GINGER (*Zingiber officinale*) YIELD VARIABILITY UNDER DIFFERENT CLIMATE CHANGE SCENARIOS

by

FATHIMA SONA N.

(2019-11-046)

DEPARTMENT OF AGRICULTURAL METEOROLOGY

COLLEGE OF AGRICULTURE

VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

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FATHIMA SONA N.

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THESIS

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DEPARTMENT OF AGRICULTURAL METEOROLOGY

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2021

DECLARATION

I hereby declare that this thesis entitled **"GINGER (*Zingiber officinale*) YIELD VARIABILITY UNDER DIFFERENT CLIMATE CHANGE SCENARIOS"** 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, fellowship or other similar title, of any other University or Society.

FATHIMA SONA N.

(2019-11-046)

Vellanikkara

Date : 22.11.2021

CERTIFICATE

Certified that this thesis entitled **"Ginger (*Zingiber officinale*) yield variability under different climate change scenarios"** is a bonafide record of research work done independently by **Mrs. Fathima Sona N (2019-11-046)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellanikkara

Date : 22.11.2021

Dr. Shajeesh Jan P.
(Chairman, Advisory Committee)
Assistant Professor
Agricultural Meteorology
RARS, Ambalavayal

CERTIFICATE

We, the undersigned members of the advisory committee of **Mrs. Fathima Sona N (2019-11-046)**, a candidate for the degree of **Master of Science in Agriculture** with major field in Agricultural Meteorology, agree that this thesis entitled **"Ginger (*Zingiber officinale*) yield variability under different climate change scenarios"** may be submitted by **Mrs. Fathima Sona N** in partial fulfillment of the requirement for the degree.

Dr. Shajeesh Jan P.
(Chairman, Advisory Committee)
Assistant Professor
Agricultural Meteorology
RARS, Ambalavayal

Dr. B. Ajithkumar
(Member, Advisory Committee)
Associate Professor and Head
Department of Agricultural Meteorology
College of Agriculture, Vellanikkara

Dr. Laly John C.
(Member, Advisory Committee)
Professor
Department of Agricultural Statistics
College of Agriculture, Vellanikkara

Dr. Anitha S.
(Member, Advisory Committee)
Professor (Agronomy)
Instructional Farm, KAU,
Vellanikkara

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CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
1	INTRODUCTON	1-3
2	REVIEW OF LITERATURE	4-19
3	MATERIALS AND METHODS	20-33
4	RESULTS	34-103
5	DISCUSSION	104-115
6	SUMMARY	116-118
	REFERENCES	i -xii
	APPENDICES	
	ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
3.1	Mechanical composition of soil of the experimental field	20
3.2	Treatments used in the experiment	22
3.3	Weather parameters used in the experiment	24
3.4	Chemical properties of soil	27
3.5	Description of representative concentration pathway (RCP) scenarios	31
3.6	Time slices considered for the study.	33
4.1	Number of days from planting to 50% sprouting	35
4.2	Number of days from 50% sprouting to active tillering	35
4.3	Number of days from active tillering to bulking	36
4.4	Number of days from bulking to physiological maturity	36
4.5.a	Effect of dates of planting on plant height at weekly interval	38
4.5.b.	Effect of varieties on plant height at weekly interval	39
4.5.c.	Interaction between dates of planting and varieties on plant height at weekly interval	40
4.6.a.	Effect of dates of planting on leaf area at fortnightly interval	44
4.6.b.	Effect of varieties on leaf area at fortnightly interval	44
4.6.c	Interaction between dates of planting and varieties on leaf areaat fortnightly interval	45
4.7.a	Effect of dates of planting on number of tillers at fortnightly interval	47
4.7.b	Effect of varieties on number of tillers at fortnightly interval	47
4.7.c	Interaction between dates of planting and varieties on number of tillers at fortnightly interval	48
4.8.a	Effect of dates of planting on number of fully opened leaves	50
4.8.b	Effect of varieties on number of fully opened leaves	51
4.8.c	Interaction between dates of planting and varieties on number of fully opened leaves	52
4.9.a	Effect of dates of planting on girth of main tiller at fortnightly interval	54
4.9.b	Effect of varieties on girth of main tiller at fortnightly interval	54
4.9.c	Interaction between dates of planting and varieties on girth at fortnightly interval	55
4.10.a	Effect of dates of planting on dry matter accumulation at fortnightly interval	57
4.10.b	Effect of varieties on dry matter accumulation at fortnightly interval	57

LIST OF TABLES (Contd.)

Table No.	Title	Page No.
4.10.c	Interaction between date of planting and varieties on dry matter accumulation at fortnightly interval	58
4.11.a	Effect of dates of planting on phenological observations	61
4.11.b	Effect of varieties on phenological observations	61
4.11.c	Interaction between dates of planting and varieties on phenological observations	62
4.12.a	Effect of dates of planting on yield and yield attributes	65
4.12.b	Effect of varieties on yield and yield attributes	65
4.12.c	Interaction of dates of planting and varieties on yield and yield attributes	66
4.13	Soil analysis	64
4.14	Correlation between yield of ginger and weather variables	69
4.15	Correlation between rhizome length of ginger and weather variables	71
4.16	Correlation between rhizome width of ginger and weather variables	74
4.17	Correlation between internodal length of ginger and weather variables	75
4.18	Correlation between dry yield of ginger and weather variables	77
4.19	Importance of components obtained after PCA analysis for *Maran*	78
4.20	Loading values of weather variables in forming principal components in *Maran*	80
4.21	Importance of components obtained after PCA analysis for *Varada*	81
4.22	Loading values of weather variables in forming principal components in *Varada*	83
4.23	Comparison of predicted yield and observed yield of ginger varieties *Maran* and *Varada.*	84
4.24	RMSE Value of weather parameters	85
4.25	Future climate of the phenophase planting to 50% sprouting	86
4.26	Future climate of the phenophase 50% sprouting to active tillering	89
4.27	Future climate of the phenophase active tillering to bulking	92
4.28	Future climate of the phenophase bulking to physiological maturity	95
4.29	Percent deviation in yield from the observed value in *Maran* under RCP 4.5 scenario	100
4.30	Percent deviation in yield from the observed value in *Maran* under RCP 8.5 scenario	100
4.31	Percent deviation in yield from the observed value in *Varada* under RCP 4.5 scenario	102

LIST OF TABLES (Contd.)

Table No.	Title	Page No.
4.32	Percent deviation in yield from the observed value in *Varada* under RCP 8.5 scenario	102
5.1	Effect of maximum temperature on yield of ginger	108
5.2	Effect of minimum temperature on yield of ginger	108
5.3	Effect of soil moisture on yield of ginger	108

LIST OF FIGURES

Figure No.	Title	Between pages
3.1	Layout of the experiment plot in split plot design	23-24
4.1.a	Phenological calendar of *Maran*	35-36
4.1.b	Phenological calendar of *Varada*	35-36
4.2	Scree plot of cumulative proportion of different weather parameters of *Maran*	78-80
4.3	Variables factor map obtained after PCA in *Maran*	78-80
4.4	Scree plot of cumulative proportion of variances in *Varada*	81-83
4.5	Variables factor map obtained after PCA in *Varada*	81-83
4.6	RMSE Value of weather parameters	84-86
5.1	Effect of maximum and minimum temperature on germination of ginger	104-105
5.2	Effect of soil temperature at 5 cm depth on germination of ginger	104-105
5.3	Effect of rainfall on germination of ginger	106-107
5.4	Number of days for physiological maturity taken by *Maran* (V1) and *Varada* (V2)	106-107
5.5	Effect of rainfall on number leaves in *Maran* (V1) and *Varada* (V2)	106-107
5.6.a	Effect of wind speed on leaf area in *Maran*	106-107
5.6.b	Effect of wind speed on leaf area in *Varada*	106-107
5.7	Effect of dates of planting on ginger yield	106-107
5.8	Effect of cumulative rainfall on yield of ginger	107-108
5.9	Effect of maximum temperature on yield of ginger	107-108
5.10	Effect of minimum temperature on yield of ginger	108-109
5.11	Effect of soil moisture on yield of ginger	108-109
5.12.a	Percentage change in yield of *Maran* planted on May 15th date of planting under RCP 4.5 scenario.	109-110
5.12.b	Percentage change in yield of *Maran* planted on May 15th date of planting under RCP 8.5 scenario.	109-110
5.13.a	Percentage change in yield of *Maran* planted on June 1st date of planting under RCP 4.5 scenario.	109-110

LIST OF FIGURES (Contd.)

Figure No.	Title	Between pages
5.13.b	Percentage change in yield of *Maran* planted on June 1st date of planting under RCP 8.5 scenario.	109-110
5.14.a	Percentage change in yield of *Maran* planted on June 15th date of planting under RCP 4.5 scenario	110-111
5.14.b	Percentage change in yield of *Maran* planted on June 15th date of planting under RCP 8.5 scenario.	110-111
5.15.a	Percentage change in yield of *Maran* planted on July 1st date of planting under RCP 4.5 scenario.	110-111
5.15.b	Percentage change in yield of *Maran* planted on July 1st date of planting under RCP 8.5 scenario.	110-111
5.16.a	Percentage change in yield of *Varada* planted on 15th May date of planting under RCP 4.5 scenario.	111-112
5.16.b	Percentage change in yield of *Varada* planted on 15th May date of planting under RCP 8.5 scenario.	111-112
5.17.a	Percentage change in yield of *Varada* planted on June 1st date of planting under RCP 4.5 scenario.	111-112
5.17.b	Percentage change in yield of *Varada* planted on June 1st date of planting under RCP 8.5 scenario.	111-112
5.18.a	Percentage change in yield of *Varada* planted on June 15th date of planting under RCP 4.5 scenario.	112-113
5.18.b	Percentage change in yield of *Varada* planted on June 15th date of planting under RCP 8.5 scenario.	112-113
5.19.a	Percentage change in yield of *Varada* planted on July 1st date of planting under RCP 4.5 scenario.	112-113
5.19.b	Percentage change in yield of *Varada* planted on July 1st date of planting under RCP 8.5 scenario.	112-113

LIST OF FIGURES (Contd.)

Figure No.	Title	Between pages
5.20	Yield variability of *Maran* with respect to maximum temperature under 4.5 scenario.	113-114
5.21	Yield variability of *Maran* with respect to maximum temperature under 8.5 scenario.	113-114
5.22	Yield variability of *Varada* with respect to maximum temperature under 4.5 scenario	113-114
5.23	Yield variability of *Varada* with respect to maximum temperature under 8.5 scenario.	113-114
5.24	Yield variability of *Maran* with respect to rainfall under 4.5 scenario.	114-115
5.25	Yield variability of *Maran* with respect to rainfall under 8.5 scenario.	114-115
5.26	Yield variability of *Varada* with respect to rainfall under 4.5 scenario.	114-115
5.27	Yield variability of *Varada* with respect to rainfall under 8.5 scenario.	114-115

LIST OF PLATES

Plate No.	Title	Between pages
1	Liming of the field	23-24
2	Field preparation	23-24
3	Planting	23-24
4	Field view after 45 days of first planting	23-24
5	Overall view of the experimental field	23-24

Introduction

1. INTRODUCTION

Spices, the pride crops of India, are highly bestowed for their flavour, smell, colour, medicinal and nutritional qualities. Being the largest producer, consumer and exporter of spices in the world, India possesses a wide variety of spice crops. Spices play a vital role in the agricultural economy of the country, with an area of 39,39,915 ha, with a production of 92,69,036 tonnes in 2018-19 [DASD, 2020]. Among the spices, ginger (*Zingiber ofjicinale*) is the main cash crop supporting the livelihood and improving the economic level of many ginger growers all over the country. Ginger is a perennial herbaceous monocotyledon and is believed to have originated in Southeast Asia, but was under cultivation from ancient times in India and China. Ginger, which is aromatic and pungent, lends a unique flavour to a variety of foods and has been used in Asian cuisine for ages. It is extensively cultivated in most of the Indian states including Karnataka, Assam, West Bengal, Madhya Pradesh, Meghalaya, Mizoram, Arunachal Pradesh, Nagaland and Manipur.

The climate of Earth has varied significantly throughout its history. The periodic and episodic changes caused by natural and anthropogenic climate forcings have induced considerable changes in planetary climate on a range of timescales. Anomalies in temperature and climatic regime of the earth system have prompted worries that global climate change is a serious stressor for agriculture and world food production since plants are directly related and respond to environmental CO_2 and temperature (Kersebaum and Nendel, 2014). Changes in extremes are becoming larger with each additional degree of global warming. For example, every 0.5°C increase in global warming causes clear increases in the intensity and frequency of hot extremes, such as heat waves, heavy precipitation and agricultural and ecological droughts in some regions (IPCC, 2021). With more global warming, heavy precipitation events are likely to intensify and become more frequent in most regions. Extreme daily precipitation events are expected to intensify by about 7% on a global scale for every 1°C of global warming (IPCC, 2021). Socio-economic and emission scenarios are used in climate research to offer realistic descriptions of how the future may evolve in terms of a variety of variables such as socio-economic change, technological change, energy, land usage, greenhouse gas and air pollution emissions. They serve as input for climate model runs as well as a foundation for assessing potential climate consequences, mitigation measures and costs. RCPs are a collection of four newpaths established for the climate modeling community to use as a foundation forlong- term and near-term modeling studies. The RCPs may be used in new studieson climate change impacts after the climate model runs are completed. This will necessitate knowledge on future socioeconomic conditions (Vuuren *et al.*, 2011).

Climate and weather changes have a direct impact on the yield and qualityof food crops, which is critical to human well-being. The food security of a country like India may be placed under progressively greater pressure due to increasing temperatures, heat extremes, floods, droughts and increasing year-to-year rainfall variability that can interrupt rain-fed agricultural food production and adversely impact crop yield (Dhara *et al.*, 2020). According to Murugan *et al.* (2009) crop production in the tropics is expected to decline even at moderate climate change (1.4°C increase in 2040), in contrast to high latitudes. Despite significant advancements in technology and crop yield potential, agricultural production remains heavily dependent on climate due to the influence of solar radiation, temperature and precipitation. Ginger yields are said to vary substantially based on varieties, climate, planting period and harvest maturity (Peter *et al.*, 2005). A study was done by Parthasarathy *et al.*, (2008) to understand the impact of climate change on the suitability of ginger growing zones with Eco-crop model revealed that if the temperature rises by 1.5 to 2˚C, the suitability of Orissa and West Bengal for ginger production will drop dramatically from high to marginal, indicating the impact of climate change.

In this context, the present study entitled, “Ginger (*Zingiber officinale*) yield variability under different climate change scenarios” was undertaken with the major objective of climate change impact assessment on phenological characters and yield of ginger, using statistical tools and projected climate changescenarios.

Review of literature

2. REVIEW OF LITERATURE

Climate change is the most serious global environmental threat facing by civilization, with consequences for natural ecosystems, agriculture and human health. Long-term measurements from the top of the atmosphere to the depths of the oceans show a warming trend. Climate change is posing increasing threats to human health and safety, as well as the country's quality of life and economy. While climate change is a worldwide phenomenon, it is unlikely to be uniform across the globe. The agricultural sector has been a natural focus for research because the climate is a direct input into the agricultural production process. The possible influence of changes in climate parameters on ginger, one of the high-value spice crops, in various parts of the world is the key area of worry regarding global climate change.

The chapter reviews and presents the relevant literature to the current experiment, termed "Ginger (*Zingiber officinale*) yield variability under different climate change scenarios."

1. Significance of ginger crop
2. Effect of dates of planting on growth and yield of ginger
3. Effect of varieties on growth and yield of ginger
4. Effect of temperature on growth and yield of ginger
5. Effect of rainfall on growth and yield of ginger
6. Crop weather relationships of ginger
7. Climate change and climate change simulations
8. Impact of climate change on growth and yield of ginger
9. Pest and diseases of ginger

2.1. Significance of ginger crop

The cost and profits of ginger production in Himachal Pradesh are estimated by Sharma *et al.* (1989). They discovered that as farm size grows, the gross and net returns per hectare from ginger decline significantly. It is because small farms have better management and input usage perhectare than large farms.

According to Andrews and Salim (1990), the availability of exportable ginger varieties hasalways been a concern. Domestic consumption, on the other hand, is increasing as a result of its growing appeal in culinary preparations and expanded applications in medicine, confectioneries, and non alcoholic beverages.

Ginger (*Zingiber officinale* Rosc.) is one of the world's most important and frequently used spices. Because of its esteemed aroma and lemon flavour, it has spread to tropical and subtropicalregions from the Indo-China region, where ginger production has been practiced since prehistorictimes (Nybe and Miniraj, 2004).

Since ginger has been cultivated in Kerala from the dawn of time, there exists a wide range of yield and quality aspects among cultivated ginger varieties. Geographical distribution, combined with mutation-induced genetic differentiation into regionally adapted populations, couldbe the primary driver of variation in this clonally propagated crop (Ravindran *et al*., 2004).

It is one of the first eastern spices to be discovered in Europe and it is still in high demand today. The genus *Zingiber*, which belongs to the *Zingiberaceae* family, has over 150 species that are found throughout tropical and subtropical Asia as well as far East Asia. As a spice family "*Zingiberaceae*" is extremely important. Turmeric, cardamom, giant cardamom, grain of paradise and several other spices of commercial and medicinal value are all members of this family (Ravindran *et al*., 2004).

The rhizomes of black ginger, which have a blue-black hue inside, are said to have therapeutic benefits and are grown solely for personal use by Mizoram residents. It is also reportedto be sold for a very high price, owing to its therapeutic significance (Yadav *et al*., 2004).

Kala *et al*. (2016) reported that ginger oil is also used in soft drinks as food flavouring agents, like spices in bakery products, confectionery items, pickles and sauces.

Ginger is a valuable plant with a variety of therapeutic and nutritional properties that have long been utilized in Asian and Chinese traditional medicine. Ginger and its general compounds, including Fe, Mg, Ca, vitamin C, flavonoids, phenolic compounds (gingerdiol, gingerol, gingerdione and shogaols), sesquiterpenes, and paradols, have long been used as herbal medicine to treat a variety of symptoms including vomiting, pain, cold symptoms and it has been shown to have anti-inflammatory, anti-apoptotic, anti-tumor, anti-platelet, anti-tumourigenic, anti- hyperglycaemic, antioxidant and anti-diabetic properties (Shahrajabian *et al*., 2019).

2.2. Effect of dates of planting on growth and yield of ginger

Under Orissa conditions, Mohanty *et al*. (1990) found that ginger yields were higher whenplanted on April 1st and decreased when planted on July 1st.

Aggarwal *et al*. (2002) reported the highest leaf area index of ginger in June planting, followed by May planting and March planting. The lowest LAI was recorded in March planting, claiming that planting ginger on the 15th of May was appropriate under Solan (H.P) conditions.

Bandopadhyay *et al.* (2005) also found that turmeric planted on May 1st grew better underWest Bengal conditions.

Turmeric planted on May 15th resulted in greater vegetative development under Coimbatore conditions, according to Kandiannan and Chandaragiri (2008).

Shadap *et al.* (2013) reported that June planting (63.90) had the highest harvest index, followed by April planting (59.86) and March planting (59.39). August planting having the lowest (41.49) harvest index. Planting rhizome in May yielded the highest fresh rhizome production per hectare (17.09t), followed by June planting (16.49 t), while August planting yielded the lowest fresh rhizome yield (4.98 t). He concluded that the favorable weather conditions in the northern dry zone of Karnataka in May and June must have contributed to better yields.

May planting had the highest plant height (48.30cm), which was on par with June planting(47.93cm), compared to the lowest in March planting (27.11cm). May planting had a bigger pseudostem girth (2.45cm), which was comparable to June planting (2.42cm), while August planting had the lowest (1.74cm). June planting (14.25) recorded a higher number of tillers per clump which was on par with May planting (14.05). March planting (9.08) recorded the lowest number of tillers (Shadap *et al.,* 2013).

Shadap *et al.* (2013) also stated the quality attributes such as essential oil content and oleoresin were higher in the early planting dates and steadily decreased, with rhizomes planted inAugust having the lowest content of these quality qualities.

2.3. Effect of varieties on growth and yield of ginger

Varada, a new kind of ginger developed by the Indian Institute of Spices Research in Calicut, has a fiber level of 3.2%. This type is being multiplied at the Ginger Development Station in Umsning, Meghalaya, and the results are promising (Yadav *et al.,* 2004).

There are various indigenous cultivars particular to specific regions, such as Maran, Kuruppanlpadi, Jorhat, Bajpai, Karakal, Wayanad, Himachal and Nadia, as well as the Rio-de- Janeiro cultivar, which is popular throughout India. From the rich pool of germplasm kept at the Indian Institute of Spices Research, improved varieties for high quality and production have beenproduced and disseminated. Due to its exceptional quality and yield, IISR Varada, issued by IISR under lCAR, has acquired favour in the country's ginger-growing regions (Parthasarathy *et al*., 2008).

A study by Kallappa *et al.* (2015) on the performance of ginger (*Zingiber officinale* Rosc.) varieties for yield and quality attributes under the hill zone of Karnataka, evaluated ten varieties of ginger for yield and quality attributes. In terms of yield and quality parameters, there were significant variances amongst the types. Variety *Maran* had the highest fresh rhizome productionof 29.37 t/ha, followed by

Rio-de-Janeiro (28.04 t/ha) and Karakal Local (25.84 t/ha), according to the results. The variety Karakal Local had the highest crude fibre content (6.73%), while variety IISR-Varada had the lowest (3.70 %).

2.4. Effect of temperature on growth and yield of ginger

According to a study conducted by Whiley (1974) temperature above 32˚C can cause sunburn and low temperature can induce dormancy in ginger.

The ginger crop requires an optimum soil temperature of 25-26˚C for germination and 27.5˚C for growth (Evenson *et al*., 1978). Ginger thrives well under the Kerala condition of 28- 35˚C (Purseglove *et al*., 1981).

Since temperature and light are the primary determinants of phenological response, most of the responses are centered on thermal accumulation (Hodges., 1990). Low temperatures, along with low light intensity, appear to promote the formation of morechlorophyll in ginger plants growing in the shade, resulting in a bigger number of leaves (Vastard *et al.*, 2006).

Although the climate in northeast India is favourable for ginger production, the low temperatures seen during crop growth and rhizome development result in plumpy rhizomes with limited dry recovery and high fibre content, rendering them unsuitable for dry ginger or ginger powder (Parthasarathy *et al*., 2008).

Increasing temperature deteriorated the antibacterial properties of ginger drastically (Sah and Tamimi, 2012).

Temperature is a critical climate variable that has a direct impact on both human, plant andenvironmental systems. The global mean surface temperature is an important indicator of climate change since it rises quasi-linearly in response to cumulative greenhouse gas emissions, as demonstrated in many IPCC assessment reports, including the Fifth Assessment Report (AR5; IPCC 2013).

According to Shetty *et al.* (2016), for the increased leaf area in ginger, a day temperature of 28-35ºC and high relative humidity are required throughout the crop period.

2.5. Effect of rainfall on growth and yield of ginger

Ideal rainfall for the ginger crop is 1500-3000 mm which is well distributed in 8-10 months (CSIR, 1976).

Balakrishnan (1990) reported that the high fibre content of ginger from the North-Eastern states is an issue. This is primarily because this area experiences frequent rainfall and lacks sufficient sunlight, preventing the ginger from drying entirely. This ginger cultivar is rarely found in markets, both within and outside the country, in both fresh and dried forms.

Yadav *et al.* (2004) stated that heavy rainfall causes high infestation with weeds, pests and diseases and leaching of nutrients.

In Meghalaya, the eastern and western parts are highly suitable for ginger, but the central part is less suitable due to heavy rainfall (Utpala *et al*., 2005).

Nybe and Shylaja (2004) reported dry spells with moderate showers at the time of planting, heavy rains during the growing season and a one-month dry interval before harvest are ideal for improved ginger production.

Unlike other cardamom-growing regions in South India, the Malanad region in Karnataka has a long dry season that lasts over 142 days. This leads to a lack of moisture during key stages of panicle initiation, growth and flowering, which harms setting and productivity in cardamom. (Leela *et al*., 2008).

From 2001 to 2015, there was a substantial positive link between ginger yield and rainfall amount (r = 0.606). This is because as the amount of annual rainfall grows, so do the yearly ginger yields (Abaje, 2018).

2.6. Crop weather relationships of ginger

Garner and Allard (1923) found that short photoperiods resulted in better tubers than long photoperiods in potatoes.

With reference to Hackett and Carolane (1982) ginger crop is sensitive to waterlogging, frost and salinity, tolerant to wind and drought conditions.

Rathcke and Lacy (1985) defined phenology as the study of the seasonal timing of life cycle events, it also refers to the development, growth, differentiation and initiation of organs.

Thermal time requirements for completion of distinct phenological phases have been used for predicting the time of occurrence of different developmental phases in a dynamic simulation developed by Ritchie and Nesmith (1991).

Tillering and rhizome growth were both linked to photoperiods. This could be due to the ratio of gibberlic and abscisic acids. For continual tillering and growth without entering dormancy, the ginger crop requires a long day length of 12 hours or more during its development period and a gradually decreasing day length of 10-11 hours for seed rhizome formation (Pandey *et al*., 1996).

According to studies by Yun *et al.* (1998), photosynthesis reaches saturation between 400 and 900 moles of light intensity.

In the case of ginger cultivation, shade might help to improve air humidity. Air humidity, being the primary determinant of atmospheric moisture content, can alter the stomatal opening of plant leaves, influencing plant transpiration rate (E) andnet photosynthetic rate (NPR) (Xu, 1999).

The high production of ginger in northeastern states is due to its climatic conditions and good local varieties whereas in the case of states like Tamil Nadu and Gujarat, the climate is only marginally suitable and the area under cultivation is less (Utpala *et al*., 2005).

Peter *et al.* (2008) given that the environment has a significant impact on ginger productivity, identifying places with appropriate soil and climatic conditions is critical for achieving high yields in ginger.

The climatic conditions in India, particularly in southern India, Orissa, and the north- eastern provinces are ideal for growing ginger (Parthasarathy., 2008).

A light intensity of 1290 micromoles m^{-2} s^{-1} was found to be optimal for single leaf photosynthesis in ginger, whereas a canopy light intensity of 1950 moles $m^{-2}s^{-1}$ was shown to be optimal (Parthasarathy., 2008).

Parthasarathy *et al.* (2008) also reported that when compared to ginger grown in full sunlight orheavy shadow, a partial shade of roughly 25% resulted in greater production and quality. In the case of open locations, much more sunshine causes reduced yields.

Curcumin and essential oil yield and content vary according to environmental and soil nutrients, as well as agroclimatic conditions in different zones. As a result, variation in secondary metabolites in response to various environmental circumstances is crucial for their increased export potential in the worldwide market (Anandaraj *et al.*, 2014).

2.7. Climate change and climate change simulations

Vuuren *et al*. (2011) stated that the Representative Concentration Pathways (RCPs) were the scenarios utilized by models in the Coupled Model Inter comparison Project Phase 5 (CMIP5) that contributed to the IPCC AR5 and covered the period from 2006 to 2100.

With rising GHGs, the AR5 assessment determined that Global Mean Surface Temperature (GMST) will continue to climb in the twenty-first century. In comparison to 1986–2005, the increase in GMST for 2081–2100 will most likely be in the 5–95 percent range of 0.3–1.7 °C underRCP2.6 and 2.6–4.8 °C under RCP8.5 (Collins *et al*., 2013).

Climate change, as defined by the IPCC (2013), is a change in the state of the climate thatmay be detected (e.g., using statistical tests) by changes in the mean and or variability of its attributes over time, generally decades or more. Any change in climate over time, whether caused by natural variability or human activity, is referred as climate change.

In all scenarios, according to the AR5 assessment of ocean changes, the global ocean will warm. The primary contributors to the twentieth-century global mean sea-level increase have beenthermal expansion owing to ocean warming and glacier melt (Church *et al*., 2013).

According to Hartmann *et al.* (2013) warming is predicted to increase the rate of evaporation and the amount of moisture in the atmosphere. Indeed, the amount of water vapour inthe atmosphere has increased globally, as measured by specific humidity, on both land and sea.

Multiple independent lines of investigations from the industrial revolution have revealed increasingly persuasive evidence that human activities have drastically impacted the Earth's climate. Since 1850, each of the last three decades has been warmer at the Earth's surface than the previous decade and 2001–2018 have been 18 of the 19 warmest years in the observational record (Stocker *et al*., 2013).

Precipitation in tropical land areas increased over the decade ending in 2012, reversing a drying trend that began in the mid-1970s and continued into the mid-1990s. Large-scale changes in precipitation patterns over land have also been influenced by human activity (Bindoff *et al.*, 2013).

While climate change is a worldwide phenomenon, climate changes are unlikely to be uniform across the globe. For example, Arctic temperatures are rising significantly faster than global average temperatures (Stocker *et al*., 2013).

Singh *et al.* (2014) discovered a statistically significant rise in the intensity and frequency of extreme wet and dry spells during the Indian Summer Monsoon (ISM) from 1951 to 2011 in a recent study.

Since about 1950, the number of cold days and nights has likely dropped while the number of warm days and nights has likely grown, according to the IPCC AR5 (2014). Over the period 1901–2012, regional trends are sufficiently complete to reveal that nearly the whole planet, including both land and ocean, has undergone surface warming.

Rainfall may be decreasing as a result of multi-decadal epochal variability linked to an east-west shift in monsoon rainfall due to anomalous warming of the Indo-Pacific warm pool (Guhathakurta *et al*., 2015).

Kulkarni *et al.* (2017) discussed that there is significant spatial variability in precipitation changes around the country. During the period 1976–2015, rainfall decreased by 1–5 mm/day throughout central India (the core monsoon zone), Kerala and the extreme northeastern sections of India and increased over the Jammu and Kashmir region, as well as areas of western India, compared to the period 1901–1975.

According to Allen *et al.* (2018) from the pre-industrial periods, human-induced climate forcing has increased global average near-surface air temperature of about 1°C and if the current trend continues global warming will most likely hit 1.5 degrees Celsius between 2030 and 2052.

Long-term climate variability may also a reason for the rising trend in floods (Najibi and Devineni, 2018). Ali *et al.* (2019) discussed the extreme floods in the South Asia cluster during excessive monsoons and these extremes have been increasing in river basins across India since the1950s.

Regarding Sonali *et al.*(2018) the observed changes in maximum temperature during the post-monsoon and minimum temperature during the pre-monsoon and monsoon seasons in South India between 1950 and 2005 are assessed to be detectably different from natural internal climate variability and these temperature changes are attributed to climate change induced by anthropogenic effects with confidence. These conclusions are based on observational datasets and multiple Atmosphere-Ocean Coupled General Circulation Model (AOGCM) outputs from historical simulation experiments conducted in the fifth phase of the Coupled Model Inter comparison Project (CMIP5), which allowed human and natural causes of climate change to be identified and quantified.

Modern climate models predict that anthropogenic global warming and associated climate change will continue in the twenty-first century, with significant implications for India (Krishnan *et al*., 2020).

According to Krishnan *et al*. (2020), the four RCPs were defined as RCP2.6, which represents a low emissions pathway with a radiative forcing (RF) of roughly 2.6 W/m^2 at the end of the twenty-first century, RCP4.5, and RCP6, which represent intermediate emission pathways with RFs of 4.5 W/m^2 and 6 W/m^2 respectively at the end of the twenty-first century at the same time a scenario with large emissions RCP8.5 is a scenario in which GHG emissions continue to rise, resulting in an RF of around 8.5 W/m^2 by the end of the twenty-first century.

Temperatures of the warmest day and coldest night of the year have risen by around 0.63°Cand 0.4°C, respectively, over the last 30 years (1986–2015). Under the RCP8.5 scenario, these temperatures are anticipated to climb by approximately 4.7°C and 5.5°C by the end of the twenty-first century respectively, compared to the equivalent temperatures in the recent past (1976–2005 average) (Krishnan *et al.* 2020).

Warm days and nights are expected to increase by 55 percent and 70 percent, respectively, by the end of the twenty-first century, compared to the reference period 1976-2005, under the RCP8.5 scenario. In the RCP8.5 scenario, the frequency of summer heat waves across India is anticipated to be 3 to 4 times greater by the end of the twenty-first century, compared to the 1976–2005 baseline period (Krishnan *et al*., 2020).

IPCC sixth assessment report (2021) stated that since 1970, global surface temperatures have risen faster than in any other 50-year period in the last 2000 years. Temperatures in the last decade (2011–2020) have surpassed those of the most recent multi-century warm period, which occurred around 6500 years ago [0.2°C to 1°C relative to 1850-1900].

6^{th} Assessment Report scenarios consider a broader range of emissions in the future than the 5^{th} Assessment Report, including high CO_2 emissions scenarios without climate change mitigation and a low CO_2 emissions scenario that achieves net-zero CO_2 emissions by mid-century. A core set of five scenarios

SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 are used in the 6th Assessment Report to investigate climate change in the 21st century and beyond. The RCPs and SSP-based scenarios, on the other hand, are not directly comparable. First, the gas-to-gas compositions differ; for example, compared to RCP8.5, the SSP5-8.5 scenario has higher CO_2 but lower methane concentrations. Second, even if the projected 21st -century trajectories result in the same radiative forcing by 2100, they may differ. Third, the overall effective radiative forcing for SSPs and RCPs with the same nominal stratospheric-temperature-adjusted radiative forcing label may differ and tends to be higher for SSPs (IPCC, 2021).

In observations of atmospheric temperature and some aspects of circulation, the effects of human-induced climate change have been identified and these effects are likely to intensify in the future. With continued net greenhouse gas emissions, tropospheric warming and stratospheric cooling are almost certain to continue. Several aspects of atmospheric circulation are likely to have changed since the mid-20th century and human influence is very likely to have contributed to the observed pole ward expansion of the Southern Hemisphere Hadley Cell and pole ward shift of the Southern Hemisphere extra tropical jet in summer (IPCC, 2021).

2.8. Impact of climate change on growth and yield of ginger

The threat of extinction of some wild ginger species is significant due to climate change (increased danger of drought) and the slow-growing capabilities of some wild ginger species, hence research into ways for enhancing ginger species output through improved cultivation technologies is critical (Yadav *et al.,* 2004).

According to Grzanna *et al*. (2005) the species of ginger, the maturity of the rhizome, the climatic condition in which the plants are cultivated, the harvesting stage and the method of extraction of compounds are the key elements that determine the relative content of the extract.

India is also one of the countries in the world with a high frequency of hail storms, which are often accompanied by violent thunderstorms and many updrafts and downdrafts.

These are more widespread in the Himalayan foothills, due to large-scale agriculture (De *et al.*, 2005).

In contrast to the plains of the tropics, rising climate change extremes may enhance plant disease and pest outbreaks in tropical mountain agro ecosystems (Deutsch *et al*. 2008).

Murugan *et al*. (2008) stated that rainfall is decreasing in the eastern slopes of the cardamom hills, which are semi-arid. Under a decreasing rainfall pattern, combined with a continuing atmospheric warming scenario, agriculture and sustainable development in this resource (water) poor semi-arid ecosystem could be jeopardized in the near future. Climate and agriculture scientists may face significant challenges in the coming years as demand for water increases by 20-80% in this densely populated valley.

Ginger is mostly grown as a rainfed crop in Kerala. The absence of late summer showers coupled with extremely high temperatures at the time of sowing, and extremely high precipitation during the crop growth period all have an impacton the growth and production of the crop (Nybe and Shylaja, 2008).

Parthasarathy *et al.* (2008) reported that elevated temperature and CO_2 may boost ginger- growing areas in Himachal Pradesh and north-eastern sections of the country, but these benefits could be negated by increased floods and frost. Climate change, in the form of rising temperatures and corresponding increases in light intensity, may diminish ginger yields in southern states as theoptimum canopy light intensity is 1950 moles $m^{-2}S^{-1}$.

Singh (2008) suggested that since spices are grown in both plains and high elevations, it is critical to consider long-term climate changes and their impact on productivity. There is also varietal variation, therefore it is crucial to look into how a variety reacts in certain situations. Growing the same variety under different agro-climatic conditions while keeping all other inputs constant can be used to investigate the temperature effect. It's also crucial to look into the combined effects of higher temperatures and CO_2 on spice productivity.

With reference to Singh (2008) rainfall, minimum temperature, and rainy days were all positively correlated with the productivity of turmeric, showing that higher precipitation and lower temperatures may have a favourable impact on rhizome yield. Although there was a negative link between maximum temperature and solar radiation which was not significant. It appears that raising these two factors will reduce productivity.

Because Indian agriculture is reliant on seasonal rains, inter-annual variability in synoptic- scale weather systems is critical to the country's socio-economic fabric (Ajaymohan *et al.*, 2010).

The high ranges, growing belt of thermo sensitive spice crops like cardamom, tea, black pepper and cocoa are under the threat of widening of temperature range, which eventually resulted in climate shift from B4-B3 to B2-B1 based on thermal and moisture regime. It caused a transition of wetness to dryness within the humid climate in Kerala (Kandiannan, *et al*., 2014).

Increased temperature, water stress, and a reduction in the number of rainy days have already had a severe impact on wheat and paddy yields in parts of India. Significant negative consequences have been predicted with medium-term (2040-2069) climate changes, which include yield reduction by 4.5 to 9%, depending on the magnitude and distribution of warming (Kumar *et al.*, 2018).

The studies revealed significant changes in weather elements have a significant impact on the production of spice crops such as small cardamom, seed spices, and black pepper (Muthusami *et al*. 2021).

2.9. Pest and diseases of ginger

Trujillo (1964) reported that *Pythium* soft rot of ginger could be a concern in Hawaii if there is a lot of rain and the soil isn't well-drained. He also found out that when temperatures are above 90°F, young ginger plants are extremely vulnerable to sunburn. Sunburn is caused by high light intensity rather than high temperatures and acute sunburn damages the entire stem, but mild sunburn only affects the leaves.

Pantomorus godmani (Crotch), the Fullers rose beetle, feeds on several plants, including ginger. The species is more common at higher elevations, and it appears that it needs cooler temperatures to survive (Trujillo, 1964).

Bacterial wilt (*Ralstonia solanacearum)* thrives in tropical, subtropical, and warm-climate zones where the temperature and humidity are ideal for its growth (Singh, 1978).

In various hosts, a rise in temperature to a range of 30 to 35^{o}C is linked to a worsening of the disease produced by *R. solanacearum*. Plants that are resistant to *R. solanacearum* at moderate temperatures become more sensitive to *R. solanacearum* at higher temperatures (Wang and Lin, 2005).

High temperatures (i.e.30-35°C) encourage the spread of *Ralstonia solanacearum*-caused disease, whereas soil temperatures below 20°C are inhospitable to the infection (Wang and Lin, 2005).

The greatest concern in heavy rainfall locations is the prevalence of a favourable climate for the proliferation and spread of soft rot and bacterial wilt pathogens, resulting in the substantial economic loss (Parthasarathy *et al.*, 2008).

According to a study conducted by Stanley *et al* (2009) weather parameters such as minimum temperature, evening relative humidity, rainy days and sunshine hours were all positively connected with *C. punctiferalis* damage which was found to complete its life-cycle within a shorter period in castor, followed by cardamom, guava and ginger. They also found that the rainfall was discovered to have a favourable relationship with the pest's parasitization rate. The parasitization rate increased by 2.8% for every unit increase in rainfall.

A study conducted by Edmundus (2015) on sweet potato revealed that only the soil and weather variables showed significant relationships in Pearson correlations of bacterial root rot and Rhizopus soft rot incidence with all variables.

Temperatures have a substantial impact on the attachment of Infectile Juveniles (IJ) of Entomo pathogenic Nematodes (EPNs) which predate on ginger shoot borer (*Conogethes punctiferalis* Guen.). Its attachment was higher at 30°C thanat 25°C at all test temperatures (Parvez*et al.*, 2016).

The correlation study was done by Devi *et al.* (2016) on *C. punctiferalis* infestation on guava shows that maximum and minimum temperature have a significant but negative relationship, as does rainfall, however, relative humidity has a significant positive relationship with the number of larvae and fruit infestation of *C. punctiferali*.

Materials and methods

3. MATERIALS AND METHODS

The study on “Ginger (*Zingiber officinale*) yield variability under different climate change scenarios” was carried out during the year 2020-2021 at the Department of Agricultural Meteorology, College of Agriculture, Vellanikkara, Thrissur. The materials used and methods applied were described below:

3.1 DETAILS OF THE EXPERIMENT

3.1.1. Location of the experiment

The field experiment was conducted at Instructional Farm (IF), Kerala Agricultural University (KAU), Vellanikkara, during May 2020 to January 2021. The field is located at 10.54˚N latitude and 76.27˚E longitudes. The place is situated at an altitude of 22m above themean sea level.

3.1.2. Soil characters

The texture of soil was found to be sandy loam. The physical properties of soil is depicted inthe table 3.1 below.

Table 3.1. Mechanical composition of soil of the experimental field

Sl. No.	Particulars	Method adopted
1	Coarse sand (%)	International pipette method (Piper,1967)
2	Fine sand (%)	
3	Silt (%)	
4	Clay (%)	

3.1.3. Climate

The experimental area is a typical warm humid tropical environment. During the experimental period, the area benefitted by both southwest and northeast monsoons. The average maximum temperature observed during the entire crop period was 31.35°C and the average minimum temperature was 22.66°C. The cumulative rainfall during the crop period was 2664.90 mm and the highest amount of rainfall was recorded in August (607.7 mm).

