PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays* L.) TO PHOTOPERIOD AND TEMPERATURE

M. SWETHA SREE

B.Sc. (Ag)

MASTER OF SCIENCE IN AGRICULTURE

(CROP PHYSIOLOGY)

2017

PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays* L.) TO PHOTOPERIOD AND TEMPERATURE

BY

M. SWETHA SREE

B.Sc. (Ag.)

THESIS SUBMITTED TO THE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE

(CROP PHYSIOLOGY)

CHAIRPERSON: Dr. V. RAJA RAJESWARI

DEPARTMENT OF CROP PHYSIOLOGY

SRI VENKATESWARA AGRICULTURAL COLLEGE, TIRUPATI
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
GUNTUR – 522 509, A.P.

2017

DECLARATION

I, **M. SWETHA SREE,** hereby declare that the thesis entitled **"PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays* L.) TO PHOTOPERIOD AND TEMPERATURE"** submitted to the Acharya N.G. Ranga Agricultural University, for the degree of **MASTER OF SCIENCE IN AGRICULTURE** is the result of original research work done by me. I also declare that no material contained in this thesis has been published earlier in any manner.

Place : Tirupati

Date :

(M. SWETHA SREE)
I.D. No:TAM/2015-43

CERTIFICATE

M. SWETHA SREE has satisfactorily prosecuted the course of research and that the thesis entitled **"PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays* L.) TO PHOTOPERIOD AND TEMPERATURE"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has not been previously submitted by him for a degree of any university.

Place : Tirupati

Date :

(Dr. V. RAJA RAJESWARI)
Chairperson
Associate Dean
S.V. Agricultural College,
Tirupati – 517 502, A.P.

CERTIFICATE

This is to certify that the thesis entitled **"PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays* L.) TO PHOTOPERIOD AND TEMPERATURE"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** to the Acharya N.G. Ranga Agricultural University, Guntur is a record of the bonafide original research work carried out by **M. SWETHA SREE** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

Thesis approved by the Student's Advisory Committee

Chairperson	:	**Dr. V. RAJA RAJESWARI** Associate Dean S.V. Agricultural College, Tirupati – 517 502, A.P.	______________
Member	:	**Dr. P. LATHA** Scientist, Department of Crop Physiology, Institute of Frontier Technology, Regional Agricultural Research Station, Tirupati -517 502, A.P.	______________
Member	:	**Dr. T. PRATHIMA** Senior Scientist Agrometeorology Regional Agricultural Research Station, Tirupati – 517 502, A.P.	______________

Date of final viva-voce:

ACKNOWLEDGEMENTS

No creation in this world is a solo effort, neither is this thesis. I would like to take this opportunity to acknowledge all, who supported me directly or indirectly, bringing in this thesis to a really good shape.

*Firstly, I thank the almighty **GOD** for his love and blessings, without which I would not have been able to complete my studies hitherto and present this piece of work.*

*In explicable in fervent to my parents **Smt. Munagala Jhansi Rani** and **Sri Melnati Muneeswaraiah** under who's grooming I learnt the concepts of life. They have been a foundation of inspiration throughout my life. To their feet, I bow with my head with great reverence.*

*I am privileged to avail this opportunity to express my deep and heartfelt gratitude and veneration to my major advisor and chairman of the Advisory Committee, **Dr. V. RajaRajeswari, Associate Dean, S.V. Agricultural College, Tirupathi** for her impeccable and highly informative advice and guidance and for her incessant encouragement during the course of the study.*

*I am pleased to place my profound etiquette to the member of my Advisory Committee **Dr. P. Latha,** Scientist, Institute of Frontier Technology, RARS, Tirupati, for her amiable suggestions, benevolent and noble ideas and kind co-operation during the pursuit of my research work.*

*I wish to express my deep sentiments of gratitude and reverence to, **Dr. T. Prathima,** Senior Scientist, Agrometeorology, RARS, Tirupati of my Advisory Committee for her inspiring, meticulous and valuable guidance, constructive advice during the entire period of my investigation.*

*I am very much thankful to and feel it a great privilege to place on my record with sincere regards and thanks to **Dr. P. Sudhakar,** Professor and Head, Department of Crop Physiology, Tirupati for his keen interest, caring attitude, whole-hearted co-operation, inspiring and valuable guidance during the entire period of my investigation.*

*I express my fidelity and respectable regards to the staff members **Dr. V. Umamahesh,** Assistant Professor, Department of Crop Physiology, S.V. Agricultural College, Tirupati, for their valuable guidance, constant encouragement, constructive criticism, perspicacity and meticulous scrutiny which embellished the study.*

I am greatly beholden and accolade my highest respects with deep sense of honour in expressing my over whelming sense of affection and gratitude to my loving brothers ***Niranjan Kumar****,* ***Sai Mourya Theja, Ramakrishna, Charan, Chaitanya*** *and also my beloved sisters* ***Thanuja*** *and* ***Harini.***

I feel elated to express my bountiful thanks to my family members ***Late Melnati Ramachandraiah, Munirthnamma, Munagala Govindarajulu,*** *and my family members* ***Pushpamma, Bharathy, Nirmala, Susheelamma, Ramana, Shekhar*** *and* ***Ramesh*** *for their undiminishing love, benign care and zealous encouragement throughout this endeavor and also my special thanks to my loving aunts* ***Chandra Kumari*** *and* ***Shanthamma.***

With utmost satisfaction I acknowledge the enormous help of my colleague ***Akhila*** *and* ***Nagalakshmi*** *also my Juniors* ***Surekha, Sai Maheswari, Pavani and Bharghavi*** *for their friendly assistance and valuable cooperation during my study.*

It gives me immense pleasure to express my profound thanks to my Seniors ***Usha, Leshma****,* ***Sreelatha, Aparna****,* ***Rajitha, Reshma, Zuby, Haseena, Merlin, Ashwathi, Ramya, Yohan, Venkat (Smart Centre), Somla Naik*** *and* ***Mrudula*** *for their constant encouragement to bring out my best in all endeavours.*

I respectfully acknowledge my gratitude to ***Sri A. Muneendra Babu,*** *Farm Superintendent,* ***Sri T. Lokanadham,*** *Farm Manager and* ***Sri M. Mahendra,*** *Agriculture Extension Officer and other field staff for their sustained help and cooperation during my research work with utmost satisfaction.*

Diction is predilection to express my heartful thanks to my joyful friends gallery, ***Tressa, Manisha, Divya, Vasavi, Sushu, Bharathy, Prassu, Bhuvana, Maneesha, Kalai, Sandhya, Mahuravani, Sreevani, Krishna, Tushar*** *and* ***Sravani*** *for their company, affection and encouragement during my study period.*

I am very thankful to ***Smt. Sirisha, Shoba Rani, Geetha*** *and* ***Valli*** *Technical Assistants, Agrometeorology, RARS, Tirupati for their help, friendly assistance and valuable cooperation during my research work.*

I extend my sincere thanks to ***Sri Srinivasan,*** *who helped me in successful completion of this humble piece of work.*

I express my thankfulness to ***Nagaraja, Damodhar*** *and* ***Sudhakar*** *for their timely and invaluable help to carry out the analysis in the lab.*

Special thanks to staff and non-teaching staff of RARS, Tirupati for their timely help and proper guidance during the pursuit of my research work.

I am grateful to ***Acharya N.G. Ranga Agricultural University****, Hyderabad for providing me with the opportunity and financial assistance to pursue my post graduation.*

In finale, I thank all my well wishers and others who helped me directly or indirectly not placed here, for their kind cooperation and support rendered to me.

Swetha Sree...

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF PLATES

LIST OF ABBREVIATIONS AND SYMBOLS

%	:	Per cent
@	:	At the rate
°C	:	Degree Celsius
°E	:	Degree east
°N	:	Degree north
µg	:	Micro grams
AGDD	:	Accumulated Growing Degree Days
APSIM	:	Agricultural Production System Simulation
CD	:	Critical difference
CERES	:	Crop Environment Resource Synthesis
CGR	:	Crop growth rate
CIMMYT	:	International maize and wheat improvement Centre
Cm	:	Centimetre
cm^2	:	Square centimeter
d- Index	:	Willmott d index
DAP	:	Di ammonium phosphate
DAS	:	Days after sowing
day^{-1}	:	Per day
dSm^{-1}	:	Decisiemen per metre
DSSAT	:	Decission supporting Agrotechnology Transfer.
et al.	:	and other people
EVP	:	Evaporation
Fig	:	Figure
FN	:	Fortnight
g $plant^{-1}$	:	Gram per plant
G	:	Gram
g^{-1}	:	Per gram
GDD	:	Growing degree days
ha^{-1}	:	Per hectare
HI	:	Harvest index
HTU	:	Helio thermal Units
HTUE	:	Heliothermal heat use efficiency
HUE	:	Heat use efficiency
K	:	Potassium
Kg ha^{-1}°C day^{-1}	:	Kilogram per hectare per degree Celsius per day
Kg	:	Kilogram
L	:	Litre
LAD	:	Leaf Area Duration

LAI	:	Leaf area index
M	:	Million
m.ha	:	Million hectare
m.t	:	Million tonnes
m^{-2}	:	Per square meter
MAE	:	Mean Absolute Error
MBE	:	Bias
mg	:	Milligram
MOP	:	Muriate of potash
N	:	Nitrogen
N	:	North
NAR	:	Net assimilation rate
NS	:	Non-significant
^{O}C day	:	Degree Celsius per day
P	:	Phosphorous
PAR	:	Photosynthetically Active Radiation
$Plant^{-1}$	:	Per plant
ppm	:	Parts per million
PTU	:	Photothermal units
r	:	Correlation Co-efficient
R^2	:	Regression Co-efficient
RGR	:	Relative growth rate
RH I	:	Morning relative humidity
RH II	:	Afternoon relative humidity
RH	:	Mean Relative humidity
RMSE	:	Root mean square effort
SEm	:	Standard error mean
SS	:	Sunshine hours
TDM	:	Total dry matter
Tmax	:	Maximum Temperature
Tmin	:	Minimum Temperature
viz.,	:	Namely
WOFOST	:	World Food Studies

ABSTRACT

Name of the Author	:	**M. SWETHA SREE**
Title of the Thesis	:	**PHENOLOGICAL RESPONSES OF MAIZE (*Zea mays L.*) TO PHOTOPERIOD AND TEMPERATURE**
Major Advisor	:	**Dr. V. RAJARAJESWARI**
Degree to which Thesis is submitted	:	**MASTER OF SCIENCE**
Faculty	:	**AGRICULTURE**
Major field	:	**CROP PHYSIOLOGY**
University	:	**ACHARYA N. G. RANGA AGRICULTURAL UNIVERSITY**
Year of submission	:	**2017**

The experiment on phenological responses of maize (*Zea mays. L*) to photoperiod and temperature was conducted at Tirupathi located at 13.65^{0}N and 79.42°E of Southern Agro-climatic region of Andhra Pradesh. The experiment was conducted during *kharif*, 2016 in a split plot design with three replications. The treatments included are three hybrids (DS 900M, Pinnacle and CP818) of maize and dates of sowing (June II FN, July I FN, July II FN and August I FN)

The data on crop weather interactions interms of temperatures (GDD-Growing degree days), Day length (PTU- Photothermal units), Sunshine hours (HTU) and HUE (heat use efficiency) were calculated for the three hybrids sown at different dates of sowing. The data reveals that Pinnacle hybrid recorded higher accumulation of GDD (3053.3°C), PTU (3615.1°C day hour) and HUE of 1.0 kg ha^{-1}°C day^{-1} compared to D.S 900M and CP818. Incidentally the hybrid Pinnacle recorded higher physiological efficiency interms of leaf area index, drymatter accumulation and kernel yield and its attributes compared to other two hybrids.

Among the four dates of sowing photothermal units *i.e.,* GDD, HTU, PTU varied across the different growth stages. First date of sowing (June II FN) had favourable agro-climatic conditions particularly temperature, day length and sunshine hours interms of higher accumulated GDD, PTU and HTU from sowing to physiological maturity compared to other dates of sowing. Consequently LAI, drymatter accumulation and yield attributes

were higher from the crop sown early *i.e.*, June II FN. This early planting crop resulted in higher kernel yields and Harvest index compared to delay sowings because of higher heat use efficiency of 1.2 kg ha^{-1} ^{o}C day^{-1}. LAI and drymatter accumulation showed significantly positive correlation with yield at different crop growth stages.

Using the data obtained from the field experiments conducted during *kharif*, 2016. The experimental file (AGCG1601MZ), weather file (ACGC2016), soil file (ACGC060016) were created for CERES-Maize validation. The crop genetic coefficients already developed for the three hybrids were also used as input for CERES-Maize validation. The model validated excellently for grain yield, number of days to anthesis and physiological maturity, number of grains per m^{-2} were as it was fair for unit grain weight at maturity and poor for stover weight and harvest index.

It is concluded that Pinnacle hybrid sown during second fortnight of June is effective interms of better accumulation of temperature, photoperiod and sunshine hours especially at grain filling stage there by higher dry matter, kernel yield and Harvest index. Estimation of heat use efficiency is an useful indicator for appraisal of yield potential of maize in different dates of sowing.

Chapter ~ I

Introduction

Chapter – I

INTRODUCTION

Maize is the third most important cereal crop species in the world after wheat and rice. It is grown across a wide range of climates, but mainly in the warmer temperate regions and humid subtropics. Maize has multiple uses, including human foods, animal feeds and the manufacture of pharmaceutical and industrial products. It is the staple food source for people in many countries. As an animal feed it is highly desirable because of the high energy and feed value of the kernel, leaf and stem. It is becoming increasingly important in many countries for industrial and pharmaceutical applications. It can be used to produce starch, ethanol and plastics and as a base for antibiotic production.

Over the past 40 years the total global area sown to maize has increased by about 40 per cent, and production has doubled. The United States produces 40 per cent of the world's harvest, other top producing countries include China, Brazil, Mexico, Indonesia, India, France and Argentina. Worldwide production of maize is more than rice and wheat. Maize is cultivated on nearly 178 m ha in about 160 countries and contributes to 50 per cent to the global grain production. In India maize constitutes 9 per cent of total volumes of cereals and is third most important crop after rice (42%) and wheat (32%). In India maize is cultivated in an area of about 9.72 ha with production of 24.35 lakh tonnes and productivity of 2583 kg ha^{-1}. In Andhra Pradesh it is cultivated in an area of 864 ha with production of 3658 tonnes and productivity of 4234 kg ha^{-1} (www.Indiastat.com, 2014).

Global climate change has been increasing significantly in industrial era. The major green house gases like CO_2, NH_4, N_2O and CFC has been increasing at alarming rate in the recent past. Intergovermental Panel on

Climate Change (IPCC) projects that with the current scenario the global mean temperature rises between 1.56 to 5.44°C by the year 2100 (IPCC, 2007). Change in the precipitation, temperature and vapourations can be known by Global circulation models (GCM's). The change in the climate has spatiotemporal variations. Global climate change has effect on the crop productivity in the world and particularly in India.

Climatic variability has great impact on food production. The variation is especially related to abnormal rainfall, drought, temperature and photoperiodism. Of these changes temperature and photoperiod has great influence on the crop production.

Maize is a C_4 (tropical) plant and uses carbon dioxide, solar radiation, water and nitrogen more efficiently during photosynthesis than C_3 plants. Most suitable temperature for germination is 21°C and for growth is 32°C (Jain, 1973). Extremely high temperature, moisture stress and low humidity during flowering damage the flowering and the foliage, desiccation of pollen and interfere with the pollination resulting in poor grain formation. Thus, rate of development of maize from planting to anthesis is a function of temperature rather than photosynthesis (Brower *et al.* 1970). Simulations based warmer climate change scenario have shown that maize yield is expected to decrease by more than 5 per cent by 2050 (Waongo *et al*. 2015).

Temperature increases can impact crop production in a number of ways, but arguably the most important of these is the impact of temperature on crop phenology. Plant phenology is one of the major factors determining yield of crop. Temperature and photoperiod are the two important environmental factors affecting phenological development. The influence of temperature on phenology and yield of crops are expressed under the accumulated heat units system (Sikdar, 2009).

The phenology of a crop will determine its adaptation to a region, its ability to mature and set grain within a growing season, and the synchrony of key developmental phases with ambient environmental conditions critical for productivity. The phenology of the plant varies with the cultivar, planting dates and growing conditions. Plants have a definite temperature requirement before they attain certain phenological growth stages and to forecast the phenology and crop production attributes for a large acreage their has been development of crop models. (Jones *et al*. 2003).The heat unit system is adopted to predict the dates of attaining crop growth stages. Though maize is a day neutral plant, flowering and maturity of genotypes are dependent on available temperature and sunshine hours and is location specific. (Rao *et al.* 2000). Hence the knowledge on the calculation of the heat units i.e., Growing degree days (GDD), Heliothermal units (HTU), Photothermal units (PTU) and heat use efficiency (HUE) are the basic principles to understand the phenology and follow proper planting dates for different genotypes over temporal and spatial separations. Sowing time is probably the most important for crop production because of the differences in weather at sowing time between the season and also among the hybrid

Crop modeling is defined as the science and art of mimicking the growth and development of the crop. A model is a simplified representation of a system. Crop models are used in defining research priorities, technology transfer, yield estimation, as well as for predicting the effects of climate change. A well validated crop simulation model can simulate crop growth, development and yield with accuracy. It also serves as a viable tool for optimizing crop production. The use of modeling tool is gaining importance day by day. Simulation is the building of mathematical model and the study of their behaviour (Dewitt, 1965).

Several dynamic simulation crop models such as CERES, SUCROS, WOFOST and APSIM have been developed in the last few decades. Among these CERES –Maize model a part of DSSAT is one of the most widely used model (Jones and Kiniry, 1986; Jones *et al.* 2003). Consequently, differences in model prediction of crop developmental phases can have significant impacts on the accuracy of the effects of forecast climate change on crop productivity. There are a variety of thermal functions such as GDD, PTU, HTU and HUE in current crop models that capture the relationship between temperature and maize development. These functions vary in a number of ways, including parameter values, the quantity and quality of the data from which they were formulated, the complexity of the algorithm used to capture the relationship. In assessing the impact of temperature on crop productivity, assumptions are generally made about the hybrids adapted for a region or the date on which the hybrid to be planted. It is also imperative to validate CERES-Maize model in this southern agro-climatic zone to predict maize yields in response to photoperiod and temperature under different dates of sowings.

The experiment is conducted at Tirupati located at 13.65°N and 79.42°E, which is situates in southern agro climatic region of Andhra Pradesh. Studies on effect of photoperiod and temperature on physiological indices due to climatic variation was less attempted. An assessment on the impact of climatic variability on maize would provide basic information required for evaluating climatic potential of the region. In southern zone variability in photoperiod is less compared to temperature which is highly variable. Accordingly, maize crop yields are highly variable in this region across the seasons as well as among different dates of sowings.

Hence studying temperature and photoperiod interaction on different growth stages of maize crop with respect to accumulation of dry matter and its partitioning, is a research priority.

OBJECTIVES

1. To study the influence of photoperiod and temperature on various growth attributes dry matter partitioning and yield in maize genotypes.
2. To correlate the effect of photothermal units on various phenological growth stages of maize.
3. Validation of CERES-Maize model for southern agro-climatic zone.

Chapter ~ II

Review of Literature

Chapter – II

REVIEW OF LITERATURE

Three important climatic parameters viz., temperature, rainfall and light are most important for optimum crop growth and development thereby exploits the potentiality of crop. Among these temperature plays a vital role in almost all the biological processes of crop plants. The effect of temperature on crop is accounted through the concept of heat unit which is based on the fact that crop needs certain heat units to complete a stage of its ontogeny. Maize being highly sensitive for temperature and photoperiod, its sowing time assumes greater importance for higher sustained production and efficient resource use and conservation.

The variation in sowing date in maize modifies the radiative and thermal conditions during its growth. Temperature affects the duration of crop growth (Warrington and Kanemasu, 1983) and final leaf number (Hesketh *et al.* 1969; Tollenaar and Hunter, 1983) and leaf canopy development (Warrington and Kanemasu, 1983) which define crop leaf area index, thereby determine the proportion of the incident radiation intercepted by the crop and accumulation of dry matter. The grain yield improvement of maize hybrids appears to be the result of increased dry matter accumulation (Tollenaar, 1989). Plant phenology is one of the major factors determining yield of crop. Temperature and photoperiod are the two important environmental factors affecting phenological development.

Temperature based indices such as growing degree days (GDD), Heat Use efficiency (HUE), Heliothermal units (HTU) and Photothermal units (PTU) can be relatively useful in predicting growth and yield of crops. Efficiency of converting heat into drymatter depends on the genetic factors, sowing time and crop type (Rao *et al.*, 1994).

2.1 CROP WEATHER RELATIONSHIPS

2.1.1 Effect of Temperature

Rouanet (1987) reported the ideal temperature requirement for germination of maize crop is from 16 to 32°C. According to Sprague and Dudley (1998), optimum germination and emergence occurs when temperatures reach 20 to 22°C. According to Wallace and Bressman (1937), maize usually emerges in 5 to 6 days if the soil is wet enough and at an average temperature of 21°C.

According to Sprague and Dudley (1988) air temperature around 25 to 35^0 during the early vegetative stages are considered optimum for rapid leaf growth. Increase in temperature during vegetative growth stage hastened growth rate more than developmental rate resulting in taller plants with higher total biomass.

Temperatures of around 24°C during late vegetative stage resulted in yields near normal (Sprague and Dudley, 1988). The optimum temperatures for this period range from 21 to 33°C. Grezesaik *et al*. (2008) observed increased leaf area and dry weight of maize at 15°C night temperature and reduced relative growth and net assimilation rate with decrease in night temperature (<15°C). LAI and LAD were significantly higher during winter (Nov-April) over monsoon sown crop due to low day/night temperatures and high cumulative sunshine duration (Kumar and Singh, 1999).

The duration of grain filling decreased with increasing temperature, and the shorter grain-filling period was often associated with lower grain yield (Hunter *et al*., 1974; Badu-Apraku *et al*., 1983). However, even with shorter duration of grain-filling due to higher temperature, the grain yield was unchanged (Muchow, 1989) due to coincidentally higher incident radiation with higher temperatures. Mean temperature of 24.8°C during the grain filling period resulted in maximum grain size through kernel growth rate of 6.84 mg day and an effective grain filling of 30.9 days (CIMMYT, 1975).

More number of grains cob were observed when the day/night temperature regimes during winter was 20-27 / 15-18°C as against lesser grain number obtained during monsoon with higher temperature regimes (30-35 / 25-28°C) during the corresponding phase (Kumar and Singh, 1999).

Endres and Mudstock (1989) noticed reduced grain filling period due to reduction in air temperature and solar radiation from silking to maturity stage.

2.1.2 Effect of Solar Radiation

Radiation is one of the important environmental parameters in maize growth and development; it is responsible for the formation of dry matter through photosynthesis. The role of radiation within maize is not limited only to photosynthesis, but it is also necessary for photo-hormonal reactions (Hatfield, 1977).

Total dry matter production of a crop is known to be proportional to the total amount of intercepted radiation, which itself is largely determined by the size of leaf area and its distribution with time (Biscoe and Gallagher, 1978).

LAI of 3.0 is generally required for the interception of 90-95 per cent of incoming radiation (Hipps *et al*., 1983).

The variation in sowing date in maize modifies the radiative and thermal conditions during its growth. The amount of incident radiation and its proportion that is intercepted by the crop directly determines crop growth rate. Linear relationship between growth intercepted PAR in maize was reported by Andrade *et al.* (1999).

The first prerequisite for high yields is more production of total dry matter (TDM) per unit area. The principal means for enhancing TDM including a) optimizing the assimilate area LAI (Leaf Area Index) and LAD

(Leaf Area Duration) to enhance the interception of photosynthetically active radiation (PAR), b) improving the radiation use efficiency and redistribution of photosynthates in order to maximize economic yield.

2.1.3 Relative Humidity

Afternoon relative humidity range during tasseling and silking should be about 75 per cent and any variation could influence the yield. Similarly, maximum relative humidity range during the same phenophase could vary from 90-92 per cent; and as per statistical analysis, one per cent increase during this period reduces yield and 1 per cent decrease will have beneficial effect on maize yield. It was observed that grain yield of maize positively correlated with relative humidity at flowering and pollination (Huda *et al*., 1976 and Baktash, 1985).

2.1.4 Photoperiod

The critical photoperiod for maize is 12.5 hr. photoperiod extension increased the duration of the period from emergence to tassel initiation and increased the number of leaves (Birch *et al*., 1998).

2.2 PHOTOPERIOD AND TEMPERATURE INTERACTIONS

2.2.1 Growing Degree Days

Dhiya and Narwal (1989) reported that maize cultivars showed variation among the sowing dates depending on the temperature during crop growth and phase and also cultivar.

Thavaprakash *et al.* (2007) indicated that the accumulated temperature could be utilized for studying biomass accumulation pattern at different phenological stages which influences plant productivity in baby corn. The experiment was conducted in four seasons late rabi 2002, *kharif* 2002, late rabi 2002-03 and summer 2003. Heat units required to attain individual growth stages varied among seasons. During *kharif* 2002 season, required degree days to attain seedling (363.3) and peak vegetative stages (749.3) was higher were as during late rabi 2002 season, all the stages required only minimal heat units.

Pandey *et al*. (2010) also reported lower consumption of heat units under delayed sowing (October 25) in maize. The requirement of GDD was higher for normal growing condition than the late growing condition. This was due to longer period for all the phenological stages in the normal growing condition. Late sowing decreased the duration of phenology as compared to normal sowing due to fluctuated unfavourable high temperature during the growing period. So, the requirement of heat units decreased for different phenological stages with late sowing

Girijesh *et al.* (2011) indicated a higher degree of linear relationship between GDD and drymatter accumulation of maize across the dates of sowing. The maximum heat unit of 1768.8 degree days from sowing to physiological maturity were recorded by sowing in first fortnight of July and is almost equal to June first fortnight sowing (1766.8 degree days). sHowever, highest heat units were recorded in June first fortnight sowing at seedling stage (30 DAS).

Gowda *et al.* (2013) reported that GDD required for Kargil 900M gold from planting to physiological maturity is 1330.7 to 1611.0^{o}C days in 2010 and 1244.8 to 1523.7^{o}C days in 2011. The experiment was conducted under four planting dates viz., June first fortnight, June second fort night, July first fortnight and July second fort night with four cropping systems and resulted that June first fortnight sown maize took significantly more number days (111 days) and growing degree days (1569.1) to complete physiological maturity and recorded high heat use efficiency (0.363 g plant^{-1} °C day $^{-1}$) as compared to subsequent delayed sowing but was on par with June II fortnight sowing.

Ahmad *et al.* (2016) reported that increase in the maize yields might be due to increased days of GDD, PTI and HTU at tasseling, silking and physiological maturity by spraying of chemicals viz., Ascorbic acid, Hydrogen peroxide and Salicylic acid during early and late planting dates which increases the duration of assimilates towards grain formation. Early planting (1^{st} Feb) required lower GDD than normal planting (22^{nd} Feb) i.e., earlier planted crop required 32, 651, 713 and 1804 GDD for emergence, tasseling, silking and physiological maturity whereas normal planting (22^{nd} Feb) took GDD of 54, 811, 878 and 1230 respectively. The variation of sunshine hours recorded at different developmental stages of maize has affected the magnitudes of the HTU though there were records of higher GDD at advanced stages of the maize.

Growing degree days were found to be significant both at earing and maturity of different dates of sowing. Significantly higher GDD from sowing to earing were recorded in October 25 date of sowing

2.2.2 Photothermal Unit

Gouri *et al.* (2013) reported phenothermal index increased with delay in sowing during silking to maturity phase in maize. The crop sown in first fortnight of January recorded higher photothermal index (14.6) as compared to crop sown during other dates. The crop matured on accumulating 1324 ± 48 degree days regardless of sowing dates.

Gowda *et al*. (2013) reported phenothermal index (PTI) in maize at different phenophases differed significantly due to influence of planting dates. June first fortnight sown maize recorded significantly higher PTI at seeding stage (14.76), vegetative growth (14.11), at flowering and fertilization (14.14) as compared to subsequent sowing dates. However, during grain filling and maturity period PTI increased significantly with delayed sowing (14.50) in July 1^{st} fortnight sowing to 14.07 in June 1^{st} fortnight sowing).

2.2.3 Heliothermal Unit (HTU)

Girijesh *et al.* (2011) reported that grain yield in maize was inversely related to heliothermal units. HTU were higher during first fortnight of July from sowing to physiological maturity because the growth of later sown crops extended upto November second week in monsoon ceases and grain filling stages of delayed sown crops subjected to bright sunny days coupled with long dry spells. HTU under delayed sowings was higher and the reduction in yield due to delayed sowing was only to the extent of 9.4 percent in short duration genotypes and 40 percent in other genotypes.

Hariram *et al.* (2012) reported consumption of HTU was higher in case of early sown crop than the late sown crop in wheat. This might be due to delay in maturity in late sown crop. October 25 sown crop accumulated higher HTU at earing (6286.6°C day hour) compared to all other dates of sowing and was on par with November 5 (5984.5°C day hour) dates of sowing which was statistically proven.

Gouri *et al*. (2013) observed that HTU required in different dates of sowing ranged from 9087 to 9709. Maize crop sown in first fortnight of January recorded higher heliothermal units. However, early sown crop during first fortnight of November also recorded higher HTU due to comparatively higher number of growing degree days coupled with more number of sunshine hours than other dates of sowing.

2.2.4 Heat use Efficiency (HUE)

Thavaprakash *et al*. (2007) studied corn under four seasons of late rabi 2002, *kharif* 2002, late rabi 2002-2003 and summer 2003. Higher HUE was recorded in late rabi 2002 season. Higher HUE attributed to higher grain yield as the temperature was optimum throughout the growing period, it utilized heat more efficiently and increased biological activity that confirms higher yield. Optimum mean temperature and short day length during late rabi 2002 season resulted higher corn yields via optimum metabolic activities thereby high Heliothermal use efficiency.

Girijesh *et al.* (2011) reported a short duration genotype of corn exhibited a higher HTUE than longer duration genotypes. The crop was sown in three dates of sowing (first fortnight of June, second fortnight of June and first fortnight of July) with six cultivars of corn (NAC 60004, NAC-6002, All rounder, 30R-77, NAH-2049 and 30-V 92). Crop sown in first fortnight of June recorded high HTUE (0.143 g m^{-2} deg day^{-1}) at maturity with total dry matter of 251.8 g $plant^{-1}$. Short duration genotype (NAC-6002) exhibited high HTUE than longer duration genotypes due to exposure of long duration genotypes to bright sunny days coupled with long dry spells at their grain filling stage.

Rajesh *et al.* (2015) resulted HUE for different genotypes of wheat under different environmental conditions varied considerably. Higher HTUE was observed in kanchan followed by GW-273 but with respect to sowing dates maximum HUE was observed under 5 December (0.46 g m^{-2} deg day^{-1}) sowing followed by 15 December (0.44 g m^{-2} deg day^{-1}) sowing and minimum HUE was observed under January 5 (0.37 g m^{-2} deg day^{-1}).

Shrestha *et al*. (2016) reported GDD was similar in different planting dates in maize and Hue was higher in early dates of sowing (7^{th} April) were as PTI was higher in delayed sowing days (7^{th} May) of the crop.

2.3 MORPHOLOGICAL AND GROWTH ATTRIBUTES (AT PHENOLOGICAL GROWTH STAGES OF CROP)

2.3.1 Plant Height

Yusafzai *et al.* (2002) studied the effect of sowing dates (15 July, 30 July and 15 August) with six maize cultivars in *kharif* season. Early sowing 15 July reported higher plant height (152cm) and grain yield (4419 kg ha^{-1}). Delayed sowing 15^{th}August resulted in lower yields comparatively. Among the cultivars Sarhad reported highest plant height and grain yield (3354 kg ha^{-1}).

Kosgasago (2006) reported significant difference in plant height among the dates of sowing in maize crop. Early planting date showed highest plant height (178.4 cm) and late planting date resulted lowest height (146.1 cm) and also superior yields were seen in case of early planting (6426.4 kg ha^{-1}) compared to late planting (4783.6 kg ha^{-1}). Plants with early sowing reached flowering and maturity in 70 DAS and 183.4 DAS respectively compared to late sowing i.e., 77DAS and 181.1 DAS respectively.

Environmental changes associated with different sowing dates (sunshine, temperature) have a modifying effect on the growth and development of maize plants. Each hybrid has an optimum sowing date, and greater the deviation from this optimum (early or late sowing), the greater yield loss. (Berzsenyi and Lap, 2001)

Overall impact of delayed planting in corn is also reflected in the form of shortening of plant height, reduction in number of internodes, days to heading, days to maturity and grain filling period and ultimately in the reduction of yield and yield components (Miralles *et al*. 2001; Rahman *et al.* 2009).

Williams and Lindquist (2007) showed that a sweet corn hybrid grew 9 per cent taller when planted the third week of June in Illinois compared with the first week of May.

Williams (2008) reported that maize crop sown in the mid June and early July resulted in 11 to 25 per cent fewer maximum leaves compared to earlier planting dates. Delayed planting resulted in fewer leaves and slower rates of leaf appearance which decreased by 22 per cent.

Azadbakth *et al.* (2012) showed significant difference among the planting dates from viz., April 29, May 11, May 2 and June 4 on three maize hybrids.The mean plant height was 238.3cm was highest during April 29 and the plant height was reduced as the planting dates postponed.

Hussain *et al.* (2012) reported that interaction between sowing dates and wheat cultivars had significant effect on plant height, tillering capacity, grain and straw yield, HUE and TDM accumulation of wheat. Maximum plant height was observed in 10^{th}Nov planted LS-08 (115.9 cm) while TD-1 planted on 10th and 25^{th}Dec recorded minimum plant height

Amjadian *et al.* (2013) reported that plant height of maize among the different dates of sowing was reduced during flowering stage. Early planting crop showed highest plant height compared to late planted crop.

Hossein *et al.* (2014) reported that maize varieties SC108 and SC301 sown at different dates (22^{nd} June, 1^{st} July and 11^{th} July) and planting densities. Irrespective of genotypes early sown 22^{nd}June crop resulted in higher plant height (198.4 cm) and SC108 resulted in higher plant height.

2.3.2 Dry matter Partitioning

Dry matter accumulation in maize plants is gradual and low during early stages of growth and gets rapid after 45 DAS after sowing to till maturity. Murthy *et al.* (1973) observed dry matter production in maize of 0.5, 3.3 and 3.5 g $plant^{-1}day^{-1}$ at seeding, silking and grain filling stages respectively. Both photoperiod and temperature affected plant DM yield, with the longer photoperiod and cooler temperature producing the highest final dry weight.

Hunter *et al*. (1997) reported that the longer photoperiod and cooler temperature treatment produced the highest final plant dry weight in maize.

Temperature plays a dominant role during vegetative growth and grain filling (Stewart *et al.* 1998). High temperature during these stages resulted in limited assimilate availability or reduced capacity for continued metabolism due to kernel moisture decrease and this leads to reduced grain filling period. This shortened grain filling can lead to a complete cessation of kernel growth through formation of a black abscission layer. Resulting artificial shortening of the grain filling duration reduced kernel size (sink) and ultimately yield.

Nielsen *et al*. (2002) reported that flowering and grain maturation timing of three dent corn hybrids were altered when planted at increasingly later dates. The net effect of delayed planting on the calendar timing of grain maturation was a reduction of about 9 days for late versus early plantings or about 0.25 d per day of delayed planting.

According to Zheng *et al.* (2005) in China, maize requires particular temperature and day length in various developmental stages for successful growth and yield. From sowing to emergence 12, 25 and 31°C minimum, optimum and maximum temperature, respectively and from emergence to tasseling 14.8, 24 and 33°C minimum, optimum and maximum temperature, respectively and 12.5 hours of day length; from tasseling to silking 14.9, 28 and 33°C minimum, optimum and maximum temperature, respectively and 12.5 hours of day length and from silking to maturing 12.7, 25 and 33°C minimum optimum and maximum temperature, respectively and 12.5 hours of day length.

Sulochana *et al.* (2015) indicated that the maximum dry matter accumulation plant^{-1}of maize was produced in June 30 sown crop but on par with July 15 sown crop. Date of sowing did not influence dry matter accumulation plant^{-1} at 15, 45 and 75 DAS by Pratap makka-5 at 30 DAS (3.27 g), 45 DAS (39.04 g) andharvest (157.13 g) which was significantly superior over PEHM-2, HQPM-1 and Pratap QPM-1 by 6.2, 9.4, 10 per cent at 30DAS, 8.1, 12.2 and 14.2 per cent at 45 DAS and 4, 5.3 and 6.1 per cent at harvest, respectively but on par with BIO-9637.

2.3.3 Leaf Area

Daynard (1972) found a reduction in leaf dimension in maize when the day/night temperature was raised from 25°C / 20°C to 30°C / 25°C. The optimal average temperature for leaf size and leaf area per plant appears to be in the range of 20-25°C, since leaf dimensionand leaf area per plant. It also decrease by lowering the average temperature below 20°C.

Wilson *et al.* (1995) reported temperature can affect leaf area per plant in maize. The plants grown at an average temperature of 21°C had a higher LAI and a greater leaf area duration after silking than plants grown at average temperatures of 25°C and 18°C. The higher LAI and greater leaf area duration after silking resulted in higher dry weight increase after silking.

Warrington *et al.* (1983) reported that leaf appearance rates varied up to three or four-fold at any particular temperature in corn. Rate of change in leaf appearance rate with temperature within the 16 to 26°C range. However, more similar ranging from 0.21 to 0.3 leaves day^{-1} $°C^{-1}$. Both leaf initiation and leaf appearance rates increased with an increase in photoperiod, particularly under constant 18°C conditions.

Muchow and Carberry (1989) obtained mathematical relationships describing phenology, development and maintenance of leaf area for use in crop-simulation models describing phenology and maintenance of leaf area in semi-arid tropical environments. Leaf appearance increased exponentially with thermal time and the relationship was coincident for all sowings.

Madhavi (2007) reported that LAI was significantly higher in maize at all growth stages during the third June planting date and decreased with delay in planting date in second week of July and first week of august.

Dahmardeh and Dahmareh (2010) reported that sowing date and cultivar of corn significantly effected leaf area index (LAI), Crop Growth

Rate (CGR), Leaf Area Duration (LAD). Maize at optimum sowing date resulted in higher LAI, CGR and LAD. Differences among different planting dates might be due to the different climatic conditions which are based on high temperature during the plant life cycle.

Zaker *et al.* (2014) reported the effect of planting date was significant only for leaf number per plant in maize. The plants were seeded on 25 June had grater leaf number compared with those were seeded on 14 June.

Sulochana *et al.* (2015) reported that higher leaf area index and dry matter accumulation obtained under June 30 sown crop probably caused by interaction of environmental factors (temperature, rainfall and relative humidity etc.,) higher over June 15 and July 15 sown crops by 50 and 12.5 per cent, respectively. Pratap Makka-5 was significantly superior over PEHM-2, HQPM-1and Pratap QPM-1 interms of Leaf area index by 12.5, 28.6 and 50 per cent at 15 DAS and 8.2, 13.1 and 15.3 per cent at 75 DAS, respectively but at par with BIO-9637.

Bhushal and Jagdish (2016) reported that no significant difference was found in terms of leaf area index between genotypes. Highly significant difference was found in terms of leaf area index considering the planting dates. Highest leaf area index was observed when genotypes were planted in September 22 (0.018) and lowest in September 2 (0.015). Radiation interception is largely determined by leaf area index (LAI) which in turn is influenced by genotype, temperature and photoperiod (Muchow and Carberry, 1989).

Majumder *et al.* (2016) observed a positive linear regression relationship of Heat use efficiency with maximum leaf area index (R^2 =60.6), dry matter (R^2=97.3) and grain yield (R^2 = 55.1) of maize.

2.4 CROP PHENOLOGICAL PARAMETERS

Several researchers have shown influence of temperature on phenology and yield of crops and expressed it under field conditions through accumulated heat unit system (Sikdar, 2009; Bishnoi *et al.,* 1995).

