean[2]	72.4	72.0		73.2^{b}	73.9^{a}		72.8	73.0	
SE of mean	0.3		0.4	0.2		0.3	0.2		0.3

Table 4.18. Mean curd weight (g/plant) with respect to time of planting, variety and time x variety interaction

Time of planting	2010-11			2011-12		
	V1	V2	**Mean[1]**	V1	V2	**Mean[1]**
1st November	156.2^{b}	152.3^{b}	154.3^{b}	611.7^{a}	452.7^{b}	532.2^{a}
15th November	157.1^{b}	198.1^{a}	177.6^{a}	337.1^{c}	340.5^{c}	338.8^{b}
1st December	144.3^{b}	115.6^{c}	129.9^{c}	278.8^{d}	209.3^{e}	244.1^{c}
15th December	114.4^{c}	94.3^{c}	104.3^{d}	163.8^{ef}	151.8^{f}	157.8^{d}
1st January	67.5^{d}	42.8^{d}	55.1^{e}	78.3^{g}	66.9^{g}	72.6^{e}
Mean[2]	127.9	120.6		294.0^{a}	244.2^{b}	
SE of mean	3.8		5.9	7.9		12.5

Means with same alphabets as superscripts do not differ significantly

V1- Basant V2- Pusa Kartik Sankar Mean[1] – Mean value for the planting time Mean[2] – Mean value for the variety

Plate 4.2. Comparison between the 1st November and 1st January planted crops

Plate 4.3. Harvested curds of 1st November planted crop

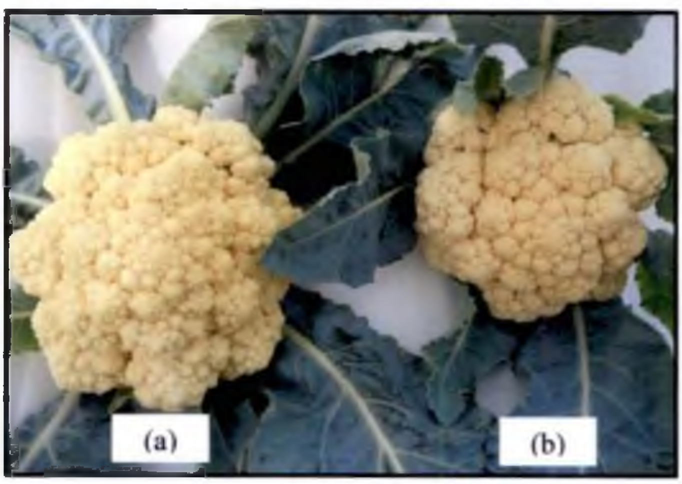


Plate 4.4. Comparison between the curds of Basant (a) and Pusa Kartik Sankar (b)

when planted on 15th November (59 days) and in 2011-12, Basant planted on 1st November was earlier in reaching harvest maturity from the transplanting stage (66.7 days). The longest duration was observed in the 1st December planted Pusa Kartik Sankar in 2010-11 (83 days) and 15th November planted Pusa Kartik Sankar and Basant in 2011-12.

4.6. CURD WEIGHT

The time of planting, variety and their interaction effects were found to be significant with respect to curd weight in both the years except the effect of varieties in 2010-11 (Appendix II-page iv). The mean curd weight per plant for different times of planting, varieties and their interactions is given in Table 4.18.

The curd weight was low in the first year compared to the second year because of the incidence of the bacterial disease black rot. The curd weight decreased with each delay in planting time and the highest curd yield in 2011-12 was 532.2g, obtained from the 1st November planting (Plate 4.3) and the lowest was 72.6g from the 1st January planting. When the interaction between time of planting and variety was considered, it was observed that in 2011-12, Basant planted on 1st November gave the highest yield (611.7g) and it was noted as the superior variety with respect to curd weight. A comparison between the curd size of Basant and Pusa Kartik Sankar in the 1st November planting is given in Plate 4.4.

4.7. HEAT UNIT REQUIREMENT OF CAULIFLOWER

The various agro-meteorological indices like growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) were calculated for different growth stages of cauliflower *viz.,* transplanting to curd initiation, curd initiation to harvest and transplanting to harvest and are presented below.

4.7.1. Growing Degree Days (GDD)

The details regarding the GDD requirement of cauliflower in the present study is given in Table 4.19. Accumulated GDD was observed to be more in 2011-12, except for the 1st December and 1st January plantings, for the transplanting to curd initiation

Table 4.19. Accumulated GDD during different growth phases of cauliflower

Crop phase	2010-11				2011-12				Mean[1]	SD
	V1	V2	Mean	SE	V1	V2	Mean	SE		
1st November planting										
T-CI	1141.5	1089.0	1115.3	20.7	1141.0	1217.5	1179.3	20.2	1147.3	58.4
CI-H	435.8	416.2	426.0	11.7	393.3	356.6	374.9	16.0	400.5	42.2
T-H	1577.3	1505.2	1541.3	18.4	1534.3	1574.1	1554.2	9.5	1547.7	34.8
15th November planting										
T-CI	976.1	931.6	953.9	12.4	1407.1	1391.4	1399.2	14.5	1176.6	234.7
CI-H	338.8	383.3	361.0	12.4	376.8	407.8	392.3	11.4	376.7	32.2
T-H	1314.9	1314.9	1314.9	8.3	1783.9	1799.1	1791.5	7.6	1553.2	249.6
1st December planting										
T-CI	1254.1	1332.9	1293.5	18.9	1193.0	1223.3	1208.1	10.2	1250.8	57.0
CI-H	584.6	552.7	568.7	13.2	465.4	459.8	462.6	11.4	515.6	62.4
T-H	1838.7	1885.1	1862.2	13.6	1658.4	1683.1	1670.7	10.0	1766.4	103.8
15th December planting										
T-CI	1216.0	1170.7	1193.3	13.9	1313.1	1296.6	1304.8	8.2	1249.1	64.1
CI-H	508.1	553.3	530.7	12.7	445.6	446.0	445.8	5.1	488.2	49.8
T-H	1724.0	1724.0	1724.0	8.8	1758.6	1742.6	1750.6	8.0	1737.3	24.0
1st January planting										
T-CI	1330.5	1267.0	1298.8	16.2	1275.7	1299.5	1287.6	11.4	1293.2	33.3
CI-H	465.1	503.2	484.1	12.2	430.7	407.0	418.8	7.0	451.5	41.2
T-H	1795.6	1770.2	1782.9	14.3	1706.4	1706.4	1706.4	5.6	1744.7	47.3

T-CI - Transplanting to curd initiation
CI-H - Curd initiation to harvest
T-H - Transplanting to harvest

V1 - Basant
V2 - Pusa Kartik Sankar
Mean[1] - Mean value for the two years

phase and also for the total crop duration. However, for the curd initiation to harvest phase, GDD was more in 2010-11, except for the 15th November planting.

The accumulated GDD varied from 953.9 °C days in the 15th November planting to 1298.8 °C days in 1st January planting in 2010-11 and 1179.3 °C days in 1st November planting to 1399.2 °C days in 15th November planting in 2011-12 for the transplanting to curd initiation phase. The curd initiation to harvest took 361.0 °C days in 15th November planting to 568.7 °C days in the 1st December planting in 2010-11 and 374.9 °C days in 1st November planting to 462.6 °C days in the 1st December planting in 2011-12. To reach the harvest stage from transplanting, the crop took 1314.9 °C days in 15th November planting to 1862.2 °C days in the 1st December planting in 2010-11 and 1554.2 °C days in 1st November planting to 1791.5 °C days in the 15th November planting in 2011-12.

The two year mean data showed that least GDD requirement to reach curd initiation and final harvest from transplanting was in the 1st November planted crop followed by 15th November planted crop whereas, to reach harvest from curd initiation, 15th November planting took the minimum compared to 1st November planting. The 1st January planted crop took more GDD to reach curd initiation whereas, the 1st December planted crop took more to reach harvest. The mean GDD requirements for the different growth phases are 1147.3-1293.2 °C days for transplanting to curd initiation phase, 376.7-515.6 °C days for the curd initiation to harvest phase and 1547.7-1766.4 °C days for the complete growth from transplanting to harvest.

4.7.2. Heliothermal Units (HTU)

The details regarding the HTU requirement of cauliflower in the present study is given in Table 4.20. For the transplanting to curd initiation phase, accumulated HTU was observed to be more in 2011-12 in all the planting times, but for the curd initiation to harvest phase, HTU was more in 2010-11, except for the 15th November planting. For the total crop duration, the crop exhibited more HTU requirement in 2011-12, except in the 1st December and 1st January plantings.

Table 4.20. Accumulated HTU during different growth phases of cauliflower

Crop phase	2010-11				2011-12				Mean[1]	SD
	V1	V2	Mean	SE	V1	V2	Mean	SE		
1st November planting										
T-CI	5715.7	5228.3	5472.0	193.7	8124.8	8626.3	8375.5	137.1	6923.8	1566.1
CI-H	3190.5	3258.3	3224.4	118.2	3016.2	2913.2	2964.7	106.6	3094.5	295.8
T-H	8906.2	8486.6	8696.4	109.3	11141.0	11539.4	11340.2	96.0	10018.3	1401.4
15th November planting										
T-CI	5299.8	5012.8	5156.3	78.6	10700.6	10552.3	10626.5	142.7	7891.4	2869.3
CI-H	2283.9	2570.9	2427.4	78.6	3496.9	3798.8	3647.8	110.9	3037.6	675.7
T-H	7583.7	7583.7	7583.7	48.4	14197.5	14351.1	14274.3	76.9	10929.0	3497.3
1st December planting										
T-CI	9187.6	9955.2	9571.4	184.6	9920.3	10224.5	10072.4	101.9	9821.9	435.5
CI-H	5605.2	5145.6	5375.4	140.1	4282.2	4178.7	4230.4	91.5	4802.9	658.8
T-H	14792.8	15100.8	14946.8	92.4	14202.5	14403.1	14302.8	72.7	14624.8	388.3
15th December planting										
T-CI	10208.3	9751.2	9979.8	140.5	11265.2	11128.6	11196.9	67.7	10588.3	685.8
CI-H	4226.4	4683.4	4454.9	127.9	4036.1	4026.1	4031.1	43.1	4243.0	314.1
T-H	14434.7	14434.7	14434.7	74.7	15301.4	15154.7	15228.0	73.3	14831.4	448.9
1st January planting										
T-CI	11311.2	10906.4	11108.8	101.3	11801.6	12051.9	11926.8	120.5	11517.8	500.1
CI-H	4434.9	4592.5	4513.7	110.1	3545.2	3294.8	3420.0	82.9	3966.9	614.8
T-H	15746.1	15498.9	15622.5	139.0	15346.8	15346.8	15346.8	45.6	15484.6	281.1

T-CI - Transplanting to curd initiation
CI-H - Curd initiation to harvest
T-H - Transplanting to harvest

V1 - Basant
V2 - Pusa Kartik Sankar
Mean[1] - Mean value for the two years

For the transplanting to curd initiation phase, the accumulated HTU ranged between 5156.3 °C day hrs in 15th November planting and 11108.8 °C day hrs in 1st January planting in 2010-11 and 8375.5 °C day hrs in 1st November planting to 11926.8 °C day hrs in 1st January planting in 2011-12. The HTU requirement from curd initiation to harvest exhibited the same pattern as that of GDD and the crop took 2427.4 °C day hrs in 15th November planting to 5375.4 °C day hrs in the 1st December planting in 2010-11 and 2964.7 °C day hrs in 1st November planting to 4230.4 °C day hrs in the 1st December planting in 2011-12. For the entire crop growth, from transplanting to harvest, the crop took 7583.7 °C day hrs in 15th November planting to 15622.5 °C day hrs in the 1st January planting in 2010-11 and 11340.2 °C day hrs in 1st November planting to 15346.8 °C day hrs in the 1st January planting in 2011-12.

The two year mean of HTU exhibited the same pattern as that of GDD and the least HTU requirement to reach curd initiation and final harvest from transplanting was in the 1st November planted crop whereas, to reach harvest from curd initiation, 15th November planting took the least. The 1st January planted crop took more HTU to reach curd initiation and to complete crop duration, but the 1st December planted crop took more HTU to reach harvest stage from curd initiation. The mean HTU requirements for the different growth phases are 6923.8 - 11517.8 °C day hrs for transplanting to curd initiation phase, 3037.6 - 4802.9 °C day hrs for the curd initiation to harvest phase and 10018.3 - 15484.6 °C day hrs for the complete growth from transplanting to harvest.

4.7.3. Photothermal Units (PTU)

The details regarding the PTU requirement of cauliflower in the present study is given in Table 4.21. The calculated PTU was in accordance with that of accumulated GDD and for the transplanting to curd initiation phase and also for the total crop duration, it was found to be more in 2011-12, except for 1st December and 1st January plantings. But for the curd initiation to harvest phase, PTU was more in 2010-11, except for the 15th November planting.

The accumulated PTU varied from 11005.0 °C day hrs in 15th November planting to 15182.5 °C day hrs in 1st January planting in 2010-11 and

Table 4.21. Accumulated PTU required for the completion of different growth phases in cauliflower

Crop phase	2010-11				2011-12				Mean[1]	SD
	V1	V2	Mean	SE	V1	V2	Mean	SE		
1st November planting										
T-CI	13193.8	12589.6	12891.7	238.8	13189.7	14069.4	13629.5	232.7	13260.6	672.1
CI-H	5034.6	4802.4	4918.5	135.1	4537.9	4118.8	4328.4	183.4	4623.4	486.3
T-H	18228.4	17392.0	17810.2	212.9	17727.5	18188.3	17957.9	110.5	17884.1	403.5
15th November planting										
T-CI	11260.9	10749.1	11005.0	143.0	16251.0	16069.3	16160.2	167.6	13582.6	2716.7
CI-H	3923.7	4435.4	4179.5	142.7	4372.4	4734.5	4553.4	131.5	4366.5	375.2
T-H	15184.5	15184.5	15184.5	96.0	20623.5	20803.8	20713.6	90.2	17949.1	2895.6
1st December planting										
T-CI	14478.7	15393.7	14936.2	219.7	13767.9	14119.0	13943.4	790.5	14439.8	662.0
CI-H	6869.5	6509.1	6689.3	152.8	5448.3	5388.4	5418.3	132.9	6053.8	743.2
T-H	21348.2	21902.8	21625.5	160.2	19216.1	19507.4	19361.8	117.7	20493.6	1226.9
15th December planting										
T-CI	14092.2	13558.1	13825.1	164.4	15240.0	15044.7	15142.8	582.9	14484.0	757.0
CI-H	5995.0	6529.1	6262.1	150.4	5257.5	5263.2	5260.3	60.7	5761.2	587.8
T-H	20087.2	20087.2	20087.2	103.7	20497.5	20308.9	20403.2	94.3	20245.2	284.3
1st January planting										
T-CI	15556.9	14808.0	15182.5	191.7	14912.9	15193.5	15053.2	849.0	15117.8	392.7
CI-H	5572.5	6017.6	5795.1	144.2	5143.1	4862.5	5002.8	81.8	5398.9	496.2
T-H	21129.5	20825.7	20977.6	171.9	20056.0	20056.0	20056.0	66.7	20516.8	569.5

T-CI - Transplanting to curd initiation
CI-H - Curd initiation to harvest
T-H - Transplanting to harvest

V1 - Basant
V2 - Pusa Kartik Sankar
Mean[1] - Mean value for the two years

13629.5 °C day hrs in 1st November planting to 16160.2 °C day hrs in 15th November planting in 2011-12 for the transplanting to curd initiation phase. The curd initiation to harvest took 4179.5 °C day hrs in 15th November planting to 6689.3 °C day hrs in the 1st December planting in 2010-11 and 4328.4 °C day hrs in 1st November planting to 5418.3 °C day hrs in the 1st December planting in 2011-12. To reach the harvest stage from transplanting, the crop took 15184.5 °C day hrs in 15th November planting to 21625.5 °C day hrs in the 1st December planting in 2010-11 and 17957.9 °C day hrs in 1st November planting to 20713.6 °C day hrs in the 15th November planting in 2011-12.

The two year mean PTU also showed the same pattern as that of GDD and the least PTU to reach curd initiation and final harvest from transplanting was in the 1st November planted crop followed by 15th November planted crop but to reach harvest from curd initiation, 15th November planting took the minimum compared to 1st November planting. The 1st January planted crop took more PTU to reach curd initiation and to complete crop duration, but the 1st December planted crop need more to reach harvest from curd initiation. The mean PTU requirements for the different growth phases are 13260.6 - 15117.8 °C day hrs for transplanting to curd initiation phase, 4366.5 - 6053.8 °C day hrs for the curd initiation to harvest phase and 17884.1-20516.8 °C day hrs for the complete growth from transplanting to harvest.

4.8. CROP WEATHER RELATIONSHIPS

Simple linear correlations between weather elements and important growth and yield characters of cauliflower were worked out and are presented below.

4.8.1. Influence of weather parameters on the plant height at the time of harvest

The results of the correlation analysis between weather parameters one to seven weeks prior to harvest and the plant height at the time of harvest are given in Table 4.22.

4.8.1.1. Surface air temperature, relative humidity and vapour pressure deficit

Maximum and mean temperatures showed non-significant positive influence on the final plant height except three weeks prior to harvest. Minimum temperature also

Table 4.22. Correlation between weekly weather parameters prior to harvest and the plant height at the time of harvest

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	-0.271*	-0.019	-0.201	-0.197	0.298*	0.306*	-0.311*	-0.299*	0.129	0.141	0.276*	0.240	0.109
2	-0.079	-0.404**	-0.238	0.174	-0.246	-0.184	0.237	0.111	0.330*	a	-0.015	-0.005	0.117
3	-0.123	0.150	-0.034	-0.179	-0.556**	-0.173	0.592**	0.043	0.046	0.075	-0.135	-0.161	0.542**
4	0.013	0.084	0.063	-0.036	-0.157	-0.171	0.180	0.084	-0.026	-0.166	0.028	0.075	0.134
5	0.109	0.305*	0.231	-0.156	-0.168	-0.124	0.182	0.124	-0.150	-0.190	0.278*	0.234	0.143
6	0.138	0.364**	0.425**	-0.116	0.135	-0.001	-0.118	0.041	0.188	0.334**	-0.033	-0.032	-0.119
7	0.209	0.159	0.328*	0.049	-0.177	-0.105	0.223	0.118	-0.074	0.064	0.104	0.098	-0.036

Table 4.23. Correlation between weekly weather parameters prior to harvest and the number of leaves at the time of harvest

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	-0.430**	-0.053	-0.333**	-0.295*	0.346**	0.499**	-0.374**	-0.505**	0.17	-0.034	-0.163	-0.201	-0.306*
2	-0.256*	-0.286*	-0.316*	-0.089	-0.290*	-0.021	0.274*	-0.086	0.144	a	-0.156	-0.150	0.158
3	-0.140	-0.110	-0.177	-0.068	-0.559**	-0.150	0.567**	0.057	-0.247	-0.320*	0.080	0.068	0.463**
4	-0.171	0.077	-0.100	-0.176	-0.323*	-0.190	0.335**	0.084	-0.248	-0.074	0.150	0.221	0.335**
5	-0.113	0.253	0.064	-0.341**	-0.029	0.102	0.046	-0.142	-0.103	-0.089	0.010	0.002	0.058
6	-0.205	0.432**	0.159	-0.378**	0.394**	0.262*	-0.398**	-0.253	0.282*	0.254*	-0.274*	-0.274*	-0.101
7	-0.093	-0.062	-0.139	-0.027	0.430**	0.276*	-0.406**	-0.257*	0.235	0.186	-0.258*	-0.273*	-0.523**

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

exhibited positive correlation with plant height except two weeks prior to harvest. DTR showed non-significant negative influence except in the second and seventh weeks prior to harvest.

Forenoon relative humidity showed negative relationship with final plant height except in the first and sixth weeks before harvest. Afternoon relative humidity also exhibited negative influence on plant height except in the first week. The influences of forenoon and afternoon vapour pressure deficits on plant height were observed to be in contrast to the effect of corresponding relative humidity.