During the trial, the average amount of sunshine received was 4.3 hours per day. The mean relative humidity was 78 percent. The average wind speed was 2.9 kilometers per hour. Weekly weather parameters during the period of experiment 2020-2021is presented in Appendix. III, page number IV.

3.2. EXPERIMENTAL MATERIALS AND METHODS

3.2.1. Variety

The experiment was conducted using ginger varieties *Maran*, a local variety procured from Regional Agriculture Research Station (RARS) Ambalavayal and *Varada*, an improved variety released from Indian Institute of Spices Research (IISR), Kozhikode, procured from IISR Kozhikode. Both of the varieties have a total duration of 200 days.

3.2.2. Design of the experiment

The statistical design followed in the experiment was split plot design, with date of planting as main plot treatment and varieties as sub plot treatment. There were four dates of planting starting from 15th May. Consecutive plantings were done at fortnight interval, at 1st June, 15th June and 1st July. Two varieties *ie*., *Maran* (V1) and *Varada* (V2) were used as subplot treatments. Four replications were given for each treatments. The details of treatmentsare given in Table. 3.2.

Design : Split plot

Main plot Treatments: Four dates of planting

15th May 2020 (D1)

1st June 2020 (D2)

15th June 2020 (D3)

1st July 2020 (D4)

Sub plot treatments: Two varieties

Maran (V1)

Varada (V2)

Replications : 4

Table 3.2. Treatments used in the experiment

MAIN PLOT TREATMENT	**SUB PLOT TREATMENT**
Dates of planting	Vaieties
D1: 15th May 2020	V1 – *Maran*
	V2 – *Varada*
D2: 1st June 2020	V1 – *Maran*
	V2 – *Varada*
D3: 15th June 2020	V1 – *Maran*
	V2 – *Varada*
D4: 1st July 2020	V1 – *Maran*
	V2 – *Varada*

3.2.3. Layout of the experiment

The field layout is shown in Fig 3.1 the treatments included were four dates of planting starting from 15th May to 1st July at 15 days interval and two varieties, *Maran* and *Varada*. The field was divided into 32 plots of 3 x 1 m^2 size each. The spacing adopted was 25 x 25 cm.

3.3. CROP MANAGEMENT

3.3.1. Land preparation and planting

The land was ploughed 15-20 cm depth with a tractor using disc plough and optimum tilth was obtained with rotovator. Stubbles and big stones were removed from the field.

3.3.2. Manuares and Fertilizers

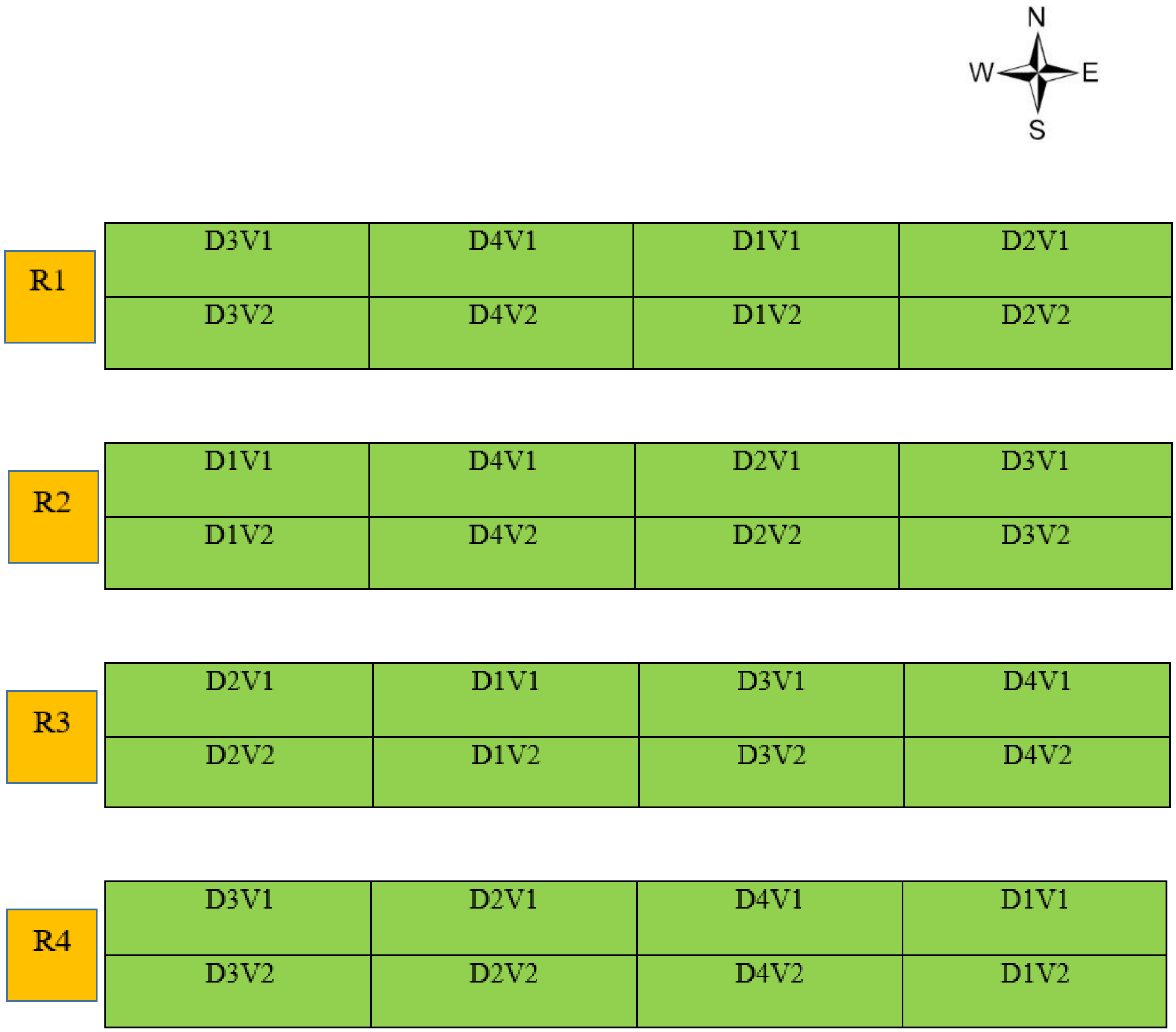
Farm Yard Manure (FYM) and neem cake were applied to the field at the rate of 20t/ha. To ensure proper growth of the crop N: P_2O_5: K_2O was applied at a rate of 75:50:50 kg/ha as different doses. Full dose of P_2O_5 and 50% of K_2O was applied as basal. The remaining 50% of K_2O was applied at 120 days after planting. N was applied at two doses, 50% of that at 60 days after planting and next 50% at 120 days after planting. Fertilizers like urea, rajphos and murate ofpotash were used to provide required nutrients. A micronutrient formulation *Sampoorna* was also applied at 45 days after planting.

3.3.3. Mulching

The plots were mulched immediately after sowing with *Glyricidia* leaves. The mulching were repeated at 60 days after planting and 90 days after planting.

3.3.4. After cultivation

Hand weeding was practiced to remove weeds. The weeding was repeated



D1: May 15th 2020; D2: June 1st 2020; D3: June 15th 2020; D4: July 1st 2020

V1: *Maran*; V2: *Varada*

Figure 3.1 Layout of the experiment plot in split plot design

Plate 1. Liming of the field

Plate 2. Field preparation

Plate 3. Planting

Plate 4. Field view after 45 days of first planting

Plate 5. Overall view of the experimental field

up to bulking stage based on the requirements. Earthing up of the plant was done after first mulching.

3.4. OBSERVATIONS

3.4.1. Weather data

Different weather parameters like Maximum temperature, minimum temperature, rainfall, relative humidity, rainy days, bright sunshine hours, wind speed, evaporation, soil temperature and soil moisture were collected from Principal Agromet Observatory, *Vellanikkara* on daily basis (Table 3.3).

Table 3.3. Weather parameters used in the experiment

Weather parameter	**Unit**
Maximum temperature	˚C
Minimum temperature	˚C
Rainfall	mm
Relative humidity	%
Rainy days	Days
Bright sunshine hours	hrs
Solar radiation	MJ m^{-2} day^{-1}
Wind speed	km hr^{-1}
Evaporation	Mm
Soil temperature	˚C
Soil moisture	%
Vapour pressure deficit	MmHg

3.4.2. Biometric characters

Five plants were randomly selected from each bed for biometric and phenological observations. Border plants were avoided for better results.

3.4.2.1. Plant height

The plant height was recorded at weekly interval in cm using a meter scale. The height was recorded by measuring the length of plant from base to the tip of fully opened leaves. The mean height of five plants were calculated.

3.4.2.2. Leaf area

The leaf area was observed at fortnightly intervals. The fourth leaf from the top of each plant was taken for measuring length and breadth. The leaf area was studied by using the model developed by Kandiannan *et al*. (2009) and it was depicted in cm^2.

Leaf area (LA) = -0.0146 + 0.6621 x L x W,

where L= length of leaf (cm) from the tip of lamina to the point of petiole intersection

W= maximum leaf width (cm), measured at the widest point perpendicular to midrib.

3.4.2.3.Number of tillers per plant

The total number of tillers per each observational plants were recorded at biweeklyintervals. The average value of five selected plants were recorded as number of tillers.

3.4.2.4. Number of fully opened leaves per plant

Total number of leaves per plant was counted manually on weakly interval basis.

3.4.2.5. Girth of main tiller

The girth of main tiller was recorded at biweekly interval with a flexible centimeter scale.

3.4.2.6. Dry matter accumulation

Plants uprooted at each months were undergo even drying to record dry matteraccumulation. It was expressed in kg ha^{-1}.

3.4.3. Yield and yield attributes

3.4.3.1. Length of primary rhizome

The primary rhizome of the plant was identified and length was measured with a centimeter scale.

3.4.3.2. Width of primary rhizome

Width of primary rhizome was measured with vernier caliper and it is expressed in cm.

3.4.3.3. Internodal length

The distance between two internodes was measured with a centimeter scale.

3.4.3.4. Fresh yield

Plants were harvested at their physiological maturity stage, which was indicated by dryingof the leaves. Rhizomes were removed from the plants, and after removing the dirt and roots adhering to it, the weight of the rhizomes was recorded.

3.4.3.5. Dry yield

The fresh rhizomes were given uniform drying and dry weight was measured. It is expressed kg ha^{-1}.

3.4.4. Phenological observations

3.4.4.1. Germination at 30 days after planting

The percentage of germination at 30 days after planting was recorded.

3.4.4.2. Number of tillers after 90, 120 and 150 days after planting

Number of tillers per plant was recorded in all the five observation plants. The average ofthese five plants were taken at 90, 120 and 150 days after planting.

3.4.4.3. Days to physiological maturity

The physiological maturity of ginger crop was decided when it dried. Number of days takenfor drying of the plants were recorded.

3.4.5. Soil analysis

Soil samples were collected from the field before sowing with the help of an auger. It was collected from different locations in zig-zag manner at a depth of 15cm.The collected soil was cleaned from stubbles and roots, sieved and undergone analysis. These samples were dried and powdered separately and were analyzed for pH, electrical conductivity available phosphorous, available potassium and organic carbon content (Table. 3.4).

Table. 3.4. Chemical properties of soil

Sl. No.	Parameter	Method adopted
1	Organic carbon (%)	Walkley and Black method (Jackson,1958)
2	Soil pH	1:2.5 (soil: water) suspension, pH meter (Jackson, 1958)
3	Electrical conductivity (dS m^{-1})	1:2.5 (soil: water) suspension, EC meter (Jackson, 1958)
5	Available phosphorous (kg ha^{-1})	Bray-1 extractant- ascorbic acid reductant method (Watanabe and Olsen, 1965)
6	Available potassium (kg ha^{-1})	Neutral normal ammonium acetate extractant- flame photometry

3.5. STATISTICAL ANALYSIS

The experimental data was statistically analyzed using Fisher's standard procedure for splitplot design (1947). ANOVA was used to determine whether there was a significant difference between main plot treatments (planting dates) and sub plot treatments (varieties) and theirinteraction.

For comparing the main plot treatments *i.e.* dates of planting critical difference has been calculatedusing the given formula,

$CD_1 = t_1 \times SE_1$

Where, t_1 is the t value at degrees of freedom for main plot error

$SE_1$is standard error of the difference between main plot treatment means

$$SE_1 = \sqrt{\frac{2E_1}{rb}}$$

Where, $E_1$is the error mean square value of the main plot treatment, r is the number of replicationsand b is the number of sub plot treatments

For comparing two sub plot treatments (varieties) the given formula was used to calculatethe CD value,

$CD_2 = t_2 \times SE_2$

Where, t_2 is the t value at degrees of freedom for sub plot error.

SE_2 is the Standard error of difference between two sub plot treatments

$$SE_2 = \sqrt{\frac{2E_2}{rb}}$$

Where, E_2 is error mean square value of sub plot treatments in ANOVA, r is the number of replications, a is number of main plot treatments.

For the comparison of two main plot treatment means at the same or different levels of sub plottreatment CD value was calculated using the formula:

$CD_3 = t \times SE_3$

Where,

$$t = \frac{(b-1)\{E_2 t_2 + E_1 t_1}{(b-1)E_2 + E_1}$$

t_1 is the table value corresponding to the degrees of freedom of main plot error

t_2 is the table value corresponding to the degrees of freedom of sub plot error

$SE_3$is the Standard two main plot treatment means at the same or different levels of subplot treatment

$$SE_3 = \sqrt{\frac{2[(b-1)E_2\,] + E_1}{rb}}$$

E_1 = Error mean square value of main plot treatment in ANOVA

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

r = Number of replications

b = Number of sub plot treatments

Correlation was used to examine the impact of weather parameters on plant growth and development. Weather variables were correlated with various yield and yield attributes during each phenophase. Regression equations were developed between yield and weather parameters experienced on different phenophases based on the correlation results. For various statistical analyses, different software packages such as Microsoft Excel, SPSS, and R studio were used.

3.5.1. Crop weather models using Principal Component Analysis for *Maran* and *Varada*

To fit a regression model for *Maran* and *Varada,* Principal Component Analysis (PCA) was carried out as a first step. Different weather observations experienced during the crop growthperiod was used for deriving the best principal components. PCA helps to minimize the multicollinearity and complexity of the data sets to a lower appropriate dimension. Principal components obtained by this method were used for developing regression model with the help of SPSS software for better yield forecast.

3.5.2. Evaluation of model

Model was evaluated through the statistical analysis normalized root mean squareerror (RMSE).

3.5.2.1 Root Mean Square Error (RMSE)

Normalized root mean square error (RMSE), calculated as explained by Loague andGreen (1991) with the help of following Equation:

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

Where n is the number of observations, Pi and Oi are predicted and observed values respectively;M is the observed mean value. It is a good measure of how accurately the model predicts the response. The value of the RMSE should be minimum or in other word should approach zero (Pathak *et al*., 2004).

3.6. CLIMATE CHANGE PROJECTIONS

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has established a new method of constructing scenarios. These scenarios are referred to astypical concentration pathways because they cover a wide range of possible radiative forcing (RCPs). The IPCC Assessment Report5 uses RCPs to describe concentration paths (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community. The radiative forcing produced by the end of the twenty-first century defines the pathways. The Radiative forcing is the amount of heat retained in the lower atmosphere as a resultof increased greenhouse gas levels, measured in Wm^{-2} (Table 3.5). The future climate was estimated using climate change projections generated using CCSM4 model for near century (2010- 2039), midcentury (2040-2069) and End of century (2070-2099) based on RCP 4.5 and 8.5.

Table 3.5. Description of representative concentration pathway (RCP) scenarios

Type	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
	Low	Intermediate	Intermediate	High
Radiative forces	2.6 to 3 Wm^{-2}	4.5 Wm^{-2}	6.0 Wm^{-2}	8.5 Wm^{-2}
CO_2 concentration peaks	2050s (421 ppm)	2040s (538 ppm)	2060s (670ppm)	2100s (936 ppm)
Temperature increase by 2081-2100	1.0°C	1.8°C	2.2°C	3-7°C
Sea level increase by 2081-2100	0.4 m	0.47 m	0.48 m	0.63 m
References	Vuuren *et al* (20011)	Clarke *et al* (2007)	Fujino *et al* (2006)	Riahi *et al* (2007)

3.6.1. Climate change models

There are various General circulation models (GCMs) like GFDL CM3, developed by the NOAA Geophysical Fluid Dynamics Laboratory in the United States, Had CM2, developed by the Hadley Centre in the United Kingdom and

CCSM4 , developed at the University Corporation for Atmospheric Research (UCAR). Community Climate System Model (CCSM) is a general circulation climate model that includes components for the atmosphere, land, ocean, and sea ice. The components are linked by a coupler that exchanges state information and fluxes. The CCSM has been used to investigate several paleoclimate epochs, as well as the climate of the recent pastand future climate change projections. The first version of the CCSM, was released in 1996 (Boville and Gent, 1998), and it was the first climate model to maintain a stable present-day simulation without the use of flux corrections. The CCSM2 was released in 2002 (Kiehl and Gent, 2004), and the CCSM3 was released in June 2004 (Collins *et al*. 2006). The twentieth-century runs of the CCSM4 start in January 1850 and finish in December 2005. They are forced by solar output, greenhouse gases, a variety of aerosols, and volcanic activity over time. On April 1, 2010, the CCSM Web site (http://www.cesm.ucar.edu/models/ccsm4.0/) made the most recent version, CCSM4, available to the public.

3.6.2. Time slices of projected climate

The baseline study was done in the time period of 2020 May to 2021 January. The obtained result was projected to RCP 4.5 and 8.5 scenarios of near century, which constitute the time period from 2010 to 2039, midcentury 2040 to 2069 and late century 2070 to 2099 (Table 3.6).

Table 3.6. Time slices considered for the study

Scenario	**Time slices**
Baseline period	2020-2021
RCP4.5/8.5 Near-term	2010-2039
RCP4.5/8.5 Mid-Century	2040-2069
RCP4.5/8.5 End-of-Century	2070-2099

3.6.3. Percentage relative yield difference (R.D%)

Percentage relative difference from base year (study period) for ginger productivity was worked out for future years viz., near century (2010-2039), mid-century (2040-2069) and end of century (2070-2099) using the following formula.

$$RD = \frac{\text{Mean of future yield} - \text{Mean of base period yield}}{\text{Mean of base period yield}}$$

Result

4. RESULTS

A study on “Ginger (*Zingiber officinale*) yield variability under different climate change scenarios” was carried out at the Department of Agricultural Meteorology, College of Agriculture, *Vellanikkara* during the period 2020-2021. The growth and development of ginger were significantly influenced by complex and uncontrolled environmental factors. The crop weather relationship of the two ginger varieties was carried out. A statistical model was developed with Principal Component Analysis (PCA) and regression analysis, for assessing the impacts of climate change on ginger yield under projected climate change scenarios. Dynamically downscaled outputs of General Circulation Model (GCM) namely CCSM4 was used for generating future climate. RegCM4.4 was employed for dynamical downscaling of GCM outputs to project the future climate under RCP 4.5 and 8.5 scenarios driven by radiative forcing adopted by the IPCC fifth Assessment Report (AR5).

4.1. THE PHENOLOGICAL STAGES (NUMBER OF DAYS) TAKEN FOR VARIOUS BIOTICEVENTS WERE DESCRIBED BELOW

The life cycle of ginger is characterized by four distinct stages and these are listed below

1. Planting to 50% sprouting (P1)
2. 50% sprouting to active tillering (P2)
3. Active tillering to bulking (P3)
4. Bulking to physiological maturity (P4)

The phenological calendar for both *Maran* and *Varada* was given below (Fig. 1.1 (a) and (b)). It shows the duration of phenophases P1-P4 for four different dates of planting. Each phenophase was plotted against standard meteorological weeks. The duration of phenophases varied among the dates of planting as well as varieties

4.1.1. Number days from planting to 50% sprouting

The result revealed that the number of days taken for sprouting was more in *Maran* (45) and *Varada* (40) on the May 15th planting date. The other three planting dates took fewer days to germinate in the caseof both varieties (Table 4.1).

Table 4.1. Number of days from planting to 50% sprouting

Crop stage	Date of planting							
	15th May		1st June		15th June		1st July	
	V1	V2	V1	V2	V1	V2	V1	V2
Planting to 50% sprouting	45	40	21	19	19	22	16	20

4.1.2. Number of days from 50% sprouting to active tillering

The number of days taken from 50% sprouting to active tillering was highest in July 1st planted crop for both *Maran* (73 days) and *Varada* (70 days), but it was lowest in the case of May 15th planted crop for both varieties, *ie*., 34 and 41 for *Maran* and *Varada* respectively (Table 4.2).

Table 4.2. Number of days from 50% sprouting to active tillering

Crop stage	Date of planting							
	15th May		1st June		15th June		1st July	
	V1	V2	V1	V2	V1	V2	V1	V2
50% Sprouting to active tillering	34	41	54	57	60	56	73	70

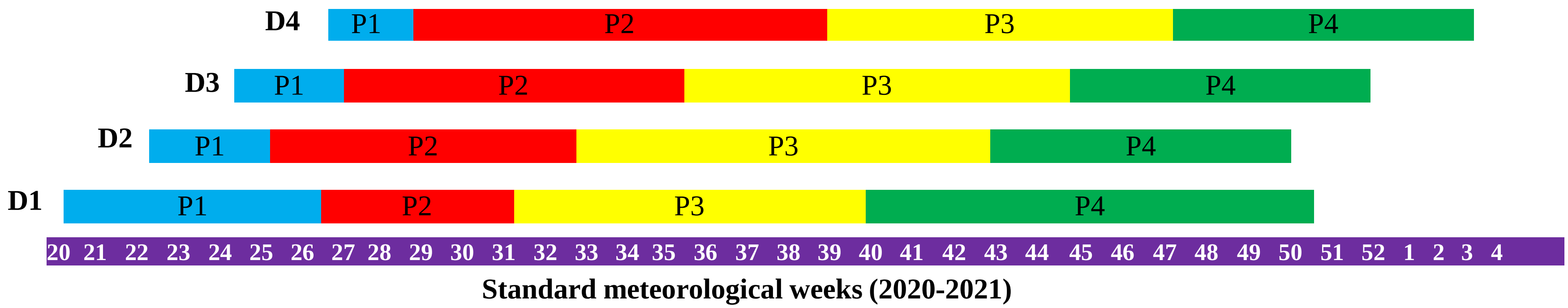


Fig 4.1 (a) Phenological calendar of *Maran*

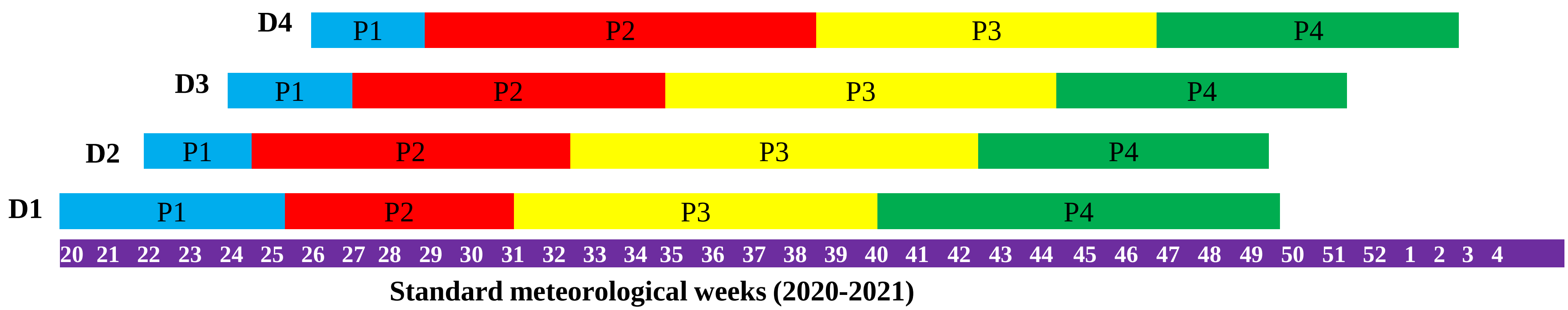


Fig 4.1 (b) Phenological calendar of *Varada*

D1: 15th May 2020	P1: Planting to 50% sprouting
D2: 1st June 2020	P2: 50% sprouting to active tillering
D3: 15th June 2020	P3: Active tillering to bulking
D4: 1st July 2020	P4: Bulking to physiological maturity

4.1.3. Number of days from active tillering to bulking

The days required from active tillering to bulking were found to be highest (73 days) on the second date of planting, *ie.*, June 1st planted crop, whereas it was less (61 days) in July 1st planted crop for both varieties (Table 4.3).

Table 4.3. Number of days from active tillering to bulking

Crop stage	**Date of planting**							
	15th May		**1st June**		**15th June**		**1st July**	
	V1	**V2**	**V1**	**V2**	**V1**	**V2**	**V1**	**V2**
Active tillering to Bulking	62	65	73	73	68	70	61	61

4.1.4. Number of days from bulking to physiological maturity

May 15th planted crop took more days to attain physiological maturity in both *Maran* (79 days) and *Varada* (72 days). It was comparatively less and almost similar in all other three dates of planting (Table 4.4).

Table 4.4. Number of days from bulking to physiological maturity

Crop stage	**Date of planting**							
	15th May		**1st June**		**15th June**		**1st July**	
	V_1	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**	**V_1**	**V_2**
Bulking to physiological maturity	79	72	53	52	53	52	53	54

4.2. EFFECTS OF DATES OF PLANTING AND VARIETIES ON PLANT CHARACTERS

4.2.1. Biometric characters of ginger

4.2.1. 1. Plant height (cm)

Analysis of variance was carried out for plant heights recorded at weekly intervals up to the 23rd week and the results are presented in

Appendix IV- page x-xi. Date of planting hada significant influence on plant height for both varieties.

Plant height differed significantly with respect to dates of planting for all weeks except 6th, 9th, 10th, 11th, 12th and 15th. During the first three weeks of plant growth, July 1st planted crops had more height, these were found to be on par with each other. June 1st and July 1st planted crops produced more height in 4th and 5th planting dates and were on par with each other. The highest plant height was recorded on May 15th date of planting during the 7th week, May 15th, June 1st and July 1st planting dates produced more height in the 8th week and which were on par with each other. The June 1st planted crop was found to have more height in the 13th and 14th weeks. From the 16th to 20th weeks, May 15th, June 1st and June 15th planted crops were found to have more height and they were on par. In the last three weeks, more plant height was recorded on May 15th and June 1st crop, which were found to be on par with each other (Table 4.5.a).

A comparison was made between varieties for the plant height at different weeks after planting and the results are presented in Table 4.5.b. There was significant difference between varieties on plant height at 3rd to 9th, 11th, 13th, 14th and 16th to 23rd weeks. During all the weeks, the *Varada* variety was found to have more height than the *Maran* variety.

The interaction between dates of planting and varieties on plant height was significant from the 6th to 11th weeks only (Table 4.5.c). In case of *Maran*, from 6th to 11th weeks, May 15th, June 1st and July 1st planted crops attained more height and which are on par with each other. In case of *Varada,* May 15th and June 1st planted crops were on par and attained more height during 6th week. On 7th week, May 15th planted crops attained more height. During 8th and 11th weeks, May 15th, June 1st and June 15th dates of planting produced more height.

Table. 4.5.a Effect of date of planting on plant height at weekly interval

Dates of planting	Week Number											
	1	2	3	4	5	6	7	8	9	10	11	12
D1	8.1^{c}	15.5^{c}	26.3^{c}	33.6^{b}	39.9^{bc}	50.7	56.3^{a}	59.5^{a}	61.5	64.17	65.6	66.6
D2	17.5^{b}	25.0^{b}	32.4^{b}	38.2^{a}	43.5^{ab}	46.3	48.8^{bc}	53.9^{ab}	57.6	64.4	69.2	72.8
D3	18.6^{b}	25.2^{b}	27.4^{c}	30.4^{b}	36.4^{c}	42.6	45.8^{c}	52.6^{b}	55.5	60.6	64.4	68.6
D4	24.9^{a}	31.2^{a}	35.8^{a}	40.6^{a}	45.8^{a}	47.5	51.9^{b}	56.0^{ab}	58.1	61.3	64.4	67.8
CD	3.09	3.45	2.84	3.59	3.67	NS	4.33	6.01	NS			

Table. 4.5.a Effect of date of planting on plant height at weekly interval (Contd.)

Dates of planting	Week Number										
	13	14	15	16	17	18	19	20	21	22	23
D1	72.3^{b}	76.4^{b}	79.9	84.5^{a}	85.7^{a}	87.0^{a}	87.8^{ab}	88.4^{a}	88.8^{ab}	89.0^{ab}	88.6^{ab}
D2	80.0^{a}	83.4^{a}	85.5	88.3^{a}	89.9^{a}	91.0^{a}	91.5^{a}	91.5^{a}	91.6^{a}	91.3^{a}	91.3^{a}
D3	73.0^{b}	76.3^{b}	78.9	82.9^{ab}	85.3^{a}	87.2^{a}	86.7^{ab}	85.8^{ab}	85.1^{bc}	84.8^{bc}	84.8^{bc}
D4	71.3^{b}	73.3^{b}	75.1	76.8^{b}	78.0^{b}	78.7^{b}	85.5^{b}	79.6^{b}	80.2^{c}	81.1^{c}	80.7^{c}
CD	6.23	6.63	NS	6.4	6.5	6.36	5.2	6.3	6.4	6.3	6.3

D1 : 15th May 2020, D2 : 1st June 2020 , D3 : 15th June 2020, D4 : 1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.5.b Effect of varieties on plant height at weekly interval

Varieties	Week Number											
	1	2	3	4	5	6	7	8	9	10	11	12
V1	16.7	25.5	28.5^{b}	33.3^{b}	38.3^{b}	43.3^{b}	47.5^{b}	52.0^{b}	54.9^{b}	58.9	60.9^{b}	63.8
V2	17.8	23.0	32.5^{a}	38.1^{a}	44.5^{a}	50.2^{a}	53.9^{a}	59.0^{a}	61.5^{a}	66.3	70.9^{a}	74.1
CD	NS		2.2	2.4	3.31	2.32	1.84	1.82	1.98	NS	6.25	NS

Table. 4.5.b Effect of varieties on plant height at weekly interval (Contd.)

Varieties	Week Number										
	13	14	15	16	17	18	19	20	21	22	23
V1	69.3^{b}	72.7^{b}	75.8	77.7^{b}	79.2^{b}	80.2^{b}	81.0^{b}	80.7^{b}	80.9^{b}	81.2^{b}	81.1^{b}
V2	79.0^{a}	82.0^{a}	83.9	88.5^{a}	90.2^{a}	91.8^{a}	94.9^{a}	91.9^{a}	91.9^{a}	91.9a	91.7^{a}
CD	4.16	4.53	NS	4.8	4.9	5.01	6.0	5.04	4.97	4.93	4.9

D1 : 15^{th} May 2020, D2 : 1^{st} June 2020 , D3 : 15^{th} June 2020, D4 : 1^{st} July 2020, V1: *Maran*, V2: *Varada*

Table. 4.5.c Interaction between date of planting and varieties on plant height at weekly interval

Dates of planting	Week number											
	1		2		3		4		5		6	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	7.6	8.6	7.6	8.6	23.59	29.1	30.8	36.4	36.0	43.9	46.2^{a}	55.2^{a}
D2	18.3	16.8	18.3	16.8	31.05	33.7	36.6	39.8	40.5	46.5	42.6^{ab}	50.0^{ab}
D3	16.3	20.8	16.3	20.8	24.15	30.7	26.4	34.5	32.7	40.2	37.5^{b}	47.7^{b}
D4	24.8	25.0	24.8	25.0	35.2	36.4	39.3	41.8	44.2	47.4	47.1^{a}	47.9^{b}
CD	NS										6.38	

Table. 4.5.c Interaction between date of planting and varieties on plant height at weekly interval (Contd.)

Dates of planting	Week number											
	7		8		9		10		11		12	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	51.6^{a}	60.9^{a}	55.0^{a}	64.1^{a}	57.5^{a}	65.5	60.4^{a}	67.8	60.7^{ab}	70.4^{ab}	61.9	71.2
D2	45.8^{b}	51.8^{b}	50.0^{ab}	57.8^{ab}	55.4^{ab}	59.8	62.2^{a}	66.7	64.1^{a}	74.34^{a}	66.3	79.3
D3	40.8^{b}	50.7^{b}	47.5^{b}	57.6^{ab}	49.7^{b}	61.4	53.7^{b}	67.7	56.7^{b}	72.1^{ab}	61.6	75.6
D4	51.7^{a}	52.1^{b}	55.5^{a}	56.6^{b}	57.0^{a}	59.2	59.2^{ab}	63.3	62.2^{ab}	66.6^{b}	65.3	70.3
CD	5.06		6.54		7.31		6.53		7.06		NS	

D1 : 15th May 2020, D2 : 1st June 2020 , D3 : 15th June 2020, D4 : 1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.5.c Interaction between the date of planting and varieties on plant height at weekly interval (Contd.)

Dates of planting	Week number											
	13		14		15		16		17		18	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	61.9	71.2	70.3	82.6	75.7	84.1	78.4	90.7	80.0	91.3	80.9	93.1
D2	66.3	79.3	78.8	87.9	80.7	90.3	81.8	94.8	82.5	97.4	83.2	98.8
D3	61.6	75.6	70.7	81.9	73.9	83.9	76.1	89.8	78.7	91.9	80.4	94.0
D4	65.3	70.3	71.0	75.7	72.9	77.3	76.1	78.9	75.8	80.1	76.3	81.4
CD	NS											

Table. 4.5.c Interaction between the date of planting and varieties on plant height at weekly interval (Contd.)

Dates of planting	Week number									
	19		20		21		22		23	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	81.6	94.0	82.1	94.8	82.1	94.8	82.5	95.5	82.3	94.9
D2	83.9	99.1	84.9	98.1	84.9	98.1	85.4	97.2	85.6	97.1
D3	79.8	93.7	78.8	92.8	78.8	92.8	78.0	91.6	78.0	91.6
D4	78.8	92.8	77.1	82.0	77.1	82.0	78.8	83.4	78.4	83.0
CD	NS									

D1 : 15th May 2020, D2 : 1st June 2020 , D3 : 15th June 2020, D4 : 1st July 2020, V1: *Maran*, V2: *Varada*

4.2.1. 2. Leaf Area

Analysis of variance was carried out for leaf area recorded at biweekly intervals up to the 210 days after planting are presented in Appendix IV- page xi-xii.

The effect of dates of planting on leaf area was found to be significant at all intervals of observations except 30 and 165 days after planting (Table. 4.6.a). After 45 days of planting, the leaf area of May 15th (32.84 cm^2) planting was on par with the June 1st (31.85 cm^2) date of planting and it was found to produce more leaf area. At 60 days after planting, more leaf area was observed on June 1st (39.31 cm^2) date of planting and minimum on July 1st (23.96 cm^2) planted crop. The more leaf area noticed at 75, 90 and 105 days after planting was on May 15th, June 1st and June 15th dates of planting and which were on par with each other. 120 days after planting, more leaf area was noticed on June 15th (42.94 cm^2) date of planting. At 135 days after planting, more leaf area was observed on May 15th (33.31 cm^2) date of planting. After 150 days of planting, the leaf area of June 1st (33.59 cm^2) planting was more. At 180 days after planting, more leaf area was observed on May 15th (26.41 cm^2), June 1st (26.58 cm^2) and June 15th (25.75 cm^2) dates of planting, which was on par with each other. The more leaf area noticed after 195 days of planting was on June 15th (30.36 cm^2) date of planting. At 210 days after planting, more leaf area was recorded by May 15th (27.92 cm^2) and June 1st (27.66 cm^2) dates of planting, which were on par.

The effect of varieties on leaf area was found to be significant only after 60, 75, 90 and 195 days of planting. During all these intervals, the *Maran* variety produced more leaf area than *Varada* (Table 4.6.b).

There was no significant interaction between the dates of planting and varieties at 30 and 45 days after planting (Table 4.6.c). After 60 days of planting, more leaf area was observed on May 15th (40.38 cm^2), June 1st (38.78 cm^2) and June 15th (32.51 cm^2) date of planting in *Maran* which was on par with each other. In *Varada* it was more on June 1st (39.83 cm^2) date of planting. The lowest was recorded on May 15th (23.95 cm^2), June

15th (31.31 cm^2) and July 1stdate of planting, which was on par with each other. More leaf area in *Maran* after 75 days of planting was observed on May 15th (47.61 cm^2) and June 1st (44.61 cm^2) dates of planting, which was on par with each other. In *Varada* leaf area was more on the June 15th (34.29 cm^2) date of planting. The interaction effect was found to be not significant at 90 days after planting. After 105 days of planting, more leaf area was observed on May 15th (40.33 cm^2), June 1st (39.65 cm^2) and June 15th (37.86 cm^2) date of planting, which was on par with each other in *Maran*. In *Varada* it was more on June 15th (42.99 cm^2) date of planting. The leaf area at 135 days after planting was more at May 15th (32.28 cm^2) and June 1st (30.73 cm^2) planted crop. In the case of *Varada* higher leaf area was observed on May 15th (34.35 cm^2) and the lowest was on June 15th (24.33 cm^2) after 135 days of planting. More leaf area in *Maran* after 150 days of planting was observed on June 15th (32.72 cm^2), May 15th (29.35 cm^2) and June 1st (32.39 cm^2) date of planting, which was on par with each other. In *Varada* leaf area was more on the June 1st (34.80 cm^2) date of planting. After 165 days of planting, more leaf area was on June 15th (31.11 cm^2) date of planting in *Varada*. The leaf area at 210 days after planting in *Maran* was more at May 15th (28.13 cm^2) and June 1st (27.66 cm^2) which was on par with each other. In the case of *Varada*, more leaf area was observed on May 15th (27.71 cm^2) and June 1st (27.67cm^2) planted crops that were on par with each other.

4.2.1.3. Number of tillers per plant

Analysis of variance was carried out for the number of tillers at biweekly intervals up to 210 days after planting, and are represented in Appendix IV page number xii-xiii.

In the first 30 days of planting, the June 1st planting date produced more tillers and the least were at May 15th planted one. May 15th planting date produced a higher number of tillers in all other biweekly intervals except in 195 and 210 days after planting (Table 4.7.a).

Table. 4.6.a. Effect of date of planting on leaf area at fortnightly interval

Dates of planting	Days after planting												
	30	45	60	75	90	105	120	135	150	165	180	195	210
D1	24.05	32.84^{a}	32.16^{b}	35.78^{a}	41.69^{a}	37.74^{a}	29.35^{c}	33.31^{a}	28.95^{b}	27.49	26.41^{a}	27.67^{b}	27.92^{a}
D2	24.24	31.85^{a}	39.31^{a}	34.76^{a}	42.91^{a}	38.10^{a}	29.59^{c}	29.28^{b}	33.59^{a}	28.38	26.58^{a}	28.20^{b}	27.66^{a}
D3	24.45	24.79^{b}	31.91^{b}	33.11^{a}	42.14^{a}	40.43^{a}	42.94^{a}	24.27^{c}	28.25^{b}	30.41	25.75^{a}	30.36^{a}	25.22^{b}
D4	22.27	24.09^{b}	23.96^{c}	24.25^{b}	27.84^{b}	31.74^{b}	34.90^{b}	28.37^{b}	29.30^{b}	28.49	22.31^{b}	22.87^{c}	22.02^{c}
CD	NS	1.59	6.27	4.44	5.97	3.33	2.62	2.16	2.55	NS	2.29	1.95	1.05

Table. 4.6.b Effect of varieties on leaf area at fortnightly interval

Varieties	Days after planting												
	30	45	60	75	90	105	120	135	150	165	180	195	210
V1	23.93	28.15	33.97^{a}	37.21^{a}	45.41^{a}	37.14^{a}	34.90^{a}	28.72	30.60	29.57	25.63	28.12^{a}	25.79
V2	23.57	28.64	29.70^{b}	26.74^{b}	36.19^{b}	36.86^{a}	33.49^{a}	28.90	29.45	27.82	24.90	26.43^{b}	25.62
CD	NS		3.71	2.91	4.58	2.64	3.25	NS				1.26	NS

D1: 15th May 2020, D2 : 1st June 2020 , D3 : 15th June 2020, D4 : 1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.6. c. Interaction between date of planting and varieties on leaf area at fortnightly interval

Dates of planting	Days after planting											
	30		45		60		75		90		105	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	24.31	23.79	33.01	32.67	40.38^{a}	23.95^{b}	23.95^{b}	23.91^{b}	44.01	39.37	40.33^{a}	35.16^{b}
D2	24.42	24.06	31.50	32.20	38.78^{a}	39.83^{a}	24.91^{b}	24.91^{b}	46.52	39.30	39.65^{a}	36.54^{b}
D3	24.46	24.44	24.07	25.52	32.51^{a}	31.31^{b}	34.29^{a}	34.29^{a}	43.26	41.02	37.86^{a}	42.99^{a}
D4	22.54	22.00	24.00	24.18	24.21^{b}	23.70^{b}	23.82^{b}	23.82^{b}	30.62	25.07	30.72^{b}	32.76^{b}
CD	NS				8.18		6.07		NS		5.03	

Table. 4.6. c Interaction between date of planting and varieties on leaf area at fortnightly interval (Contd.)