The knowledge on the calculation of the heat summation unit (HSU), mostly called the growing degree days (GDD) and their further mathematical derivations like heliothermal unit (HTU), phenothermal index (PTI) and heat use efficiencies (HUE) will be the basic principles to understand the phenology and follow the proper planting times for different crop varieties over the spatial and temporal variations (Rajput, 1980).

Phenology is the study of growth phases during plant life cycle. Crop performance is strongly influenced by prevailing weather conditions and temperature and solar radiation are among the driving forces to modulate assimilates production and development rate of crops (Reynolds *et al*., 2002).

Plants have a definite temperature requirement before they attain certain phenological stages and to forecast the phenology and crop production attributes for a large acreage, there has been the development of crop models (Dooraiswamy and Thompson, 1982; Jones *et al.,* 2003).

2.4.1 Days to Emergence

Nahar *et al.* (2010) reported that early planted wheat experiences smaller germination phase than late planting but days taken to start anthesis and booting stages notably decreased in late sown wheat due to elevated heat stress later in the season.

Sulochana *et al.* (2015) reported that date of sowing in maize has significant variation in number of days taken to attain emergence, fifth leaf, knee high and maturity stage. The crop sown on June 15th took significantly higher number of days (5.1) of emergence and knee high (32.7) as compared to reproductive phenophases in comparison to the sowing on June 15th and June 30th.

Majumder *et al*. (2016) reported maize crop took 9 days to complete its emergence and the accumulated GDD, HTU and PTU was 28.6°C day, 191.7°C day hour and 319°C day hour, respectively. The crop took 17 days to for five leaves emergence and the accumulated GDD, HTU and PTU was 98.4°C day, 656.8°C day hour and 1106.3°C day hour, respectively and to attain knee high stage the crop consumed 34 days to and the accumulated GDD, HTU and PTU was 286.8°C day, 2110.08°C day hour and 3292.28°C day hour, respectively.

2.4.2 Days to Tasseling Stage

Hunter *et al.* (1997) reported fewer days to tassel initiation as daylength decreased from 20 to 10 h in corn.Interaction amid sowing dates and wheat cultivars had significant effect on PTU accumulation to switch into different phenophases except to start tillering.

Birch *et al*. (1998) reported the base, optimum and maximum temperatures for maize crop ontogeny from tassel initiation to silking (8, 34 and 40°C) are the same as for emergence to tassel initiation in maize. However, after silking, the base temperature is 0°C, the optimum and maximum temperatures remain 34 and 40°C.

Hayat khan *et al*. (2009) conducted experiment on different sowing dates i.e., 25 April (D_1), 25 May (D_2), 16 June (D_3), 26 July (D_4) and 18 August (D_5) with different genotypes of maize. Days to 50% tasselling and 50% silking decreased as the date of sowing was delayed from D_1 to D_5. Days to maturity decreased as the date of sowing was delayed from D1 to D_3 and then increased again as sowing was delayed from D_3 to D_5.

Amgain *et al.* (2011) reported that high temperature at the early vegetative phases of maize resulted in reduced number of days for attaining different phenological stages under normal planting. Under the 1st September planting, Rampur Composite required 5 days for emergence, 35 days for knee high, 48 days for tasseling, 63 days for anthesis, 100 days for grain filling and 135 days for maturity, whereas for Pool-12 genotype the mentioned growth duration were 4, 33, 45, 60, 92 and 123 days, respectively. The higher temperature and lengthy days after anthesis stages of late planting maize showed the lowest days to attain the accumulative heat unit within the shorter periods.

Shrestha *et al*. (2016) reported significant difference exist among the genotypes in maize to attain different phenological stages for different sowing dates. 7th April showed higher days to attain knee high stage (31.42 days), anthesis (53.75 days), silking (58.08 days) and seed fill duration (51.25 days) than other sowing dates (22nd April and 7th May). In case of anthesis 7th May planted has higher GDD (1007 degree days) than others.

The extension of photoperiod significantly increased the time from emergence to tassel initiation and the final number of leaves in maize (Birch *et al.,* 1989).

2.4.3 Days to Silking

Martin and Williams (2008) reported that days from crop emergence to silking varied with planting date in maize crop. As planting was delayed from midApril to early July, 23 to 35 per cent fewer days until silking were observed. Similarly Nielsen *et al*. (2002) showed that thermal time to silking changed little for three commonly grown dent corn hybrids of the North Central United States as planting was delayed from early May to midJune.

Nahar *et al*. (2010) observed that early planted wheat had small germination phase than late planting but days taken to start anthesis and booting stages notably declined in late sown wheat due to elevated heat stress (high temperature) later in the season.

Sulochana *et al*. (2015) reported that dates of sowing brought about significant variation in accumulated GDD at all phenological stages except 50 per cent silking, dough and maturity stages in maize. Crop sown on June 15 required maximum GDD at knee high (598°C day), 1sttassel initiation (909°C day), 50 per cent tasseling (957°C day), 1stsilk initiation (973°C day), 50 per cent silking (991°C day), milking (1205°C day) and dough (1419°C day).

Majumder *et al*. (2016) reported a corn plant took 93 DAS for silking and the GDD, HTU and PTU required by the crop to complete silking were observed to be 3154.5°C day, 27544.6°C day hour and 39226.3°C day hour, respectively.

2.4.4 Days to Physiological Maturity

The heat unit system was adopted for determining the maturity dates of different crops (Bierhuizen, 1973) from which accurate yield and maturity prediction could be assessed. Though maize is a day neutral plant, the flowering and maturity of its varieties are however, dependent to available temperature and sunshine hours and it is location specific (Bonhaomme *et al.*, 2000; Rao *et al.*, 2000).

Hariram *et al*. (2012) reported October 25 took maximum calendar days, growing degree days, Photothermal units and Heliothermal units in maize for earing (106.6, 1119.1, 11823.6, 6286.6) and maturity (168, 2163.7, 24358.2, 16033.8) respectively. The late sown crop completed its life cycle at an accelerated pace, leading to shortening of days taken to earing and maturity.

Majumder *et al.* (2016) reported maize crop took 127 days to complete its life cycle and accumulated 5062.3°C day growing degree days (GDD), 45795.3°C day hour heliothermal unit (HTU) and 64664.7°C Photothermal units.

2.5 YIELD AND YIELD COMPONENTS

2.5.1 Number of Cobs m^{-2}

Rajesh *et al*. (2015) reported wheat significant reduction in yields with delay in sowing time (December) and the number of ear heads per meter decreased as the sowing date delayed and varied with the genotypes. The crop sown in November resulted more number of ear heads per meter (279 m^2) compared to December sown crop (311 m^2).

2.5.2 Number of Seed Rows Cob^{-1}

Yusafzai *et al.* (2002) studied the effect of sowing dates (15 July, 30 July and 15 August) with six maize cultivars. Early sowing 15 July reported higher number of seeds per cob (378.1) and grain yield (4419 kg ha^{-1}). Delayed sowing 15 August resulted in lower yields comparatively. Among the cultivars Sarhad reported highest number of seeds per cob (327.3) and grain yield (3354 kg ha^{-1}).

Tripathi and Shrivastava (2004) reported that, sowing of maize on 12 May produced significantly more number of grains per cob than earlier sowings of 22 April and 2 May. Thousand grain weight did not differ significantly due to dates of sowing.

Jaliya *et al*. (2008) studied the effect of three dates of planting (10, 20 and 30 June) and four NPK levels in maize. 20 June crop resulted in higher number of rows per cob (488.2) compared to 10 June (451.3) and 30 June (354).

Nammakka *et al*. (2008) reported significant reduction exist in cob length, cob diameter and cob weight in maize crop with delay in sowing date and the significant increase in the leaf area index early sown crop which resulted in more light interception and probably higher photosynthesis.

High night temperatures result in loss of more sugars for respiration and reduce the availability for kernel filling in maize, thereby lowering potential grain yield (Thomison, 2010).

Hossein *et al.* (2014) reported that maizevarieties SC108 and SC301 sown at different dates (22 June, 1 July and 11 July) and planting densities. Among the dates of sowing June 22 sown crop resulted higher number of rows per cob (18.4) than 1stJuly and 1stJuly. SC301 resulted in higher number of rows per cob.

Shrestha *et al*. (2016)reported maize genotype with high higher kernel rows ear^{-1}, kernel per row and HI results in high grain yield. It is also indicated that number of ears ha^{-1} is insignificant for all sowing dates and maize cultivars. Kernel row ear^{-1} (12.89) and kernels row^{-1} (24.47) in 7th April planted maize were recorded highest followed by 22nd April and 7th April planted maize cultivars. The reason is due to favorable temperature in early sown maize cultivars. A number of factors could be responsible for reduction in number of kernels per row under heat stress, such as reduced pollen viability and receptivity of silk, increased frequency of kernel abortion, decreased cell division in endosperm, reduced silk capacity of developing kernel.

2.5.3 Number of Seeds Row^{-1}

Srinivasulu *et al*. (2008) reported maize crop grown during second fortnight of August resulted in higher yield compared to second fortnight July, first fortnight August and first fortnight September at Tirupathi, Andhra Pradesh. The high yield is due to enhanced yield attributes number of seeds per row (15.19), number of seed rows per cob (12.45), cob weight (65.33 g), cob length (13.17 cm) and cob girth (12.44 cm), test weight (215.0) and shelling percentage (69.8).

Hossein *et al*. (2014) reported that maize varieties SC108 and SC301 sown at different dates (22nd June, 1st July and 11th July) and planting densities. Irrespective of genotypes June 22 sown crop resulted higher number of seeds per row than 1st July and 11th July. Among the genotypes SC108 resulted higher number of seeds per row (30.66).

2.5.4 100 Grain Weight (g)

Yusafzai *et al.* (2002) studied the effect of sowing dates (15th July, 30th July and 15th August) with six maize cultivars. Early sowing 15th July reported higher thousand grain weight (209.1 g) and grain yield (4419 kg ha^{-1}). Delayed sowing 15th August resulted in lower yields comparatively. Among the cultivars, Sarhad reported highest thousand grain weight (214.9 g) and grain yield (3354 kg ha^{-1}).

Hariram *et al.* (2012) reported higher 1000 grain weight (36.1 g) during October 25 compared other dates of sowing November 25 (34.2), November 15 (33.6), November 25 (32.8), December 5 (32.4), December 15 (30.8) and December 25 (30.5).

Hossein *et al*. (2014) reported that maize varieties SC108 and SC301 sown at different dates (22nd June, 1st July and 11th July) and planting densities. Irrespective of genotypes early sown 22nd June crop resulted in higher 1000 kernel weight (355.6) and SC301 among the genotypes showed higher 1000 kernel weight compared to other genotypes.

Shrestha *et al.* (2016) observed 1000 grain weight were higher and statistically similar between maize planted in 7th April (232.0) and 22nd April (231.3) than 7th May (224.3).

2.5.5 Cob Yield (kg ha^{-1})

Yusafzai *et al*. (2002) studied the effect of sowing dates (15th July, 30th July and 15thAugust) with six maize cultivars. Early sowing 15th July reported maximum emergence m^{-2} (12.11) and grain yield (4419 kg ha^{-1}). Delayed sowing 15^{th} August resulted in lower yields comparatively. Among the cultivars Sarhad reported highest emergence (10.4) and grain yield (3354 kg ha^{-1}).

Jaliya *et al*. (2008) studied the effect of three dates of planting (10, 20 and 30 June) and four NPK levels of maize. 10^{th} June (5.54 t ha^{-1}) sown crop resulted higher cob yield compared to 20^{th} June (5.21 t ha^{-1}) and 30^{th} June (3.91 t ha^{-1}).

2.5.6 Cob Length (cm)

Arif *et al.* (2001) concluded that planting methods, varieties and their interaction significantly affected maize cob length, number of grains cob^{-1}, grain weight cob^{-1}, biological yield and grain yield.

Srinivasulu *et al*. (2008) reported maize crop grown during second fortnight of August resulted in higher yield compared to second fortnight July, first fortnight August and first fortnight September at Tirupati, Andhra Pradesh. The cob length was recorded 13.7 cm as highest.

2.5.7 Grain yield (kg ha^{-1})

Bauer and Carter (1986) not only found a correlation between the sowing date and the grain yield of maize, but noted that later sowing led to more brittle grains, causing storage problems. In addition, there was a 4-6 per cent reduction in the grain yield per hectare in late sown plots.

Elemo (1991) stated that the maize yield components decrease with delay in sowing and the yield losses owing to delay by three weeks were about 80 kg $ha^{-1}day^{-1}$.

Nafziger (1994) stated that corn yields increased from mid-April to late April planting dates, then declined as planting was delayed to late May. Pandey *et al.* (2010) also reported similar observations under delayed sowing and delayed sowing hastened the crop phenological development, thereby causing significant reduction in wheat yields.

Arif *et al.* (2001) concluded that planting methods, varieties and their interaction significantly affected maize cob length, number of grains cob^{-1}, grain weight cob^{-1}, biological yield and grain yield.

Hayat Khan *et al*. (2009) conducted experiment on different sowing dates from 25th April (D_1), 25th May (D_2), 16th June (D_3), 26th July (D_4) and 18th August (D_5) with different genotypesSweet corn landrace. Swabi produced maximum (7292 kg ha^{-1}) biological yield from D_1 sowing compared to minimum (7083 kg ha^{-1}) produced by Parachinar on D_5. Azam produced maximum grain yield (4097 kg ha^{-1}) and harvest index (27.21%) when sown on D_4, where as minimum grain yield (621 kg ha^{-1}) and harvest index (7.16%) was observed for Parachinar and Mingora, respectively on D_5 sowing.

Hariram *et al.* (2012) reported significant reduction in grain yield of timely sown varieties of wheat was recorded when sowing was delayed beyond November 15. Highest grain yields was recorded on October 25 (59.22 q ha^{-1}) which was statistically on par with November 5 but significantly higher than later dates of sowing. This might be due to higher yield attributes, GDD, HTU and PTU in October 25 sowing whereas detrimental effect of heat stress at later stages of crop growth and earing in delayed sowing had adverse effect on grain yield.

Hossein *et al*. (2014) reported that maize varieties SC108 and SC301 sown at different dates (22nd June, 1stJuly and 11th July) and planting densities. Irrespective of genotypes June 22 (7.9 t ha^{-1}) sown gave higher yields compared to 1 July (7.3 tha^{-1}) and 11 July (6.7 t ha^{-1}).

Zaker *et al*. (2014) studied the effects of planting dates and nitrogen rate on yield and quality of forage corn (*Zea mays* L.) and resulted that fresh and dry forage yields in maize increased significantly 137 per cent and 115 per cent, respectively. Planting date of 25 June are recommended for forage corn production in Isafahan. High night temperatures on the consumption of carbohydrates will have a significantly negative effect on yield.

Sulochana *et al.* (2015) reported that the maximum heat use efficiency was produced in June 30 sown maize crop at 30 (0.41 kg ha^{-1} $°C^{-1}$ day^{-1}) and 60 (5.27 kg ha^{-1} $°C^{-1}$ day^{-1}) DAS which was significantly superior over June 15 by 18.1 and 16.3 per cent. The maximum heat use efficiency was produced in June 30 sown crop at grain (3.33 kg ha^{-1} $°C^{-1}$ day^{-1}) and biological yield (8.83 kg ha^{-1} $°C^{-1}$ day^{-1}) basis was significantly superior over June 15 and July 15 sown crops by 16.0 and 14.4 per cent and 9.1and 8.2 per cent, respectively.

Majumder *et al.* (2016) reported the regression analysis between temperature and grain yield under different treatments showed negative relation indicating a decrease in grain yield of maize by 2.8 q ha^{-1} with increase in canopy temperature by 1°C. Global warming has adverse impact on maize productivity.

Shrestha *et al.* (2016) reported growing maize in rainfed cultivation in late spring is risky and the increase in temperature beyond optimum level decreased yields. 22^{nd} April and7^{th} May reduced yields by 20 per cent and 27.9 per cent respectively.

2.5.8 Stover Yield (kg ha^{-1})

Sreenivasulu *et al.* (2008) reported maize genotype DHM103 performed well when sown during second fortnight august. The grain yield and stover yield were highest for DHM103 during second fortnight august were 2145 kg ha^{-1} and stover yield 4446 kg ha^{-1} compared to other dates of sowing and genotypes.Genotypic variation of maize were also reported by Thakur *et al.* (2000).

2.5.9 Harvest Index (%)

Hayatkhan *et al*. (2009) conducted experiment on different sowing dates i.e., 25 April (D_1), 25 May (D_2), 16 June (D_3), 26 July (D_4) and 18 August (D_5) with different maize genotypes Harvest indices of sweet corn landraces were significantly affected by sowing dates, landraces and their interaction. Highest value of harvest index (27.21%) was noted for Azam sown on D_4, whereas lowest (7.78%) for Parachinar on D_5 sowing.

Jeswemi *et al*. (2013) reported harvest index was higher for corn plant sown on 22nd May than 13th July and the longer duration varieties have high HI than short duration varieties due to longer seed fill duration, high LAI and LAD.

Shrestha *et al*. (2016) reported high harvest index was observed during 7th April (0.347) maize compared to other two dates of sowing (22nd April and 7th May).

2.6 NITROGEN CONTENT

Pathak and Tiwari (1972) studied the nutrient uptake of maize in relation to nitrogen under two sowing dates (20th June and 5th July) at Kanpur and observed that, the uptake of nitrogen, phosphorous and potassium was markedly higher in crops sown on 5th July in those sown on 20th June. The higher uptake of nitrogen helped the plants to synthesize more photosynthates because of high rate of photosynthesis and high photosynthetic production which were accumulated in reproductive parts.

2.7 VALIDATION WITH CERES – MAIZE MODEL

Plants have a definite temperature requirement before they attain certain phenological stages and to forecast the phenology and crop production attributes for a large acreage, there has been the development of crop models (Dooraiswamy and Thompson, 1982, Jones *et al.* 2003). The heat unit system was adopted for determining the maturity dates of different crops (Bierhuizen, 1973) from which accurate yield and maturity prediction could be assessed.

CERES maize model one of the Decision support system for Agrotechnology Transfer, DSSAT (Hoogenboom *et al*. 2010), can be used to simulate crop growth and development under scenario of varying climatic conditions and to evaluate management strategies

Shekh and Rao (1996) revealed that the prediction of silking by CERES-Maize model showed deviation from -1 to +2 days with mean deviation of -2.3 days, model predicted deviation in physiological maturity ranged from -10 to +5 days with a mean difference of -3.7 days. The prediction of grain yield ranged from -28.9 to +18.4 per cent.

Roman Paoli *et al.* (2000) Gungula *et al*. (2003) and TojoSoler *et al*. (2007) also reported close prediction of days to flowering in maize by using CERES-Maize in different environments. The model closely predicted number of grains per cob, number of grains m^{-2} but could not simulate single grain weight

Karthikeyan (2002) indicated that CERES-Maize predicted the date of tasseling and grain yield satisfactorily. But the model poorly predicted the biomass yield and harvest index. Mastrorilli *et al*. (2003) also reported less than 13 per cent variation in grain yield of simulated and observed grain yield under Mediterranean conditions by using CERES-Maize model.

Deepak and Mathauda (2004) reported CERES Maize model prediction was well matched during the reproductive phase of the crop. The model predicted over estimation of 3.61-3.71 per cent in grains m^{-2} and underestimation of 5.90-23.11 per cent.

Tojosoler (2007) reported that the CERES Maize model is a promising tool for yield forecasting for maize hybrids and was able to predict phenology and grain yield with less than 15 per cent. The planting date analysis showed delayed planting date decreased average yield of 55 per cent for rainfed conditions and 21 per cent for irrigated conditions.

Singh *et al*. (2010) reported less error percentage of 2.8 per cent, when observed yield was validated with the simulated values of yield over anthesis and 6.5 per cent at physiological maturity and yield attributing characters of Uttar Pradesh. Similar results were also reported by Hodges *et al*. (1987).

Ramawath *et al*. (2012) reported simulated grain yield (5341 kg ha^{-1}) were slightly higher than the observed data (5124 kg ha^{-1}). In general grain yield data were slightly higher than the observed data.The difference between the simulated and observed days to flowering and maturity days of different varietieson different dates of sowing (June 1, June 10, June20 and June 30) with four varieties showed a difference ranging from 0 to 7 days and CV of 3.46 and 2.3 per cent respectively.

Leela *et al*. (2014) reported CERES maize model serves as tool for determining the sowing time and nitrogen level for maize under rainfed conditions of semiarid environment Hyderabad. Optimum sowing window for rainfed maize was from 8 June to 29 June and could potentially assist resource poor farmers in Andhra Pradesh by providing alternate management practices.

Bwalya *et al*. (2015) reported planting date significantly effected grain and biomass yield. CERES Maize model predicted a percent deviation from 2 to 39 per cent for tops weight at maturity and harvest index of 8 to 9 per cent.

Chapter ~ III

Material and Methods

Chapter – III

MATERIAL AND METHODS

The details of material and methods adopted in the present investigation on **"Phenological responses of maize (*Zea mays* L.) to photoperiod and temperature"** are briefly described in this chapter.

3.1 LOCATION OF EXPERIMENTAL SITE

To study the impact of temperature and photoperiod on maize crop, a field experiment was conducted at Regional Agricultural Research Station Farm, Tirupati during *kharif* season, 2016. According to Trolls classification it falls under Semi arid tropics and is geographically situated at 13.65°N latitude and 79.42°E longitude, with an altitude of 182.9 m above the mean sea level of Southern Agro-Climatic Zone of Andhra Pradesh.

3.2 SOIL CHARACTERISTICS

Composite samples of soil were drawn at random from 0 to 30 cm depth from the experimental field during *kharif* 2016. Initially, soil samples were dried and sieved through a 2 mm sieve and soil samples were analyzed for various physico-chemical properties.

The particulars of physico-chemical properties and methods employed for each of them are presented in Table 3.1. The soil of the experimental site was sandy loam in texture, neutral in soil reaction, low in available nitrogen and organic carbon, high in phosphorus and medium in potassium.

Table 3.1. Physico-chemical properties of soil of the experimental field

Particulars	Soil depth (cm)	Method adopted
	0-30 cm	
I. Physical characteristics		
Coarse sand (%)	37.55	
Fine sand (%)	28.56	
Silt (%)	7.90	Bouyoucos Hydrometer (Piper, 1950)
Clay (%)	28.55	
Soil texture	Sandy, Loam	
II. Physico-Chemical characteristics		
Soil pH (1.0: 2.5 soil water suspension)	6.90	Glass electrode pH meter (Jackson, 1973)
Electrical Conductivity (dS m^{-1})	0.18	Conductivity bridge (Jackson, 1973)
III. Chemical characteristics		
Organic carbon (%)	0.43	Wet digestion method (Walkley and Black, 1934)
Available N (kg ha^{-1})	188.00	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	44.20	Olsen's method (Olsen *et al*. 1954)
Available K_2O (kg ha^{-1})	154.20	Flame photometry (Jackson, 1973)

3.3 WEATHER DURING CROP GROWTH SEASON

The weather data during the crop period (June II FN to August I FN) recorded at S.V. Agricultural College Meteorological Observatory located at Regional Agricultural Research Station, Tirupathi. Day length of this location obtained from the source www.timeanddate.com. The weekly mean meteorological data during the crop growth period are furnished in Fig. 3.1 and Table 3.2.

3.3.1 Rainfall

A total rainfall of 512.1 mm was received during the crop growth period in 30 rainy days.

3.3.2 Temperature

The weekly mean maximum temperature during the crop period ranged from 31.7°C to 36.2°C, with an average of 33.97°C. The weekly mean minimum temperature during the crop growth period varied from 17°C to 27°C, with an average of 23.8°C.

3.3.3 Sunshine Hours

The weekly mean bright sunshine hours day^{-1} during the crop growth period ranged from 1.1 to 8.67, with an average of 5.07.

3.3.4 Relative Humidity

The weekly mean relative humidity during the crop growth period ranged from 52.9 to 75 per cent, with an average of 62.3 per cent.

3.3.5 Mean Evaporation

During the crop period, the weekly mean evaporation (USWB Class-A Open Pan evaporimeter) ranged from 2.7 to 7.7 mm day^{-1}, with an average of 5.07 mm day^{-1}.

Table 3.2. Standard week wise meteorological data during the crop growth period of maize (11-06-2016 to 10-12-2016)

Standard week	Date and month	Temperature (°C)				Mean relative humidity (%)		Rainfall (mm)		No. of rainy days		Mean evaporation (mm day^{-1})		Mean bright sunshine (hours day^{-1})		Day length hours
		Maximum		Minimum												
		A	DN	A	DN	A	DN	A	DN	A	DN	A	DN	A	DN	A
24	11 June – 17 June	33.3	-0.27	25.9	-0.94	57.07	4.27	18.5	3.54	1	-0.1	6.0	-1.01	6.60	1.90	12.55
25	18 June – 24 June	31.7	-3.37	24.1	-2.45	66.93	13.20	111.5	96.24	4	2.6	4.3	-3.02	3.14	-1.43	12.55
26	26 June – 01 July	34.3	-5.00	24.8	-1.95	72.93	20.61	40.0	22.59	2	0.6	4.0	-3.62	1.09	-3.79	12.54
27	02 July – 08 July	35.7	-1.54	25.9	-0.49	64.71	11.58	17.8	-0.46	3	2.0	4.1	-3.01	2.54	-1.04	12.52
28	09 July – 15 July	33.4	0.14	26.5	0.35	58.14	2.70	0.0	-25.82	0	-1.5	6.8	-0.36	5.26	1.26	12.49
29	16 July – 22 July	33.4	-1.60	24.2	-1.79	66.79	8.78	37.2	18.10	3	1.9	5.1	-1.51	3.87	0.43	12.45
30	23 July – 29 July	32.5	-1.54	24.3	-1.17	68.79	9.71	50.0	34.55	3	1.2	4.4	-1.52	4.39	1.01	12.42
31	30 July – 05 Aug.	35.5	-1.98	25.2	-0.67	65.36	8.02	71.2	56.85	1	0.1	3.7	-2.50	2.06	-1.06	12.38
32	06 Aug. – 12 Aug.	35.7	0.33	26.1	0.33	59.36	2.25	0.0	-19.23	0	-1.1	6.8	-0.18	7.80	3.73	12.33
33	13 Aug. – 19 Aug.	36.2	1.36	26.0	1.21	56.21	-6.41	0.0	-45.66	0	-2.9	7.1	1.75	8.00	3.08	12.28
34	20 Aug. – 26 Aug.	33.3	2.43	27.0	2.90	54.29	-10.85	0.0	-45.10	0	-2.3	7.7	2.65	8.03	2.94	12.23
35	27 Aug. – 02 Sept.	34.0	-0.22	25.8	1.48	65.57	1.33	40.8	6.40	1	-0.6	4.2	-0.99	2.27	-1.90	12.18
36	03 Sept. – 09Sept.	32.8	0.54	24.8	0.61	59.79	-4.90	13.5	-27.64	2	0.2	5.7	0.98	5.93	1.79	12.13
37	10 Sept. – 16Sept.	33.3	-0.62	25.3	1.36	65.00	-2.75	0.0	-30.41	0	-1.9	4.2	-0.24	2.13	-2.83	12.08
38	17 Sept. – 23Sept.	34.4	-0.05	24.0	0.10	67.50	2.65	22.4	4.12	3	1.9	4.5	-0.25	3.94	-1.14	12.02
39	24 Sept. – 30Sept.	34.4	0.57	26.2	2.56	62.21	-2.71	1.0	-30.78	0	-1.6	5.6	0.46	3.90	-1.81	11.64
40	01 Oct. – 07 Oct.	35.8	0.82	24.5	0.90	63.79	-1.90	6.2	-25.99	1	-0.2	5.0	0.34	5.07	-0.17	11.52
41	08 Oct. – 14 Oct.	35.6	1.94	25.4	2.56	57.57	-8.76	0.0	-24.82	0	-1.5	5.4	0.88	4.73	-0.97	11.47
42	15 Oct. – 21 Oct.	35.3	3.08	20.9	-1.51	52.93	-16.33	0.0	-29.15	0	-1.9	5.6	1.15	8.67	2.97	11.41
43	22 Oct. – 28 Oct.	32.5	4.07	20.2	-1.87	55.71	-17.49	0.0	-51.04	0	-3.0	5.4	1.77	7.29	2.77	11.38
44	29 Oct. – 04 Nov.	33.9	2.02	24.1	2.26	68.93	-7.36	11.2	-52.93	2	-0.9	4.0	0.43	3.29	-1.13	11.34
45	05 Nov. – 11 Nov.	32.9	3.96	19.9	-1.09	54.71	-19.68	0.0	-43.21	0	-1.6	5.2	1.48	7.64	2.22	11.29
46	12 Nov. – 18 Nov.	34.1	3.37	21.5	1.30	66.21	-7.16	0.8	-54.12	0	-2.1	5.3	1.39	7.29	2.35	11.26
47	19 Nov. – 25 Nov.	33.3	1.49	19.0	-1.45	57.64	-16.23	0.0	-38.62	0	-2.0	4.8	1.16	7.29	1.89	11.25
48	26 Nov. – 02 Dec.	31.7	2.62	17.1	-2.80	56.00	-19.11	0.0	-61.82	0	-1.7	4.2	0.76	5.87	1.59	11.24
49	03 Dec. – 10 Dec.	34.3	0.49	20.5	0.60	75.07	0.75	70.0	39.00	4	2.7	2.7	0.70	3.84	-1.02	11.20

A: Actual; DN: Deviation from normal (Decennial mean)

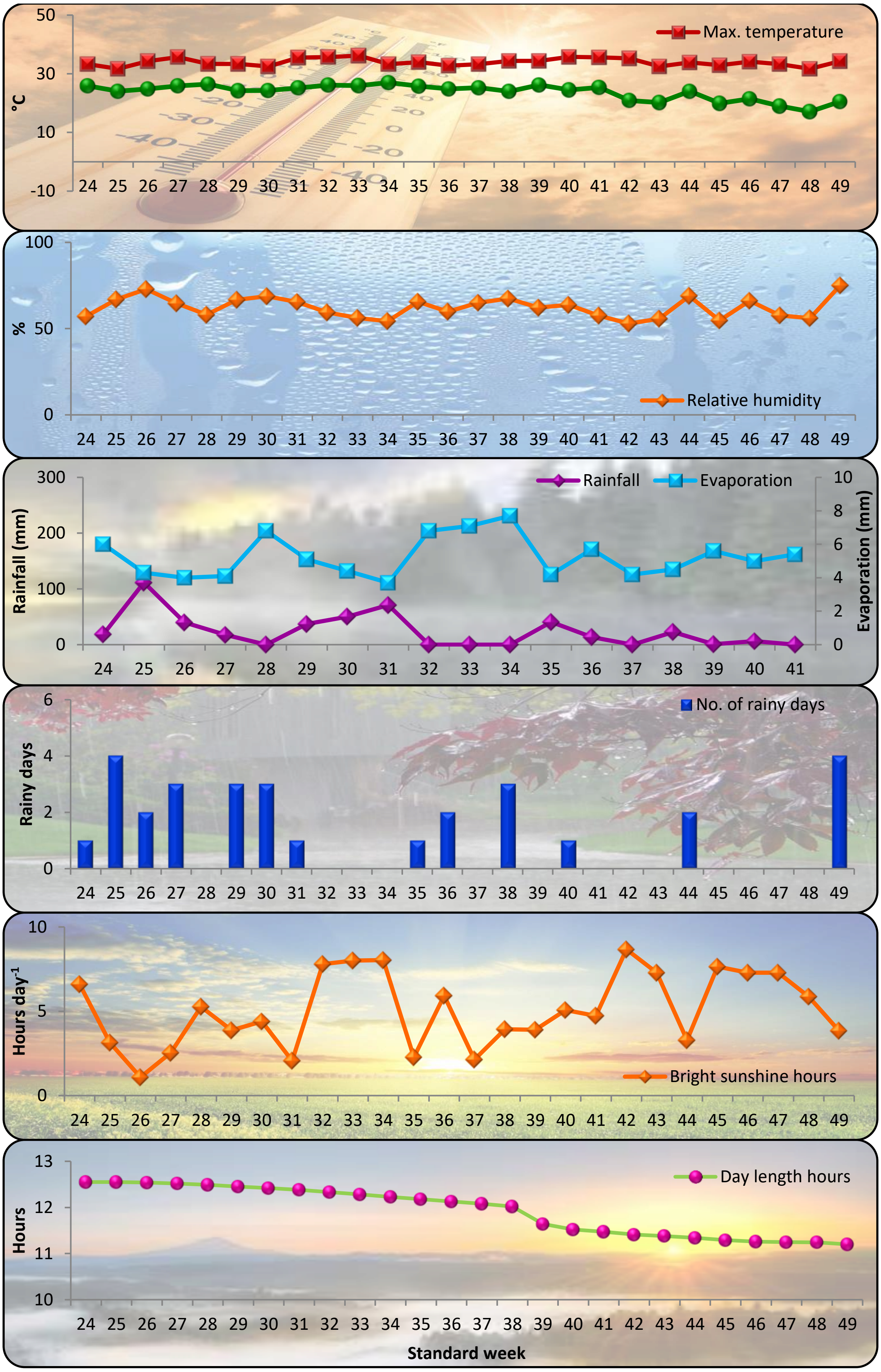


Fig 3.1. Standard week wise meteorological data during the crop growth period (11-06- 2016 to 10-12-2016)

3.3.6 Day Length

During the crop growth period, weekly day length ranged from 11.20 hours to 12.55 hours with an average of 11.92 hours.

3.4 EXPERIMENTAL DETAILS

3.4.1 Design and Layout

The experiment was laid out in a split plot design with twelve treatments and replicated thrice (layout of the plan is given in Fig. 3.2 and Plate 1).

3.4.2 Treatments

Phenological responses of maize *(Zea mays* L.) to photoperiod and temperature was studied under given following treatments:

Location of Work	:	Farm of Regional Agricultural Research Station (RARS), Tirupati.
Season	:	*kharif*
Crop	:	Maize
Spacing	:	60 × 20 cm
Gross plot size	:	22.7 m^2
Design	:	Split plot design
Replications	:	3
Treatments	:	12

Major treatments: Hybrids (3)

H_1 : Decalb Super 900M (D.S 900M)

H_2 : Pinnacle

H_3 : CP 818

Sub treatments: Dates of sowing (4)

D_1 : Second fortnight of June.

D_2 : First fortnight of July.

D_3 : Second fortnight of July.

D_4 : First fortnight of August

	D1	D2	D3	D4
	Irrigation Channel			
R I	H_1	H_2	H_3	H_1
	H_2	H_3	H_1	H_2
	H_3	H_1	H_2	H_3
R II	H_1	H_2	H_3	H_1
	H_2	H_3	H_1	H_2
	H_3	H_1	H_2	H_3
RIII	H_1	H_2	H_3	H_1
	H_2	H_3	H_1	H_2
	H_3	H_1	H_3	H_3

5.4 m

← 4.2 m →

Design : Split pot Design
Plot size : 4.2 × 5.4 m (22.7 sq m)

Replications : Three
Spacing : 60 × 20 cm

Treatments : 12

Major Treatments : Hybrids (Three)
H_1 : Decalb Super 900M
H_2 : Pinnacle
H_3 : CP818

Sub Treatments : Dates of sowing (Four)
D_1 : Second FN of June
D_2 : First FN of July
D_3 : Second FN of July
D_4 : First FN of August

Fig. 3.2. Layout plan of the experimental field

Plate 1. Overall view of the experimental field layout

3.5 CULTIVATION DETAILS

3.5.1 Preparatory Cultivation

The experimental field was ploughed with tractor drawn M.B. plough followed by two harrowings. The land within each plot was levelled in order to maintain uniform irrigation water application.

3.5.2 Fertilizers

A uniform dose of 200 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied through urea, single super phosphate and muriate of potash, respectively to all the treatments. Nitrogen was applied in the form of urea (46% N) in three equal splits (1/3 each at basal, at knee high and tasseling). Similarly the remaining potassium was applied along with urea during second top dressing at tasseling.

3.5.3 Seeds and Sowing

A seed rate of 12 kg ha^{-1} was used. Bold and healthy treated seeds were hand dibbled at the rate of two seeds per hill by adopting spacing of 60 cm × 20 cm. After establishment of crop, thinning was done at 10 days leaving one seedling per hill after emergence.

3.5.4 Weed Management

Atrazine 50% W.P @ 1.0 Kg a.i ha^{-1} was applied one day after sowing (DAS). Hand weeding was done twice at 20 DAS and 35 DAS to keep the experimental plot free of weeds.

3.5.5 Water Management

Need based irrigation was provided from sowing to harvest.

3.5.6 Plant Protection

Crop was free from major pests and diseases during cropping season except stem borer at 10-15 days after emergence. Carbofuron 3G granules @ 7.5 kg ha^{-1} were applied in leaf whorls for control of stem borer.

3.5.7 Harvesting and Threshing

The crop was harvested at physiological maturity. The cobs and stover were harvested separately from net plot and sun dried thoroughly. The shelling of maize cobs was done by the hand operated maize sheller.

3.6 OBSERVATIONS RECORDED

3.6.1 MORPHOLOGICAL AND GROWTH ATTRIBUTES (AT PHENOLOGICAL GROWTH STAGES OF CROP)

The following morphological attributes were recorded at six leaf stage, tasseling stage, silking stage, soft dough stage, hard dough stage and physiological maturity.

3.6.1.1 Plant height (cm)

Plant height was measured from the base of the plant to the tip of the fully opened leaf at phenological growth stages from randomly labeled three plants in each net plot area and expressed in cm.

3.6.1.2 Dry matter production (g $plant^{-1}$)

Sampling was done at phenological growth stages of crop. Three plants from each treatment or plot were dug out with roots. The plants were thoroughly washed to free from dirt and surface dried with blotting paper. The leaf area was taken separately and then different plant parts were dried in hot air oven at 100°C for 15 minutes and then at 80°C for 48 hours until they attained constant weights.

3.6.1.3 Leaf area (cm^2 $plant^{-1}$)

Leaf area was estimated in three plants in each plot at phenological growth stages of crop. After separation of leaves from the plant, leaf area was estimated using leaf area meter (Li-COR model LI 3100) and expressed as cm^2 $plant^{-1}$.

3.6.1.4 Leaf area Index (LAI)

Leaf area index was calculated by using the formula as proposed by Watson (1952).

$$LAI = \frac{\text{Leaf area}}{\text{Ground area}}$$

3.7 CROP PHENOLOGY

The time of occurrence of phenological events of maize crop were recorded in four dates of sowing as suggested by Hanway (1962) *viz.*, emergence (Ve), Six leaf stage (V_1), Tasselling stage (R_2), Silking stage (R_3), Soft dough stage (R_4), Hard dough stage (R_5) and physiological maturity (R_6). These phenological stages were considered to study the correlation between weather and crop growth parameters.

3.8 YIELD AND YIELD COMPONENTS

3.8.1 Number of rows cob^{-1}

Five cobs were randomly selected from each plot, the number of rows was counted and finally the mean number of rows cob^{-1} was achieved.

3.8.2 Number of seeds row^{-1}

From randomly selected five cobs, the number of seeds per row $^{-1}$ was counted and finally the mean number of seeds row $^{-1}$ was determined.

3.8.3 100 Grain Weight (g)

Hundred kernels were randomly drawn from the composite sample of kernel yield from each of the net plot area, weighed and expressed in grams.

3.8.4 Unit Grain Weight (g) at Maturity

Weight of single grain at maturity is recorded in maize hybrids at four dates of sowing and recorded in grams.

3.8.5 Cob Yield (kg ha^{-1})

The cobs were harvested from each plot were separated and weight of cobs of each plot was recorded and expressed as cob yield kg ha^{-1}.

3.8.6 Cob Length (cm)

The cobs were harvested from each plot and five cobs from each plot selected randomly and cob length was recorded in cm.