4.8.1.2. Rainfall and rainy days

Rainfall exhibited positive correlation with plant height except in the fourth, fifth and seventh weeks prior to harvest. Rainy days also showed positive correlation except in the fourth and fifth weeks.

4.8.1.3. Sunshine hours and solar radiation

Bright sunshine hours (BSS) showed positive influence on harvest-time plant height, except in the second, third and sixth weeks prior to harvest. Solar radiation also exhibited the same effect as that of BSS.

4.8.1.4. Wind speed

Wind speed showed positive correlation with final plant height except in the sixth and seventh weeks prior to harvest.

4.8.2. Influence of weather parameters on the number of leaves at the time of harvest

The results of the correlation analysis between weather parameters one to seven weeks prior to harvest and the number of leaves at the time of harvest are given in Table 4.23.

4.8.2.1. Surface air temperature, relative humidity and vapour pressure deficit

Maximum temperature showed negative influence on the final number of leaves with significant correlations in the first and second weeks prior to harvest. Minimum temperature also showed negative correlation with number of leaves except in the fourth, fifth and sixth weeks prior to harvest. The influence of mean temperature was also negative with the exception of fifth and sixth weeks prior to harvest. DTR exhibited negative influence on the harvest-time leaf number.

Forenoon relative humidity showed negative relationship with final number of leaves in the second to fifth weeks and in all other weeks, the correlation was positive. Afternoon relative humidity exhibited negative influence on number of leaves from second to fourth weeks prior to harvest and the correlation was observed to be positive in all other weeks. Forenoon VPD showed positive influence on final number of leaves except in first, sixth and seventh weeks prior to harvest where the correlations were negative with high significance. Afternoon VPD exhibited negative influences on number of leaves at the time of harvest except in the third and fourth weeks before harvest.

4.8.2.2. Rainfall and rainy days

Rainfall showed positive influence on final number of leaves except in the third to fifth weeks prior to harvest and the rainy days exhibited negative correlation except in the sixth and seventh weeks.

4.8.2.3. Sunshine hours and solar radiation

The influence of bright sunshine hours on final number of leaves was just opposite to that of rainfall and the correlation was positive from third to fifth weeks prior to harvest. Solar radiation also exhibited similar pattern.

4.8.2.4. Wind speed

Wind speed showed positive correlation with harvest-time leaf number except in the first, sixth and seventh weeks prior to harvest as that of forenoon VPD.

4.8.3. Influence of weather parameters on plant dry weight at the time of harvest

The results of the correlation analysis between weather parameters one to seven weeks prior to harvest and the plant dry weight are given in Table 4.24. Weather

Table 4.24. Correlation between weekly weather parameters prior to harvest and the plant dry weight at harvest

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	-0.710**	-0.518**	-0.742**	-0.210	-0.423*	0.370*	0.308	-0.558**	-0.499**	-0.850**	-0.316	-0.369*	-0.523**
2	-0.724**	-0.124	-0.668**	-0.640**	-0.410*	0.328	0.003	-0.478**	a	0.423*	-0.652**	-0.653**	0.545**
3	-0.732**	-0.600**	-0.821**	-0.457*	-0.101	0.436*	0.063	-0.545**	-0.449*	-0.606**	0.012	0.136	0.578**
4	-0.826**	0.532**	-0.548**	-0.875**	-0.005	0.365*	0.002	-0.435*	-0.410*	0.042	0.206	0.240	0.423*
5	-0.799**	-0.426*	-0.832**	-0.392*	0.722**	0.729**	-0.725**	-0.756**	0.266	0.330	-0.642**	-0.633**	-0.590**
6	-0.752**	0.569**	-0.706**	-0.730**	0.899**	0.792**	-0.888**	-0.814**	0.384*	0.149	-0.812**	-0.808**	-0.639**
7	-0.797**	0.120	-0.774**	-0.751**	0.826**	0.880**	-0.783**	-0.881**	0.325	0.583**	-0.819**	-0.833**	-0.463*

Table 4.25. Correlation between weekly weather parameters prior to curd initiation and the duration from transplanting to curd initiation

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	0.558**	0.190	0.597**	0.345**	0.096	-0.345**	-0.079	0.396**	0.092	0.006	0.166	0.117	-0.095
2	0.585**	-0.374**	0.246	0.682**	-0.124	-0.574**	0.077	0.600**	-0.680**	-0.655**	0.510**	0.477**	0.035
3	0.363**	-0.256*	0.096	0.508**	-0.478**	-0.525**	0.476**	0.510**	-0.127	-0.381**	0.238	0.271*	0.394**
4	0.438**	-0.044	0.341**	0.326*	-0.585**	-0.594**	0.549**	0.562**	-0.382**	-0.296*	0.612**	0.618**	0.480**
5	0.659**	0.029	0.580**	0.478**	-0.435**	-0.665**	0.405**	0.677**	-0.336**	-0.533**	0.754**	0.750**	0.363**

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

influenced the total dry matter production in the similar way as it affected the curd weight.

4.8.3.1. Surface air temperature, relative humidity and vapour pressure deficit

High significant negative correlation was observed between weekly maximum and mean temperatures and plant dry weight at the time of harvest. Minimum temperature showed negative influence on plant dry weight except in the fourth, sixth and seventh weeks prior to harvest. Obviously, the plant dry weight was negatively influenced by the diurnal temperature range.

Forenoon relative humidity showed negative relationship with plant dry weight up to four weeks prior to harvest and from fifth week onwards the correlation became positive and significant. The relative humidity in the afternoon exhibited positive influence on curd weight. Forenoon VPD showed positive influence on plant dry weight up to four weeks prior to harvest, but during the early crop growth stages, the correlation was high significant and negative. Afternoon VPD exhibited high significant negative influence on plant dry weight.

4.8.3.2. Rainfall and rainy days

Rainfall exhibited negative correlation with plant dry weight at the time of harvest up to four weeks prior to harvest, but in the initial crop growth stages, the correlation was positive. Rainy days exhibited significant negative influence in the first and third weeks prior to harvest.

4.8.3.3. Sunshine hours and solar radiation

Bright sunshine hours showed negative influence on plant dry weight except in the third and fourth weeks prior to harvest. The solar radiation also exhibited the same influence as that of sunshine hours.

4.8.3.4. Wind speed

Wind speed showed negative correlation with plant dry weight except in the second, third and fourth weeks prior to harvest.

Table 4.24. Correlation between weekly weather parameters prior to harvest and the plant dry weight at harvest

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	-0.710**	-0.518**	-0.742**	-0.210	-0.423*	0.370*	0.308	-0.558**	-0.499**	-0.850**	-0.316	-0.369*	-0.523**
2	-0.724**	-0.124	-0.668**	-0.640**	-0.410*	0.328	0.003	-0.478**	a	0.423*	-0.652**	-0.653**	0.545**
3	-0.732**	-0.600**	-0.821**	-0.457*	-0.101	0.436*	0.063	-0.545**	-0.449*	-0.606**	0.012	0.136	0.578**
4	-0.826**	0.532**	-0.548**	-0.875**	-0.005	0.365*	0.002	-0.435*	-0.410*	0.042	0.206	0.240	0.423*
5	-0.799**	-0.426*	-0.832**	-0.392*	0.722**	0.729**	-0.725**	-0.756**	0.266	0.330	-0.642**	-0.633**	-0.590**
6	-0.752**	0.569**	-0.706**	-0.730**	0.899**	0.792**	-0.888**	-0.814**	0.384*	0.149	-0.812**	-0.808**	-0.639**
7	-0.797**	0.120	-0.774**	-0.751**	0.826**	0.880**	-0.783**	-0.881**	0.325	0.583**	-0.819**	-0.833**	-0.463*

Table 4.25. Correlation between weekly weather parameters prior to curd initiation and the duration from transplanting to curd initiation

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	0.558**	0.190	0.597**	0.345**	0.096	-0.345**	-0.079	0.396**	0.092	0.006	0.166	0.117	-0.095
2	0.585**	-0.374**	0.246	0.682**	-0.124	-0.574**	0.077	0.600**	-0.680**	-0.655**	0.510**	0.477**	0.035
3	0.363**	-0.256*	0.096	0.508**	-0.478**	-0.525**	0.476**	0.510**	-0.127	-0.381**	0.238	0.271*	0.394**
4	0.438**	-0.044	0.341**	0.326*	-0.585**	-0.594**	0.549**	0.562**	-0.382**	-0.296*	0.612**	0.618**	0.480**
5	0.659**	0.029	0.580**	0.478**	-0.435**	-0.665**	0.405**	0.677**	-0.336**	-0.533**	0.754**	0.750**	0.363**

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

4.8.4. Influence of weather on the duration from transplanting to curd initiation

The results of the correlation analysis between weather parameters one to five weeks prior to curd initiation and the duration from transplanting to curd initiation are given in Table 4.25.

4.8.4.1. Surface air temperature, relative humidity and vapour pressure deficit

Maximum temperature showed significant positive correlation with the days taken to curd initiation in all the seven weeks prior to harvest. Mean temperature also exhibited positive correlation whereas, minimum temperature showed negative influence on the duration from transplanting to curd initiation except in the first and fifth weeks prior to harvest. The influence of DTR on the days taken to curd initiation was observed to be positive and significant.

Relative humidity exhibited negative influence with high significant correlations in the case of afternoon relative humidity, but the influence of forenoon relative humidity was non-significant in the first and second weeks prior to harvest. The influences of forenoon and afternoon VPD were observed to be opposite to that of the corresponding relative humidity, exhibiting high significant positive correlations with respect to afternoon VPD.

4.8.4.2. Rainfall and rainy days

Rainfall and rainy days exhibited negative influence on the duration from transplanting to harvest except in the first week prior to harvest.

4.8.4.3. Sunshine hours and solar radiation

Both bright sunshine hours and solar radiation showed positive influence on the duration from transplanting to harvest.

4.8.4.4. Wind speed

Wind speed showed positive correlation with the duration from transplanting to harvest except in the first week prior to harvest.

4.8.5. Influence of weather parameters on crop duration (duration from transplanting to harvest)

The results of the correlation analysis between weather parameters one to seven weeks prior to harvest and the duration from transplanting to harvest (crop duration) are given in Table 4.26.

4.8.5.1. Surface air temperature, relative humidity and vapour pressure deficit

Maximum temperature showed significant positive correlation with the crop duration in all the seven weeks prior to harvest. Mean temperature also showed positive correlation except in the first week prior to harvest whereas, minimum temperature showed negative influence on crop duration except in the third week prior to harvest. In the case of DTR, the influence on crop duration was positive and high significant.

Forenoon and afternoon relative humidity exhibited negative influence on crop duration with high significant correlations in afternoon relative humidity. In contrast, the effect of VPD on crop duration was positive with high significant correlations in afternoon VPD.

4.8.5.2. Rainfall and rainy days

Rainfall exhibited negative influence on crop duration except in the first and third weeks prior to harvest. Rainy days influenced crop duration in the similar way as that of rainfall.

4.8.5.3. Sunshine hours and solar radiation

Both bright sunshine hours and solar radiation showed high significant positive influence on crop duration for all the seven weeks prior to harvest.

4.8.5.4. Wind speed

Wind speed showed positive correlation with crop duration except in third and seventh weeks prior to harvest.

Table 4.26. Correlation between weekly weather parameters prior to harvest and the duration from transplanting to harvest

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	0.279*	-0.365**	-0.042	0.480**	-0.288*	-0.351**	0.280*	0.337**	0.203	0.214	0.500**	0.577**	0.268*
2	0.571**	-0.063	0.394**	0.645**	-0.409**	-0.755**	0.382**	0.732**	-0.230	a	0.754**	0.766**	0.239
3	0.532**	0.029	0.482**	0.448**	-0.281*	-0.565**	0.320*	0.517**	0.039	0.093	0.498**	0.390**	-0.112
4	0.521**	-0.101	0.384**	0.461**	-0.168	-0.545**	0.135	0.536**	-0.084	-0.318*	0.377**	0.386**	0.052
5	0.355**	-0.159	0.139	0.510**	-0.584**	-0.690**	0.553**	0.656**	-0.384**	-0.544**	0.525**	0.551**	0.612**
6	0.569**	-0.409**	0.200	0.601**	-0.562**	-0.698**	0.522**	0.667**	-0.439**	-0.289*	0.622**	0.643**	0.386**
7	0.702**	-0.119	0.578**	0.527**	-0.223	-0.635**	0.168	0.628**	-0.399**	-0.552**	0.623**	0.594**	-0.022

Table 4.27. Correlation between weekly weather parameters prior to harvest and the curd weight

Weeks prior to harvest	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	WS
1	-0.748**	-0.348	-0.667**	-0.393*	-0.417*	0.437*	0.330	-0.612**	-0.328	-0.696**	-0.516**	-0.560**	-0.466**
2	-0.803**	-0.234	-0.780**	-0.665**	-0.201	0.507**	0.021	-0.637**	a	0.203	-0.702**	-0.695**	0.326
3	-0.725**	-0.626**	-0.825**	-0.436*	-0.050	0.418*	-0.016	-0.514**	-0.518**	-0.673**	0.005	0.133	0.538**
4	-0.815**	0.413*	-0.602**	-0.816**	-0.100	0.315	0.099	-0.383*	-0.434*	-0.016	0.205	0.206	0.395*
5	-0.862**	-0.230	-0.765**	-0.578**	0.756**	0.806**	-0.738**	-0.836**	0.383*	0.482**	-0.670**	-0.651**	-0.542**
6	-0.774**	0.509**	-0.774**	-0.727**	0.907**	0.803**	-0.903**	-0.824**	0.406*	0.204	-0.781**	-0.771**	-0.574**
7	-0.820**	-0.027	-0.845**	-0.730**	0.804**	0.871**	-0.773**	-0.873**	0.380*	0.622**	-0.850**	-0.864**	-0.469**

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

4.8.6. Influence of weather parameters on curd weight

The results of the correlation analysis between weather parameters one to seven weeks prior to harvest and curd weight are given in Table 4.27.

4.8.6.1. Surface air temperature, relative humidity and vapour pressure deficit

A high significant negative correlation was observed between weekly maximum and mean temperatures and curd weight. Minimum temperature showed negative influence on curd weight except in the fourth and sixth weeks prior to harvest. Obviously, the curd weight was negatively influenced by the diurnal temperature range.

Forenoon relative humidity showed negative relationship with curd weight up to four weeks prior to harvest and from fifth week onwards the correlation became positive and significant. In contrast, relative humidity in the afternoon exhibited positive influence on curd weight. Forenoon and afternoon relative humidity during the initial crop growth stage showed high significant positive correlation. Forenoon VPD showed negative influence on curd weight except in first, second and fourth weeks prior to harvest where the correlations were positive and non-significant. Afternoon VPD exhibited high significant negative influence on curd weight.

4.8.6.2. Rainfall and rainy days

Rainfall exhibited negative correlation with curd yield up to four weeks prior to harvest, but in the initial crop growth stages, the correlation was positive. Rainy days also exhibited the same influence except in the second week prior to harvest.

4.8.6.3. Sunshine hours and solar radiation

Bright sunshine hours showed high significant negative influence on curd weight except in the third and fourth weeks prior to harvest. The solar radiation also exhibited the same influence as that of sunshine hours.

4.8.6.4. Wind speed

Wind speed showed negative correlation with curd weight except in the second, third and fourth weeks prior to harvest.

4.9. INFLUENCE OF HEAT UNITS ON THE DURATION OF DIFFERENT GROWTH STAGES

The correlation of heat units with the duration of different crop growth stages were determined by using the accumulated growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) for the corresponding growth stages (Table 4.28).

Table 4.28. Influence of heat units on the duration of different growth stages

Growth stage	GDD	HTU	PTU
T-CI	0.989**	0.785**	0.983**
CI-H	0.966**	0.899**	0.950**
T-H	0.980**	0.824**	0.967**

T-CI - Duration from transplanting to curd initiation

CI-H - Duration from curd initiation to harvest

T-H - Duration from transplanting to harvest

The different heat units exhibited high significant positive correlation with each crop growth stages and the highest correlation coefficients were obtained with the accumulated growing degree days followed by photothermal units. The GDD and PTU exhibited more correlation with the duration from transplanting to curd initiation, whereas HTU showed high correlation with the duration of curd initiation to harvest phase.

4.10. MODEL FOR THE PREDICTION OF CURD WEIGHT

Multiple linear regression equations were developed for predicting the curd weight using mean weather variables experienced by the crop during the transplanting to curd initiation period in 2011-12. The prediction equation developed is given below.

$$\text{Curd weight} = 474.743\ T_{max} - 569.084\ T_{min} + 77.06\ \text{RH II} - 418.844\ \text{BSS} - 2547.22$$
$$(R^2 = 0.95)$$

Where, T_{max}, T_{min}, RH II and BSS are the maximum temperature, minimum temperature, afternoon relative humidity and bright sunshine hours experienced by the crop during the transplanting to curd initiation phase.

4.11. INCIDENCE OF PESTS, DISEASES AND PHYSIOLOGICAL DISORDERS

During the course of investigation, incidence of various pests, diseases and physiological disorders were noticed in accordance with the changing weather conditions. Fluctuations in the kind and severity of different pests and diseases affected the general performance of the crop in the first year whereas in second year, the crop was observed to be free from the severe incidence of pests and diseases.

4.11.1. Incidence of pests

Incidence of several major pests of cauliflower was observed in the experiment depending upon the weather prevailed and the stage of crop growth and the pests observed were more in 2010-11 compared to 2011-12. The different pests noticed are Tobacco caterpillar (*Spodoptera litura)*, Painted bug (*Bagrada hilaris)*, Cabbage green semilooper (*Trichoplusia ni*), Cabbage stem borer (*Helhula undalis*), Diamond back moth (*Plutella xylostella)*, Cotton aphid (*Aphis gossypii)*, and Cabbage leaf webber (*Crocidolomia binotalis)*. The pests observed in crops under different planting times in both the years are given in Table 4.29 and Plate 4.5.

Tobacco caterpillar was observed as a regular pest with variations in severity in both the years regardless of the growth stage of the crop, but its activity was low in the delayed plantings compared to 1st November, 15th November and 1st December plantings and the 15th December and 1st January plantings in 2011-12 were completely free from the incidence of tobacco caterpillar. The incidence of cabbage stem borer, semilooper and leaf webber were also observed in the early plantings where they were not observed in the 15th December and 1st January plantings. Painted bug was observed as a serious pest in 1st November and 15th November planted crops in 2010-11 whereas, it was not observed in the 2011-12 experiment. Diamondback moth

Table 4.29. Pests observed in different times of planting

Week No.	Time of planting									
	1st November		15th November		1st December		15th December		1st January	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
1	T,S	-	P	T	T,P,S	-	-	-	-	-
2	T,P,W	T,B,	T,P	T	-	-	-	-	-	-
3	P,B,W	T,B	P,B,W	-	-	T,A	-	-	-	-
4	B	S,B	P,B	T,B	T,W	T,A	T	-	D	-
5	T,P,S	T,S,W	-	T,B,A,W	W	T	A	-	D	-
6	P	S,A	W	T,A	T,P,S,D	-	-	A	-	-
7	P,W	T,A	T,W	T,S,A	D,A	T,W	D	A	-	A
8	T,P,S	T,S	-	T,B,A,W	T,D,A,W	B	D,A	-	T,D,A	A
9	T,P,W	T		T,A,W	D	A	-	A	D,A	A
10	-	T		T	D	A	A	A	A	A
11				-	-	B,A	A	-	T,A	
12					D,A					

T - Tobacco caterpillar
P - Painted bug
S - Cabbage green semilooper
B - Cabbage stem borer
D - Diamond back moth
A - Cotton aphid
W - Cabbage leaf webber

(a) Diamondback moth

(b) Cabbage semilooper

(c) Cabbage leaf webber

(d) Painted bug

(e) Tobacco caterpillar

(f) Cabbage stem borer

(g) Cotton aphid

Plate 4.5. Pests observed during the experiment

was noticed in the delayed plantings in 2010-11 and the incidence was severe in the 1st December planting. The incidence of cotton aphid was observed in each delayed planting from 1st December onwards in 2010-11, whereas it was present in all crops in 2011-12 especially during the curd initiation phase and noticed until harvest.