Dates of planting	Days after planting													
	120		135		150		165		180		195		210	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	31.46	27.24	32.28^{a}	34.35^{a}	29.35^{ab}	28.54^{b}	30.82^{a}	24.15^{c}	26.80	26.02	28.31^{b}	27.03^{a}	28.13	27.71
D2	31.58	27.61	30.73^{a}	27.83^{b}	32.39^{a}	34.80^{a}	30.32^{a}	26.44^{bc}	26.36	26.80	28.18^{b}	28.22^{a}	27.66	27.67
D3	41.51	44.37	24.22^{c}	24.33^{c}	32.72^{a}	23.79^{c}	29.72^{a}	31.11^{a}	24.09	27.41	32.83^{a}	27.90^{a}	25.25	25.18
D4	35.07	34.74	27.67^{b}	29.07^{b}	27.94^{b}	30.66^{b}	27.41^{a}	29.58^{ab}	22.33	22.29	23.16^{c}	22.58^{b}	22.11	21.93
CD	NS		2.54		3.60		4.15		NS		2.65		NS	

D1: 15th May 2020, D2 : 1st June 2020 , D3 : 15th June 2020, D4 : 1st July 2020, V1: *Maran*, V2: *Varada*

The effect of the number of tillers on varieties was also significant in such a way that the *Maran* variety produced more tillers than the *Varada* variety at all intervals (Table 4.7.b).

The interaction between the date of planting and varieties was only significant in 90, 105,120, 195 and 210 days after planting. At 90 days after planting, May 15th, June 1st and 15thdate of plantings showed more tillers in *Maran.* In the case of *Varada,* May 15th and June 1st crops gave more tillers. At 105,120,190 and 210 days after plantings, June 1st planted crops gave more tillers in both varieties (Table 4.7.c).

4.2.1.4. Number of fully opened leaves

Analysis of variance was carried out for the number of fully opened leaves recorded at weekly intervals up to 23rd week are represented in Appendix IV page xiii-xiv.

The number of fully opened leaves differed significantly between the dates of planting at all intervals except the 4th week. In the first three weeks, more leaves were produced on the July 1st planted crop. During the 5th week of development, more leaves were observed on May 15th (41.93), June 1st (37.11) and June 15th (37.78) dates of planting, which were on par with each other. From the 6th to 12th weeks more leaves were observed on the May 15th date of planting. From the 7th to 12th weeks, the May 15th date of planting produced more leaves. Fromthe 13th to 23rd weeks except in the 17th week, more leaves were observed on May 15th and June 1st planted crops, which were on par with each other. During the 17th week, the highest number of leaves (149.43) was observed on the May 15th date of planting (Table 4.8.a).

A significant difference was observed between varieties on the number of fully opened leaves at 2nd, 6th, 8th, 9th, 10th, 12th and 16th weeks. During all these weeks except 16th, more number of leaves were produced by *Varada* variety. In the 16th week, more leaves were observed on the *Maran* variety (4.8.b).

Table. 4.7. a. Effect of date of planting on number of tillers at fortnightly interval

Dates of planting	Days after planting												
	30	45	60	75	90	105	120	135	150	165	180	195	210
D1	0.00^{d}	4.92^{a}	6.32^{a}	9.71^{a}	13.76^{a}	14.49^{a}	17.95^{a}	19.31^{a}	19.4^{a}	19.7^{a}	19.7^{a}	15.7^{b}	15.7^{b}
D2	2.49^{a}	3.70^{b}	5.45^{b}	8.21^{b}	12.01^{b}	12.21^{b}	13.60^{b}	14.22^{b}	14.5^{b}	14.6^{b}	15.1^{b}	19.5^{a}	19.5^{a}
D3	1.36^{b}	4.38^{a}	6.67^{a}	6.50^{c}	10.48^{b}	11.08^{c}	12.05^{b}	11.90^{c}	13.7^{bc}	14.5^{b}	15.2^{b}	15.2^{b}	15.2^{b}
D4	0.98^{c}	1.75^{c}	2.95^{c}	4.17^{d}	5.80^{c}	7.40^{d}	8.92^{c}	11.20^{c}	12.2^{c}	13.1^{b}	12.6^{c}	12.6^{c}	12.6^{c}
CD	0.200	0.64	0.73	0.71	1.52	1.02	1.71	1.67	1.87	1.8	1.94	2.05	2.05

Table. 4.7. b. Effect of varieties on number of tillers at fortnightly interval

varieties	Days after planting												
	30	45	60	75	90	105	120	135	150	165	180	195	210
V1	1.21^{a}	3.64^{a}	5.50	7.60^{a}	11.01^{a}	11.7^{a}	13.9^{a}	15.01^{a}	15.6^{a}	16.0^{a}	16.2^{a}	16.2	16.2
V2	1.20^{a}	3.74^{a}	5.19	6.69^{b}	10.0^{b}	10.8^{b}	12.28^{b}	13.30^{b}	14.3^{b}	14.9^{b}	15.2^{b}	15.3	15.3
CD	0.35	0.50	NS	0.66	0.78	0.64	0.79	1.35	0.84	0.74	0.76	NS	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4: 1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.7. c Interaction between dates of planting and varieties on number of tillers at fortnightly interval

Dates of planting	Days after planting													
	30		45		60		75		90		105		120	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	0.0	0.0	0.0	0.0	5.2	5.4	10.4	10.95	12.3^{a}	11.6^{a}	12.8^{b}	12.8^{b}	13.85^{b}	13.4^{b}
D2	2.3	2.3	2.3	2.3	6.5	6.8	9.9	9.4	12.0^{a}	12.0^{a}	14.4^{a}	14.3^{a}	18.3^{a}	17.9^{a}
D3	1.2	1.5	1.2	1.5	7.1	6.1	9.6	6.7	12.2^{a}	8.6^{b}	12.6^{b}	9.5^{c}	13.5^{b}	10.5^{c}
D4	1.0	0.8	1.0	0.8	3.2	2.6	6.0	4.5	8.2^{b}	5.8^{c}	10.4^{c}	8.3^{c}	12.5^{b}	10.7^{c}
CD	NS								1.57		1.56		2.25	

Table. 4.7. c Interaction between dates of planting and varieties on number of tillers at fortnightly interval (Contd.)

Dates of planting	Days after planting											
	135		150		165		180		195		210	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	14.5	13.7	15.08	14.2	15.5	14.7	15.8	15.7	15.6^{b}	16.25^{b}	15.6^{b}	16.25^{b}
D2	20.1	18.8	20.1	19.0	20.3	19.1	20.3	19.1	20.5^{a}	18.9^{a}	20.5^{a}	18.9^{a}
D3	14.2	11.5	14.9	12.4	15.7	13.3	16.3	14.1	16.3^{b}	14.12^{b}	16.3^{b}	14.12^{b}
D4	14.6	12.9	16.0	14.5	17.0	14.7	17.0	14.7	17.1^{b}	14..8^{c}	17.1^{b}	14..8^{c}
CD	NS								2.25		2.25	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

The interaction between the date of planting and varieties on the number of fully opened leaves is presented in 4.8.c. No significant interaction was found in the first five weeks and 7th week. From the 6th to 12th weeks, the May 15th date of planting produced more leaves in both *Maran* and *Varada* varieties. From the 13th week to the end of the crop period more leaves in *Maran* were observed on the June 1st planted crop. In the case of *Varada*, it was more on May 15th planted crop.

4.2.1. 5. Girth of main tiller (cm)

Analysis of variance was carried out for girth of main tiller recorded at biweekly intervals up to 210 days are represented in Appendix IV page xv.

There was a significant difference between dates of planting on the girth of main tiller observed at all intervals of observations, except at 30 and 165 days after planting. At 45, 60 and 75 days after planting, more girth was observed on May 15th and June 1st dates of planting and which were on par with each other. At 90 days after planting May 15th planted crop (2.23 cm) had more girth. At 105 days after planting, the crop planted on May 15th and June 1st had more girth, which was on par with each other. At 120, 135 and 150 days after planting the highest girth was produced by the June 1st planted crop. At 180 days after planting, both May 15th (3.12 cm) and June 1st (3.05 cm) crops were on par and showed higher girth. Main tiller girth at 195 and 210 days after planting was highest on June 1st planted crop (Table 4.9.a).

The effect of varieties on the girth of main tiller is presented in Table 4.9.b. The significant difference exists only on 120,135, 165, 195 and 210 days after planting. At all these intervals *Maran* variety produced more girth.

The interaction between dates of planting and varieties on girth of main stem was presented in Table 4.9.c. In *Maran*, the interaction was observed at 105 and 120 days after planting. The highest girth at 105 and 120 days after planting was observed on May 15th and June 1st planted crops that were on par with each other. In *Varada* the highest girth at 105, 195 and 210 days after planting was

Table. 4.8.a Effect of date of planting on number of fully opened leaves

Dates of planting	Number of fully opened leaves											
	1	2	3	4	5	6	7	8	9	10	11	12
D1	2.35^{c}	11.05^{b}	16.77^{c}	29.73	41.93^{a}	58.91^{a}	78.61^{a}	89.28^{a}	99.81^{a}	107.69^{a}	115.25^{a}	117.13^{a}
D2	8.43^{b}	15.04^{b}	22.22^{b}	29.42	37.11^{ab}	48.69^{b}	62.24^{b}	70.74^{b}	80.47^{b}	88.40^{b}	95.12^{b}	99.54^{c}
D3	6.44^{b}	13.17^{b}	22.22^{b}	29.76	37.78^{ab}	47.41^{b}	58.65^{b}	66.74^{b}	74.65^{b}	80.47^{c}	87.06^{c}	105.37^{b}
D4	12.78^{a}	19.67^{a}	25.00^{a}	29.63	35.51^{b}	39.85^{c}	43.29^{c}	47.11^{c}	51.84^{c}	56.86^{d}	61.44^{d}	66.96^{d}
CD	3.51	4.19	2.71	NS	5.06	6.34	5.84	4.54	6.15	5.62	6.67	5.77

Table. 4.8.a Effect of date of planting on number of fully opened leaves (Contd.)

Dates of planting	Number of fully opened leaves										
	13	14	15	16	17	18	19	20	21	22	23
D1	123.51^{a}	125.58^{a}	132.33^{a}	138.91^{a}	149.43^{a}	153.93^{a}	156.22^{a}	156.22^{a}	160.17^{a}	160.17^{a}	165.60^{a}
D2	115.81^{a}	120.68^{a}	129.92^{a}	134.78^{a}	141.78^{b}	147.57^{a}	153.07^{a}	153.07^{a}	157.06^{a}	157.06^{a}	161.97^{a}
D3	97.39^{b}	103.82^{b}	104.65^{b}	116.17^{b}	119.96^{c}	124.48^{b}	126.86^{b}	126.86^{b}	131.81^{b}	131.81^{b}	137.40^{b}
D4	72.75^{c}	79.76^{c}	85.34^{c}	89.90^{c}	96.68^{d}	99.85^{c}	102.94^{c}	102.94^{c}	106.36^{c}	106.36^{c}	107.23^{c}
CD	7.87	8.10	10.78	9.34	7.34	7.89	8.14	8.14	7.72	7.87	7.88

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.8.b Effect of varieties on number of fully opened leaves

Varieties	Number of fully opened leaves											
	1	2	3	4	5	6	7	8	9	10	11	12
Maran (V1)	7.36	12.88^{b}	19.76	29.82	35.60	46.43^{b}	58.48	65.62^{b}	73.15^{b}	79.00^{b}	84.56	94.06^{b}
Varada (V2)	7.64	16.60^{a}	23.34	29.45	40.56	51.0^{a}	62.91	71.31^{a}	80.24^{a}	87.70^{a}	94.88	100.45^{a}
CD	NS	3.50	NS			3.37	NS	3.06	3.21	3.17	NS	4.84

Table. 4.8. b Effect of varieties on number of fully opened leaves (Contd.)

Varieties	Number of fully opened leaves										
	13	14	15	16	17	18	19	20	21	22	23
Maran (V1)	99.60	105.83	112.48	122.95^{a}	127.65	132.70	136.33	136.33	141.08	141.08	147.11
Varada (V2)	105.12	109.09	113.63	116.92^{b}	126.28	130.21	133.21	133.21	136.62	136.62	138.99
CD	NS			5.67	NS						

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.8.c Interaction between dates planting and varieties on number of fully opened leaves

Dates of planting	Number of fully opened leaves											
	Week 1		Week 2		Week 3		Week 4		Week5		Week 6	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	2.20	2.50	9.15	12.96	14.59	18.96	32.99	26.47	36.88	46.99	55.13^{a}	62.68^{a}
D2	8.59	8.28	13.5	16.50	20.32	24.12	31.45	27.40	36.45	37.78	44.00^{b}	53.38^{b}
D3	6.31	6.58	10.92	15.42	20.32	24.12	26.50	33.02	34.95	40.61	45.60^{b}	49.22^{b}
D4	12.35	13.22	17.85	21.50	23.82	26.19	28.35	30.92	34.13	36.89	40.98^{b}	38.72^{c}
CD	NS										7.93	

Table. 4.8.c Interaction of dates of planting and varieties on number of fully opened leaves (Contd.)

Dates of planting	Number of fully opened leaves											
	Week 7		Week 8		Week 9		Week 10		Week11		Week 12	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	74.32	82.89	83.96^{a}	94.60^{a}	92.95^{a}	106.68^{a}	98.49^{a}	116.88^{a}	104.48^{a}	126.02^{a}	106.19^{a}	128.08^{a}
D2	58.59	65.89	63.59^{b}	77.89^{b}	74.05^{b}	86.89^{b}	81.05^{b}	96.55^{b}	88.94^{b}	101.30^{b}	96.19^{b}	102.90^{b}
D3	58.05	59.26	66.91^{b}	66.57^{c}	73.85^{b}	75.46^{c}	79.85^{b}	81.09^{c}	84.16^{b}	89.95^{c}	108.11^{a}	102.63^{b}
D4	42.96	43.62	48.04^{c}	46.19^{d}	51.75^{c}	51.94^{c}	56.63^{c}	57.02^{d}	60.64^{c}	62.25^{d}	65.74^{c}	68.18^{c}
CD	NS		6.29		7.64		7.19		8.70		9.03	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.8.c Interaction of dates of planting and varieties on number of fully opened leaves (Contd.)

Dates of planting	Number of fully opened leaves											
	Week 13		Week 14		Week 15		Week 16		Week17		Week 18	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	106.82^{b}	140.19^{a}	114.82^{ab}	136.35^{a}	123.14^{b}	141.52^{a}	132.79^{b}	145.02^{a}	136.56^{b}	162.29^{a}	141.49^{b}	166.37^{a}
D2	119.82^{a}	111.80^{b}	125.82^{a}	115.53^{b}	139.30^{a}	120.53^{b}	146.92^{a}	122.64^{b}	152.92^{a}	130.64^{b}	158.07^{a}	137.07^{b}
D3	100.45^{b}	94.32^{c}	105.34^{b}	102.29^{c}	104.00^{c}	105.29^{c}	123.59^{b}	108.75^{c}	127.18^{b}	112.75^{c}	132.22^{b}	116.75^{c}
D4	71.32^{c}	74.18^{d}	77.34^{c}	82.18^{d}	83.50^{d}	87.18^{d}	88.51^{c}	91.28^{c}	93.92^{c}	99.44^{d}	99.03^{c}	100.66^{d}
CD	9.81		11.21		14.67		12.33		11.97		12.84	

Table. 4.8.c Interaction of date of planting and varieties on number of fully opened leaves (Contd.)

Dates of planting	Number of fully opened leaves									
	Week 19		Week 20		Week 21		Week 22		Week23	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	142.09^{b}	170.35^{a}	142.09^{b}	170.35^{a}	146.23^{b}	174.11^{a}	146.23^{b}	174.11^{a}	152.97^{b}	178.23^{a}
D2	164.07^{a}	142.07^{b}	164.07^{a}	142.07^{b}	167.00^{a}	147.11^{b}	167.00^{a}	147.11^{b}	173.35^{a}	150.59^{b}
D3	135.02^{b}	118.70^{c}	135.02^{b}	118.70^{c}	141.80^{b}	121.82^{c}	141.80^{b}	121.82^{c}	150.68^{b}	124.12^{c}
D4	104.15^{c}	101.72^{d}	104.15^{c}	101.72^{d}	109.31^{c}	103.42^{d}	109.31^{c}	103.42^{d}	111.43^{c}	103.04^{d}
CD	12.79		12.79		12.06		12.29		12.80	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.9.a Effect of dates of planting on girth of main tiller at fortnightly interval

Dates of planting	Girth of main tiller (cm)												
	30	45	60	75	90	105	120	135	150	165	180	195	210
D1	1.88	1.99[a]	2.08[a]	2.17[a]	2.23[a]	2.31[a]	2.56[b]	2.64[b]	2.79[b]	2.90	3.12[a]	3.23[b]	3.27[b]
D2	1.78	1.96[a]	2.06[a]	2.15[a]	2.2[b]	2.35[a]	2.63[a]	2.73[a]	2.88[a]	2.90	3.05[ab]	3.31[a]	3.33[a]
D3	1.57	1.81[b]	1.99[b]	2.07[b]	2.15[c]	2.22[b]	2.35[c]	2.63[b]	2.73[c]	2.88	2.95[bc]	3.14[c]	3.17[c]
D4	1.53	1.71[c]	1.95[b]	2.05[b]	2.14[c]	2.22[b]	2.35[c]	2.6[b]	2.70[c]	2.84	2.92[c]	3.07[d]	3.15[c]
CD	NS	0.51	0.045	0.050	0.022	0.053	0.06	0.058	0.055	NS	0.113	0.055	0.039

Table. 4.9.b Effect of varieties on girth of main tiller at fortnightly interval

Varieties	Girth of main tiller (cm)												
	30	45	60	75	90	105	120	135	150	165	180	195	210
V1	1.77	1.93	2.04	2.10	2.16	2.27	2.55[a]	2.91[a]	2.91	3.02[a]	3.10	3.29[a]	3.32[a]
V2	1.61	1.82	2.00	2.12	2.21	2.28	2.39[b]	2.64[b]	2.64	2.75[b]	2.92	3.09[b]	3.14[b]
CD	NS						0.081	0.083	NS	0.137	NS	0.157	0.150

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.9.c Interaction between dates of planting and varieties on girth at fortnightly interval

Dates of planting	Girth (cm)											
	30 DAP		45 DAP		60 DAP		75 DAP		90 DAP		105 DAP	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	1.92	1.85	2.02	1.95	2.12	2.05	2.14	2.19	2.22	2.25	2.32^{ab}	2.31^{ab}
D2	1.88	1.69	1.95	1.97	2.07	2.05	2.12	2.19	2.14	2.25	2.36^{a}	2.34^{a}
D3	1.66	1.49	1.90	1.72	1.99	2.00	2.08	2.06	2.12	2.19	2.19^{c}	2.25^{ab}
D4	1.62	1.44	1.86	1.65	1.98	1.92	2.08	2.03	2.14	2.15	2.22^{bc}	2.22^{b}
CD	NS										1.56	

Table. 4.9.c Interaction between dates of planting and varieties on girth at fortnightly interval (Contd.)

Dates of planting	Girth (cm)													
	120 DAP		135 DAP		150 DAP		165 DAP		180 DAP		195 DAP		210 DAP	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	2.73^{a}	2.39^{ab}	2.80	2.48	2.94	2.65	3.03	2.78	3.23	3.01	3.23^{a}	3.01^{ab}	3.23^{a}	3.01^{ab}
D2	2.76^{a}	2.49^{a}	2.87	2.59	3.01	2.75	3.03	2.78	3.05	3.05	3.05^{a}	3.05^{a}	3.05^{a}	3.05^{a}
D3	2.36^{b}	2.35^{b}	2.75	2.52	2.87	2.60	3.02	2.74	3.08	2.82	3.08^{a}	2.82^{ab}	3.08^{a}	2.82^{ab}
D4	2.36^{b}	2.35^{b}	2.73	2.47	2.84	2.56	2.98	2.70	3.04	2.80	3.04^{a}	2.80^{b}	3.04^{a}	2.80^{b}
CD	0.162		NS								2.55		2.55	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

observed on May 15th, June 1st and June 15th dates of planting, which were on par with each other. At 120 days after planting more girth was recorded as at June 1st (2.49 cm) and May 15th (2.39 cm) crops, which was on par with each other.

4.2.1.6. Dry matter accumulation (kg ha^{-1})

Analysis of variance was carried out for dry matter accumulation recorded at monthly intervals up to 180 days are represented in Appendix IV page xvi.

The effect of date of planting on dry matter accumulated was presented in Table 4.10.a. The dry matter accumulated after 30 days of planting was highest in July 1st planting (2464 kg ha^{-1}) and June 1st planting (2326 kg ha^{-1}) which was on par with each other. There were no significantdifference between dates of planting on dry matter accumulation at 60 and 90 days after planting.At 120 and 210 days after planting, more dry matter accumulation was observed on May 15th andJune 1st dates of planting, which were on par with each other.

There was significant difference between varieties on dry matter accumulation at all the observation periods except 180 days after planting (Table 4.10.b). After 30 days of planting, highest dry matter accumulation was observed in *Varada* (2339 kg ha^{-1}) than *Maran* (2098 kg ha$^{- 1}$). At all other intervals *Maran* variety recorded highest dry matter accumulation.

The interaction between dates of planting and varieties on dry matter accumulation was found to be significant only at 30 days after planting. Highest dry matter production was observedon July 1st (2380 kg ha^{-1}) and June 1st (2256 kg ha^{-1}) dates of planting in *Maran.* Highest dry matter production in *Varada* was July 1st (2548 kg ha^{-1}), June 1st (2396 kg ha^{-1}) and May 15th (2256 kg ha^{-1}), which were on par with each other (Table 4.10.c).

4.2.2. Phenological observations

Analysis of variance was carried out for phonological observations are representedin Appendix IV page xvi.

Table. 4.10.a Effect of dates of planting on dry matter accumulation at fortnightly interval

Dates of planting	Dry matter accumulation (kg ha^{-1})						
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP
D1	2120^{bc}	2622	4052	8768^{a}	10163.13^{a}	9049.1^{a}	8311.5^{a}
D2	2326^{ab}	2700	3820	8820^{a}	9176.25^{a}	8082.6^{a}	7370.5^{a}
D3	1964^{c}	2314	3790	7480^{b}	7402.25^{b}	6329.0^{b}	4931.0^{b}
D4	2464^{a}	2686	4070	7128^{b}	7258.00^{b}	6171.5^{b}	2018.1^{c}
CD	212.79	NS		877.7	877.7	1103.50	1802.62

Table. 4.10.b Effect of varieties on dry matter accumulation at fortnightly interval

Varieties	Dry matter accumulation (kg ha^{-1})						
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP
V1	2098^{b}	2918^{a}	4228^{a}	8393^{a}	6986.4^{a}	6986.4	6986.42^{a}
V2	2339^{a}	2243^{b}	3638^{b}	7705^{b}	4329.2^{b}	4329.1	4329.1^{b}
CD	301.0	213.6	141.99	365.64	535.16	NS	1031.7

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.10.c Interaction between dates of planting and varieties on dry matter accumulation at fortnightly interval

Dates of planting	Dry matter accumulation (kg ha^{-1})													
	30 DAP		60 DAP		90 DAP		120 DAP		150 DAP		180 DAP		210 DAP	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	1984^{bc}	2256^{ab}	2924	2320	4376	3728	9216	8320	9636.7	8461.5	16116	2924	9374.9^{a}	7247.9^{a}
D2	2256^{ab}	2396^{ab}	3104	2296	3992	3648	9352	8288	8346.3	7819.0	17568	3104	10198.7^{a}	4542.4^{b}
D3	1772^{c}	2156^{b}	2748	1880	4216	3364	7760	7200	6069.3	6254.3	14884	2748	5843.0^{b}	4019.0^{b}
D4	2380^{a}	2548^{a}	2896	2476	4328	3812	7244	7012	6088.8	5688.8	12404	2896	2529.0^{c}	1507.2^{c}
CD	301.00		NS										2242.7	

D1: 15[th] May 2020, D2: 1[st] June 2020, D3: 15[th] June 2020, D4:1[st] July 2020, V1: *Maran*, V2: *Varada*

4.2.2.1. Sprouting percentage

The percentage of sprouting after 30 days of planting showed significant difference among date of planting (Table 4.11.a). Highest percentage of sprouting was observed on July 1st (78.37%), June 15th (76.00%) and June 1st (73.61%) planting dates which were on par with each other. The minimum sprouting was observed on May 15th (42.87%) planting.

There were no significant difference on sprouting percentage after 30 days of planting amongthe varieties (Table 4.11.b).

Interaction between dates of planting and varieties were also absent (Table 4.11.c).

4.2.2.2. Number of tillers

Number of tillers at 90 (13.9 tillers), 120 (17.9 tillers) and 150 (19.4 tillers) days after planting were more on May 15th planted crop. Less number of tillers were observed on July 1st planting in case of 90 (5.8 tillers), 120 (8.9 tillers) and 150 (12.2 tillers) days after planting (Table4.11.a).

Among the varieties *Maran* variety produced more number of tillers at 90, 120 and 150 days after planting when compared to *Varada* variety (Table 4.11.b).

A significant difference between date of planting and varieties were observed at 90 and 120 days after planting. After 90 days of planting, more tillers were observed on May 15th (12.3),June 1st (12.0) and June 15th (12.2) planting dates, which were on par with each other. Less numberof tillers were observed on July 1st (8.2) planted crop. In variety *Varada*, more number of tillers were observed on May 15th (11.6) and June 1st (12) date of planting, less number of tillers were observed on July 1st (5.8) date of planting. After 120 days of planting, more tillers were observedon June 1st (18.3). Less was observed on July 1st (12.5), May 15th (13.8) and June 15th (13.5) planted crop, which were on par with each other. In case of variety *Varada*, highest number of tillers were observed on June 1st (17.9) and lowest was on June 15th (10.5) and July 1st (10.7) planting dates, which was on par with each other (Table 4.11.c).

4.2.2.3. Days to physiological maturity

Number of days to attain physiological maturity was more on May 15th (218.8) and less was noticed on June 15th (188) date of planting (Table 4.11.a).

Among the two varieties, *Maran* (202.8) took more days to maturity than *Varada* (199.8) (Table 4.11.b).

The interaction between days to physiological maturity and varieties were in such way that, more days to maturity was noticed on May 15th (221.0) date of planting in variety *Maran* and less number of days on June 15th (197.7) date of planting. The *Varada* variety recorded more days to maturity on May 15th (216.7) date of planting, while the less was on July 1st (190.5) and June 15th (188.25) planted crops, which was on par with each other (Table 4.11.c).

4.3. EFFECTS OF DATES OF PLANTING AND VARIETIES ON YIELD AND YIELDATTRIBUTES

Analysis of variance was carried out for yield and yield attributes are represented in Appendix IV page xvii.

4.3.1. Fresh yield

There was significant difference between the dates of planting on the fresh yield of ginger (Table.4.12.a). The May 15th (33702.51 kg ha^{-1}) date of planting gave more yield when comparedto the other dates of planting, whereas the July 1st (7990 kg ha^{-1}) date of planting gave very less yield among the four.

In case of varieties there is no significant difference between *Maran* and *Varada* in terms of fresh yield (Table.4.12.b).

Interaction between dates of planting and varieties with respect to yield was found to be nonsignificant (Table.4.12.c).

4.3.2. Dry yield

There was significant difference between dates of planting on the dry yield of ginger. The May 15th (8271.14 kg ha^{-1}) date of planting gave a better yield when

Table. 4.11.a. Effect of dates of planting on phenological observations

Dates of planting	Sprouting percentage	Number of tillers			Days to physiological maturity
		90 DAP	120 DAP	150 DAP	
D1	42.87^{b}	13.76^{a}	17.95^{a}	19.4^{a}	218.87^{a}
D2	73.61^{a}	12.01^{b}	13.60^{b}	14.5^{b}	206.50^{a}
D3	76.00^{a}	10.48^{b}	12.05^{b}	13.7^{bc}	188.00^{d}
D4	78.37^{a}	5.80^{c}	8.92^{c}	12.2^{c}	192.00^{c}
CD	13.97	1.52	1.71	1.87	2.04

Table. 4.11.b Effect of varieties on phenological observations

Varieties	Sprouting percentage	Number of tillers			Days to physiological maturity
		90 DAP	120 DAP	150 DAP	
V1	68.50	11.01^{a}	13.9^{a}	15.6^{a}	202.87^{a}
V2	66.92	10.0^{b}	12.28^{b}	14.3^{b}	199.81^{b}
CD	NS	0.78	0.79	0.84	1.37

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.11.c Interaction between dates of planting and varieties on phenological observations

Dates of planting	Sprouting percentage		Days to physiological maturity	
	V1	V2	V1	V2
D1	37.25	48.50	221.00[a]	216.75[a]
D2	71.2	76.02	209.25[b]	203.75[b]
D3	81.21	70.80	187.75[d]	188.25[c]
D4	84.36	72.38	193.5[c]	190.50[c]
CD	NS		2.83	

Table. 4.11.c Interaction between dates of planting and varieties on phenological observations (Contd.)

Dates of planting	Number of tillers					
	90 DAP		120 DAP		150 DAP	
	V1	V2	V1	V2	V1	V2
D1	12.3[a]	11.6[a]	13.85[b]	13.4[b]	15.08	14.2
D2	12.0[a]	12.0[a]	18.3[a]	17.9[a]	20.1	19.0
D3	12.2[a]	8.6[b]	13.5[b]	10.5[c]	14.9	12.4
D4	8.2[b]	5.8[c]	12.5[b]	10.7[c]	16.0	14.5
CD	1.57		2.25		NS	

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

compared to the other dates of planting, whereas the July 1st (1545.39 kg ha^{-1}) date of planting gave very less dry yield amongthe four (Table.4.12.a).

In case of varieties there was significant difference between dry yield of *Maran* (6785.57 kgha^{-1}) and *Varada* (3843.46 kg ha^{-1}) (Table.4.12.b).

The Interaction between dates of planting and varieties with respect to dry yield was found to be significant. The higher dry yield in *Maran* was observed in May 15th (9834 kg ha^{-1}) and June1st (9741.68 kg ha^{-1}) date of planting, which were on par with each other and lowest was on July 1st (2072.04 kg ha^{-1}) date of planting. In *Varada*, higher yield was observed on May 15th (6707.73 kg ha^{-1}) date of planting. Lowest was on July 1st (1018.73 kg ha^{-1}) and June 15th (3562.02 kg ha^{-1}) planted crops, which were on par with each other (Table.4.12.c).

4.3.3. Length of rhizome

The dates of planting and varieties was found to have significant influence on the length of ginger rhizome (Table.4.12.a). The May 15th (5.69 cm) date of planting gave more length when compared to the other dates of planting, whereas the July 1st (4.33 cm) and June 15th (4.80 cm) dates of planting gave lowest length, which was on par with each other.

There was significant difference between the varieties on length of ginger rhizome (Table.4.12.b). *Varada* (5.16 cm) recorded more length than that of *Maran* (4.75 cm).

Interaction between dates of planting and varieties was non significant (Table.4.12.c).

4.3.4. Width of rhizome

The dates of planting and varieties was found to have significant influence on the width of ginger rhizome (Table.4.12.a). The May 15th (2.48 cm) and June 1st (2.36 cm) dates of planting gave more width, which was on par with each other. The July 1st (1.95 cm) date of planting gave very less width.

There was no significant difference between rhizome width of varieties (Table.4.12.b).

The interaction between dates of planting and varieties with respect to width of rhizome alsofound to be non significant (Table.4.12.c).

4.3.5. Internodal length

There was no significant effect of date of planting (Table.4.12.a), varieties (Table.4.12.b) and interaction between dates of planting and varieties on intermodal length of ginger (Table.4.12.c).

4.4. SOIL ANALYSIS

The soil analysis was presented in Table.4.13. The texture of soil was found to be sandy loam.The nature of soil was acidic with a pH value of 4.46. The electrical conductivity was 1.73 dS m^{-1}. Amount of organic carbon (1.15%) present in the soil was medium. The plot hadsufficient available potassium (334.9 kg ha^{-1}) but deficient in available phosphorous (3.57 kg ha^{-1}).

Table 4.13. Soil analysis

Sl. No.	Parameter	Amount	Remark
Chemical composition of soil			
1	Organic carbon (%)	1.15	Medium
2	Soil Ph	4.46	Acidic
3	Electrical conductivity (dS m^{-1})	1.73	Alkaline
5	Available phosphorous (kg ha^{-1})	3.57	Less
6	Available potassium (kg ha^{-1})	334.9	More
Mechanical composition of soil			
7	Coarse sand (%)	44.37	sandy loam
8	Fine sand (%)	50.59	
9	Silt (%)	0.06	
10	Clay (%)	0.56	

Table. 4.12.a Effect of dates of planting on yield and yield attribute

Dates of planting	Fresh yield (kg ha^{-1})	Dry yield(kg ha^{-1})	Length of rhizome (cm)	Width of rhizome (cm)	Inter nodal length (cm)
D1	33702.5^{a}	8271.14^{a}	5.69^{a}	2.48^{a}	0.76
D2	26337.5^{b}	6913.52^{a}	5.00^{b}	2.36^{ab}	0.75
D3	17737.5^{c}	4474.02^{b}	4.80^{bc}	2.20^{b}	0.82
D4	7990.0^{d}	1545.39^{c}	4.33^{c}	1.95^{c}	0.73
CD	3702.38	2029.08	0.56	0.21	NS

Table. 4.12.b Effect of varieties on yield and yield attributes

Dates of planting	Fresh yield (kg ha^{-1})	Dry yield (kg ha^{-1})	Length of rhizome (cm)	Width of rhizome (cm)	Inter nodal length (cm)
V1	21736.88	6758.57^{a}	4.75^{b}	2.28^{a}	0.77
V2	21146.88	3843.46^{b}	5.16^{a}	2.22^{a}	0.76
CD	NS	1120.47	0.40	0.13	NS

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

Table. 4.12. c Interaction of date of planting and varieties on yield and yield

Dates of planting	Fresh yield (kg ha^{-1})		Dry yield (kg ha^{-1})		Length of rhizome (cm)		Width of rhizome(cm)		Inter nodal length (cm)	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
D1	33900.0	33505.0	9834.54^{a}	6707.73^{a}	5.67	5.72	2.45	2.52	0.78	0.75
D2	26457.5	26217.5	9741.68^{a}	4085.36^{b}	4.92	5.08	2.33	2.40	0.74	0.76
D3	18675.0	16800.0	5386.02^{b}	3562.02^{bc}	4.53	5.07	2.35	2.05	0.81	0.83
D4	7915.0	8065.0	2072.04^{c}	1018.73^{c}	3.86	4.80	1.98	1.91	0.77	0.70
CD	NS		2572.97		NS					

D1: 15th May 2020, D2: 1st June 2020, D3: 15th June 2020, D4:1st July 2020, V1: *Maran*, V2: *Varada*

4.5. CROP – WEATHER RELATIONSHIP OF GINGER

The relationship between various weather parameters at each growth stages and yield, yieldattributes and plant characters were studied.

4.5.1. Influence of weather parameters on the yield of ginger

4.5.1.1. PLANTING TO SPROUTING

The weather experienced in the initial stage of plant growth have significant influenceon final yield of ginger. The varieties of ginger *Maran* and *Varada* showed significant positive correlation with maximum temperature, minimum temperature, wind speed, sunshine hours, solar radiation, evaporation, forenoon and afternoon soil temperature at both 5 cm and 20 cm depth at one percent level. Rainy days of these period showed a positive correlation at five percent level. Significant negative correlation with yield was showed by relative humidity and soil moisture at 5 cm and 20 cm depth at five percent significant level (Table.4.14).

4.5.1.2. SPROUTING TO ACTIVE TILLERING

The second phenophse of ginger variety *Maran* showed a significant positive correlation with minimum temperature, forenoon soil temperature at 5 cm depth and afternoonsoil temperature at 20 cm depth at one percent significant level. Significant negative correlationexist with wind speed, rainfall, rainy days, sunshine hours, solar radiation, evaporation, afternoon soil temperature at five cm depth, soil moisture at 5 cm and 20 cm depth at one percent significant level. The trend is same in variety *Varada* also, except that the negative correlation with solar radiation was significant at five percent level and there is no significantcorrelation between afternoon soil temperature at 5 cm level and yield of *Varada* (Table.4.14).

4.5.1.3. ACTIVE TILLERING TO BULKING

Both varieties showed significant positive correlation with minimum temperature, relative humidity, rainfall and rainy days at one percent significance level. In case of *Maran* forenoon soil temperature at 5 cm depth and soil moisture at 5 cm depth also experiences positive correlation with yield. Whereas a negative correlation was shown by maximum temperature, wind speed, sunshine hours, solar radiation and evaporation at one percent significance level in case of both varieties, Other than this, *Maran* variety showed negative correlation in afternoon soil temperature at 5 cm depth with one percent significance and forenoon soil temperature at 20 cm depth with five percent significance. But in case of *Varada,* afternoon soil temperature at 5 cm depth showed negative correlation at five percent significantlevel along with the other negatively correlated parameters (Table.4.14).

4.5.1.4. BULKING TO PHYSIOLOGICAL MATURITY

The correlation study between yield and weather parameters in bulking to physiologicalmaturity stage in *Maran* revealed that there was a significant positive correlation with relativehumidity, rainfall, rainy days, solar radiation, forenoon and afternoon vapour pressure deficit (one percent significance). A negative correlation exist between wind speed and soil temperature at all depths at one percent significance. The correlation in *Varada* was in such away that it showed positive correlation with relative humidity, rainfall, rainy days, forenoon and afternoon vapour pressure deficit (one percent significance) and solar radiation (five percent significance). There is significant one percent negative correlation with minimum temperature, afternoon soil temperature at both 5 and 20 cm depth (Table.4.14).

4.5.2. Rhizome length of ginger influenced by weather parameters

4.5.2.1. PLANTING TO SPROUTING

Weather experienced at the initial stage of plant growth have significant influence on rhizome length of ginger. The variety of ginger *Maran* showed significant positive correlationwith maximum temperature, minimum temperature, wind speed, rainfall, rainy days, sunshine hours, solar radiation, evaporation and forenoon and soil temperature at both 5 cm and 20 cmdepth. A significant negative correlation was showed by relative humidity and soil moisture at 5 cm and 20 cm depth with rhizome length at five percent significant level. In case of *Varada,* Maximum and minimum temperature, sunshine hours, evaporation and forenoon and

Table.4.14. Correlation between yield of ginger and weather variables

Growth Stage	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	stI5 (˚C)	stI20 (˚C)	stII5 (˚C)	stII20 (˚C)	SM5 (%)	SM20 (%)
P1	V1	.963**	.972**	-.895**	.808**	0.473	.808**	.921**	.970**	.804**	.961**	.975**	.896**	.960**	-.502*	-.580*
	V2	.953**	.969**	-.949**	.855**	0.043	.589*	.872**	.713**	.755**	.932**	.973**	.883**	.945**	-.949**	-.920**
P2	V1	0.375	.869**	0.008	-.942**	-.805**	-.837**	-.512*	-.860**	-.963**	.970**	0.463	-.626**	.870**	-.897**	-.936**
	V2	-0.4	.771**	0.0	-.951**	-.707**	-.626**	-.580*	-.618*	-.958**	-.920**	-0.2	0.0	.841**	-.893**	-.920**
P3	V1	-.955**	.967**	.926**	-.813**	.902**	.891**	-.946**	-.934**	-.707**	.979**	-.546*	-.915**	-0.496	.720**	-.620*
	V2	-.933**	.965**	.891**	-.813**	.831**	.819**	-.913**	-.897**	-.731**	0.425	-0.489	-.600*	-0.489	0.214	-0.34
P4	V1	0.276	-0.186	.911**	-.969**	.722**	.759**	-0.185	.817**	0.223	-.670**	-.717**	-.895**	-.642**	0.085	0.085
	V2	0.4	-.627*	.922**	-.975**	.741**	.773**	-0.4	.561*	-0.2	-0.3	-0.4	-.705**	-.729**	0.2	-0.196

*Significant at 5% level, ** Significant at 1% level, P1: Planting to sprouting, P2: Sprouting to active tillering, P3: Active tilleringto bulking, P4: Bulking to physiological maturity, V1: *Maran*, V2: *Varada*

afternoon soil moisture at both 5 and 20 cm showed positive correlation at five percent level. Relative humidity and soil moisture at 20 cm depth showed a significant negative correlation (Table 4.15).

4.5.2.2. SPROUTING TO ACTIVE TILLERING

Second phenophse of ginger variety *Maran* showed a significant positive correlation with minimum temperature at five percent level and all the soil temperatures except forenoon soil temperature at 5 cm depth at one percent level. The negative significant correlation exist with wind speed, rainfall, rainy days, solar radiation, evaporation, forenoon soil temperature at 5 cm depth and soil moisture at 5 cm and 20 cm depth at one percent significant level. There was no positive correlation with any of the parameters in case of *Varada*, negative correlation exist between wind speed, rainfall and evaporation (Table 4.15).