3.8.7 Number of Cobs (m^{-2})

The number of cobs per meter was counted from each plot and was recorded**.**

3.8.8 Number of Grains (m^{-2})

Grain number was taken from cob sub samples were averaged and expressed in grams.

3.8.9 Grain Yield (kg ha^{-1})

The kernels from the air dried cobs from each net plot were separated, cleaned and dried to obtain atleast 13 per cent of moisture. Weight of grains of each plot was recorded separately and expressed as grain yield kg ha^{-1}.

3.8.10 Stover Yield (kg ha^{-1})

The stover obtained from each plot was weighed after it is completely sun dried and expressed as stover yield in kg ha-^{1}

3.8.11 Harvest Index (%)

Harvest Index (HI) is the ratio of economic yield to the total biological yield and was calculated by using the following formula given by Donald (1962) and expressed in percentage.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.9 NITROGEN ANALYSIS IN PLANT SAMPLES

Plant samples of maize were collected for dry matter estimation at six leaf stage, tasseling stage and physiological maturity stages from different treatments and the same were utilized for analysis of nitrogen content. Nitrogen content in the plant samples was estimated by Microkjeldhal method (Piper, 1996).

3.10 PHOTOPERIOD AND TEMPERATURE INTERACTION PARAMETERS

Agrometeorological indices like Growing degree days (GDD), Heliothermal units (HTU), Photothermal units (PTU) and Heliothermal units (HUE) were computed during different phases of maize by adopting the procedure laid out by Rajput (1980).

3.10.1 Growing Degree Days

A degree day is the difference between the mean temperature of the day and base temperature. Growing Degree Days (GDD) are used to match the crop requirements for heat to the amount of heat available. The base temperature for calculating growing degree days is the minimum threshold temperature at which plant growth starts. Base temperature of 10°C was used for computation of GDD on daily basis (Leong and Ong, 1983).

$$\textbf{Growing degree days (°C)} = \sum \frac{Tmin + Tmax}{2} - T_b$$

Growing degree days (°C), Tmin = minimum temperature (°C), Tmax= maximum temperature and T_b = Base temperature = 10°C (Narcico *et al.* 1992).

3.10.2 Photothermal Units

The photothermal units for each day represent the product of GDD and the day length. The accumulated PTU for each phenophase was determined by the following formula.

Accumulated PTU (°C day hr) = GDD × Day length (hrs.)

3.10.3 Heliothermal Units

The heliothermal units for a given day represent the product of GDD and the actual hours of bright sun shine for that day. The sum of the HTU for the duration of each phenophase was determined by using the formula.

Accumulated HTU (°C day hr) = GDD × Duration of sunshine hour

3.10.4 Heat Use Efficiency

Heat Use Efficiency (HUE) for economic yield (grain yield, kg/ha) was calculated using the following formula.

$$\textbf{HUE (kg ha}^{-1}\textbf{ °C day}^{-1}\textbf{)} = \frac{\text{Dry wt. of grains / unit area}}{\text{GDD}}$$

3.11 STATISTICAL ANALYSIS

The experimental data was analyzed statistically applying analysis of variance technique for split plot design. The significance was tested by F test (Snedecor and Cochron, 1967). Critical difference for examining treatment means for their significance was calculated at 5 per cent level of probability (P=0.05).The influence of weather parameters was studied by comparing different hybrids for four dates of sowing thus constituting twelve treatment combinations. Understanding the influence of weather that prevailed during the phenophases is rather easy, than understanding the influence of the weather that prevailed during the different periods as expressed in days after sowing. Hence, maize crop growth period was divided into seven phases *viz.*, P_1 = sowing to emergence P_2 = Emergence to six leaf stage; P_3= Tasseling to silking stage; P_4= Silking stage to soft dough stage; P_5= Soft dough stage to hard dough stage; Hard dough stage to physiological maturity.

3.12 VALIDATION OF DSSAT V4.5 CERES - MAIZE MODEL

3.12.1 Model description

To assess the role of simulation models in agriculture research, the Decision supporting system for Agro-technology Transfer (DSSAT) v4.5 CERES-Maize model was used. DSSATv4.5 is an upgrade model of technology DSSAT v4.0. DSSAT v4.5 is MS Window-based model. The preferred operating system is Windows XP.

Crop growth and development are simulated by the CERES –Maize model in DSSAT v4.5 (Hoogenboom *et al*. 2010) with daily step from planting to maturity using physiological process models that describe the response of maize to soil and environmental conditions. Potential growth is dependent on photosynthetically active radiation and its interception, whereas actual biomass production on any day is constrained by suboptimal temperatures, soil water deficits (Ritchie and Godwin, 1989: Ritchie, 1998). There are four types of input data to the model : weather, plant, soil and management.

3.12.2 Input requirement to run CERES –Maize model

For use of CERES – Maize model, minimum Datasets (MDS) on crop management, macro and micro environmental parameters associated with weather, soil and crop are required as input. Input data files of CERES-Maize model are as per IBSNAT standard input/output formats and file structure described in DSSAT v4.5 (Hoogenboom *et al*. 2010).

3.12.3 Weather information

The weather input data set of the CERES- Maize model includes the daily sum of radiation (MJ m^{-2} day^{-1}), the daily minimum and maximum air temperatures (^{0}C) and daily precipitation (mm).These daily weather data including site specific information were collected and used for creating weather file and running CERES-Maize model.

3.12.4 Genetic Coefficients

Plant parameters and physiological characteristics are given in the form of genotypic coefficients, which describe physiological process such as developmental photosynthesis and growth for individual crop varieties.

To simulate CERES-Maize model the hybrids are selected which are having genotypic coefficients.

3.12.5 Crop management file

Experiment input files for the experiment was created as per the defined treatments and treatment combinations, and are used as input to experimental file. The experimental details are already prescribed in the earlier section of this chapter (3.4) were used as input to experimental file.

3.12.6 Simulation Studies

After the weather, soil, genotype and crop management input files were created for a specified simulation experiment, CERES-Maize model was run and output files were generated. These simulation results were compared with observed data.

3.12.7 Statistical Analysis and Interpretation of Results

Performance of the model was evaluated using absolute and normalized root mean square error (RMSE and NRMSE), and the Wilmot d index (Willmott *et al*. 1985). Statistical based criteria provide a more objective method for evaluation of the performance of models (Ducheney, 2000).

$$\text{MBE} = \sum_{i=0}^{n} \frac{[P_i - O_i]}{n}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=0}^{n} [P_i - O_i]^2}$$

$$\text{NRMSE} = \left(\frac{\text{absolute RMSE}}{\overline{O}} \right) \times 100$$

$$\text{D index} = 1 - \frac{\sum_{i=1}^{n} \left[(P_i - \overline{O}) - (O_i - \overline{O}) \right]^2}{\sum_{i=1}^{n} \left(\left| P_i - \overline{O} \right| + \left| O_i - \overline{O} \right| \right)^2}$$

where, P*i*, O*i* are the predicted and observed values, n is the number of observations, $\overline{O}$ is the mean of the observed values.

$$\text{PE} = \frac{\text{simulated} - \text{observed}}{\text{observed}} \times 100$$

where PE indicates error percent

The values of RMSE and d- index determine the ability of the model to predict the experimental data. Low RMSE and d value close to one indicate good agreement between the experimental data and model output. The normalized RMSE (%) indicates the relative difference between simulated and observed values. The model simulation were considered excellent, good, fair and poor based on the respective normalized RMSE (NRMSE) values of <10%, 10-20%, 20-30% and >30%.

MAE and RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between Predicted and observed. The statistic MBE describes the direction of the error bias. The value of MBE is related to the magnitude of the values under investigation. Negative MBE indicates that the predictions are smaller in values than those of the corresponding observations.

Chapter ~ IV

Results & Discussion

Chapter – IV

RESULTS AND DISCUSSION

"Phenological responses of maize (*Zea mays* L.) to photoperiod and temperature" was conducted during *kharif* season, 2016. The experiment was carried out to study the influence of photoperiod and temperature on growth attributes and yield of maize by correlating the photo thermal units on various phenological growth stages and validation of CERES-Maize model for Southern Agro climatic zone.

4.1 CROP WEATHER RELATIONSHIPS

4.1.1 Maximum Temperature (°C)

The data pertaining to maximum temperature recorded during the crop growth period of three maize hybrids sown at different dates of sowing expressed in °C are presented in Table 4.1.

During the period of study from the time of sowing to physiological maturity, the mean maximum temperature for D.S 900M (H_1), Pinnacle (H_2) and CP818 (H_3) ranged from 34.4 to 33.7°C across the dates of sowing.

Highest maximum temperature of 36.3°C from Sowing to emergence was recorded in D_4 (August I FN sowing) and least maximum temperature of 32°C from sowing to emergence in D_1 (June II FN)

4.1.2 Minimum Temperature (°C)

The data corresponding to minimum temperature recorded during the crop growth period of maize hybrids sown at different dates of sowing, expressed in °C are presented in Table 4.1.

From the time of sowing to physiological maturity, the mean minimum temperature ranged from 25.6°C to 23.1°C.

Maize hybrids has recorded highest minimum temperature of 29.4°C from sowing to emergence (D_1) and least minimum temperature of 19.6°C from soft dough stage to hard dough stage in D_4 sowing (August I FN).

4.1.3 Relative Humidity (RH I and RH II) (%)

The data pertaining to Relative humidity (RH) including RH I and RH II recorded during the crop growth period of maize hybrid sown at different dates of sowing, expressed in per cent are presented in Table 4.1.

During the period of investigation from the time of sowing to physiological maturity, the RH I and RH II ranged from 76.4 to 72.0 per cent and 50.1 to 45.4 per cent respectively, across the dates of sowing.

Maize hybrids recorded highest RH I of 82.5 per cent from sowing to emergence in D1 and least RH I of 68.5 per cent from sowing to emergence in D_4.

Maize hybrids recorded highest RH II of 58.8 per cent from first sowing to emergence in D1 and least RH II of 35.3 per cent tasseling to silking stage (D_4).

4.1.4 Mean Relative Humidity (RH) (%)

The data pertaining to mean Relative humidity (RH) recorded during the crop growth period of maize hybrids sown at different dates of sowing, expressed in per cent are presented in Table 4.1.

From the time of sowing to physiological maturity, mean Relative humidity (RH) ranged from 63.6 to 60.1 per cent. Hybrids of maize recorded highest RH I of 70.7 per cent from sowing to emergence in D_1 (June II FN) and least RH I of 53.8 per cent from sowing to emergence in D_4 (August I FN).

Table 4.1. Mean of different weather parameters during various phenophases of maize hybrids (D.S 900M, Pinnacle and CP818)

Phenophases	Temperature (°C)		Relative humidity (%)		Relative humidity mean (%)	Sun shine hours (hrs)	Rain fall (mm)	Evaporation (K pa)	Day length
	Maximum	Minimum	Morning	Afternoon					
Sowing to emergence									
D_1 : June II FN	32.0	29.4	82.5	58.8	70.7	1.1	40.0	3.4	12.55
D_2 : July I FN	33.7	24.1	80.8	55.0	67.9	4.9	37.2	6.0	12.5
D_3 : July II FN	34.2	25.6	76.8	51.0	63.9	1.8	4.8	3.9	12.49
D_4 : August I FN	36.3	26.7	68.5	39.3	53.9	9.3	0.0	7.6	12.48
Emergence to six leaf stage									
D_1 : June II FN	34.7	25.6	76.4	49.6	63.0	4.3	55.0	5.5	12.50
D_2 : July I FN	32.9	24.8	76.9	55.4	66.1	3.0	121.2	4.1	12.45
D_3 : July II FN	35.8	26.2	69.9	43.7	56.8	8.0	0.0	7.0	12.44
D_4 : August I FN	33.7	25.5	74.6	49.9	62.3	4.0	54.3	5.3	12.40
Six leaf stage to tasseling stage									
D_1 : June II FN	34.6	25.5	73.2	48.8	61.0	5.8	121.8	4.1	12.36
D_2 : July I FN	35.0	25.9	72.7	46.0	59.3	6.4	54.3	6.3	12.28
D_3 : July II FN	34.6	25.5	73.2	48.8	61.0	5.8	121.8	5.8	12.27
D_4 : August I FN	34.1	25.1	78.2	48.1	63.2	3.9	29.6	4.9	12.26
Tasseling to silking stage									
D_1 : June II FN	33.3	25.5	79.8	53.9	66.8	2.7	53.9	4.1	12.24
D_2 : July I FN	32.9	24.9	75.1	54.0	64.6	2.5	16.0	3.9	12.22
D_3 : July II FN	34.4	25.2	80.7	46.2	63.4	4.3	7.2	5.3	12.14
D_4 : August I FN	35.4	20.8	73.8	35.3	54.5	8.2	0.0	5.6	12.13

Cont…

Table 4.1. Contd…

Phenophases	Temperature (°C)		Relative humidity (%)		Relative humidity mean (%)	Sun shine hours (hrs)	Rain fall (mm)	Evaporation (K pa)	Day length
	Maximum	Minimum	Morning	Afternoon					
Silking to soft dough stage									
D_1 : June II FN	33.8	25.1	71.4	47.6	59.5	4.9	0.4	6.0	12.18
D_2 : July I FN	33.6	25.3	79.2	51.5	65.4	3.6	6.4	5.0	12
D_3 : July II FN	35.7	23.7	73.4	37.9	55.7	6.1	0.0	5.4	11.57
D_4 : August I FN	34.0	22.3	79.0	44.2	61.6	5.5	11.2	4.7	11.56
Soft dough to hard dough stage									
D_1 : June II FN	33.2	24.8	78.4	53.0	65.7	3.6	23.9	4.3	12.10
D_2 : July I FN	34.9	24.8	80.3	43.3	61.8	4.7	7.2	5.0	11.59
D_3 : July II FN	35.4	20.4	81.4	35.5	58.4	7.9	0.0	5.4	11.45
D_4 : August I FN	33.3	19.6	73.4	41.4	57.4	7.6	0.0	5.2	11.44
Hard dough to physiological maturity									
D_1 : June II FN	34.5	25.0	81.6	44.9	63.3	4.4	6.9	5.3	11.84
D_2 : July I FN	35.7	22.6	72.8	36.7	54.8	7.3	0.0	5.5	11.49
D_3 : July II FN	33.4	21.6	74.8	43.8	59.3	5.9	11.6	4.8	11.36
D_4 : August I FN	31.3	19.6	78.8	48.5	63.6	5.9	70.8	4.1	11.34
Sowing to physiological maturity									
D_1 : June II FN	34.1	25.6	76.3	50.1	63.2	4.5	301.9	5.3	12.25
D_2 : July I FN	34.3	25.0	72.0	46.9	63.6	9.4	242.2	5.4	12.16
D_3 : July II FN	34.4	24.3	75.2	45.4	60.3	5.5	145.4	5.4	11.96
D_4 : August I FN	33.7	23.1	76.4	45.8	61.1	3.0	165.9	3.4	11.94

4.1.5 Bright sunshine hours

The data pertaining to sunshine hours recorded during the crop growth period of maize hybrids sown at different dates of sowing are presented in Table 4.1.

From the time of sowing to physiological maturity, sunshine hours of maize hybrids ranged from 9.4 hours to 3 hours across the dates of sowing.

Hybrids of maize recorded highest sunshine hours of 9.4 from sowing to emergence in D_1 (June II FN) and least sunshine hours of 1.1 from sowing to emergence in D_4 (August I FN).

4.1.6 Day Length

The data pertaining to day length recorded during the crop growth period of maize hybrids sown at different dates of sowing are presented in Table 4.1.

From the time of sowing to physiological maturity, day length period of maize hybrids ranged from 11.94 to 12.25 across the four dates of sowing.

Hybrids of maize recorded highest day length of 12.55 from sowing to emergence in D_1 (June II FN) and least day length of 11.34 from sowing to emergence in D_4 (August I FN).

4.1.6 Rainfall (mm)

The data pertaining to rainfall recorded during the crop growth period of maize hybrids sown at different dates of sowing, expressed in (mm) are presented in Table 4.1.

From the time of sowing to physiological maturity, total rainfall ranged from 295mm. Hybrids of maize recorded highest rainfall of 121.2

mm from emergence to six leaf stage in D_2 (July I FN) and least rainfall of 0.0 mm at different growth stages across the Hybrids.

4.1.7 Evaporation

The data pertaining to evaporation recorded during the crop growth period of maize hybrids sown at different dates of sowing, expressed in are presented in Table 4.1.

From the time of sowing to physiological maturity, evaporation ranged from 5.4 K Pa to 3.4 K Pa across the dates of sowing.

Hybrid of maize recorded highest evaporation of 7.6 K Pa from sowing to emergence in D_4 (August I FN) and least evaporation of 3.4 KPa from sowing to emergence in D_1 (June II FN).

4.2 PHOTOPERIOD AND TEMPERATURE INTERACTIONS

4.2.1 Growing Degree Days

The data on accumulated growing degree days (AGDD) computed at all the growth stages of maize Table 4.2.

The data revealed that during the crop growing season, GDD accumulated across all the sowing dates ranged from 3170.4 to 2920.8°C and hybrids 2994.1 to 3053.3°C with a standard deviation of 129.1°C and 32.7°C from sowing to physiological maturity.

The GDD accumulation was higher in case of Pinnacle (3053.3°C) followed by D.S 900M (3049.1°C) and CP818 (2994.1°C) from sowing to physiological maturity. At vegetative stages of crop growth their was no much variation among the hybrids. The variation was observed from tasseling to maturity stages. D.S 900M recorded highest GDD from tasseling to maturity stages except at soft dough stage were Pinnacle recorded highest GDD.

Table 4.2. Calendar days and agrometeorological indices at different growth stages of maize hybrids at different dates of sowing

Treatments	Sowing to Emergence				Emergence to Six leaf stage				Six leaf stage to Tasselling stage			
	C day	**GDD**	**PTU**	**HTU**	**C day**	**GDD**	**PTU**	**HTU**	**C day**	**GDD**	**PTU**	**HTU**
Hybrids												
H_1 : D.S 900M	6	222.5	2781.3	1102.4	18.0	539.4	6742.5	4417.5	35	1072.9	13261.0	6264.7
H_2 : Pinnacle	7	212.1	2651.3	1015.5	18.0	524.2	6552.5	4300.7	33	1022.1	12633.2	5492.2
H. : CP818	6	222.2	2777.5	1040.2	18.0	532.8	6660	4490.7	38	1052.3	13006.4	5585.9
Mean	6	218.9	2736.7	1052.7	18.0	532.1	6651.7	4403.0	35	1049.1	12966.9	5780.9
SD	0.9	5.9	74.0	44.8	0.0	7.6	95.3	95.8	2.4	25.6	315.8	421.6
CV (%)	14.4	2.7	2.7	4.3	0.0	1.4	1.4	2.2	6.8	2.4	2.4	7.3
Dates of Sowing												
D_1 : June II FN	5	176.3	2212.6	188.0	18.0	534.9	6686.3	2276.3	34	1079.8	13346.3	6118.3
D_2 : July I FN	5	136.6	1707.5	669.3	17.0	482.2	6003.4	8305.4	34	1058.6	12999.6	8305.4
D_3 : July II FN	4	121.7	1520.0	222.8	19.7	580.9	7226.4	4672.1	36	1080.3	13255.3	4883.2
H_4 : August I FN	7	222.2	2773.1	2077.9	17.7	530.5	6578.2	2358.1	36	977.7	11986.6	3816.8
Mean	5.4	164.2	2053.3	789.5	18.1	532.1	6623.6	4403.0	35.1	1049.1	12897.0	5780.9
SD	1.3	45.0	562.0	886.4	1.1	40.4	501.3	2828.7	1.1	48.7	624.4	1927.9
CV (%)	24.3	27.4	365.4	112.3	6.3	7.6	7.6	64.2	3.1	4.6	2065.5	33.3

C day: Calendar days; GDD: Growing degree days (°C); PTU=Photothermal units (°C day hr); HTU=Heliothermal units (°C day hr)

Cont…

Table 4.2. Contd…

Treatments	Tasseling to silking stage				Silking to soft dough stage				Soft dough to hard dough stage			
	C day	**GDD**	**PTU**	**HTU**	**C day**	**GDD**	**PTU**	**HTU**	**Cday**	**GDD**	**PTU**	**HTU**
Hybrids												
H_1 : D.S 900M	8	239.2	2927.8	1032.5	10.3	312.1	3801.4	1591.3	11	282.8	3444.5	1568.9
H_2 : Pinnacle	9	202.9	2483.5	947.3	13.0	302.8	3688.1	1514.1	16	621.1	7565.0	2885.3
$H_.$: CP818	8	233.0	2851.9	1080.3	10.3	282.8	3444.5	1268.1	11	320.9	3908.6	1823.8
Mean	8.3	225.0	2754.4	1020.0	11.2	299.2	3644.7	1457.9	12.6	408.3	4972.7	2092.7
SD	0.6	19.4	237.7	67.4	1.6	15.0	182.4	168.8	3.0	185.3	2257.0	698.2
CV (%)	7.5	8.6	8.6	6.6	14.2	5.0	5.0	11.6	23.7	45.4	45.4	33.4
Dates of Sowing												
D_1 : June II FN	10	236.7	2897.2	705.1	9.0	256.5	3124.2	1136.1	15	674.8	8165.1	2385.9
D_2 : July I FN	7	194.6	2378.0	471.1	8.7	284.0	3408.0	1044.7	12	340.2	3942.9	1560.1
D_3 : July II FN	7	229.5	2786.1	1014.9	10.7	290.9	3365.7	1720.7	10	256.1	2932.3	1770.4
H_4 : August I FN	9	239.3	2902.7	1889.0	11.0	365.5	4225.2	1929.9	12	261.9	2996.1	1388.1
Mean	8.2	225.0	2741.4	1020.0	9.8	299.2	3530.8	1457.9	12.3	383.3	4509.1	1776.1
SD	1.5	20.7	1.2	620.7	1.2	46.6	479.5	434.4	2.2	198.1	2480.8	435.5
CV (%)	17.8	9.2	4.2	60.8	11.9	15.6	736.3	29.8	18.1	51.7	55.0	24.5

C day: Calendar days; GDD: Growing degree days (°C); PTU=Photothermal units (°C day hr); HTU=Heliothermal units (°C day hr)

Cont…

Table 4.2. Contd…

Treatments	Hard dough stage to Physiological maturity				Sowing to Physiological maturity				
	Cday	GDD	PTU	HTU	Cday	GDD	PTU	HTU	HUE at maturity
Hybrids									
H_1 : D.S 900M	16	402.4	4869.04	2358.5	104	3049.1	36101.1	17074	0.9
H_2 : Pinnacle	16	345.6	4181.76	3219.5	112	3053.3	36151.1	17098	1.0
$H_.$: CP818	12	379.6	4593.16	2278.5	102	2994.7	35457.2	16770.3	1.0
Mean	14.8	375.9	4548.0	2618.8	106	3032.3	35903.1	16980.8	1.0
SD	2.2	28.6	345.9	521.8	5.3	32.7	387.0	183.1	0.0
CV (%)	14.7	7.6	7.6	19.9	5.0	1.1	1.1	6.2	4.8
Dates of Sowing									
D_1 : June II FN	12	368.3	4360.7	2357.12	104	3170.4	38837.4	20288	1.2
D_2 : July I FN	15	359	4124.9	2312.32	100	2990	36358.4	19734	1.0
D_3 : July II FN	12	370.3	4206.6	2268.4	100	2920.8	34932.8	15501.9	0.9
H_4 : August I FN	20	450.5	5108.7	2618.4	112	3079.6	3677.0	14163.4	0.6
Mean	14	387.0	4450.2	2389.0	103	3065.2	37023.2	18811.8	1
SD	4.1	42.6	449.7	157.1	6.9	129.9	1731.0	2222.3	0.3
CV (%)	29.	11.0	10.1	6.5	6.7	4.2	4.6	11.8	28.4

C day: Calendar days; GDD: Growing degree days (°C); PTU: Photothermal units (°C day hr); HTU: Heliothermal units (°C day hr); HUE: Heat Use Efficiency (kg/ha/°C).

The shifting of sowing dates corresponds to fluctuations in temperatures either lengthing or shortening of the growing periods. Among the dates of sowing D_1 (June II FN) recorded highest GDD (3170.4°C) followed by D_2 and D_3 (July II FN) recorded lowest GDD (2920°C). Among the dates of sowing GDD varied among all the crop growth stages due to the fluctuated unfavourable conditions high temperatures during the crop growth period the accumulated heat units decreased for different phonological growth stages among the dates of sowing. Similar variability was also reported by Pandey *et al*. (2010), Girijesh *et al*. (2011) and Ahmad *et al*. (2016).

4.2.2 Photothermal Unit

The data on Photothermal unit (PTU) computed at all the growth stages of maize Table 4.2.

The data revealed that during the crop growing season, Mean PTU across all the hybrids and sowing dates was 35903.1°C day hour and 37023.2°C day hour respectively, with a standard deviation of 387 and 1731.1.

The PTU was higher in case of Pinnacle (36151.1°C day hour) followed by D.S 900M (36101.3°C day hour) and CP818 (35457.2°C day hour) from sowing to physiological maturity. At vegetative stages of crop growth their was no much variation among the hybrids. The variation was observed from tasseling to maturity stages.

The shifting of sowing dates corresponds to fluctuations in temperatures either lengthing or shortening of the growing periods. Among the dates of sowing D_1 (June II FN) recorded highest PTU (38837.4°C day hour) followed by D_2 and D_3. Due to increased number of calendar days to attain physiological maturity D_4 recorded higher PTU (3677.04°C day hour). Among the dates of sowing PTU varied among all the crop growth stages. Similar variability was also observed by Gowda *et al*. (2013).

4.2.3 Heliothermal Units (HTU)

The data on Heliothermal unit (HTU) computed at all the growth stages of maize Table 4.2.

The data revealed that during the crop growing season, Mean HTU across all the hybrids and sowing dates was 16980.88°C day hour and 18811.8°C day hour respectively with a standard deviation of 183.12 and 222.3.

The HTU was higher in case of Pinnacle (17098°C day hour) followed D.S 900M and CP818 from sowing to physiological maturity. HTU was varying among the crop growth stages of maize.

The shifting of sowing dates corresponds to fluctuations in temperatures either lengthing or shortening of the growing periods. Among the dates of sowing D_1 (June II FN) recorded highest HTU (20288°C day hour) and D_4 (August I FN) recorded lowest HTU (14163.4°C day hour). Similar variability was also observed by Girijesh *et al*. (2011) and Hariram *et al*. (2012).

4.2.4 Heat Use Efficiency

The data on Heat Use Efficiency (HUE) computed at all the growth stages of maize Table 4.2.

The data revealed that during the crop growing season, Mean HUE across all the hybrids and sowing dates was 1.0 and 1.0 respectively with a standard deviation of zero and 0.3.

The HUE was higher in case of Pinnacle and CP818 was 1 kg ha^{-1} ^{o}C day^{-1} and D.S 900M (0.91 kg ha^{-1} ^{o}C day^{-1}) from sowing to physiological maturity.

Among the dates of sowing D_1 (June II FN) recorded highest HUE (1.2 kg ha^{-1} ^{o}C day^{-1}) and lowest by D_4 (August I FN, 0.6 kg ha^{-1} ^{o}C day^{-1}).

Higher HUE represents that plant utilized the heat more efficiently by increasing biological activity and higher grain yield. Similar variability was also observed by Thavaprakash *et al*. (2007), Girijesh *et al*. (2011) and Rajesh *et al*. (2015) in wheat.

4.3 MORPHOLOGICAL AND GROWTH ATTRIBUTES (AT PHENOLOGICAL GROWTH STAGES OF CROP)

4.3.1 Plant Height (cm)

Plant height is an important aspect of the ecology of a plant species. The benefit of height is pre-emptive access to light. The plant height of maize hybrids sown at different dates of sowing in *kharif* was recorded at six growth stages and presented in the Table 4.3 and Fig. 4.1.

Irrespective of hybrids and dates of sowing the plant height increased as the growth advanced. The exponential increase in plant height was observed from six leaf stage to silking stage and there after plant height showed only marginal increase till physiological maturity. Such phenotypic variability was reported in maize by Amjadian *et al.* (2013).

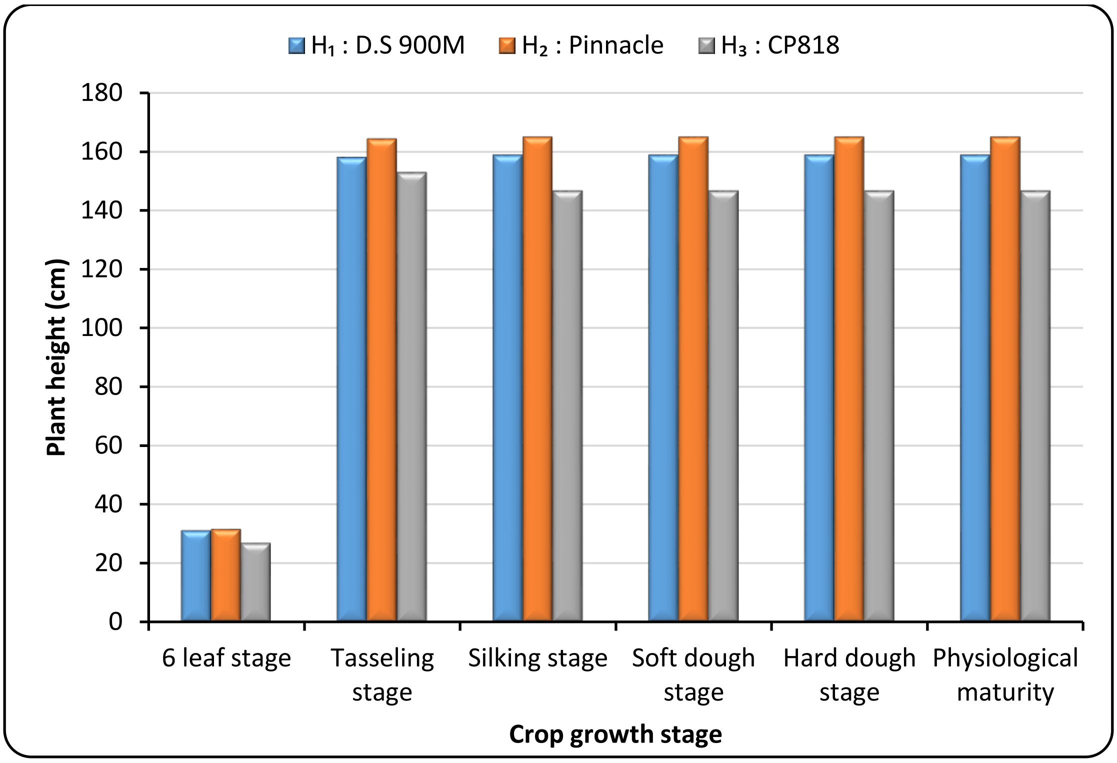
Among the hybrids significant variability for plant height was observed at six leaf stage and tasseling stage. Among the three hybrids Pinnacle recorded significantly highest plant height at silking stage (165 cm) followed by D.S 900 M (158.8 cm) whereas CP818 recorded lowest plant height (146.7 cm).

Among the dates of sowing significant variability was seen throughout the growth stages among the four dates of sowing. D_1 (June II FN) recorded significantly highest plant height (165 cm) at all growth stages followed by D_2 (July I FN), D_3 (July II FN) and D_4 (August I FN). The early sown crop responded to favorable temperatures with respect to optimum temperatures and solar radiation which resulted in good growth compared to later dates of sowings. The results are in conformity with the findings of Kosgasago (2006) and Amjadian *et al*. (2013) in maize.

Table 4.3. Effect of photoperiod and temperature on plant height (cm) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	31.3	158.0	158.8	158.8	158.8	158.8
H_2 : Pinnacle	31.6	164.3	165.0	165.0	165.0	165.0
H_3 : CP818	27.1	152.9	146.7	146.7	146.7	146.7
CD (P=0.05)	1.4	3.3	NS	NS	NS	NS
Dates of Sowing						
D_1 : June II FN	35.1	177.8	178.4	178.4	178.4	178.4
D_2 : July I FN	32.0	170.8	162.0	162.0	162.0	162.0
D_3 : July II FN	29.1	151.5	152.3	152.3	152.3	152.3
D_4 : August I FN	23.9	134.3	134.6	134.6	134.6	134.6
CD (P=0.05)	3.0	4.5	19.3	19.3	19.3	19.3
Interaction (D × H)						
D_1H_1	37.3	176.6	177.4	177.4	177.4	177.4
D_1H_2	36.3	1683.1	183.4	183.4	183.4	183.4
D_1H_3	31.7	173.7	174.3	174.3	174.3	174.3
D_2H_1	34.9	170. 6	171.7	171.7	171.7	171.7
D_2H_2	33.0	176.0	176.9	176.9	176.9	176.9
D_2H_3	28.1	163.7	137.4	137.4	137.4	137.4
D_3H_1	29.5	152.1	152.3	152.3	152.3	152.3
D_3H_2	31.7	159.6	161.4	161.4	161.4	161.4
D_3H_3	26.2	142.7	143.4	143.4	143.4	143.4
D_4H_1	23.4	132.8	133.7	133.7	133.7	133.7
D_4H_2	25.6	138.5	138.3	138.3	138.3	138.3
D_4H_3	22.6	131.5	131.7	131.7	131.7	131.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Hybrids



Dates of sowing

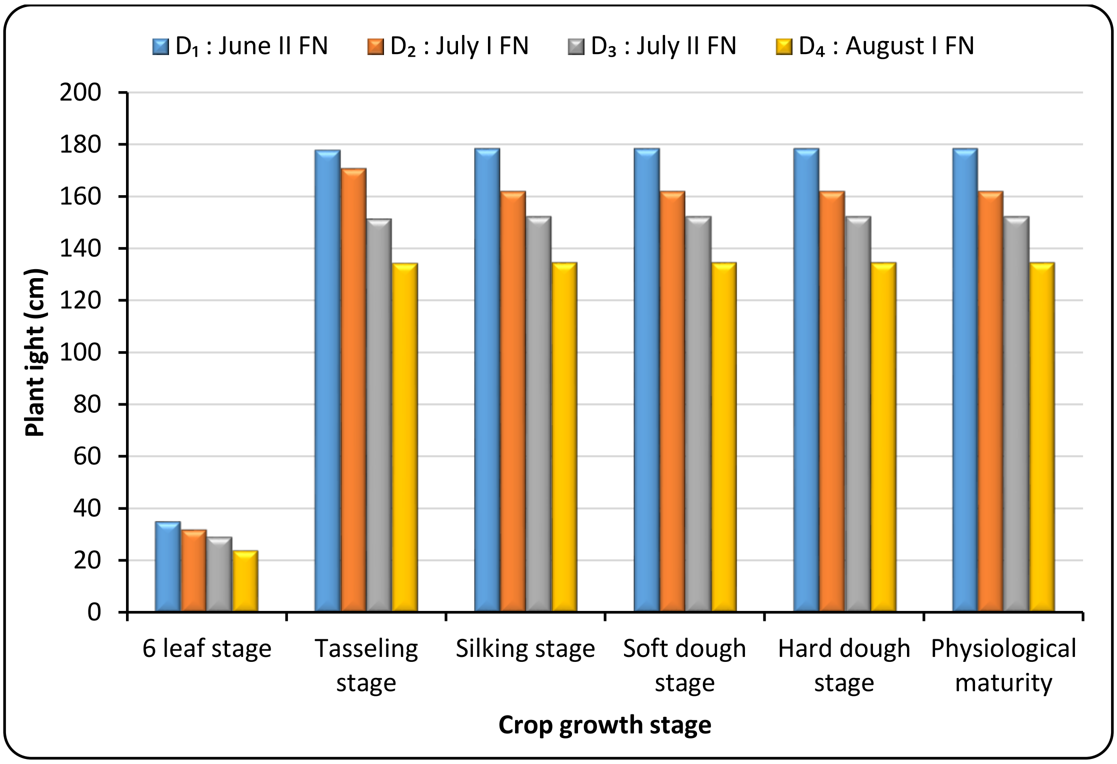


Fig. 4.1. Plant height (cm) of maize hybrids at different crop growth stages as influenced by dates of sowing

The interaction of hybrids and the dates of sowing were non-significant throughout the crop growth stages. D_1H_2 *i.e.*, Pinnacle sown at first FN of July recorded numerically higher plant height (183.4 cm) compared to all other interaction effects. Variability in plant height of tested maize hybrids at different dates of sowing is attributed to variability in crop requirement of temperature and photoperiod *viz.*, Growing degree days (GDD), Photothermal Units (PTU) and Heliothermal units (HTU). Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Williams and Lindsquist (2007) and Hussain *et al.* (2012).

4.3.2 Dry matter Partitioning (g plant^{-1})

4.3.2.1 Leaf dry weight (g plant^{-1})

Leaf dry matter denotes the leaf area and leaf density, which quantifies chloroplast apparatus. Leaf dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.4 and Fig. 4.2.

Leaf dry matter was gradually increased up to tasseling stage and there after decreased till harvest. Significant differences for leaf dry weight was recorded irrespective of hybrids and dates of sowing at all the growth stages of except at six leaf stage.

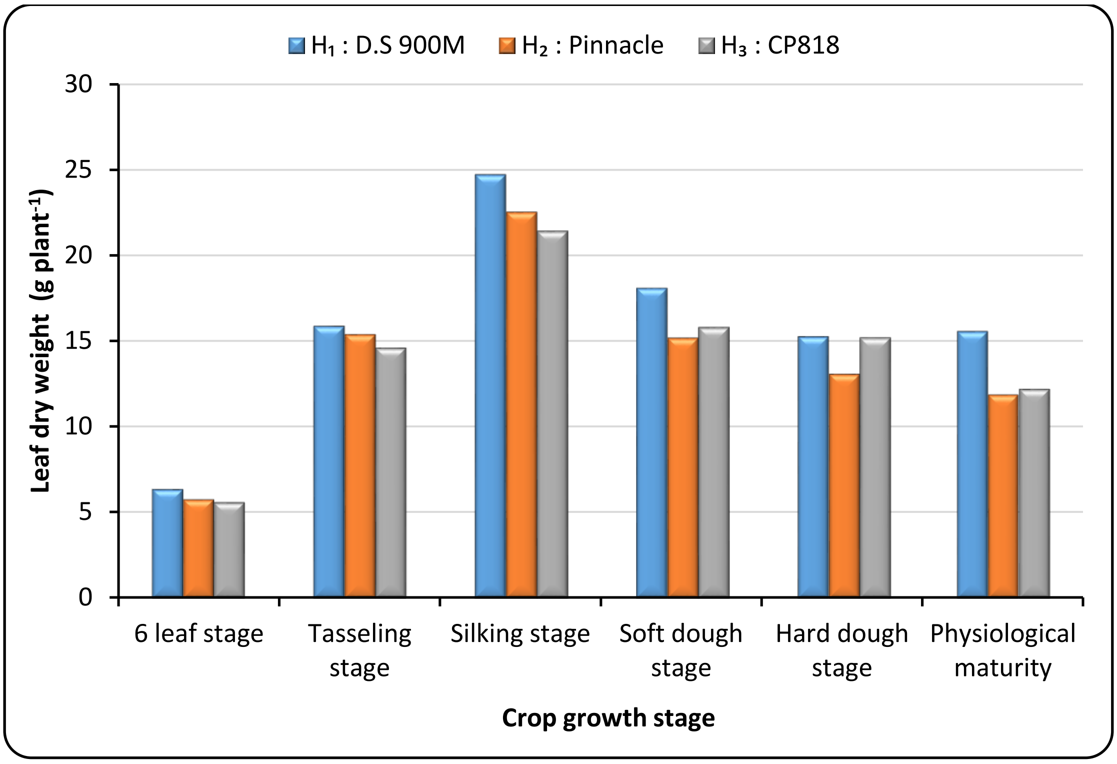
Among the hybrids highest leaf dry weight was recorded by D.S 900 M (24.7 g plant^{-1}) due to higher accumulation of GDD, HTU and PTU followed by Pinnacle (22.5 g plant^{-1}) and lowest leaf dry weight was recorded in CP818 (21.4 g plant^{-1}).