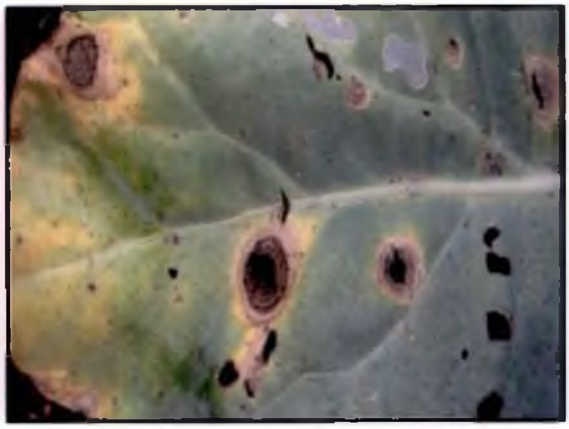
4.11.2. Incidence of diseases

The incidence of diseases was also less in 2011-12, where none of the observed diseases resulted in yield reduction, but in 2010-11, the occurrence of Black rot which is a bacterial disease caused by *Xanthomonas campestris* pv. *campestris* caused considerable yield reduction in the earlier plantings, whereas this disease did not occurred in 2011-12. The other diseases noticed in the experiment were Soft rot caused by *Erwinia caratovora* and Leaf spot caused by *Alternaria brassicola*. Damping off caused by *Pythium aphanidermatum* was observed in the seedlings of 1st November and 15th November plantings in both the years in nursery.

Black rot was observed in all the crops in 2010-11 coupled with the incidence of Soft rot. The incidence of soft rot was also seen in the 1st November and 15th November plantings in 2011-12. Both Soft rot and Black rot were observed during the curd development period, whereas Alternaria leaf spot occurred irrespective of crop growth stage. In both years, Alternaria leaf spot was noticed in the 1st November planting. It was also observed in 15th November, 1st December and 1st January plantings in 2010-11, whereas it was not observed in 2011-12 for plantings after 1st November. In 2011-12, no disease was observed beyond 15th November planting. The diseases observed in crops under different planting times in both the years are given in Table 4.30 and Plate 4.6.

4.11.3. Incidence of physiological disorders

Physiological disorders like bracting, leafiness, riceyness, blindness and buttoning were observed in different plantings depending on the weather conditions experienced. Bracting was noticed in the earlier plantings of 1st November, 15th November and 1st December, whereas in delayed plantings leafiness was observed and it was found in the 15th December and 1st January plantings in both the years. Riceyness appeared in the 1st November and 15th November plantings of

(a) Damping off (b) Alternaria leaf spot

(c) Soft rot


(d) Black rot

Plate 4.6. Diseases observed during the experiment

Table 4.30. Diseases observed in different times of planting

Week No.	Time of planting									
	1st November		15th November		1st December		15th December		1st January	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
1	-	-	A	-	-	-	-	-	-	-
2	A	A	A	-	-	-	-	-	-	-
3	A	A	-	-	-	-	-	-	A	-
4	A	A	-	-	-	-	-	-	-	-
5	-	A	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-
7	-	-	B,S	-	-	-	-	-	-	-
8	S	-	B,S	-	-	-	-	-		-
9	B,S	S		-	-	-	-	-	A	-
10	B,S	S		-	-	-	B	-	B,A	-
11				S	B	-	B	-	B	
12					B,S					

A - Alternaria leaf spot
B - Black rot
S - Soft rot

Table 4.31. Physiological disorders observed in different times of planting

Time of planting	Year	Physiological disorder				
		Bracting	Leafiness	Riceyness	Blindness	Buttoning
1st November	2010-11	✓		✓	✓	
	2011-12				✓	
15th November	2010-11	✓		✓	✓	
	2011-12					
1st December	2010-11	✓	✓			
	2011-12			✓		
15th December	2010-11		✓			✓
	2011-12		✓			✓
1st January	2010-11		✓			
	2011-12		✓			✓

(a) Blindness

(b) Riceyness

(c) Buttoning

(d) Bracting

(e) Leafiness

Plate 4.7. Physiological disorders observed during the experiment

2010-11 and 1st December planting of 2011-12. Blindness was observed in the 1st November plantings in both the years and 15th November planting in 2011-12 whereas, buttoning was found in the 1st December planting in 2010-11 and 15th December plantings in both the years. The physiological disorders observed in crops under different planting times in both the years are given in Table 4.28 and Plate 4.7.

Discussion

5. DISCUSSION

Cauliflower is very much exacting in climatic requirements compared to other cole crops (Ara *et al.* 2009). Hence, planting at the appropriate time using the suitable variety is essential to ensure a healthy crop and to get good curd yield with high market value. Since the planting time is influenced by the prevailing weather conditions, determination of the different growth-affecting weather factors is very much important. Thus the study of crop weather relationships became essential in crop calender. The results of the present attempt to ascertain the crop weather relationships in cauliflower are discussed below.

5.1. EFFECT OF WEATHER ON GROWTH AND DEVELOPMENT OF CAULIFLOWER

5.1.1. Plant height

The weekly plant heights differed significantly for the different times of planting and the pattern was found to be dissimilar for the two years. But during the harvest-time, the plant height was higher in the delayed plantings in 2010-11 (Fig. 5.1), which was in agreement with the finding of Suseela and Rangaswami (2011) that higher temperatures increased plant height in cauliflower. The maximum height was found in the 1st December planting in 2010-11 (14.0 cm), since the crop duration was long in that crop compared to other plantings which allowed the plant to get exposed to higher temperatures for more number of days and thereby the plant height increased.

But in 2011-12, the higher plant height was observed in the 1st November planted crop (14.8 cm) because of the active vegetative growth during the curd initiation phase favoured by the low mean and minimum temperatures and higher forenoon and afternoon relative humidity compared to the first year. Reduction in plant height with respect to delay in planting time as observed in 2011-12 was also noted by Srivastava *et al.* (2002), BingLiang *et al.* (2005) and Ara *et al.* (2009).

The plant height was observed to be similar in both Basant and Pusa Kartik Sankar indicating that these genotypes had similar responses to the weather parameters influencing plant height. Even though, there were differences in plant

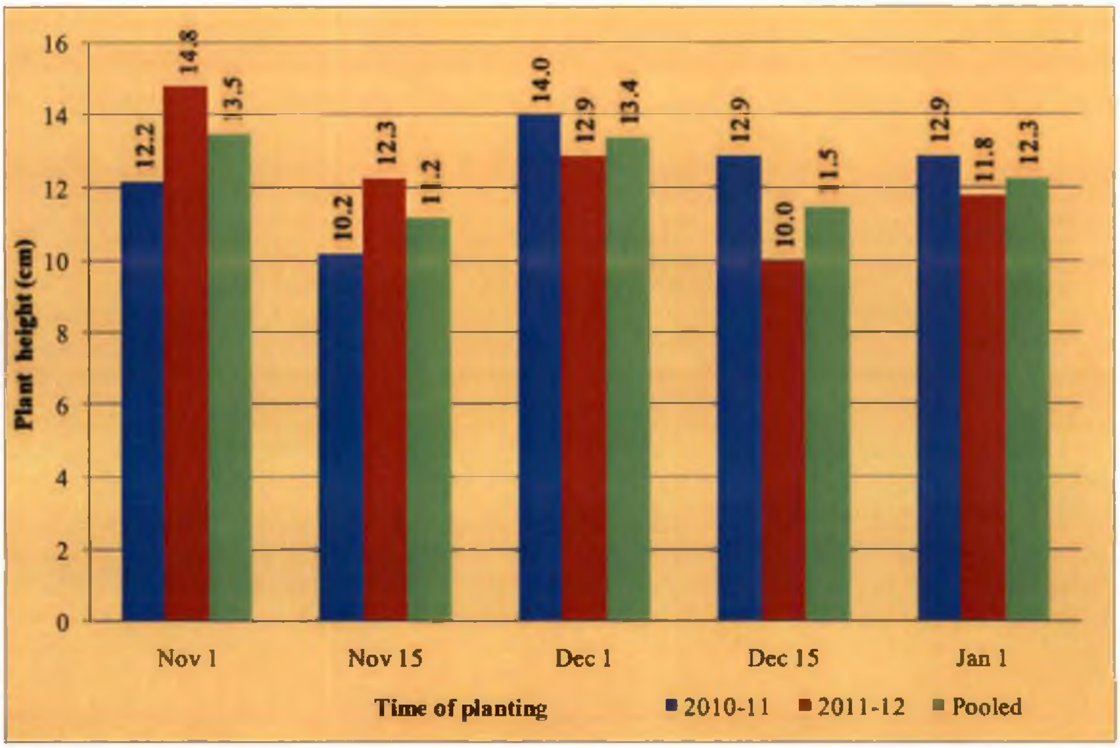


Fig. 5.1. Plant height of different times of planting at the time of harvest

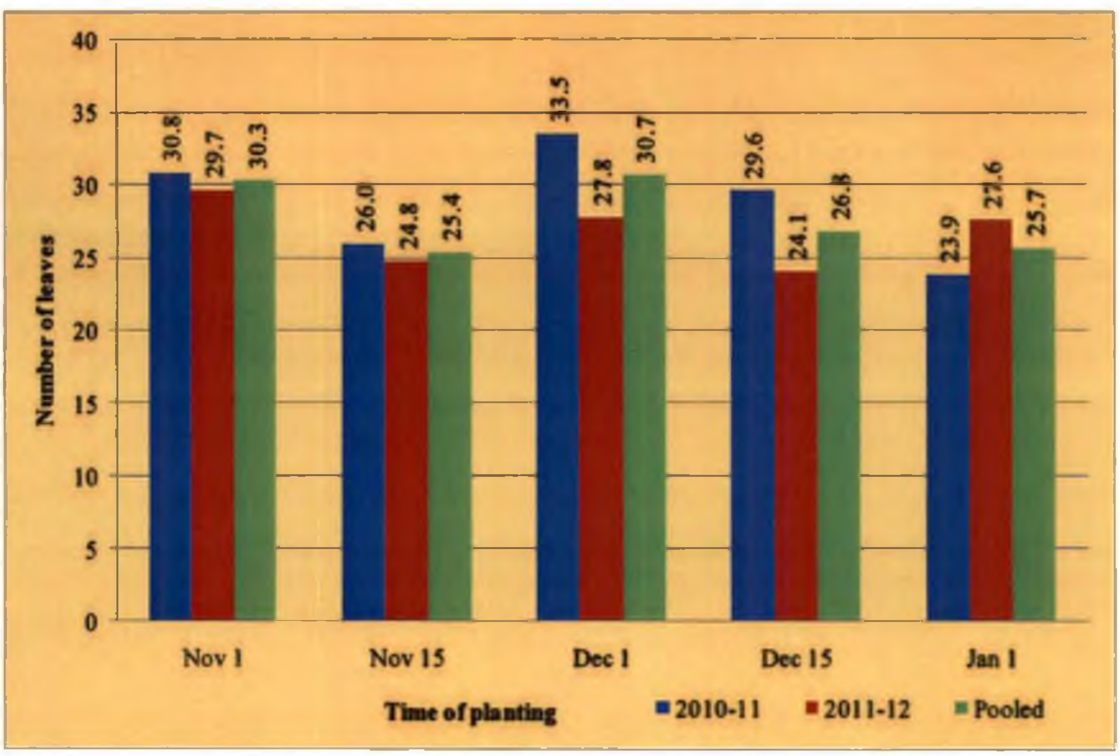


Fig. 5.2. Number of leaves of different times of planting at the time of harvest

height with respect to time of planting in both the years, pooled analysis showed that times of planting were similar (11.2-13.5 cm) because of the high variability between the two years. The year-to-year variation for the same planting time may be attributed by the fluctuation in the minimum temperature in both the years during the experimental period.

The maximum, minimum and mean temperatures showed positive correlation with plant height (Suseela and Rangaswami, 2011) until curd initiation and after that increase in temperature exhibited negative effect on harvest-time plant height, but the diurnal temperature range exhibited negative effect on plant height. Increase in forenoon and afternoon vapour pressure deficit in response to decrease in the corresponding humidity also favoured enhanced plant height. Bright sunshine hours, solar radiation and wind speed also showed positive effect on plant height. Rahman *et al.* (2007a) observed lengthier stem in cauliflower under high incident radiation conditions.

5.1.2. Number of leaves

Number of leaves showed variation with respect to prevailing weather conditions because at the time of transplanting the number of leaves was 3.8-4.4 for the different times of planting in 2010-11, but at the time of harvest it ranged between 23.9 and 33.5.

Compared to first year, leaf production was less in the second year (Fig. 5.2) because of the higher temperature and solar radiation along with lower humidity and higher vapour pressure deficit experienced by the crop. Even though, variation with respect to leaf number was observed in individual years for different planting times, no significant difference was noticed in the pooled analysis (25.4-30.3 leaves) because of the considerable variation observed between the same planting times in both the years. The year-to-year variation for the same planting time may be attributed by the fluctuation in minimum temperature during the experimental period in both the years. Though, no specific pattern in leaf production was noticed with respect to planting time in this study, decrease in leaf number in response to delay in planting time was

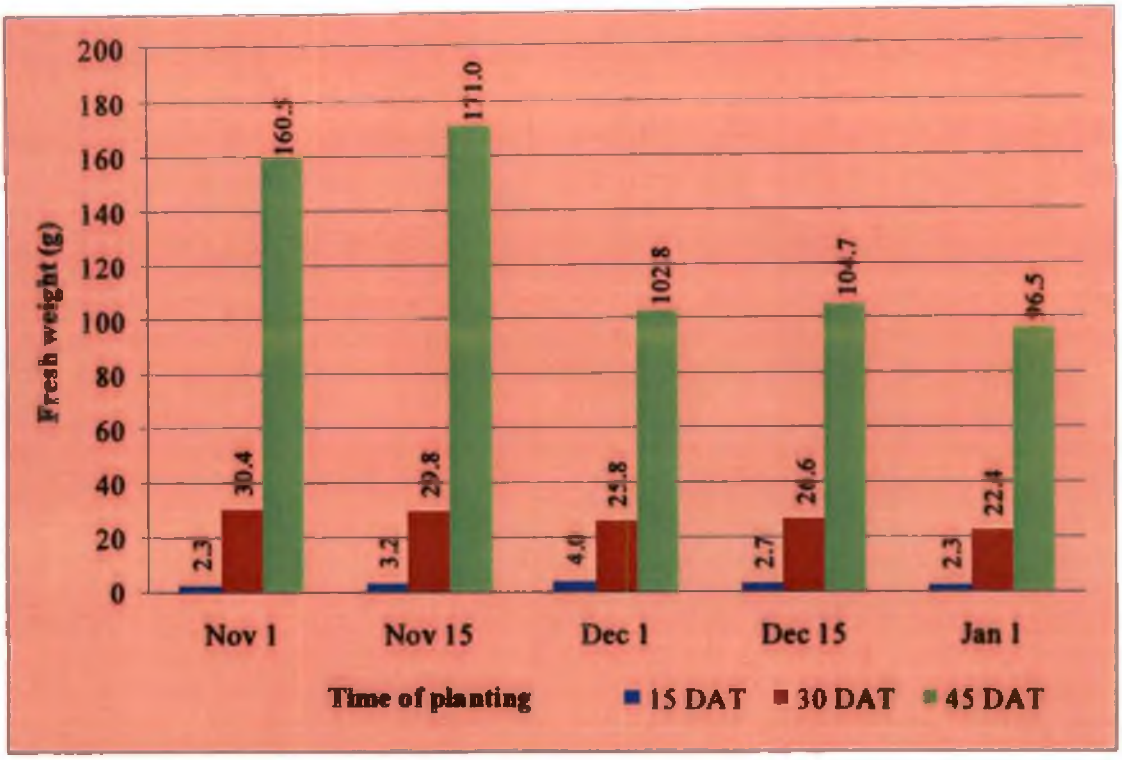


Fig. 5.3. Plant fresh weight of different times of planting at 15 DAT, 30 DAT and 45 DAT

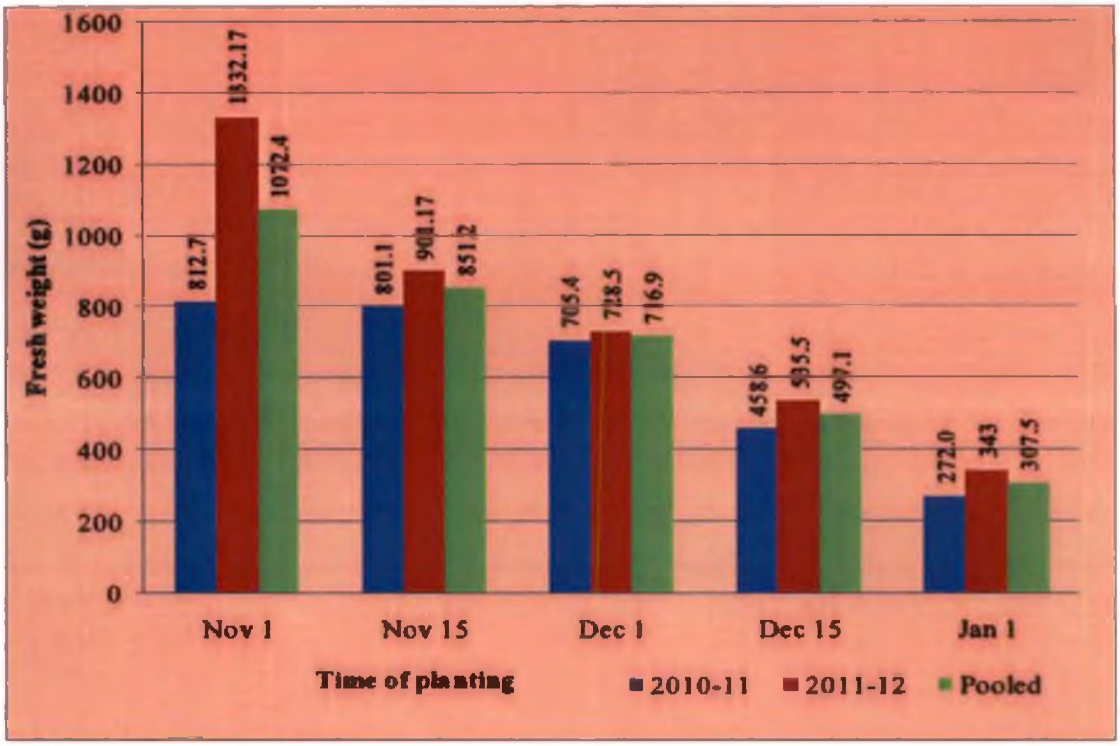


Fig. 5.4. Plant fresh weight of different times of planting at the time of harvest

observed by Nanda *et al.* (1995), Srivastava *et al.* (2002), BingLiang *et al.* (2005) and Kaur *et al.* (2007).

The correlation analysis revealed that the production of leaves decreased with increase in maximum temperature and diurnal temperature range. According to Nowbuth and Pearson (1998), warmer temperatures reduced the production of leaves. But in temperate varieties of cauliflower, it is reported that increase in temperature favours leaf production (Wurr *et al.*, 1996; Nowbuth, 1997). Kage and Stutzel (1999) observed that there was a relationship between temperature sum and leaf number. In the initial weeks after transplanting increase in relative humidity enhanced the leaf production, but as the crop approached to curd initiation, relative humidity showed a negative influence until the curd development is over.

The number of leaves at the time of harvest was more in the 1st November planting (29.7 leaves) in 2011-12, because of the active vegetative growth favoured by the weather conditions, especially the lower maximum temperature, but in 2010-11, the highest number of leaf was recorded in 1st December planting (33.5 leaves) because of the lowest minimum temperature experienced by the crop during its crop growth. Enhancement of vegetative growth in cauliflower by the effect of low mean temperature was noticed by Uzun and Peksen (2000). The number of leaves was observed to be similar for both Basant and Pusa Kartik Sankar indicating that these varieties have similar responses to the weather parameters influencing leaf production.