4.5.2.3. ACTIVE TILLERING TO BULKING

Variety *Maran* showed significant positive correlation with relative humidity, rainfall, rainy days, sun shine hours and forenoon soil temperature at 20 cm depth at one percent significance. Negative correlation was showed by minimum temperature, rainfall, solar radiation, evaporation, forenoon soil temperature at 5 cm depth and afternoon soil temperature at 20 cm depth at one percent significance level. But in case of *Varada* positive correlation at five percent significant was showed with minimum temperature and negative correlation was showed by evaporation (Table 4.15).

4.5.2.4. BULKING TO PHYSIOLOGICAL MATURITY

The correlation study between rhizome length and weather parameters in bulking to physiological maturity stage in *Maran* revealed that there was a significant positive correlation with relative humidity, rainfall, rainy days and solar radiation and afternoon (one percent significance). Negative correlation exist between wind speed and soil temperature at all depths atone percent significance. The correlation in *Varada* was in such a way that it showed positive correlation with relative humidity, rainfall, rainy days (one percent significance) and negative correlation with afternoon soil temperature at 20 cm depth (Table 4.15).

Table.4.15. Correlation between rhizome length of ginger and weather variables

Growth Stage	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr-1)	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	stI5 (˚C)	stI20 (˚C)	stII5 (˚C)	stII20 (˚C)	SM5 (%)	SM20 (%)
P1	V1	.870**	.926**	-.69**	.940**	.522*	.810**	.833**	.838**	.810**	.821**	.883**	.821**	.884**	-.775**	-.803**
	V2	.530*	.517*	-.522*	0.404	0.249	0.487	.543*	0.463	.528*	.539*	.517*	.538*	.530*	-0.453	-.545*
P2	V1	0.226	.547*	0.197	-.94**	-.674**	-.724**	-.603*	-.883**	-.923**	.906**	.775**	-.527*	.804**	-.961**	-.960**
	V2	-0.286	0.346	-0.208	-.508*	-.500*	-0.47	-0.125	-0.2	-.530*	-0.379	0.078	0.217	0.323	-0.424	-0.46
P3	V1	1	-.79**	.915**	.714**	-.558*	.669**	.679**	-.767**	-.761**	-.515*	.851**	-0.424	-.749**	-0.446	.547*
	V2	-0.438	.527*	0.431	-0.343	0.399	0.354	-0.478	-0.489	-.511*	0.091	-0.38	-0.479	-0.38	0.171	-0.009
P4	V1	0.106	0.164	.946**	-.93**	.777**	.786**	-0.419	.668**	0.246	-.540*	-.739**	-.946**	-.796**	-0.166	-0.166
	V2	0.005	-0.491	.506*	-0.491	.509*	.523*	-0.341	0.184	0.137	-0.364	-0.359	-0.474	-.516*	-0.13	-0.327

*Significant at 5% level, ** Significant at 1% level, P1: Planting to sprouting, P2: Sprouting to active tillering, P3: Active tillering to bulking, P4: Bulking to physiological maturity, V1: *Maran*, V2: *Varada*

4.5.3. Rhizome width of ginger influenced by weather parameters

4.5.3.1. PLANTING TO 50% SPROUTING

The weather experienced in the initial stage of plant growth have significant influence on rhizome width of ginger. The variety of ginger *Maran* showed significant positive correlation with maximum temperature, minimum temperature, sunshine hours, forenoon soil temperature at 20 cm depth and afternoon soil temperature at 5 and 20 cm depth at five percent level. There was a positive correlation at one percent significance with solar radiation and forenoon soil temperatureat 5 cm depth. Significant negative correlation was showed by relative humidity at one percent significant level. In case of *Varada,* maximum and minimum temperatures, wind speed, sun shine hours and all the soil temperatures showed positive correlation at one percent level. Relative humidity and soil moisture at 5 and 20 cm depth showed significant negative correlation (Table 4.16).

4.5.3.2. 50% SPROUTING TO ACTIVE TILLERING

The second phenophse of ginger variety *Maran* was showed a significant positive correlation with minimum temperature at one percent level and forenoon soil temperature at 5 cmdepth and afternoon soil temperature at 20 cm depth at five percent level. A negative correlation was showed by wind speed, rain fall, rainy days and evaporation (five percent level). In case of *Varada* positive correlation exist with minimum temperature and afternoon soil temperature at 20cm depth (one percent level). The negative relation was experienced with wind speed, solar radiation, evaporations, soil temperature at 5 cm depth, soil moisture at 5 and 20 cm depth (one percent significance) and sun shine hours (five percent significance level) (Table 4.16).

4.5.3.3. ACTIVE TILLERING TO BULKING

Variety *Maran* showed a significant positive correlation with relative humidity, rainfall, rainy days, forenoon soil temperature at 5 cm depth, soil moisture at 5 cm depth (one percent significance level) and minimum temperature (five percent significance). A negative correlation was showed by maximum temperature, wind speed, sunshine hours (one percent significance), evaporation, after noon soil temperature at 5 cm depth (five percent). In case of *Varada*, one percent significant positive correlation was shown with minimum temperature, relative humidity. Rainfall, rainy days, forenoon and afternoon relative humidity. Negative correlation was shown by maximum, wind speed, sunshine hours, solar radiation (one percent significance) and evaporation (five percent significant) (Table 4.16).

4.5.3.4. BULKING TO PHYSIOLOGICAL MATURITY

The correlation study between rhizome width and weather parameters in bulking to physiological maturity stage in *Maran* revealed that there was significant positive correlation with solar radiation at five percent significance level, whereas the negative correlation exist only with wind speed at five percent level. The correlation in *Varada* was in such a way that it showed positive correlation with minimum temperature, relative humidity, rainfall, rainy days (one percent significance) and negative correlation with maximum temperature, wind speed, sunshine hours, solar radiation (one percent level) and evaporation (five percent level) (Table 4.16).

4.5.4. Internodal length of ginger influenced by weather parameters

There was no significant correlation between internodal length and weather parameters in any of the four stages of growth (Table 4.17).

4.5.5. Dry yield of ginger influenced by weather parameters

4.5.5.1. PLANTING TO SPROUTING

Weather experienced in the initial stage of plant growth have significant influence on dry yield of ginger. The varieties of ginger *Maran* and *Varada* showed significant positive correlation with maximum temperature, minimum temperature, wind speed, sunshine hours, solar radiation, forenoon soil temperature at five and twenty cm depth and afternoon soil temperature at one percent level. There was a positive correlation at five percent significance with rainy days. Significant negative correlation was showed by relative humidity and soil moisture at five and

Table.4.16. Correlation between rhizome width of ginger and weather variables

Growth Stage	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	stI5 (˚C)	stI20 (˚C)	stII5 (˚C)	stII20 (˚C)	SM5 (%)	SM20 (%)
P1	V1	.604*	.562*	-.662**	0.343	0.223	0.445	.585*	.643**	0.44	.632**	.613*	.547*	.592*	-0.085	-0.121
	V2	.813**	.834**	-.792**	.787**	-0.074	0.429	.726**	.621*	.612*	.772**	.834**	.745**	.808**	-.89**	-.79**
P2	V1	0.374	.658**	-0.137	-.553*	-.546*	-.551*	-0.152	-0.462	-.563*	.601*	0.131	-0.44	.564*	-0.451	-0.495
	V2	-0.17	.636**	0.118	-.839**	-.530*	-0.451	-.608*	-.626**	-.89**	-.820**	-0.353	0.013	.735**	-.812**	-.83**
P3	V1	-.663**	.582*	.676**	-.646**	.679**	.657**	-.665**	-.650**	-.539*	.641**	-0.314	-.621*	-0.359	.658**	-0.241
	V2	-.796**	.819**	.744**	-.689**	.684**	.691**	-.755**	-.732**	-.556*	0.354	-0.427	-0.477	-0.427	0.087	-0.407
P4	V1	0.284	-0.373	0.477	-.562*	0.357	0.399	0.078	.568*	0.106	-0.471	-0.38	-0.455	-0.236	0.241	0.241
	V2	-.796**	.819**	.744**	-.689**	.684**	.691**	-.755**	-.732**	-.556*	0.354	-0.427	-0.477	-0.427	0.087	-0.407

*Significant at 5% level, ** Significant at 1% level, P1: Planting to sprouting, P2: Sprouting to active tillering, P3: Active tilleringto bulking, P4: Bulking to physiological maturity, V1: *Maran*, V2: *Varada*

Table.4.17. Correlation between intermodal length of ginger and weather variables

Growth Stage	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	stI5 (˚C)	stI20 (˚C)	stII5 (˚C)	stII20 (˚C)	SM5 (%)	SM20 (%)
P1	V1	-0.032	-0.076	-0.046	-0.177	0.056	-0.011	-0.006	-0.029	-0.012	-0.008	-0.049	0	-0.041	0.231	0.23
	V2	0.03	0.043	-0.16	-0.146	0.118	0.075	-0.006	-0.213	-0.044	0.121	0.07	-0.029	0.011	0.018	-0.066
P2	V1	0.188	0.008	-0.247	0.112	-0.066	-0.047	0.254	0.181	0.072	-0.085	-0.13	0.143	0.01	0.15	0.13
	V2	0.329	0.369	-0.198	-0.019	-0.202	-0.228	0.061	0.221	-0.111	0.052	-0.023	-0.325	-0.183	0.108	0.067
P3	V1	0.033	-0.068	-0.009	0.012	0.005	-0.036	0	-0.018	-0.121	-0.055	-0.12	-0.032	-0.122	0.008	0
	V2	-0.231	0.087	0.287	-0.328	0.337	0.33	-0.254	-0.255	-0.182	0.429	0.306	0.124	0.306	0.461	0.249
P4	V1	-0.089	-0.235	-0.101	0.105	-0.019	-0.01	0.031	-0.106	0.123	0.13	-0.008	0.107	0.081	0	0
	V2	0.254	-0.138	-0.062	-0.041	-0.12	-0.083	0.321	0.421	-0.188	0.065	0.279	0.196	0.083	0.248	0.159

*Significant at 5% level, ** Significant at 1% level, P1: Planting to sprouting, P2: Sprouting to active tillering, P3: Active tilleringto bulking, P4: Bulking to physiological maturity, V1: *Maran*, V2: *Varada*

twenty cm depth at one percent significant level. (Table 4.18).

4.5.5.2. SPROUTING TO ACTIVE TILLERING

The second phenophase of ginger variety *Maran* showed significant positive correlation with minimum temperature, forenoon soil temperature at 5 cm and afternoon soil temperature at 20 cm depths one percent level (one percent level). Negative correlation was showed by wind speed, rain fall, rainy days, sunshine hours, solar radiation, soil temperature at twenty cm depth, evaporation and soil moisture at all depths. In case of *Varada* positive correlation exist with minimum temperature (one percent significance). A negative correlation was showed by wind speed, rain fall, rainy days, forenoon soil temperature at five cm depth, evaporation and soil moisture at all depths (Table 4.18).

4.5.5.3. ACTIVE TILLERING TO BULKING

Variety *Maran* showed a significant positive correlation with minimum temperature, relative humidity, rainfall, rainy days, fore noon soil temperature at five cm depth and soil moisture at fivecm depth (one percent significance level). A negative correlation was showed by maximum temperature, wind speed, sunshine hours, solar radiation and afternoon soil temperature at 5 cm depth (one percent significance level). Increase of *Varada,* all the relations are same as that of *Maran,* except that, there were no correlation with forenoon soil temperature and soil moisture at 5 cm depth (Table 4.18).

4.5.5.4. BULKING TO PHYSIOLOGICAL MATURITY

In *Maran*, there was a positive correlation between dry yield and relative humidity, solar radiation (one percent significance), rainfall and rainy days (five percent significance). Negative correlation was showed by wind speed, forenoon and afternoon soil temperature at 5 cm depth. In *Varada*, there was a positive correlation with relative humidity, rainfall, rainy days (one percent significance), solar radiation (five percent significance). Negative correlation was showed by minimum temperature, wind speed, afternoon soil temperature at 5 and 20 cm depth (Table 4.17).

Table 4.18. Correlation between dry yield of ginger and weather variables

Growth Stage g	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS ($kmhr^{-1}$)	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	stI5 (˚C)	stI20 (˚C)	stII5 (˚C)	stII20 (˚C)	SM5 (%)	SM20 (%)
P1	V1	.789**	.816**	-.71**	.737**	0.227	.590*	.728**	.820**	.586*	.777**	.825**	.679**	.791**	-.87**	-.564*
	V2	.895**	.893**	-.922**	.690**	0.276	.712**	.862**	.664**	.787**	.919**	.902**	.855**	.886**	-.810**	-.904**
P2	V1	0.151	.741**	0.235	-.860**	-.564*	-.604*	-.599*	-.856**	-.811**	.867**	0.43	-.726**	.681**	-.812**	-.828**
	V2	-0.259	.745**	-0.243	-.878**	-.810**	-.755**	-0.353	-0.384	-.919**	-.709**	-0.064	0.124	.571*	-.734**	-.794**
P3	V1	-.840**	.824**	.807**	-.75**	.784**	.820**	-.79**	-.75**	-0.457	.856**	-0.216	-.69**	-0.262	.741**	-0.22
	V2	-.859**	.913**	.850**	-.749**	.809**	.762**	-.892**	-.896**	-.825**	0.383	-0.467	-.655**	-0.467	0.374	-0.084
P4	V1	0.429	-0.027	.767**	-.859**	.506*	.539*	-0.026	.826**	-0.027	-.742**	-0.486	-.754**	-0.472	0.22	0.22
	V2	0.252	-.75**	.835**	-.872**	.743**	.780**	-0.375	.523*	-0.007	-0.423	-0.4	-.675**	-.755**	0.028	-0.335

*Significant at 5% level, ** Significant at 1% level, P1: Planting to sprouting, P2: Sprouting to active tillering, P3: Active tilleringto bulking, P4: Bulking to physiological maturity, V1: *Maran*, V2: *Varada*

4.6. CROP WEATHER MODEL USING STATISTICAL TOOLS

According to the objective of the study, crop weather model was developed with statistical tools for the two varieties of ginger, *Maran* and *Varada.* The Principal Component Analysis (PCA) and regression method were used for the analysis.

Extracted principal components were used as explanatory variables, along with ginger yield as explained variable, a principal component regression model developed using stepwise regression.

4.6.1. Crop weather model using Principal Component Analysis in *Maran*

The Principal Component Analysis was carried out for ginger variety *Maran* by using the weather parameters experienced in four stages of ginger *ie.*, planting to 50% sprouting, 50% sprouting to active tillering, active tillering to bulking and bulking to physiological maturity. Weather parameters considered include maximum temperature (Tmax), minimum temperature (Tmin), rainfall (RF), rainy days (RD), relative humidity (RH), wind speed (WS) and solar radiation (SRAD). The number of principal components were retained using scree plot methods. Two principal components at varying proportions were identified and that are given in Table 4.19.

Table 4.19. Importance of components obtained after PCA analysis for

	Component 1	Component 2	Cumulative proportion of variances
Eigen Value	19.75	5.36	-
Proportion of variance	70.54	19.16	89.70

From the table it was observed that a cumulative proportion of 89.70% was obtained for first two components *ie.,* component 1 and component 2. Component 1 contributed a variance of 70.54 percent, with eigen value 19.75 and component 2, a variance percent of 9.16 with 5.36 eigen value. The cumulative proportion of different weather parameters is represented in a scree plot (Fig 4.2). So, for the yield prediction of

Maran only first two components were used in fitting the regression equation. The importance of various weather parameters in forming the two components are depicted in the variables factor map obtained from PCA and are given Fig.4.3. The loading values of different weather parameters are listed in the Table 4.20.

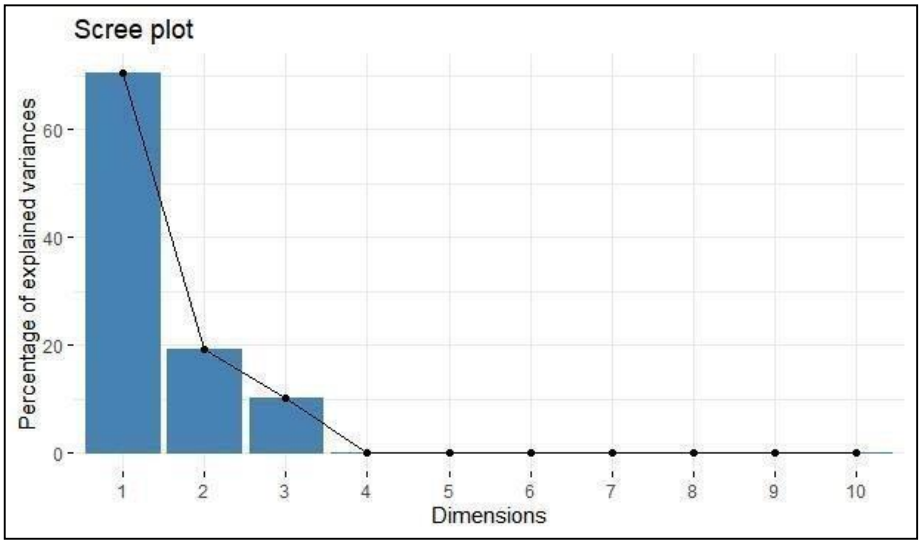


Fig. 4.2. Scree plot of variance percentage of cumulative proportion of different weather parameters of *Maran*

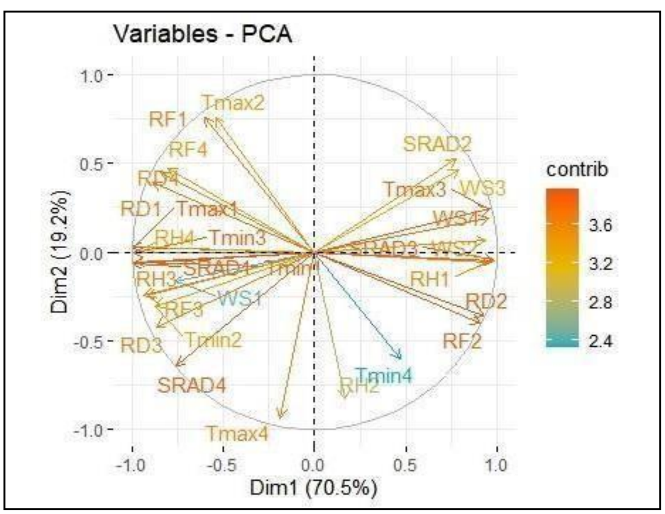


Fig. 4.3. Variables factor map obtained after PCA in *Maran*

Table 4.20. Loading values of weather variables in forming principal components in

Variables	Component 1	Component 2
Maximum temperature at P1 (Tmax1)	-0.22	0.01
Minimum temperature at P1 (Tmin1)	-0.22	-0.02
Relative humidity at P1 (RH1)	0.21	-0.02
Wind speed at P1 (WS1)	-0.17	-0.07
Rainfall at P1 (RF1)	-0.14	0.33
Rainy days at P1 (RD1)	-0.20	0.17
Solar radiation at P1 (SRAD1)	-0.22	-0.03
Maximum temperature at P2 (Tmax2)	-0.12	0.33
Minimum temperature at P2 (Tmin2)	-0.20	-0.13
Relative humidity at P2 (RH2)	0.04	-0.36
Wind speed at P2 (WS2)	0.21	0.03
Rainfall at P2 (RF2)	0.20	-0.17
Rainy days at P2 (RD2)	0.21	-0.16
Solar radiation at P2 (SRAD2)	0.17	0.23
Maximum temperature at P3 (Tmax3)	0.22	0.10
Minimum temperature at P3 (Tmin3)	-0.22	0.00
Relative humidity at P3 (RH3)	-0.21	-0.10
Wind speed at P3 (WS3)	0.18	0.20
Rainfall at P3 (RF3)	-0.21	-0.11
Rainy days at P3 (RD3)	-0.20	-0.18
Solar radiation at P3 (SRAD3)	0.22	-0.02
Maximum temperature at P4 (Tmax4)	-0.04	-0.40
Minimum temperature at P4 (Tmin4)	0.11	-0.26
Relative humidity at P4 (RH4)	-0.21	0.01
Wind speed at P4 (WS4)	0.21	0.08
Rainfall at P4 (RF4)	-0.18	0.20
Rainy days at P4 (RD4)	-0.19	0.19
Solar radiation at P4 (SRAD4)	-0.17	-0.28

The regression analysis was carried out with the help of SPSS software, by keeping the component 1 and component 2 as independent and yield as dependent variable.

$Y=7653.13-83.35X_1$ $-44.82X_2$***

X_1 = Score of principal component 1

X_2 = Score of principal component 2

The comparison between estimated yield and predicted yield is given in table 4.23.

4.6.2. Crop weather model using Principal Component Analysis in *Varada*

From the Table 4.21 it was observed that 84.42% of total variance was obtained for component 1 and component 2. Component 1 showed a variance percent of 62.78 with eigen value of 17.57 and component 2 showed a variance percent of 21.64 with 6.05 eigen value. The cumulative proportion of weather parameters were plotted in a scree plot (Fig 4.5). For the yield prediction of *Varada* only first two components were used in fitting the regression equation. The importance of various weather parameters in forming the two components were represented in the variables factor map obtained after PCA analysis are given in the Fig.4.6. The loading values of different weather parameters were recorded in the Table 4.22. The regression equation was fitted and comparison between estimated yield and predicted yield were made (Table 4.23).

Table 4.21. Importance of components obtained after PCA analysis for *Varada*

	Component 1	Component 2	Cumulative percentage of variance
Eigen value	17.57	6.05	-
Variance percent	62.78	21.64	84.42

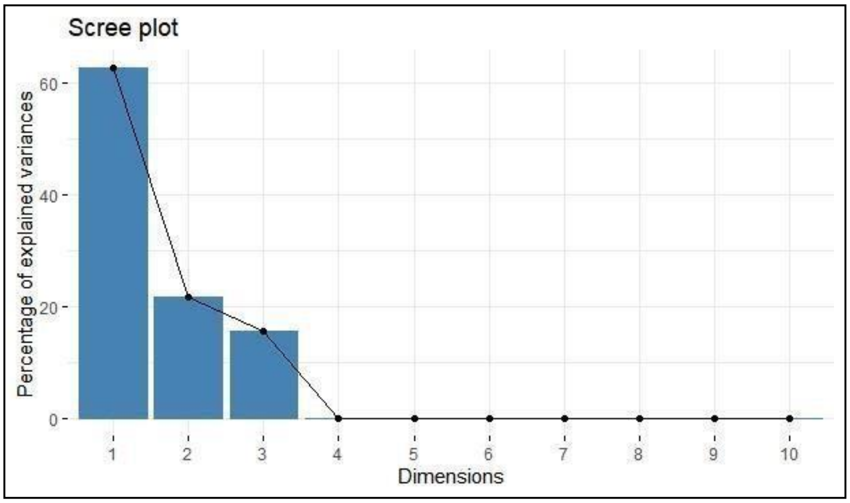


Fig. 4.4.Scree plot of cumulative proportion of variances in *Varada*

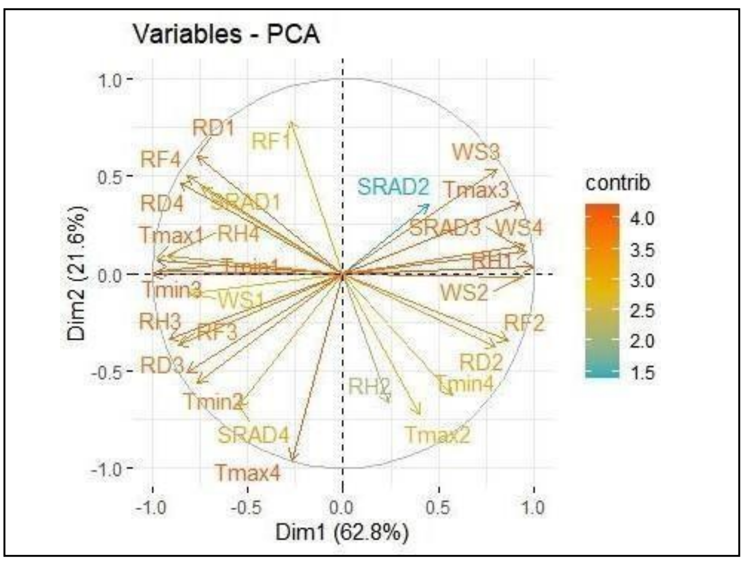


Fig. 4.5. Variables factor map obtained from PCA in *Varada*

The regression analysis was carried out with the help of SPSS software, by keeping the component 1 and component 2 as independent and yield as dependent variable.

Y=19845.19-65.93X1**

X_1 = Score of Principal component 1

Table 4.20. Loading values of weather variables in forming principal components in *Varada*

Variables	Component 1	Component 2
Maximum temperature at P1 (Tmax1)	-0.23	0.03
Minimum temperature at P1 (Tmin1)	-0.23	0.00
Relative humidity at P1 (RH1)	0.24	0.01
Wind speed at P1 (WS1)	-0.19	-0.04
Rainfall at P1 (RF1)	-0.07	0.32
Rainy days at P1 (RD1)	-0.18	0.25
Solar radiation at P1 (SRAD1)	-0.18	0.18
Maximum temperature at P2 (Tmax2)	0.10	-0.30
Minimum temperature at P2 (Tmin2)	-0.18	-0.23
Relative humidity at P2 (RH2)	0.06	-0.27
Wind speed at P2 (WS2)	0.23	-0.01
Rainfall at P2 (RF2)	0.21	-0.14
Rainy days at P2 (RD2)	0.19	-0.15
Solar radiation at P2 (SRAD2)	0.11	0.15
Maximum temperature at P3 (Tmax3)	0.22	0.15
Minimum temperature at P3 (Tmin3)	-0.24	0.00
Relative humidity at P3 (RH3)	-0.22	-0.14
Wind speed at P3 (WS3)	0.19	0.22
Rainfall at P3 (RF3)	-0.21	-0.15
Rainy days at P3 (RD3)	-0.19	-0.21
Solar radiation at P3 (SRAD3)	0.23	0.04
Maximum temperature at P4 (Tmax4)	-0.06	-0.39
Minimum temperature at P4 (Tmin4)	0.14	-0.25
Relative humidity at P4 (RH4)	-0.22	0.04
Wind speed at P4 (WS4)	0.23	0.06
Rainfall at P4 (RF4)	-0.19	0.20
Rainy days at P4 (RD4)	-0.20	0.19
Solar radiation at P4 (SRAD4)	-0.13	-0.28

Table.4.23. Comparison of predicted yield and observed yield of ginger varieties *Maran* and *Varada*.

Dates of planting	*Maran*		*Varada*	
	Estimated yield	Observed yield	Estimated yield	Observed yield
D1	33293.8	33900.0	33111.0	33505.0
D2	22704.3	26457.5	19273.6	26217.5
D3	22687.2	18675.0	22658.4	16800.0
D4	7663.5	7915.0	9544.3	8065.0

4.7. IMPACT OF CLIMATE CHANGE ON YIELD OF GINGER

A regression model, developed with principal components as independent variables was used to assess the impacts of climate change on ginger production under projected climate change scenarios. For generating future climate, dynamically downscaled outputs of General Circulation Model (GCM) namely CCSM4 was used. RegCM4.4 was employed for dynamical downscaling of GCM outputs to project the future climate under RCP 4.5 and 8.5 scenarios.

4.7.1. Evaluation of CCSM4 model

The accuracy of CCSM4 model was estimated by comparing the model predicted value and observed value of climatic data for the past thirty years (Table 4.24). All the weather parameters considered for the study showed low RMSE value, less than 5, indicating good accuracy of the model (Fig.4.6).

Table.4.24. RMSE Value of weather parameters

Month	Weather parameters					
	Tmax	Tmin	RH	RF	RD	WS
January	0.03	0.03	2.71	0.08	0.01	0.86
February	0.30	0.14	3.22	0.29	0.01	0.79
March	0.65	0.04	2.19	0.02	0.00	0.57
April	0.70	0.19	1.26	0.03	0.01	0.48
May	0.68	0.31	0.95	0.02	0.00	0.49
June	0.24	0.10	0.93	0.24	0.03	0.39
July	0.39	0.34	0.45	4.34	0.07	0.33
August	0.33	0.17	0.40	1.81	0.01	0.34
September	0.18	0.08	0.33	1.32	0.05	0.29
October	0.05	0.00	0.19	1.54	0.08	0.23
November	0.04	0.18	0.01	0.76	0.03	0.24
December	0.10	0.23	1.76	0.10	0.01	0.75

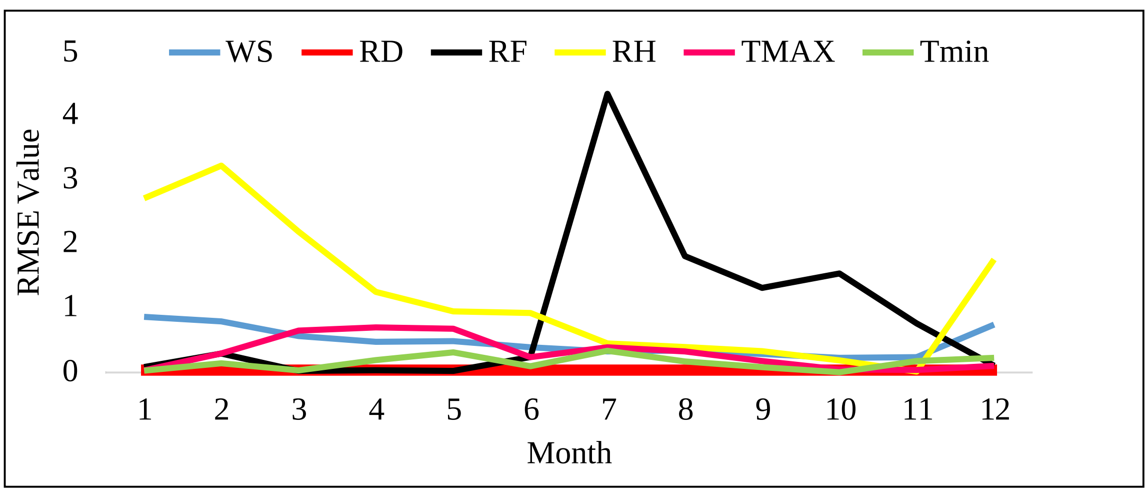


Fig.4.6. RMSE Value of weather parameters

4.7.2. Future climate data of Vellanikkara station during the crop period

The future climate during various phenophase were presented in Table 25-28.

Table 4.25. Future climate of the phenophase planting to 50% sprouting

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of Century	Near century	Mid century	End of century
D1	Maran	SRAD	14.5	18.6	18.6	19.5	20.0	20.0	19.4
		Tmax	32.2	31.4	31.4	31.5	31.3	31.6	31.9
		Tmin	24.3	25.2	25.2	25.4	24.8	25.6	26.6
		RF	406.1	295.4	295.4	251.8	200.4	206.7	253.2
		RD	25	22	26	22	23	22	25
		RH	83.1	81.6	81.6	81.3	81.6	82.0	81.6
		WS	1.7	2.0	2.0	2.0	2.0	1.9	1.9
	Varada	SRAD	14.6	19.5	18.7	19.8	20.2	20.2	19.7
		Tmax	32.4	31.3	31.4	31.5	31.4	31.6	31.9
		Tmin	24.3	24.8	25.2	25.4	24.8	25.6	26.5
		RF	373.0	200.0	265.4	217.6	172.3	183.2	217.8
		RD	22.0	18.0	22.0	19.0	19	19	20
		RH	83.1	81.6	81.6	81.2	81.5	81.9	81.6
		WS	1.8	2.0	2.0	2.0	2.0	1.9	1.9
D2	Maran	SRAD	13.0	17.6	16.6	18.7	18.5	18.5	17.7
		Tmax	31.3	31.3	31.4	31.5	31.3	31.6	31.9
		Tmin	23.8	24.9	25.2	25.4	25.0	25.7	26.7
		RF	263.5	137.0	181.3	143.9	109.1	122.4	153.0
		RD	15.0	12.0	15.0	10.0	12	12	14
		RH	85.5	82.0	82.0	81.4	81.9	82.6	82.2
		WS	1.5	2.1	2.1	2.1	2.0	2.0	2.0

(D1: 15^{th} May; D2: 1^{st} June; D3: 15^{th} June; D4: 1^{st} July, Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.25. Future climate of the phenophase planting to 50% sprouting (Contd.)

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
D2	Varada	SRAD	12.7	17.6	16.7	19.0	18.5	18.6	17.8
		Tmax	31.3	31.3	31.4	31.5	31.3	31.6	31.9
		Tmin	23.8	24.9	25.2	25.4	25.0	25.7	26.6
		RF	250.6	120.2	156.7	123.4	100.6	110.2	134.1
		RD	13	11.0	13.0	10.0	11	11	12
		RH	85.2	82.0	82.1	81.3	82.0	82.6	82.2
		WS	1.6	2	2.1	2.1	2	2	2
D3	Maran	SRAD	12.4	17.6	17.2	17.5	18.0	17.7	17.6
		Tmax	31.0	31.3	31.4	31.5	31.3	31.5	31.8
		Tmin	23.4	24.9	25.3	25.5	25.1	25.8	26.8
		RF	291.5	114.8	150.1	151.0	107.4	108.9	141.2
		RD	14.0	12	11.0	12.0	13	11	12
		RH	84.8	82.0	81.6	81.8	81.5	82.1	82.0
		WS	0.8	2.1	2.2	2.1	2.0	2.0	2.0
	Varada	SRAD	11.8	17.6	17.3	17.4	18.2	17.7	17.8
		Tmax	30.7	31.3	31.4	31.5	31.3	31.5	31.8
		Tmin	23.4	24.9	25.3	25.5	25.1	25.8	26.8
		RF	85.7	136.7	171.2	168.9	124.3	126.7	155.5
		RD	366.2	12.0	13.0	12.0	12	11	13
		RH	17.0	82.1	81.7	81.7	81.6	82.1	81.9
		WS	0.8	2.1	2.2	2.1	2.0	2.0	2.0

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July Obs: Observed data (2020-2021); NearCentury (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.25. Future climate of the phenophase planting to 50% sprouting (Contd.)

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of Century
D4	Maran	SRAD	10.4	16.7	16.2	17.6	18.3	17.9	18.4
		Tmax	30.3	31.2	31.3	31.4	31.3	31.5	31.8
		Tmin	23.1	24.9	25.4	25.6	25.2	25.8	26.9
		RF	311.0	138.0	173.2	116.2	92.4	98.8	101.6
		RD	13.0	11.0	11.0	9.0	9	10	10
		RH	88.2	82.0	81.7	81.5	81.5	82.0	81.9
		WS	1.0	2.2	2.3	2.1	2.1	2.1	2.0
	Varada	SRAD	12.6	16.4	16.0	17.3	18.4	17.9	18.5
		Tmax	30.2	31.2	31.4	31.4	31.3	31.5	31.8
		Tmin	23.1	24.9	25.4	25.6	25.2	25.8	26.9
		RF	321.5	168.8	197.3	144.4	102.2	111.7	111.2
		RD	14.0	14.0	13.0	12.0	11	12	11
		RH	88.0	82.0	81.7	81.6	81.6	82.0	81.8
		WS	1.0	2.2	2.3	2.2	2.1	2.1	2.0

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July, Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.26. Future climate of the phenophase 50% sprouting to active tillering

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
D1	Maran	SRAD	11.9	16.2	16.2	19.5	18.3	17.7	18.3
		Tmax	30.5	31.2	31.3	31.5	31.2	31.5	31.8
		Tmin	23.1	25.0	25.4	25.4	25.1	25.8	26.9
		RF	706.5	303.2	339.8	251.8	192.0	201.1	215.9
		RD	23.0	23	23	19.0	18	12	20
		RH	86.40	82.0	81.6	81.3	81.7	81.9	81.8
		WS	1.2	2.3	2.4	2.0	2.1	2.1	2.1
	Varada	SRAD	12.1	16.4	16.3	17.1	18.3	17.8	18.2
		Tmax	30.1	31.2	31.3	31.4	31.2	31.5	31.8
		Tmin	23.1	24.9	25.4	25.5	25.1	25.8	26.9
		RF	792.3	342.2	387.4	346.5	234.1	233.3	266.0
		RD	27.0	26.0	26.0	23.0	18	12	20
		RH	86.20	82.0	81.6	81.6	81.8	82.0	81.7
		WS	1.1	2.2	2.3	2.2	2.1	2.1	2.1
D2	Maran	SRAD	11.6	16.5	16.3	17.0	18.4	17.7	18.3
		Tmax	30.1	31.2	31.3	31.4	31.2	31.4	31.8
		Tmin	23.1	24.9	25.4	25.5	25.0	25.8	26.8
		RF	87.4	461.3	514.1	475.1	301.2	312.3	332.3
		RD	1286.3	34.0	32.0	32.0	28	30	30
		RH	39.0	82.0	81.7	81.6	81.8	82.0	81.8
		WS	1.3	2.3	2.3	2.2	2.1	2.1	2.1

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July, Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.26. Future climate of the phenophase 50% sprouting to active tillering (Contd.)

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
	Varada	SRAD	11.70	16.6	16.3	17.0	18.4	17.7	18.2
		Tmax	30.4	31.2	31.3	31.4	31.2	31.4	31.8
		Tmin	23.1	24.9	25.4	25.5	25.1	25.8	26.8
		RF	1300.2	615.1	720.0	639.5	418.8	446.9	504.2
		RD	41.0	40.0	41.0	34.0	32	33	33
		RH	87.50	82.0	81.7	81.6	81.7	82.0	81.8
		WS	1.3	2.3	2.3	2.2	2.1	2.1	2.1
D3	Maran	SRAD	13.2	16.0	16.0	16.9	18.4	18.0	18.5
		Tmax	30.4	31.2	31.3	31.3	31.2	31.4	31.7
		Tmin	23.1	24.8	25.2	25.4	25.0	25.7	26.8
		RF	1125.4	601.0	661.8	546.4	341.1	334.2	376.2
		RD	36.0	41.0	41.0	35.0	31	31	32
		RH	86.30	82.1	81.9	81.6	81.8	82.1	81.8
		WS	1.5	2.4	2.4	2.3	2.1	2.1	2.1
	Varada	SRAD	13.40	15.9	15.9	16.9	18.3	17.9	18.4
		Tmax	30.4	31.2	31.3	31.3	31.2	31.4	31.7
		Tmin	23.1	24.8	25.2	25.4	25.0	25.7	26.8
		RF	1040.5	565.4	621.6	513.7	316.7	306.8	353.1
		RD	32.0	41.0	40.0	35.0	30	31	31
		RH	86.00	82.0	81.9	81.6	81.8	82.1	81.7
		WS	1.5	2.4	2.4	2.3	2.1	2.1	2.1

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July, Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.26. Future climate of the phenophase 50% sprouting to active tillering (Contd.)

Date of planting	Variety	Weather parameter	Observed	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
D4	Maran	SRAD	13.5	16.9	16.9	17.2	19.2	18.4	19.2
		Tmax	30.2	31.1	31.2	31.3	31.1	31.3	31.7
		Tmin	22.8	24.6	25.1	25.2	24.7	25.5	26.6
		RF	1429.1	625.1	713.7	621.3	376.2	362.9	386.3
		RD	44.0	46.0	45.0	40.0	34	34	33
		RH	86.75	82.2	82.0	81.8	81.4	82.2	81.8
		WS	16.5	2.3	2.3	2.3	2.1	2.1	2.0
	Varada	SRAD	12.7	17.0	16.9	17.2	19.2	18.4	19.2
		Tmax	30.2	31.1	31.2	31.3	31.1	31.3	31.7
		Tmin	22.8	24.6	25.1	25.2	24.7	25.5	26.6
		RF	1418.6	625.1	713.7	621.3	376.2	362.9	386.3
		RD	43.0	43.0	44.0	38.0	32	32	33
		RH	86.77	82.2	82.0	81.8	81.4	82.2	81.8
		WS	1.6	2.3	2.3	2.3	2.1	2.1	2.0

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July, Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.27. Future climate of the phenophase active tillering to bulking

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
D1	Maran	SRAD	13.7	17.4	17.3	17.6	19.4	18.7	19.5
		Tmax	30.1	31.1	31.2	31.3	31.1	31.3	31.7
		Tmin	22.7	24.5	24.9	25.1	24.6	25.4	26.5
		RF	1149.7	476.4	566.3	457.6	291.5	274.5	292.3
		RD	37.0	34	35	33	27	27	26
		RH	86.9	82.2	82.1	81.8	81.2	82.2	81.8
		WS	1.6	2.2	2.3	2.2	2.1	2.1	2.0
	Varada	SRAD	14.4	18.0	17.7	18.1	19.9	19.0	19.7
		Tmax	30.3	31.1	31.2	31.3	31.1	31.3	31.6
		Tmin	22.6	24.4	24.9	25.0	24.5	25.4	26.4
		RF	1097.6	480.1	571.9	456.4	287.5	274.7	295.6
		RD	36.0	35.0	35.0	33.0	27	27	26
		RH	86.3	81.9	82.1	81.8	81.0	82.1	81.8
		WS	1.6	2.2	2.2	2.2	2.1	2.1	2.0
D2	Maran	SRAD	15.4	19.6	19.0	19.7	21.3	20.4	20.7
		Tmax	30.5	31.2	31.2	31.3	31.2	31.4	31.7
		Tmin	22.3	24.3	24.7	24.8	24.3	25.2	26.3
		RF	1015.3	397.1	509.6	359.6	238.2	221.9	261.7
		RD	37.0	31.0	32.0	26.0	22	22	23
		RH	84.9	80.8	81.4	80.8	79.5	81.1	81.0
		WS	1.5	2.2	2.2	2.2	2.2	2.1	2.0

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.27. Future climate of the phenophase active tillering to bulking (Contd.)