Among the dates of sowing D_1 (June II FN) recorded significantly highest leaf dry weight at silking stage (28.9 g plant^{-1}) followed by D_2, D_3 and D_4. The plant leaf dry weight decreased as the sowings delayed. Lowest plant leaf dry weight (12.5 g plant^{-1}) was recorded in the D_4 (August I FN).

Table 4.4. Effect of photoperiod and temperature on leaf dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	6.4	15.9	24.7	18.1	15.3	15.6
H_2 : Pinnacle	5.8	15.4	22.5	15.2	13.1	11.9
H_3 : CP818	5.6	14.6	21.4	15.8	15.2	12.2
CD (P=0.05)	Ns	0.6	1.4	1.4	0.8	0.7
Dates of Sowing						
D_1 : June II FN	12.4	19.5	28.9	24.4	23.4	21.6
D_2 : July I FN	7.0	17.2	24.8	15.5	13.5	12.6
D_3 : July II FN	2.5	13.9	22.7	13.7	11.5	10.1
D_4 : August I FN	1.6	10.6	14.9	11.8	10.3	8.8
CD (P=0.05)	0.6	1.3	2.7	1.6	1.4	1.2
Interaction (D × H)						
D_1H_1	14.2	19.8	33.4	29.9	21.5	24.8
D_1H_2	11.3	20.2	27.9	24.3	19.6	19.3
D_1H_3	11.8	18.5	25.4	21.9	29.0	20.6
D_2H_1	7.2	17.1	24.2	18.2	17.0	17.0
D_2H_2	7.5	18.6	24.9	13.1	10.8	10.43
D_2H_3	6.4	15.8	25.4	15.1	12.3	10.2
D_3H_1	2.3	16.2	22.8	15.7	13.3	11.2
D_3H_2	2.6	13.3	23.3	11.7	11.5	9.5
D_3H_3	2.6	12.4	22.1	13.6	9.9	9.7
D_4H_1	1.86	10.9	18.3	11.4	10.8	9.6
D_4H_2	1.6	9.5	13.9	11.5	10.5	8.4
D_4H_3	1.4	11.5	12.5	12.6	9.7	8.5
CD (P=0.05)	Ns	1.2	2.1	2.8	1.7	1.4

Hybrids



Dates of sowing

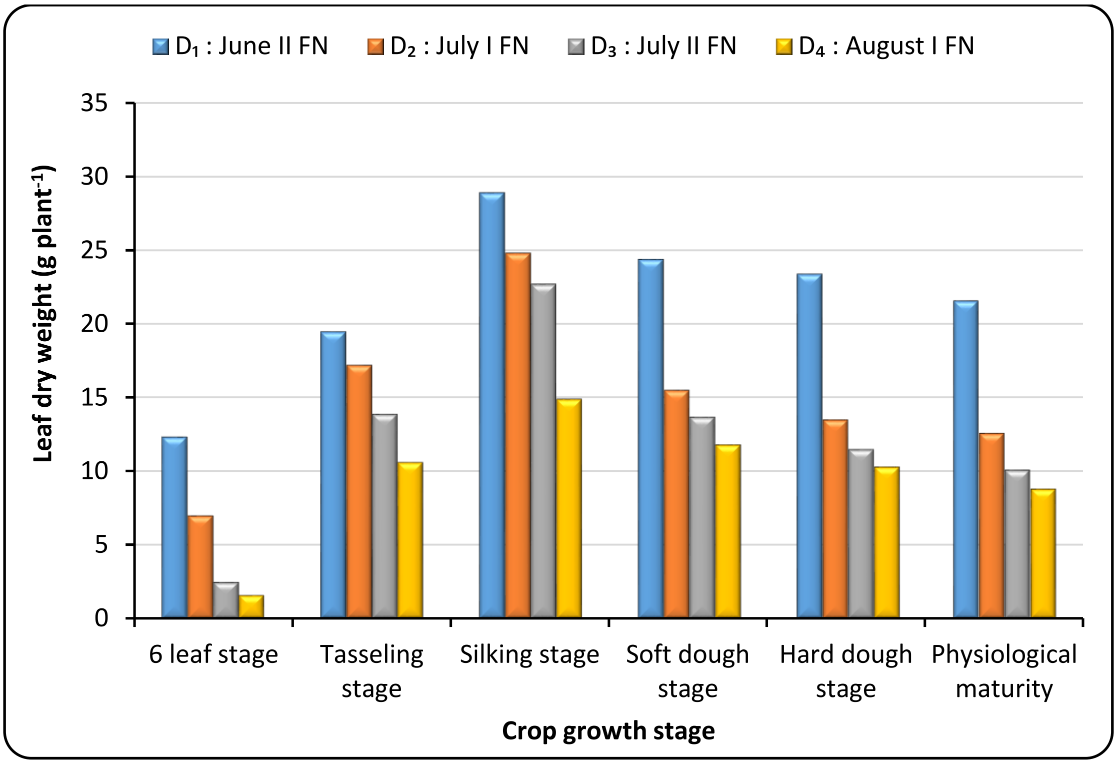


Fig. 4.2. Leaf dry weight (g plant^{-1}) of maize hybrids at different crop growth stages as influenced by dates of sowing

The interaction of hybrids and the dates of sowing were significant throughout the crop growth stages except at six leaf stage. D_1H_2 *i.e.,* D. S 900 M at D_1 recorded significantly higher leaf dry weight among all the growth stages of crop growth compared to all other interactions effects. Due to higher accumulation of heat units at grand growth phase for D_1 date of sowing the total leaf dry weight may be higher than D_2, D_3 and D_4. Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Nielsen *et al.* (2002) and Sulochana *et al*. (2015).

4.3.2.2 Stem dry weight (g plant^{-1})

Stem dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.5 and Fig. 4.3

Irrespective of the hybrids and dates of sowing the stem dry weight continuously increased from emergence to physiological maturity (5.52, 57.6, 77.3, 77.6, 78.6, 78.9 g plant^{-1}).

Among the hybrids D. S 900 M (78.9 g plant^{-1}) stem dry weight was numerically higher than Pinnacle (77.47 g plant^{-1}) and CP818 (76.50 g plant^{-1}). Significant difference among the hybrids was found only at tasseling stage.

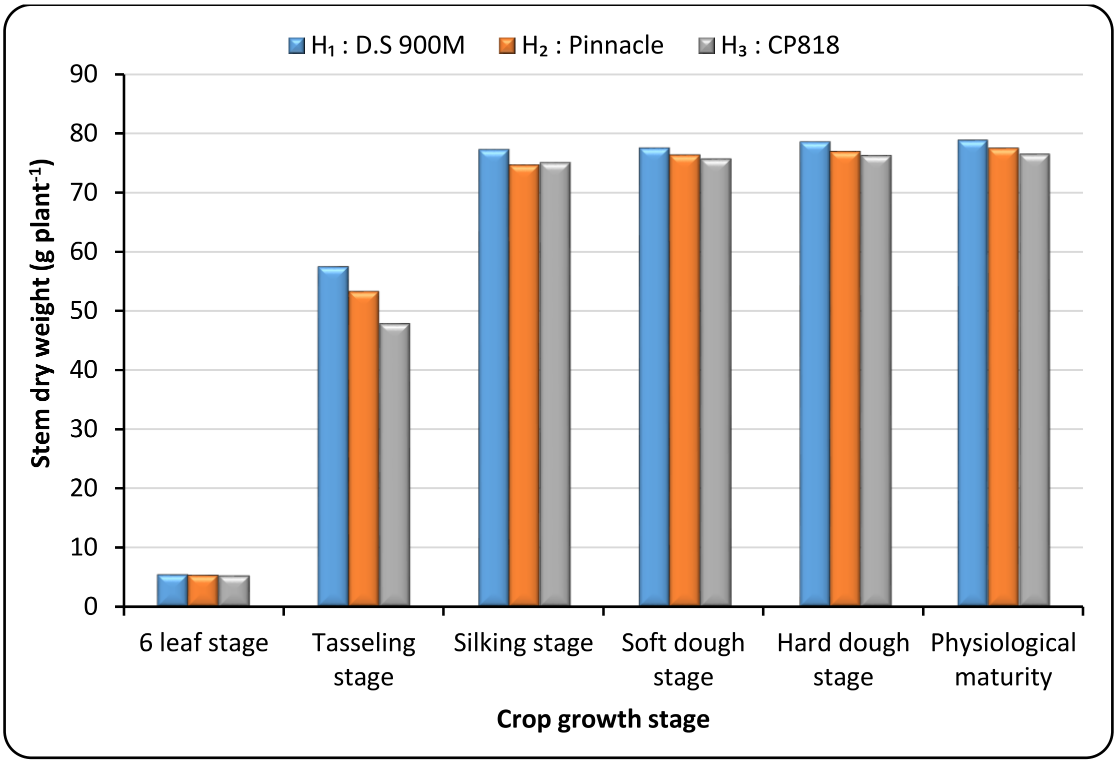
Among the dates of sowing D_1 (June II Fortnight) recorded significantly higher stem dry weight (95.9 g plant^{-1}) compared to all the other dates of sowing (D_2, D_3 and D_4) at all the growth stages of crop growth.

The interaction of hybrids and the dates of sowing were significant throughout the crop growth stages except at six leaf stage. D_1H_3 i.e., CP 818 at D_1 (June II FN) recorded significantly higher stem dry weight among all the growth stages of crop growth compared to all other interactions. Higher stem dry weight at first date of sowing can be correlated to higher accumulation of GDD and PTU from sowing to Tasseling stage. Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Nielsen *et al.* (2002) and Sulochana *et al*. (2015).

Table 4.5. Effect of photoperiod and temperature on stem dry weight (g plant $^{-1}$) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	5.5	57.6	77.3	77.6	78.6	78.9
H_2 : Pinnacle	5.4	53.4	74.7	76.4	77.0	77.5
H_3 : CP818	5.3	47.9	75.1	75.7	76.3	76.5
CD (P=0.05)	NS	2.7	NS	NS	NS	NS
Dates of Sowing						
D_1 : June II FN	9.3	85.2	93.9	94.8	95.2	95.9
D_2 : July I FN	7.5	66.8	81.8	82.6	83.2	83.6
D_3 : July II FN	2.4	35.6	69.4	70.3	71.3	71.7
D_4 : August I FN	2.3	24.4	57.6	58.6	59.5	59.6
CD (P=0.05)	0.8	5.2	4.6	4.2	2.9	3.1
Interaction (D × H)						
D_1H_1	8.7	96.7	94.6	95.1	95.6	96.3
D_1H_2	9.2	87.8	90.6	92.2	92.6	93.9
D_1H_3	9.9	71.03	96.5	97.2	97.3	97.5
D_2H_1	8.9	70.4	77.3	77.0	77.5	77.8
D_2H_2	7.1	67.1	84.6	87.0	87.6	88.0
D_2H_3	6.5	62.9	83.4	84.0	84.4	84.3
D_3H_1	2.4	39.1	74.3	75.0	75.6	75.9
D_3H_2	2.8	34.3	67.3	68.8	69.7	69.9
D_3H_3	2.1	33.3	66.6	67.3	68.6	69.1
D_4H_1	2.0	24.4	62.9	63.7	65.7	65.7
D_4H_2	2.3	24.5	56.3	57.6	58.0	58.1
D_4H_3	2.5	24.3	53.6	54.4	55.0	55.6
CD (P=0.05)	Ns	5.5	5.4	5.6	5.3	4.8

Hybrids



Dates of sowing

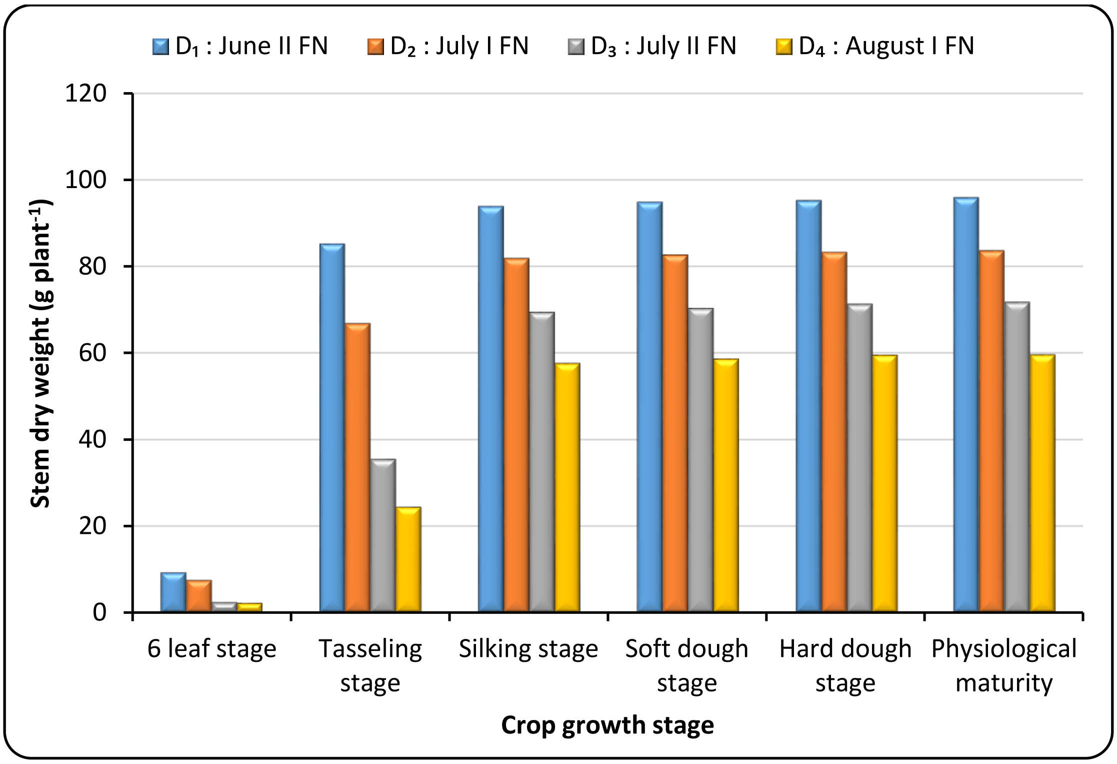


Fig. 4.3. Stem dry weight (g plant^{-1}) of maize hybrids at different crop growth stages as influenced by dates of sowing

4.3.2.3 Root dry weight (g plant^{-1})

Root dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.6.

Irrespective of the hybrids root dry weight increased upto soft dough stage and decreased till maturity.

Among the hybrids D.S 900 M recorded numerically higher root dry weight (29.4 g plant^{-1}) at soft dough stage followed by Pinnacle (28.4 g plant^{-1}) and lowest root dry weight was recorded by CP818. There was no significant difference among the hybrids during six leaf stage, tasseling stage and Soft dough stage. Increased heat unit accumulation in case of D.S 900M increased root dry weight compared to Pinnacle and CP818.

Among the dates of sowing D_1 (June II FN) recorded significantly higher root dry weight (42.7 g plant^{-1}) among all growth stages of crop growth followed by D_2, D_3 and D_4 recorded significantly lower root dry weight (21.3 g plant^{-1}).

The interaction of hybrids and the dates of sowing D_1H_2 i.e., Pinnacle at D_1 (June II FN) recorded significantly higher root dry weight (13.3 g plant^{-1}) at six leaf stage. Were as at silking stage D.S 900M recorded significantly higher root dry weight (29.2 g plant^{-1}). Lower root dry weight (1.6 g plant^{-1}) was recorded by D_4 (August I FN) Pinnacle at Six leaf stage and Silking stage. First date of sowing accumulated more het units at vegetative stage. So, the root dry weight increased compared to D_2, D_3 and D_4. Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Nielsen *et al*. (2002) and Sulochana *et al*. (2015).

Table 4.6. Effect of photoperiod and temperature on root dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	6.24	14.7	25.4	29.4	28.0	25.3
H_2 : Pinnacle	6.4	15.6	22.9	28.4	27.5	26.2
H_3 : CP818	6.4	14.6	22.5	27.7	25.3	24.3
CD (P=0.05)	NS	NS	1.4	NS	1.7	0.8
Dates of Sowing						
D_1 : June II FN	13.2	26.8	26.7	42.7	42.5	41.0
D_2 : July I FN	8.3	15.3	28.2	27.4	24.8	21.6
D_3 : July II FN	2.3	10.6	20.8	22.6	21.2	19.4
D_4 : August I FN	1.6	7.1	18.6	21.3	19.5	19.0
CD (P=0.05)	0.5	1.0	1.5	1.2	3.3	1.7
Interaction (D × H)						
D_1H_1	13.2	26.2	29.2	43.23	41.6	38.6
D_1H_2	13.3	26.8	25.8	42.0	43.9	44.0
D_1H_3	13.2	27.7	25	42.8	41.8	40.5
D_2H_1	7.6	15.6	31.0	29.3	27.6	23.1
D_2H_2	8.7	16.5	28.5	26.8	24.9	21.8
D_2H_3	8.7	13.8	24.9	26.0	21.1	19.9
D_3H_1	2.4	10.7	20.7	22.8	22.3	19.2
D_3H_2	2.3	10.8	20.6	22.7	21.3	20.3
D_3H_3	2.1	10.3	21.8	22.2	19.1	18.7
D_4H_1	1.8	6.4	20.6	22.2	20.6	20.3
D_4H_2	1.3	8.3	17.1	22.0	19.7	18.6
D_4H_3	1.6	6.4	18.2	19.7	18.2	18.3
CD (P=0.05)	0.6	NS	2.8	NS	NS	1.7

4.3.2.4 Tassel Dry Weight (g plant^{-1})

The data on tassel dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing are presented in the Table 4.7

Irrespective of the hybrids tassel dry weight decreased as the growth advanced. Among the hybrids D.S 900M (H_1) and Pinnacle (H_2) recorded significantly higher tassel dry weight (4.9 g plant^{-1}) compared to CP818 (4.5 g plant^{-1}).

Among the dates of sowing D_1 (June II FN) recorded significantly higher tassel dry weight (5.4 g plant^{-1}) among all growth stages of crop growth followed by D_2, D_3 and D_4 recorded significantly lower tassel dry weight (3.9 g plant^{-1}).

The interaction of hybrids and the dates of sowing D_1H_1 i.e., Pinnacle at D_1 (June II FN) recorded numerically higher tassel dry weight (5.7 g plant^{-1}) at tasseling stage. D_4H_3 *i.e.*, fourth date of sowing CP818 recorded lowest tassel dry weight (3.7 g plant^{-1}). Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Nielsen *et al*. (2002) and Sulochana *et al.* (2015).

4.3.2.5 Cob Dry Weight (g plant^{-1})

The data on cob dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing are presented in the Table 4.8 and Fig. 4.4.

Irrespective of hybrids cob dry weight was increased as the growth advanced toward physiological maturity. Among the hybrids D.S 900M (H_1) and Pinnacle (H_2) recorded significantly higher cob dry weight (179.8 g plant^{-1}) compared to CP818 (4.5 g plant^{-1})

Among the dates of sowing D_1 (June II FN) recorded significantly higher cob dry weight (194 g plant^{-1}) among all growth stages of crop growth followed by D_2, D_3 and D_4 recorded significantly lower tassel dry weight (162.5 g plant^{-1}).

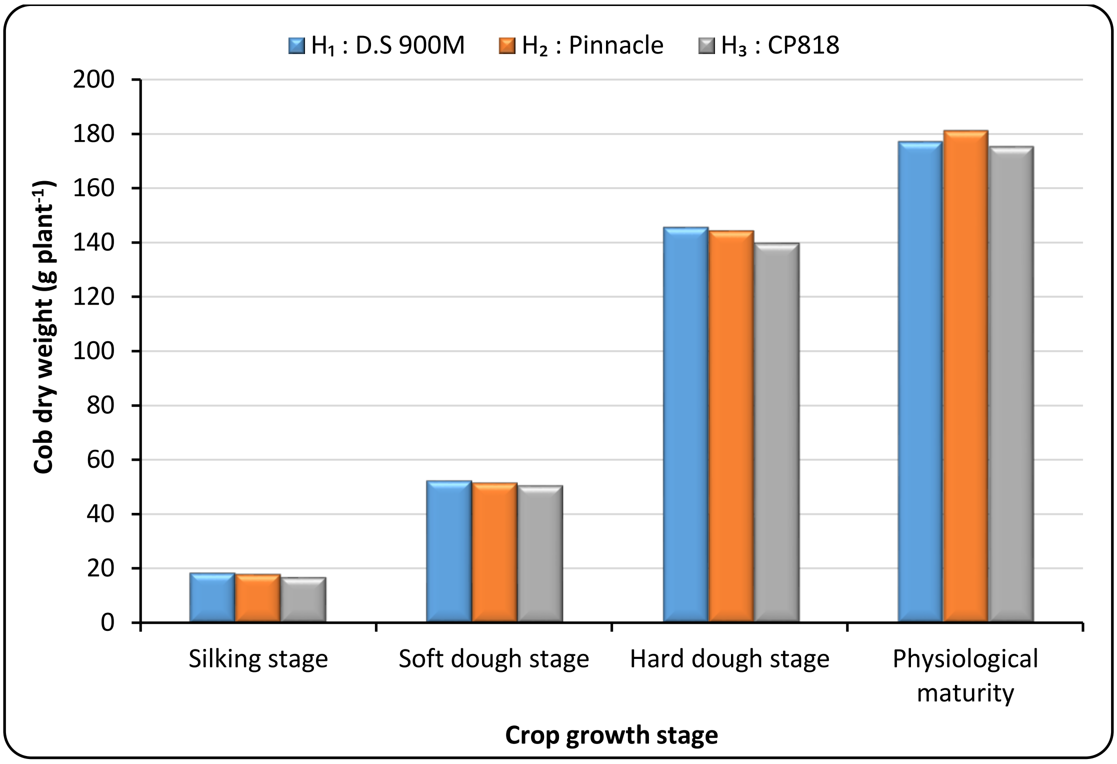
Table 4.7. Effect of photoperiod and temperature on tassel dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing

Treatments	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids					
H_1 : D.S 900M	4.9	4.2	3.8	3.2	2.6
H_2 : Pinnacle	4.9	4.1	3.9	3.2	2.5
H_3 : CP818	4.5	4.1	3.7	3.1	2.3
CD (P=0.05)	0.2	0.2	0.1	0.1	0.1
Dates of Sowing					
D_1 : June II FN	5.4	4.7	4.2	3.9	3.1
D_2 : July I FN	5.1	4.3	3.9	3.2	2.7
D_3 : July II FN	4.5	4.1	3.7	2.8	2.2
D_4 : August I FN	3.9	3.5	3.3	2.7	1.8
CD (P=0.05)	0.3	0.1	0.2	0.1	0.2
Interaction (D × H)					
D_1H_1	5.7	4.7	4.1	3.9	3.2
D_1H_2	5.5	4.8	4.3	4.1	3.1
D_1H_3	5.1	4.6	4.2	3.8	3.0
D_2H_1	5.2	4.5	3.9	3.3	2.9
D_2H_2	5.4	4.3	4	3.2	2.7
D_2H_3	4.8	4.2	3.9	3.2	2.5
D_3H_1	4.6	4.1	3.8	2.9	2.3
D_3H_2	4.6	4.2	3.8	2.9	2.2
D_3H_3	4.3	4.0	3.5	2.8	2.1
D_4H_1	3.9	3.8	3.7	2.7	1.9
D_4H_2	4.0	3.4	3.4	2.7	1.8
D_4H_3	3.7	3.3	3.2	2.6	1.7
CD (P=0.05)	NS	0.2	NS	NS	NS

Table 4.8. Effect of photoperiod and temperature on cob dry weight (g plant^{-1}) of maize hybrids sown at different dates of sowing

Treatments	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids				
H_1 : D.S 900M	18.5	52.7	145.7	177
H_2 : Pinnacle	18.0	51.9	144.5	181.2
H_3 : CP818	16.9	50.7	139.8	175.2
CD (P=0.05)	0.7	0.7	2.0	2.3
Dates of Sowing				
D_1 : June II FN	21.5	58.5	157.5	193.2
D_2 : July I FN	19.2	55.7	153.5	183.4
D_3 : July II FN	16.9	48.1	135.4	172
D_4 : August I FN	13.8	44.7	127	162.5
CD (P=0.05)	0.9	1.2	1.5	3.1
Interaction (D × H)				
D_1H_1	22.3	58.9	161.7	192
D_1H_2	21.8	58.9	157.3	196
D_1H_3	20.4	57.7	153.6	191.7
D_2H_1	19.7	56.3	154.6	180.7
D_2H_2	19.2	56.4	156.6	190
D_2H_3	18.7	54.5	149.4	179.7
D_3H_1	17.7	49.5	138	172.7
D_3H_2	16.8	47.5	137.1	172.8
D_3H_3	16.2	47.3	131.1	170.6
D_4H_1	14.2	45.7	128.6	162.6
D_4H_2	14.4	44.8	127.2	165.9
D_4H_3	12.8	43.4	125.2	159
CD (P=0.05)	NS	NS	NS	4.6

Hybrids



Dates of sowing

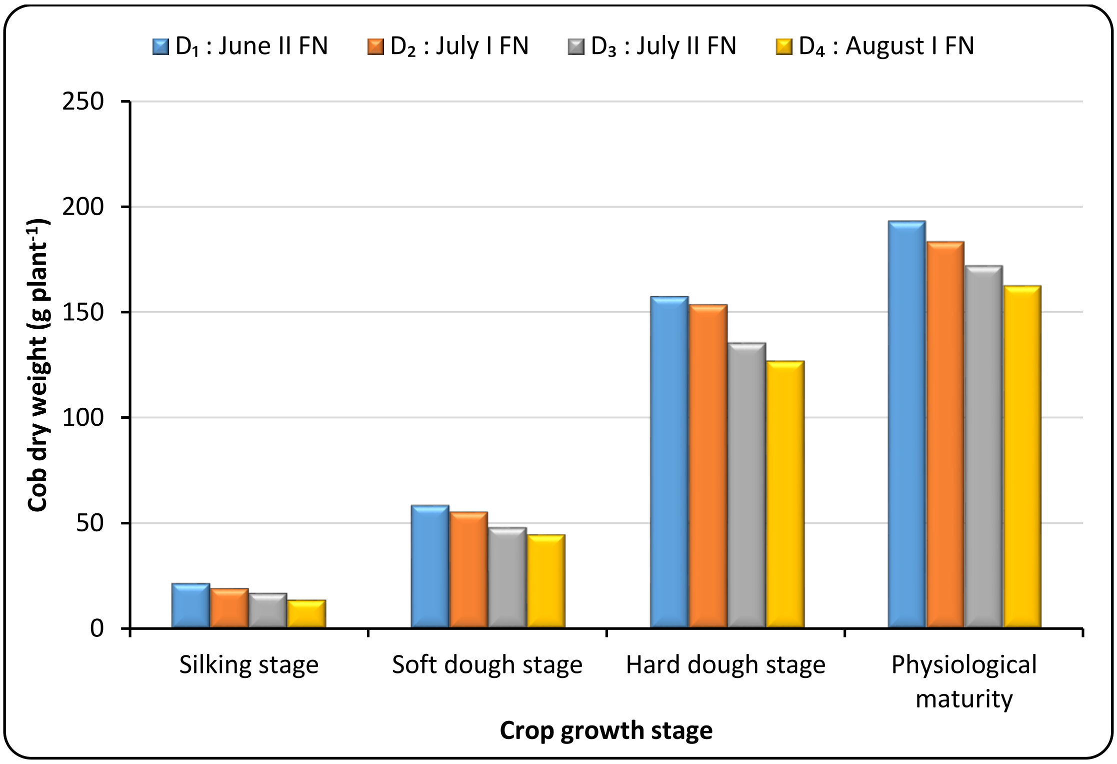


Fig. 4.4. Cob dry weight (g plant^{-1}) of maize hybrids at different crop growth stages as influenced by dates of sowing

Variability in the total dry matter of tested maize hybrids at different dates of sowing is attributed to variability in crop requirement of temperature and photoperiod *viz.*, Growing degree days (GDD), Photothermal Units (PTU) and Heliothermal units (HTU).Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Nielsen *et al*. (2002) and Sulochana *et al.* (2015).

4.3.2.6 Total dry matter (g plant^{-1})

The data on total dry matter of maize hybrids sown at different dates of sowing are presented in the Table 4.9 and Fig. 4.5.

The total dry matter of any variety at given temperature and photoperiod denotes its source strength. The total dry matter of maize hybrids sown at different dates of sowing increased significantly throughout the growth stages. The variability for total dry matter ranges from 266.2 g to 274.1 g at harvest. Highest total dry matter was recorded by D.S 900M (274.1g) which was on par Pinnacle (273.1 g) and CP818 (266.2 g) respectively. Due to higher accumulation of GDD, PTU and HTU in case of D.S 900M and Pinnacle higher dry matter accumulation was recorded.

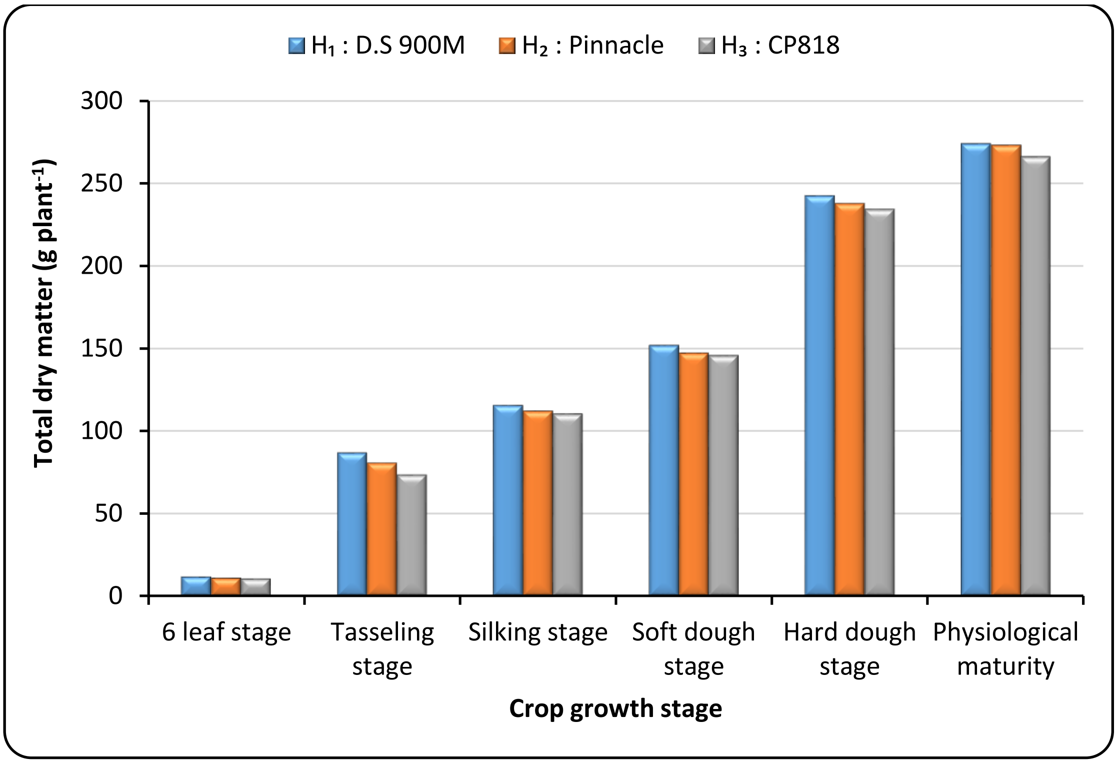
Among the dates of sowing total dry matter increased exponentially from six leaf stage to Physiological stages. Significantly highest total dry matter was observed in D_1 (June II FN) sowing (313.8 g) followed by D_2 (July I FN) sowing (282.3 g) and D_3 (July II FN) sowing (256 g) and lowest was recorded by D_4 (August I FN) sowing (232.7 g) respectively at physiological maturity. Similar results were reported by Nielson *et al*. (2002) and Sulochana *et al*. (2015).

The interaction of hybrids with dates of sowing showed significant increase in total dry matter at all the growth stages except at six leaf stage. Highest total dry matter among all the interaction recorded by D.S 900M (316.3 g) in D_1 (June I FN) sowing whereas dry matter was recorded by CP818 (54.29g) in D_4 (August I FN) sowing at physiological maturity.

Table 4.9. Effect of photoperiod and temperature on total dry matter (g plant^{-1}) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	11.9	87.2	115.9	152.2	242.8	274.1
H_2 : Pinnacle	11.15	80.8	112.3	147.4	237.8	273.1
H_3 : CP818	10.85	73.7	110.6	145.9	234.4	266.2
CD (P=0.05)	NS	2.9	3.1	3.4	3.3	3.1
Dates of Sowing						
D_1 : June II FN	21.71	119.5	139.5	181.9	280	313.8
D_2 : July I FN	14.52	96.7	122.5	157.7	253.4	282.3
D_3 : July II FN	4.93	62.8	104.3	135.8	221	256
D_4 : August I FN	3.92	43.3	85.5	118.4	199.5	232.73
CD (P=0.05)	0.6	4.9	5.9	5.8	3.3	4.1
Interaction (D × H)						
D_1H_1	22.9	135.8	141.3	188	282.7	316.3
D_1H_2	20.5	121.2	137.4	179.7	273.6	312.3
D_1H_3	21.7	101.5	139.9	181	283.7	312.8
D_2H_1	16.1	99.8	118.5	155.4	252.4	278.4
D_2H_2	14.6	97.3	126.7	160.5	258.2	291.13
D_2H_3	12.9	93.1	122.1	157.5	249.3	276.7
D_3H_1	4.7	66.5	112.3	144	229.8	262.1
D_3H_2	5.4	62.2	101.3	131.8	221.2	254.4
D_3H_3	4.7	59.7	99.2	131.7	212.4	251.5
D_4H_1	3.86	46.7	91.8	124.5	207.8	239.8
D_4H_2	3.9	42.5	83.6	117.3	198.4	234.2
D_4H_3	3.9	40.6	81.2	113.6	192.5	224.8
CD (P=0.05)	NS	5.9	6.3	6.8	6.7	6.1

Hybrids



Dates of sowing

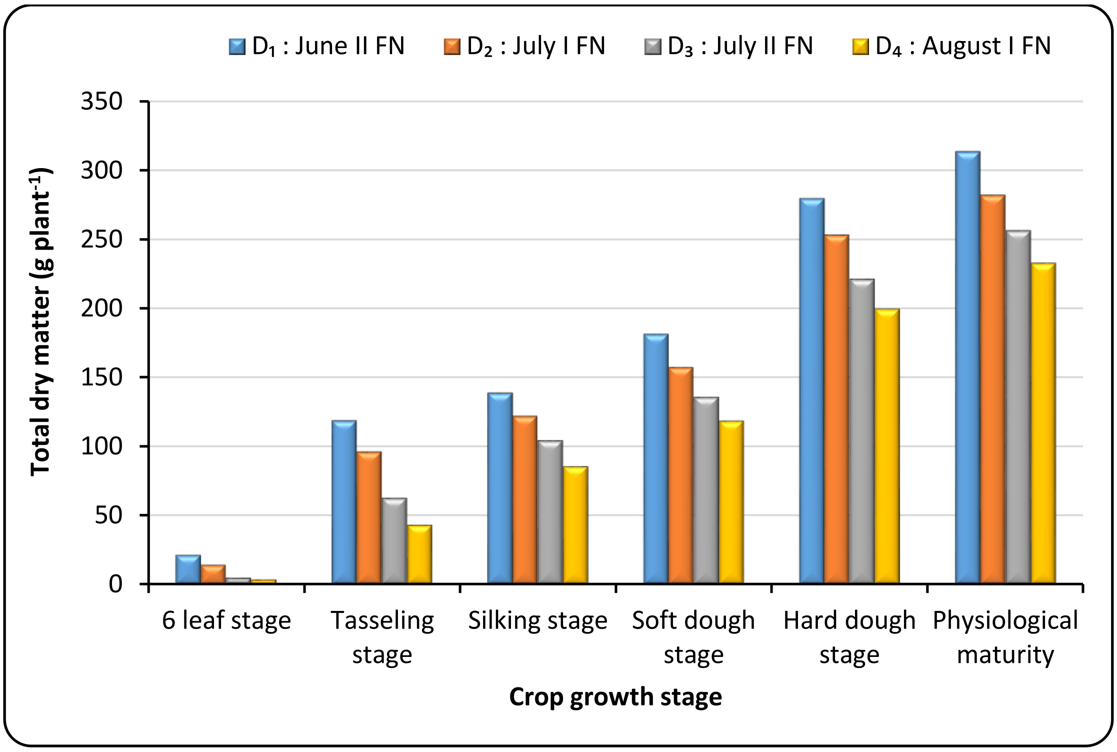


Fig. 4.5. Total dry matter (g plant^{-1}) of maize hybrids at different crop growth stages as influenced by dates of sowing

Variability in the total dry matter of tested maize hybrids at different dates of sowing is attributed to variability in crop requirement of temperature and photoperiod *viz.,* Growing degree days (GDD), Photothermal Units (PTU) and Heliothermal units (HTU). Higher Heat units accumulation was higher in case of D_1 (June II FN) compared to late sowings could be due to higher accumulation of GDD and PTU at grand growth stage i.e., six leaf stage to tasseling stage. It denotes that both temperature and daylength at grand growth stage influenced total dry matter.

4.3.2.7 Dry matter partioning (g plant^{-1})

The data on dry matter partitioning of maize hybrids sown at different dates of sowing are presented in the Table 4.10 and Fig. 4.6.

At Physiological maturity, total dry matter and its partitioning to leaf, stem and cob was analyzed statistically and found to vary significantly with the sowing dates.

Among the hybrids significantly higher leaf (15.6 g plant^{-1}), stem (78.9 g plant^{-1}), tassel (2.6 g plant^{-1}) and cob weight (177 g plant^{-1}) was observed in D.S 900M on par with Pinnacle and CP818. Among the phenophases GDD of D.S 900M and Pinnacle at grain filling stage was higher which resulted in higher dry matter partitioning.

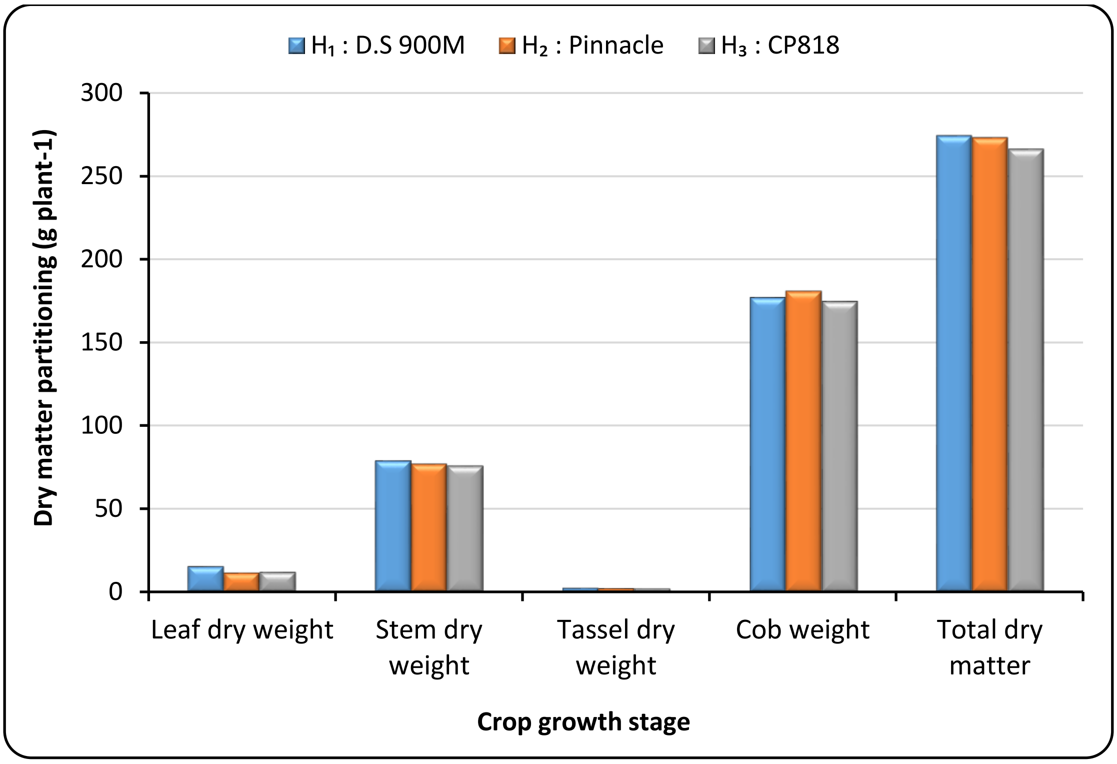
Among the dates of sowing significantly higher leaf (21.6 g plant^{-1}), stem (95.9 g plant^{-1}), tassel (3.2 g plant^{-1}) and cob weight (192 g plant^{-1}) was observed in D_1 (June II FN) followed by D_2, D_3 and D_4.