In delayed plantings, irrespective of the year, plants produced shorter leaves even though the leaf number varied. The high incident solar radiation coupled with high temperature might have resulted in small leaf size. Koike *et al.* (2009) observed the production of small leaves at high temperature. Olesen and Grevsen (1997) reported that high irradiance can reduce leaf area expansion rate, but Rahman *et al.* (2007a) reported more leaf in higher radiation conditions. Olesen and Grevsen (1997) observed low leaf area expansion when the mean leaf surface temperature exceeded 21°C. Kaur *et al.* (2007) observed less production of leaves in delayed planting which were having less leaf area index. Sharma *et al.* (2006a) observed reduction in vegetative growth with gradual increase in temperature. More number of leaves with

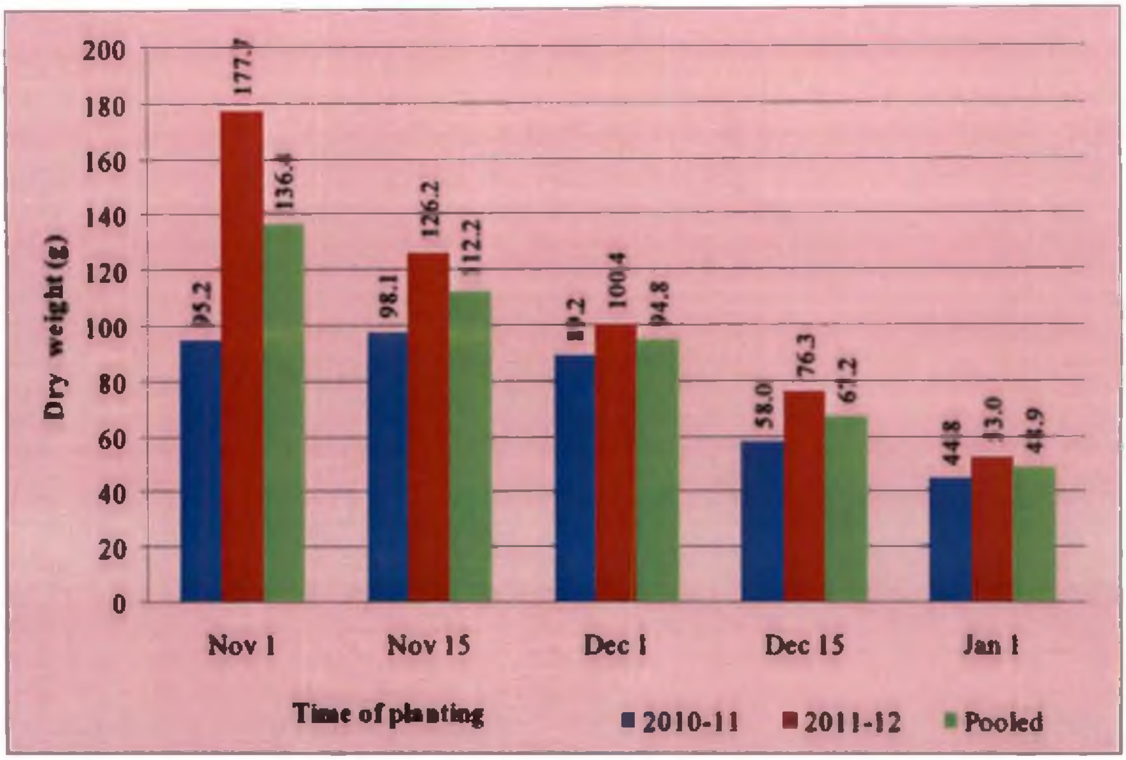


Fig. 5.5. Plant dry weight of different times of planting at the time of harvest

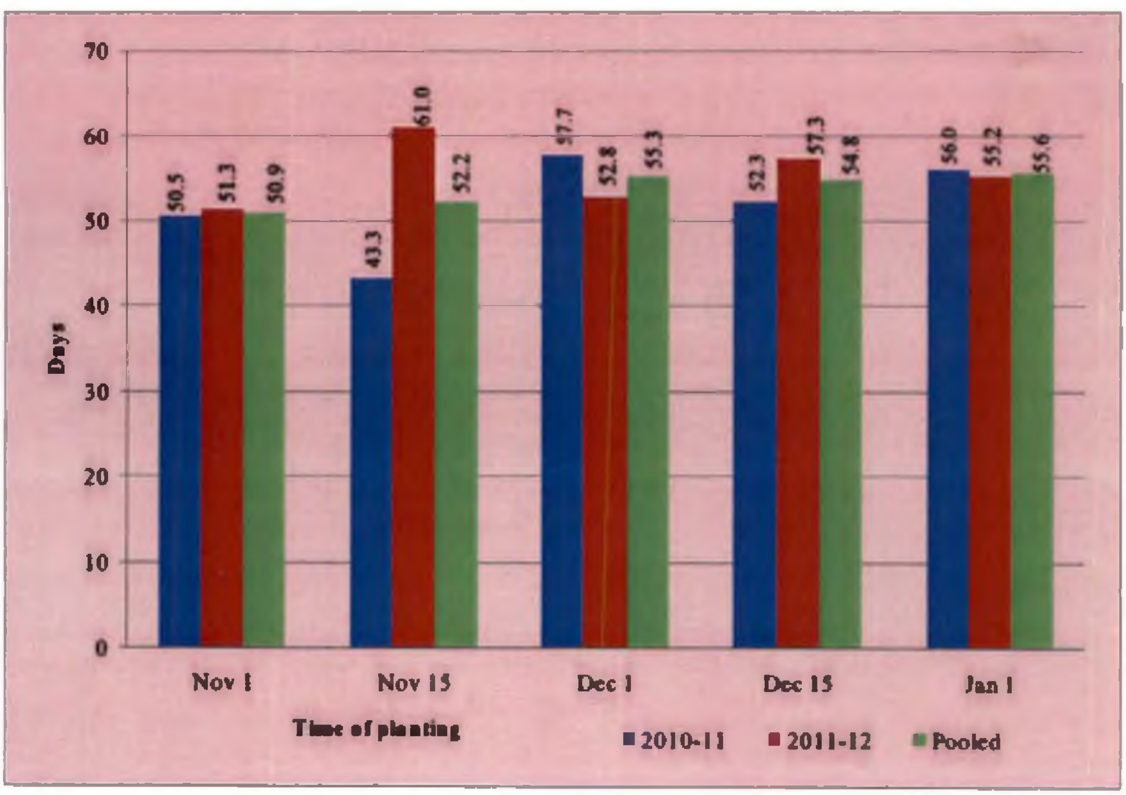


Fig. 5.6. Duration of transplanting to curd initiation period in different times of planting

higher leaf size in earlier plantings observed in this study is in conformity with that of Gautam *et al.* (1998).

5.1.3. Plant weight

The influence of planting time on the whole plant weight was recognized in this study. In the initial crop growth stage, the plant fresh and dry weights were observed to be more in the 1st December plantings in both the years, but at 45 DAT, the 1st November and 15th November planted crops recorded the highest fresh and dry weights (Fig. 5.3) because of the higher vegetative growth. The vegetative stages of these early plantings were observed to be very active in the respective growing environments with low temperature, low incident radiation, high humidity and low vapour pressure deficit. Plant weights were low in the delayed plantings because of the stunted plant growth as a result of higher temperature (Sharma *et al.*, 2006a) and solar radiation (Olesen and Grevsen, 1997).

The plant weight was high in early plantings at the harvest time also (Fig. 5.4 and 5.5), which was attributed by the active vegetative growth before the curd initiation phase along with the higher curd weight. The fresh and dry plant weights obtained in 2011-12 were 1332.2g and 177.7g in 1st November planting and 343.0g and 53.0g in 1st January plantings, respectively. The plant weight of 2010-11 is not considered since there was reduction in curd yield due to the incidence of black rot disease which resulted in decreased plant weight. Rahman *et al.* (2007b) reported that the radiation conversion coefficients for both plant and curd of cauliflower were high under lower incident radiation levels than higher radiation levels. Thus they indicated that the rate of increase per unit incident radiation integral is greater under lower radiation conditions.

5.2. EFFECT OF WEATHER ON THE DURATION OF DIFFERENT GROWTH STAGES

5.2.1. Duration from transplanting to curd initiation

The duration from transplanting to curd initiation showed considerable variation with respect to time of planting in both the years (Fig. 5.6). Grevsen (1990)

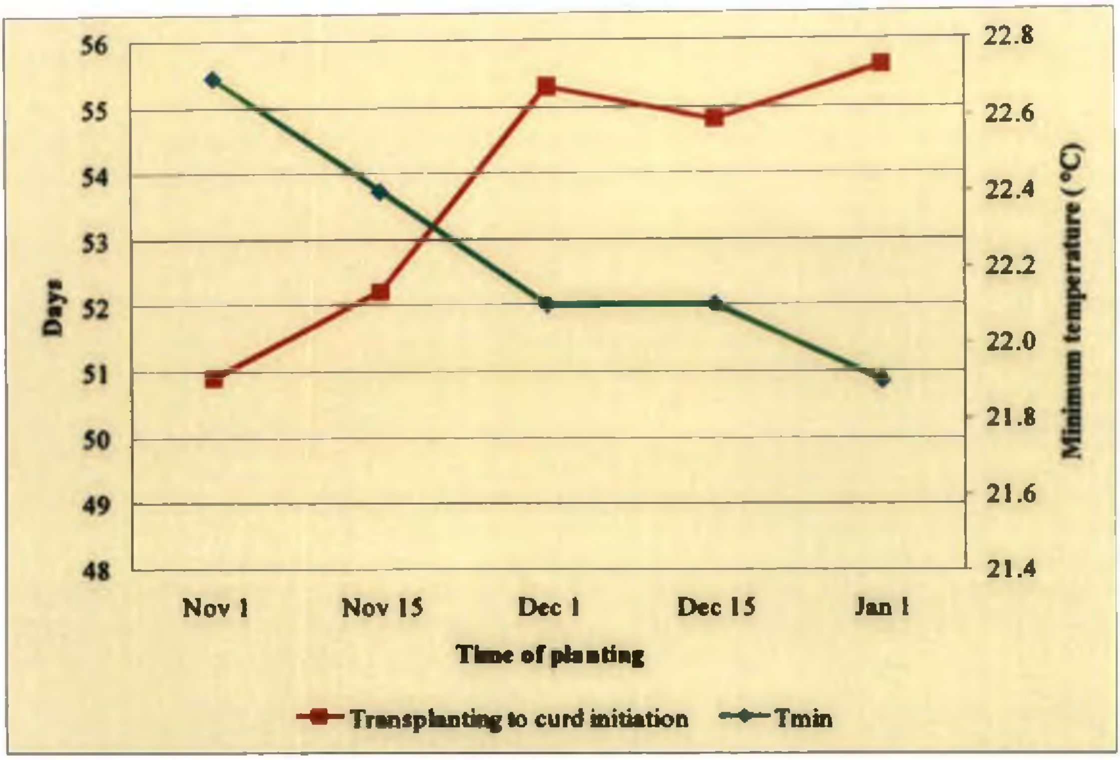


Fig. 5.7. Relationship between minimum temperature and the duration of transplanting to curd initiation phase

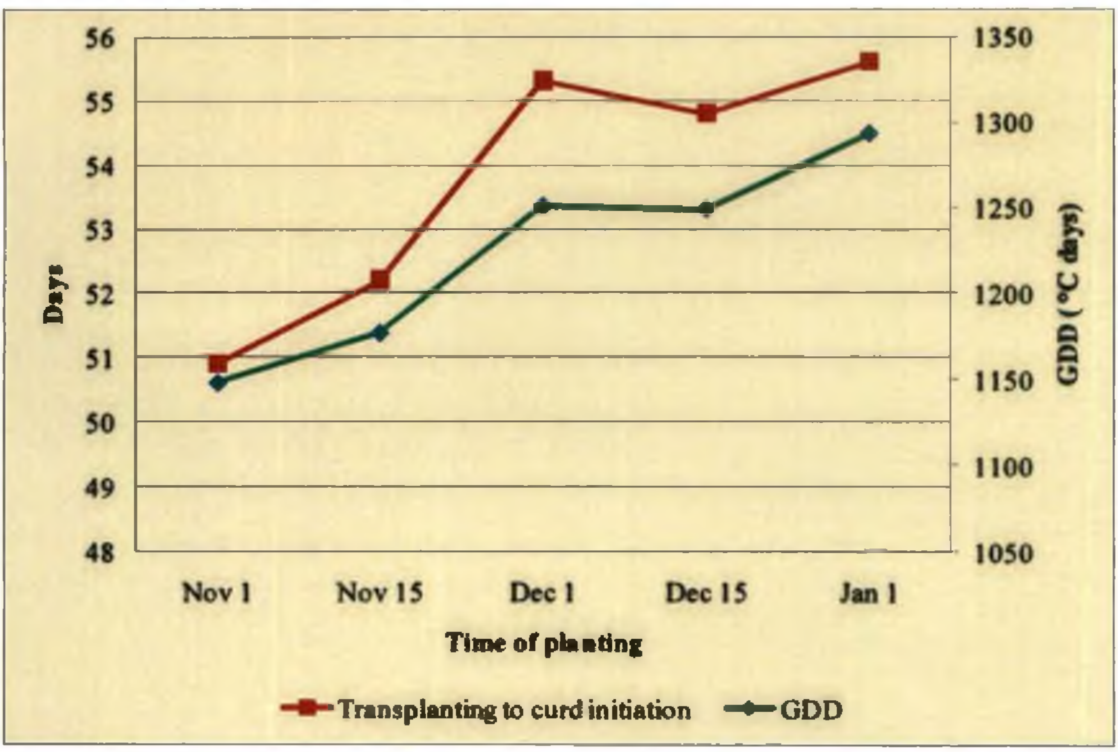


Fig. 5.8. Relationship between growing degree days and the duration of transplanting to curd initiation phase

observed that the period between transplanting and curd initiation showed more variation than that from curd initiation to harvest. The curd yield was observed to be high when the duration of this phase was short. Duration of this growth stage varied between 50.9 days and 55.6 days in the pooled analysis. The shortest duration in 2010-11 was observed in the 15th November planting (43.3 days) because of the low mean temperature experienced by the crop during this period compared to that of 1st November planting which took 50.5 days for curd initiation and the mean temperature experienced (26.4°C) was very low compared to all other planting times. But in the second year 15th November planted crop took more number of days to reach curd initiation phase (61.0 days) because the crop underwent high diurnal variation in temperature (9.3°C) compared to 15th November planting (8.5°C).

From the correlation analysis, it was identified that maximum and mean temperatures and diurnal temperature range exhibited positive influence on the duration of this phase. The bright sunshine hours and solar radiation also showed positive influence on the duration of this phase. Delayed initiation of curd due to increase in temperature was also noted by many workers (Liptay, 1981; Wheeler *et al.*, 1995; Wurr *et al.*, 1996; Wurr and Fellows, 1998; Chatterjee and Kabir, 2002; Wurr *et al.*, 2004; Singh, 2008). The minimum temperature showed an overall negative influence on the duration from transplanting to curd initiation (Fig. 5.7), but for the curd initiation to occur, the minimum temperature should be low in the preceding week.

Relative humidity showed negative influence and VPD showed positive influence on the duration from transplanting to curd initiation. The heat units exhibited positive influence indicating the effect of both temperature and sunshine hours and among the different heat units, growing degree days were appeared to have high correlation with the duration of this phase and the influence of GDD on the duration from transplanting to curd initiation is depicted in Fig. 5.8.

5.2.2. Duration from curd initiation to harvest

In both the years, the duration to curd maturity was shorter in the earlier plantings (Fig. 5.9) and the shortest duration was observed in the 15th November

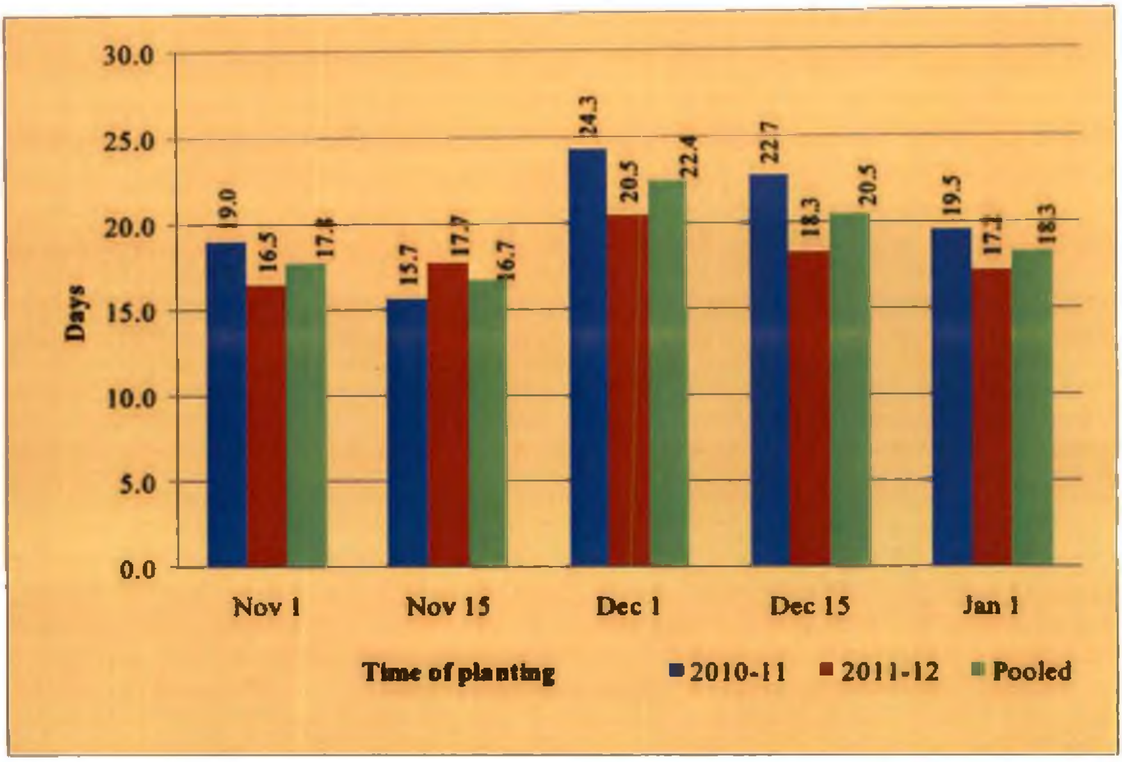


Fig. 5.9. Duration of curd initiation to harvest period in different times of planting

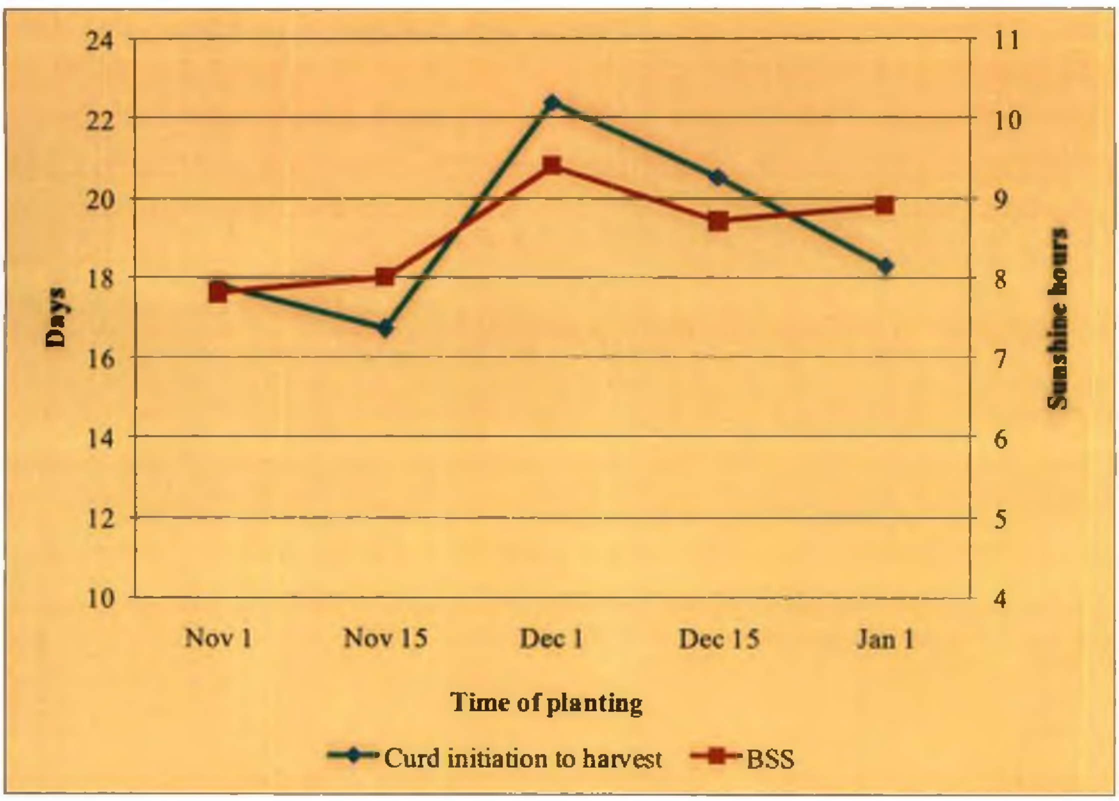


Fig. 5.10. Relationship between bright sunshine hours and duration of curd initiation to harvest phase

planting (16.7 days) whereas the longest was noticed in 1st December planting (22.4 days). During this phase, the most critical weather variables influencing the duration were observed to be bright sunshine hours and solar radiation and these were exhibited positive impact. The influence of BSS on the duration of this growth stage is depicted in Fig.5.10. Maximum and mean temperatures and DTR also showed positive influence on the duration of curd initiation to harvest period. Booij (1990a) also noted the increase in the duration of this phase with respect to temperature.