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
	Varada	SRAD	15.5	19.5	18.9	19.7	21.3	20.4	20.7
		Tmax	30.5	31.2	31.2	31.3	31.2	31.4	31.7
		Tmin	22.2	24.3	24.7	24.8	24.3	25.2	26.3
		RF	1014.3	396.3	508.6	359.4	237.9	220.9	261.0
		RD	37.0	27.0	30.0	24.0	19	20	22
		RH	84.8	80.9	81.4	80.8	79.6	81.2	81.1
		WS	1.5	2.2	2.2	2.2	2.1	2.1	2.0
D3	Maran	SRAD	15.3	21.3	20.7	21.4	22.8	21.7	22.1
		Tmax	30.8	31.5	31.4	31.6	31.5	31.6	31.9
		Tmin	22.0	24.3	24.7	24.7	24.2	25.1	26.2
		RF	1003.8	158.7	198.3	141.1	98.6	94.8	91.5
		RD	33.0	19.0	22.0	16.0	11	14	15
		RH	84.2	79.0	79.7	78.9	77.4	79.2	79.3
		WS	1.6	2.4	2.3	2.3	2.4	2.2	2.1
	Varada	SRAD	15.4	20.8	20.0	20.7	22.2	21.2	21.5
		Tmax	30.9	31.4	31.4	31.5	31.4	31.6	31.8
		Tmin	22	24.3	24.7	24.8	24.2	25.1	26.2
		RF	1014.0	223.8	317.8	225.9	149.6	151.0	154.7
		RD	34.0	19	23	16	13	15	15
		RH	83.9	79.6	80.2	79.5	78.0	79.7	79.8
		WS	1.7	2.4	2.3	2.3	2.3	2.2	2.1

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.27. Future climate of the phenophase active tillering to bulking (Contd.)

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				Near century	Mid century	End of century	Near century	Mid century	End of century
D4	Maran	SRAD	17.3	21.4	20.6	21.9	22.6	21.9	21.8
		Tmax	31.9	31.8	31.7	31.9	31.8	31.9	32.2
		Tmin	21.7	24.4	24.7	24.9	24.3	25.2	26.3
		RF	453.9	90.1	123.5	62.4	45.2	41.9	69.4
		RD	16	9.0	12.0	5.0	4	5	7
		RH	77	77.1	77.6	76.8	75.7	76.9	77.4
		WS	2.7	2.8	2.7	2.7	2.8	2.6	2.5
	Varada	SRAD	17.3	21.4	20.6	21.9	22.6	21.9	21.8
		Tmax	31.9	31.8	31.7	31.9	31.8	31.9	32.2
		Tmin	21.7	24.4	24.7	24.9	24.3	25.2	26.3
		RF	453.9	90.1	123.5	62.4	45.2	41.9	69.4
		RD	16	8.0	12.0	5.0	4	5	6
		RH	77	77.1	77.6	76.8	75.7	76.9	77.4
		WS	2.7	2.8	2.7	2.7	2.8	2.6	2.5

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.28. Future climate of the bulking to physiological maturity

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)	2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)
D1	Maran	SRAD	16.9	20.7	19.8	21.3	20.9	20.8	20.8
		Tmax	32.0	31.9	31.9	32.1	32.3	32.6	32.9
		Tmin	21.9	24.3	24.7	24.8	23.8	24.7	25.9
		RF	426.2	124.5	171.8	87.8	21.6	22.8	24.9
		RD	14.0	11	16	7	6	5	7
		RH	73.7	76.3	76.8	75.9	73.2	72.5	72.8
		WS	3.8	3.1	3.0	3.0	4.0	3.8	4.0
	Varada	SRAD	16.7	20.6	19.8	21.3	21.6	21.4	21.2
		Tmax	32.1	32.0	31.9	32.2	32.0	32.2	32.5
		Tmin	21.8	24.4	24.7	24.9	24.3	25.2	26.4
		RF	425.6	103.7	143.8	73.9	50.5	44.4	54.4
		RD	14.0	10.0	14.0	7.0	5	5	6
		RH	73.70	76.0	76.4	75.4	74.7	75.3	75.9
		WS	3.8	3.2	3.1	3.1	3.2	3.0	3.0
D2	Maran	SRAD	17.1	19.6	19.1	20.5	20.6	20.6	20.5
		Tmax	32.7	32.2	32.2	32.4	32.2	32.4	32.7
		Tmin	22.0	24.4	24.8	25.0	24.5	25.3	26.5
		RF	63.8	80.1	98.5	54.6	41.9	31.2	35.4
		RD	3.0	7.0	10.0	5.0	4	4	4
		RH	69.8	75.2	75.3	74.5	74.3	74.0	74.8
		WS	4.6	3.5	3.5	3.5	3.5	3.4	3.4

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.28. Future climate of the bulking to physiological maturity (Contd.)

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)	2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)
D2	Varada	SRAD	16.8	19.6	19.1	20.6	20.5	20.6	20.5
		Tmax	32.7	32.2	32.2	32.4	32.2	32.4	32.7
		Tmin	22.0	24.4	24.8	25.0	24.5	25.3	26.5
		RF	63.8	80.3	97.9	54.6	42.0	31.5	35.5
		RD	3.0	7.0	11.0	5.0	4	3	4
		RH	69.63	75.2	75.3	74.4	74.2	74.1	74.8
		WS	4.7	3.5	3.5	3.5	3.5	3.4	3.4
D3	Maran	SRAD	16.8	19.2	18.5	20.0	20.2	20.3	20.1
		Tmax	32.4	32.2	32.1	32.4	32.3	32.5	32.8
		Tmin	21.8	24.3	24.6	24.8	24.3	25.1	26.3
		RF	17.0	81.8	111.7	63.0	36.4	31.0	35.7
		RD	2.0	7.0	10.0	5.0	3	3	3
		RH	66.1	75.0	75.2	74.0	73.9	73.4	74.2
		WS	6.0	3.6	3.5	3.7	3.8	3.6	3.7
	Varada	SRAD	16.8	19.2	18.5	20.0	20.2	20.3	20.1
		Tmax	32.3	32.2	32.1	32.4	32.3	32.5	32.8
		Tmin	21.9	24.3	24.6	24.8	24.3	25.1	26.3
		RF	17.0	81.8	111.7	63.0	36.4	31.0	35.7
		RD	2.0	7	10	5	3	3	3
		RH	66.05	75.0	75.2	74.0	73.9	73.4	74.2
		WS	6.0	3.6	3.5	3.7	3.8	3.6	3.7

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

Table 4.28. Future climate of the bulking to physiological maturity (Contd.)

Date of planting	Variety	Weather parameter	2020-2021	RCP 4.5			RCP 8.5		
				2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)	2010-2039 (NC)	2040-2069 (MC)	2070-2099 (LC)
D4	Maran	SRAD	16.4	20.4	19.7	20.8	20.9	20.8	20.8
		Tmax	31.9	32.3	32.2	32.6	32.3	32.6	32.9
		Tmin	22.0	24.0	24.4	24.7	23.8	24.7	25.9
		RF	53.1	57.5	83.4	43.9	21.6	22.8	24.9
		RD	2.0	4.0	8.0	3.0	2	2	2
		RH	65.7	73.3	73.9	73.0	73.2	72.5	72.8
		WS	6.8	3.9	3.8	3.9	4.0	3.8	4.0
	Varada	SRAD	16.5	20.4	19.7	20.8	20.9	20.8	20.8
		Tmax	31.9	32.3	32.2	32.6	32.3	32.6	32.9
		Tmin	22.0	24.0	24.4	24.7	23.8	24.7	25.9
		RF	53.1	57.5	83.4	43.9	21.6	22.8	24.9
		RD	2.0	4.0	7.0	3.0	2	4	2
		RH	65.8	73.3	73.9	73.0	73.2	72.5	72.8
		WS	6.7	3.9	3.8	3.9	4.0	3.8	4.0

(D1: 15th May; D2: 1st June; D3: 15th June; D4: 1st July; Observed data (2020-2021); Near Century (2010-2039); Mid Century (2040-2069); End of Century (2070-2099))

4.7.2. Projected ginger productivity (kg/ha) for *Maran* under RCP 4.5 scenario

In the variety *Maran* all the four planting dates except July 1st date of planting showed decrease in yield in the future climate change scenario of RCP 4.5. The observed yield in base period was 33293.8 Kg ha^{-1} in May 15th planted crop. It was reduced to 20762.9 Kg ha^{-1} in near century, 23057.8 Kg ha^{-1} in midcentury and 20648.8 Kg ha^{-1} in end of century. The base yield in June 1st date of planting was 22704.3 Kg ha^{-1}, it was further reduced to 17319.7 Kg ha^{-1}, 19360.1 Kg ha^{-1} and 16128.8 Kg ha^{-1}in near, mid and end of century. The observed yield in June 15th planting period was 22687.2 Kg ha^{-1}, which was reduced to 10441.4 Kg ha^{-1} in near century, 10926.0 Kg ha^{-1} in midcentury and 10324.8 in end of century. July 1st planted crop showed increased yield of 8402.7 kg ha^{-1} in near century, 9026.7 kg ha^{-1} in midcentury and 7674.3 kg ha^{-1}in end of century, from the base yield of 7663.5 Kg ha^{-1} (Table. 4.29).

4.7.3. Percent Relative Difference (R.D%) of ginger productivity for *Maran* under RCP4.5 scenario

Among the four dates of planting, all planting dates except July 1st showed decrease in yield under all the three time slices. On May 15th date of planting, projected yield reduction was 37.6% in near, 30.7% in mid and 38 in end of the century. On June 1st date of planting, end of century recorded more percentage of yield reduction, *ie.,* 29% followed by near century (23.7%) and midcentury (14.7%). On June 15th date of planting, yield reduction of 54% was observed in near century, 51.8% in midcentury and 54.5% in end of century. A percentage increase of 9.6 was observed in near century, 17.7% in midcentury and 0.14% in endof century (Table. 4.29).

4.7.4. Projected ginger productivity (kg/ha) for *Maran* under RCP 8.5 scenario

In the future climate change scenario RCP 8.5, all four planting dates, showed a decrease in yield in the variety *Maran*. The observed yield in base period was 33293.8 Kg ha^{-1} in May 15thplanted crop. It was reduced to 16964.0 Kg ha^{-1} in near century, 16594.2 Kg ha^{-1} in midcentury and 17030.9 Kg ha^{-1} in end of century. The base yield in June 1st date of planting was 22704.3 Kg ha^{-1}, it was further reduced to 18307.5 Kg ha^{-1}, 18105.8 Kg ha^{-1} and 19372.4 Kg ha^{-1} in near, midand end of century. The observed yield in June 15th planting period was 22687.2 Kg ha^{-1}, which was reduced to 11097.0 Kg ha^{-1} in near century, 11203.5 Kg ha^{-1} in midcentury and 10746.6 Kg ha^{-1} in end of century. July 1st planted crop showed an increased yield of 9249.3 Kg ha^{-1} in near century, 9417.3 Kg ha^{-1} in midcentury and 9943.8 Kg ha^{-1} in end of century, from the base yield of 7663.5 Kg ha^{-1} (Table. 4.30).

4.7.5. Percent Relative Difference (R.D. %) of ginger productivity for *Maran* under RCP 8.5 scenario

All four planting dates, with the exception of July 1st, showed a decrease in yield across all three time slices. The highest percentage of yield decrease from the base period in the May 15thplanted crop (50.2%) was seen in midcentury followed by near century (49.0%) and end of century (48.8%). On June 1st planting, yield decrease of 19.4% was observed in near century, 20.3% in midcentury and 14.7% in end of century. On June 15th planting, end of century recorded the highest percent decrease in yield (52.6%) followed by near century (51.1%) and midcentury (50.6%). Percentage yield increase was observed on July 1st planted crops. Highest percent yield increase was observed in end of century (29.7%), followed by midcentury (22.8%) and near century (20.6%) (Table. 4.30).

4.7.6. Projected ginger productivity (kg ha^{-1}) for *Varada* under RCP 4.5 scenario

All the four planting dates except July 1st panted crop showed decrease in yield of *Varada* variety of ginger in the future climate change scenario of RCP 4.5. The observed yield in base period was 33111.0 Kg ha^{-1} in May 15th planted crop. It was reduced to 25835.7 Kg ha^{-1} in near century, 27384.0 Kg ha^{-1} in midcentury and 25152.9 Kg ha^{-1} in end of century. The base yield in June 1st date of planting was 19273.6 Kg ha^{-1}, it was further reduced to 19082.6 Kg ha^{-1}, 18963.4 Kg ha^{-1} and 17892.9 Kg ha^{-1}in near, mid and end of century. The observed yield in June 15th

planting period was 22658.4 Kg ha^{-1}, which was reduced to 17020.2 Kg ha^{-1} in near

Table 4.29. Percent deviation in yield from the observed value in *Maran* under RCP 4.5 scenario

Observed		**D1**	**D2**	**D3**	**D4**
		33293.8	22704.3	22687.2	7663.5
Near Century (2010-2039)	Predicted	20762.9	17319.7	10441.4	8402.7
	% Change	-37.6	-23.7	-54.0	9.6
Mid century (2040-2069)	Predicted	23057.8	19360.1	10926.0	9026.7
	% Change	-30.7	-14.7	-51.8	17.7
End of century (2070-2099)	Predicted	20648.8	16128.8	10324.8	7674.3
	% Change	-38.0	-29.0	-54.5	0.14

Table 4.30. Percent deviation in yield from the observed value in *Maran* under RCP 8.5 scenario.

		D1	**D2**	**D3**	**D4**
Observed		33293.8	22704.3	22687.2	7663.5
Near Century (2010-2039)	Predicted	16964.0	18307.5	11097.0	9249.3
	% Change	-49.0	-19.4	-51.1	20.6
Mid century (2040-2069)	Predicted	16594.2	18105.8	11203.5	9417.3
	% Change	-50.2	-20.3	-50.6	22.8
End of century (2070-2099)	Predicted	17030.9	19372.4	10746.6	9943.8
	% Change	-48.8	-14.7	-52.6	29.75

century 17526.6 Kg ha^{-1} in midcentury and 17017.6 Kg ha^{-1} in end of century. In contrast to these, July 1st planted crop showed an increase in yield of 10581.5 Kg ha^{-1} in near century, 10504.1 Kg ha^{-1} in midcentury and 11024.3 Kg ha^{-1} in end of century, from the base yield of 9544.3 Kg ha^{-1} (Table.4.31).

4.7.7. Percent Relative Difference (R.D. %) of ginger productivity for *varada* RCP4.5scenario

Among the four dates of planting, all the four except July 1st showed decrease in yield under all the three time slices. In May 15th (24.0%) and June 1st (7.2%) planted crop maximum percentage of yield decrease from the base period was showed by end of century. Near and end of century showed maximum percent decrease in yield (24.9%) in June 15th planting. The July 1st date of planting reported maximum percent yield increase (15.5%) in end of century (Table. 4.31).

4.7.8. Projected ginger productivity (kg/ha) for *Varada* under RCP 8.5 scenario

In the future climate change scenario RCP 8.5, all four planting dates, except July 1st, showed a decrease in yield in the variety *Varada*. The observed yield in base period was 33111.0Kg ha^{-1} in May 15th planted crop. It was reduced to 23736.7 Kg ha^{-1} in near century, 23590.3 Kg ha^{-1} in midcentury and 23719.7 Kg ha^{-1} in end of century. The base yield in June 1st date of planting was 19273.6 Kg ha^{-1}, it was further reduced to 19320.9 Kg ha^{-1}, 18479.0 Kg ha^{-1} and 17999.2 Kg ha^{-1} in near, mid and end of century. The observed yield in June 15th planting period was 22658.4Kg ha^{-1}, which was reduced to 18952.0 Kg ha^{-1} in near century, 19060.4 Kg ha^{-1} in midcentury and 18153.0 Kg ha^{-1} in end of century. In contrast to these, July 1st planted crop showed an increase in yield of 11223.2 kg ha^{-1} in near century, 11320.0 kg ha^{-1} in midcentury and 11833.3 kg ha^{-1} in end of century (Table. 4.32).

Table 4.31. Percent deviation in yield from the observed value in *Varada* under RCP 4.5 scenario

Observed		**D1**	**D2**	**D3**	**D4**
		33111.0	19273.6	22658.4	9544.3
Near Century (2010-2039)	Predicted	25835.7	19082.6	17020.2	10581.5
	% Change	-22.0	-1.0	-24.9	10.9
Midcentury (2040-2069)	Predicted	27384.0	18963.4	17526.6	10504.1
	% Change	-17.3	-1.6	-22.6	10.1
End of century (2070-2099)	Predicted	25152.9	17892.9	17017.6	11024.3
	% Change	-24.0	-7.2	-24.9	15.5

Table 4.32. Percent deviation in yield from the observed value in *Varada* under RCP 8.5 scenario

Observed		**D1**	**D2**	**D3**	**D4**
		33111.0	19273.6	22658.4	9544.3
Near Century (2010-2039)	Predicted	23736.7	19320.9	18952.0	11223.2
	% Change	-28.3	0.2	-16.4	17.6
Midcentury (2040-2069)	Predicted	23590.3	18479.0	19060.4	11320.0
	% Change	-28.8	-4.1	-15.9	18.6
End of century (2070-2099)	Predicted	23719.7	17999.2	18153.0	11833.3
	% Change	-28.4	-6.6	-19.9	24.0

4.7.9. Per cent Relative Difference (R.D. %) of ginger productivity for *Varada* RCP 8.5 scenario

All four planting dates, with the exception of July 1st, showed a decrease in yield across all three time slices. The maximum percentage of yield decrease from the base period in the May 15th planted crop (28.8%) was seen in midcentury. In June 1st planting, the maximum yield decrease (6.6%) was observed in end of century. In June 15th planting, end of century showed thehighest percent decrease in yield (19.9%). The maximum percent yield increase was reported in July 1st planting was at end of century (24.0 %) (Table. 4.32).

Discussion

5. DISCUSSION

The experiment "Ginger (*Zingiber* officinale) yield variability under different climate changescenarios" was aimed at studying the phenology and climate change impact of two ginger varieties *ie*., *Maran* and *Varada* have grown under different dates of planting. The phenology, yield and climate change impact were studied andthe results obtained from the experiments are discussed in this chapter.

5.1 EFFECT OF WEATHER ON PHENOLOGY OF GINGER

Phenology is the study of the relationship between various environmental physical factors and seasonal changes in plant growth and development during their life cycles (Newmann and Beard, 1962). Temperature and light are the major factors influencing the phenological responses of plants (Hodges, 1990). The results of the study showed that most of the weather parameters have a significant influenceon the phenology, growth and yield of ginger.

The study revealed that the maximum and minimum temperatures have a positive influence on the number of days taken from sowing to germination. The highest maximum and minimum temperature were experienced on the May 15th planted crop and more days for germination were taken by the same. Subsequent plantings received low maximum and minimum temperatures and the time taken for germination was also less in these plantings (Fig.5.1). The findings are in good agreement with that of Kandiannan and Chandragiri (2008). According to them, thermal accumulation, which is directly proportional to both maximum and minimum temperatures, is directly correlated to the germination of turmeric. The thermal time required for 50% germination was higher on the May 15th planted crop. Whereas it was less in the subsequent plantings of June 15th and July 15th.

A study by Kandiannan *et al*. (2010) also reported that ginger crop planted on 30th April and 15th May took 27 and 23 days respectively for germination, whereas it was reduced to 17 and 12 days respectively on May 30th and June 15th planting dates. The number of days taken for germination was influenced by rainfall and soil temperature also. In the initial days of planting the soil temperature at 5 cm depth

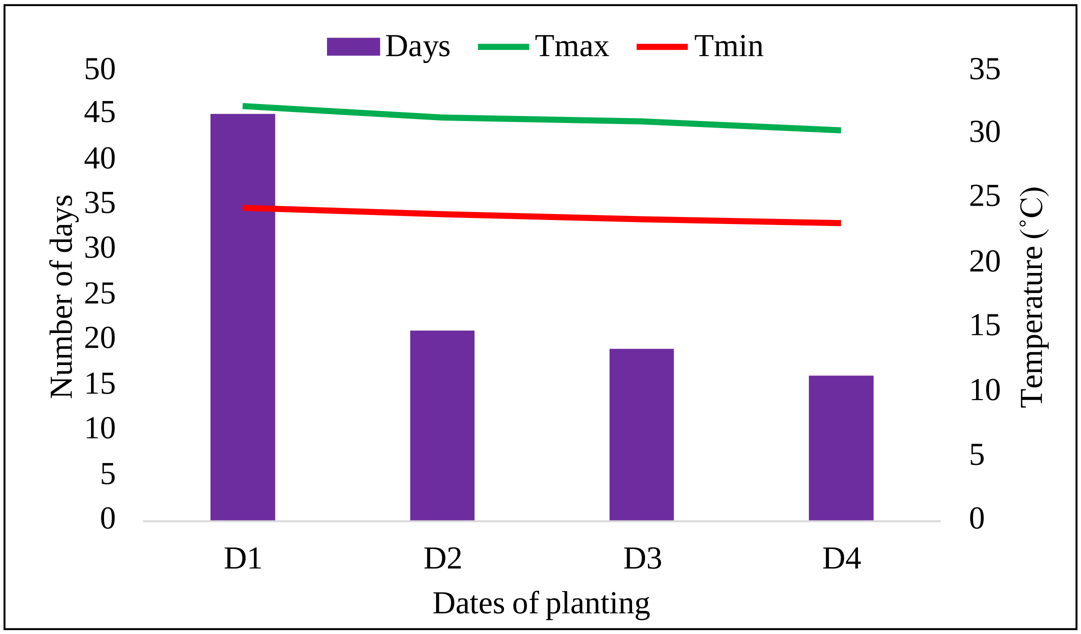


Fig. 5.1 Effect of maximum and minimum temperature on germination of ginger

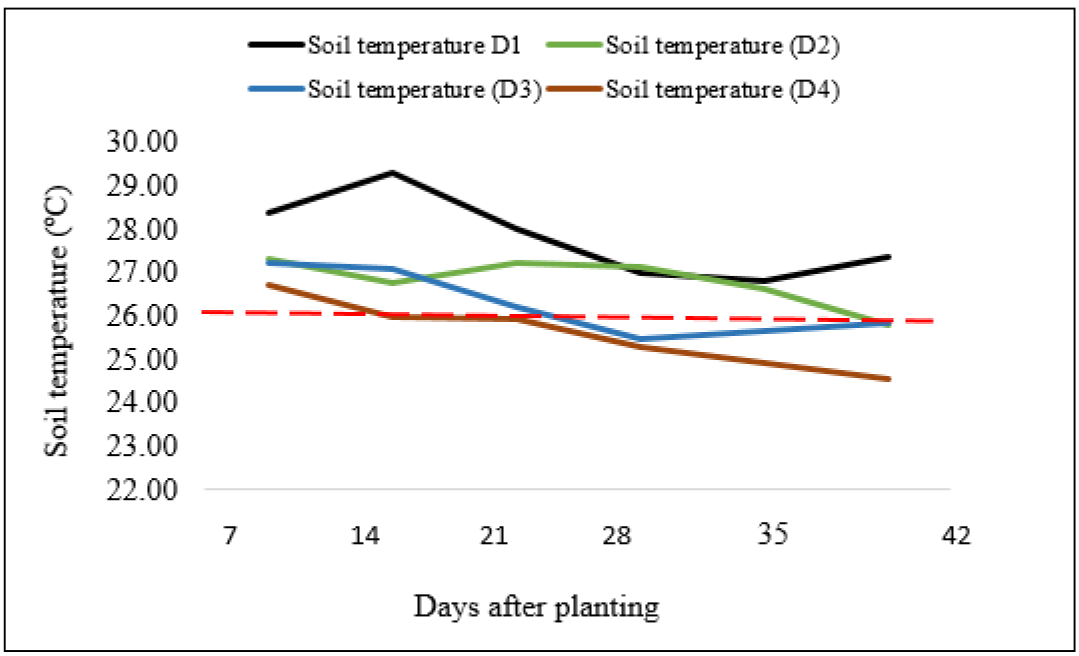


Fig.5.2. Effect of soil temperature at 5 cm depth on germination of ginger

was more on the May 15th planted crop. The soil temperature was reduced in the subsequent plantings (Fig. 5.2). It was observed that the germination took place when the soil temperature reached below 27˚C, and above which the germination process is very slow. This may be the reason for delayed germination in the May 15th planting. The result was justified by the study of Evenson *et al*. (1978). They reported that the soil temperature range of 25-26 ˚C is optimum for ginger germination.

The amount of rainfall received also influenced the germination process. 50% germination was observed in all dates of planting after receiving an amount of nearly 300 mm rainfall. May 15th planted crop took more days to receive this amount of rainfall when compared to other planting dates, hence the germination was delayed in May 15th planting (Fig.5.3).

The time taken for harvest was found to be more in early planted ginger crops. May 15th planted crops of both *Maran* (221) and *Varada* (217) varieties took more days to come to maturity when compared to other dates of planting (Fig.5.4). The result was justified by the findings of Kandiannan *et al.* (2010), according to them the days taken for maturity was 275, 260, 245 and 230 days in 30th April, 15th May, 30th May and June 15th planted crops, respectively. Early-planted crops stay in the field for longer and use the entire season for better growth and production than later-planted crops.

5.2. EFFECT OF WEATHER ON PLANT CHARACTERS OF GINGER

5.2.1. Number of leaves

It was observed that during the active tillering to bulking stage there was a positive correlation between the number of leaves in ginger and rainfall. More leaves were recorded on May 15th planted crops, but the least was on July 1st planted crop (Fig.5.5). These findings are in good agreement with that of Shaikh *et al* (2004). Shaikh *et al* (2004) conducted a study on the correlation between weather parameters and growth characters of ginger grown under different growing situations and found out that there is a positive correlation between rainfall and the number of leaves in ginger.

5.2.2. Leaf area

The study revealed that there was a negative correlation between wind speed and leaf area of ginger crop. The leaf area of ginger was found to increase up to 120 days on all dates of planting and a decrease in the same was observed afterward. Both *Maran* (Fig.5.6.a) and *Varada* (Fig.5.6.b) varieties showed the same effect. These findings are in agreement with that of Channappagoudar *et al*. (2013). In turmeric, they found an increase in leaf area from 60 to 120 DAP and a decrease from 180 DAP to harvest. The wind speed showed a negative correlation with that of leaf area. With the increase in wind speed at the final stages, the leaf area was found to decrease. The lowest leaf area was observed in the July 1st planted crop, where a high wind speed was observed. Plant growth was influenced by temperature and windspeed. The smaller leaf area was detected as a response to strong wind, along with the increasedaltitude gradient (Pan *et al*., 2009). According to Schymanski and Or (2016), if the plant is subjected to high wind speeds, having a smaller leaf area can help it avoid serious damage. Plant stress was caused by strong winds and cold temperatures for extended periods. Because of the higher wind speed in the highlands, leaves rolled up, reducing the amount of leaf area available for photosynthesis.

5.3. EFFECT OF DATES OF PLANTING ON YIELD OF GINGER

Among the four dates of planting yield was more in the early planted crop *ie.*, May 15th planted crop followed by June 1st dates of planting. Less yield was reported in the July 1st planted crop (Fig.5.7). These findings are in good agreement with that of Shadap *et al* (2014). Shadap *et al.* (2014) reported that planting ginger rhizome in May recorded a higher fresh yield of rhizome (17.09 t). It was closely followed by June planting (16.49 t). Kandiannan and Chandragiri (2006) reported that May 15th planted crops recorded higher yield and better quality than the delayed plantings like June 15th and July 15th. Dry recovery and curcumin content also were higher on the May 15th planted crop.

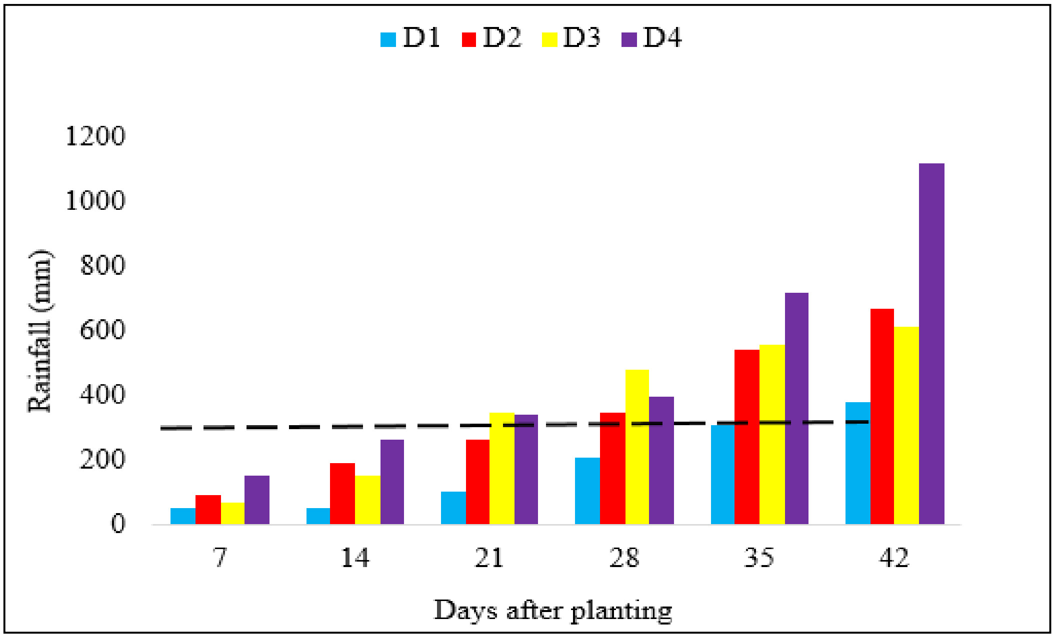


Fig.5.3. Effect of rainfall on germination of ginger

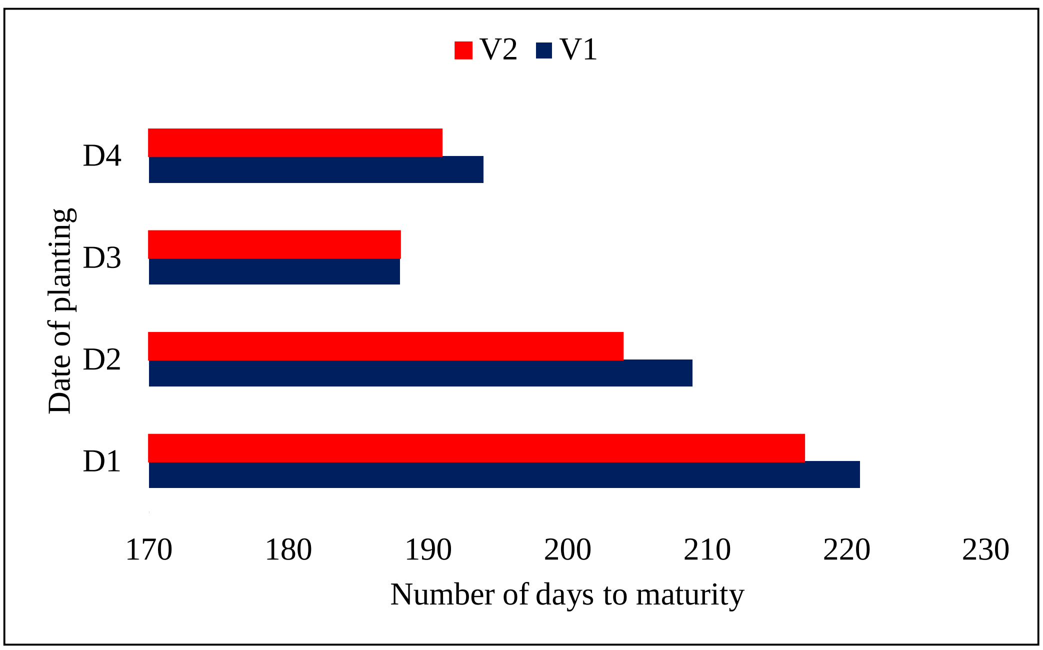


Fig.5.4. Number of days for physiological maturity taken by *Maran* (V1) and *Varada* (V2)

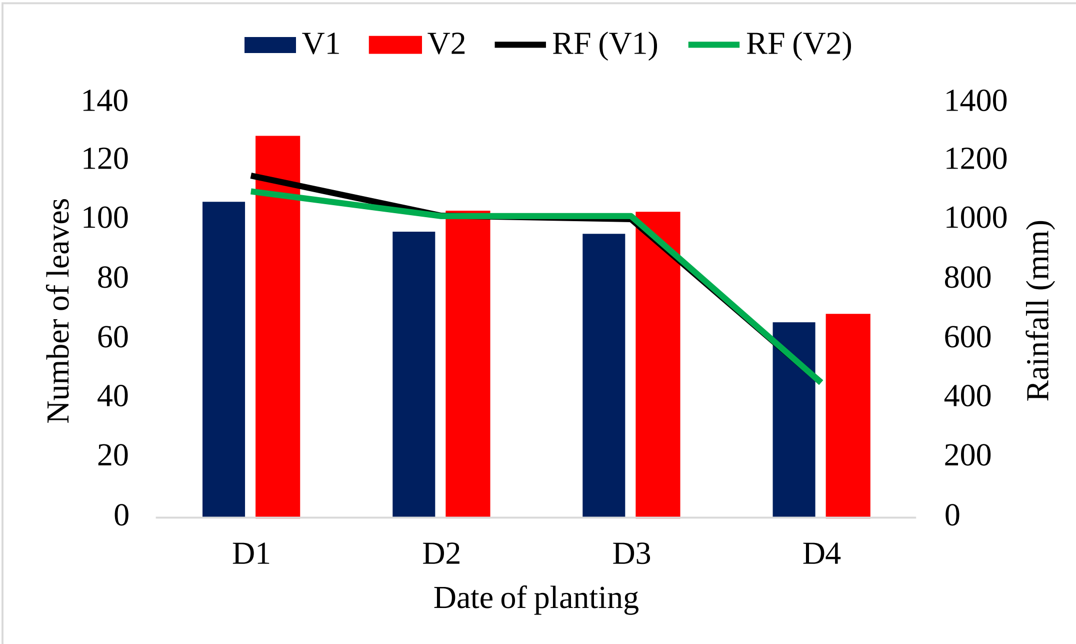


Fig. 5.5. Effect of rainfall on number leaves in *Maran* (V1) and *Varada* (V2)

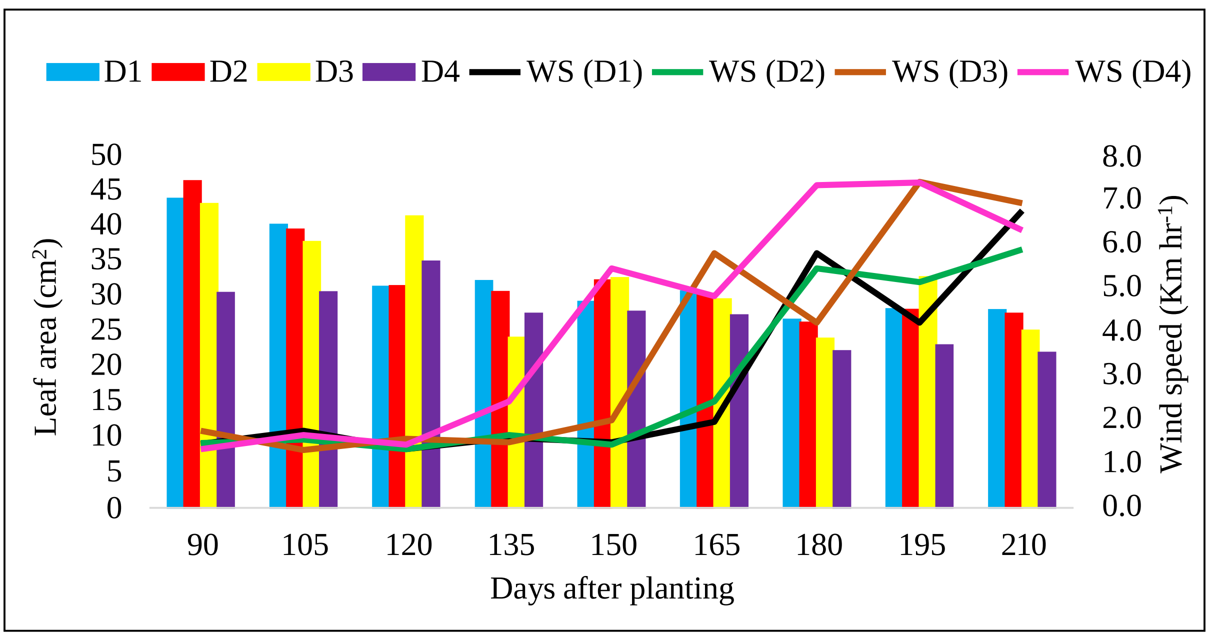


Fig.5.6.a. Effect of wind speed on leaf area in *Maran*

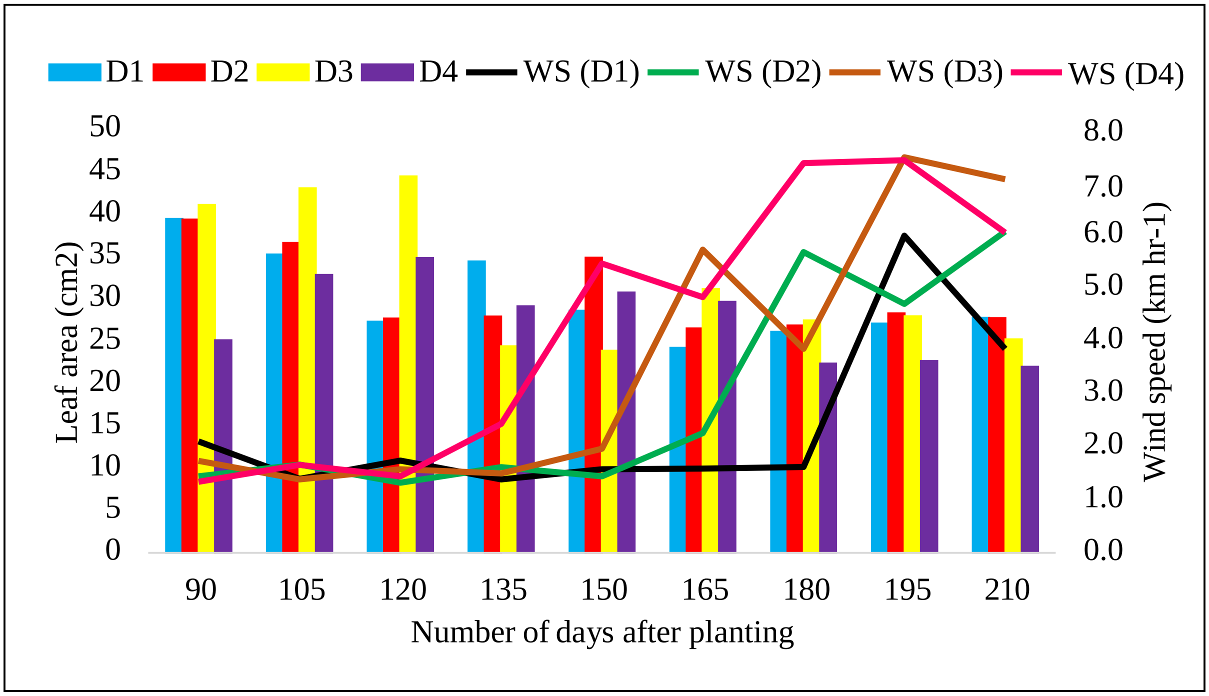


Fig.5.6.b. Effect of wind speed on leaf area in *Varada*

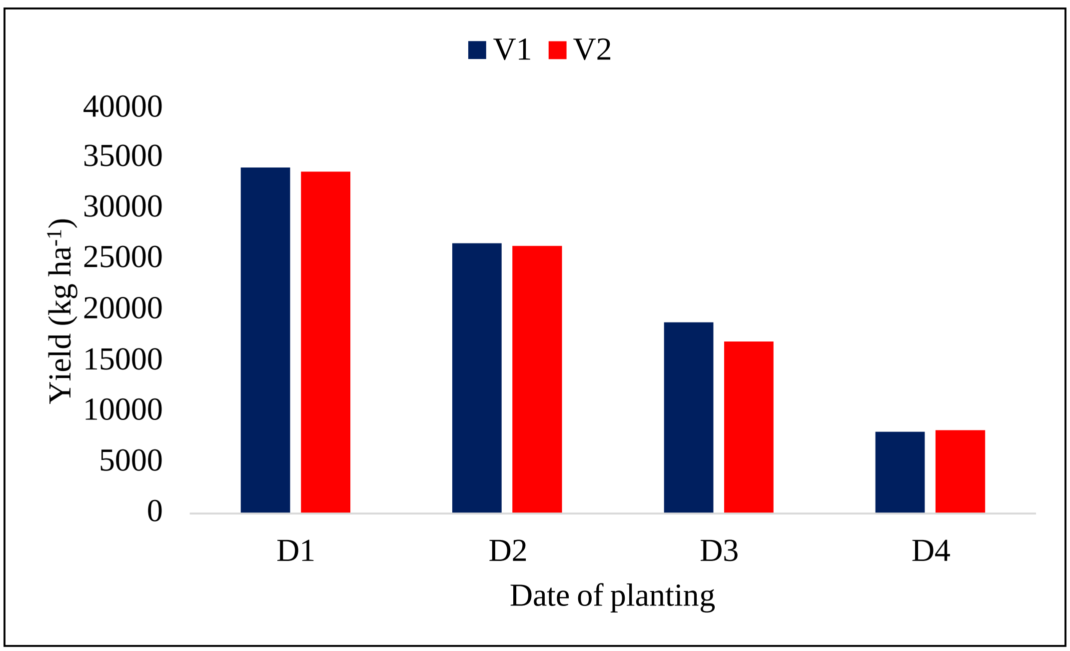


Fig.5.7. Effect of date of planting on ginger yield

The highest green ginger yield was recorded by the early (April 15th) planted crop of ginger and the lowest yield was produced by the June 15th planted crop (Yadav *et al.*, 2013). Kandiannan *et al*. (2010) reported that the highest fresh rhizome yield was recorded on the May 15th planted crop, followed by the April 30th planted crop. The lowest yield was recorded on the June 15th planted crop.