Among the interaction of hybrids and dates of sowing D_1H_1 (June II FN, D.S 900M) recorded significantly higher leaf (24.8 g plant^{-1}), stem (96.3 plant^{-1}) and total dry matter (316.3 g plant^{-1}) were as D_4H_3 (August I FN, CP818) recorded significantly higher leaf (8.5 g plant^{-1}), stem (55.6 plant^{-1}) and total dry matter (224.8 g plant^{-1}). Delay in sowing is directly

Table 4.10. Effect of photoperiod and temperature dry matter partitioning (g) at physiological maturity of maize hybrids sown at different dates of sowing

Treatments	Leaf dry weight	Stem dry weight	Tassel dry weight	Cob weight	Total dry matter
Hybrids					
H_1 : D.S 900M	15.6	78.9	2.6	177	274.1
H_2 : Pinnacle	11.9	77.5	2.5	181.2	273.1
H_3 : CP818	12.2	76.5	2.3	175.2	266.2
CD (P=0.05)	0.7	NS	0.1	2.3	3.1
Dates of Sowing					
D_1 : June II FN	21.6	95.9	3.1	193.2	313.8
D_2 : July I FN	12.6	83.6	2.7	183.4	282.3
D_3 : July II FN	10.1	71.7	2.2	172	256
D_4 : August I FN	8.8	59.6	1.8	162.5	232.73
CD (P=0.05)	1.2	3.1	0.1	3.1	4.1
Interaction (D × H)					
D_1H_1	24.8	96.3	3.2	192	316.3
D_1H_2	19.3	93.9	3.1	196	312.3
D_1H_3	20.6	97.5	3	191.7	312.8
D_2H_1	17	77.8	2.9	180.7	278.4
D_2H_2	10.43	88	2.7	190	291.13
D_2H_3	10.2	84.3	2.5	179.7	276.7
D_3H_1	11.2	75.9	2.3	172.7	262.1
D_3H_2	9.5	69.9	2.2	172.8	254.4
D_3H_3	9.7	69.1	2.1	170.6	251.5
D_4H_1	9.6	65.7	1.9	162.6	239.8
D_4H_2	8.4	58.1	1.8	165.9	234.2
D_4H_3	8.5	55.6	1.7	159	224.8
CD (P=0.05)	1.4	4.8	NS	4.6	6.1

Hybrids



Dates of sowing

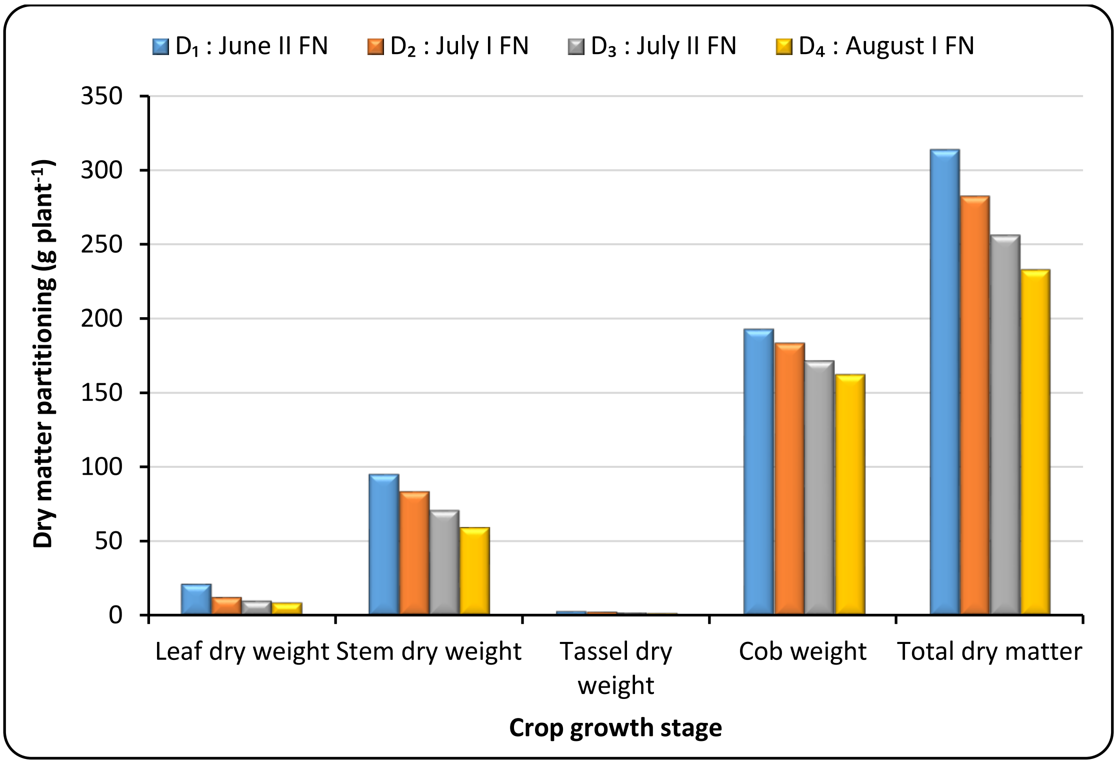


Fig. 4.6. Dry matter partitioning (g plant^{-1}) of maize hybrids at different crop growth stages as influenced by dates of sowing

influenced by both temperature and daylength. Consequently the phasic development and partitioning of drymatter. June II FN (D_1) during grain filling stage recorded higher GDD, PTU and HTU which resulted in high dry matter production. Similar results were reported by Nielson *et al*. (2002) and Sulochana *et al*. (2015).

4.3.3 Leaf area (cm^2 $plant^{-1}$)

Leaf area per plant is an important determinant in production and photosynthesis. The total leaf area of the plant is one of the important characters to be that represents total photosynthetic surface for higher productivity. Leaf area of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.11 and Fig. 4.7.

Irrespective of hybrids and dates of sowing the leaf area increased as the growth advanced. The exponential increase in leaf area was observed from six leaf stage to silking stage and there after leaf area gradually decreased till physiological maturity due to progress of senescence.

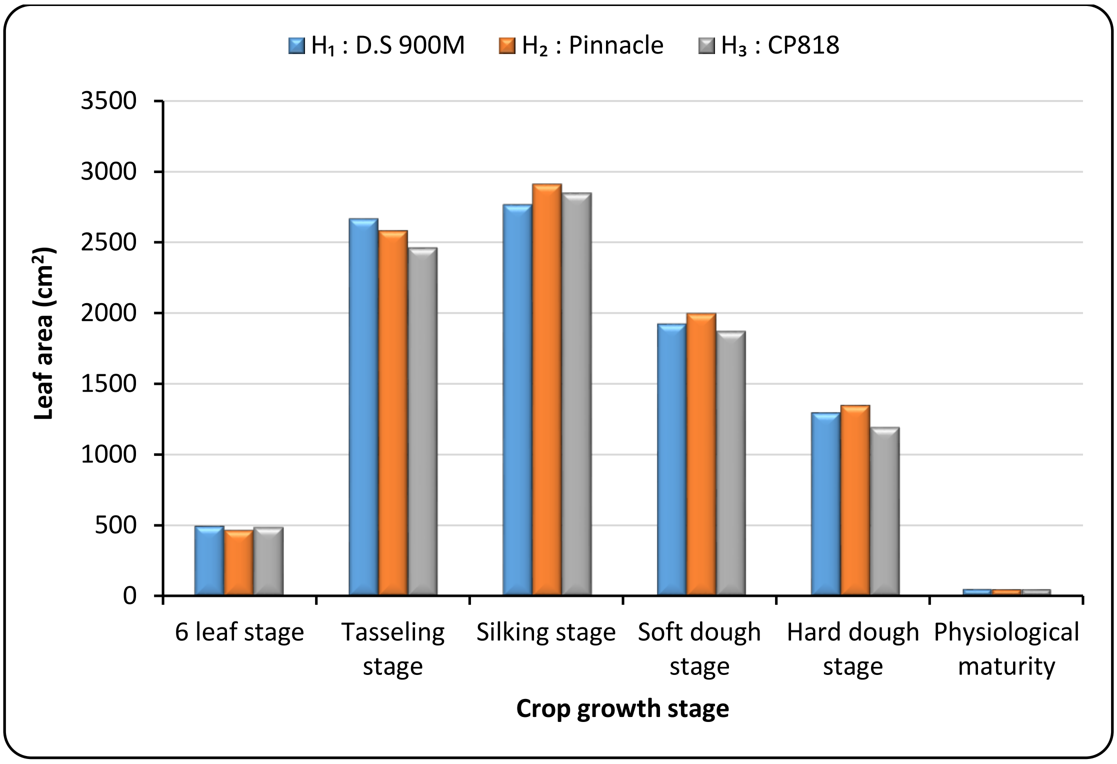
Among the hybrids maximum leaf area was recorded at silking stage by Pinnacle (2911.1 cm^2 $plant^{-1}$) followed by CP 818 (2847 cm^2 $plant^{-1}$). Lowest leaf area was recorded by D.S 900 M (2766.65 cm^2 $plant^{-1}$). Radiation interception largely determines the leaf area index. The results are in conformity with the findings of Muchow and Carberry (1989), Sulochana *et al*. (2015) in maize crop.

Among the dates of sowing D_1 (June II FN) recorded significantly higher leaf area (4532 cm^2 $plant^{-1}$) at all the growth stages except at soft dough stage. D_1 (June second fortnight) was significantly higher than D_2 (July I FN), D_3 (July II FN), D_4 (August I FN) at all the growth stages except at soft dough stage. There was no significant difference between D_3 (July II FN) and D_4 (August I FN) at six leaf stage and tasseling stage.

Table. 4.11. Effect of photoperiod and temperature on leaf area (cm^2) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	501.4	2666.4	2766.7	1929.3	1305.9	51.8
H_2 : Pinnacle	467.7	2582.1	2911.1	1998.1	1350.3	49.1
H_3 : CP818	493.3	2462.3	2847.3	1876.7	1201.8	47.9
CD (P=0.05)	NS	NS	NS	NS	77.5	1.6
Dates of Sowing						
D_1 : June II FN	831.3	4495.7	4532.1	2976.9	2460.7	62.2
D_2 : July I FN	501.4	2537.7	2876.2	2096.1	1222.7	51.7
D_3 : July II FN	356.0	1870.4	1937.1	1417.3	850.5	49.2
D_4 : August I FN	261.0	1380.2	1541.2	1249.7	610.3	35.3
CD (P=0.05)	176.5	180.5	812.2	NS	152	2.3
Interaction (D × H)						
D_1H_1	907.8	5062.5	4822.4	3149.6	2723.1	67.7
D_1H_2	678.9	4222.9	4439.5	3004.4	2517.9	60.0
D_1H_3	907.4	4201.6	4334.4	2776.4	2141.0	58.8
D_2H_1	465.86	2354.9	3235.5	1809.7	1067.8	54.5
D_2H_2	627.2	2832.6	3299.9	2369.2	1372.0	51.0
D_2H_3	411.0	2416.6	2163	2111.5	1228.6	49.7
D_3H_1	376.2	1758.2	1660.8	1399.9	772.3	48.7
D_3H_2	318.6	1992.3	2304.5	1467.2	902.3	51.0
D_3H_3	374.4	1860.7	1846.0	1384.9	876.8	47.9
D_4H_1	256.3	1489.7	1347.8	1360.6	660.5	36.3
D_4H_2	246.4	1280.6	1670.3	1154.2	609.1	34.3
D_4H_3	280.4	1370.1	1605.6	1234.2	561.4	35.2
CD (P=0.05)	NS	509.4	NS	NS	155.1	3.3

Hybrids



Dates of sowing

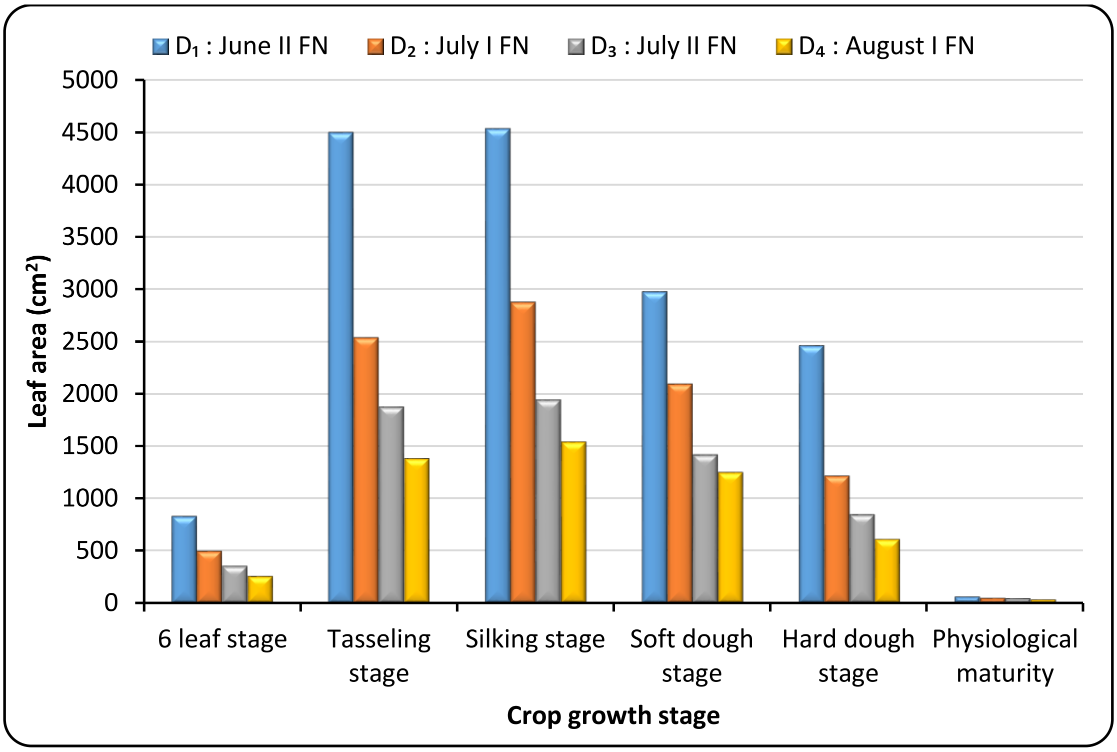


Fig. 4.7. Leaf area (cm^2) of maize hybrids at different crop growth stages as influenced by dates of sowing

Radiative and thermal conditions during the crop growth are effected by the sowing dates. Favorable temperatures during the early sowing conditions increases the leaf area and crop growth. Higher GDD and PTU accumulation at six leaf stage to tasseling stage during June II FN resulted in higher leaf area because of higher daily average temperatures compared to D_2,D_3 and D_4.The results are in conformity with the findings of Wilson *et al.* (1995), Muchow and Carberry (1989) and Zaker *et al*. (2014).

The interaction of hybrids and the dates of sowing were significant throughout the crop growth stages except six leaf stage, tasseling stage and Soft dough stage. D_1H_1 *i.e.,* D.S 900 M at second FN of June recorded highest compared to all other interactions. Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Dahmardeh and Dahmareh (2010).

4.3.3.1 Leaf Area Index (LAI)

Leaf area index is the most determinant in production and photosynthesis. The data on leaf area index of maize hybrids sown at different dates of sowing are presented in the Table 4.12.

Irrespective of hybrids and dates of sowing LAI increased as the growth advanced. The exponential increase in LAI was observed from six leaf stage to silking stage thereafter LAI decreased.

Among the hybrids maximum LAI was recorded by Pinnacle (2.8) followed by D.S 900M (2.2) and CP818 (2.1). Radiation interception largely determines LAI. Pinnacle was significantly higher at silking, hard dough and physiological maturity stages. Increase in LAI for Pinnacle can be explained as it accumulated higher GDD and PTU compared to other hybrids.

Table 4.12. Effect of photoperiod and temperature on leaf area index (LAI) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids						
H_1 : D.S 900M	0.42	2.3	2.2	1.6	1.1	0.043
H_2 : Pinnacle	0.39	2.4	2.8	1.7	1.2	0.041
H_3 : CP818	0.41	2.1	2.1	1.6	1	0.04
CD (P=0.05)	NS	NS	0.12	NS	0.06	0.001
Dates of Sowing						
D_1 : June II FN	0.69	3.7	3.8	2.5	2.1	0.052
D_2 : July I FN	0.42	2.3	2.2	1.7	1.0	0.042
D_3 : July II FN	0.29	1.6	1.6	1.1	0.7	0.041
D_4 : August I FN	0.22	1.2	1.1	1.0	0.5	0.029
CD (P=0.05)	0.14	0.44	0.25	0.074	0.12	0.002
Interaction (D × H)						
D_1H_1	0.75	4	4.2	2.6	2.2	0.056
D_1H_2	0.56	3.7	3.9	2.5	2	0.05
D_1H_3	0.75	3.6	3.5	2.3	1.8	0.049
D_2H_1	0.39	2.7	1.9	1.5	0.8	0.045
D_2H_2	0.52	2.7	2.5	1.9	1.1	0.042
D_2H_3	0.34	2.1	2	1.8	1.0	0.042
D_3H_1	0.31	1.4	1.4	1.2	0.6	0.041
D_3H_2	0.26	1.9	1.7	1.2	0.7	0.042
D_3H_3	0.31	1.5	1.6	1.2	0.7	0.041
D_4H_1	0.21	1.1	1.2	1.1	0.5	0.03
D_4H_2	0.2	1.4	1.1	0.9	0.5	0.029
D_4H_3	0.23	1.3	1.1	1.0	0.4	0.029
CD (P=0.05)	NS	NS	0.25	0.19	0.12	0.003

Among the dates of sowing D_1 (June II FN) recorded significantly highest LAI (3.8) followed by D_2 (July I FN, 2.2), D_3 (July II FN, 1.6) and lowest by D_4 (August I FN, 1.1) at all the growth stages of maize. The results are in confirmity with the finding of Zaker *et al.* (2014).

The interaction of hybrids and the dates of sowing were significant difference was found among all the growth stages of maize except at six leaf stage and tasseling stage. D_1H_1 (June II FN, D.S 900M) recorded significantly highest LAI (4.2) at silking stage and lowest at D4H3 (August I FN, CP818) physiological maturity stage.June II FN consumed relatively higher growing degree days at different phonological growth stages (Sowing to silking stage) resulted in higher LAI compared to other dates of sowing. Similar variability was also reported by Dahmardeh and Dahmerdeh, (2010).

4.4 CROP PHENOLOGICAL PARAMETERS

Number of days to different phenophases of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.13 and Fig.4.8.

Among the hybrids Pinnacle recorded highest number of days taken to physiological maturity (106) followed by D.S 900M (104) and CP818 (102). Their was no significant variability among all the growth stages of maize hybrids except at tasseling stage where CP818 recorded more number of days to attain anthesis stage (61) followed by Pinnacle and D.S 900M.

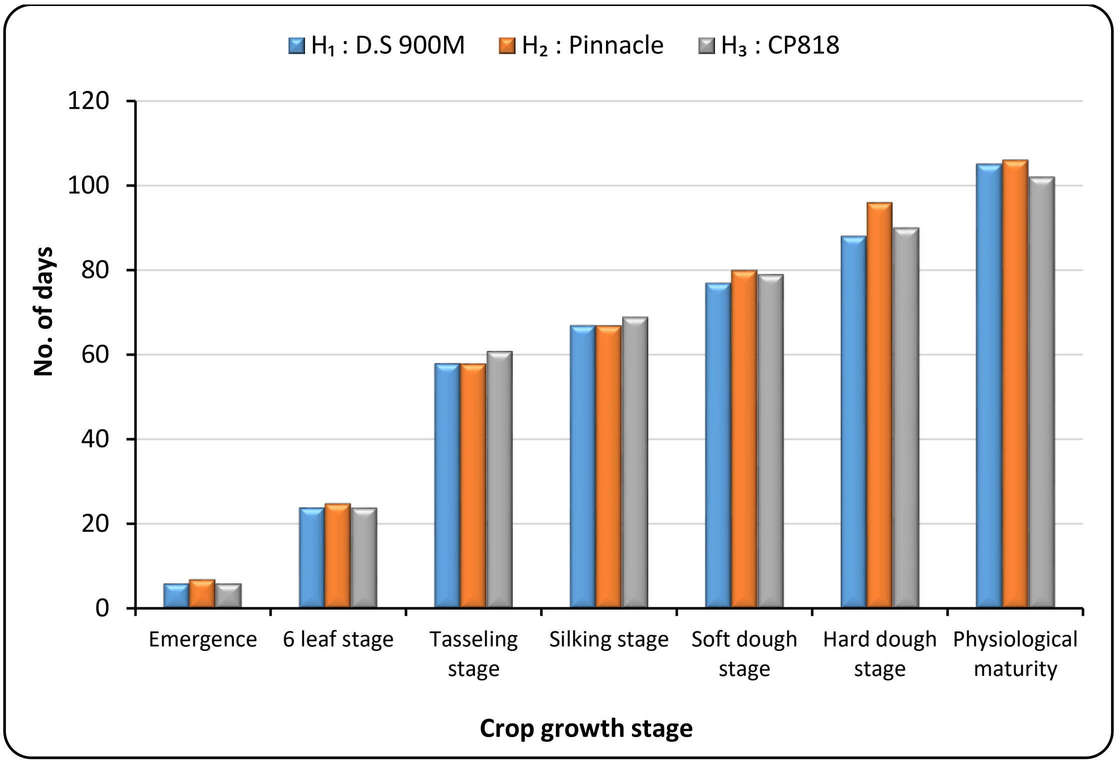
Among the dates of sowing their was significant difference only at emergence, six leaf and tasseling stage. D_4 (August I FN) recorded more number of days to attain anthesis and maturity days (61, 113) followed by D_3, D_1 and D_2.

Among the interaction of hybrids and dates of sowing significant difference were found only at emergence and six leaf stage. D_4H_1 (August I

Table 4.13. Number of days to attain different phenophases of maize as influenced by photoperiod and temperature at different dates of sowing

Treatments	Emergence	6 leaf stage	Tasseling stage	Silking stage	Soft dough stage	Hard dough stage	Physiological maturity
Hybrids							
H_1 : D.S 900M	6	24	58	67	77	88	105
H_2 : Pinnacle	7	25	58	67	80	96	106
H_3 : CP818	6	24	61	69	79	90	102
CD (P=0.05)	NS	NS	0.1	NS	NS	NS	NS
Dates of Sowing							
D_1 : June II FN	5	23	57	67	76	92	104
D_2 : July I FN	5	22	56	63	72	84	100
D_3 : July II FN	4	24	60	67	78	88	100
D_4 : August I FN	7	25	61	69	83	94	113
CD (P=0.05)	0.2	0.2	0.1	NS	NS	NS	NS
Interaction (D × H)							
D_1H_1	5	24	60	69	76	91	102
D_1H_2	5	23	51	64	74	92	105
D_1H_3	5	24	61	69	79	92	104
D_2H_1	5	22	55	62	70	83	100
D_2H_2	5	25	55	62	70	83	104
D_2H_3	5	23	58	65	75	86	96
D_3H_1	4	22	58	67	79	87	104
D_3H_2	4	25	61	66	78	92	100
D_3H_3	5	21	62	69	77	85	96
D_4H_1	8	25	60	68	82	91	114
D_4H_2	7	25	58	67	80	96	112
D_4H_3	7	25	64	73	86	96	112
CD (P=0.05)	0.3	0.3	NS	NS	NS	NS	NS

Hybrids



Dates of sowing

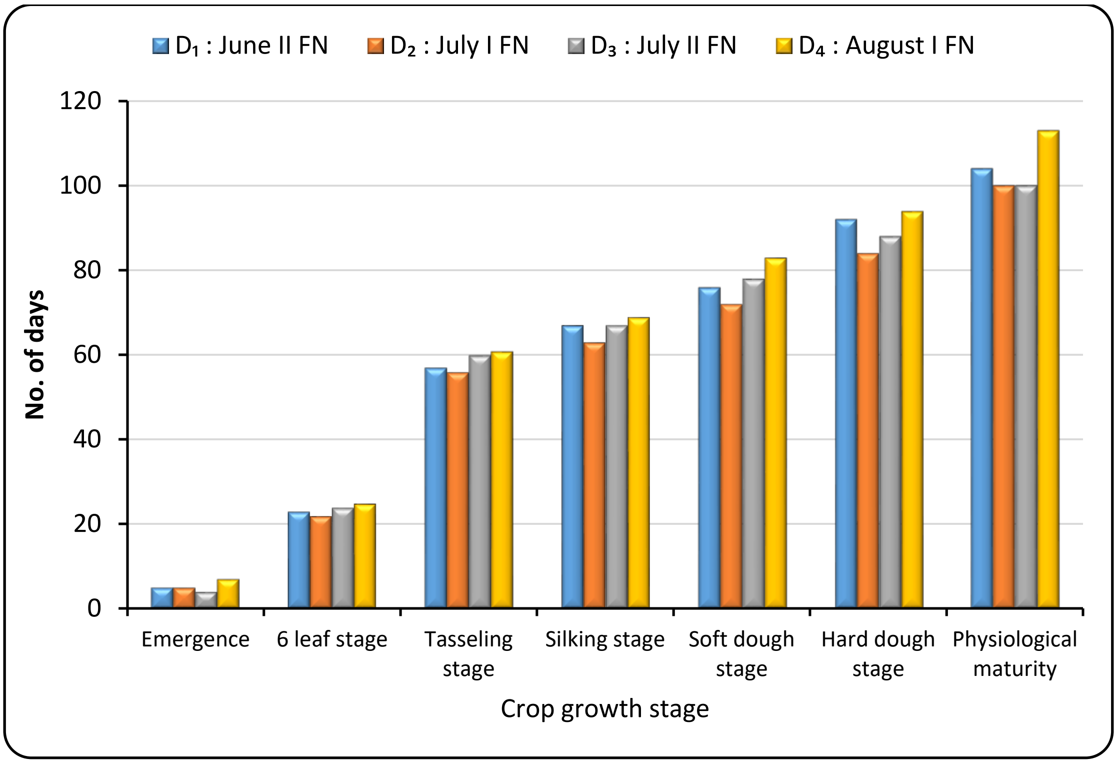


Fig. 4.8. Number of days to attain different phenophases of maize hybrids at different crop growth stages as influenced by dates of sowing

FN, D. S 900 M) recorded more number days at emergence and six leaf stage (8, 25). The data revealed that delayed sowings extended life cycle of maize crop under these southern Agroclimatic Zone. Similar variability was also observed by Amgain *et al*. (2011) and Majumder *et al.* (2016).

4.5 YIELD AND YIELD COMPONENTS

4.5.1 Number of Cobs per m^{-2}

Number of cobs per meter of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at six growth stages and presented in Table 4.14 and Fig.4.9

Among the hybrids there was significant difference and Pinnacle recorded numerically higher number of cobs m^{-2} (7.4) compared to D.S 900 M (7) and CP818 (7.1).

Among the dates of sowing D_1 (June II FN) recorded numerically higher number of cobs m^{-2} (7.9) compared to D_2 (7.3), D_3 (6.9) and D_4 (6.3).

Among the hybrids and dates of sowing D_1H_2 i.e., Pinnacle sown at Second fort night of June recorded numerically higher number of cobs m^{-2}(8.1) compared to all other interaction effects and D_4H_3 i.e., CP818 sown at First fortnight of August number of cobs m^{-2}(6.3). Which can be ascertained due to D_1 sowing accumulated high GDD and PTU. It denotes that in this region maize crop yield is influenced by temperature, daylength as well as sunshine hours. Similar variability was also reported by Rajesh *et al.* (2015) in wheat.

4.5.2 Number of seed rows per cob (number)

Number of rows per cob of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at harvest and presented in Table 4.14.

Table 4.14. Effect of photoperiod and temperature on yield attributes of maize hybrids sown at different dates of sowing

Treatments	No. of cobs m^{-2}	No. of rows cob^{-1}	No. of seeds row^{-1}	100 grain weight (g)	Cob yield (kg ha^{-1})	Cob length (cm)
Hybrids						
H_1 : D.S 900M	7	18.6	10.9	25.7	3801.1	12.7
H_2 : Pinnacle	7.4	20.8	11.7	26.4	4442.1	13.2
H_3 : CP818	7.1	17.1	11.2	24.5	4486.2	11.7
CD (P=0.05)	NS	1.4	0.7	0.4	692.6	2.2
Dates of Sowing						
D_1 : June II FN	7.9	24.5	13.3	31.5	6716.4	15.6
D_2 : July I FN	7.3	22.1	11.9	26.3	4551.1	14.1
D_3 : July II FN	6.9	17.7	10.9	22.4	3194.1	12.1
D_4 : August I FN	6.6	10.9	8.8	21.8	2522.9	8.5
CD (P=0.05)	NS	1.12	NS	0.8	NS	1.1
Interaction (D × H)						
D_1H_1	8.0	24.5	12.4	33.1	6745.8	15.2
D_1H_2	8.1	25.9	14.3	29.8	6922.1	16.5
D_1H_3	7.7	22.9	13.2	31.7	6481.2	15.1
D_2H_1	7.0	22.1	11.7	25.9	4056.3	15.1
D_2H_2	7.7	25	12.0	29.1	4688.2	13.8
D_2H_3	7.3	19.2	11.8	23.9	4908.7	13.3
D_3H_1	6.7	18.3	11.1	22.2	2483.7	12.2
D_3H_2	7.0	20.1	11.2	23.6	3483.1	13.2
D_3H_3	7.0	13.9	10.6	21.6	3615.4	10.6
D_4H_1	6.3	9.4	8.3	21.7	1954.6	8.5
D_4H_2	7.0	11.3	9.3	23.3	2674.8	9.3
D_4H_3	6.3	12.2	9.0	20.7	2939.3	7.6
CD (P=0.05)	NS	2.2	NS	1.6	NS	NS

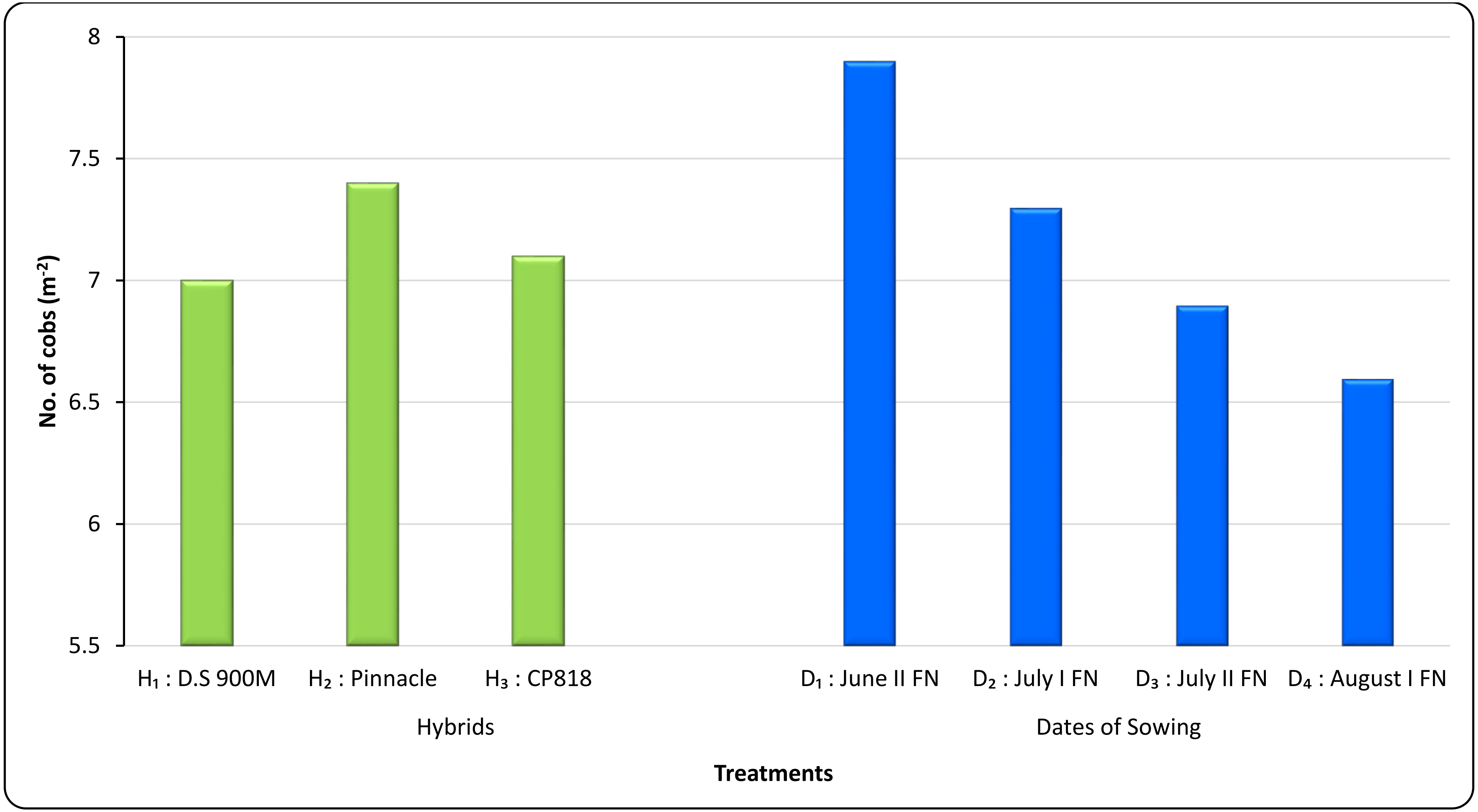


Fig. 4.9. Number of cobs m^{-2} of maize hybrids as influenced by dates of sowing

Among the hybrids Pinnacle recorded significantly higher number of rows per cob (20.80) than D.S 900 M (18.59) and CP818 (17.06). Increased GDD, HTU and PTU accumulation in case of Pinnacle resulted in increased cob filling there by number of rows per cob involved compared to CP818 and D.S 900M. Similar variability was observed in the findings of Shrestha *et al*. (2016)

Among the dates of sowing D_1 (June II FN) recorded significantly higher number of rows per cob (24.47) compared to D_2 (July I FN), D_3 (July II FN) and D4 (August I FN). The date of sowing showed variation among the accumulated GDD, HTU and PTU. June II FN sown crop took maximum GDD from sowing to maturity resulting in higher number of rows per cob compared to D_2, D_3 and D_4. The results are in conformity with the findings of Yusafzai *et al.* (2002) and Jaliya *et al*. (2008)

Among interaction of hybrids and the dates of sowing D_1H_2 i.e., first date of sowing Pinnacle hybrid recorded significantly higher number of rows (25.9) compared to all other interaction effects. D_4H_1 i.e., Fourth date of sowing D.S 900 M recorded significantly lower number of rows per cob (9.4).

Similar variability among the interaction hybrids and dates of sowing in maize was also reported by Tripathi and Shrivastava (2004), Thomison, (2010) and Hossein *et al*. (2014)

4.5.3 Number of Seeds per Row (number)

Number of seeds per row of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at harvest and presented in Table 4.14.

Among the hybrids Pinnacle recorded significantly higher number of seeds per row (11.7) than D.S 900 M and numerically higher number of seeds per row than CP818 (11.2).

Among the dates of sowing there was no significant difference but D_1 (June II FN) recorded numerically higher number of seeds per row (13.3) and lower number of seeds per row was recorded in D_4 (August I FN, 8.9). The results were controversial with the statement of Srinivasulu *et al*. (2008).

Among the hybrids and dates of sowing there was no significant difference but D_1H_2 i.e., Pinnacle sown at Second fortnight of June recorded numerically higher number of seeds per row (14.3) and D_4H_1 i.e., D.S 900 M sown at First fortnight August recorded lower number of seeds per row (8.3) compared to all other interaction effects. Similar to number f rows per cob , number of seeds per row also influenced by temperature, photoperiod and sunshine hours. The results are in conformity with the findings of Hossein *et al*. (2014).

4.5.4 100 Grain Weight (g)

Hundred grain weight of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at harvest and presented in Table 4.14.

Among the hybrids Pinnacle recorded significantly higher 100 grain weight (26.4 g) compared to D.S 900 M (25.7 g) and CP 818 (24.5 g). The results are in conformity with the Yusafzai *et al*. (2002)

Among the dates of sowing D_1 (June II FN) recorded significantly higher 100 grain weight (31.5) compared to D_2 (26.3), D_3 (22.5) and D_4 (21.9). Lowest hundred grain weight was recorded in D_4 (21.9). The increased test weight (g) in early sowing (June II FN) is highest due to accumulated GDD, PTU and HTU especially at soft dough stage compared to other delayed sowings. It denotes that temperature, daylength and sunshine hours prevailing at grain filling stage is important.

Among the hybrids and dates of sowing D_1 (June II FN) D.S 900 M recorded significantly higher hundred grain weight and D_4 (August I FN) CP818 recorded lower hundred grain weight (20.7) compared to all other interaction effects. Similar variability among the dates of sowing and genotypic interactions was also reported by Yusafzai *et al.* (2002) and Hossein *et al.* (2014).

4.5.5 Cob Yield kg ha^{-1}

Cob yield of maize hybrids sown at different dates of sowing in *kharif* was recorded at harvest and presented in Table 4.14 and Fig. 4.10

Cob yield (kg ha^{-1}) was on par among all the three hybrids. CP818 recorded 4486.2 kg ha^{-1}, Pinnacle of 4442.1 kg ha^{-1} and D.S 900 M of about 3801.1 kg ha^{-1}.

Among the dates of sowing D_1 (June II FN) recorded numerically higher cob yield (6716.4 kg ha^{-1}) compared to D_2 (July I FN, 4551.1 kg ha^{-1}), D_3 (July II FN, 3194 kg ha^{-1}) and D_4 (August I FN) recorded lower cob yield (2522.3 kg ha^{-1}). The results are in confirmity with findings of Jaliya *et al.* (2008).

Among the hybrids and dates of sowing D_1H_2 i.e., Pinnacle sown at First date of sowing recorded numerically higher cob yield (6922.1 kg ha^{-1}) compared to all other interaction effects. D_4H_1 i.e., D.S 90M sown at Fourth date of sowing recorded lower cob yield (1954.6 kg ha^{-1}). Such increased yield under first date of sowing (June II FN) is because the crop accumulated higher GDD, PTU and HTU from emergence to physiological maturity compared to delayed sowings. Similar variability in corn was also observed with the findings of Yusafzai *et al.* (2002).