5.2.3. Duration from transplanting to harvest (crop duration)

The crop duration was observed to be less in the earlier plantings (Fig. 5.11) and this was observed to be influenced by the duration from transplanting to curd initiation. The crop duration varied between 68.7 days in 1st November and 77.7 days in the 1st December planting. Booij (1987) observed that there was a correlation between the number of days from transplanting to harvesting and the date of curd initiation. He reported that late curd initiation resulted in late harvest, which was observed to be true in this study. The crop duration was positively influenced by maximum and mean temperatures, diurnal variation of temperature, bright sunshine hours and solar radiation. Relative humidity exhibited negative effect on crop duration whereas, vapour pressure deficit and wind speed showed positive effect. Heat units showed positive influence and the effect of growing degree days on the entire crop duration is depicted in Fig. 5.12.

5.3. CURD WEIGHT

Curd in cauliflower is the prefloral fleshy apical meristem and the formation of curd is the transient stage between vegetative and generative stage which is highly influenced by the prevailing weather conditions.

In the present study, curd weight decreased with each delay in planting time (Fig. 5.13) which was observed by many workers (Crisp, 1984; Gautam *et al.*, 1998; Sphehia and Korla, 2000; Pradeepkumar *et al.*, 2002; Jana and Mukhopadhyay, 2006; Ajithkumar and Savani, 2007). Maximum (Fig. 5.14) and mean temperatures and diurnal temperature range showed a negative influence on curd weight and at higher temperatures, the curd yield obtained was very less. The reduction in curd yield with

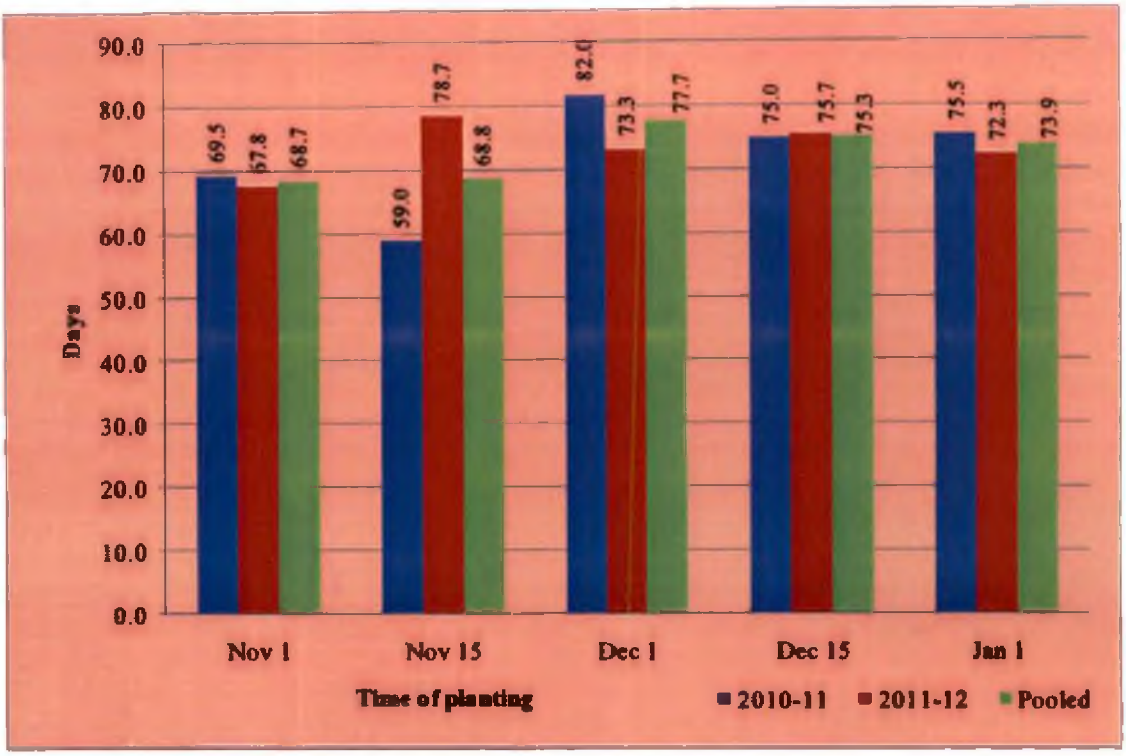


Fig. 5.11. Duration from transplanting to harvest in different times of planting

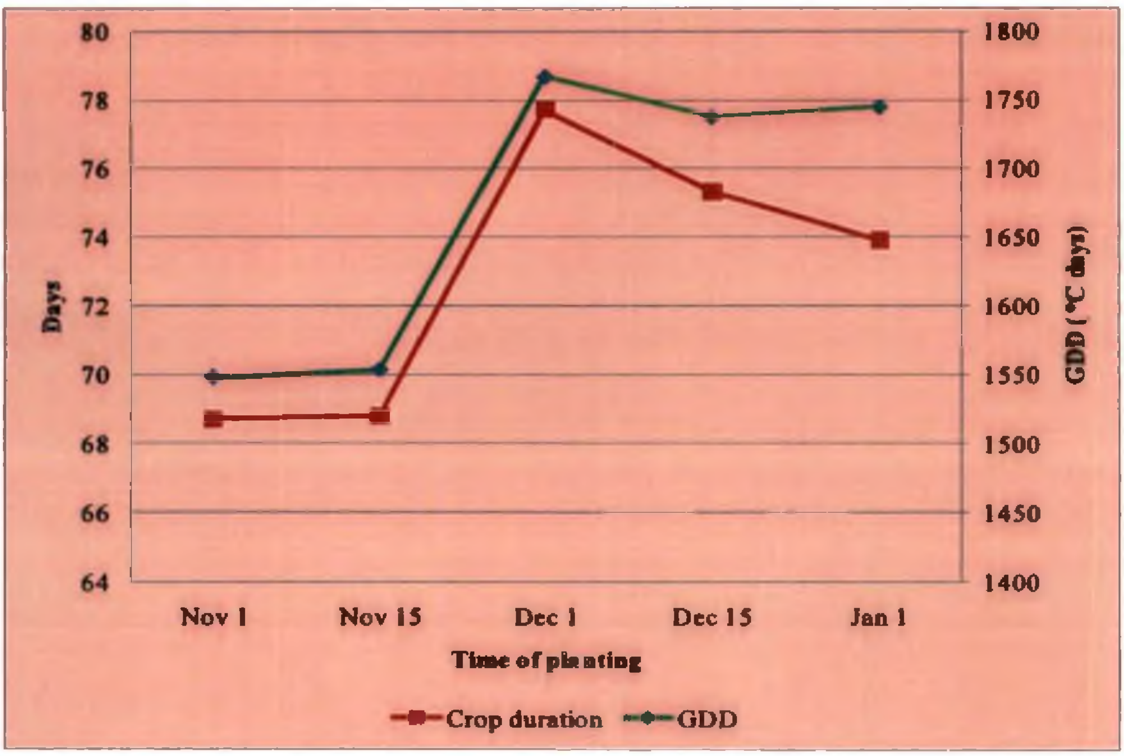


Fig. 5.12. Relationship between growing degree days and the crop duration

increase in temperature was noticed by many researchers (Wheeler *et al.*, 1995; Warland *et al.*, 2006; Suseela and Rangaswami, 2011). Minimum temperature showed negative relation with curd weight in the correlation analysis and it was observed that the temperature before curd initiation influenced the curd weight more than that after the curd initiation. For better yield, the minimum temperature should be low in the curd development phase compared to that of curd initiation phase. The highest curd yield was observed in 1st November planted crop in 2011-12 which required less heat units and it is illustrated by considering growing degree days (Fig. 5.15).

Afternoon relative humidity showed positive influence and vapour pressure deficit showed negative influence on curd weight. Bright sunshine hours and solar radiation during the early vegetative and curd development stages exhibited negative influence on curd weight. Sharma and Parashar (1982) observed that cooler and wet weather helped in increased production compared to higher temperature. Nathoo (2003) also reported similar findings. Khan and Holliday (1968) also observed the reduction in curd yield with increase in bright sunshine hours. Wind speed during the curd maturation period (one week before harvest) showed significant negative influence on curd weight.

In this study, earlier curd initiation resulted in highest curd weight which was in agreement with the finding of Singh *et al.* (1997). As reported by Jindal and Thakur (2009), curd weight was observed to be more in the plants where the whole plant weight was high. Uzun and Peksen (2000) also reported higher curd weight in plants with more vegetative growth. Booij (1990b) reported that low plant weight at the time of curd initiation reduced curd weight at maturity and the number of days from curd initiation to maturity was not related to curd weight. Incidence of black rot disease occurred in 2010-11 which resulted in low curd yield in all planting times compared to 2011-12.

According to Kumar *et al.* (2010), the average marketable curd weight of early maturing Indian cauliflowers ranges between 280g to 490g and Elavarasan (2011) reported less curd weight (34-82g) in plains for the tropical varieties. But in the present study, it was observed that, in the plains, if weather conditions are favourable, a curd yield of 535.2g can be achieved if planting is done in the first fortnight of

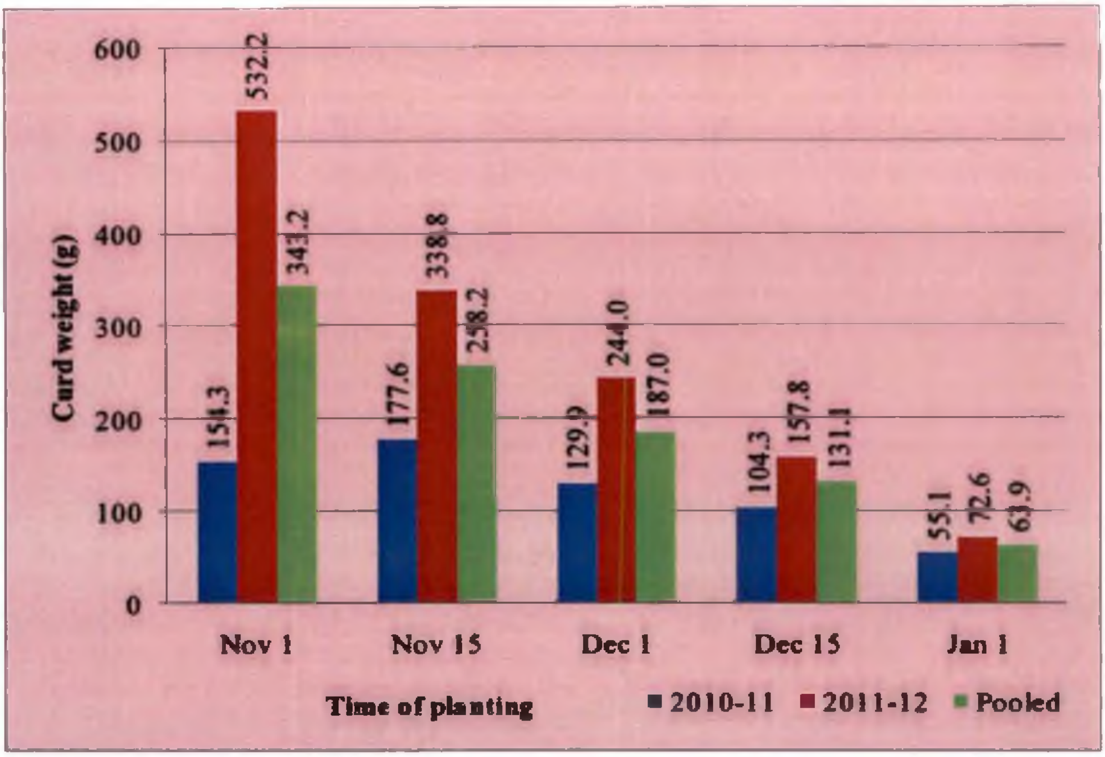


Fig. 5.13. Curd weight obtained in different times of planting

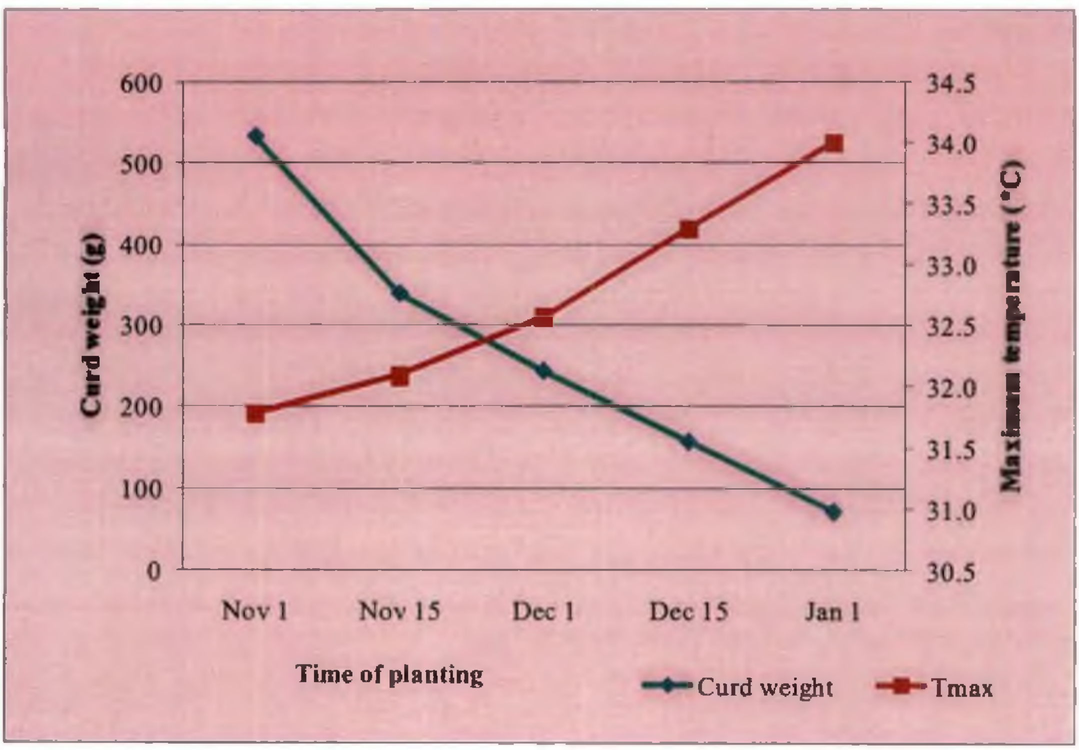


Fig. 5.14. Variation in curd weight in different times of planting as influenced by maximum temperature during the entire crop duration

November. The optimum weather variables contributing to higher yield were identified as, 31.1-31.4°C, 22.4-22.7°C, and 26.9-27.0°C of maximum, minimum and mean temperatures respectively with low DTR of 8.4-8.9°C, higher humidity of 81.1-83.6% in forenoon and 55.6-59.6% in afternoon, lower vapour pressure deficits of 3.9-4.4 mm Hg in forenoon and 13.6-15.1 mm Hg in afternoon, low bright sunshine hours and solar radiation of 5.9-6.5 hrs and 15.7-16.6 MJ m^{-2} respectively, in the transplanting to curd initiation phase followed by further low minimum temperature of 21.1-22.7 °C in the curd development phase. So planting of tropical cauliflowers can be done when the maximum temperature, mean temperature, DTR, BSS and solar radiation are, less than 31.2°C, 26.8°C, 8.8°C, 6.0 hrs, and 22.3 MJ m^{-2} respectively, with minimum temperature of 22.5°C.

Cauliflower curd has to be white or pale cream in colour. Masarirambi *et al.* (2011) opined that direct exposure to sunlight might result in the development of yellow pigments on curds by the activation of peroxidase enzyme by sunlight and curds would loosen in the sun's heat. The curd colour was slightly yellowish at the time of harvest in every planting in the present study and it was also observed by Koike *et al.* (2009). Jaya *et al.* (2002) and Singh (2007) observed that high temperature and irradiance during the curd growth phase resulted in poor quality curds.

Planting in the first fortnight of November can be adopted in plains of central Kerala for getting good yield and to ensure quality produce by means of curd colour and fewer incidences of physiological disorders. Optimum planting times for cauliflower cultivation based on curd weights were also determined by many workers for different climatic regions (Chatterjee and Som, 1990; Patil *et al.*, 1995; Gautam *et al.*, 1998; Dutta, 1999; Sphehia and Korla, 2000; Pradeepkumar *et al.*, 2002; Sharma *et al.*, 2006a; Ajithkumar and Savani, 2007; Din *et al.*, 2007; Ara *et al.*, 2009).