5.4. EFFECT OF WEATHER ON YIELD OF GINGER

The amount of cumulative rainfall received by the crop has a significant influence on the yield of both ginger varieties. The May 15th planted crop received heavy rainfall of 2688.5 mm in the total period of the crop, whereas it was only 2247.1mm in the July 1st planted crop (Fig.5.8). It was reported that the ginger crop islikely to grow better under a cumulative rainfall of 1500-3000 mm, distributed in 8- 10 months (CSIR, 1976). The Pearson moment correlation revealed a strong positive relationship (r= 0.606) between ginger yield and rainfall amount, which is statistically significant at the 95 percent confidence level (Abaje *et al*., 2018).

Ginger is primarily grown as a rainfed crop in Kerala. The absence of late summer showers, extremely high temperatures at the time of planting, and extremely high precipitation during the crop growth period all have an impact on the crop's growth and yield (Nybe and Shylaja, 2008).

It was found that an increase in maximum temperature has a negative effect on the yield of ginger (Table 5.1, Figure 5.9). In both varieties, the yield was found to decrease with an increase in maximum temperature. These findings are in good agreement with Murugan *et al* (2001). Murugan *et al* (2001) observed that the effect of increased temperature caused by highlight intensity under degraded/open forests exhibits a larger impact on capsule yield of cardamom than on vegetative growth. These effects were evident in an early and increased rate of senescence which reduced the ability of the crop to efficiently fill the seeds in the capsules of cardamom.

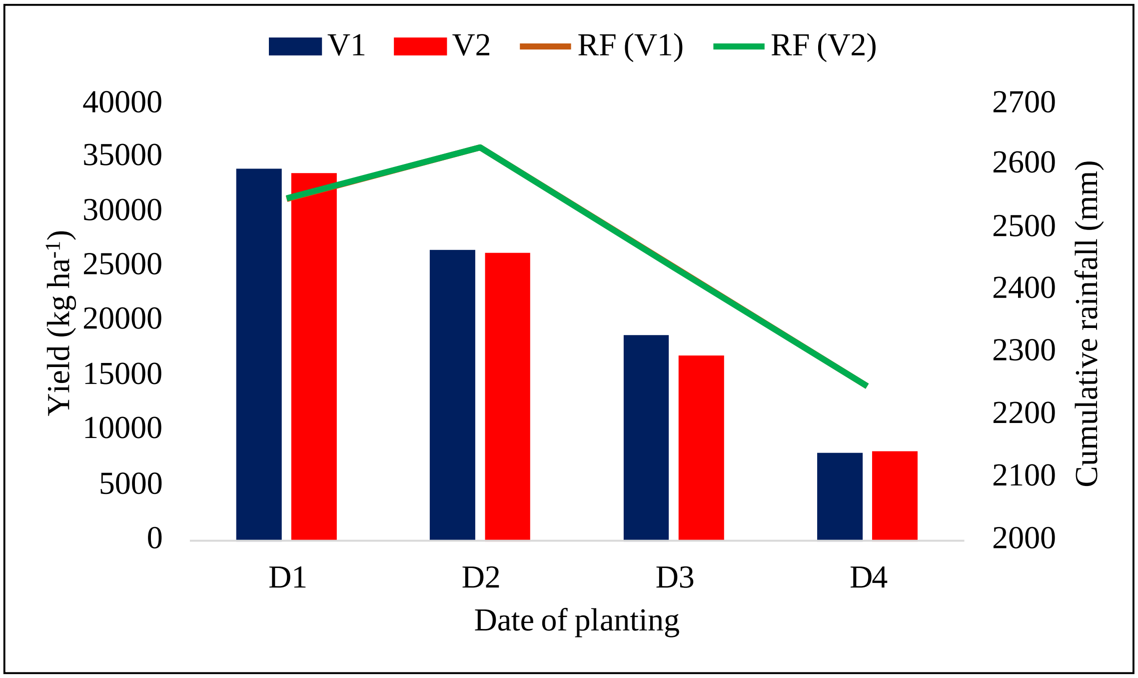


Fig.5.8. Effect of cumulative rainfall on yield of ginger

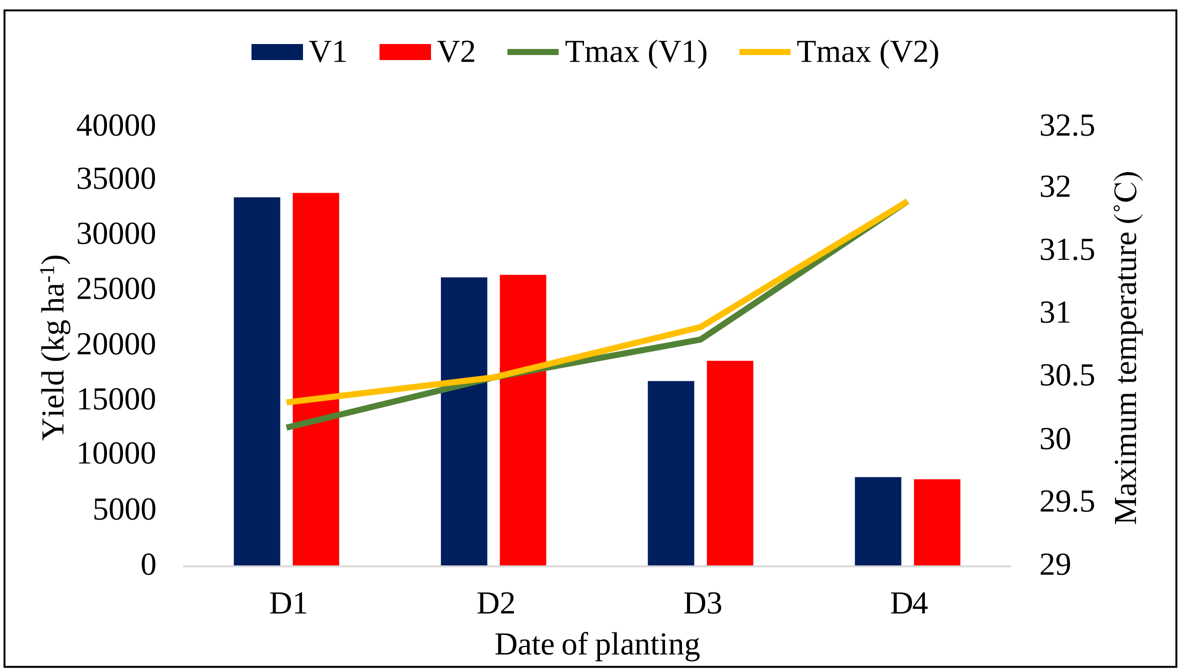


Fig.5.9. Effect of maximum temperature on yield of ginger

Table.5.1 Effect of maximum temperature on yield

Yield	Maximum temperature (°C)
Maran	-0.955**
Varada	-0.933**

There is a direct linear relationship between minimum temperature and yield of ginger. The increase in minimum temperature was found to increase the yield of ginger in the case of both *Maran* and *Varada* (Table.5.2, Fig.5.10). Singh (2008) stated that rainfall, minimum temperature and rainy days were all positively correlated with productivity in turmeric, indicating that an increase in precipitation and minimum temperatures may have a positive impact on rhizome yield.

Table.5.2. Effect of minimum temperature on yield of ginger

Yield	Minimum temperature (°C)
Maran	.967**
Varada	.965**

Soil moisture recorded at both 5 and 20 cm depth during the growth stage of germination to active tillering was negatively correlated to the yield of *Maran* and *Varada.* (Table 5.3, Fig.5.11). According to Xu and Zhao (1999), the rhizomes of ginger are formed by the expansion of basal branches. In general, the number of branches is related to ginger yield, and the diameter of the stem is related to the size of the ginger rhizome. A study by Li *et al*. (2018) showed that low soil moisture content inhibited ramet growth while simultaneously promoting height growth and diameter of the main stem.

Table.5.3 Effect of soil moisture on yield of ginger

Yield	Soil moisture (5cm)	Soil moisture (20cm)
Maran	-.897**	-.936**
Varada	-.893**	-.920**

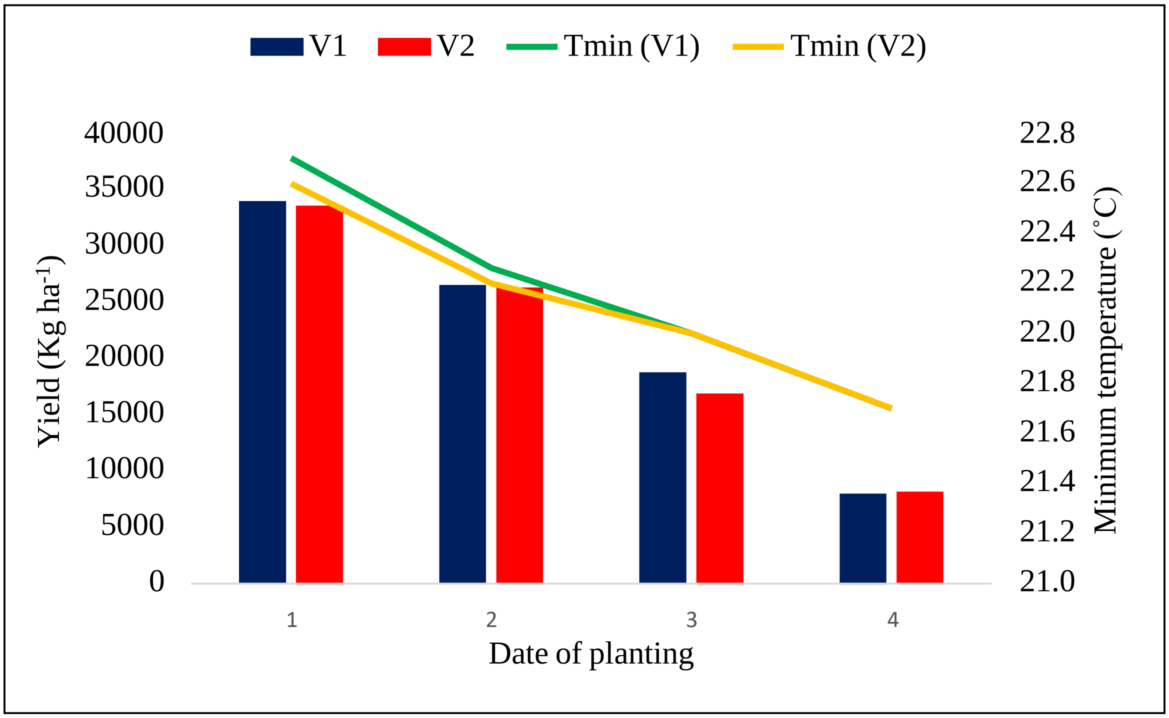


Fig.5.10. Effect of minimum temperature on yield of ginger

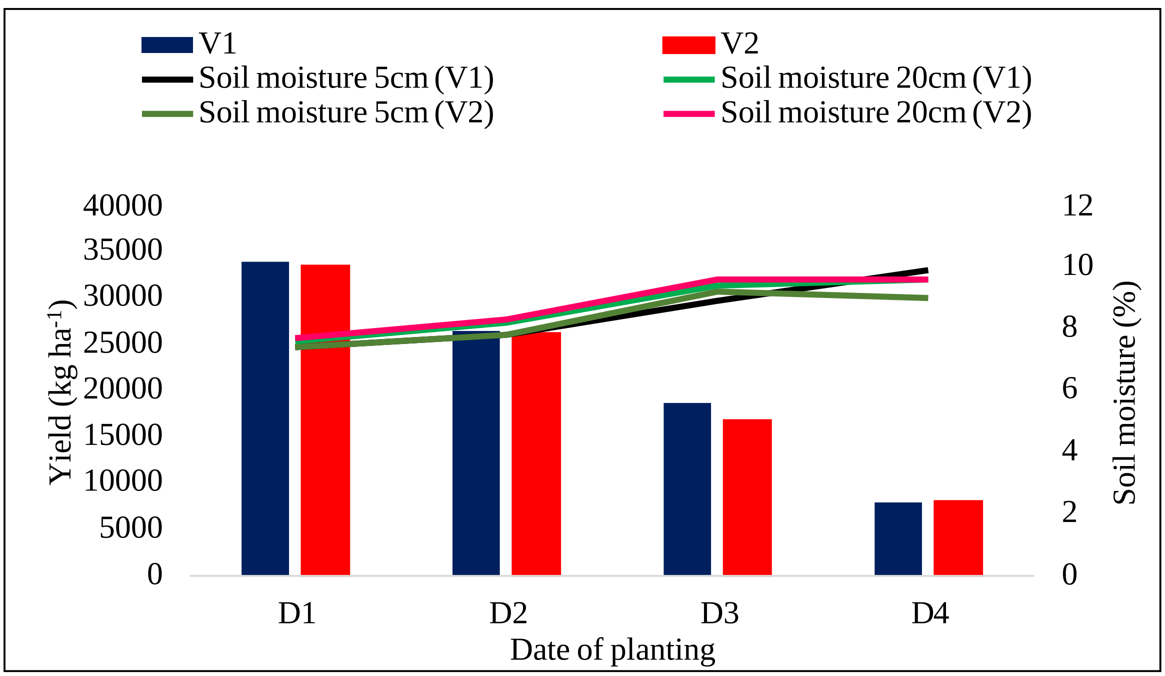


Fig.5.11. Effect of soil moisture on yield of ginger

5.5. IMPACT OF CLIMATE CHANGE ON GINGER PRODUCTION

The impact of ginger variety on the yield of ginger varieties, *Maran* and *Varada* under different climate change scenarios of RCP 4.5 and RCP 8.5 werediscussed here.

5.5.1. Projected changes in yields of *Maran* under RCP 4.5 and 8.5 scenarios

5.5.1.1. First date (May 15th) of planting

May 15th planting date of *Maran* showed a decrease in yield under both RCP 4.5 and 8.5 in all the three-time slices *ie.,* near-century, midcentury and end of century. The observed yield in the base period was 33293.8 kg ha^{-1} on the May 15th planted crop. Under RCP 4.5 it was decreased to 20762.9 kg ha^{-1} in near-century, 23057.8 kg ha^{-1} in midcentury and 20648.8 kg ha^{-1} at end of century. The percentage yield decrease was 38%, 37.6% and 30.7% in End of century, near century and midcentury respectively (Fig. 5.12.a).

Under the RCP 8.5 scenario the yield was reduced to 16964.0 kg ha^{-1} in near-century, 16594.2 kg ha^{-1} in midcentury and 17030.9 kg ha^{-1} at end of century from the base period yield of 33293.8 kg ha^{-1}. The percentage yield decrease was more than that of the RCP 4.5 scenario. It was 49% in near, 50.2% in mid and 48.8%in end of century (Fig. 5.12.b).

5.5.1.2. Second date (June 1st) of planting

The observed base period yield in June 1st planted crops was 22704.3 kg ha^{-1}, itwas further reduced to 17319.7 kg ha^{-1}, 19360.1 kg ha^{-1} and 16128.8 kg ha^{-1}in near, mid and end of century under RCP 4.5 scenario. Percentage reduction in yield was 23.7%, 14.7% and 29% in near, mid and end of century (Fig. 5.13.a).

Under the RCP 8.5 scenario the yield was reduced to 18307.5 kg ha^{-1}, 18105.8 kg ha^{-1}and 19372.4 kg ha^{-1} in near, mid and end of century from the base yield of 22704.3 kg ha^{-}1. The yield reduction was more in midcentury (20.3%) followed by near (19.4%) and end (14.7%) of century (Fig.5.13.b).

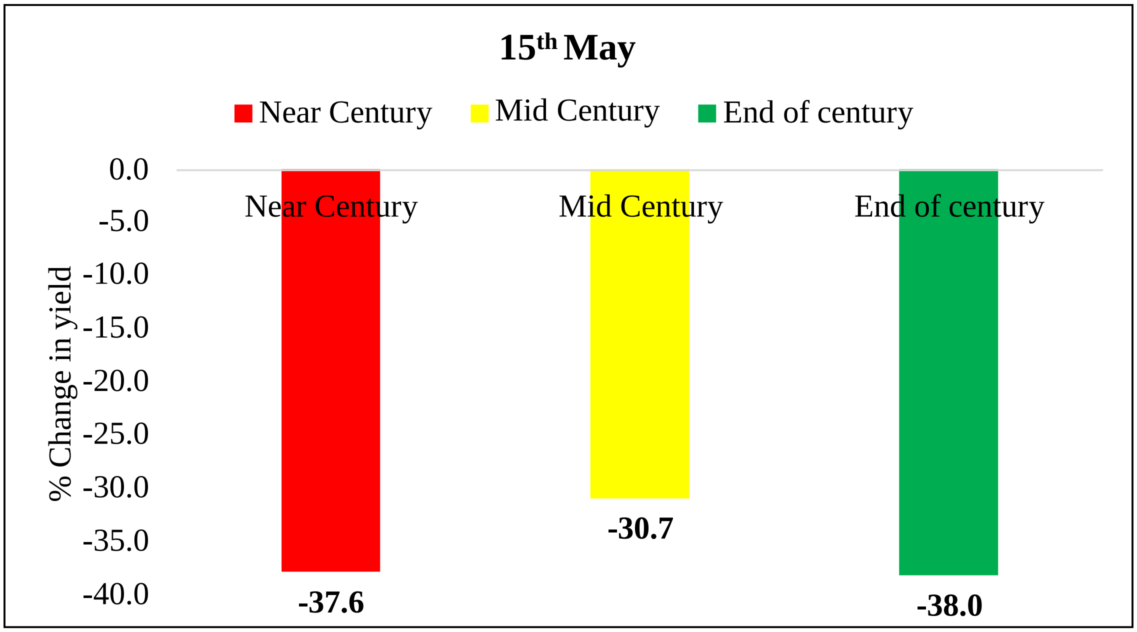


Fig.5.12.a. Percentage change in yield of *Maran* planted on May 15th date of planting under RCP 4.5 scenario.

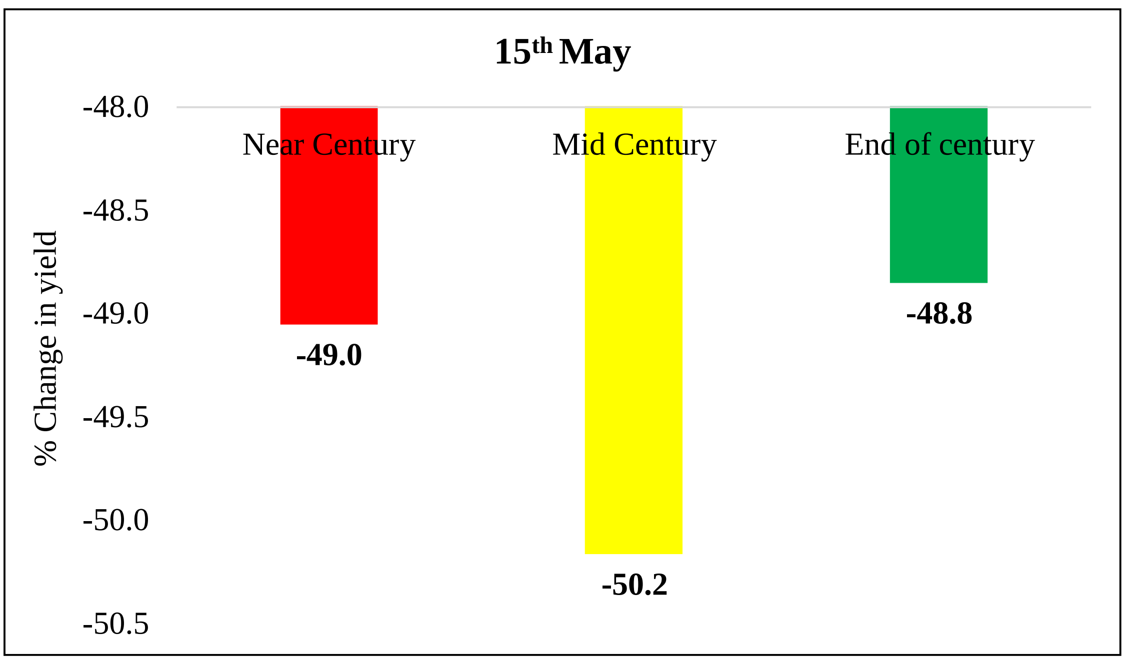


Fig.5.12.b. Percentage change in yield of *Maran* planted on May 15th date of planting under RCP 8.5 scenario.

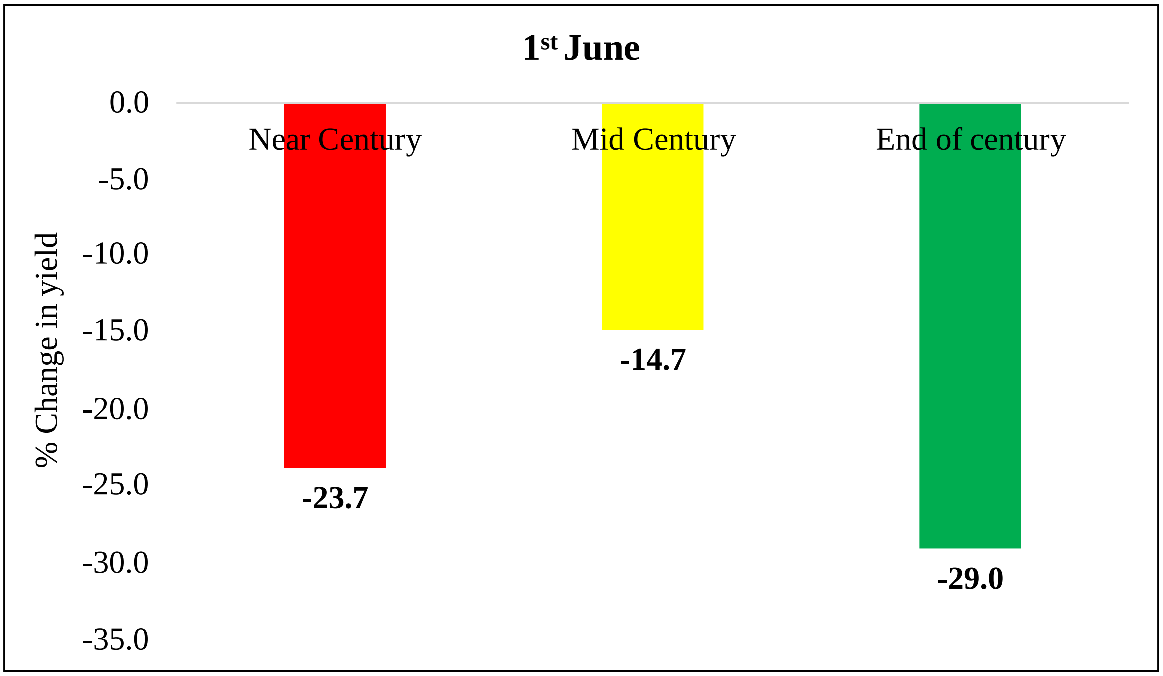


Fig.5.13.a. Percentage change in yield of *Maran* planted on June 1st date of planting under RCP 4.5 scenario.

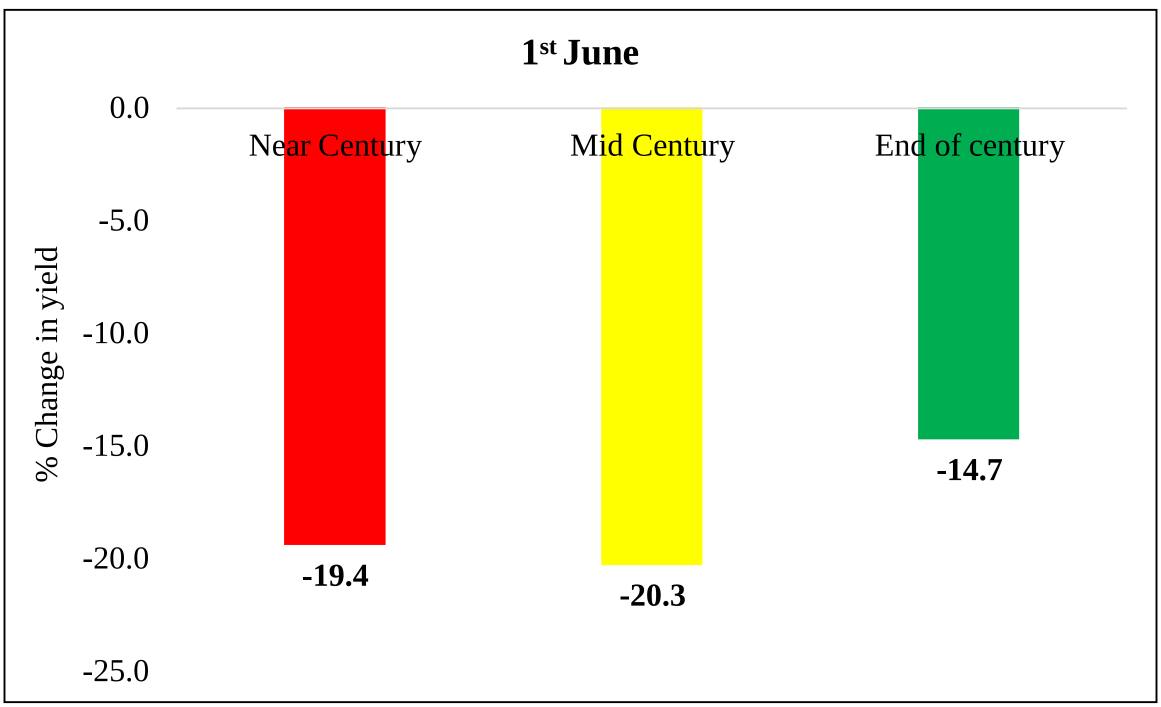


Fig.5.13.b. Percentage change in yield of *Maran* planted on June 1st date of planting under RCP 8.5 scenario.

5.5.1.3. Third date (June 15th) of planting

Projected yield under RCP 4.5 was 10441.4 kg ha^{-1} in near-century, 10926.0 kg ha^{-1} in midcentury and 10324.8 at end of century. There was a noticeable change from the base period yield of 22687.2 kg ha^{-1}. The percentage reduction in projected yield was 54%, 51.8% and 54.5% in near, mid and end of century respectively (Fig.5.14.a).

Under the RCP 8.5 scenario, the yield was reduced to 11097 kg ha^{-1}, 11203.5 kg ha^{-1} and 10746.6 kg ha^{-1} in the near, mid and end of century respectively. The percentage reduction in yield was more under end of century (52.6%) followed by near (51.1%) and mid (50.6%) centuries respectively (Fig. 5.14.b).

5.5.1.4. Fourth date (July 1st) of planting

On July 1st planting date, the base period yield was 7663.5 kg ha^{-1}, it was increased to8402.7 kg ha^{-1} in the near-century and 9026.7 kg ha^{-1} in midcentury and 7674.3 kg ha^{-1} in end of century. The percentage increase in yield was as follows, *ie.*, 9.6% in near,17.7% in mid and 0.14 % in end of century. (Fig. 5.15.a).

The projected yield was found to increase in all the time slices, under the RCP 8.5 scenario of the July 1st planted crop. The yield was increased to 9249.3 kg ha^{-1} in near, 9417.3kg ha^{-1} in mid and 9943.8 kg ha^{-1} at the end of century from the base yield of 7663.5 kg ha^{-1}. The percentage change in yield was more in end (29.7%), followed by mid (22.8%) and near (20.6%) centuries (Fig. 5.15.b).

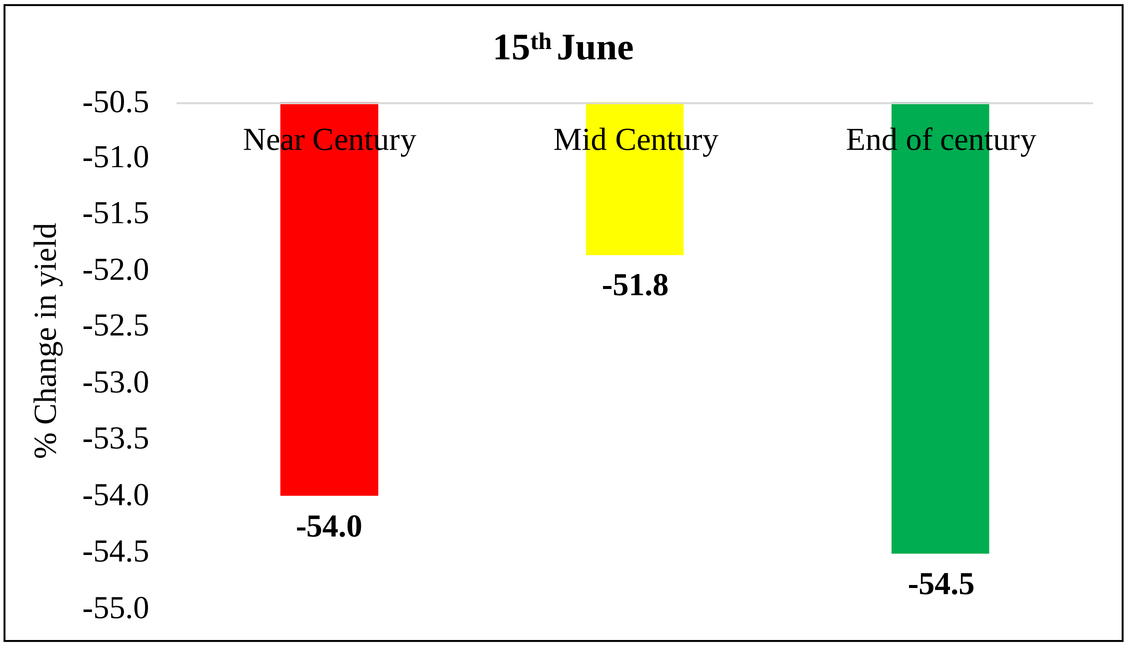


Fig.5.14.a. Percentage change in yield of *Maran* planted on June 15th date of planting under RCP 4.5 scenario.

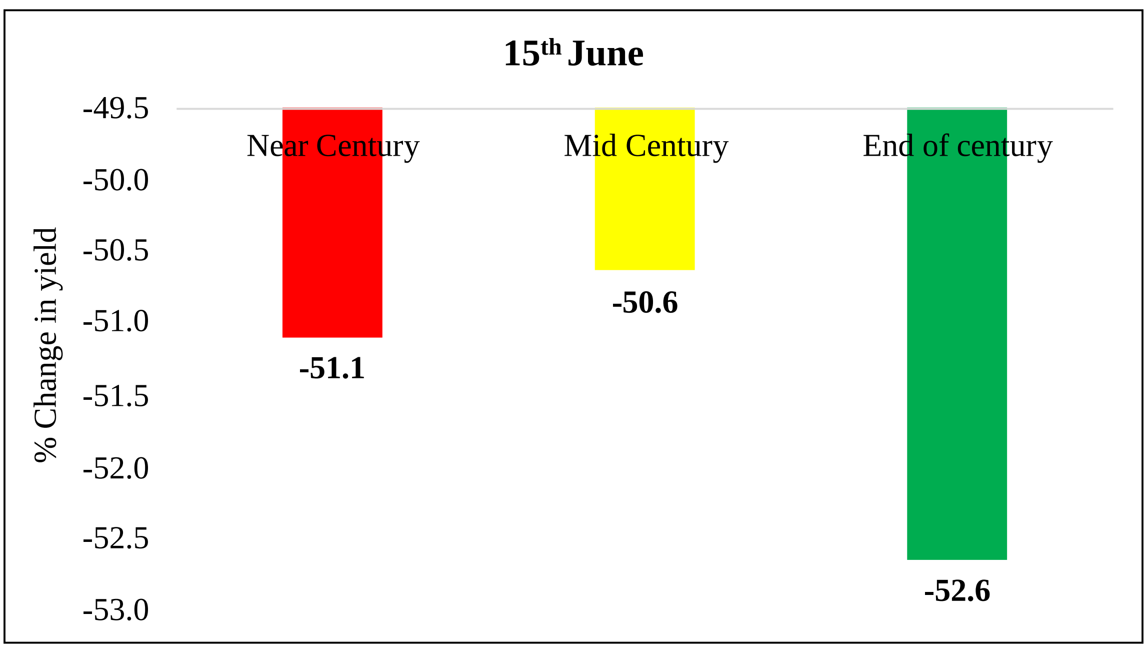


Fig.5.14.b. Percentage change in yield of *Maran* planted on June 15th date of planting under RCP 8.5 scenario.

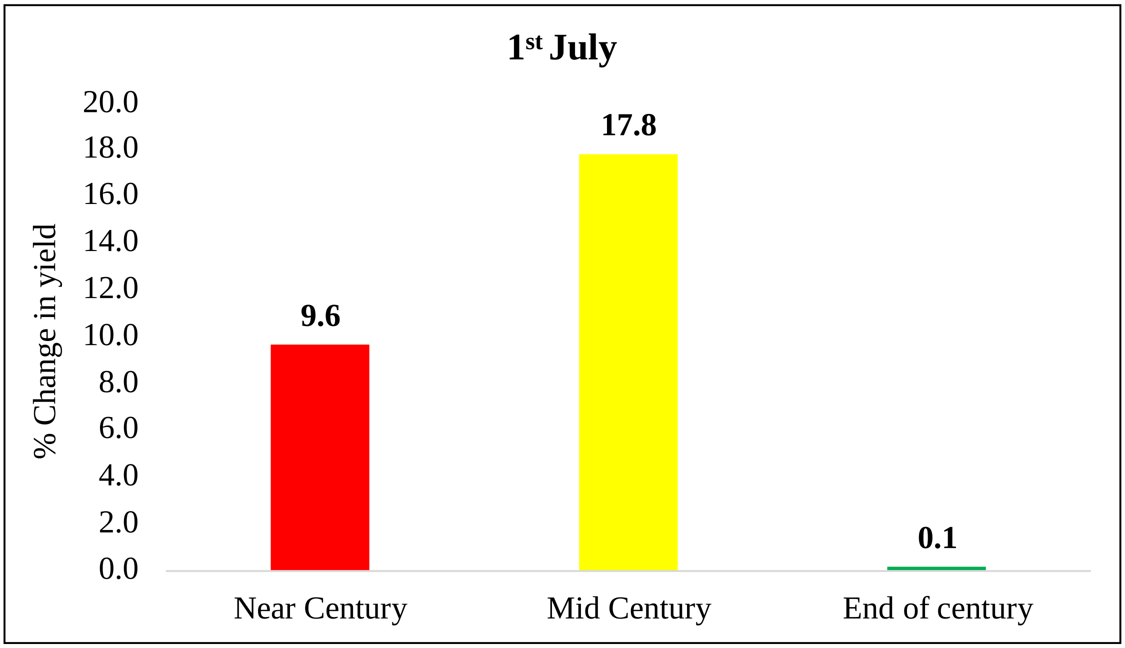


Fig.5.15.a. Percentage change in yield of *Maran* planted on July 1st date of planting under RCP 4.5 scenario.

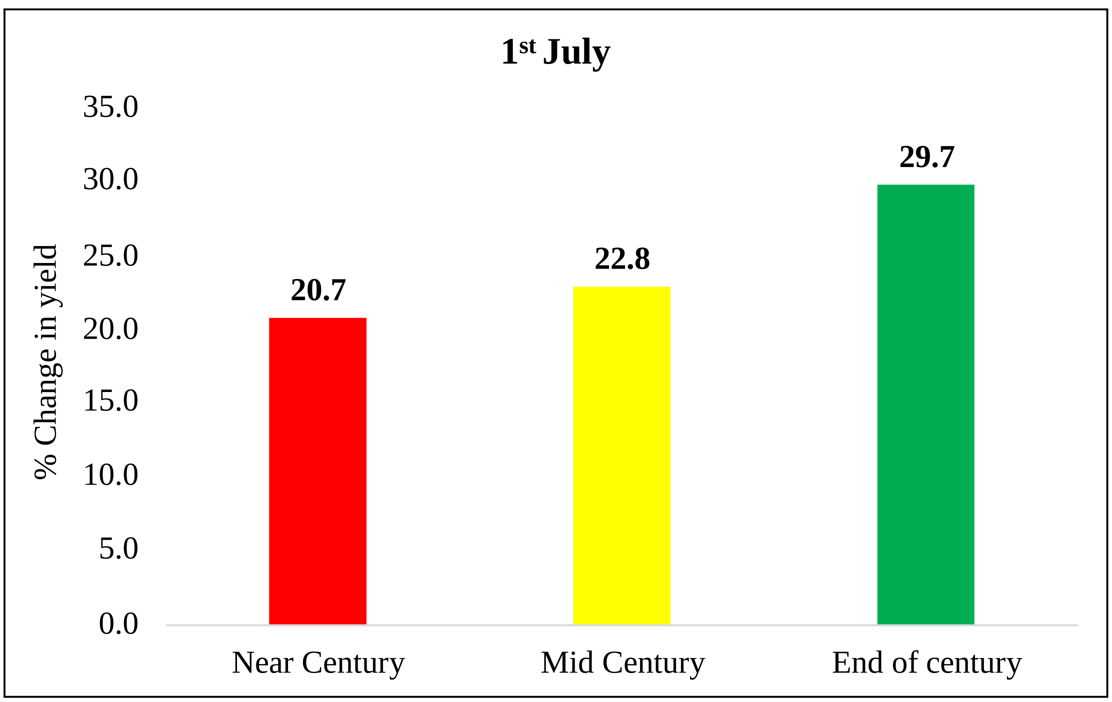


Fig.5.15.b. Percentage change in yield of *Maran* planted on July 1st date of planting under RCP 8.5 scenario.

5.5.2. Projected changes in yields of *Varada* under RCP 4.5 and 8.5 scenarios

5.5.2.1. First date (May 15th) of planting

May 15th planting date of *Varada* showed a reduction in yield under both RCP 4.5 and 8.5 scenarios in all-time slices *ie.,* near-century, midcentury and end of century. The observed yield in the base period was 33111.0 kg ha^{-1} on the May 15th planted crop. Under the RCP 4.5scenario, it was decreased to 25835.7 kg ha^{-1} in the near-century, 27384.0 kg ha^{-1} in midcentury and 25152.9 kg ha^{-1} at end of century. The percentage yield decrease was 24%, 22% and 17.3% in End of century, near century and midcentury respectively (Fig. 5.16.a).

Under the RCP 8.5 scenario the yield was reduced to 23736.7 kg ha^{-1} in near-century, 23590.3 kg ha^{-1} in midcentury and 23719.7 kg ha^{-1} in the end of century from the base period yield of 33111 kg ha^{-1}. The percentage yield decrease was more than that of the RCP 4.5 scenario. It was 28.3% in near, 28.8% in mid and 28.4% in end of century (Fig. 5.16.b).

5.5.2.2. Second date (June 1st) of planting

The base period yield in June 1st planted crops was 19273.6 kg ha^{-1}, it was further reduced to 19082.6 kg ha^{-1}, 18963 kg ha^{-1} and 17526.6 kg ha^{-1}in near, mid and end of century under RCP 4.5 scenario. Percentage reduction in yield was 1%, 1.6% and 7.2% in near, mid and end of century (Fig. 5.17.a).

Under the RCP 8.5 scenario, the yield was reduced to 18479.0 kg ha^{-1} and 17999.2 kgha^{-1} in the mid and end of century from the base yield of 19273.6 kg ha^{-1}. But it was observed that there was a very minute increase in ginger yield *ie.,* 19320 kg ha^{-1} in the near century. The yield reduction was more in the end of century (6.6%) followed by midcentury (4.1%). In the near century, there was a 0.2% increase in yield of *Varada* from the base period yield (Fig. 5.17.b).