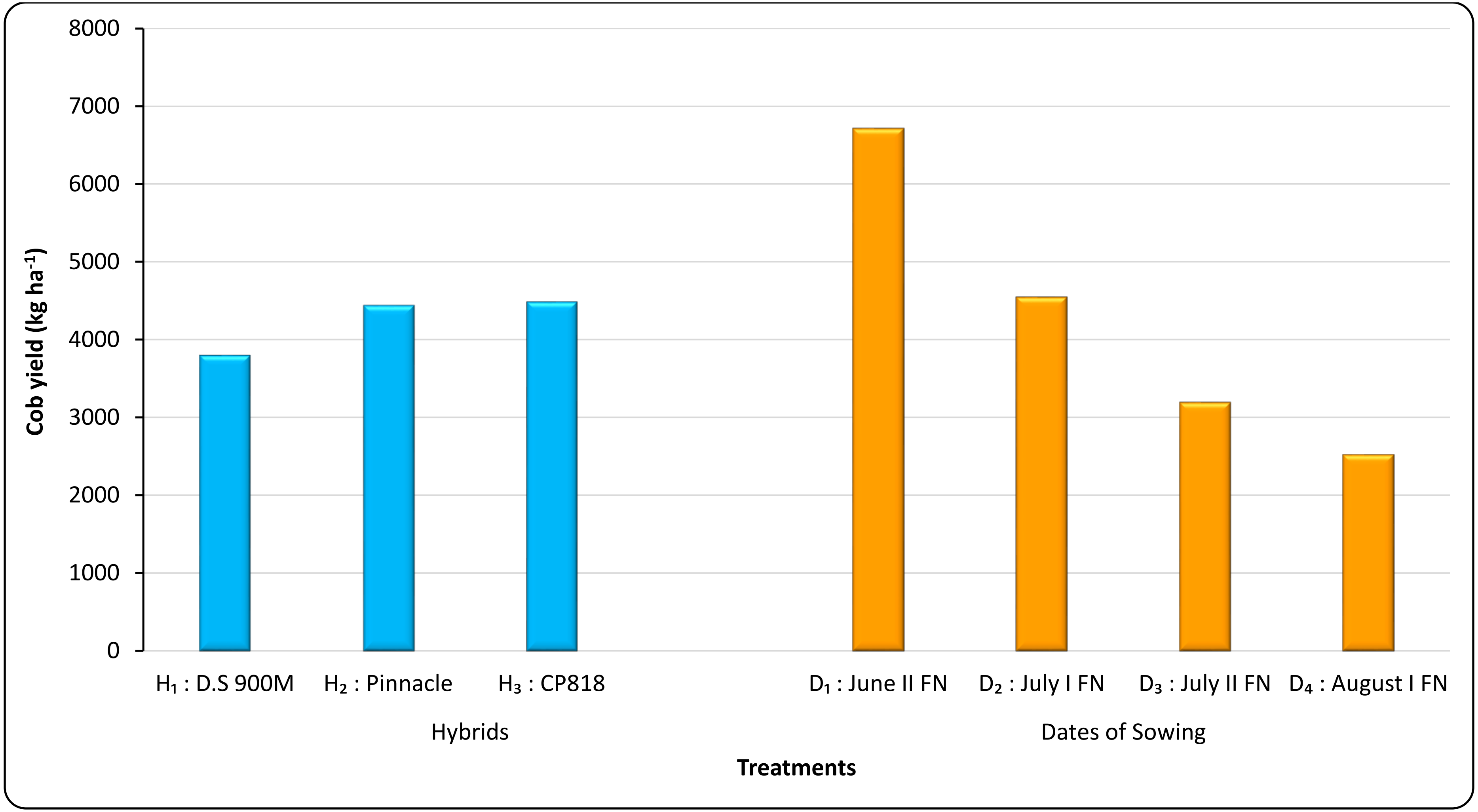


Fig. 4.10. Cob yield (kg ha^{-1}) of maize hybrids as influenced by dates of sowing

4.5.6 Cob length (cm)

Cob length of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at harvest and presented in Table 4.14.

Among the hybrids there was significant difference and Pinnacle recorded numerically higher cob length (13.2 cm) compared to D.S 900 M (12.7 cm) and CP818 (11.7 cm).

Among the dates of sowing D_1 (June II FN) recorded numerically higher cob length (15.7 cm) compared to D_2 (14.1 cm), D_3 (12.1 cm) and D_4 (8.5 cm).

Among the hybrids and dates of sowing D_1H_2 i.e., Pinnacle sown at Second fort night of June recorded numerically higher cob length (16.5 cm) compared to all other interaction effects and D_4H_3 i.e., CP818 sown at First fortnight of August lowest cob length (7.6 cm). Such increased yield under first date of sowing (June II FN) is because of the crop accumulated higher GDD, PTU and HTU from emergence to physiological maturity compared to delayed sowings. Similar variability was also reported by Srinivasulu *et al*. (2008).

4.5.7 Grain Yield (kg ha^{-1})

Grain yield of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at crop growth stages and presented in Table 4.15 and Fig.4.11.

Among the hybrids Pinnacle recorded numerically higher yield (3006.58 kg ha^{-1}) than D.S 900 M (2748 kg ha^{-1}) but was significantly higher than CP818 (2678.4 kg ha$^{`1}$). Due to increased heat use efficiency in case of Pinnacle total kernel yield increased since the grain yield is linearly related to heat use efficiency.

Among the dates of sowing D_1 (June II FN) recorded significantly higher yield (3684.36 kg ha^{-1}) than D_2 (3207.72 kg ha^{-1}), D_3 (2628 kg ha^{-1}) and D_4 (August I FN) recorded significantly lower yields (1724.26 kg ha^{-1}). The higher yields attributed to the favorable agro-climatic conditions particularly temperature, day length and sunshine hours interms of higher accumulated GDD, PTU and HTU from sowing to physiological maturity compared to other dates of sowing. The early planting dates resulted in higher yields compared to delay in sowing dates because of high heat use efficiency of 1.2 compared to other sowings.

Among interaction of hybrids and the dates of sowing D_1H_1 i.e., first date of sowing (June II FN) D.S 900M recorded significantly higher kernel yields (3747.6 Kg ha^{-1}) compared to all other interaction effects. D_4H_3 i.e., CP818 sown at first fortnight of August recorded significantly lower yields (1626 kg ha^{-1}). In case of D_2 (July I FN) and D_3 (July II FN) Pinnacle (3429 kg ha^{-1}, 3244 kg ha^{-1}) recorded higher yields than D.S 900 M (3048 kg ha^{-1}, 2399 kg ha^{-1})and CP818 (3145.1 kg ha^{-1}, 2302.7 kg ha^{-1}) respectively. The results are in conformity with the Hossein *et al.* (2014), Zaker *et al.* (2014) and Sulochana *et al*. (2015). These results indicated that build up of GDD, PTU, HTU and HUE are good estimators to study phenology and can be used as a reliable tool to optimize the sowing period for different cultivars.

Correlation of LAI with grain yield:

LAI showed positive correlation with yield (Fig. 4.12) at six leaf stage (R^2 =0.682), Tasseling stage (R^2=0.794), Silking stage (R^2=0.741), Soft dough stage (R^2=0.777), hard dough stage (R^2=0.695) and physiological maturity (R^2=0.840). It denotes the LAI plays important role not only in drymatter accumulation but also final yield in maize.

Table 4.15. Effect of photoperiod and temperature on grain yield (kg ha^{-1}), stover yield (kg ha^{-1}) and harvest index (%) of maize hybrids at different dates of sowing

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
Hybrids			
H_1 : D.S 900M	2748.9	4854.3	35.6
H_2 : Pinnacle	3006.6	4867.3	37.5
H_3 : CP818	2678.4	4947.5	34.3
CD (P=0.05)	304.7	NS	2.37
Dates of Sowing			
D_1 : June II FN	3684.4	5580.9	39.8
D_2 : July I FN	3207.7	5192.3	38.3
D_3 : July II FN	2628.8	4593.3	36.1
D_4 : August I FN	1724.3	4192.4	29.1
CD (P=0.05)	238.8	367.1	4.2
Interaction (D × H)			
D_1H_1	3747.6	5535.7	40.4
D_1H_2	3665.9	5863.3	38.5
D_1H_3	3639.5	5343.6	40.5
D_2H_1	3048.4	5317.9	36.5
D_2H_2	3429.6	4825.2	41.6
D_2H_3	3145.1	5433.8	36.7
D_3H_1	2339.5	4433.8	34.5
D_3H_2	3244.2	4564.4	41.6
D_3H_3	2302.7	4781.7	32.2
D_4H_1	1859.9	4129.7	31.1
D_4H_2	1686.5	4216.6	28.5
D_4H_3	1626.3	4231.1	27.7
CD (P=0.05)	477.7	415.7	4.7

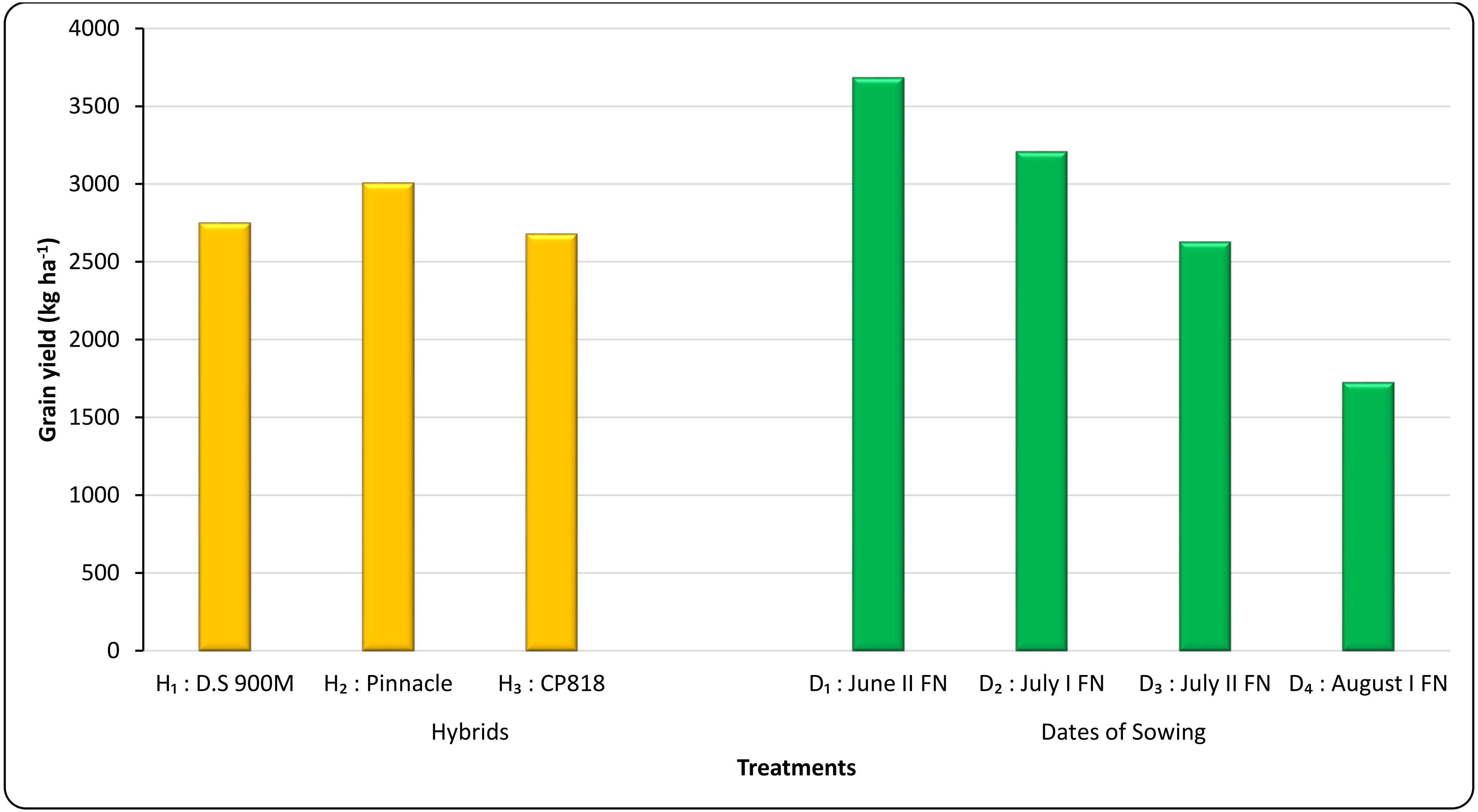
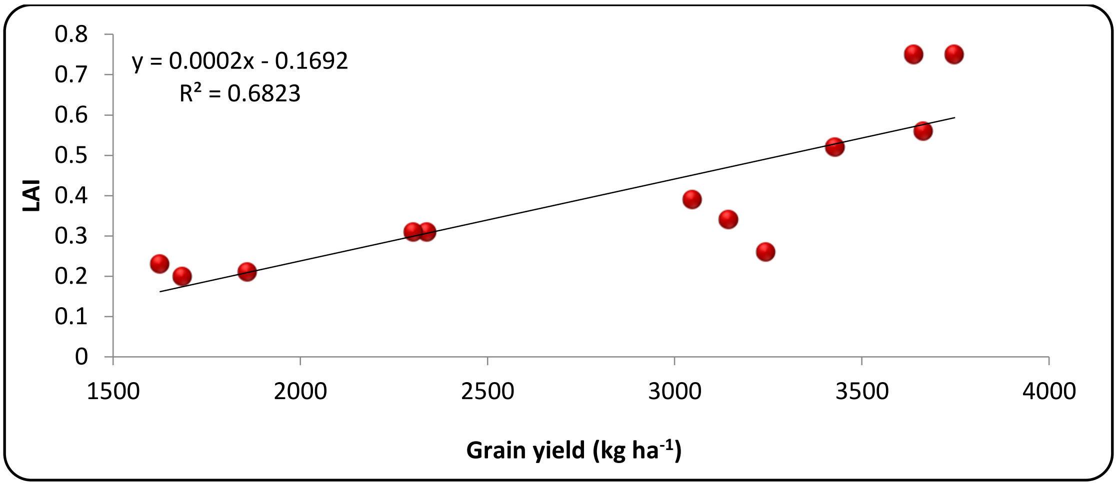
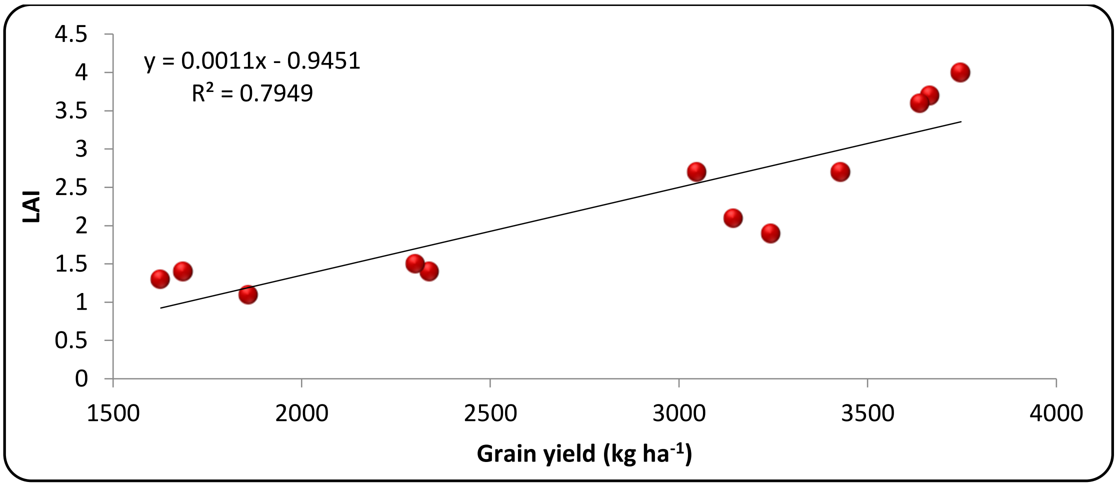


Fig. 4.11. Grain yield (kg ha^{-1}) of maize hybrids as influenced by dates of sowing



Tasseling stage



Silking stage

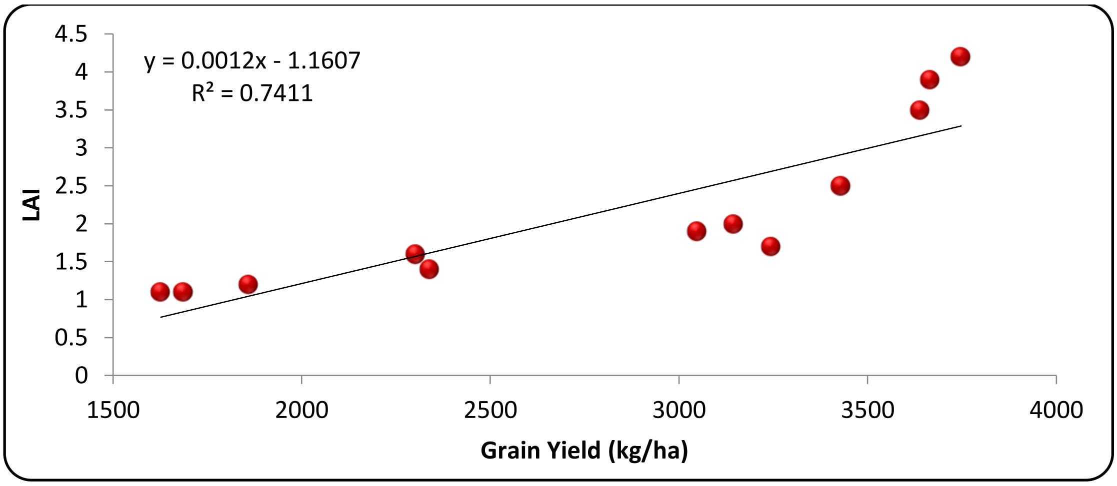
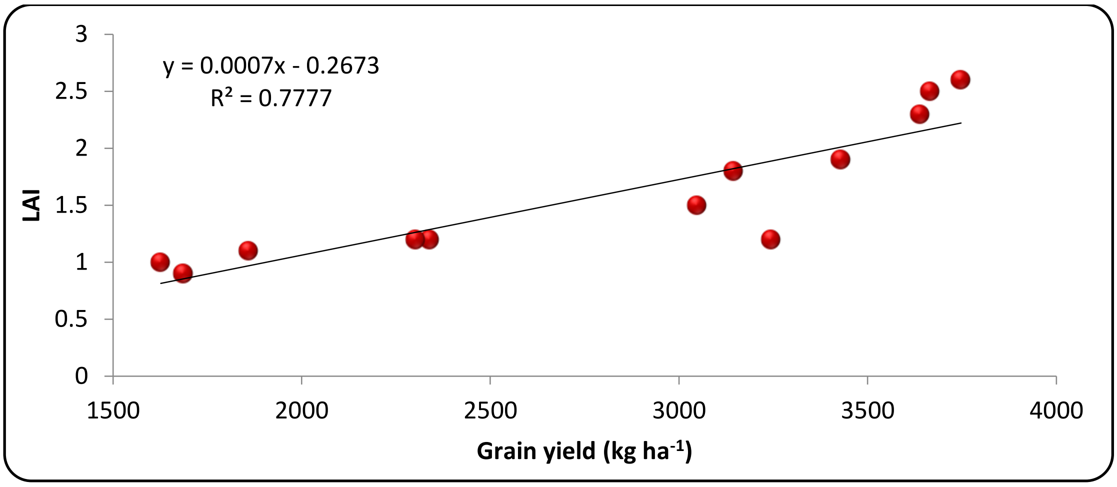


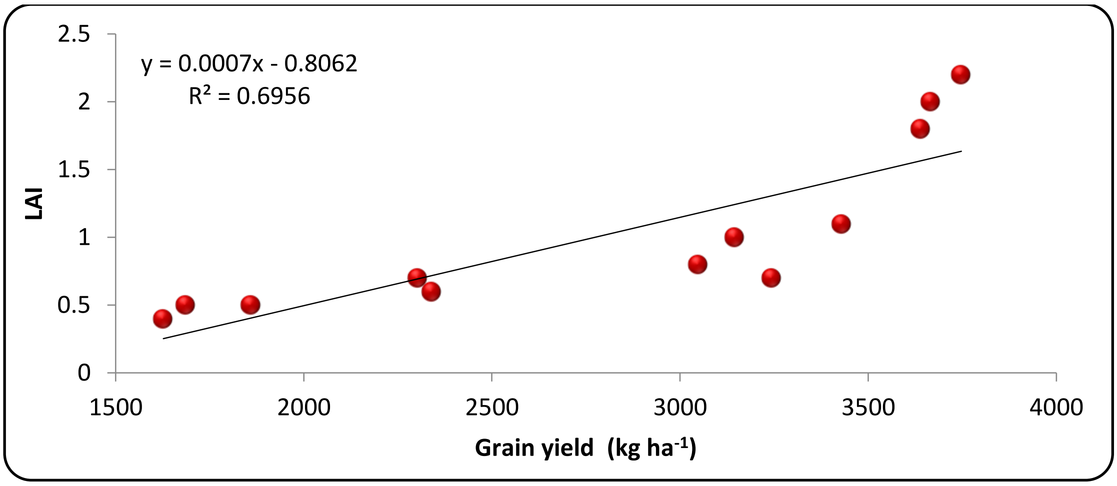
Fig. 4.12. Correlating the LAI and grain yield (kg ha^{-1}) at different crop growth stages of maize as influenced by dates of sowing

Cont…

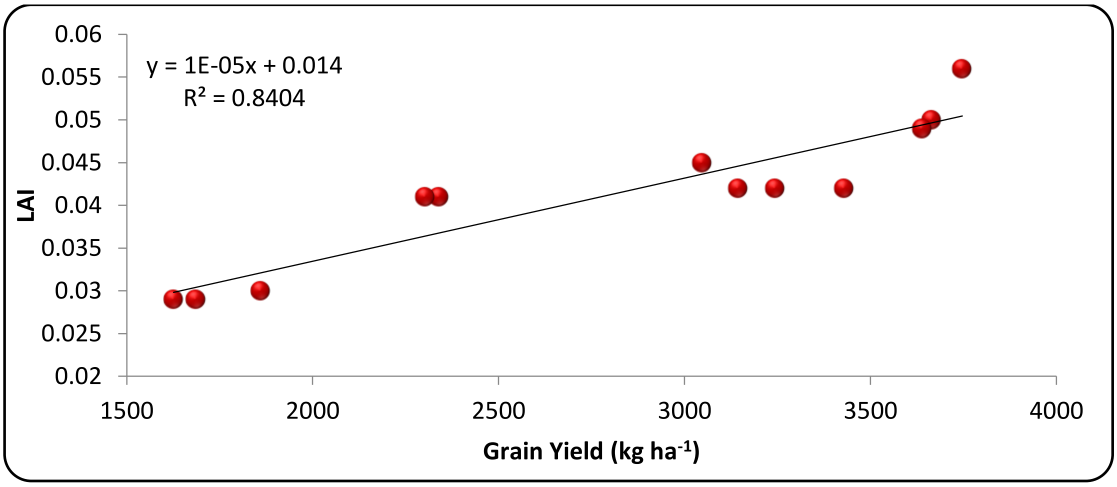
Soft dough stage



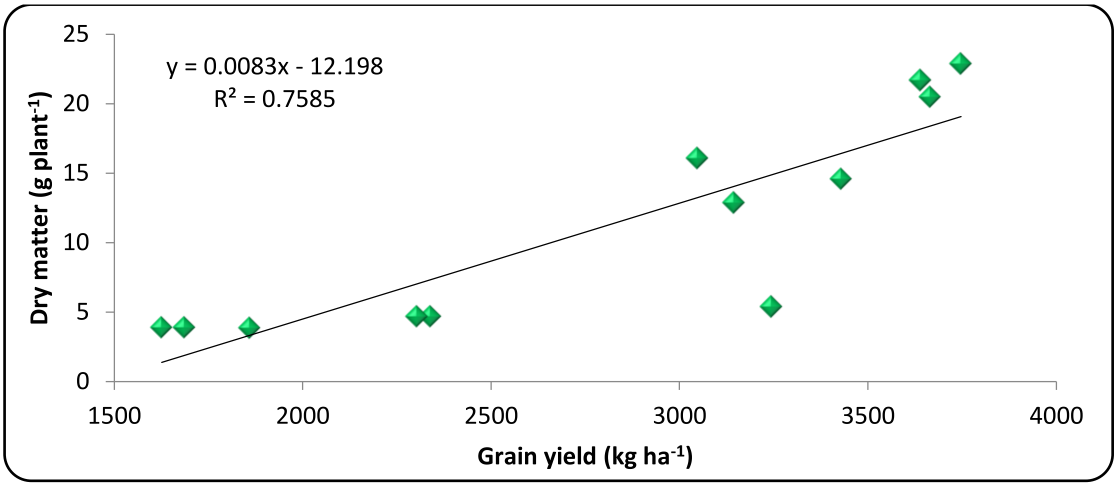
Hard dough stage



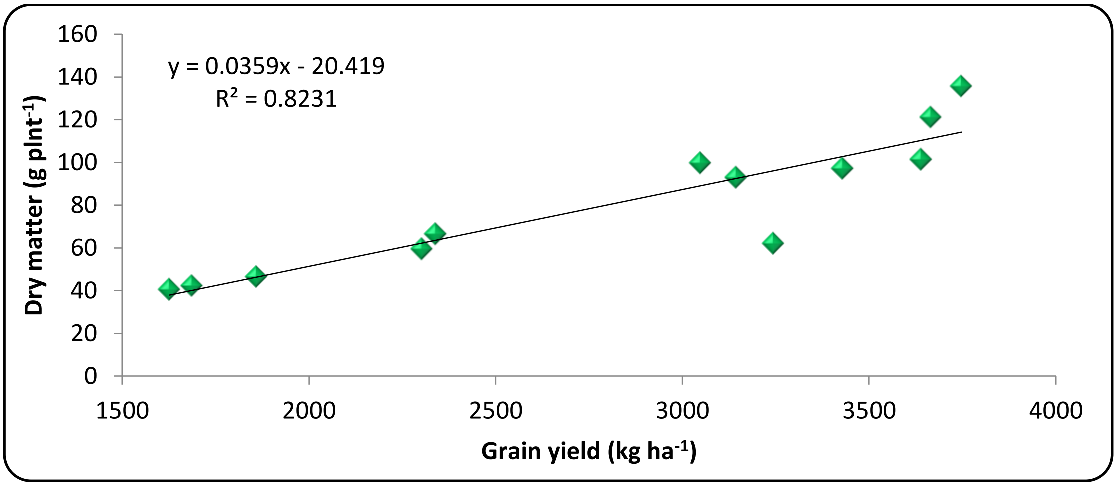
Physiological maturity



Six leaf stage



Tasseling stage



Silking stage

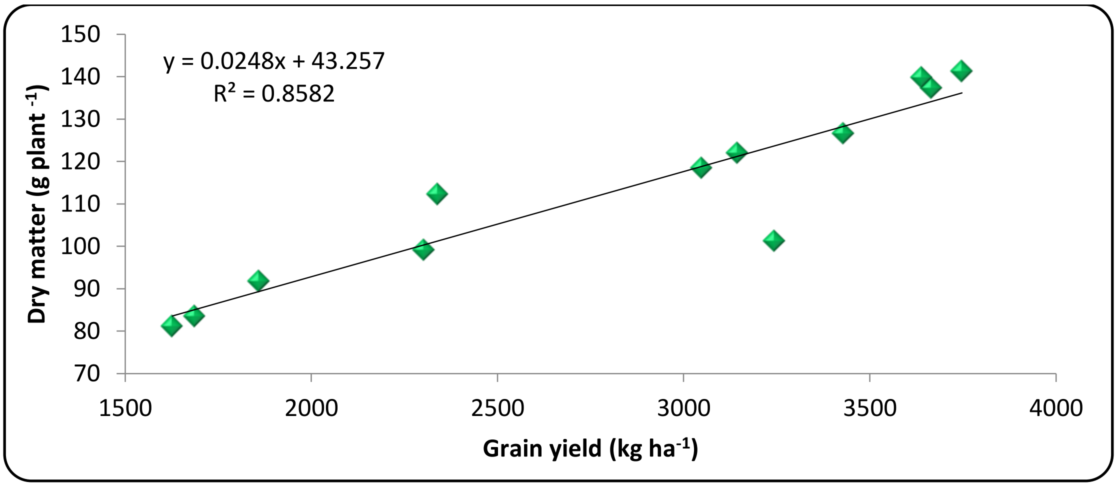
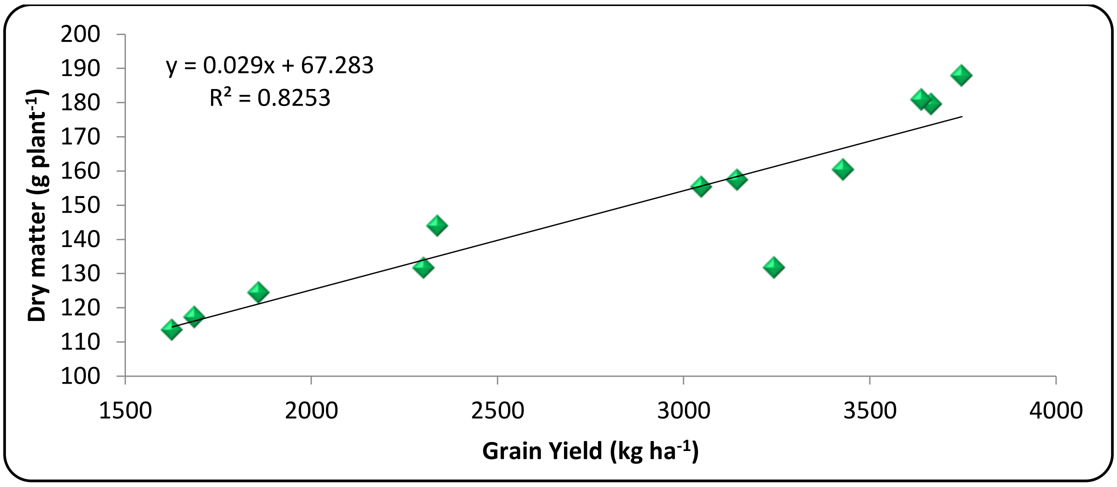


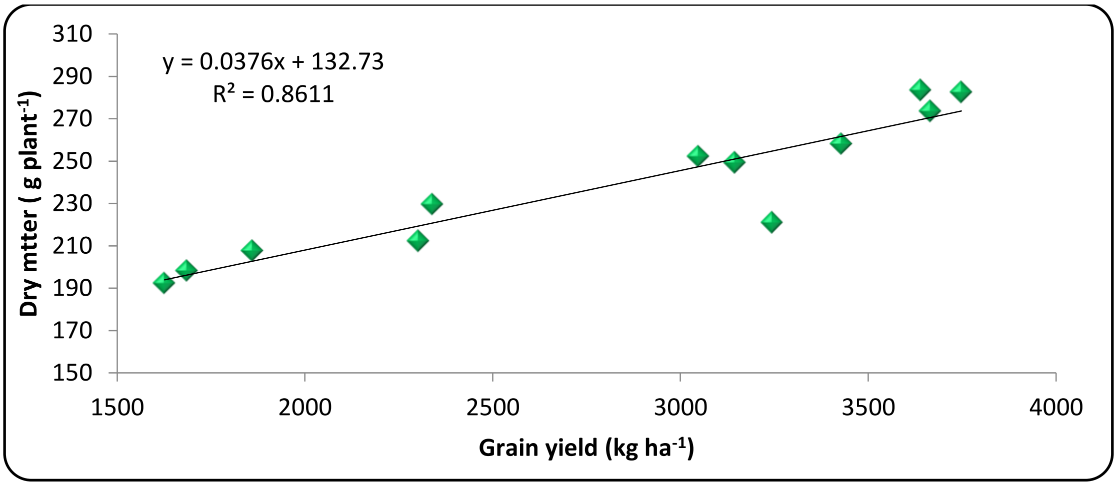
Fig. 4.13. Correlating the dry matter and grain yield (kg ha^{-1}) at different crop growth stages of maize as influenced by dates of sowing

Cont…

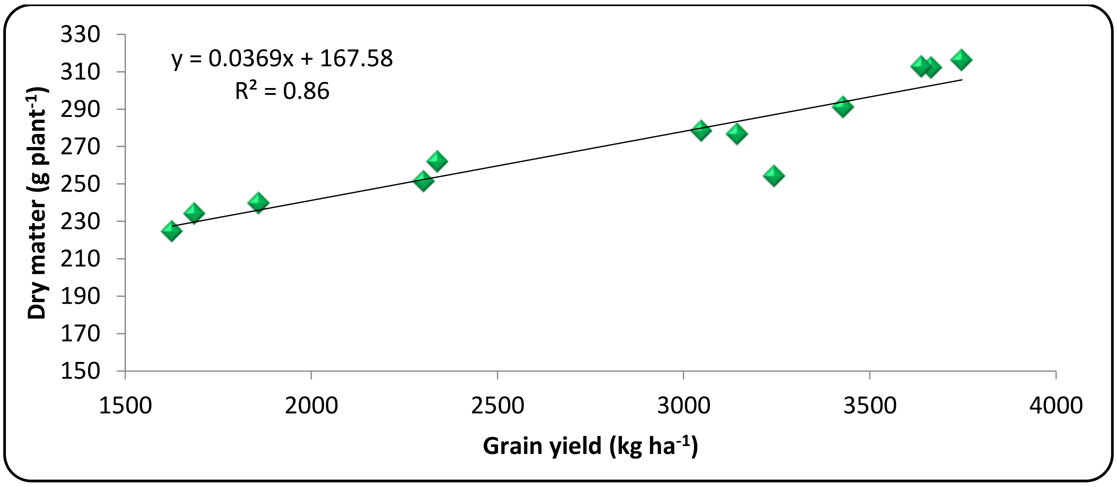
Soft dough stage



Hard dough stage



Physiological maturity



Correlation of Dry matter with grain yield:

Dry matter showed positive correlation with yield (Fig.4.13) at six leaf stage (R^2 =0.758), Tasseling stage (R^2=0.823), Silking stage (R^2=0.858), Soft dough stage (R^2=0.825), hard dough stage (R^2=0.861) and physiological maturity (R^2=0.86). It denotes the drymatter plays important role in final yield in maize.

4.5.8 Stover Weight (Kg ha^{-1})

Stover weight at maturity of maize hybrids sown at different dates of sowing in *kharif* was recorded at harvest and presented in Table 4.15 and Fig. 4.14

Similar to yield components Pinnacle recorded significantly higher Stover weight (5509.1 kg ha^{-1}) compared to D.S 900 M (5252.6 kg ha^{-1}) and CP818 (5314.3 kg ha^{-1}).

Among the dates of sowing D_1 (June II FN) also recorded significantly higher stover weight (7523.2 kg ha^{-1}) compared to all other dates of sowing. D4 (first fortnight of August) D.S 900M recorded lower stover weight (4192.4 kg ha^{-1}).

Among the hybrids and dates of sowing D_1H_2 i.e., Pinnacle sown at Second fortnight of June recorded significantly higher stover weight (7230 kg ha^{-1}) among all other interaction. D_4H_1 i.e., D.S 900M sown at First fortnight of August recorded lower unit grain weight at maturity (4129.6 kg ha^{-1}). First date of sowing (June II FN) crop exposed to favorable weather in terms of temperature, day length, sunshine hours caused higher stover yield along with grain yield. Similar results were obtained by Sreenivasulu *et al.* (2008).

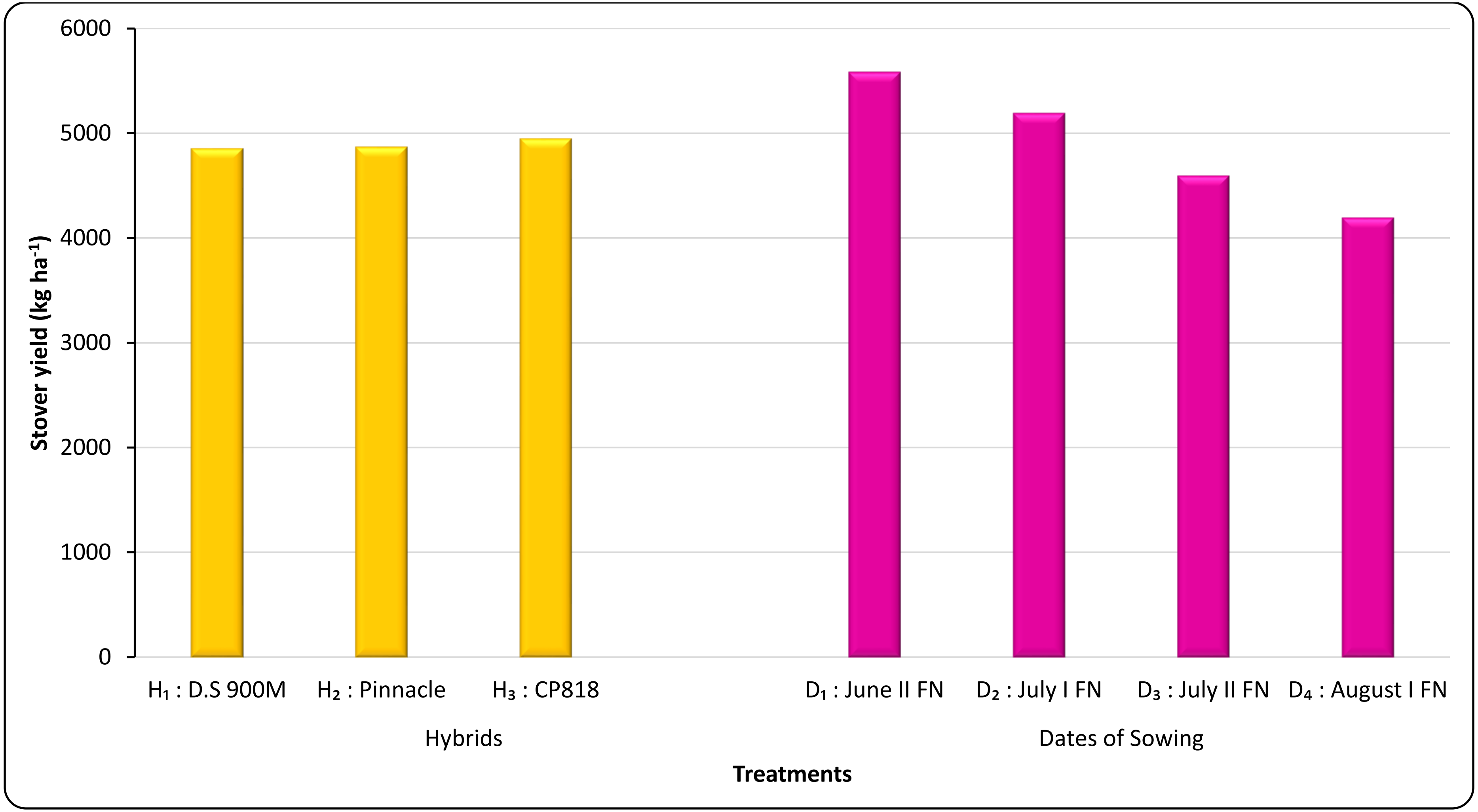


Fig. 4.14. Stover yield (kg ha^{-1}) of maize hybrids as influenced by dates of sowing

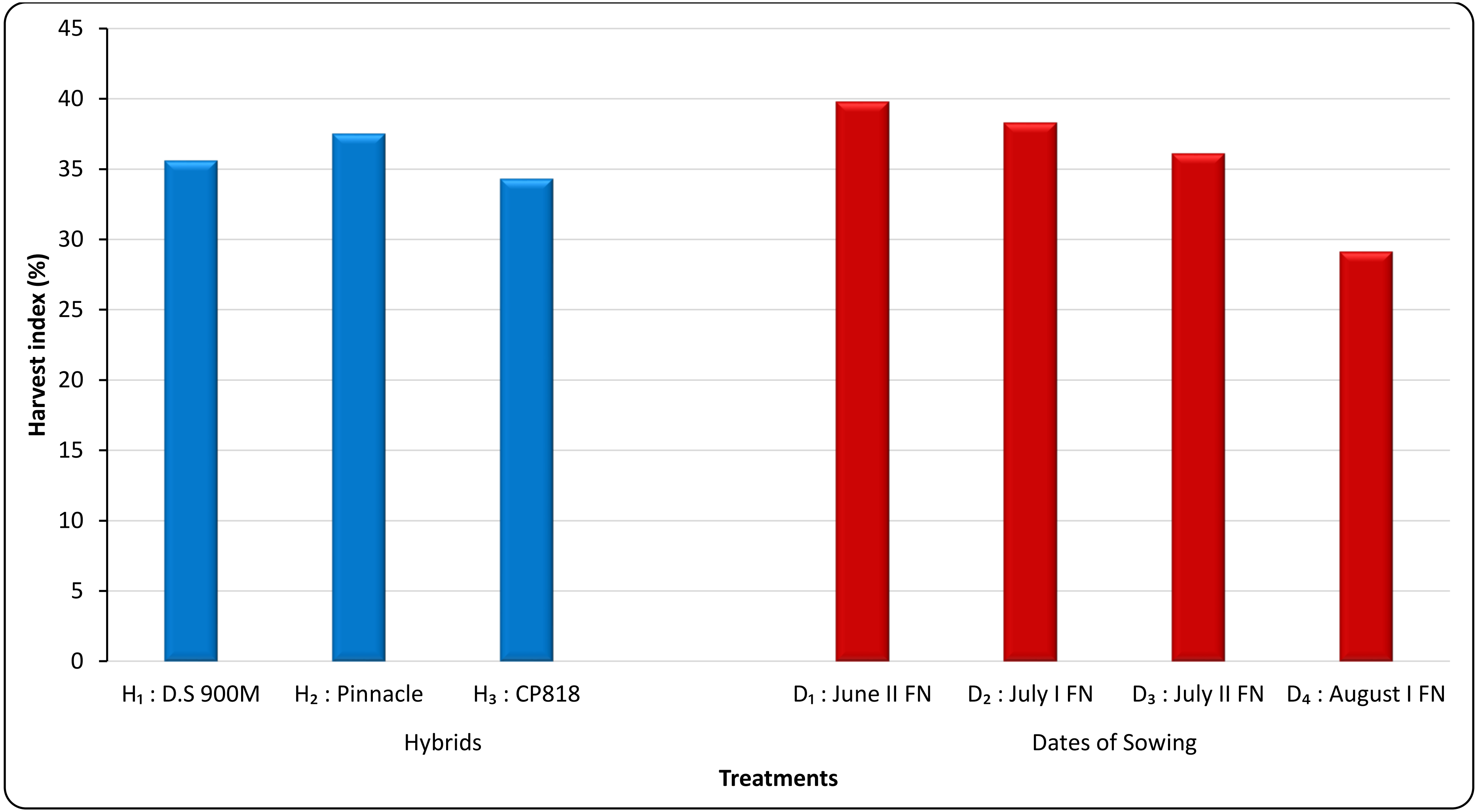


Fig. 4.15. Harvest index (%) of maize hybrids as influenced by dates of sowing

4.5.9 Harvest Index (%)

Harvest index of maize hybrids sown at different dates of sowing in *kharif* and presented in Table 4.15 and Fig. 4.15

Among the hybrids there Pinnacle recorded higher harvest index (37.5%) compared to D. S 900 M (35.6%) and CP818 (34.3%). Similarly D_1 (June II FN) recorded significantly higher harvest index (39.8%) compared to D_2 (38.3%), D_3 (36.1%) and D4 (29.1%) due to higher accumulation of GDD, PTU and HTU.