Utmost care must be taken while undertaking cauliflower cultivation in this region during this period, because the environmental conditions existing here depends on the Northeast monsoon which may be favourable for the incidence of bacterial diseases, especially black rot, which can result in considerable yield losses as noticed in 2010-11. Possibility of crop damage by way of mechanical injury and pest and

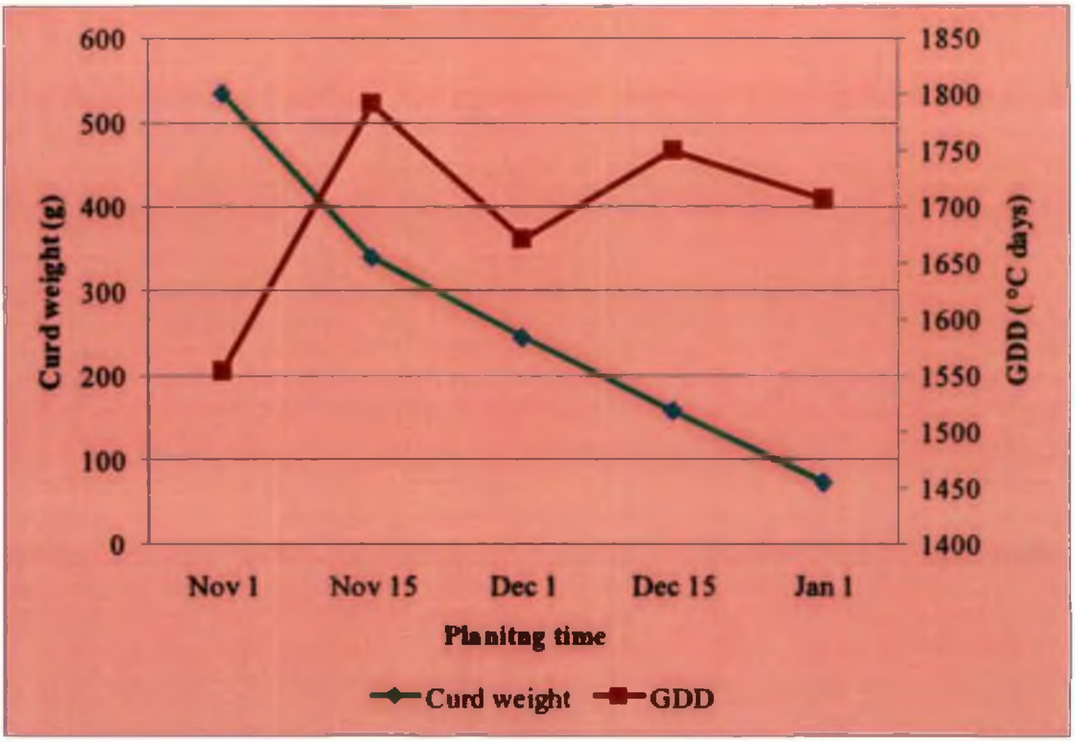


Fig. 5.15. Relationship between growing degree days and curd weight

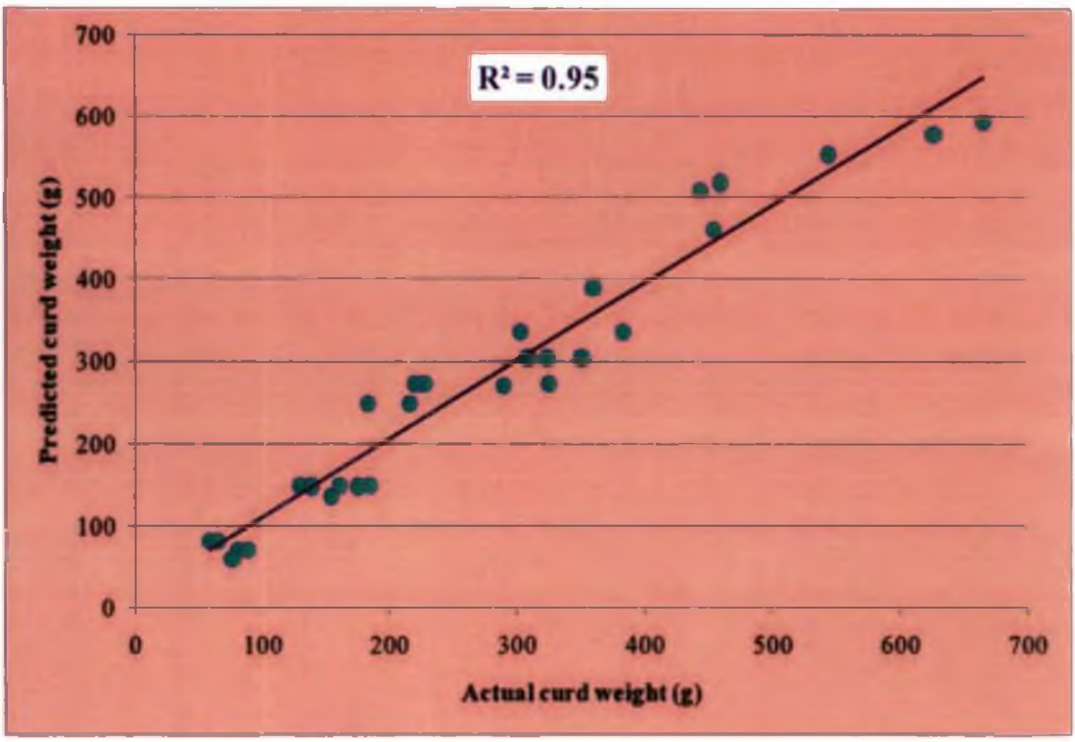


Fig. 5.16. Actual and predicted curd weight of cauliflower

disease incidence as a result of the northeast monsoon rains should be considered in extensive cultivation of cauliflower.

Basant was noted as the superior variety with respect to curd weight in this study but this variety was regarded as the most susceptible variety to black rot by Prasanna (2011). Hence trials must be conducted to identify the best suited tropical early variety with respect to resistance or tolerance to this devastating disease, which is adapted to the climate of central Kerala.

5.4. PREDICTION MODEL FOR CURD WEIGHT

Variation in the time to maturity and crop yield among plants transplanted at similar times of the year in different years resulted in large deviations from planned production programmes all over the world and the complementary technique that can be used to aid in crop marketing would be prediction of the time of crop maturity as reported by Wurr *et al.* (1990). Prediction of the yield of cauliflower based on weather variables prevailed before curd initiation is having utmost practical importance. Hence, multiple linear regression equations were fitted based on different weather variables using stepwise regression method and the best fitting equation was selected based on R^2 value. The equation developed is given below.

$$\text{Curd weight} = 474.743\ T_{max} - 569.084\ T_{min} + 77.06\ \text{RH II} - 418.844\ \text{BSS} - 2547.22$$

This equation could predict the curd yield of cauliflower with a precision of 95% (Fig. 5.16) and this can be used in crop planning in the central zone of Kerala. Prediction models to study the effect of climatic variables on crop maturity in cauliflower were also developed by Pearson *et al.* (1994), Olesen and Grevsen (2000), and Ajithkumar (2005).

5.5. WEATHER INFLUENCE ON THE INCIDENCE OF PESTS, DISEASES AND PHYSIOLOGICAL DISORDERS

Weather plays an important role in the incidence of various pests and diseases in crops. Further, growth and survival of pests and pathogens are influenced by the prevailing weather conditions. If weather is favourable, then serious outbreaks of pests and diseases may occur. Besides, environmental fluctuations at different developmental stages can cause several physiological defects that affect productivity of the crop, as it reduces the market value of the produce. Among cole crops, physiological disorders are mostly found in cauliflower because of their sensitivity to varying environments (Hazra and Som, 1999).

5.5.1. Effect of weather on the incidence of pests

The activity of Tobacco caterpillar (*Spodoptera litura*), Cabbage stem borer (*Hellula undalis*), Cabbage semilooper (*Trichoplusia ni*), leaf webber (*Crocidolomia binotalis)* and painted bug (*Bagrada hilaris)* were more in the initial plantings, where the crop life was in the months of November to January. The higher temperature, lower relative humidity and higher VPD in February and March might have resulted in the decreased activity of these pests in the delayed plantings, but these meteorological conditions favoured the activity of aphids and diamondback moth (*Plutella xylostella)*. Varalakshmi *et al.* (2006) noticed that the months of December and January were favourable for the multiplication of Tobacco caterpillar in cauliflower. Rao *et al.* (2003) reported that the larval population of Tobacco caterpillar in cauliflower was negatively correlated with temperature. Patait *et al.* (2008) reported that population of this pest was positively influenced by forenoon relative humidity and negatively by minimum temperature and afternoon relative humidity.

The incidence of cabbage borer in the earlier plantings is in agreement with the findings of Patait *et al.* (2008) that forenoon relative humidity showed positive and maximum temperature showed negative effect on the pest population. They also reported that the population of leaf webber is positively correlated with afternoon relative humidity and negatively by the action of forenoon relative humidity and minimum temperature which is also observed in this study. The increased activity of DBM in the delayed plantings is in conformity with the findings that the population of DBM is positively correlated with temperature (Varalakshmi *et al.* 2006; Wagle *et al.*, 2006), negatively related to the amount of rainfall (Jankowska, 2005) and negatively correlated with relative humidity (Ahmad and Ansari, 2010).

The incidence of painted bug was occurred in the 1st November planting which was in disagreement with the positive correlation between temperature and pest population observed in cruciferous crops but in accordance with the negative correlation observed in weeds as reported by Singh (1996). Incidence of cotton aphid (*Aphis gossypii)* was noticed in both the years for all delayed plantings whereas cabbage aphid (*Brevicoryne brassicae*) was not observed in any of the planting times. The cotton aphid incidence was observed in plantings where the average mean temperature during the entire crop duration was above 27.1°C and it was in agreement with the finding of Kersting *et al.* (1999) that the optimum temperature for the population growth of cotton aphid on cotton was 25-30°C.

5.5.2. Effect of weather on the incidence of diseases

Black rot and soft rots were observed in the curd development period of the earlier plantings. The 1st November planted crop received high rainfall before curd initiation with a total amount of 306.1mm in 13 days in 2010-11 and 240.0mm in 9 days in 2011-12, which resulted in a highly humid atmosphere with less vapour pressure deficit and more soil moisture status creating the favourable conditions for the incidence of these bacterial diseases. Capuno *et al.* (2009) reported that 100% bacterial soft rot infection occurred in cauliflower due to heavy rains when planted in open condition whereas disease was absent in the plants grown in rain-shelter.

Black rot was reported as the most serious bacterial disease of cole crops, particularly destructive in tropical regions. The yield reducing power of black rot was realized by many researchers (Akhtar, 1989; Gill and Sharma, 1996; Hazra and Som, 1999; Verma, 2002). Warm temperatures with higher humidity facilitated the incidence of black rot (Prasanna, 2011) in the first year. Dutta *et al.* (2011) reported that rate of disease increment was positively correlated with forenoon and afternoon relative humidity and rainfall and negatively correlated with maximum, minimum and mean air temperature. They also revealed that average temperature of 27-30°C and average relative humidity greater than 85% and presence of rainfall were associated with this disease. All these conditions were observed in the present study during the disease incidence which is usually experienced in this region. Hence, intensive care must be given and proper monitoring and management strategies should be adopted for the cultivation of cauliflower in the central parts of Kerala.

The maximum temperature at the time of curd initiation and during the incidence of black rot were above 30°C and as reported by Verma (2002), temperature between 25°C and 35°C is optimum for the incidence of this disease. The occurrence of dewfall during the curd initiation phase intensified the disease incidence. Hazra and Som (1999) reported that black rot disease is prevalent in regions where rainfall or dew is plenty. Singh (2007) also reported that the incidence of black rot is favoured by frequent rains. Apart from these, Basant which is one of the varieties used for the experiment is reported as the most susceptible variety to black rot by Prasanna (2011).

The heavy rainfall in the initial weeks after transplanting caused the incidence of Alternaria leaf spot disease in the 1st November plantings of both the years and 15th November planting of 2010-11. The rainfall that occurred in the 8th and 9th standard weeks with a total of 77.5mm in 3 rainy days caused the incidence of leaf spot in the 1st January planted crop in 2010-11. Duration of wetness was higher during these periods due to the prolonged exposure to rains and as reported by Mahi and Kingra (2007), magnitude of incidence of leaf spot disease depends upon the duration of wetness. Singh (2007) also reported that moist atmosphere is conducive for the incidence of leaf spot disease in cauliflower.

5.5.3. Effect of weather on the incidence of physiological disorders

Both bracting and leafiness were observed in the study, even though both of the varieties considered were adapted to higher temperatures (Singh *et al.*, 2009; Singh and Nath, 2011). As reported by many workers (Hazra and Som (1999); Grevsen *et al.* (2003); Bhat (2009)), the prevalence of higher temperature might have resulted in the occurrence of bracting and leafiness in this region and the lower temperature limit for the incidence of leafiness might be higher than that needed for bracting, since it occurred in the delayed plantings. Riceyness was observed when the minimum temperature before and after the initiation of curd was higher and it was in agreement with the opinion of Kohli *et al.* (2008) that warm cloudy nights were favourable for the riceyness disorder.

Blind cauliflower plants are those lacking the terminal bud and these type of plants were observed in the crops planted on 1st November and 15th November and as opined by Joseph and Markose (2007), the growing point might have collapsed at the early stage of growth either by insects (Hazra and Som, 1999) or by the splashing effect of continuous rainfall during the initial months of transplanting in both the years as a result of the northeast monsoon rains. Buttoning disorder of cauliflower is marked by the development of small curds when the plants are small and it was observed in the delayed plantings and was in agreement with the opinion of Hazra and Som (1999) that planting of early variety late in the season can result in this disorder.

Summary

6. SUMMARY

The experiment on "Crop weather relationships in cauliflower (*Brassica oleracea* var. *botrytis* L.)" was carried out at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara, Thrissur during 2010-11 and 2011-12. The experiment was conducted to study the effect of weather on growth and yield of cauliflower and to assess the suitability of cauliflower under various crop growing environments. The salient findings of the study are summarized as follows.

The height of the plants at different weeks after transplanting was observed to be highly variable among the different planting times with respect to prevailing weather conditions. However, at the time of harvest, no significant difference for plant height was noticed with respect to the planting time (11.2-13.5cm) in the pooled analysis. The test varieties (Basant and Pusa Kartik Sankar) were alike for plant height, indicating that these varieties have similar responses to the weather parameters.

The maximum, minimum and mean temperatures showed positive correlation with plant height until curd initiation and after that increase in temperature exhibited negative effect on plant height. The diurnal temperature range (difference between daily maximum and minimum temperatures) also exhibited negative effect. Increase in bright sunshine hours, solar radiation and wind speed exhibited positive effect on plant height. Increase in forenoon and afternoon vapour pressure deficits in response to decrease in the corresponding humidity also favoured the enhancement of plant height.

The number of leaves also showed variation in different planting times with respect to prevailing weather conditions. However, at the time of harvest, no significant difference for the number of leaves was noticed in the pooled analysis with respect to the planting time (25.4-30.7 leaves). The leaf production was observed to be less in the second year compared to the first year. The production of leaves decreased with increase in maximum temperature and diurnal temperature range. In the initial weeks after transplanting increase in relative humidity enhanced the leaf production, but as the crop approached to curd initiation, relative humidity showed negative influence until the curd development is over. In delayed plantings,

irrespective of the year, plants produced shorter leaves even though the leaf number varied.

In the initial crop growing period, the plant fresh and dry weights were observed to be more in the 1st December plantings in both the years, but at 45 DAT, the 1st November and 15th November planted crops recorded the highest fresh and dry weights because of the higher vegetative growth and the lowest plant weights were observed in the delayed plantings. At the harvest time also, the higher plant weight was recorded in earlier plantings and the highest fresh weight obtained in 2011-12 was 1332.2g in 1st November planting.

The duration from transplanting to curd initiation showed considerable variation with respect to time of planting and it ranged between 50.9 days in 1st November planting to 55.6 days in the 1st January planting and the shorter duration of this phase resulted in higher curd yield. The maximum and mean temperatures and diurnal temperature range exhibited positive influence on the duration of this phase. The bright sunshine hours and solar radiation also showed positive influence. The minimum temperature showed negative influence, but for the curd initiation to occur, the minimum temperature should be low in the preceding week. Relative humidity exhibited negative influence and vapour pressure deficit showed positive influence. The heat units also exhibited positive influence.

In both the years, the lowest duration to curd maturity was exhibited by the earlier plantings on 15th November (16.7 days) and 1st November (17.8 days). During this phase, the most critical weather variables influencing the duration were observed to be bright sunshine hours and solar radiation and these were exhibited positive impact. Maximum and mean temperatures and diurnal temperature range also showed positive influence.

The crop duration was observed to be less in the earlier plantings on 1st November (68.7 days) and 15th November (68.8 days). The crop duration was positively influenced by maximum and mean temperatures, diurnal variation of temperature, bright sunshine hours and solar radiation. Relative humidity exhibited negative effect on crop duration whereas, vapour pressure deficit and wind speed showed positive effect. Heat units also showed positive influence.

The curd yield decreased with each delay in planting time from 1st November to 1st January in response to the increase in maximum and mean temperatures and diurnal temperature range. The minimum temperature before the curd initiation phase influenced the curd weight more than that after the curd initiation and for better yield the minimum temperature should be low in the curd development phase than the curd initiation phase and it was observed that earlier curd initiation resulted in highest curd weight.

Afternoon relative humidity showed positive influence and vapour pressure deficit showed negative influence on curd weight. Bright sunshine hours and solar radiation during the early vegetative and curd development stages exhibited negative influence on curd weight and the wind speed during the curd maturation period showed significant negative influence on curd weight. With respect to heat units, the highest curd yield was observed in crops that required less heat units.

The optimum weather variables contributing to higher yield were identified as 31.1-31.4°C, 22.4-22.7°C, and 26.9-27.0°C of maximum, minimum and mean temperatures, respectively with low DTR of 8.4-8.9°C, higher humidity of 81.1-83.6% in forenoon and 55.6-59.6% in afternoon, lower vapour pressure deficits of 3.9-4.4 mm Hg in forenoon and 13.6-15.1 mm Hg in afternoon, low bright sunshine hours and solar radiation of 5.9-6.5 hrs and 15.7-16.6 MJ m^{-2}, respectively in the transplanting to curd initiation phase followed by further low minimum temperature of 21.1-22.7 °C in the curd development phase.

Incidence of black rot disease occurred in 2010-11 which resulted in low curd yield in all planting times compared to 2011-12. From the present study, it was realized that in the plains, if weather conditions are favourable, a curd yield of 535.2g can be achieved if planting is done in the first fortnight of November and utmost care must be taken while undertaking cauliflower cultivation in the central parts of Kerala, because the environmental conditions existing here are favourable for the incidence of bacterial diseases, especially black rot, which can result in considerable yield losses.

With respect to curd weight, the variety Basant was noted as superior than Pusa Kartik Sankar.

Regression model with R^2 value of 0.95 was developed for the prediction of curd weight using the weather parameters experienced by the crop during the transplanting to curd initiation phase and the equation is given below.

Curd weight = 474.743 T_{max} – 569.084 T_{min} + 77.06 RH II – 418.844 BSS – 2547.22

The different pests noticed in the study are Tobacco caterpillar (*Spodoptera litura)*, Painted bug (*Bagrada hilaris)*, Cabbage green semilooper (*Trichoplusia ni*), Cabbage stem borer (*Hellula undalis*), Diamond back moth (*Plutella xylostella)*, Cotton aphid (*Aphis gossypii)*, and Cabbage leaf webber (*Crocidolomia binotalis)*. Incidence of diseases like Black rot caused by *Xanthomonas campestris* pv. *campestris*, Soft rot caused by *Erwinia caratovora* and Leaf spot caused by *Alternaria brassicola* were noticed. Damping off caused by *Pythium aphanidermatum* was observed in the seedlings of 1st November and 15th November plantings in both the years in nursery. Various physiological disorders like bracting, leafiness, riceyness, blindness and buttoning were also observed during the experiment.

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Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax	:	Maximum temperature	RF	:	Rainfall
Tmin	:	Minimum temperature	RD	:	Rainy days
Tmean	:	Mean temperature	BSS	:	Bright sunshine
DTR	:	Diurnal Temperature Range	SR	:	Solar radiation
RH I	:	Forenoon relative humidity	WS	:	Wind speed
RH II	:	Afternoon relative humidity			
VPD I	:	Forenoon vapour pressure deficit			
VPD II	:	Afternoon vapour pressure deficit			

Heat units

GDD	:	Growing Degree Days
HTU	:	Heliothermal Units
PTU	:	Photothermal Units

Others

DAT	:	Days after transplanting	SE	:	Standard error
MSL	:	Mean sea level	SD	:	Standard deviation
FYM	:	Farmyard manure	DBM	:	Diamondback moth
IARI	:	Indian Agricultural Research Institute			
RARS	:	Regional Agricultural Research Station			

Units

g	:	gram	°C	:	degree Celsius
kg	:	kilogram	%	:	per cent
mm	:	millimetre	ha	:	hectare
cm	:	centimetre	mt	:	metric tonnes
MJ m^{-2}	:	mega joule per square metre	q	:	quintal
Km hr^{-1}	:	kilometre per hour	µmol	:	micro moles

Appendix II

ANOVA of different plant growth characters of 2010-11 and 2011-12 experiments

Plant height at different weeks after transplanting in 2010-11

Source of variation	DF	Mean sum of squares						
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	7 Week
Time of planting	4	5.404**	6.317**	5.740**	6.069**	5.620**	5.098**	8.873**
Variety	1	0.337	0.663	0.002	0.059	0.141	1.121	0.103
Time X Variety	4	0.274	0.122	0.212	0.216	0.160	0.180	0.147
Error	18	0.253	0.267	0.258	0.295	0.339	0.446	0.959

Plant height at different weeks after transplanting in 2011-12

Source of variation	DF	Mean sum of squares						
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	7 Week
Time of planting	4	1.700**	1.630**	1.402**	2.442**	4.138**	8.412**	8.586**
Variety	1	0.365*	0.512*	0.153	0.024	0.043	0.276	0.024
Time X Variety	4	0.034	0.225	0.438	0.235	0.492	0.729	0.915
Error	18	0.067	0.087	0.265	0.370	0.543	0.703	0.869

DF - Degrees of freedom **- Significant at 1% level *- Significant at 5% level

Appendix II (contd.)