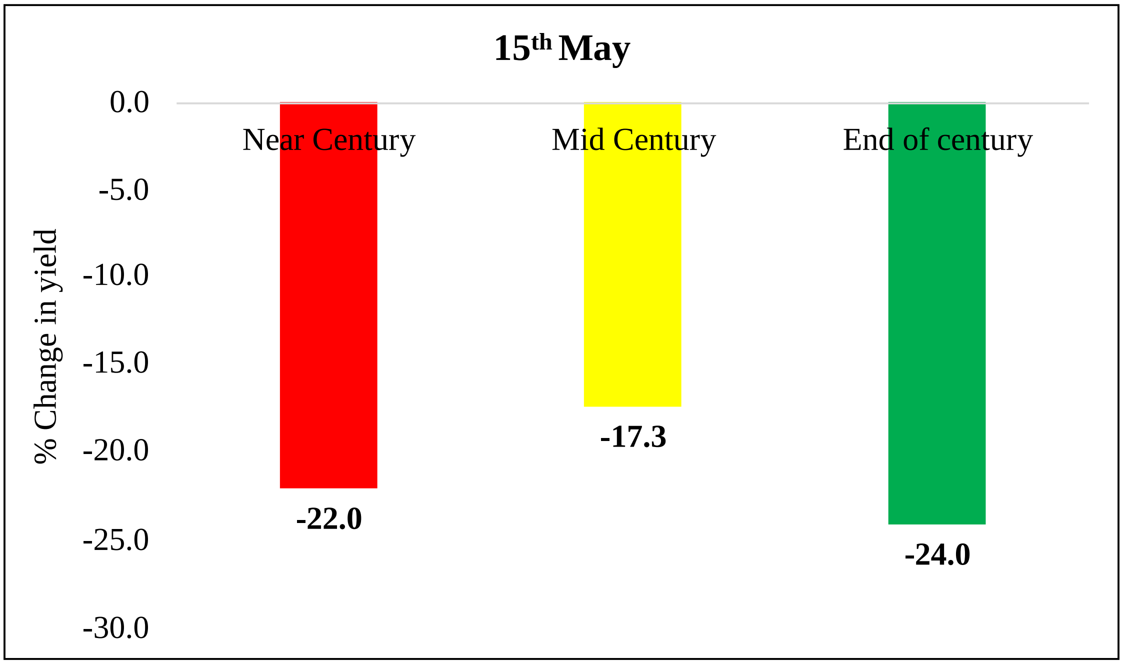


Fig.5.16.a. Percentage change in yield of *Varada* planted on 15th May date of planting under RCP 4.5 scenario.

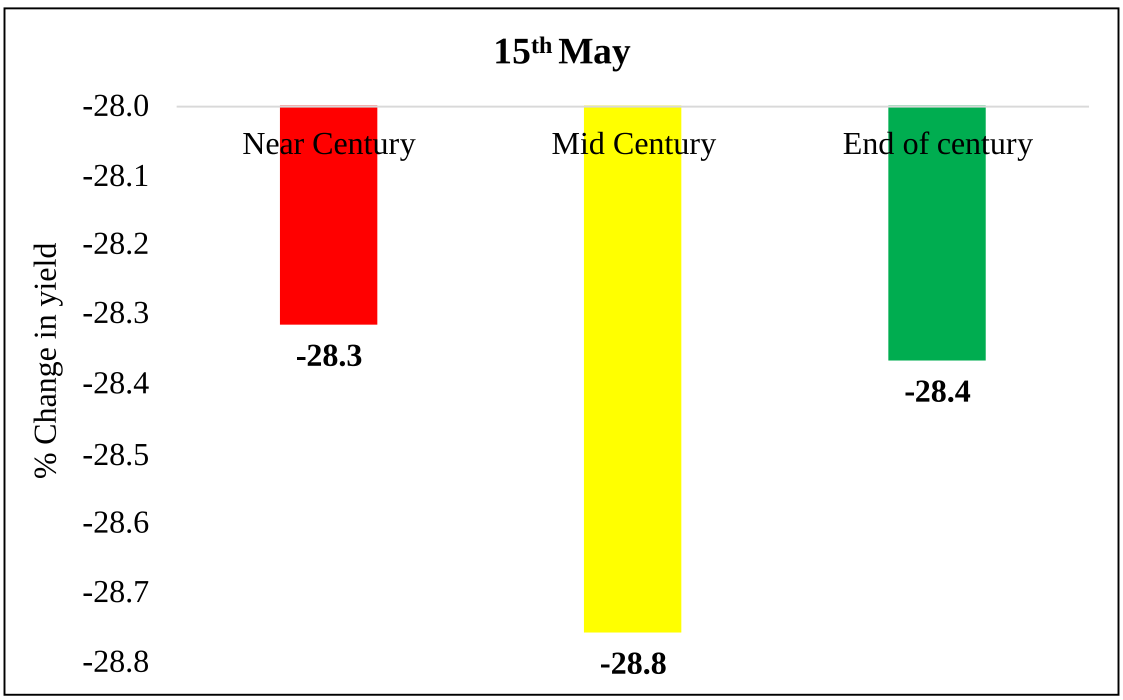


Fig.5.16.b. Percentage change in yield of *Varada* planted on 15th May date of planting under RCP 8.5 scenario.

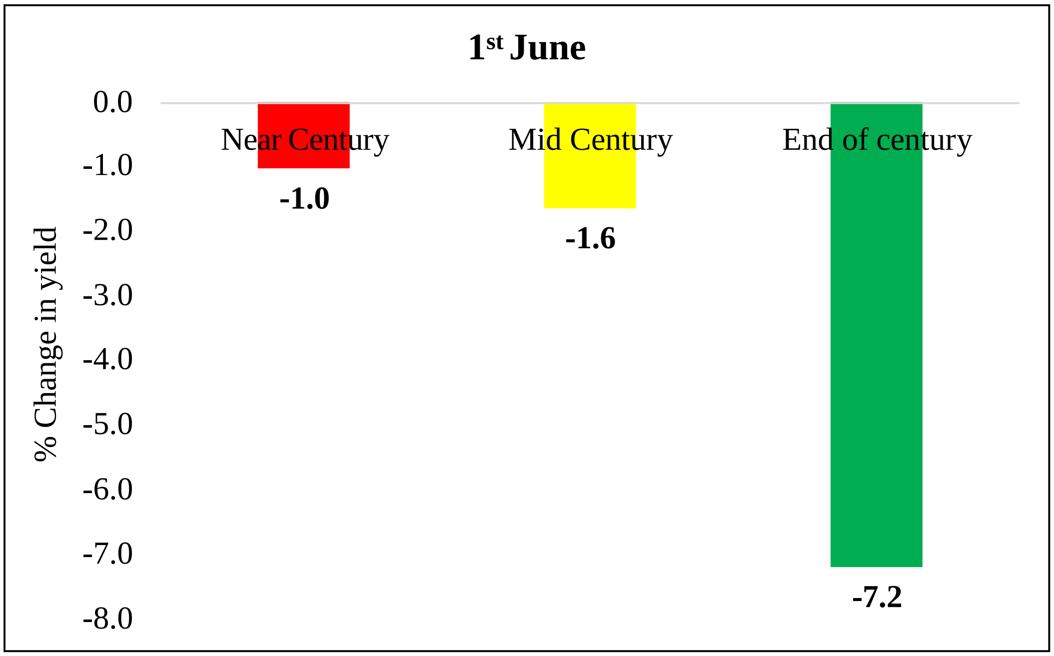


Fig.5.17.a. Percentage change in yield of *Varada* planted on June 1st date of planting under RCP 4.5 scenario.

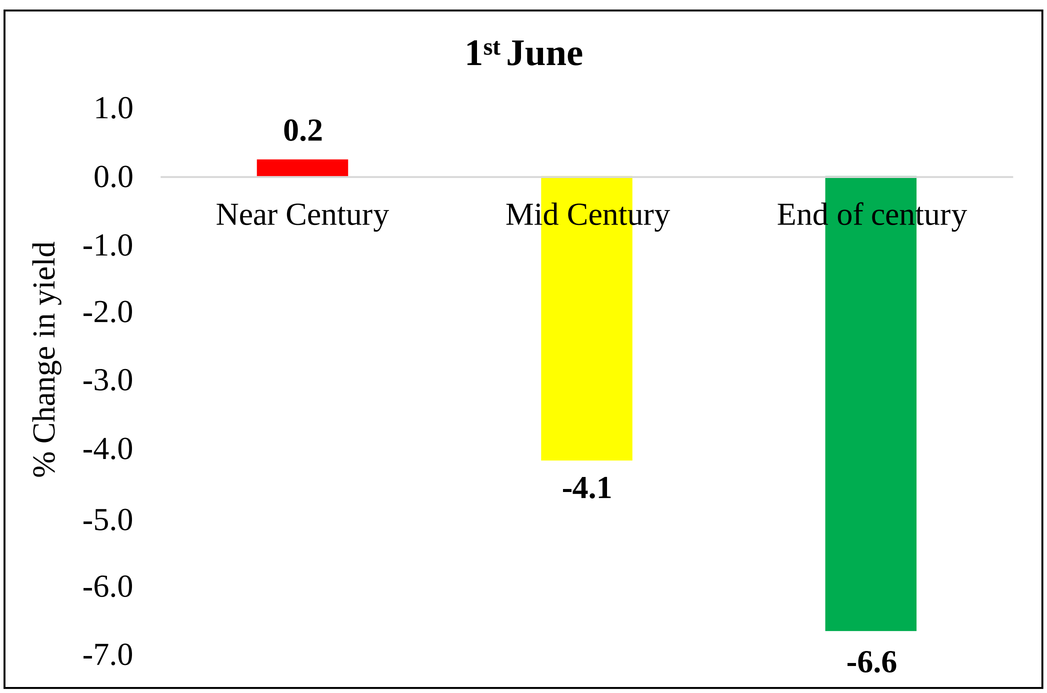


Fig.5.17.b. Percentage change in yield of *Varada* planted on June 1st date of planting under RCP 8.5 scenario.

5.5.2.3 Third date (June 15th) of planting

In the June 15th planted crop, the projected yield under RCP 4.5 was 17020.2 kg ha^{-1} in the near-century, 17526.6 kg ha^{-1} in midcentury and 17017.6 in the end of century. There was a noticeable change from the base period yield of 22658.4 kg ha^{-1}. The percentage reduction in projected yield was 24.9%, 22.6% and 24.9% in near, mid and end of century respectively (Fig. 5.18.a).

Under the RCP 8.5 scenario, the yield was reduced to 18952.0 kg ha^{-1}, 19060 kg ha^{-1} and 18153.0 kg ha^{-1} in the near, mid and end of century respectively. The percentage reduction in yield was more under end of century (19.9%) followed by near (16.4%) and mid (15.9%) centuries respectively (Fig. 5.18.b).

5.5.2.4 Fourth date (July 1st) of planting

In contrast to all other planting dates, the projected yield was found to increase from the observed base period yield in July 1st planting date under all near, mid and end of centuries. The base period yield was 9544.3 kg ha^{-1}, it was increased to 10581.5 kg ha^{-1} in the near century, 10504.1 kg ha^{-1} in midcentury and 11024.3 kg ha^{-1} in the end of century. The percentage increase in yield was as follows, *ie.*, 10.9% in near, 10.1% in mid and 15.5 % in end of century (Fig. 5.19.a).

RCP 8.5 scenario of July 1st planted crop also showed the same trend as that of RCP 4.5 scenario. The yield was found to increase in near (11223.2 kg ha^{-1}), mid (11320 kg ha^{-1}) and end (11833.3 kg ha^{-1}) of centuries from the base period yield of 9544.3 kg ha^{-1}. The percentage increase in yield was 17.6%, 18.6% and 24.0% in the near, mid and end of centuries respectively (Fig. 5.19.b).

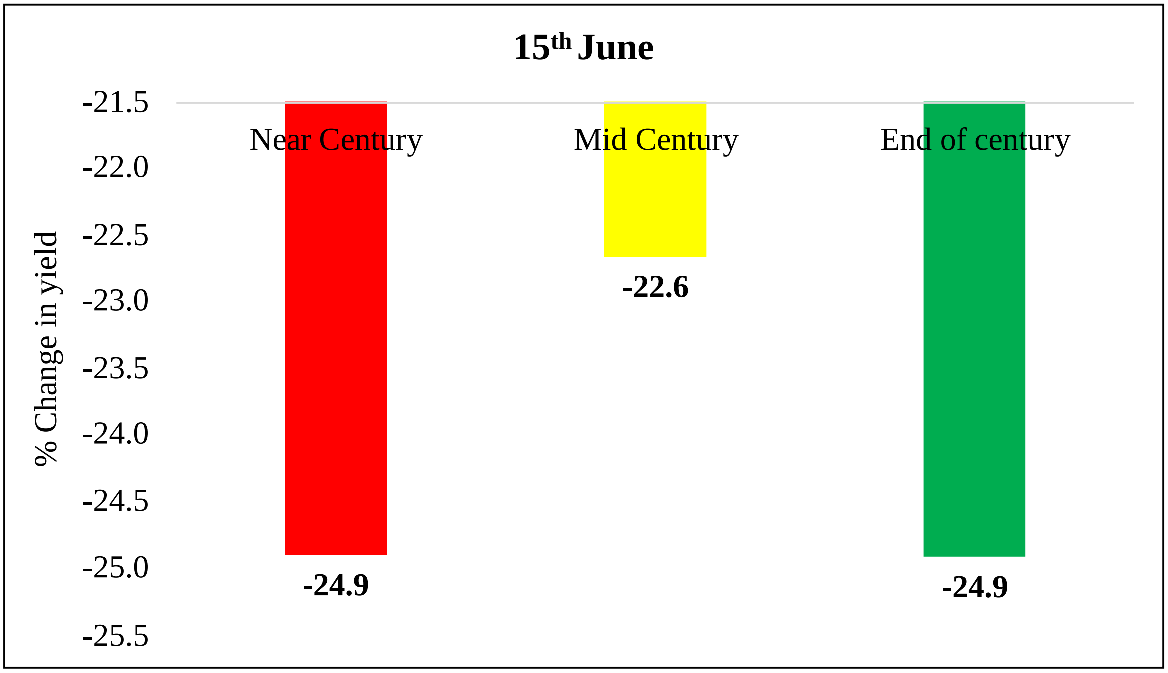


Fig.5.18.a. Percentage change in yield of *Varada* planted on June 15th date of planting under RCP 4.5 scenario.

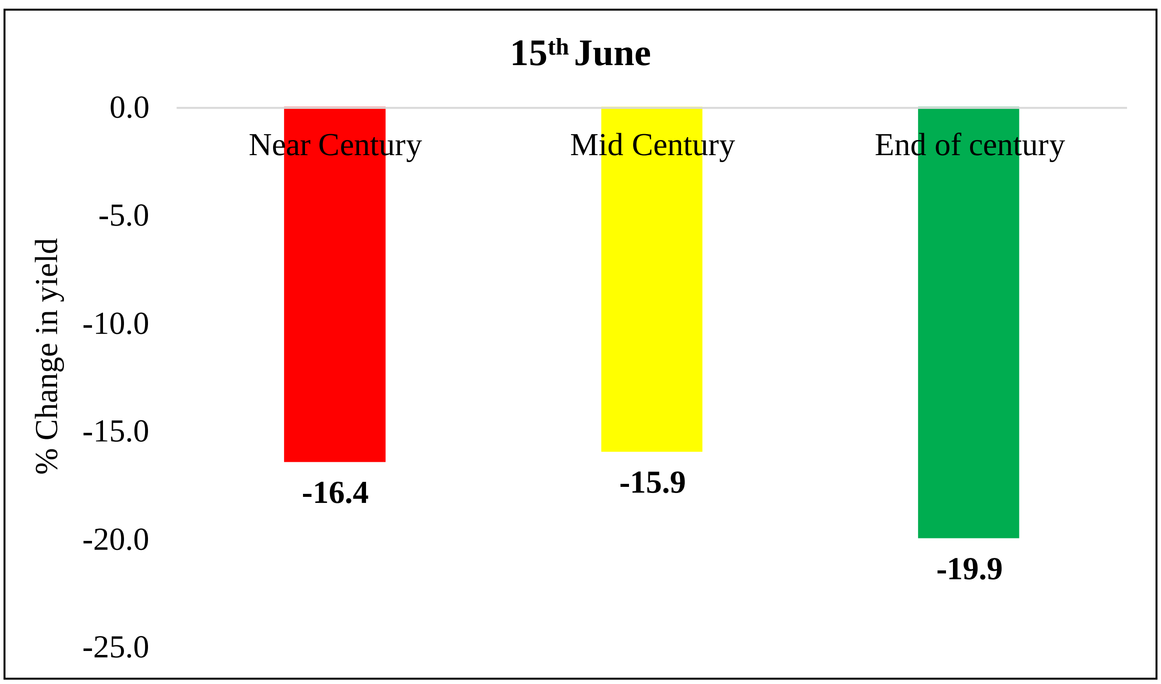


Fig.5.18.b. Percentage change in yield of *Varada* planted on June 15th date of planting under RCP 8.5 scenario.

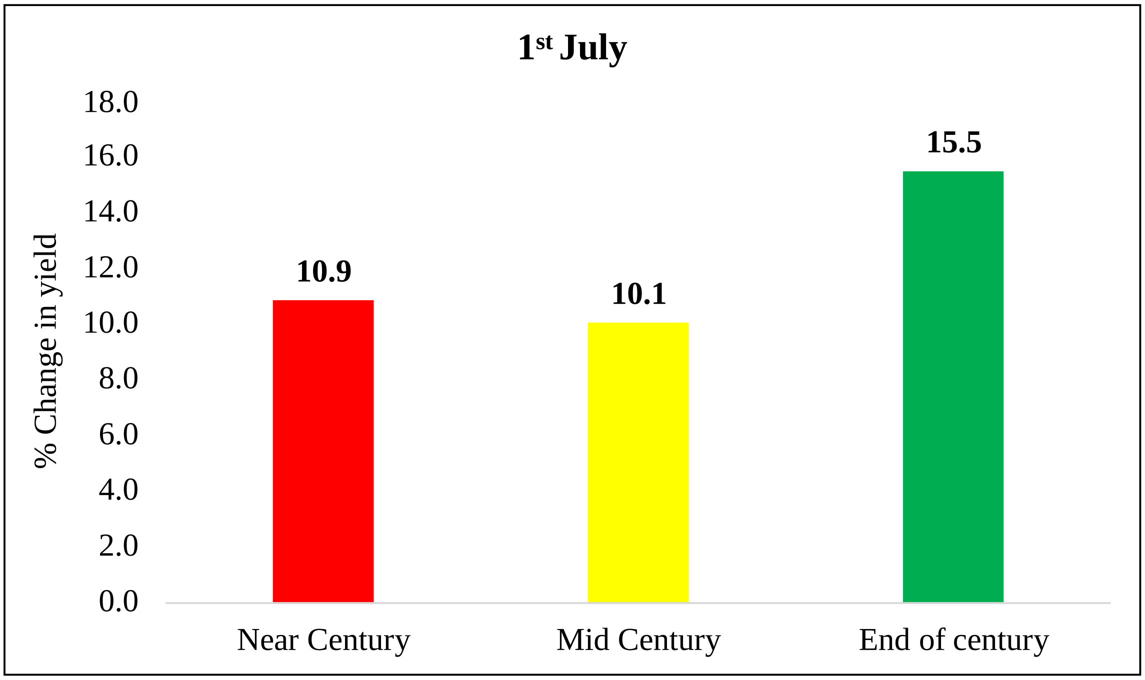


Fig.5.19.a. Percentage change in yield of *Varada* planted on July 1st date of planting under RCP 4.5 scenario.

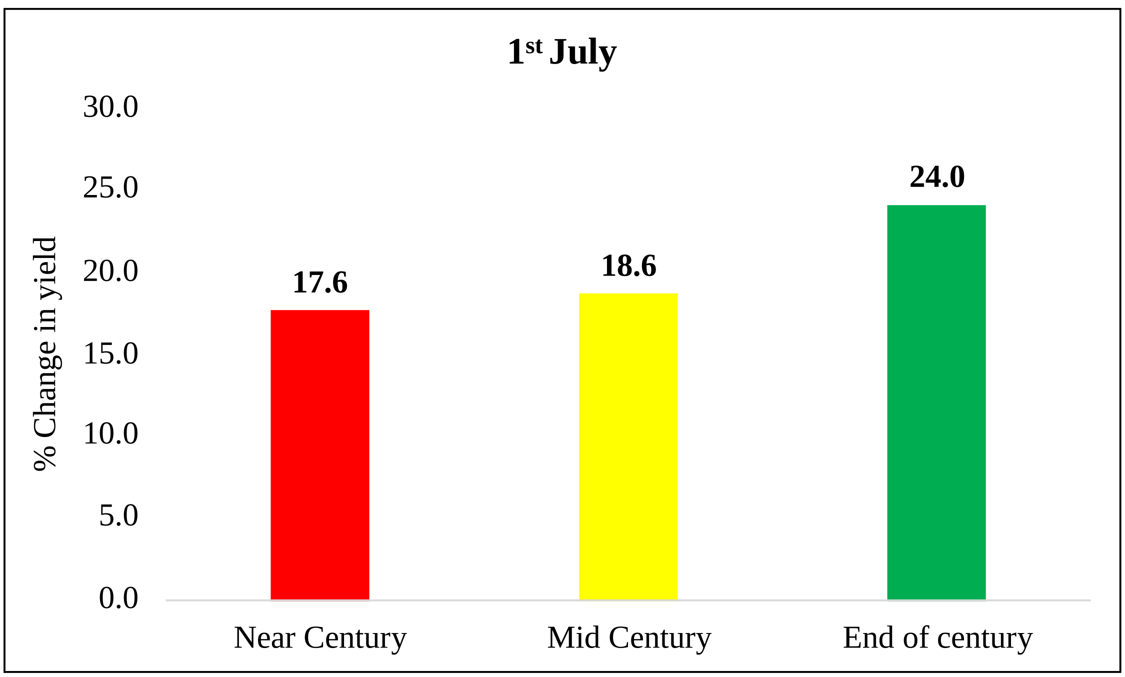


Fig.5.19.b. Percentage change in yield of *Varada* planted on July 1st date of planting under RCP 8.5 scenario.

The results of the study pointing at the decrease of ginger yield due to climate change impacts. There was a significant effect of maximum temperature on the yield of ginger, which might be the reason for the decreased yield of ginger in theprojected climate change scenarios. (Fig.20- Fig.23). These findings are in good agreement with that of Parthasarathy *et al*. (2008). Parthasarathy *et al.* (2008) made afuture prediction with DIVA GIS' Eco-crop model, by raising the temperature of 1.5˚C to 2°C and stated that the area under ginger is expected to shrink by more than half, according to the forecast map. The map showed that Orissa and West Bengal will go from the highly suitable area for ginger cultivation to marginally suitable in the near future.

Hadlee Climate Centre has developed a global regional climate model that predicts the future climate of a region based on a baseline. According to this model, by 2050, the spice- growing region of India may see a 2-3 ºC increase in temperature (Singh., 2008).

Crop production is predicted to decline across the tropics in contrast to high latitudes, even under moderate climate change (1.4◦C increase in 2040) (Murugan *etal*., 2001).

Increased temperature and CO_2 may benefit ginger-growing areas in Himachal Pradesh and the north-eastern parts of the country (Parthasarathy *et al*., 2008). But, climate change, in the form of rising temperatures and correspondingly rising light intensity, may reduce ginger yields in southern states.

Cardamom can tolerate surface air temperatures up to 32.2°C, but beyond that, both growth and development, as well as yield, are hampered (Murugan *et al*.,2012)

Yield decrease in the projected climate change scenario with respect to decreasing rainfall trend was presented in Fig.5.24. to 5.27. These findings are in agreement with Murugan *et al* (2008).

Murugan *et al* (2008) conducted a study on Centennial rainfall variation in semi-arid and tropical humid environments in the cardamom hill slopes, southern

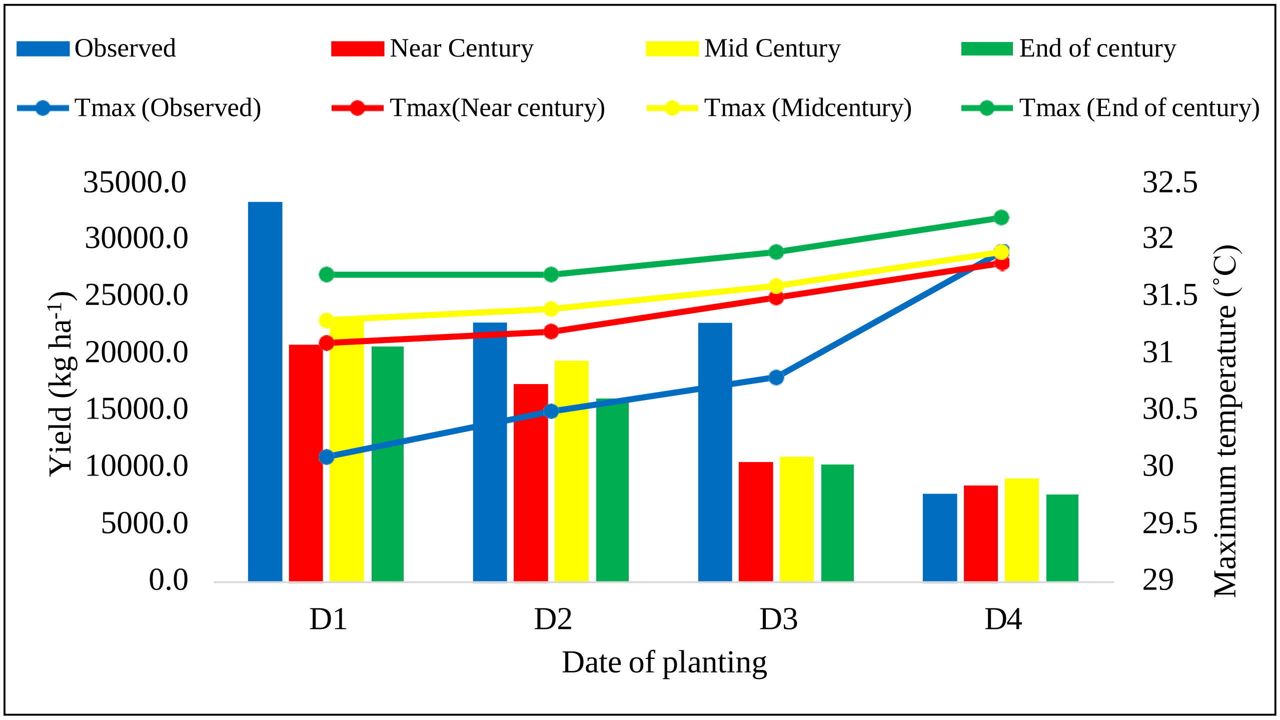


Fig.5.20. Yield variability of *Maran* with respect to maximum temperature under 4.5 scenario.

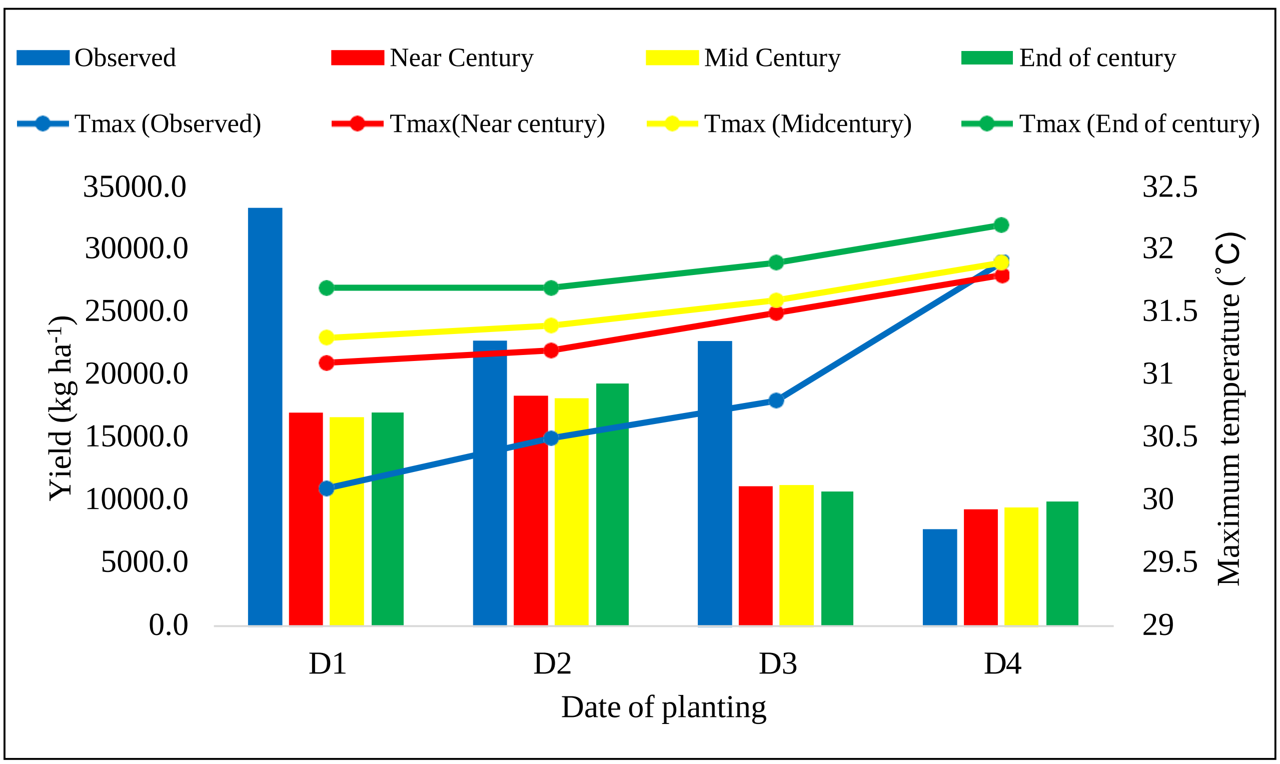


Fig.5.21. Yield variability of *Maran* with respect to maximum temperature under 8.5 scenario.

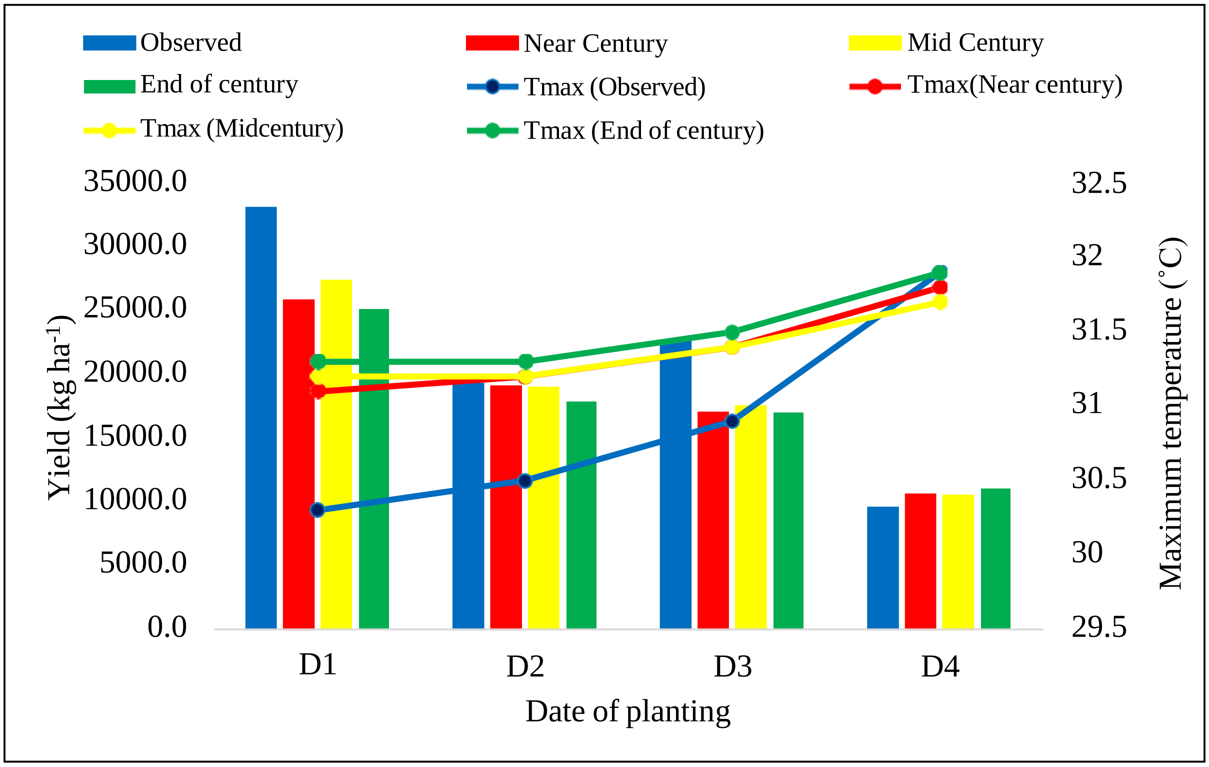


Fig.5.22. Yield variability of *Varada* with respect to maximum temperature under 4.5 scenario.

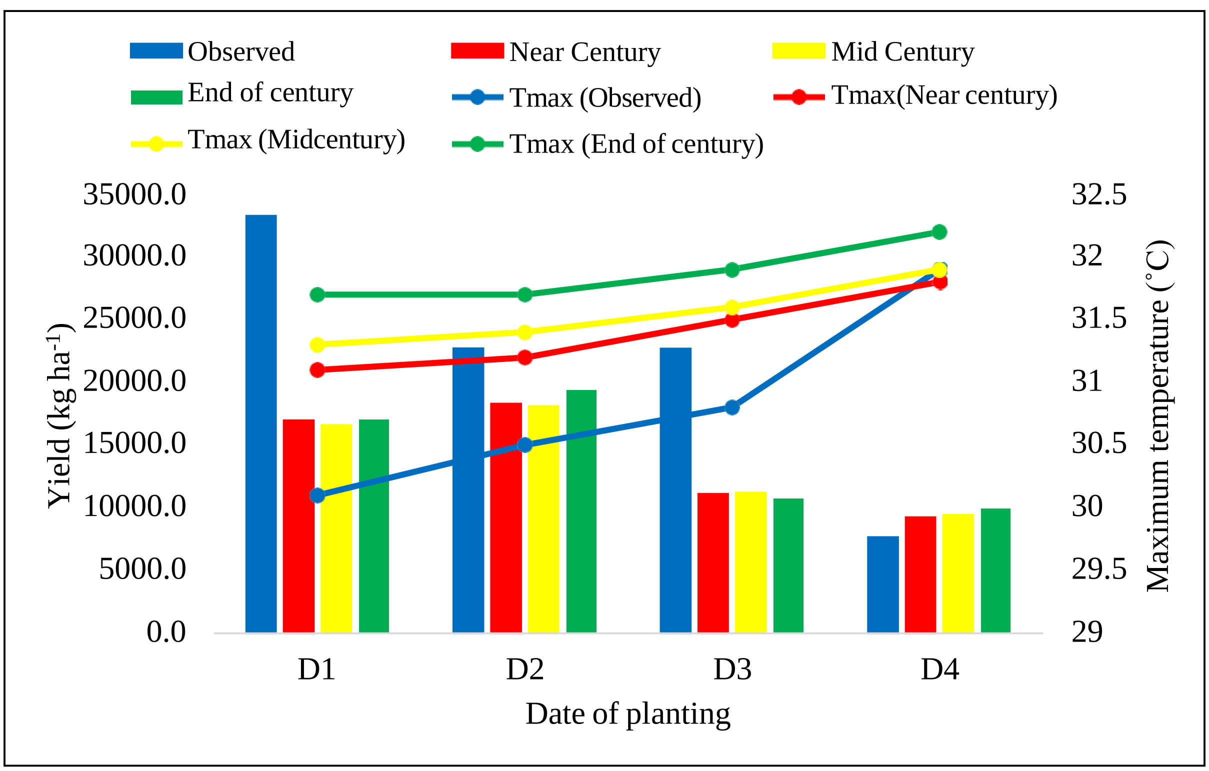


Fig.5.23. Yield variability of *Varada* with respect to maximum temperature under 8.5 scenario.

Western Ghats, India found out that many stream flows in the cardamom hill region have already been depleted and becoming short-lived. Hence the hydrology of the cardamom and tea ecosystems may be influenced in the near future as the demand for water is predicted to increase dramatically. As a result, because cardamom is extremely vulnerable to drought, the ecological deterioration could be far worse and may reduce the cardamom yield than it is now.

Due to the effects of climate change, Indian pepper production has been rapidly declining over the last ten years. It has decreased by more than half from nearly one lakh tonne of annual production. According to a recent study by Kerala Agricultural University's Agricultural Market Intelligence Centre, the area under pepper farming has decreased by 24 percent in nine years, while production has decreased by nearly half due to declining productivity and rising production costs (Ravi., 2012).

Large-cardamom production peaked in Sikkim, India, early in the twenty-first century, making India the world's largest producer, but fell sharply after 2004. According to a study conducted by (Sharma *et al*.,2016), climate change in the cardamom-growing region of Sikkim has resulted in altered seasons, erratic or scant rainfall, prolonged dry spells, temperature rises, soil moisture loss, and an increase in disease and pest outbreaks.

A study using the INFOCROP-POTATO model to assess the impact of climate changeon potato production found that at 550 ppm CO_2 and a 1°C rise in temperature, potato production will increase by 11.12 percent, but at 550 ppm CO_2 and a likely rise in temperature to 3°C, potato production will decline by 13.72 percent in the year 2050 (Singh *et al*., 2013).

Increased respiration, altered photosynthesis, and partitioning of photosynthates to economic parts would all result from a temperature rise. It could also change phenology, reduce crop duration, flowering and fruiting days, and hasten fruit maturity, ripening, and senescence. Individual crop temperature sensitivity is determined by inherent tolerance and growing habits. Due to their longer flowering periods, indeterminate crops are less susceptible to heat stress

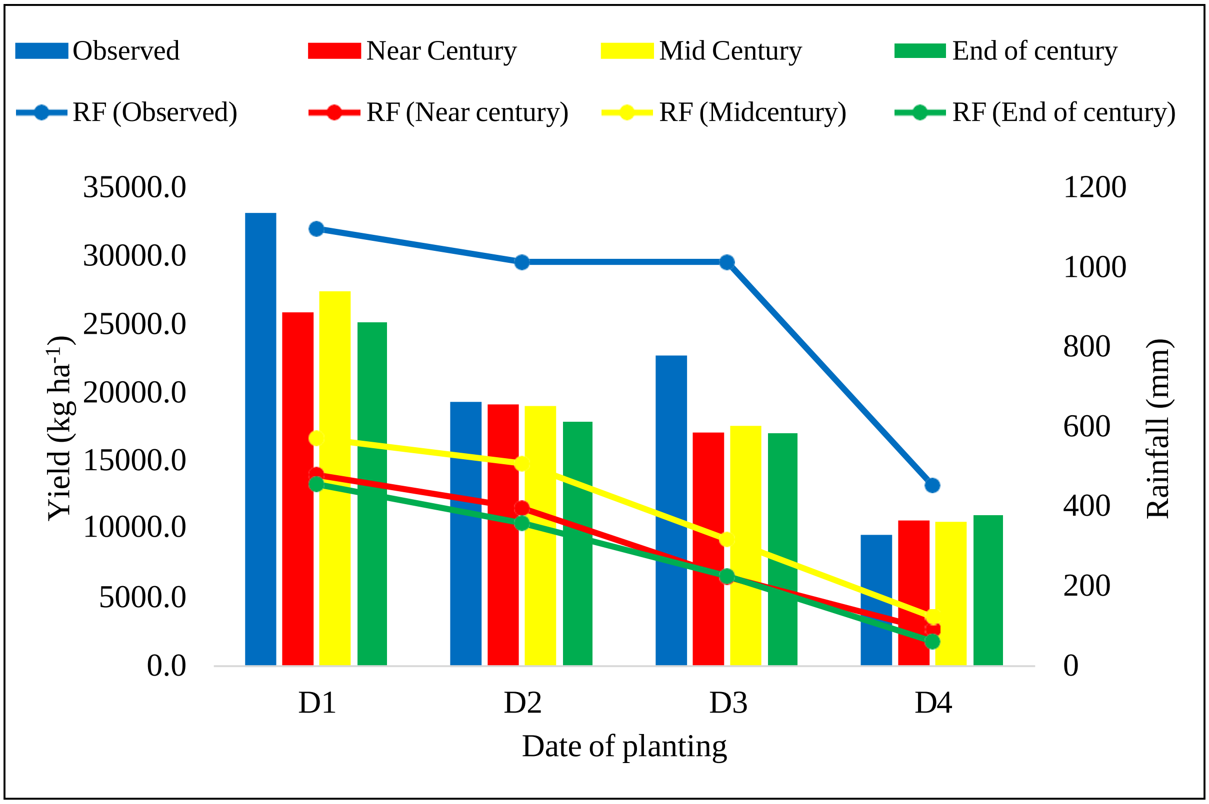


Fig.5.24. Yield variability of *Maran* with respect to rainfall under 4.5 scenario.