Among the hybrids and dates of sowing D_1H_1 i.e., D.S 900M sown at Second fort night of June recorded significantly higher harvest index (40.8%) compared to all other interaction effects and D_4H_3 i.e., CP818 sown at First fortnight of August lowest harvest index (27.7%). Similar results were obtained by Shrestha *et al.* (2008).

4.6 NITROGEN CONTENT

Nitrogen Content of maize hybrids sown at different dates of sowing in *kharif* was recorded and observed at different growth stages and presented in Table 4.16.

Irrespective of the hybrids nitrogen content in leaf and stem increased upto tasseling stage and decreased till maturity whereas grain nitrogen content increased at physiological maturity stages.

Among the hybrids Pinnacle recorded significantly higher nitrogen content in leaf and stem (0.48 g plant^{-1}, 0.47 g plant^{-1}) at tasseling stage followed by D.S 900M (0.47 g plant^{-1}, 0.46 g plant^{-1}) and lowest nitrogen content in leaf and stem was recorded by CP818 (0.44 g plant^{-1} , 0.44 g plant^{-1}) respectively. There was significant difference among the hybrids at all the growth stages of maize.

Table 4.16. Effect of photoperiod and temperature nitrogen content ($g\ plant^{-1}$) of maize hybrids sown at different dates of sowing

Treatments	6 leaf stage		Tasseling stage		Physiological maturity			
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Cob	Total
Hybrids								
H_1 : D.S 900M	0.22	0.19	0.48	0.46	0.19	0.21	1.39	1.80
H_2 : Pinnacle	0.34	0.32	0.47	0.47	0.19	0.26	1.39	1.85
H_3 : CP818	0.25	0.20	0.44	0.44	0.17	0.19	1.3	1.67
CD (P=0.05)	0.012	0.022	0.007	0.07	0.025	NS	0.023	0.15
Dates of Sowing								
D_1 : June II FN	0.31	0.28	0.64	0.64	0.23	0.24	1.51	1.99
D_2 : July I FN	0.29	0.25	0.45	0.45	0.21	0.23	1.45	1.85
D_3 : July II FN	0.25	0.22	0.43	0.43	0.16	0.19	1.37	1.80
D_4 : August I FN	0.23	0.20	0.34	0.34	0.15	1.15	1.2	1.42
CD (P=0.05)	0.17	0.034	0.008	0.03	0.009	NS	0.014	0.229
Interaction (D × H)								
D_1H_1	0.25	0.23	0.68	0.66	0.25	0.26	1.53	2.0
D_1H_2	0.39	0.38	0.62	0.60	0.23	0.24	1.52	1.99
D_1H_3	0.29	0.25	0.61	0.60	0.22	0.23	1.49	1.95
D_2H_1	0.21	0.21	0.42	0.40	0.21	0.21	1.48	1.90
D_2H_2	0.37	0.34	0.48	0.47	0.22	0.23	1.50	1.96
D_2H_3	0.32	0.20	0.45	0.44	0.18	0.19	1.40	1.78
D_3H_1	0.21	0.17	0.45	0.43	0.17	0.18	1.38	1.73
D_3H_2	0.33	0.28	0.44	0.39	0.17	0.22	1.40	1.94
D_3H_3	0.21	0.19	0.42	0.37	0.16	0.17	1.35	1.68
D_4H_1	0.21	0.17	0.37	0.33	0.16	0.16	1.21	1.53
D_4H_2	0.27	0.27	0.35	0.29	0.15	0.15	1.17	1.47
D_4H_3	0.20	0.16	0.31	0.27	0.14	0.15	1.19	1.26
CD (P=0.05)	0.025	NS	0.014	0.019	NS	NS	0.046	NS

At physiological maturity the nitrogen content in grain of D.S 900M and Pinnacle recorded highest Nitrogen content (1.39 3 g plant^{-1}) followed by CP818 (1.3 g plant^{-1}).

Among the dates of sowing D_1 (June II fortnight) recorded significantly higher nitrogen content in leaf and stem (0.64 g plant^{-1}) among all growth stages of crop growth followed by D_2, D_3 and D_4 recorded significantly nitrogen content in leaf and stem (0.34 g plant^{-1}).

At physiological maturity grain nitrogen content at D_1 (June II FN) recorded significantly highest value (1.51 g plant^{-1}) and D_4 (August I FN) recorded lowest grain nitrogen content (1.42 g plant^{-1}).

The interaction of hybrids and the dates of sowing D_1H_1 i.e., D.S 900M at D_1 (June II FN) recorded significantly higher leaf and stem nitrogen content at tasseling stage (0.68 g plant^{-1} and 0.66 g plant^{-1}). Similar variability was also observed by Pathak and Tiwari (1972).

4.7 VALIDATION OF DSSAT v4.5 CERES - MAIZE MODEL

Using the data obtained from the field experiments conducted during *kharif*, 2016. The experimental file (AGCG1601MZ), weather file (AGCG2016), soil file (AGCG060016) were created for CERES-Maize validation. The crop genetic coefficients already developed for the three hybrids were also used as input for CERES-Maize validation.

Using the above input files, DSSAT V.4.5 CERES-Maize model was run and the simulated results were compared with the corresponding actual observed results obtained during the experimentation for growth, development and yield of maize crop. The results are presented here under.

4.7.1 Grain Yield (kg ha^{-1})

The data on grain yield (kg ha^{-1}) was computed at all the treatments of maize Table 4.17 and Fig. 4.16.

The results showed that grain yield of maize varied from 3748 kg ha^{-1} (June II FN, D.S 900M) to 1626 kg ha^{-1} (August I FN, CP818) while the model simulated grain yield ranged from 3769 kg ha^{-1} (July I FN, Pinnacle) to 1407 kg ha^{-1} (August I FN, CP818).

The percent error between simulated and observed yield ranged from -0.5 (June II FN, Pinnacle) to 18.3 (July II FN, D.S 900M). The error percentage between simulated and observed for kernel yield was lower at First and second dates of sowing (June II FN and July I FN) for all the hybrids compared to third and fourth date of sowing (July II FN and August I FN). Evaluation of the model showed that observed mean yield was 2811.2 ± 802.8 during the crop season while the simulated mean yield was 2769.9 ± 846.1. The MAE computed was found 202 and the RMSE was 244.3 kg ha^{-1} which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered excellent with NRMSE values being less than 10 per cent. The d-index value was 0.99 indicating that the model was able to simulate grain yield well within the bounds of experimental uncertainity. Similar variability was also reported by Tojoseller *et al*. (2007), Ramawath *et al*. (2012) and Leela *et al.* (2014).

4.7.2 Anthesis Days

The comparison between observed and simulated anthesis days are presented in Table 4.18 and Fig. 4.17.

The results showed anthesis days varied from 55 days (July I FN, Pinnacle) to 62 days (July II FN, CP818) while the model simulated 49 days (July I FN, Pinnacle) to 67 days (June II FN, D.S 900M) .

Table 4.17. Comparison of simulated and observed grain yield (kg ha^{-1}) in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	3529	3748	-5.8
D_2 : July I FN	3294	3048	8.1
D_3 : July II FN	2766	2339	18.3
D_4 : August I FN	1935	1860	4
Pinnacle (H_2)			
D_1 : June II FN	3647	3666	-0.5
D_2 : July I FN	3769	3430	9.9
D_3 : July II FN	3693	3244	13.8
D_4 : August I FN	1863	1686	10.5
CP818 (H_3)			
D_1 : June II FN	1864	3640	-1.4
D_2 : July I FN	3055	3145	-2.9
D_3 : July II FN	2417	2302	5
D_4 : August I FN	1407	1626	-13.5
Average	**2769.92**	**2811.7**	
Sd±	**846.1**	**802.8**	
Test parameter			
MBE	-102		
MAE	202		
RMSE	244.3		
NRMSE	8.6		
d-stat	0.9		

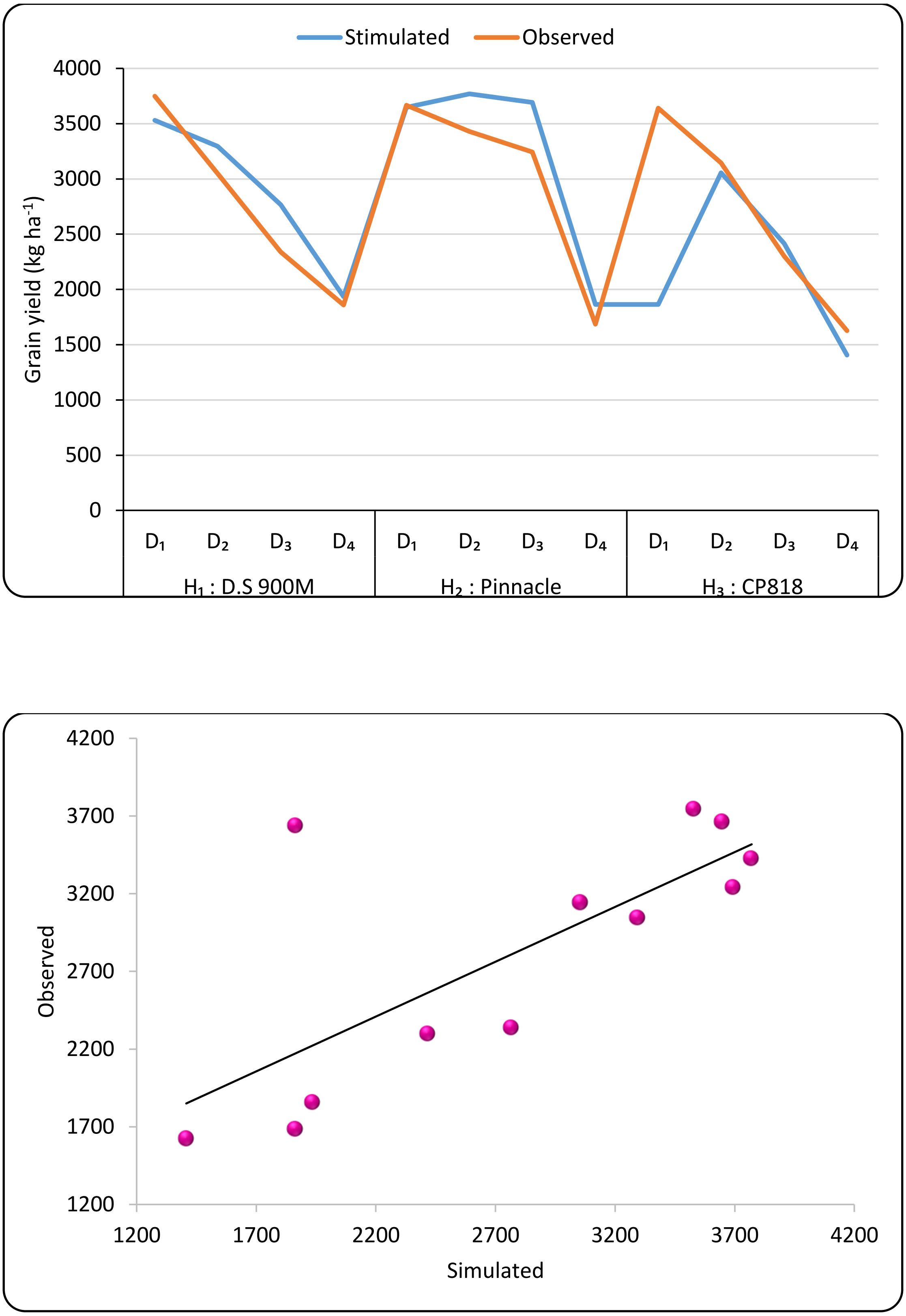
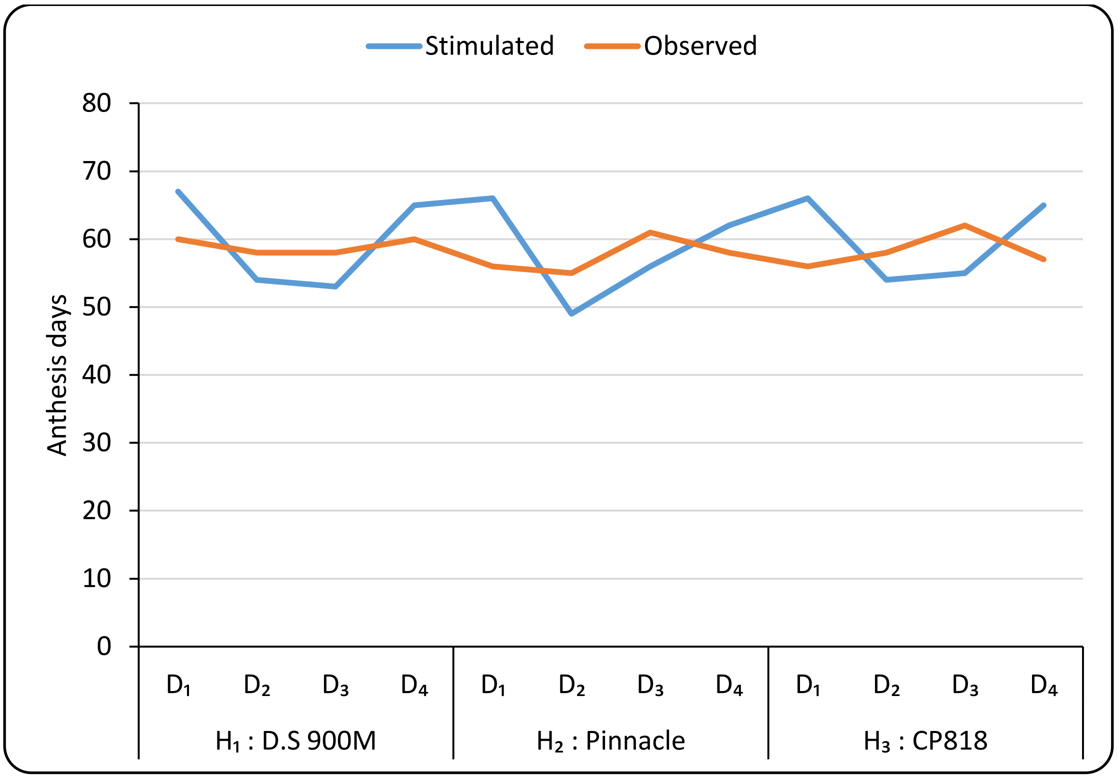


Fig. 4.16. Simulated vs observed values for grain yield (kg ha^{-1}) of maize hybrids at different dates of sowing

Table 4.18. Comparison of simulated and observed days to anthesis in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	67	60	11.67
D_2 : July I FN	54	58	-6.90
D_3 : July II FN	53	58	-8.62
D_4 : August I FN	65	60	8.33
Pinnacle (H_2)			
D_1 : June II FN	66	56	17.86
D_2 : July I FN	49	55	-10.91
D_3 : July II FN	56	61	-8.20
D_4 : August I FN	62	58	6.90
CP818 (H_3)			
D_1 : June II FN	66	56	17.86
D_2 : July I FN	54	58	-6.90
D_3 : July II FN	55	62	-11.29
D_4 : August I FN	65	57	14.04
Average	**59.3**	**58.3**	
Sd±	**6.41**	**2.13**	
Test parameter			
MBE	-1.08		
MAE	6.25		
RMSE	6.58		
NRMSE	11.3		
d-stat	0.98		



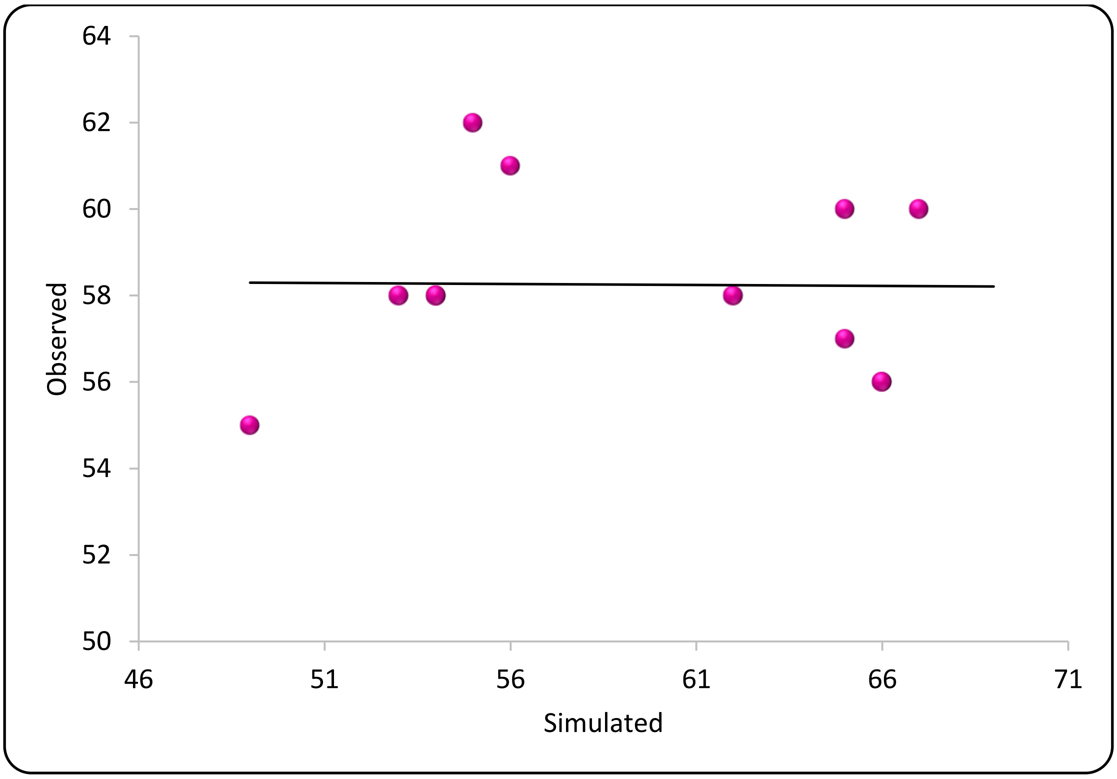


Fig. 4.17. Simulated vs observed days to anthesis of maize hybrids at different dates of sowing

The error percent between simulated and observed ranged from -11.29 (July II FN CP818) to 17.86 (July II FN, Pinnacle and July II FN, CP818). The error percentage between simulated and observed days for anthesis was higher at First date of sowing (June II FN) for all the hybrids compared to second, third and fourth date of sowing (July I FN, July II FN and August I FN).

Evaluation of the model showed that observed mean anthesis days was 58.3 ± 2.13 during the crop season while the simulated mean anthesis days was 59.3 ± 6.41.The RMSE was 6.58 days which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered good with NRMSE values being less than 20 per cent. The d-index value was 0.98 indicating that the model was able to simulate anthesis days well within the bounds of experimental uncertainity. Similar variability was also reported by Roman Paoli *et al*. (2000) and Singh *et al*. (2010)

4.7.3 Physiological Maturity Days

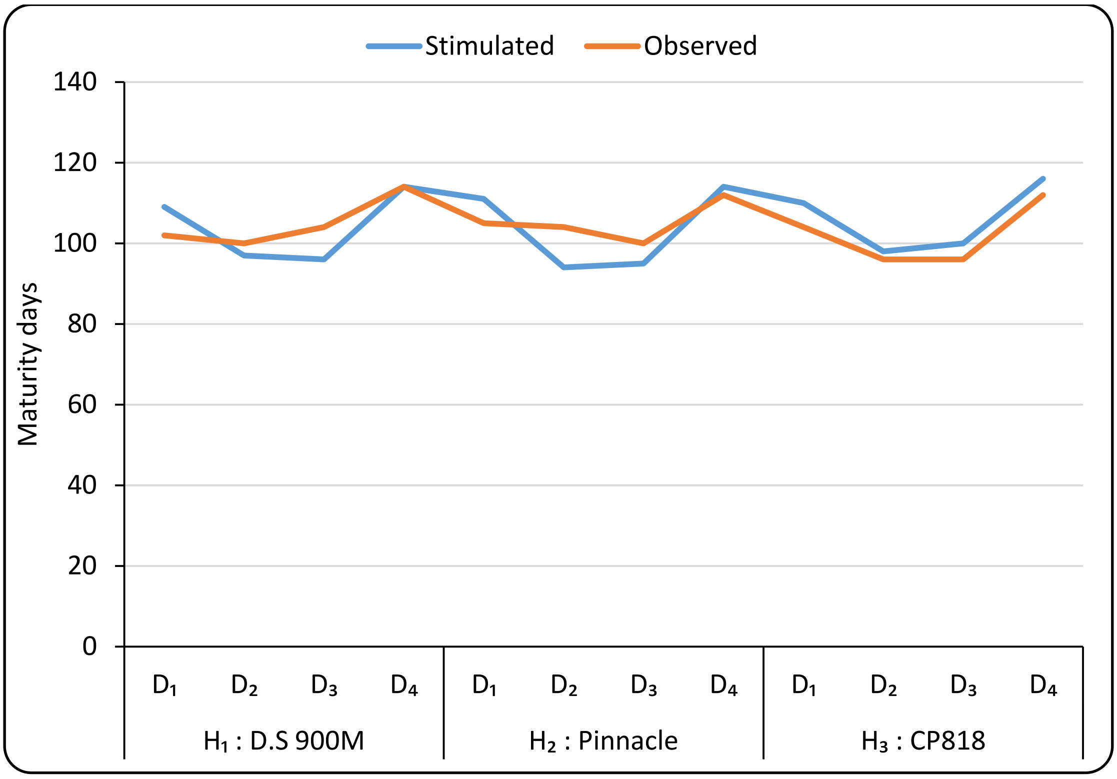
The comparison between observed and simulated physiological maturity days are presented in Table 4.19 and Fig.4.18.

The observed results showed physiological maturity days varied from 96 days (July I and July II FN of CP818) to 114 days (August I FN, D.S 900M) while the model simulated 94 days (July I FN, Pinnacle) to 116 days (August I FN, CP818).

The error percent between simulated and observed ranged from -9.62 (July I FN, Pinnacle) to 6.86 (June II FN, D.S 900M). The error percentage between simulated and observed days for physiological maturity was higher at First date of sowing (June II FN) for all the hybrids compared to Second, third and fourth date of sowing (July I FN, July II FN and August I FN).

Table 4.19. Comparison of simulated and observed days to physiological maturity in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	109	102	6.86
D_2 : July I FN	97	100	-3.00
D_3 : July II FN	96	104	-7.69
D_4 : August I FN	114	114	0.00
Pinnacle (H_2)			
D_1 : June II FN	111	105	5.71
D_2 : July I FN	94	104	-9.62
D_3 : July II FN	95	100	-5.00
D_4 : August I FN	114	112	1.79
CP818 (H_3)			
D_1 : June II FN	110	104	5.77
D_2 : July I FN	98	96	2.08
D_3 : July II FN	100	96	4.17
D_4 : August I FN	116	112	3.57
Average	**104.5**	**104.08**	
Sd±	**8.51**	**5.97**	
Test parameter			
MBE	-0.41		
MAE	4.75		
RMSE	5.46		
NRMSE	5.25		
d-stat	0.99		



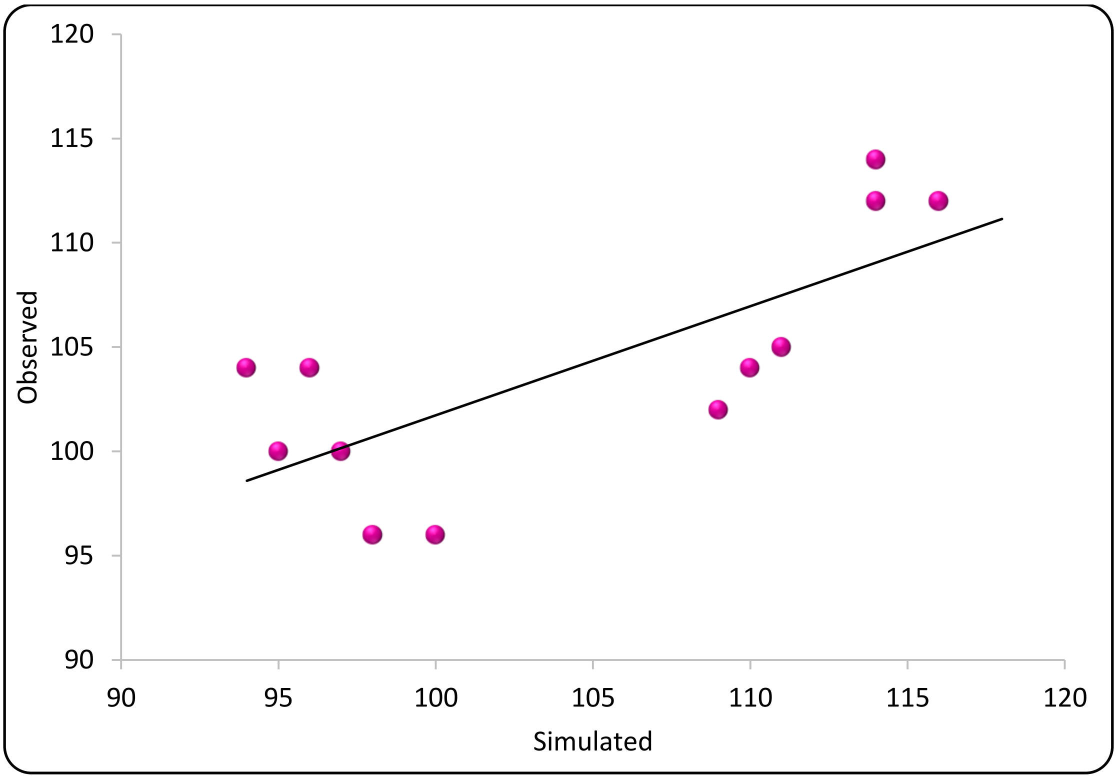


Fig. 4.18. Simulated vs observed values for days to attain physiological maturity of maize hybrids at different dates of sowing

Evaluation of the model showed that observed mean maturity days was 104.08 ± 5.97 during the crop season while the simulated mean maturity days was 104.5 ± 8.51. The MAE computed was found 4.75 and the RMSE was 5.46 days which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered excellent with NRMSE values being less than 10 per cent. The d-index value was 0.99 indicating that the model was able to simulate maturity days well within the bounds of experimental uncertainity. Similar variability was also reported by Roman Paoli *et al.* (2000) and Singh *et al.* (2010).

4.7.4 Number of Grains m^{-2}

The comparison between observed and simulated number of grains m^{-2} are presented in Table 4.20 and Fig. 4.19.

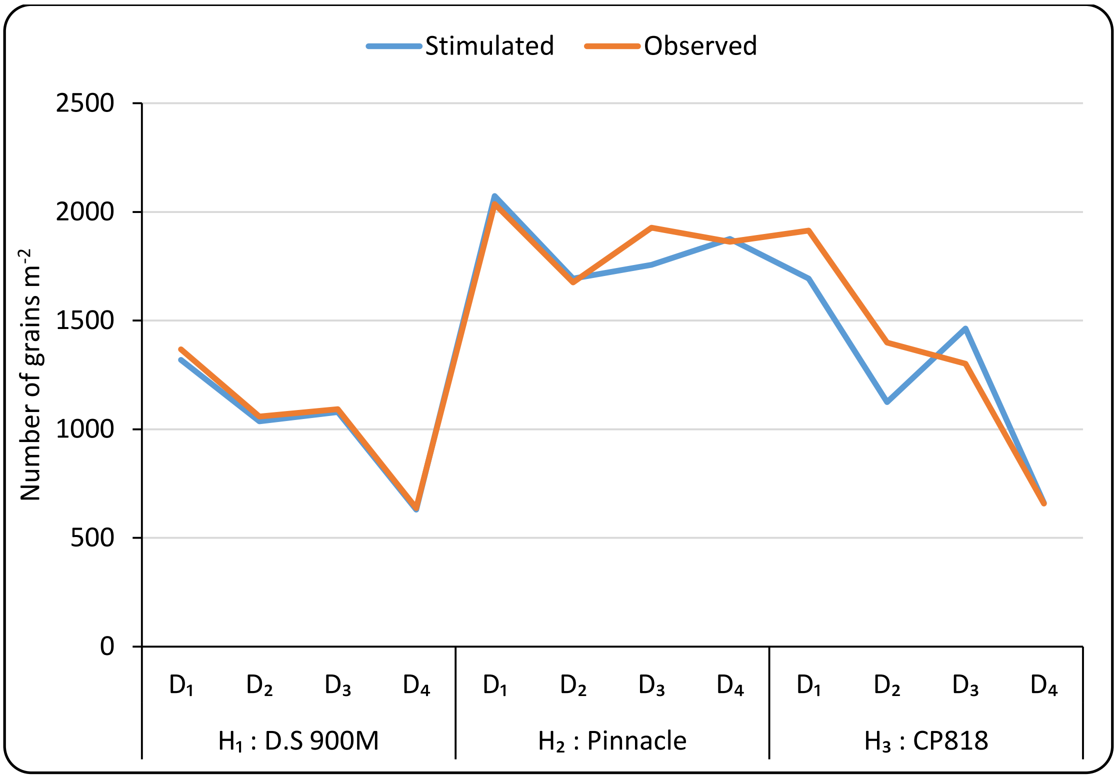
The results showed number of grains m^{-2} for observed results varied from 637 grains m^{-2} (August I FN, D.S 900M) to 2037 grains m^{-2} (June II FN, Pinnacle) while the model simulated 630 grains^{-2} (August I FN, D.S 900M) to 2073.6 grains^{-2} (June II FN, Pinnacle).

The error percent between simulated and observed ranged from -24.4 (July I FN, CP818) to 11.07 (July II FN, CP818). The error percentage between simulated and observed for number of grains m^{-2} was higher at D_1, D_2 and D_3 dates of sowing in case of CP818 compared to D.S 900M and Pinnacle.

Evaluation of the model showed that observed mean number of grains m^{-2} was 1411.1 ± 485.5 during the crop season while the simulated mean number of grains m^{-2} was 1367.3 ± 469.8. The MAE computed was found 82.6 and the RMSE was 124 which shows reasonably good agreement with the observed values.

Table 4.20. Comparison of simulated and observed number of grains m^{-2} in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	1320	1368	-3.64
D_2 : July I FN	1036	1059	-2.22
D_3 : July II FN	1078.7	1093	-1.33
D_4 : August I FN	630	637	-1.11
Pinnacle (H_2)			
D_1 : June II FN	2073.6	2037	1.77
D_2 : July I FN	1694	1676	1.06
D_3 : July II FN	1757	1928	-9.73
D_4 : August I FN	1876	1863	0.69
CP818 (H_3)			
D_1 : June II FN	1694	1915	-13.05
D_2 : July I FN	1124.2	1399	-24.44
D_3 : July II FN	1463	1301	11.07
D_4 : August I FN	661.5	658	0.53
Average	**1367.3**	**1411.1**	
Sd±	**469.8**	**485.5**	
Test parameter			
MBE	-43.8		
MAE	82.6		
RMSE	124		
NRMSE	9.07		
d-stat	0.99		



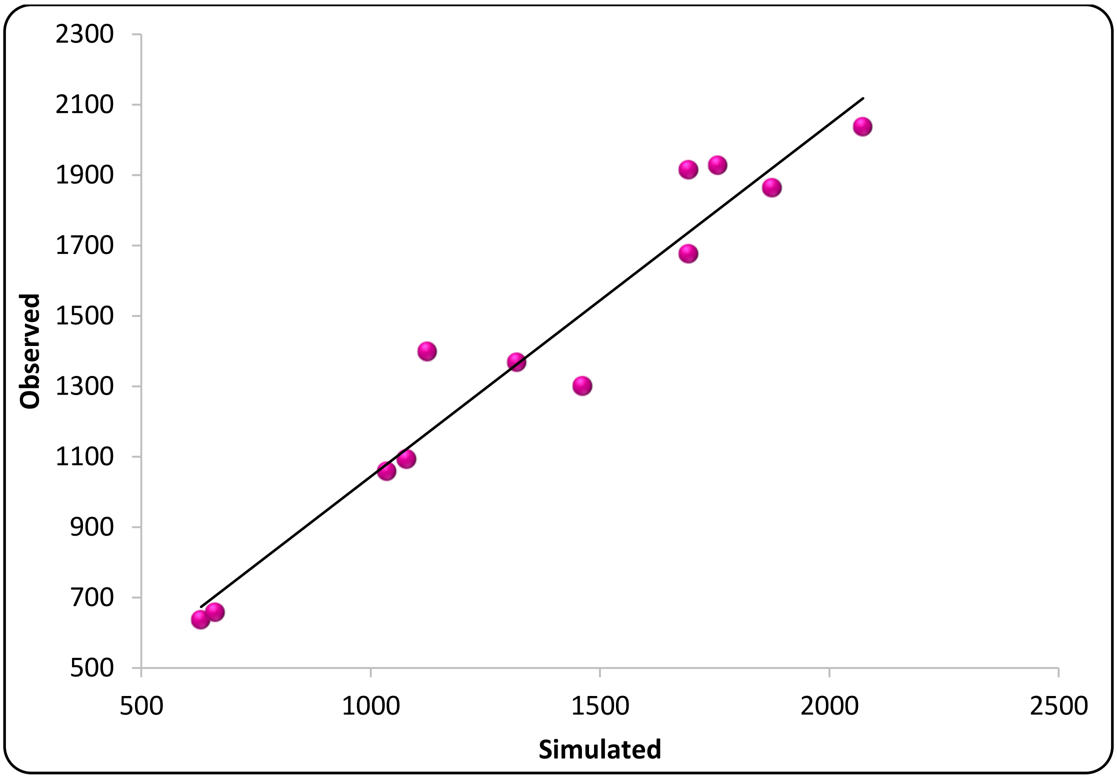


Fig. 4.19. Simulated vs observed number of grains m^{-2} of maize hybrids at different dates of sowing

During the crop growth season simulation can be considered excellent with NRMSE values being less than 10 per cent. The d-index value was 0.99 indicating that the model was able to simulate maturity days well within the bounds of experimental uncertainty. Similar variability was also reported by Deepak *et al.* (2004).

4.7.5 Unit Grain Weight at Maturity

The comparison between observed and simulated number of unit grain weight at maturity are presented in Table 4.21 and Fig. 4.20.

The results showed unit grain weight at maturity for observed results varied from 0.21 g (August I FN, CP818) to 0.33 g (June II FN, D.S 900M) while the model simulated 0.21 g (August I FN,CP 818) to 0.31g (June II FN, D.S 900M).

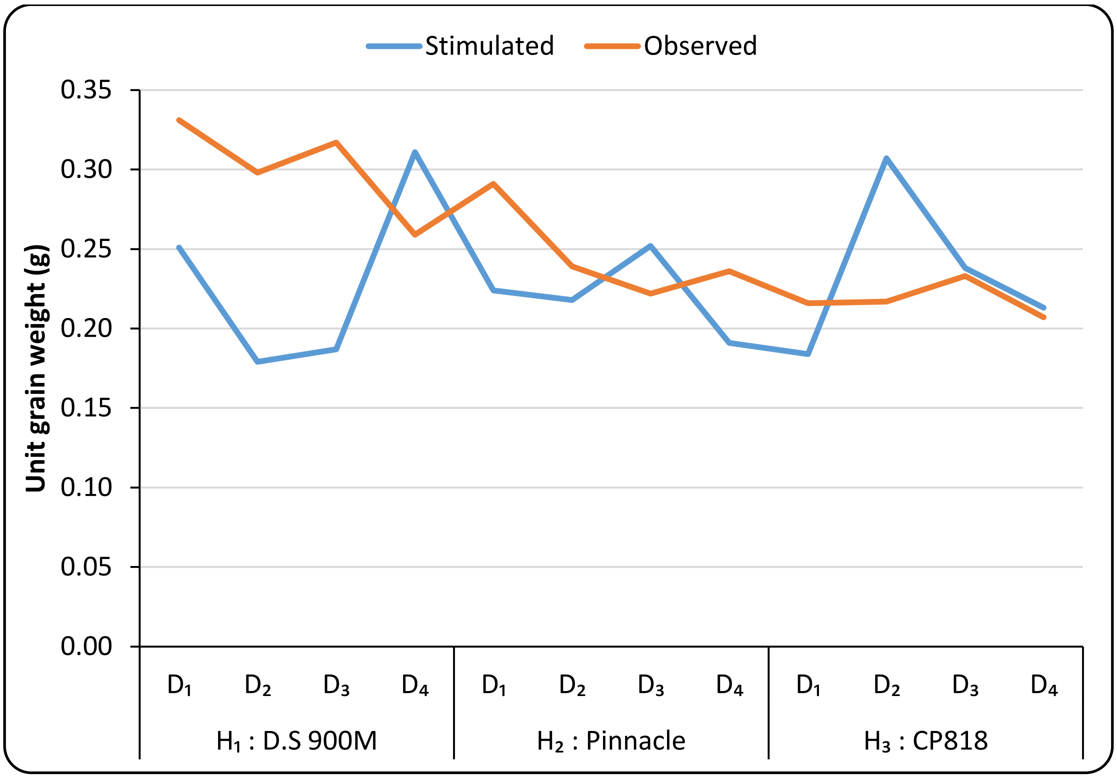
The error percent between simulated and observed ranged from -41 (July II FN, D.S 900M) to 41.5 (July I FN, CP818). The error percentage between simulated and observed for unit grain weight at maturity was higher at D_1 (June II FN) for all the hybrids compared to remaining dates of sowing.