Leaf number at different weeks after transplanting in 2010-11

Source of variation	DF	Mean sum of squares						
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	7 Week
Time of planting	4	0.465	0.435	0.991*	1.378	5.091*	19.997**	57.099**
Variety	1	1.281*	2.700**	3.888**	5.461**	7.301	1.281	1.281
Time X Variety	4	0.105	0.577	0.951	0.851	0.825	0.231	2.208
Error	18	0.200	0.266	0.257	0.624	1.685	2.765	5.856

Leaf number at different weeks after transplanting in 2011-12

Source of variation	DF	Mean sum of squares						
		1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	7 Week
Time of planting	4	6.929**	7.210**	2.684**	7.679**	13.513**	20.752**	26.268**
Variety	1	0.919*	3.008**	2.408**	2.700	1.302	1.752	3.169
Time X Variety	4	0.231	0.685**	1.174**	2.971*	2.354	2.898	4.518
Error	18	0.165	0.133	0.222	0.681	0.967	2.000	1.976

DF - Degrees of freedom   **- Significant at 1% level   *- Significant at 5% level

Appendix II (contd.)

Curd weight, plant height and leaf number at the time of harvest

Source of variation	DF	Mean sum of squares					
		Curd weight		Plant height[1]		Leaf number[1]	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Time of planting	4	13437.868**	188521.333**	12.216**	17.909**	88.251**	32.583**
Variety	1	398.653	18550.533**	0.394	0.594	1.925	1.102
Time X Variety	4	1225.039**	6766.440**	1.140	1.616	3.909	3.331
Error	18	211.415	935.010	1.173	1.190	5.383	5.269

Duration of different growth stages

Source of variation	DF	Mean sum of squares					
		Transplanting to curd initiation		Curd initiation to harvest		Transplanting to harvest	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Time of planting	4	188.367**	87.283**	68.467**	14.117**	447.450**	97.300**
Variety	1	9.633*	4.800	4.033	0.033	1.200	4.033*
Time X Variety	4	9.467**	4.050	3.867*	1.450	4.950*	2.033*
Error	18	1.307	1.570	1.141	0.656	1.122	0.552

DF - Degrees of freedom   [1] - At the time of harvest   ** - Significant at 1% level   * - Significant at 5% level

Appendix II (contd.)

Plant fresh weight at 15 DAT, 30 DAT, 45 DAT and at the time of harvest

Source of variation	DF	Mean sum of squares							
		15 DAT		30 DAT		45DAT		At harvest	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Time of planting	4	8.930**	2.166**	16.154	185.706**	8890.011**	7347.246**	335780.859**	858388.300**
Variety	1	11.126**	0.778**	272.044**	9.252	3893.102	121.605	19902.691*	55126.533**
Time X Variety	4	1.324	1.288**	13.662	6.211	331.309	12.970	13931.354**	4419.200
Error	18	1.042	0.036	28.180	4.356	1844.321	105.749	2664.897	6280.248

Plant dry weight at 15 DAT, 30 DAT, 45 DAT and at the time of harvest

Source of variation	DF	Mean sum of squares							
		15 DAT		30 DAT		45DAT		At harvest	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Time of planting	4	0.426**	0.428*	0.403	3.340**	234.689*	133.538**	3486.780**	13900.949**
Variety	1	0.348**	0.187	6.759**	0.004	51.903	0.481	97.705	1817.875**
Time X Variety	4	0.052	0.266	0.296	0.105	12.967	1.342	153.340*	284.632
Error	18	0.035	0.124	0.727	0.170	73.135	7.612	46.589	181.492

DF - Degrees of freedom **- Significant at 1% level *- Significant at 5% level

Appendix III

Pooled ANOVA of important plant growth characters

Source of variation	**DF**	**Mean sum of squares**	
		Plant height[2]	Leaf number[2]
Year	1	0.059	19.372
Time of planting	4	4.414	25.402
Variety	1	0.004	0.018
Time X Variety	4	0.448	0.494
Year X Time X Variety	9	2.746	7.575
Pooled Error	36	1.182	5.326

Source of variation	**DF**	**Mean sum of squares**		
		Transplanting to curd initiation[1]	Curd initiation to harvest[1]	Transplanting to harvest[1]
Year	1	9.339	24.200*	63.606
Time of planting	4	17.320	21.288*	64.134
Variety	1	0.138	0.556	0.140
Time X Variety	4	2.262	1.070	0.806
Year X Time X Variety	9	52.610	3.175	34.655
Pooled Error	36	0.837	0.899	1.439

DF - Degrees of freedom
* - Significant at 5% level
1 - Duration
2 - At harvest

Appendix IV

Daily weather parameters during 2010-11 experiment

Date	Tmax (°C)	Tmin (°C)	Tmean (°C)	DTR (°C)	RH I (%)	RH II (%)	VPD I (mm)	VPD II (mm)	RF (mm)	RD	BSS (hrs)	SR (MJ/m^2)	Wind (km/hr)
01-11-10	30.1	23.5	26.8	6.6	96	75	0.9	7.3	35.5	1	0.4	23.5	3.7
02-11-10	30.2	21.5	25.9	8.7	96	71	0.9	9.4	0.0	0	7.2	21.5	3.0
03-11-10	31.8	22.3	27.1	9.5	92	70	1.9	10.2	0.0	0	8.8	22.3	2.7
04-11-10	31.1	23.8	27.5	7.3	95	68	1.2	10.5	4.0	1	6.4	23.8	2.7
05-11-10	30.0	23.6	26.8	6.4	93	68	1.6	10.1	16.2	1	3.9	23.6	2.5
06-11-10	28.4	21.5	25.0	6.9	96	72	0.9	8.1	0.0	0	0.0	21.5	1.3
07-11-10	28.2	22.7	25.5	5.5	97	80	0.7	5.7	0.0	0	0.0	22.7	1.3
08-11-10	31.8	22.0	26.9	9.8	95	58	1.2	14.6	0.0	0	9.7	22	2.5
09-11-10	30.9	22.3	26.6	8.6	95	70	1.2	9.9	32.9	1	5.2	22.3	2.7
10-11-10	32.1	22.5	27.3	9.6	96	66	0.9	12.2	66.1	1	6.8	22.5	2.3
11-11-10	28.8	21.5	25.2	7.3	98	98	0.4	0.4	26.1	1	0.3	21.5	1.6
12-11-10	31.4	20.9	26.2	10.5	96	65	0.9	11.8	0.0	0	9.2	20.9	2.3
13-11-10	30.6	23.3	27.0	7.3	95	74	1.2	8.6	0.0	0	4.4	23.3	1.7
14-11-10	32.6	23.2	27.9	9.4	95	56	1.2	16.0	0.0	0	9.3	23.2	3.2
15-11-10	32.7	22.8	27.8	9.9	88	58	2.9	15.0	0.0	0	8.6	22.8	2.9
16-11-10	32.7	22.5	27.6	10.2	92	66	2.0	11.4	2.8	1	3.0	22.5	1.7
17-11-10	30.2	22.5	26.4	7.7	96	79	0.9	6.1	30.4	1	1.8	22.5	3.2
18-11-10	31.4	22.2	26.8	9.2	85	71	3.8	9.9	2.1	0	6.1	22.2	3.7
19-11-10	31.4	23.0	27.2	8.4	84	70	3.9	9.3	0.0	0	2.7	23	3.1
20-11-10	32.2	22.4	27.3	9.8	90	64	2.3	12.7	1.0	0	6.8	22.4	2.3
21-11-10	30.0	22.8	26.4	7.2	96	68	0.9	9.8	47.6	1	0.9	22.8	3.7
22-11-10	30.3	22.1	26.2	8.2	87	75	3.0	7.2	9.1	1	3.9	22.1	3.7
23-11-10	31.0	21.8	26.4	9.2	96	63	0.9	12.0	0.0	0	5.1	21.8	3.8
24-11-10	28.9	23.0	26.0	5.9	90	76	2.3	7.0	1.2	0	0.0	23	3.0
25-11-10	27.8	22.5	25.2	5.3	96	79	0.9	5.2	0.0	0	0.0	22.5	5.9
26-11-10	27.5	21.7	24.6	5.8	85	72	3.4	7.4	1.4	0	0.1	21.7	4.0

Appendix IV (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
27-11-10	28.4	24.5	26.5	3.9	91	71	2.1	7.8	0.0	0	0.3	24.5	4.1
28-11-10	28.8	22.5	25.7	6.3	87	88	3.0	2.7	6.4	1	0.1	22.5	10.3
29-11-10	30.0	22.8	26.4	7.2	79	63	5.0	11.5	0.0	0	2.8	22.8	9.5
30-11-10	31.2	24.0	27.6	7.2	73	54	6.6	15.3	0.0	0	8.7	24	6.1
01-12-10	27.9	23.7	25.8	4.2	82	81	4.4	5.0	0.7	0	0	23.7	6.1
02-12-10	30.7	23.5	27.1	7.2	85	65	3.6	11.1	2.4	0	3.0	23.5	5.5
03-12-10	29.3	22.5	25.9	6.8	93	67	1.6	9.7	0.0	0	0.8	22.5	3.5
04-12-10	31.0	21.5	26.3	9.5	86	64	3.2	10.9	0.0	0	3.9	21.5	4.7
05-12-10	30.6	21.3	26.0	9.3	80	51	4.3	15.9	0.0	0	4.3	21.3	2.9
06-12-10	31.9	20.5	26.2	11.4	94	54	1.2	15.4	0.0	0	5.9	20.5	2
07-12-10	33.2	20.0	26.6	13.2	86	53	2.8	17.6	0.0	0	8.5	20	2.3
08-12-10	30.6	21.5	26.1	9.1	93	65	1.5	11.1	0.0	0	1.7	21.5	1.3
09-12-10	31.4	21.5	26.5	9.9	93	56	1.5	14.9	0.0	0	5.8	21.5	2
10-12-10	31.2	21.5	26.4	9.7	95	65	1.0	10.8	0.0	0	5.8	21.5	2.4
11-12-10	31.1	21.2	26.2	9.9	95	67	1.0	10.2	0.0	0	3.5	21.2	2.5
12-12-10	30.8	22.1	26.5	8.7	88	54	2.7	15.3	0.0	0	10.0	22.1	3.4
13-12-10	31.9	19.4	25.7	12.5	94	52	1.1	16.1	0.0	0	9.1	19.4	2.6
14-12-10	31.6	20.9	26.3	10.7	91	54	1.8	16.1	0.0	0	9.1	20.9	2.8
15-12-10	31.9	21.8	26.9	10.1	91	61	1.9	12.7	3.0	1	6.4	21.8	3.2
16-12-10	30.4	23.4	26.9	7.0	83	63	4.0	12.0	16.0	1	4.6	23.4	4
17-12-10	30.9	23.0	27.0	7.9	83	56	3.9	14.4	0.0	0	8.8	23	5.6
18-12-10	30.9	23.7	27.3	7.2	80	58	4.6	13.8	0.0	0	5.7	23.7	6.7
19-12-10	30.5	23.1	26.8	7.4	75	42	5.6	18.8	0.0	0	9.5	23.1	10.3
20-12-10	31.1	23.5	27.3	7.6	78	55	5.1	19.6	2.4	0	10.0	23.5	10.7
21-12-10	30.6	23.2	26.9	7.4	73	57	6.6	13.9	0.0	0	9.9	23.2	8.6
22-12-10	31.6	22.2	26.9	9.4	73	69	5.8	10.7	0.0	0	10.1	22.2	7.4
23-12-10	30.6	21.2	25.9	9.4	77	47	4.5	17.4	0.0	0	9.8	21.2	6.3
24-12-10	30.0	20.7	25.4	9.3	77	47	4.5	16.8	0.0	0	9.5	20.7	6.2
25-12-10	30.1	20.4	25.3	9.7	75	49	4.9	16.3	0.0	0	6.6	20.4	4.5

Appendix IV (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
26-12-10	31.1	20.5	25.8	10.6	76	53	4.8	15.5	0.0	0	9.8	20.5	5.6
27-12-10	31.2	21.3	26.3	9.9	76	51	4.9	16.6	0.0	0	9.8	21.3	6.0
28-12-10	31.3	21.7	26.5	9.6	74	47	5.3	16.8	0.0	0	6.9	21.7	8.9
29-12-10	30.2	24.2	27.2	6.0	67	56	7.8	13.9	0.0	0	2.8	24.2	7.2
30-12-10	31.1	23.3	27.2	7.8	75	53	5.8	15.5	0.0	0	8.0	23.3	6.4
31-12-10	31.4	22.3	26.9	9.1	85	54	3.3	15.9	0.0	0	7.1	22.3	3.5
01-01-11	32.3	22.7	27.5	9.6	90	50	2.2	18.1	0.0	0.0	7.3	22.7	3.2
02-01-11	31.2	22.5	26.9	8.7	90	57	2.1	13.9	0.0	0.0	7.1	22.5	3.7
03-01-11	31.0	21.1	26.1	9.9	91	63	1.8	11.3	0.0	0.0	4.2	21.1	2.7
04-01-11	32.5	20.7	26.6	11.8	89	39	2.1	22.2	0.0	0.0	9.8	20.7	5.2
05-01-11	31.6	23.1	27.4	8.5	75	50	5.6	16.9	0.0	0.0	6.7	23.1	6.3
06-01-11	32.3	22.5	27.4	9.8	75	47	5.7	18.6	0.0	0.0	8.8	22.5	4.9
07-01-11	33.1	23.7	28.4	9.4	75	49	5.8	17.9	0.0	0.0	7.6	23.7	3.7
08-01-11	32.9	22.7	27.8	10.2	95	52	1.1	16.7	0.0	0.0	6.1	22.7	3.0
09-01-11	33.9	23.3	28.6	10.6	91	45	2.0	20.9	0.0	0.0	5.1	23.3	2.6
10-01-11	33.5	23.8	28.7	9.7	93	52	1.6	17.6	0.0	0.0	5.5	23.8	2.3
11-01-11	33.6	24.0	28.8	9.6	95	48	1.2	19.5	0.0	0.0	6.3	24	3.3
12-01-11	33.8	22.1	28.0	11.7	78	40	4.5	23.3	0.0	0.0	6.9	22.1	4.9
13-01-11	31.8	20.5	26.2	11.3	79	32	4.0	23.8	0.0	0.0	4.6	20.5	5.3
14-01-11	32.2	19.8	26.0	12.4	65	25	6.7	26.4	0.0	0.0	9.0	19.8	5.2
15-01-11	32.2	18.2	25.2	14.0	67	35	6.9	22.5	0.0	0.0	10.0	18.2	6.2
16-01-11	32.6	23.8	28.2	8.8	76	48	5.6	18.7	0.0	0.0	8.9	23.8	5.6
17-01-11	32.9	22.8	27.9	10.1	83	47	3.7	19.2	0.0	0.0	9.8	22.8	4.5
18-01-11	33.4	22.3	27.9	11.1	78	35	4.7	24.1	0.0	0.0	9.8	22.3	6.4
19-01-11	33.4	21.7	27.6	11.7	63	30	7.5	26.1	0.0	0.0	10.2	21.7	5.7
20-01-11	33.6	18.8	26.2	14.8	72	23	5.3	30.1	0.0	0.0	10.1	18.8	5.8
21-01-11	32.8	19.0	25.9	13.8	72	34	5.6	24.3	0.0	0.0	9.9	19	8.8
22-01-11	31.8	21.9	26.9	9.9	67	38	7.1	20.9	0.0	0.0	9.9	21.9	7.6
23-01-11	32.0	21.0	26.5	11.0	64	32	7.9	23.8	0.0	0.0	9.9	21	9.7

Appendix IV (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
24-01-11	32.0	23.2	27.6	8.8	64	33	7.9	23.1	0.0	0.0	9.9	23.2	10.0
25-01-11	31.5	22.7	27.1	8.8	70	39	6.3	20.6	0.0	0.0	9.8	22.7	11.1
26-01-11	32.1	23.3	27.7	8.8	67	41	7.3	20.4	0.0	0.0	9.8	23.3	13.7
27-01-11	32.8	24.9	28.9	7.9	68	46	7.9	19.1	0.0	0.0	9.8	24.9	8.6
28-01-11	32.8	23.0	27.9	9.8	70	35	6.6	23.4	0.0	0.0	9.5	23	6.1
29-01-11	33.7	22.1	27.9	11.6	77	35	5.3	25.1	0.0	0.0	10.0	22.1	9.1
30-01-11	34.0	23.5	28.8	10.5	66	35	7.7	25.6	0.0	0.0	10.1	23.5	10.1
31-01-11	34.1	24.4	29.3	9.7	57	23	10.3	30.1	0.0	0.0	10.6	24.4	9.2
01-02-11	34.6	23.9	29.3	10.7	61	23	9.3	28.1	0.0	0.0	9.1	23.9	9.6
02-02-11	32.0	22.8	27.4	9.2	51	26	11.9	25.9	0.0	0.0	7.0	22.8	9.4
03-02-11	33.1	23.2	28.2	9.9	54	25	10.9	27.0	0.0	0.0	9.8	23.2	7.1
04-02-11	33.4	20.4	26.9	13.0	63	35	7.6	24.5	0.0	0.0	9.8	20.4	5.7
05-02-11	34.1	18.3	26.2	15.8	50	23	11.6	30.1	0.0	0.0	10.4	18.3	8.3
06-02-11	33.8	21.9	27.9	11.9	64	24	7.5	29.5	0.0	0.0	10.4	21.9	4.9
07-02-11	34.1	19.7	26.9	14.4	65	37	7.9	25.0	0.0	0.0	7.7	19.7	3.7
08-02-11	34.5	22.6	28.6	11.9	86	38	3.1	25.1	0.0	0.0	8.9	22.6	4.1
09-02-11	34.5	22.4	28.5	12.1	73	37	5.8	24.3	0.0	0.0	8.7	22.4	5.0
10-02-11	35.0	21.3	28.2	13.7	69	16	6.1	34.7	0.0	0.0	10.5	21.3	6
11-02-11	34.4	20.9	27.7	13.5	66	16	6.7	34.1	0.0	0.0	10.5	20.9	10
12-02-11	33.6	23.6	28.6	10.0	48	17	11.7	31.7	0.0	0.0	10.4	23.6	9.4
13-02-11	34.7	20.8	27.8	13.9	45	17	11.5	34.7	0.0	0.0	10.3	20.8	6.2
14-02-11	35.0	19.3	27.2	15.7	74	26	4.6	30.2	0.0	0.0	10.3	19.3	4.4
15-02-11	32.7	21.5	27.1	11.2	78	46	4.6	19.7	0.0	0.0	9.2	21.5	3.9
16-02-11	32.9	21.2	27.1	11.7	89	42	2.3	20.9	0.0	0.0	9.1	21.2	3.1
17-02-11	34.0	20.7	27.4	13.3	94	50	1.2	18.9	0.0	0.0	9.8	20.7	3.4
18-02-11	32.9	21.0	27.0	11.9	94	45	1.2	20.4	0.0	0.0	9.7	21	3.4
19-02-11	33.7	19.7	26.7	14.0	93	50	1.3	18.5	0.0	0.0	9.8	19.7	3.2
20-02-11	33.6	21.9	27.8	11.7	91	59	1.9	13.8	0.0	0.0	5.0	21.9	3.1
21-02-11	32.4	23.6	28.0	8.8	87	57	3.1	15.5	0.0	0.0	5.9	23.6	2.9