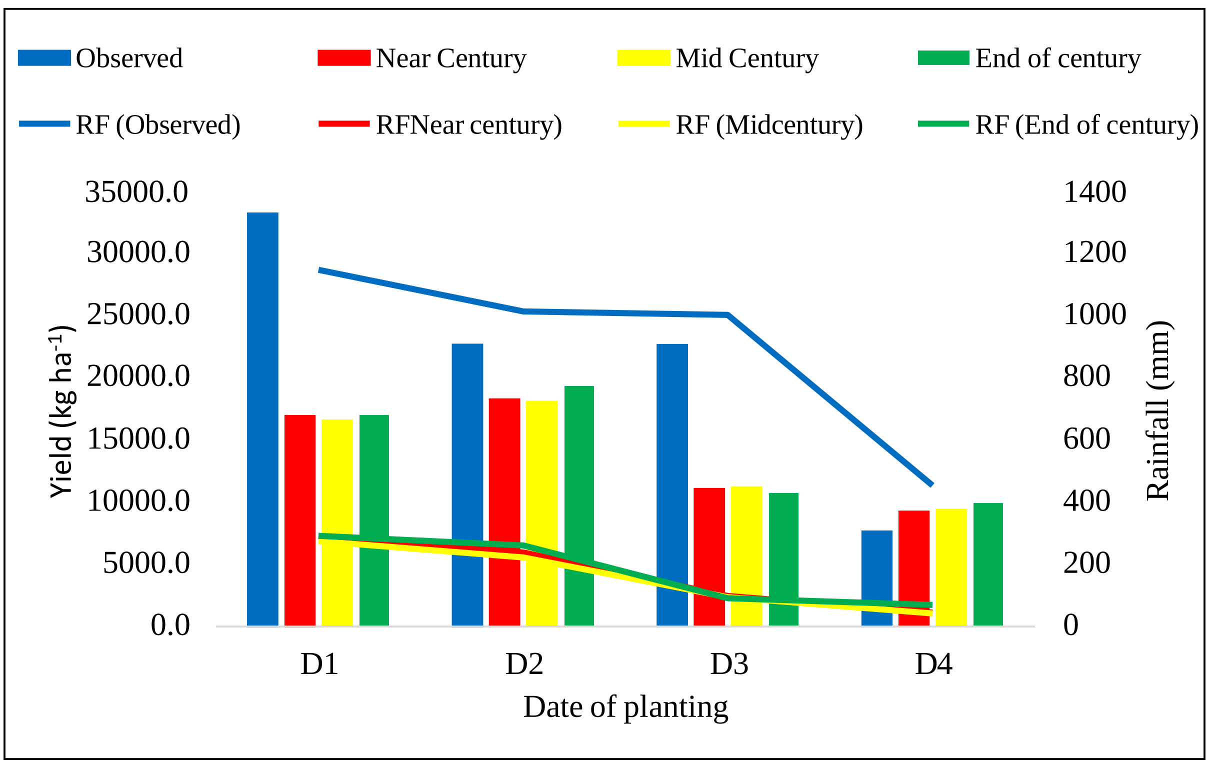


Fig.5.25. Yield variability of *Maran* with respect to rainfall under 8.5 scenario.

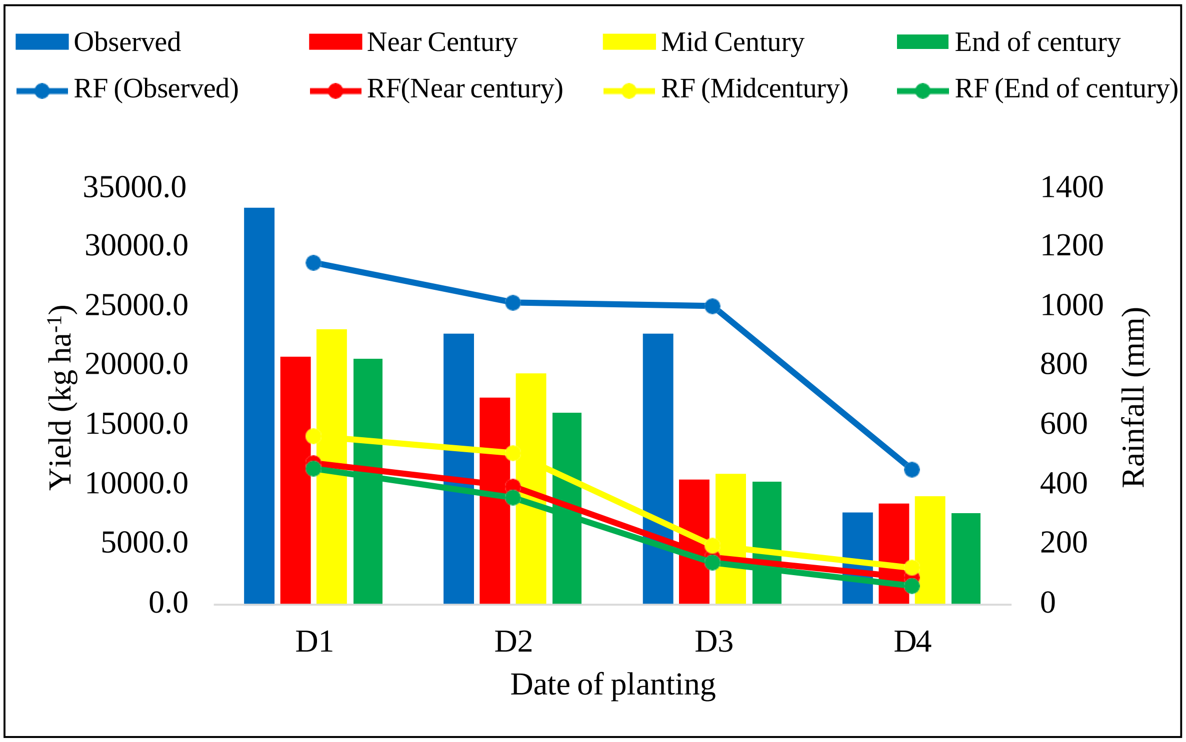


Fig.5.26. Yield variability of *Varada* with respect to rainfall under 4.5 scenario.

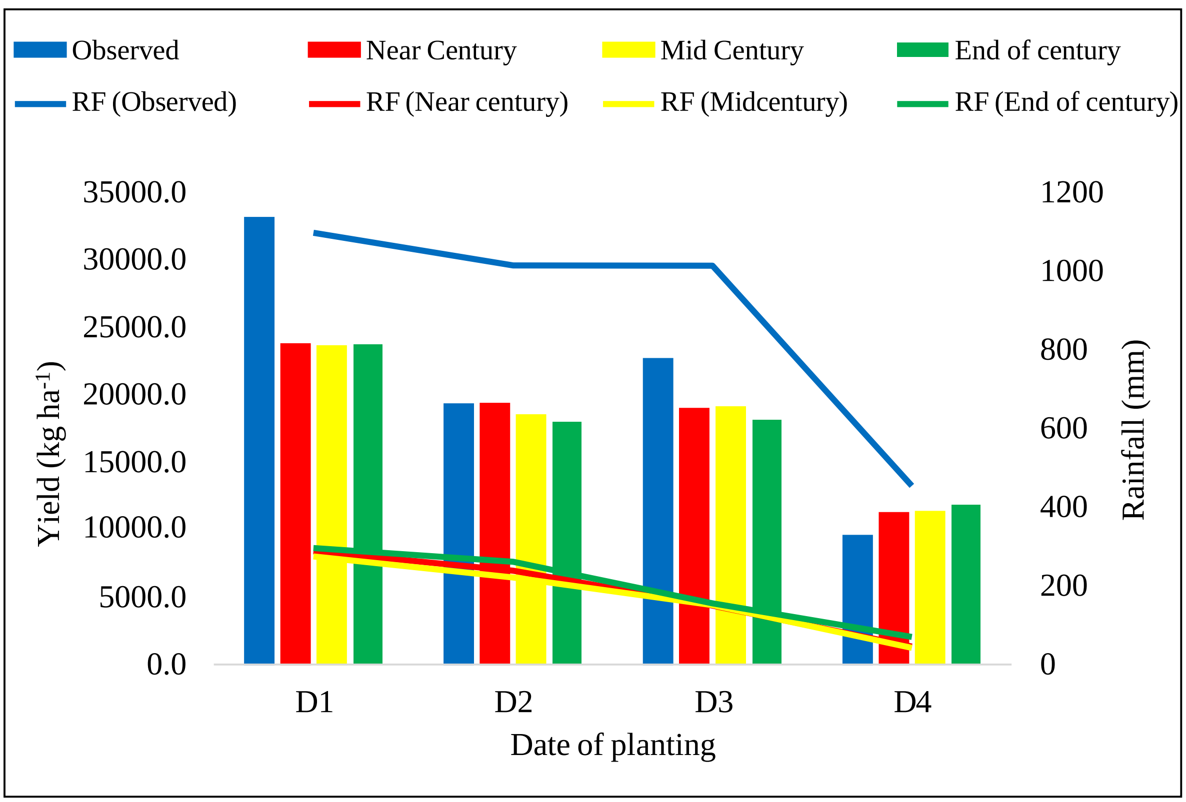


Fig.5.27. Yield variability of *Varada* with respect to rainfall under 8.5 scenario.

than determinate crops (Malhotra., 2016)

Rainfall under future climatic conditions was found to pose a decreasing trend under both RCP 4.5 and 8.5. As cumulative rainfall is highly important to the growth and yield of ginger, a decrease in rainfall may cause a major threat to productivity. From the study, it was observed that the projected productivity was decreasing with the decrease in rainfall under RCP 4.5 and 8.5 scenarios for both Maran (Fig. 5.24 and Fig. 5.25) and Varada(Fig. 5.26 and Fig. 5.27).

Parthasarathy *et al* (2008) reported that, as ginger cultivation is predominantly dependent on rainfall, a reduction in rainfall may reduce the yield drastically. Nagachan and Deka (2008) also stated the same that years with a good amount of rainfall resulted in better quality and productivity of ginger.

Summary

6. SUMMARY

The research on "Ginger (*Zingiber officinale*) yield variability under different climate change scenarios" was conducted at Department of Agricultural Meteorology, College of Agriculture, Vellanikkara during 2020-2021. The crop weather relationship and climatechange impact on ginger yield under RCP 4.5 and 8.5 scenarios were studied with the help of statistical models and climate data downscaled from CCSM4 global climate model.

Observations like weather, biometric, phenological, yield and yield attributes and soil were collected at predetermined intervals for different planting dates. Regression equation were fitted for *Maran* and *Varada* using Principal Component Analysis (PCA).The climate change studies were carried out with past weather data (1983-2020) from Principle Agromet Observatory, Vellanikkara. The future climate of Vellanikkara for near century (2010-2039), midcentury (2040-2069) and End of century (2070-2099) under RCP 4.5and 8.5 were downscaled from CCSM4 model. The assessment of climate change were done with the help of this data. The assessment of climate change impact on ginger varieties at different planting dates were performed by statistical model. The summarized results of this experiment are givenbelow:

- The May 15th planted crop took more days for sprouting, when compared to subsequentplantings.
- The early planted crop, *ie.*, May 15th date of planting, took more days to attain physiological maturity.
- Significant difference was observed for plant height in all weeks except 6th, 9th, 10th, 11th,12th and 15th weeks. Among the varieties *Varada* exhibited more height than *Maran*.
- At the end of the crop period, more number of leaves were observed on May 15th and June 1st planed crops, which was on par with each other.

- At the end of crop period, more tillers were produced by June 1st planted crop. Amongthe varieties, *Maran* variety produced more tillers.
- There were significant difference between dates of planting and leaf area of ginger at biweekly intervals of observations except 30 and 165 days after planting. The significant difference in leaf area among varieties were observed only at 60, 75, 90 and 195 days after planting. During all these intervals, *Maran* variety produced more leaf area than *Varada*.
- Dry matter accumulation was more on May 15th and June 1st planted crops, which wereon par with each other. Among varieties, *Maran* accumulated more dry matter.
- Among all the four planting dates, May 15th planted crop took more days to germinateand to exhibit physiological maturity.
- It was observed that a cumulative rainfall between 200-300 mm favoured the germination of ginger crop.
- Soil temperature between 26-27˚C also favoured germination of the ginger crop.
- More fresh yield was produced by May 15th planted crop and less was produced by July1st planted crop.
- Length and width of rhizome was found to be more in May 15th planted crop.
- The yield of ginger was found to increase with increase in cumulative rainfall and minimum temperature. It was found to decrease with maximum temperature and soil moisture.
- Regression equations were fitted for *Maran* and *Varada* by adopting Principal Component Analysis (PCA).
- The yield prediction model of *Maran* obtained using principal component analysis withtwo components as follows:

  $$\textbf{Yield} = \mathbf{7653.13 - 83.35X_1^{**} - 44.82X_2^{*}} \ (\text{Adj } R^2 = 0.854)$$

- The yield prediction model of *Varada* is given below with one component

  $$\textbf{Yield} = \mathbf{19845.19 - 65.93X_1^{**}} \ (\text{Adj } R^2 = 0.721)$$

- The projected future yield of *Maran* and *Varada* were computed by using the statistical yield prediction model and future climate data downscaled from CCSM4 model.

- The projected productivity of variety *Maran* under RCP 4.5 and 8.5 were found to decrease from the observed yield in near century, midcentury and end of century on May 15th, June 1st and June 15th dates of planting. The July 1st date of planting showedincrease in yield from the observed yield.
- In case of *Varada,* the projected productivity under RCP 4.5 and 8.5 were found to decrease from the observed yield in near century, midcentury and end of century on May 15th, June 1st and June 15th dates of planting. The July 1st date of planting showed increase in yield from the observed yield.
- Maximum temperature tend to show a warming trend at future time scales and there isa correspondent trend of yield reduction also.
- The precipitation at future showed a decreasing trend from the observed presentweather data, which may also contributed to the reduction of projected yield of ginger.

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Appendices

Appendix I

Abbreviations and units used

Weather parameters

Tmax : Maximum temperature

Tmin : Minimum temperature

RH : Relative humidity

WS : Wind Speed

BSS : Bright sunshine hours

RF : Rainfall

RD : Rainy days

Epan : Pan evaporation

ST I 5 : Forenoon soil temperature at 5cm depth

ST I 20 : Afternoon soil temperature at 20 cm depth

ST II 5 : Afternoon soil temperature at 5 cm depth

ST II 20 : Afternoon soil temperature at 20 cm depth

SM 5 : Soil moisture at 5 cm depth

SM 20 : Soil moisture at 20 cm depth

Dates of planting

D1: 15^{th} May 2020

D2: 1^{st} June 2020

D3: 15^{th} June 2020

D4: 1^{st} July 2020

Varieties

V1: *Maran*

V2: *Varada*

Appendix I (contd.)

Phenophases

P1: Sowing to 50% sprouting

P2: 50% sprouting to active tillering

P3: Active tillering to bulking

P4: Bulking to Physiological maturity

Units

°C: Degree celcius

%: Percentage

km hr^{-1} : kilo meter per hour

hrs: Hours

mm: milli meter

MJ m^{-2} day^{-1}: Mega joules per square meter per day

Appendix II

Equations used

Leaf area: Leaf area (LA) = -0.0146 + 0.6621 x L x W,

L= length of leaf (cm)

W= maximum leaf width (cm)

$$\text{Relative difference (\%)} = \frac{\text{Mean of future yield} - \text{Mean of base period yield}}{\text{Mean base period yield}}$$

Appendix III

Weekly weather prevailed during crop growth period

SMW	Tmax °C	Tmin °C	RH %	WS $kmhr^{-1}$	BSS Hrs	RF Mm	RD	Epan mm	ST I 5 °C	ST I 20 °C	ST II 5°C	ST II 20 °C
20	33.9	24.2	82	2	4.6	49.2	3.0	200	28.9	33.0	36.9	34.4
21	34.4	26.2	78	2.4	6.4	7.5	2.0	250	29.1	32.4	38.1	33.9
22	33.0	24.9	80	2.9	4.4	23.6	1.0	226	28.4	32.6	37.3	33.7
23	31.21	24.30	86	1.60	2.10	74.70	4.0	17.2	27.3	30.7	33.2	31.6
24	31.36	23.20	86	0.90	2.00	125.90	7.0	15.9	26.6	30.2	32.1	30.7
25	30.70	23.50	86	0.70	1.70	92.10	5.0	14.6	27.1	30.3	32.2	31.0
26	31.07	23.40	80	1.00	3.60	119.90	4.0	17.2	27.0	30.4	33.8	31.1
27	29.93	23.10	92	0.90	0.50	163.50	7.0	14.1	26.0	29.4	30.4	30.2
28	31.04	23.20	83	1.10	3.30	76.00	3.0	17.0	26.1	29.7	33.8	30.7
29	30.21	23.10	88	0.90	2.40	84.90	3.0	14.0	26.0	29.4	32.5	30.6
30	31.49	23.20	84	1.70	5.10	72.30	5.0	23.0	26.4	30.0	33.5	30.8
31	28.74	22.50	90	2.10	0.80	332.00	7.0	18.0	25.0	28.3	30.4	29.1
32	28.00	22.60	94	1.90	0.00	378.90	6.0	10.3	24.7	27.3	28.6	28.0
33	30.46	23.30	86	1.60	1.80	48.10	5.0	18.5	26.1	29.0	32.1	29.6
34	31.39	23.50	83	1.30	5.50	7.30	1.0	18.6	26.7	30.0	34.2	30.6
35	32.33	23.20	79	1.80	7.70	12.80	1.0	25.1	27.0	30.7	36.8	31.7
36	31.26	22.60	88	1.60	3.20	138.10	4.0	14.8	26.3	29.8	32.6	30.3
37	28.14	22.10	92	0.90	0.50	210.20	7.0	8.8	25.1	28.3	29.9	28.9
38	29.09	21.90	89	1.80	1.20	206.10	6.0	14.6	25.0	28.2	31.2	29.0

SMW	Tmax °C	Tmin °C	RH %	WS kmhr^{-1}	BSS Hrs	RF mm	RD	Epan mm	ST I 5 °C	ST I 20 °C	ST II 5°C	ST II 20 °C
39	30.73	22.70	85	1.40	3.40	22.00	3.0	17.1	26.1	29.5	33.4	30.4
40	31.17	21.70	80	1.70	7.60	17.80	1.0	20.3	25.5	29.5	35.7	31.0
41	30.30	21.60	88	1.80	2.90	187.0	5.0	15.3	25.2	28.9	32.1	29.8
42	30.09	21.50	85	1.50	4.80	96.30	5.0	16.1	25.3	28.6	32.8	29.8
43	31.37	21.10	79	1.10	5.80	9.20	1.0	15.8	25.1	29.0	34.8	30.5
44	33.01	22.50	78	1.30	5.40	0.00	0.0	16.5	26.4	30.2	36.1	31.2
45	33.67	22.00	68	4.40	7.70	46.80	1.0	28.0	25.1	29.3	35.1	30.6
46	32.94	22.60	70	6.90	5.40	8.80	1.0	28.7	25.8	29.3	33.6	30.3
47	32.9	20.4	65	3.9	7.9	0.0	0.0	25.4	24.4	28.6	33.4	29.8
48	32.8	22.7	68	4.9	7.8	0.5	0.0	27.9	26.0	29.4	34.4	30.4
49	31.5	22.5	73	5.1	2.8	7.7	1.0	19.6	25.4	28.7	31.6	29.4
50	32.5	21.1	63	5.7	8.6	0.0	0.0	29.1	25.3	29.3	35.5	30.7
51	31.0	22.7	62	8.8	5.4	0.0	0.0	36.7	26.1	29.5	34.1	30.6
52	32.5	21.3	62	7.1	7.2	0.0	0.0	38.7	26.5	30.2	35.2	31.4
1	32.1	22.2	65	8.5	6.6	43.1	1.0	34.9	26.3	29.9	35.3	31.2
2	30.9	22.4	71	5.1	2.3	2.6	0.0	19.7	24.8	28.5	30.3	29.0
3	32.3	21.1	64	6.6	7.6	0.0	0.0	31.3	24.3	28.6	35.9	30.3
4	33.7	20.1	58	3.9	9.2	0.0	0.0	31.8	25.0	29.9	36.8	31.4

Tmax - Maximum temperature

Tmin - Minimum temperature

BSS - Bright sunshine hours

RH- Mean relative humidity

WS -Wind speed

RF - Rainfall

RD - Rainy days

BSS- Bright sunshine hours

Epan -Pan Evaporation

ST I 5 – Forenoon soil temperature at 5cm depth

ST I 20 – Forenoon soil temperature at 20cm depth

ST II 5 – Afternoon soil temperature at 5cm depth

ST II 5 – Afternoon soil temperature

Weather conditions prevailed from sowing to 50% sprouting

Dates of Planting	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS ($kmhr^{-1}$)	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	STI5 (˚C)	STI20 (˚C)	STII5 (˚C)	STII20 (˚C)	SM5 (%)	SM20 (%)
D1	V1	32.2	24.3	83.1	1.7	406.1	25.0	3.5	14.5	121.0	27.8	31.4	34.6	32.4	6.6	6.9
	V2	32.4	24.3	83.1	1.8	373.0	22.0	3.6	14.6	109.8	27.8	31.5	34.7	32.5	6.6	6.9
D2	V1	31.3	23.8	85.5	1.5	263.5	15.0	2.5	13.0	50.5	27.1	30.7	32.7	31.4	6.6	6.9
	V2	31.3	23.8	85.2	1.6	250.6	13.0	2.3	12.7	45.7	27.0	30.7	32.9	31.4	6.8	6.5
D3	V1	31.0	23.4	84.8	0.8	291.5	14.0	2.4	12.4	43.1	27.0	30.3	32.6	31.0	7.4	7.6
	V2	30.7	23.4	85.7	0.8	366.2	17.0	2.1	11.8	48.4	26.9	30.1	32.4	30.8	7.4	7.6
D4	V1	30.3	23.1	88.2	1.0	311.0	13.0	1.8	10.4	37.0	26.3	29.6	31.8	30.3	7.9	7.2
	V2	30.2	23.1	88.0	1.0	321.5	14.0	1.8	12.6	42.2	26.3	29.5	32.1	30.4	7.5	7.9

D1: 15th May 2020 V1: *Maran*

D2: 1st June 2020 V2: *Varada*

D3: 15th June 2020

D4: 1st July 2020

VII

Weather conditions prevailed from sprouting to initiation of active tillering

Dates of Planting	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	STI5 (˚C)	STI20 (˚C)	STII5 (˚C)	STII20 (˚C)	SM5 (%)	SM20 (%)
D1	V1	30.5	23.1	86.40	1.2	706.5	23.0	2.7	11.9	85.0	26.2	29.2	32.5	30.5	7.4	7.6
	V2	30.1	23.1	86.20	1.1	792.3	27.0	2.7	12.1	98.4	26.3	29.6	32.6	30.5	7.4	7.7
D2	V1	30.1	23.1	87.4	1.3	1286.3	39.0	2.1	11.6	122.9	26.0	29.1	31.9	30.1	7.8	8.2
	V2	30.4	23.1	87.50	1.3	1300.2	41.0	2.2	11.70	130.4	26.3	29.4	32.0	30.5	7.8	8.3
D3	V1	30.4	23.1	86.30	1.5	1125.4	36.0	3.1	13.4	150.9	25.7	29.0	32.5	30.1	8.9	9.4
	V2	30.4	23.1	86.00	1.5	1040.5	32.0	3.1	13.40	141.7	26.4	29.6	32.1	30.2	9.2	9.6
D4	V1	30.2	22.8	86.75	1.6	1429.1	44.0	2.9	12.7	173.2	25.4	29.1	33.0	29.9	9.9	9.6
	V2	30.2	22.8	86.77	1.6	1418.6	43.0	3.0	13.3	168.0	26.4	29.6	32.5	30.3	9.0	9.6

D1: 15th May 2020 V1: *Maran*

D2: 1st June 2020 V2: *Varada*

D3: 15th June 2020

D4: 1st July 2020

Weather conditions prevailed from active tillering to bulking

Dates of Planting	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	STI5 (˚C)	STI20 (˚C)	STII5 (˚C)	STII20 (˚C)	SM5 (%)	SM20 (%)
D1	V1	30.1	22.7	86.9	1.6	1149.7	37.0	2.9	13.7	141.4	25.3	28.1	32.2	29.2	8.9	9.3
	V2	30.3	22.6	86.3	1.6	1097.6	36.0	3.3	14.4	154.0	25.7	28.9	32.3	29.9	8.9	9.3
D2	V1	30.5	22.3	84.9	1.5	1015.3	37.0	4.0	15.4	175.0	25.2	28.8	32.9	30.1	8.9	9.2
	V2	30.5	22.2	84.8	1.5	1014.3	37.0	4.1	15.5	174.9	25.8	29.2	33.3	30.2	8.8	9.1
D3	V1	30.8	22.0	84.2	1.6	1003.8	33.0	4.1	15.3	157.2	25.1	28.5	32.8	29.7	8.9	9.2
	V2	30.9	22	83.9	1.7	1014.0	34.0	4.2	15.4	165.5	25.8	29.3	33.2	30.3	9.1	9.5
D4	V1	31.9	21.7	77	2.7	453.9	16	5.9	17.3	179.9	24.9	28.6	33.4	29.9	8.7	8.8
	V2	31.9	21.7	77	2.7	453.9	16	5.9	17.3	179.9	25.6	29.1	33.1	30.1	8.7	8.8

D1 : May 15th V1 : *Maran*

D2 : June 1st V2 : *Varada*

D3 : June 15th

D4 : July 1st

Weather conditions experienced from initiation of bulking to physiological maturity

Dates of Planting	Var	Tmax (˚C)	Tmin (˚C)	RH (%)	WS (kmhr^{-1})	RF (mm)	RD	BSS (hrs)	SRAD (MJ)	Evp (mm)	STI5 (˚C)	STI20 (˚C)	STII5 (˚C)	STII20 (˚C)	SM5 (%)	SM20 (%)
D1	V1	32.1	21.8	72.51	4.0	284.4	12.0	5.9	16.7	232.5	25.1	28.6	33.6	29.8	8.1	8.2
	V2	32.2	21.8	72.88	3.9	284.4	12.0	6.0	16.7	222.9	26.1	29.6	33.3	30.6	8.1	8.2
D2	V1	32.7	22.0	69.63	4.7	63.8	3.0	6.4	17.0	187.8	25.0	28.9	33.8	29.9	7.8	7.9
	V2	32.7	22.0	69.63	4.7	63.8	3.0	6.4	16.8	187.8	25.6	29.3	34.2	30.4	7.7	7.9
D3	V1	32.3	21.9	66.05	6.0	17.0	2.0	6.5	16.8	215.1	25.2	28.8	33.7	30.0	7.5	7.5
	V2	32.3	21.9	66.05	6.0	17.0	2.0	6.5	16.8	215.1	25.5	29.3	34.3	30.4	7.5	7.5
D4	V1	31.9	22.0	65.65	6.8	53.1	2.0	6.1	16.4	227.3	25.4	28.9	33.7	29.9	7.8	7.9
	V2	31.9	22.0	65.8	6.7	53.1	2.0	6.1	16.5	230.5	25.5	29.2	34.2	30.4	7.8	7.9

D1: 15th May 2020 V1: *Maran*

D2: 1st June 2020 V2: *Varada*

D3: 15th June 2020

D4: 1st July 2020

Appendix IV

ANOVA of different plant growth characters of 2019-2020 experiment

Plant height at different weeks after planting

Source of variation	DF	Mean sum of squares						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Date of planting	3	384.97***	338.01***	156.82***	165.41**	135.63**	89.60^{NS}	160.86**
Error (a)	9	7.51	9.35	6.31	10.12	10.53	23.36	14.72
Variety	1	9.09	48.99*	128.24**	188.71**	302.70**	379.16**	325.10**
DOP x Variety	3	39.19	8.99	12.38	12.90	9.08	34.90*	37.89**
Error	12	110.15	8.18	8.17	10.09	8.57	9.13	5.76

Plant height at different weeks after planting (contd.)

Source of variation	DF	Mean sum of squares							
		Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Date of planting	3	221.30	49.16	90.64	123.67^{NS}	174.79	127.28*	145.13*	146.28
Error (a)	9	254.44	35.64	248.72	274.84	311.97	30.37	34.42	41.92
Variety	1	395.98***	343.40***	444.08***	785.91***	852.62***	747.88***	693.64***	521.34**
DOP x Variety	3	99.18*	102.61*	124.23**	40.53*	101.26	30.70	22.61	13.39
Error	12	67.39	79.85	74.03	9.20	178.62	29.28	34.67	29.76

Appendix IV (Contd.)

Plant height at different weeks after planting (contd.)

Source of variation	DF	Mean sum of squares							
		Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23
Date of planting	3	182.85*	196.48*	215.83*	50.84	205.51*	163.53*	171.37*	171.37*
Error (a)	9	32.38	33.75	31.67	21.17	31.88	31.06	31.97	31.97
Variety	1	938.49***	956.43***	1075.2***	1543.87***	1000.88***	924.53***	899.17***	899.17***
DOP x Variety	3	38.92	43.14	44.20	2.60	36.12	35.58	33.13	33.13
Error	12	40.30	40.57	42.44	60.96	42.96	41.07	40.62	40.62

Leaf area

Source of variation	DF	Mean sum of squares						
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	105 DAP	120 DAP
Date of planting	3	8.02	168.44***	314.77**	221.98***	416.94***	109.77**	324.31***
Error (a)	9	2.10	1.98	30.74	15.43	27.92	8.71	5.40
Variety	1	1.04	1.97	146.01*	875.96***	193.04*	0.60	15.98
DOP x Variety	3	0.11	1.15	133.21*	344.27***	8.62	44.38*	22.55
Error	12	1.54	1.87	23.22	14.30	35.37	11.76	17.93

Appendix IV (Contd.)

Leaf area at different weeks after planting (contd.)

Source of variation	DF	Mean sum of squares					
		135 DAP	150 DAP	165 DAP	180 DAP	195 DAP	210 DAP
Date of planting	3	110.04***	46.81**	12.13*	31.98***	79.83***	60.21***
Error (a)	9	3.68	5.12	8.75	4.12	2.99	0.87
Variety	1	0.24**	10.59	24.37	4.33*	22.79	0.22
DOP x Variety	3	9.68	58.80***	36.04*	6.44*	9.93	0.06
Error	12	1.62	5.37	5.21	8.87	2.68	2.52

Number of tillers per plant

Source of variation	DF	Mean sum of squares						
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	105 DAP	120 DAP
Date of planting	3	8.50***	15.37***	22.60***	45.33***	93.38***	70.10***	112.92***
Error (a)	9	0.03	0.32	0.42	0.40	1.81	0.81	2.30
Variety	1	0.00	0.08	0.75	6.61*	8.00*	7.03**	23.29***
DOP x Variety	3	0.10	0.61	0.85	4.27*	6.92**	5.87**	1.70
Error	12	2.54	0.43	0.83	0.75	1.03	0.70	1.05

Appendix IV (Contd.)

Number of tillers per plant (contd.)

Source of variation	DF	Mean sum of squares					
		135 DAP	150 DAP	165 DAP	180 DAP	195 DAP	210 DAP
Date of planting	3	107.96***	77.95***	66.89***	70.08***	64.99***	64.99***
Error (a)	9	2.19	2.74	2.58	2.96	3.29	3.29
Variety	1	23.20*	13.45**	10.35**	8.25*	5.99	5.99
DOP x Variety	3	8.58	1.60	1.74	2.01	2.49	2.49
Error	12	3.10	1.21	0.93	0.97	1.99	1.99

Number of fully opened leaves

Source of variation	DF	Mean sum of squares						
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Date of planting	3	150.62***	107.95**	95.02***	0.18	59.97	491.12***	1680.83***
Error (a)	9	9.67	13.74	5.77	14.64	20.06	31.44	26.68
Variety	1	0.64	110.77*	102.80	1.08	197.05*	167.17*	157.31*
DOP x Variety	3	0.46	0.85	1.46	71.64	29.96	53.06	33.3
Error	12	4.70	20.68	40.91	22.28	24.77	19.23	22.5

Appendix IV (Contd.)

Number of fully opened leaves (contd.)

Source of variation	DF	Mean sum of squares							
		Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Date of planting	3	2392.71***	3121.51***	3541.0***	3967.2***	3690.7***	4078.9***	3422.9***	3985.7***
Error (a)	9	16.17	29.64	24.7	34.8	26.1	48.5	51.4	91.0
Variety	1	258.76**	402.24***	605.3***	852.2***	326.7*	243.6*	84.9	10.5
DOP x Variety	3	127.80**	103.21*	169.1**	151.0*	264.5**	734.3***	373.2**	466.6*
Error	12	15.78	17.46	17.0	26.3	39.6	29.1	49.9	82.5

Number of fully opened leaves (contd.)

Source of variation	DF	Mean sum of squares							
		Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23
Date of planting	3	3991.3***	4507.1***	4833.1***	4989.6***	4989.6***	5042.9***	5431.6***	5815.8***
Error (a)	9	68.3	42.2	48.7	51.8	51.8	46.7	48.5	48.6
Variety	1	291.1*	15.0	49.7	78.2	78.2	159.7	261.7	526.4
DOP x Variety	3	547.7**	926.2***	851.2**	1010.6***	1010.6***	1018.1***	1103.0***	1112.3
Error	12	54.3	73.3	84.3	80.1	80.1	70.6	73.2	83.5

Appendix IV (Contd.)

Girth of main tiller

Source of variation	DF	Mean sum of squares						
		30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	105 DAP	120 DAP
Date of planting	3	0.23***	0.10***	0.03***	0.02	0.01***	0.15***	0.15***
Error (a)	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Variety	1	0.18*	0.09	0.01	0.00	0.02	0.19	0.19**
DOP x Variety	3	0.00	0.02	0.00	0.01	0.00	0.06**	0.06*
Error	12	0.02	0.02	0.01	0.01	0.01	0.01*	0.01

Girth of main tiller (contd.)

Source of variation	DF	Mean sum of squares					
		135 DAP	150 DAP	165 DAP	180 DAP	195 DAP	210 DAP
Date of planting	3	0.02*	0.05***	0.01	0.06*	0.08***	0.06***
Error (a)	9	0.01	0.00	0.00	0.01	0.00	0.00
Variety	1	0.60***	0.61***	0.57**	0.25	0.33*	0.25*
DOP x Variety	3	0.00	0.00	0.00	0.02	0.00	0.00
Error	12	0.01	0.01	0.03	0.06	0.04	0.38

Appendix IV (Contd.)

Dry matter accumulation

Source of variation	DF	Mean sum of squares						
		30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	180 DAP	210 DAP
Date of planting	3	390131**	261747	176395	6089077**	15922448***	15577556***	63335223***
Error (a)	9	35393	97935	172789	602172	951833	949502	2258647
Variety	1	464648**	3645000***	2784800***	3786752**	4009404*	3969153*	56488841***
DOP x Variety	3	24627	83336	92000	272640	917119	894466	8429728*
Error	12	37608	76899	33979	225301	482648	463028	1793741

Phenological observations

Source of variation	DF	Mean sum of squares				
		Sprouting at 30 after planting	Number of tillers			Days to physiological maturity
			90 DAP	120 DAP	150 DAP	
Date of planting	3	2224.55***	93.38***	112.92***	77.95***	1598.11***
Error (a)	9	152.59	1.81	2.30	2.74	3.28
Variety	1	19.97	8.00*	23.29***	13.45**	75.03***
DOP x Variety	3	261.23	6.92**	1.70	1.60	13.36*
Error	12	197.28	1.03	1.05	1.21	3.20

Yield and yield attributes

Source of variation	DF	Mean sum of squares				
		Fresh yield	Dry yield	Length of rhizome	Width of rhizome	Internodal length
Date of planting	3	69894527***	69894527***	2.57**	0.43**	0.01
Error (a)	9	3218224	3218224	0.25	0.03	0.00
Variety	1	67982855***	67982855***	1.40*	0.02	0.00
DOP x Variety	3	8143912*	8143912*	0.32	0.06	0.00
Error	12	2115709	2115709	0.27	0.03	0.01

GINGER (*Zingiber officinale*) YIELD VARIABILITY UNDER DIFFERENT CLIMATE CHANGE SCENARIOS

by

FATHIMA SONA N

(2019-11-046)

ABSTRACT OF THE THESIS

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ABSTRACT

Ginger (*Zingiber Officinale*) is an important commercial spice crop grown from very ancient times in India. Because of its valued aroma and lemon flavour, it has spread to tropical and subtropical regions from the Indo-China region and became one of the earliest oriental spices known to Europe (Nybe and Miniraj, 2005). Species diversity and yield of spices are threatened due to the ever increasing temperature and changes in precipitation pattern. Since spices are grownboth in plains and high altitudes, it is important to assess the long term climatic changes within a region and its influence on productivity (Sing, 2008).

The present experiment was aimed to study the impact of climate change on growth and yield aspects of ginger crop under climate change scenarios of RCP 4.5 and 8.5. Ginger varieties, *Maran* and *Varada* were raised at Instructional Farm (IF) *Vellanikkara*, by adopting split plot design. The experiment was laid out with four dates of planting (15th May, 1st June, 15th June and1st July) as main plot treatment and two varieties (*Maran* and *Varada*) as sub plot treatments. Fourreplications were given for the experiment. The crop weather relationship was analysed with correlation with the help of SPSS software. Principal Component Analysis (PCA), a multivariate statistical technique was done in order to reduce the multicollinarity of large data sets of weather variables to substantially smaller sets of new variables. The developed principal components were utilized for model development using stepwise regression analysis. The future climate was estimated by climate change projections generated using CCSM4 models for 2030, 2050 and 2080based on scenarios RCP 4.5 and 8.5.

The life cycle of ginger was characterized by four distinct stages, *ie.,* sowing to 50% germination, 50% germination to active tillering, active tillering to bulking and bulking to physiological maturity. Duration taken for each phenophases found to vary for all the four date of planting in both *Maran* and *Varada*. The May 15th date of planting took more days to germinate compared to other date of plantings. The number of days taken for sowing to germination was positively correlated with maximum temperature, minimum temperature, rainfall and soil temperature in both varieties. The

number of days taken to attain physiological maturity also foundto be more in May 15th planted crop.

The weather experienced during various phenophases have significant influence on yield and other yield attributes of ginger crop. It was found that the yield of both varieties of ginger havepositive correlation with minimum temperature at all the four phenophases except bulking to physiological maturity. Maximum temperature observed at sowing to germination was positively correlated with yield of both *Maran* and *Varada*. At active tillering to bulking stage, rainfall, rainy days and minimum temperature showed a significant positive correlation with yield, but maximum temperature, wind speed and solar radiation showed a significant negative correlation with yield.

The Principal Component Analysis was carried out for ginger varieties *Maran* and *Varada* by using the weather parameters experienced in four stages *ie.,* sowing to 50% germination, 50% germination to active tillering, active tillering to bulking and bulking to physiological maturity. Weather parameters considered include maximum temperature (Tmax), minimum temperature (Tmin), rainfall (RF), rainy days (RD), relative humidity (RH), wind speed (WS) and solar radiation (SRAD). The statistical model was developed with principal components as independentand yield as dependent variable.

Projected climatic conditions of Vellanikkara, Thrissur under climate change scenarios of RCP 4.5 and 8.5 were downscaled from CCSM4 model. The projected climate of near century (2010-2039), midcentury (2040-2069) and end of century (2070-2099) were downscaled for the study. The projected yield of the ginger variety *Maran* was found to decrease at all planting datesexcept July 1st under both the RCP 4.5 and 8.5 scenarios. Under RCP 4.5 scenario, more reductionwas reported at the end of the century on May 15th (38%), June 1st (29%) and June 15th (54.5%) dates of planting. July 1st planted crop reported increase in projected yield under near, mid and end of centuries. More increase in yield was observed in midcentury (17.7%). Under RCP 8.5

scenario, May 15th (50.2%) and June 1st (20.3%) dates of planting reported the highest percentage of yield reduction during midcentury. June 15th date of planting, recorded the highest yield reduction of 52.6% at the end of the century. July 1st planting date recorded increase in yield and it was more in end of century (15.5%). In case of *Varada,* under RCP 4.5 scenario, more yield reduction was reported at the end of century during May 15th (24%) and June 1st (7.2%) dates of planting. During June 15th planting dates, near and end of century reported the same yield reduction of 24.9%. The July 1st planted crop reported an increase in yield, which was more (15.5%) during end of century. Under RCP 8.5 scenario, more yield reduction was observed in midcentury on May 15th (28.8%) date of planting. June 1st (6.6%) and June 15th (19.9%) dates of planting reported more reduction in end of century. July 1st reported more increase of 24% in end of century.

The yield reduction under projected climate change scenario of RCP 4.5 and 8.5 are related to the changes of different weather parameters from the required optimal value. The maximum temperature was found to increase in the future under both scenarios and the amount of precipitation showed a decreasing trend from the observed base period value. The yield reductionunder projected climate change scenarios were in agreement with the increment in maximum temperature and reduction in rainfall.