Appendix IV (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
22-02-11	34.7	23.7	29.2	11.0	91	52	2.1	18.8	59.6	1.0	7.8	23.7	3.7
23-02-11	33.9	23.1	28.5	10.8	91	46	2.0	20.2	5.5	1.0	5.6	23.1	4.7
24-02-11	33.2	23.1	28.2	10.1	91	50	2.0	18.9	0.8	0.0	3.4	23.1	3.9
25-02-11	32.9	23.8	28.4	9.1	83	52	4.0	17.6	0.0	0.0	7.6	23.8	3.6
26-02-11	32.6	23.8	28.2	8.8	93	55	1.6	16.6	11.6	1.0	5.6	23.8	3.4
27-02-11	33.4	22.6	28.0	10.8	91	48	2.0	19.2	0.0	0.0	6.8	22.6	5.0
28-02-11	33.7	24.2	29.0	9.5	72	39	6.6	23.1	0.0	0.0	10.0	24.2	6.9
01-03-11	33.7	23.3	28.5	10.4	77	31	5.3	26.5	0.0	0.0	10.1	23.3	7.4
02-03-11	34.2	23.1	28.7	11.1	54	27	10.6	29.2	0.0	0.0	10.5	23.1	7.5
03-03-11	35.5	22.8	29.2	12.7	51	17	10.5	34.7	0.0	0.0	10.3	22.8	4.6
04-03-11	35.6	21.3	28.5	14.3	75	32	5.4	28.5	0.0	0.0	10.0	21.3	4.0
05-03-11	34.7	22.9	28.8	11.8	90	43	2.3	23.7	0.0	0.0	9.3	22.9	3.4
06-03-11	36.5	24.1	30.3	12.4	93	29	1.6	32.3	0.0	0.0	9.7	24.1	4.1
07-03-11	36.6	23.3	30.0	13.3	91	20	2.1	38.4	0.0	0.0	10.1	23.3	4.6
08-03-11	37.4	23.3	30.4	14.1	91	20	2.1	38.4	0.0	0.0	9.8	23.3	4.0
09-03-11	35.0	24.3	29.7	10.7	91	49	2.2	20.0	0.0	0.0	9.0	24.3	3.6
10-03-11	34.2	22.9	28.6	11.3	90	59	2.3	16.1	0.0	0.0	8.8	22.9	3.3
11-03-11	34.6	24.1	29.4	10.5	95	54	1.2	18.8	0.0	0.0	8.6	24.1	3.1
12-03-11	36.0	23.7	29.9	12.3	92	23	1.9	33.5	5.8	1.0	9.3	23.7	4.8
13-03-11	36.0	23.2	29.6	12.8	90	35	2.3	28.4	4.2	1.0	9.4	23.2	5.0
14-03-11	34.0	23.0	28.5	11.0	93	61	1.6	14.8	0.0	0.0	9.8	23	3.1
15-03-11	36.2	23.7	30.0	12.5	92	28	1.9	32.1	0.0	0.0	9.7	23.7	4.5
16-03-11	36.5	24.3	30.4	12.2	85	26	3.7	33.6	0.0	0.0	9.7	24.3	4.8
17-03-11	35.0	24.7	29.9	10.3	67	27	8.3	30.3	0.0	0.0	9.6	24.7	7.9
18-03-11	34.5	23.1	28.8	11.4	69	29	7.0	28.9	0.0	0.0	9.9	23.1	6.1

Appendix V

Daily weather parameters during 2011-12 experiment

Date	Tmax (°C)	Tmin (°C)	Tmean (°C)	DTR (°C)	RH I (%)	RH II (%)	VPD I (mm)	VPD II (mm)	RF (mm)	RD	BSS (hrs)	SR (MJ/m^2)	Wind (km/hr)
01-11-2011	28.4	24.2	26.3	4.2	88	76	3.0	6.9	14.6	1.0	0.0	24.2	3.0
02-11-2011	31.2	22.5	26.9	8.7	88	69	2.9	10.1	96.6	1.0	2.2	22.5	2.4
03-11-2011	31.2	22.8	27.0	8.4	95	67	1.1	11.1	79.2	1.0	2.5	22.8	2.1
04-11-2011	31.1	22.4	26.8	8.7	95	71	1.1	9.0	0.0	0.0	5.0	22.4	1.4
05-11-2011	32.4	24.5	28.5	7.9	88	57	2.9	15.7	10.0	1.0	4.8	24.5	3.3
06-11-2011	32.0	23.2	27.6	8.8	90	72	2.4	9.1	7.8	1.0	5.2	23.2	1.9
07-11-2011	32.4	23.5	28.0	8.9	90.0	63	2.4	13.3	16.4	1.0	5.8	23.5	2.9
08-11-2011	31.7	22.9	27.3	8.8	84	51	3.8	17.1	0.0	0.0	9.8	22.9	6.0
09-11-2011	31.1	22.3	26.7	8.8	61	39	9.0	20.6	0.0	0.0	10.2	22.3	4.1
10-11-2011	31.5	18.4	25.0	13.1	87	41	2.4	20.3	0.0	0.0	10.1	18.4	2.4
11-11-2011	31.1	19.1	25.1	12.0	91	56	1.7	14.4	0.0	0.0	5.4	19.1	1.9
12-11-2011	32.7	20.6	26.7	12.1	87	53	3.0	17.0	0.0	0.0	8.8	20.6	2.1
13-11-2011	32.6	21.6	27.1	11.0	83	55	4.0	16.4	0.0	0.0	9.6	21.6	3.2
14-11-2011	32.7	22.5	27.6	10.2	87	55	3.0	16.6	0.0	0.0	9.8	22.5	3.0
15-11-2011	32.2	22.4	27.3	9.8	75	35	6.3	23.2	0.0	0.0	10.2	22.4	5.3
16-11-2011	32.4	19.9	26.2	12.5	80	35	4.6	23.6	0.0	0.0	10.2	19.9	3.9
17-11-2011	32.1	21.9	27.0	10.2	70	52	7.4	17.3	0.0	0.0	6.5	21.9	7.0
18-11-2011	32.4	25.0	28.7	7.4	75	48	6.4	18.7	0.0	0.0	9.7	25	8.3
19-11-2011	32.0	25.6	28.8	6.4	66	49	8.8	18.1	0.0	0.0	9.2	25.6	9.3
20-11-2011	31.4	23.9	27.7	7.5	60	45	9.5	18.5	0.0	0.0	8.7	23.9	11.4
21-11-2011	30.6	24.6	27.6	6.0	60	52	9.5	15.1	0.0	0.0	6.2	24.6	10.3
22-11-2011	31.1	25.1	28.1	6.0	60	51	9.7	15.9	0.0	0.0	9.9	25.1	7.2
23-11-2011	31.0	21.4	26.2	9.6	57	41	10.5	19.7	0.0	0.0	7.0	21.4	9.6
24-11-2011	32.1	21.4	26.8	10.7	59	55	10.7	16.0	0.0	0.0	6.6	21.4	8.4
25-11-2011	27.0	25.2	26.1	1.8	76	85	6.0	3.8	3.5	1.0	0.0	25.2	8.3
26-11-2011	29.4	24.0	26.7	5.4	74	80	6.7	5.2	7.2	1.0	1.2	24	8.3

Appendix V (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
27-11-2011	30.1	23.3	26.7	6.8	87	69	3.0	9.9	4.7	1.0	0.8	23.3	3.8
28-11-2011	31.1	23.2	27.2	7.9	96	63	0.9	12.5	0.0	0.0	1.1	23.2	2.2
29-11-2011	32.8	24.2	28.5	8.6	84	55	3.8	16.3	0.0	0.0	9.1	24.2	2.6
30-11-2011	31.9	23.9	27.9	8.0	90	63	2.3	12.7	0.0	0.0	3.3	23.9	2.9
01-12-2011	32.0	24.2	28.1	7.8	91	61	2.1	13.5	0.0	0.0	4.3	24.2	2.2
02-12-2011	33.0	24.0	28.5	9.0	90	56	2.4	16.6	0.0	0.0	6.7	24	1.7
03-12-2011	33.0	23.6	28.3	9.4	95	58	1.2	15.7	0.0	0.0	8.1	23.6	1.7
04-12-2011	33.1	23.6	28.4	9.5	91	61	2.2	14.8	0.0	0.0	7.2	23.6	1.7
05-12-2011	32.0	23.4	27.7	8.6	93	70	1.7	9.4	0.0	0.0	5.2	23.4	2.6
06-12-2011	32.5	22.9	27.7	9.6	87	37	3.0	22.8	0.0	0.0	9.9	22.9	6.8
07-12-2011	31.4	22.7	27.1	8.7	74	39	5.8	21.0	0.0	0.0	9.8	22.7	6.5
08-12-2011	31.0	20.2	25.6	10.8	62	46	8.7	18.1	0.0	0.0	9.7	20.2	6.2
09-12-2011	31.9	22.9	27.4	9.0	70	49	7.2	17.8	0.0	0.0	9.5	22.9	5.2
10-12-2011	33.0	23.5	28.3	9.5	74	46	6.3	20.1	0.0	0.0	9.9	23.5	5.8
11-12-2011	33.5	23.2	28.4	10.3	76	49	5.7	18.1	0.0	0.0	9.3	23.2	5.7
12-12-2011	32.8	23.4	28.1	9.4	80	46	4.6	19.7	0.0	0.0	8.6	23.4	6.3
13-12-2011	32.0	23.6	27.8	8.4	65	50	9.0	16.9	0.0	0.0	9.2	23.6	10
14-12-2011	32.1	26.0	29.1	6.1	71	49	7.6	18.1	0.0	0.0	7.8	26	7.7
15-12-2011	33.0	23.7	28.4	9.3	71	42	7.1	21.1	0.0	0.0	9.9	23.7	10.1
16-12-2011	31.1	24.2	27.7	6.9	71	41	7.2	19.7	0.0	0.0	7.8	24.2	10.2
17-12-2011	30.2	23.9	27.1	6.3	63	46	8.5	17.0	0.0	0.0	9.4	23.9	9.2
18-12-2011	31.0	23.4	27.2	7.6	57	43	10.0	19.1	0.0	0.0	5.5	23.4	12.6
19-12-2011	31.3	24.6	28.0	6.7	62	46	9.1	17.8	0.0	0.0	6.4	24.6	6.3
20-12-2011	31.4	21.6	26.5	9.8	68	45	7.6	18.0	0.0	0.0	2.0	21.6	12.0
21-12-2011	31.3	23.5	27.4	7.8	65	41	8.0	19.9	0.0	0.0	8.4	23.5	9.9
22-12-2011	30.9	24.0	27.5	6.9	56	35	10.5	21.4	0.0	0.0	7.0	24	8.3
23-12-2011	30.6	23.4	27.0	7.2	61	51	8.8	14.6	0.0	0.0	3.7	23.4	10.6
24-12-2011	32.2	23.6	27.9	8.6	57	30	9.8	25.4	0.0	0.0	10.1	23.6	6.6
25-12-2011	33.0	19.0	26.0	14.0	73	55	5.9	16.4	0.0	0.0	10.1	19	5.3

Appendix V (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
26-12-2011	33.4	17.5	25.5	15.9	56	24	9.8	27.2	0.0	0.0	9.5	17.5	3.1
27-12-2011	31.2	17.4	24.3	13.8	90	59	1.7	13.0	0.0	0.0	4.7	17.4	1.7
28-12-2011	31.6	19.8	25.7	11.8	96	54	0.8	15.6	0.0	0.0	6.6	19.8	2.0
29-12-2011	32.7	19.7	26.2	13.0	96	52	0.7	16.5	0.0	0.0	5.1	19.7	2.0
30-12-2011	33.6	21.9	27.8	11.7	95	48	1.1	22.0	2.4	0.0	5.2	21.9	5.6
31-12-2011	25.8	21.5	23.7	4.3	84	76	3.8	6.5	0.0	0.0	0.0	21.5	8.9
01-01-2012	32.5	22.6	27.6	9.9	72	41	6.3	20.7	0.0	0.0	10.0	22.6	4.4
02-01-2012	32.5	18.8	25.7	13.7	92	39	1.4	22.2	0.0	0.0	9.9	18.8	4.0
03-01-2012	33.6	19.5	26.6	14.1	91	39	1.7	23.1	0.0	0.0	10.2	19.5	4.2
04-01-2012	33.3	21.2	27.3	12.1	88	50	2.6	18.9	0.0	0.0	9.8	21.2	4.6
05-01-2012	33.7	23.1	28.4	10.6	90	44	2.3	21.9	0.0	0.0	9.8	23.1	7.2
06-01-2012	33.4	24.0	28.7	9.4	76	48	5.7	19.8	0.0	0.0	9.9	24	7.4
07-01-2012	32.7	22.2	27.5	10.5	80	46	4.5	19.7	0.0	0.0	9.3	22.2	7.0
08-01-2012	33.5	24.0	28.8	9.5	84	44	3.3	21.3	0.0	0.0	10.4	24	5.6
09-01-2012	34.0	23.4	28.7	10.6	81	43	4.0	22.4	0.0	0.0	9.8	23.4	4.2
10-01-2012	34.3	22.3	28.3	12.0	86	43	3.1	22.0	0.0	0.0	9.6	22.3	3.6
11-01-2012	33.3	21.3	27.3	12.0	91	49	1.9	18.7	0.0	0.0	7.9	21.3	3.0
12-01-2012	33.5	21.9	27.7	11.6	86	44	3.0	21.0	0.0	0.0	10.0	21.9	5.7
13-01-2012	32.0	22.6	27.3	9.4	69	42	7.0	20.6	0.0	0.0	9.7	22.6	9.6
14-01-2012	32.0	22.8	27.4	9.2	72	42	6.3	20.3	0.0	0.0	9.8	22.8	10.3
15-01-2012	31.0	22.2	26.6	8.8	54	38	10.2	20.6	0.0	0.0	9.7	22.2	10.3
16-01-2012	31.2	20.3	25.8	10.9	65	34	6.5	21.5	0.0	0.0	10.3	20.3	7.9
17-01-2012	31.8	19.9	25.9	11.9	73	34	5.0	22.5	0.0	0.0	9.6	19.9	4.5
18-01-2012	33.8	17.3	25.6	16.5	64	30	7.1	26.4	0.0	0.0	9.7	17.3	3.3
19-01-2012	33.5	19.9	26.7	13.6	83	35	3.5	25.1	0.0	0.0	9.6	19.9	2.8
20-01-2012	30.7	21.0	25.9	9.7	91	58	1.8	13.8	0.0	0.0	5.1	21	2.6
21-01-2012	33.4	21.1	27.3	12.3	67	38	6.9	22.4	0.0	0.0	9.5	21.1	4.7
22-01-2012	32.9	21.2	27.1	11.7	59	45	8.7	19.3	0.0	0.0	9.8	21.2	7.7
23-01-2012	32.7	21.4	27.1	11.3	66	32	7.0	24.4	0.0	0.0	10.2	21.4	9.6

Appendix V (contd.)

Date	Tmax	Tmin	Tmean	DTR	RH I	RH II	VPD I	VPD II	RF	RD	BSS	SR	Wind
22-02-2012	35.5	21.1	28.3	14.4	86	23	2.8	32.8	0.0	0.0	6.7	21.1	3.8
23-02-2012	34.7	19.9	27.3	14.8	85	24	2.8	30.7	0.0	0.0	3.7	19.9	3.7
24-02-2012	36.4	18.9	27.7	17.5	62	12	7.0	41.1	0.0	0.0	10.1	18.9	6.1
25-02-2012	36.5	20.0	28.3	16.5	57	15	8.6	38.5	0.0	0.0	10.7	20	6.7
26-02-2012	36.5	22.0	29.3	14.5	34	14	15.7	37.5	0.0	0.0	10.7	22	7.2
27-02-2012	37.1	22.2	29.7	14.9	47	12	12.0	40.3	0.0	0.0	10.2	22.2	5.0
28-02-2012	35.0	19.2	27.1	15.8	87	39	2.4	25.3	0.0	0.0	8.7	19.2	3.0
29-02-2012	35.8	21.6	28.7	14.2	91	42	1.9	25.1	0.0	0.0	9.7	21.6	3.2
01-03-2012	35.4	21.9	28.7	13.5	91	56	1.9	17.6	0.0	0.0	8.3	21.9	2.9
02-03-2012	35.0	24.3	29.7	10.7	95	54	1.2	19.3	0.0	0.0	6.4	24.3	2.4
03-03-2012	33.8	23.9	28.9	9.9	93	47	1.6	20.7	0.0	0.0	9.1	23.9	3.6
04-03-2012	33.6	22.6	28.1	11.0	87	52	3.0	17.6	0.0	0.0	8.7	22.6	3.8
05-03-2012	34.6	22.3	28.5	12.3	88	58	2.8	15.6	0.0	0.0	8.4	22.3	2.8
06-03-2012	34.1	24.9	29.5	9.2	87	49	3.2	20.0	0.0	0.0	7.2	24.9	3.2
07-03-2012	33.2	23.5	28.4	9.7	91	61	2.1	14.1	0.0	0.0	6.2	23.5	3.2
08-03-2012	32.9	24.2	28.6	8.7	91	37	2.1	23.0	0.0	0.0	5.6	24.2	4.1
09-03-2012	35.1	21.6	28.4	13.5	91	36	1.9	26.1	0.0	0.0	9.1	21.6	3.8
10-03-2012	33.1	22.5	27.8	10.6	87	53	3.0	17.3	0.0	0.0	6.2	22.5	3.2
11-03-2012	36.6	23.5	30.1	13.1	90	57	3.4	16.0	0.0	0.0	8.2	23.5	3.3
12-03-2012	36.3	23.6	30.0	12.7	90	35	2.4	29.3	0.0	0.0	7.8	23.6	4.3
13-03-2012	36.9	24.6	30.8	12.3	70	34	8.2	30.3	2.5	1	8.7	24.6	6.0
22-02-2012	35.5	21.1	28.3	14.4	86	23	2.8	32.8	0.0	0.0	6.7	21.1	3.8

CROP WEATHER RELATIONSHIPS IN CAULIFLOWER (*Brassica oleracea* var. *botrytis* L.)

By

KARTHIKA V. P.
(2010-11-124)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

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2012

ABSTRACT

A field experiment was conducted during 2010-11 and 2011-12 at the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara with the objectives to study the effect of weather on growth and yield of cauliflower and to assess the suitability of cauliflower under various crop growing environments. The study included five planting times at an interval of 15 days (1^{st} November, 15^{th} November, 1^{st} December, 15^{th} December and 1^{st} January) and two tropical hybrid varieties (Basant and Pusa Kartik Sankar).

The different growth and yield characters like plant height, number of leaves, plant biomass, duration of different growth stages and curd weight were recorded along with monitoring of the incidence of various pests, diseases and physiological disorders. The daily weather parameters like maximum and minimum temperatures, forenoon and afternoon relative humidity, forenoon and afternoon vapour pressure, bright sunshine hours, wind speed, rainfall and rainy days were collected and used in this study. Based on these weather parameters, other important weather variables like mean temperature, diurnal temperature range, forenoon and afternoon vapour pressure deficits and solar radiation were determined. Various heat units like growing degree days, heliothermal units and photothermal units were also worked out.

The maximum and mean temperature, diurnal temperature range, forenoon and afternoon relative humidity, forenoon and afternoon vapour pressure deficits, bright sunshine hours and solar radiation were found to be higher in 2010-11 as compared to 2011-12. Plant height, number of leaves and the duration of different growth stages were found to be highly variable among the different planting times in both the years, but when pooled over years, these characters became non-significant (except the duration from curd initiation to harvest) with respect to the planting time as a result of the higher variability between the two years for the different weather parameters.

The curd weight and the plant fresh and weights exhibited high significant difference for the different planting times. Duration from transplanting to curd initiation

was found to be more critical for the curd yield. To determine the critical weather elements affecting the crop growth, correlation analysis was done and it was observed that the crop duration would increase with increase in the maximum temperature, bright sunshine hours, solar radiation and afternoon vapour pressure deficit whereas, the afternoon relative humidity showed a negative influence on crop duration. The curd yield and plant weight were found to be decreasing with increase in the maximum temperature and sunshine hours. The various heat units exhibited positive correlation with the duration of different growth stages. Based on the weather parameters experienced by the crop during the transplanting to curd initiation period, a regression equation with an R^2 value of 0.95 was developed to predict the curd weight.

The present study revealed that first fortnight of November is the optimum planting time for tropical cauliflower in Thrissur District, since the maximum curd size was obtained when planted on 1st November in 2011-12. The optimum weather for the planting of tropical cauliflower was observed to be less than 31.2°C of maximum temperature, less than 26.8°C of mean temperature, less than 8.8°C of diurnal temperature range, less than 6.0 hrs of bright sunshine hours and less than 22.3 MJ m^{-2} of solar radiation, with 22.5°C of minimum temperature. Intermittent rainfall and higher relative humidity observed during the earlier planting times were found to be conducive for the incidence of pests and diseases and the bacterial disease black rot was observed as a serious threat to cauliflower cultivation in this region.