Evaluation of the model showed that observed mean unit grain weight at maturity was 0.26 ± 0.04 during the crop season while the simulated mean number of unit grain weight at maturity was 0.23 ± 0.4. The MAE computed was found 0.05 and the RMSE was 0.069 which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered fair with NRMSE values being more than 20 per cent. The d-index value was 0.92 indicating that the model was able to simulate unit grain weight at maturity fair well within the bounds of experimental uncertainty. Similar variability was also reported by Deepak *et al*. (2004).

Table 4.21. Comparison of simulated and observed unit grain weight (g) at maturity

Treatment	**Simulated**	**Observed**	**Error (%)**
D.S 900M (H_1)			
D_1 : June II FN	0.251	0.331	-24.2
D_2 : July I FN	0.179	0.298	-39.9
D_3 : July II FN	0.187	0.317	-41.0
D_4 : August I FN	0.311	0.259	20.2
Pinnacle (H_2)			
D_1 : June II FN	0.224	0.291	-23.0
D_2 : July I FN	0.218	0.239	-8.8
D_3 : July II FN	0.252	0.222	13.5
D_4 : August I FN	0.191	0.236	-19.1
CP818 (H_3)			
D_1 : June II FN	0.184	0.216	-14.8
D_2 : July I FN	0.307	0.217	41.5
D_3 : July II FN	0.238	0.233	2.1
D_4 : August I FN	0.213	0.207	2.9
Average	**0.23**	**0.26**	
Sd±	**0.04**	**0.04**	
Test parameter			
MBE	0.02		
MAE	0.05		
RMSE	0.06		
NRMSE	27.02		
d-stat	0.91		



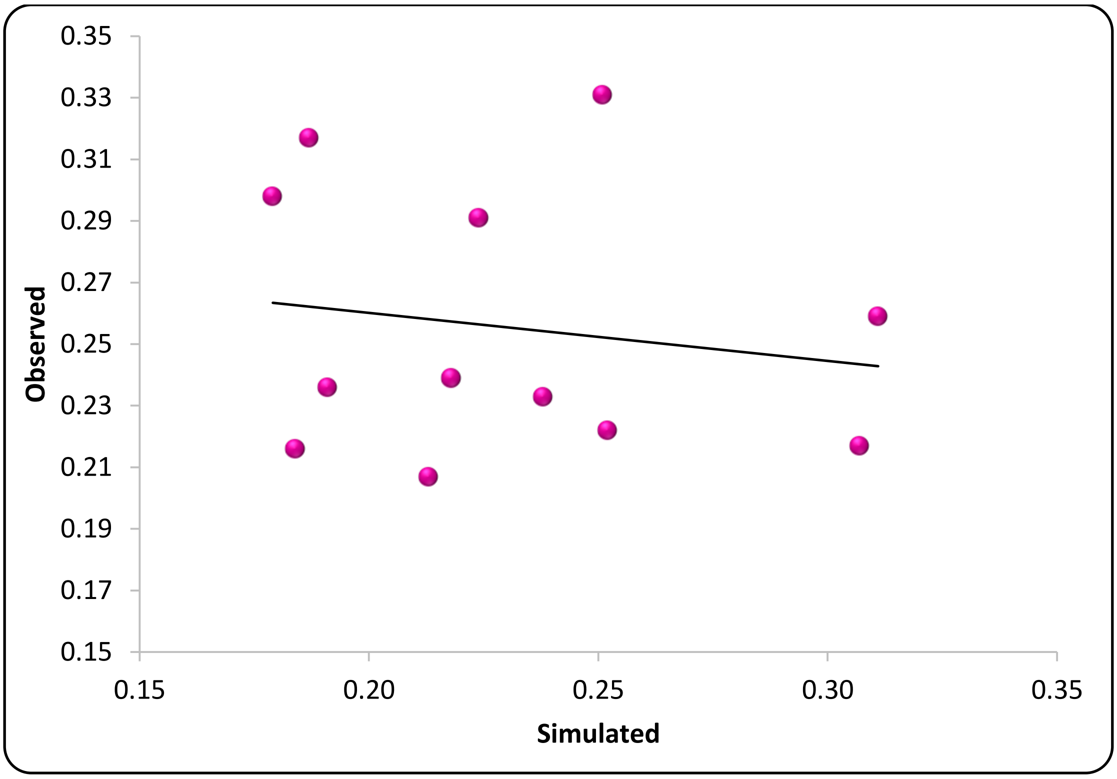


Fig. 4.20. Simulated vs observed unit grain weight (g) at maturity of maize hybrids at different dates of sowing

4.7.6 Stover Weight (kg ha^{-1})

The comparison between observed and simulated stover weight (kg ha^{-1}) are presented in Table 4.22 and Fig. 4.21

The results showed number of stover weight for observed results varied from 4129.7 kg ha^{-1} (August I FN, D.S 900M) to 5863 kg ha^{-1}(June II FN, Pinnacle) while the model simulated 2398 kg ha^{-1} (July I FN, Pinnacle) to 6041kg ha^{-1} (July II FN,CP 818).

The error percent between simulated and observed ranged from -42.78 (July II FN, CP818) to 50.3 (July I FN, Pinnacle). The error percentage between simulated and observed for stover weight was higher at D2 (July I FN, Pinnacle) compared to remaining dates of sowings.

Evaluation of the model showed that observed mean stover weight was 4851.91 ± 573.8 during the crop season while the simulated mean number of stover weight was 4153.08 ± 1221.5. The MAE computed was found 1573.5 and the RMSE was 1767 which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered poor with NRMSE values being more than 30 per cent. The d-index value was 0.82 indicating that the model was able to simulate stover weight fair and well within the bounds of experimental uncertainty. Similar variability was also reported by Karthikeyan, (2002) and Bwalya *et al*. (2015)

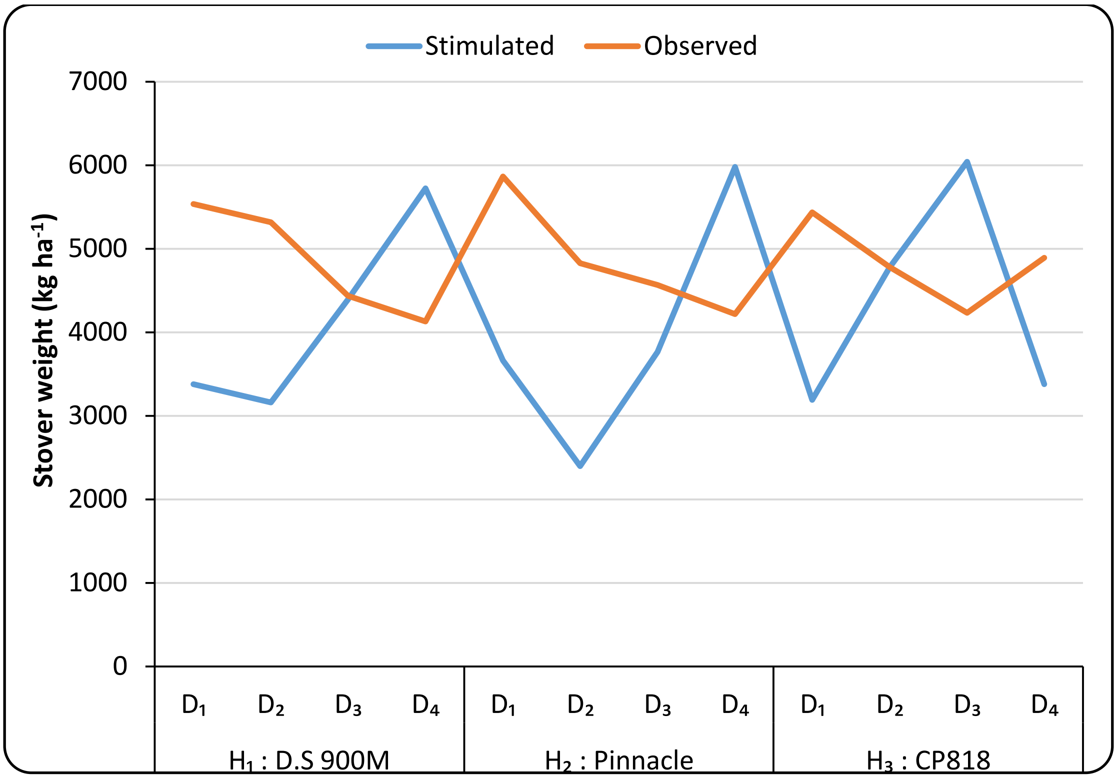
4.7.8 Harvest Index (%)

The comparison between observed and simulated harvest index (%) are presented in Table 4.23 and Fig. 4.22.

The results showed harvest index for observed results varied from 19 per cent (August I FN, D.S 900M) to 50.1 per cent (June II FN, Pinnacle) while the model simulated 27.7 per cent (August I FN, CP 818) to 41.6 per cent (June II FN, Pinnacle).

Table 4.22. Comparison of simulated and observed stover weight (kg ha^{-1}) in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	3376	5535.7	39.01
D_2 : July I FN	3158	5317.9	40.62
D_3 : July II FN	4392	4433.8	0.94
D_4 : August I FN	5723	4129.7	-38.58
Pinnacle (H_2)			
D_1 : June II FN	3662	5863.3	37.54
D_2 : July I FN	2398	4825.2	50.30
D_3 : July II FN	3766	4564.4	17.49
D_4 : August I FN	5981	4216.6	-41.84
CP818 (H_3)			
D_1 : June II FN	3189	5433.8	41.31
D_2 : July I FN	4775	4781.7	0.14
D_3 : July II FN	6041	4231.1	-42.78
D_4 : August I FN	3376	4889.733	39.01
Average	**4153.08**	**4851.8**	
Sd±	**1221.5**	**573.8**	
Test parameter			
MBE	172.5		
MAE	1573.5		
RMSE	1767		
NRMSE	36		
d-stat	0.82		



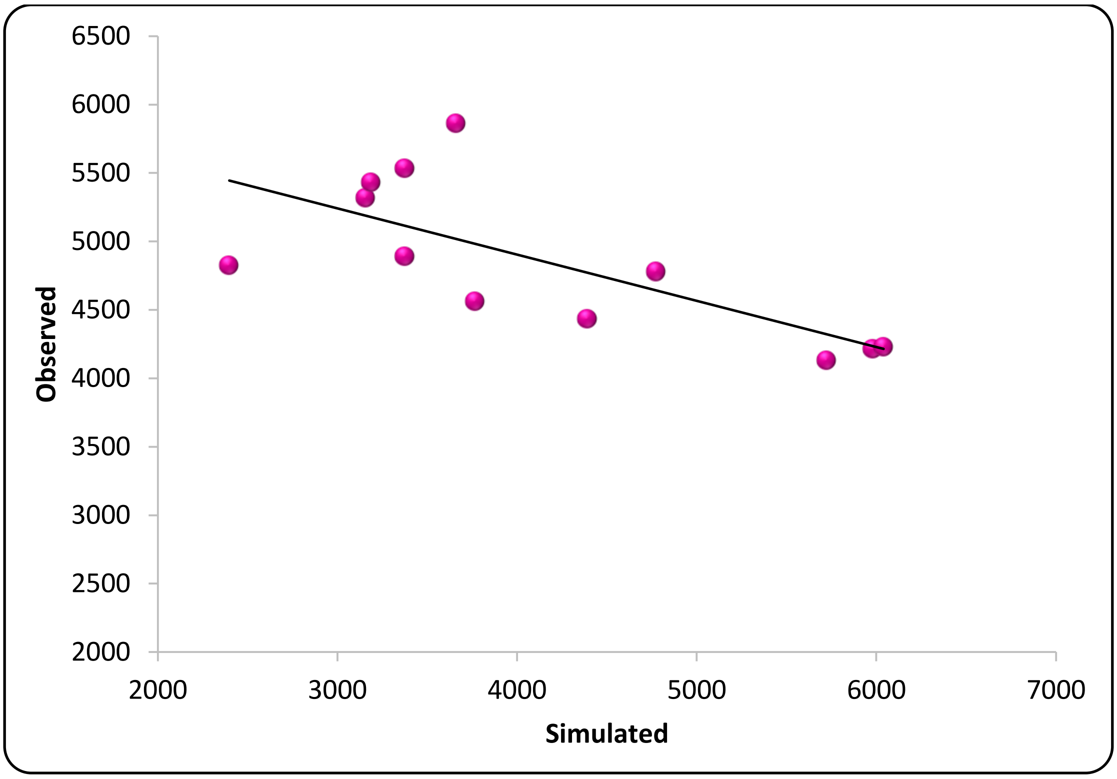
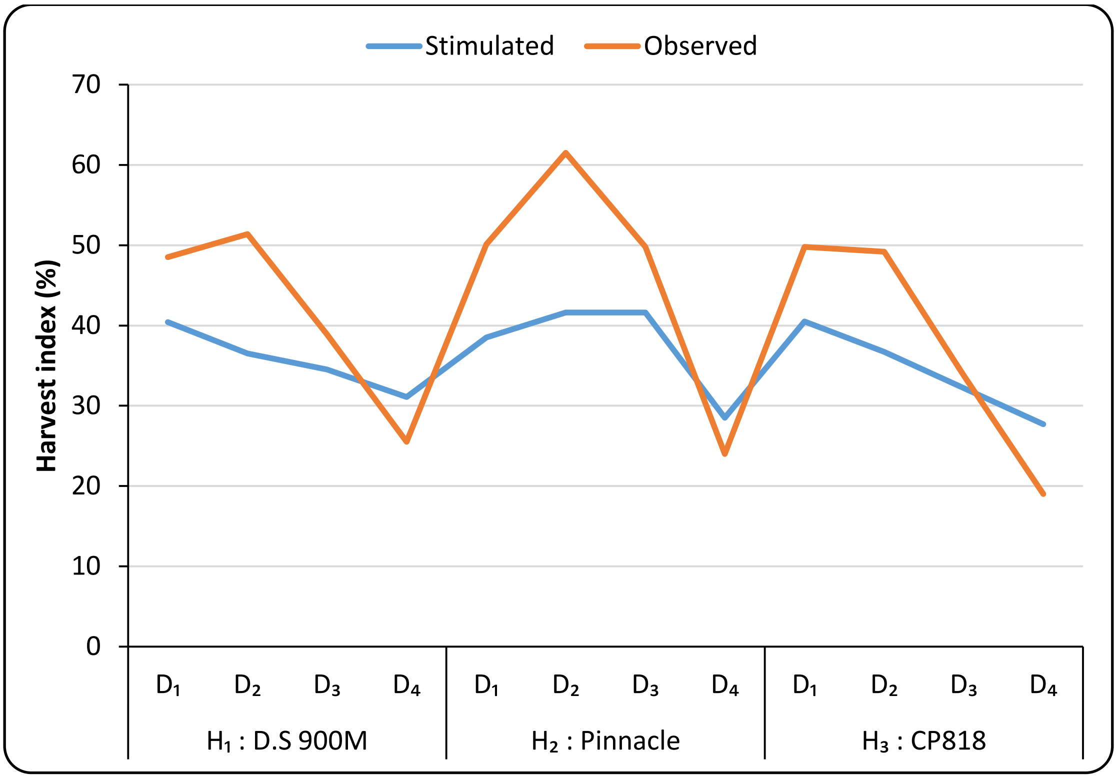


Fig. 4.21. Simulated vs observed stover weight (kg ha^{-1}) of maize hybrids at different dates of sowing

Table 4.23. Comparison of simulated and observed harvest index (%) in maize

Treatment	Simulated	Observed	Error (%)
D.S 900M (H_1)			
D_1 : June II FN	40.4	48.5	-20.05
D_2 : July I FN	36.5	51.4	-40.82
D_3 : July II FN	34.5	38.9	-12.75
D_4 : August I FN	31.1	25.5	18.01
Pinnacle (H_2)			
D_1 : June II FN	38.5	50.1	-30.13
D_2 : July I FN	41.6	61.5	-47.84
D_3 : July II FN	41.6	49.8	-19.71
D_4 : August I FN	28.5	24	15.79
CP818 (H_3)			
D_1 : June II FN	40.5	49.8	-22.96
D_2 : July I FN	36.7	49.2	-34.06
D_3 : July II FN	32.2	33.8	-4.97
D_4 : August I FN	27.7	19	31.41
Average	**35.81**	**41.8**	
Sd±	**4.99**	**13.3**	
Test parameter			
MBE	-5.97		
MAE	9.1		
RMSE	10.31		
NRMSE	28.8		
d-stat	0.92		



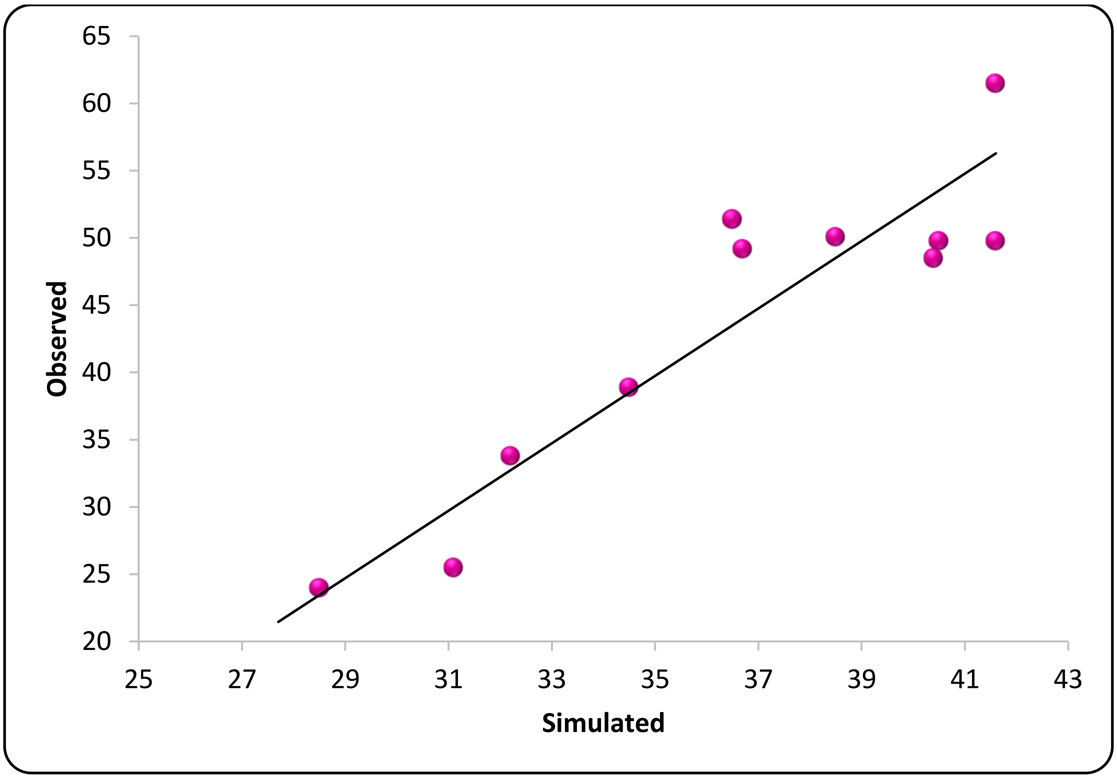


Fig. 4.22. Simulated vs observed harvest index (%) of maize hybrids at different dates of sowing

The error percent between simulated and observed ranged from -47.8 per cent (July I FN, Pinnacle) to 31.41 per cent (August I FN, CP818). Evaluation of the model showed that observed mean harvest index was 41.8 ± 13.3 during the crop season while the simulated mean harvest index was 35.81 ± 4.99. The MAE computed was found 9.1 and the RMSE was 10.31 which shows reasonably good agreement with the observed values.

During the crop growth season simulation can be considered poor with NRMSE values being more than 30 per cent. The d-index value was 0.92 indicating that the model was able to simulate harvest index fair and well within the bounds of experimental uncertainty. As the model under estimated stover weight, harvest index was also underestimated. Similar variability was also reported by Karthikeyan, (2002) and Bwalya *et al*. (2015).

Chapter ~ V

Summary & Conclusions

Chapter – V

SUMMARY AND CONCLUSIONS

Maize is the third most important cereal crop species in the world after wheat and rice. It is grown across a wide range of climates, but mainly in the warmer temperate regions and humid subtropics.

Temperature increases can impact crop production in a number of ways, but arguably the most important of these is the impact of temperature on crop phenology. Plant phenology is one of the major factors determining yield of crop. Temperature and photoperiod are the two important environmental factors affecting phenological development. The phenology of the plant varies with the cultivar, planting dates and growing conditions. The influence of temperature on phenology and yield of crops are expressed under the accumulated heat units system. Hence the knowledge on the calculation of the heat units i.e., Growing degree days (GDD), Heliothermal units (HTU), Photothermal units (PTU) and heat use efficiency (HUE) are the basic principles to understand the phenology and follow proper planting dates for different genotypes over temporal and spatial separations. Sowing time is probably the most important for crop production because of the differences in weather at sowing time between the season and also among the hybrid.

Crop modeling is the science and art of mimicking the growth and development of the crop. Differences in model prediction of crop developmental phases can have significant impacts on the accuracy of the effects of forecast climate change on crop productivity.

The experiment was conducted at Tirupati located at 13.65° N and 79.42° E, which is situates in southern agro climatic region of Andhra Pradesh. The experiment was conducted during *kharif* season of 2016 in a

Split Plot design with three replications. In this experiment, treatments included three hybrids (D.S 900M, Pinnacle and CP818) of maize and four dates of sowing (June II FN, July I FN, July II FN and August I FN).

"Phenological responses of maize (*Zea mays* L.) to photoperiod and temperature" was conducted to study the influence of photoperiod and temperature on growth attributes and yield of maize.

The weather data, photoperiod and temperature interactions, sunshine hours and morphological attributes of hybrids at different crop growth stages and yield attributes of maize as influenced by dates of sowing were collected, computed and presented. Correlation of photothermal units on various phonological growth stages and validation of CERES-Maize model for Southern Agro Climatic Zone was done.

During the period of study from the time of sowing to physiological maturity, the mean maximum and minimum temperature for the hybrids ranged from 34.4 to 33.7^{o}C and 25.6 to 23.1^{o}C respectively across the dates of sowing. The RH I and RH II ranged from 76.4 to 72 per cent and 50.1 to 45.4 per cent respectively. Sunshine hours of maize hybrids ranged from 9.4 hours to 3 hours and day length period of maize hybrids ranged from 11.94 to 12.25 across the four dates of sowing. Hybrids of maize recorded highest day length of 12.55 hours from sowing to emergence in D_1 (June II FN) and least day length of 11.34 hours from sowing to emergence in D_4 (August I FN).

The GDD accumulation was higher in case of Pinnacle (3053.3°C) followed by D.S 900M (3049.1°C) and CP818 (2994.1°C) from sowing to physiological maturity. The shifting of sowing dates corresponds to fluctuations in temperatures either lengthing or shortening of the growing periods. Among the dates of sowing D_1 (June II FN) recorded highest GDD (3170.4^{o}C) followed by D_2 and D_3 (July II FN) recorded lowest GDD (2920°C) from emergence to physiological maturity.

The PTU was higher in case of Pinnacle (36151.1°C day hour) followed by D.S 900M (36101.3°C day hour) and CP818 (35457.2°C day hour) from sowing to physiological maturity. Among the dates of sowing D_1 (June II FN) recorded highest PTU (38837.4°C day hour) followed by D_2 and D_3. At vegetative stages of crop growth their was no much variation among the hybrids and varied across the dates of sowing. The variation was observed from tasseling to maturity stages. The HTU was higher in case of Pinnacle (17098°C day hour). Among the dates of sowing D_1 (June II FN) recorded highest HTU (20288 °C day hour) and D_4 (August I FN) recorded lowest HTU (14163.4 °C day hour) from emergence to physiological maturity.

The HUE which is indicator of yield potential of a cultivar was higher in case of Pinnacle and CP818 was 1 kg ha^{-1} °C day^{-1}. Among the dates of sowing D_1 (June II FN) recorded highest HUE (1.2 kg ha^{-1} °C day^{-1}) and the lowest by D_4 (August I FN, 0.6 kg ha^{-1} °C day^{-1}). Higher HUE represents that plant utilized the heat more efficiently by increasing biological activity and higher grain yield.

The plant height, Leaf area, LAI were highest for Pinnacle and June I sowing (D_1). Variabilty in plant height of tested maize hybrids at different dates of sowing is attributed to variability in crop requirement of temperature and photoperiod *viz.*, Growing degree days (GDD), Photothermal Units (PTU) and Heliothermal units (HTU) especially at grand growth phase stage of maize.

Among the hybrids higher leaf (15.6 g $plant^{-1}$), stem (78.9 g $plant^{-1}$), tassel (2.6 g $plant^{-1}$) and cob weight (177 g $plant^{-1}$) was observed in D.S 900M on par with Pinnacle and CP818. GDD at grain filling stage influenced higher dry matter partitioning. Among the dates of sowing significantly higher leaf (21.6 g $plant^{-1}$), stem (95.9 g $plant^{-1}$), tassel (3.2 g $plant^{-1}$) and cob weight (192 g $plant^{-1}$) was observed in D_1 (June II FN) followed by D_2, D_3 and D_4. Delay in sowing is directly influenced by both temperature and daylength.

Among the hybrids the yield components such as number of cobs m^{-2}, number of rows per cob, number of seeds per row, hundred grain weight, cob length was highest for Pinnacle followed by D.S 900M and CP818. Among the dates of sowing all the yield components were higher in case of D1 followed by D_2, D_3 and D_4. In early sowing (June II FN) yield components were highest due to accumulated GDD, PTU and HTU especially at soft dough stage compared to other delayed sowings. It denotes that temperature, daylength and sunshine hours prevailing at grain filling stage is important.

Among the hybrids Pinnacle recorded numerically higher yield (3006.58 kg ha^{-1}) than D.S 900 M (2748 kg ha^{-1}) but was significantly higher than CP818 (2678.4 kg $ha^{-`1}$). Due to increased heat use efficiency in case of Pinnacle total kernel yield increased since the grain yield is linearly related to heat use efficiency.

Among the dates of sowing D_1 (June II FN) recorded significantly higher yield (3684.36 kg ha^{-1}) than D_2 (3207.72 kg ha^{-1}), D_3 (2628 kg ha^{-1}) and D_4 (1724.26 kg ha^{-1}). The higher yields attributed to the favorable agro-climatic conditions particularly temperature, day length and sunshine hours interms of higher accumulated GDD, PTU and HTU from sowing to physiological maturity compared to other dates of sowing. The early planting dates resulted in higher yields compared to delay in sowing dates because of high heat use efficiency of 1.2 kg ha^{-1} °C day^{-1} compared to other sowings.

LAI showed positive correlation with yield at six leaf stage (R^2 =0.682), Tasseling stage (R^2=0.794), Silking stage (R^2=0.741), Soft dough stage (R^2=0.777), hard dough stage (R^2=0.695) and physiological maturity (R^2=0.840). It denotes that the LAI plays important in increasing final yield in maize.

Dry matter showed positive correlation with yield at six leaf stage (R^2 =0.758), Tasseling stage (R^2=0.823), Silking stage (R^2=0.858), Soft dough stage (R^2=0.825), hard dough stage (R^2=0.861) and physiological maturity (R^2=0.86). It denotes the drymatter plays important role in final yield in maize.

Similar to yield components Pinnacle recorded significantly higher stover weight and harvest index compared to D.S 900 M and CP818. Among the dates of sowing D_1 (June II FN) also recorded significantly higher stover weight and harvest index compared to all other dates of sowing. D4 (first fortnight of August) D.S 900M recorded lower stover weight and harvest index. due to higher accumulation of GDD, PTU and HTU.

At physiological maturity the nitrogen content in grain of D.S 900M and Pinnacle recorded highest Nitrogen content (1.39 3 g plant^{-1}) followed by CP818 (1.3 g plant^{-1}). Among the dates of sowing D_1 (June II fortnight) recorded significantly higher nitrogen content in leaf and stem (0.64 g plant^{-1}) among all growth stages of crop growth followed by D_2, D_3 and D_4 recorded significantly nitrogen content in leaf and stem (0.34 g plant^{-1}).

Using the data obtained from the field experiments conducted during *kharif*, 2016. The experimental file (AGCG1601MZ), weather file (ACGC2016), soil file (ACGC060016) were created for CERES-Maize validation The crop genetic coefficients already developed for the three hybrids were also used as input for CERES-Maize validation. The model validated excellently for grain yield, Number of days to anthesis and physiological maturity, Number of grains per m^{-2} were as it was fair for unit grain weight at maturity and poor for stover weight and harvest index.

CONCLUSION

- Pinnacle proved to be superior and better adapted to southern Agro Climatic conditions compared to D.S 900M and CP818.
- Sowing of maize hybrids in June II FN is appropriate interms higher physiological maturity efficiency and yield in this zone.
- Buildup of GDD, HTU and PTU are good estimators to study maize phenology and can be used as a reliable tool to optimize the sowing period for different maize cultivars.
- Estimation of heat use efficiency is also useful for the appraisal of yield potential of maize in different dates of sowing.
- CERES Maize model v.4.5 can be used to forecast maize phenology and yield in Southern agro-climatic conditions.

FUTURE PROSPECTIVE

- The experiment with same objectives need to be conducted at different seasons and different locations.
- Genetic Coefficients for different genotypes needs to be arrived from this location for better prediction.
- CERES v.4.6 version can be used for better validation of model for this region.

Literature Cited

LITERATURE CITED

Ahmadh, I., Shehzad, M.A.B., Muhamadh, A., Muhamadh, A., Allahwasya and Hussain, S.Z. 2016. Agrometeorological, phenological and yield response of spring maize as influenced by foliar application of different plant growth regulators under suboptimal temperature of Faisalabad, Pakistan. *Journal of Agrometeorology*. 18(2): 315-319.

Amgain, L.P. 2011. Accumulated heat unit and phenology of diverse maize varieties as effected by planting dates under Rampur conditions, Nepal. *Agronomy Journal of Nepal.* 2: 201-205.

Amjadian, M., Farshadfar, M and Gholipoor, M. 2013. The effect of planting date on yield and yield components of corn (*Zea mays* L.) cultivar, single cross 704, Gorgan region. *Annals of Biological Research*. 4(4): 38-41.

Andrade, F.H., Vega, C., Uhart, S., Carilo, A., Cantarero, M and Valentinuz, O. 1999. Kernel number determination in maize. *Crop Science*. 39(2): 453-459.

Arif, M., Ihsanullah, S., Khan, F., Ghani and Yousafzai, H.K. 2001. Responses of maize varieties to different planting methods. *Sarhad Journal of Agricultural Sciences*. 17: 159-163.

Azadbakth, A., Azadbakth, G.G., Nasrollahi, H. Bitarafan, Z. 2012. Evaluation of different planting dates on three maize hybrids in koohdasht region of Iran. *International Journal of Science and Advanced Technology*. 2(3): 34-38.

Badu-Apraku, B., Hunter, R.B and Tollenar, M. 1983. Effect of temperature during grain filling on whole plant and grain yield of maize (*Zea mays* L.). *Canadian Journal of Plant Sciences.* 63: 357-363.

Baktash, F.Y. 1985. Regression of corn grain yield on air temperature and relative humidity in Iraq. *Journal of Agriculture and Water Resources*. 4(3): 1-10.

Baur, P.J and Carter, P.R. 1996. Effect of seeding date, plant density, moisture availability, soil nitrogen fertility on maize kernel breaking susceptibility. *Crop Science.* 26(6): 1220-1226.

Berzsenyi, Z and Lap. D.Q. 2001. Effect of sowing time and N fertilization on yield stability of maize (Zea mays. L) hybrids between 1991-2001. *Acta Agronomica Hungarica*. 50: 309-331.

Bhushal, T.N and Jagdish, T. 2016. Effect of weather years and climatic parameters on yield of maize varieties. *Nepal Journal of Science and Technology*.11: 17-24.

Bierhuizen, J.F. 1973. The effect of temperature on plant growth, development and yield. (In) Plant responses to Climatic factors. Proc. Uppal Symposium (Paris): 89-98.

Bihnoi, O.P., Singh, S and Niwas, R. 1995. Effect of temperature on phenological development of wheat (*Triticum aestivum* L.) crop in different row orientations. *Indian Journal of Agricultural Sciences*. 65: 21-214.

Birch, C.J., Hammes, G.L and Rickert, K.G. 1998. Temperature and photoperiod sensitivity development in fine cultivars of maize from emergence to tassel initiation. *Field Crops Research*. 55(1-2): 93-107.

Biscoe, P.U and Gallagher, J.N. 1978. Physiological analysis of cereals yield, Production of drymatter. *Agricultural Progress*. 53: 34-50.

Bonhomme, R. 2000. Beware of comparing RUE values calculated from PAR Vs. Solar radiation or absorbed *Vs.*, intercepted radiation. *Field Crops Research*. 68: 247- 252.

Brower, R., Jenneskens, P.J and Borggreve. 1970. Growth responses of shoots and roots to interruptions of irrigation supply. Jaarb. IBS: 29-36.

Bwalya, C.C., Elijah, P., Shepande, C and Sichingabala. H. 2015. Evaluating CERES-maize model using planting dates and nitrogen fertilizers in Zombia. *Journal of Agricultural Science*. 7(3).

CIMMYT Unpublished data, 1975.

Dahiya, D.S and Narwal, S.S. 1989. Effect of sowing dates on phenology and growing degree day requirement of winter maize (*Zea mays* L.). *Indian journal of Agricultural Science.* 59(9): 589-592.

Dahmardeh and Dahmardeh, M. 2010. The effect of sowing date and some growth physiological index on grain yield in three maize hybrids in South Eastern Iran. *Asian Journal of Plant Sciences*. 9(7): 432-436.

Daynard, T.B. 1972. Relationships among the black layer formation, grain moisture percentage and heat unit accumulation in corn. *Agronomy Journal*. 64: 716-719.

Deepak, P and Mathauda, S.S. 2004. Validation of CERES-Maize Model Under Different Planting Dates and Moisture Regimes. *Journal of Agricultural Physics.1: 28-34.*

Dewitt, C.I. 1965. Photosynthesis of leaf Canopies. *Agricultural Research reports*. Pudoc, Wageningen, The Netherlands. 663-664

Doraiswamy, P.C and Thomson, D.R. 1982. A crop moisture stress index for large areas and its application in the product of spring wheat phenology. *Agricultural meteorology*. 27: 1-15.

Duchney, S. 2000. Derivation of the parameters of the WAVE model using a deterministic and a stochastic approach. *Ph.D Thesis* 434, Faculty of Agriculture and Applied Biological Science. K.U.L euven, Belgium. 123.

Elemo, K.A. 1991. Maize (*Zea mays. L*) Agronomy Research in Nigerian Savanna paper presented in table 1991 workshop of Nationally Coordinated Research programme launching Maize association of Nigeria (MAAN) at IITA, Ibadan

Endres, V.C and Mudstock, C.H. 1989. Leaf area development and duration of grain filling period of three maize hybrids with two sowing dates. *Pesajuisia- Agrope Cuaria- Brasileira*. 455-459.

Girijesh, G.K., A.S. Kumaraswamy, A.S., Sreedhar, Dinesh kumar, S.M., Vageesh, T.S and Rajashekarappa, K.S. 2011. Heat unit utilization of kharif maize in transitional zone of Karnataka. Journal of *Agrometeorology*. 13(1): 43-45.

Gouri, V., Bapuji, T., Chitkaladevi, T., Kumari, M.B.G.S and Ankaiah, R. 2013. Thermal requirement of rabi maize in North Coastal zone of Andhrapradesh. *Journal of Agrometeorology*. 15(2): 167-169.

Govinda Rao, P. 1994. Recent Climatic Changes over India Climate Monitor. 23: 38-52

Gowda, T.P., Halikatti, S.I. and Manjunatha, S.B. 2013. Thermal requirement of maize (*Zea mays* L.) as influenced by planting dates and cropping systems. *Research Journal of Agricultural Sciences*. 4(2): 207-210.

Grezesaik, W. 2008. Cultivated plant fertilization [Nawo_enie ro_lin uprawnych]. PWRiL Pozna [in Polish].

Gungula, D.T., Kling, J.G and Togum, A.O. 2003. CERES-Maize predictions of maize phenology under nitrogen stressed conditions in Nigeria. *Agronomy Journal*. 95: 892-899.

Hariram, Gurjot, S., Mavi, G.S and Sohu, V.S. 2012. Accumulated heat unit requirement and yield of irrigated wheat (*Triticum aestivum* L.) varieties under different crop growing environment incentral Punjab. *Journal of Agrometeorology*. 14(2): 147-153.

Hatfield, J.L. 1977. Light Response in Maize: A Review. *World Meteorological Organisation, Agrometeorology of Maize WMO-No 481*. Chapter 5: 199-206.

Hayatkhan, Z., Khan, K., Nigar, S., Khalil, I.H., Ikramul, H., Ahmad, I., Asad, A and Yasir, K.M. 2009. Phenology and yield of sweet corn landraces influenced by planting dates. *Sarhad Journal of Agricultural sciences*. 25: 2.

Hesketh, J. D., Chase, S. S. and Nanda, D. K., 1969. Environmental and genetic modification of leaf number in maize, sorghum and Hungarian millet. *Crop Science.* 9: 460-467.

Hipps, L.E., Asrar, G and Kanemasu, E.T. 1983. Assessing the interception of photosynthetically active radiation in winter wheat. *Agriculture Meteorology*. 28: 253-259.

Hodges, T., Botner, D., Sakamoto, C and Hays Haug, J. 1987. Using the CERES-Maize model to estimate production for the U.S Corn belt. *Agriculture and Forest Meteorology*. 40: 293-303.

Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Boote, K.J. and Hunt, L.A. (2010). Maize Cultivar Specific Parameters for Decision Support System for Agrotechnology Transfer (DSSAT) Application in Tanzania. *American Journal of Plant Sciences*, Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5, Honolulu, University of Hawai, CD ROM.

Hossein, M.H and Masoud, M. Effect of the plant density and sowing date on kernel yield in early maturing maize. 2014. *International journal of plant, animal and environmental sciences.* 4- 4.

Huda, A.K.S., Ghildayal, B.P and Tomar, V.S. 1976. Contribution of climatic variables in predictiong maize yields under monsoon conditions. *Agricultural Metereology*.17: 33-47.

Hunter, R.B., Hunt, L.A and Kanneberg, L.W. 1974. Photoperiod and temperature effects on corn. *Canadian Journal of Plant Sciences*. 54: 71-78.

Hunter, R.B., Tollenar, M and Breuer, C.M. 1997. Effects of photoperiod and temperature on vegetative and reproductive growth stages of a maize (*Zea mays L*.) hybrid. *Canadian Journal of Plant Sciences*. 57(4): 1127- 1133.

Hussain, M., Shabir, G., Farooq, M., Jabran, K and Farooq, S. 2012. Developmental and phenological responses of wheat to sowing dates. *Pakistan Journal of Agricultural Science*. 49(4): 459-468.

IPCC. 2007. *Contribution of working Groups I, II and III to the Fourth Assesment Report of the Introgovernmental Panel on climate change*. Geneva. 104.

Jackson, H.L. 1973. *Soil Chemical Analysis*. Prentice Hall of Inco, New York, USA. 498.

Jain. 1973. New Agronomy boosts in maize yield. *Indian Fmg*. 23(1): 17-20.

Jaswemi, M., Darabi, F., Naseri, R., Naserirad, H and Bazdar, S. 2013. Effect of planting date and nitrogen fertilizer application on grain yield and yield components in Maize (SC704). *American-Eurasian Journal of Agricultural and Environmental sciences.* 13(7): 914-918.

Jones, C.A., and Kiniry, J.R. 1986: A simulation model of maize growth and development. *Texas A and M universities,* Press, College Station.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., Ritchie, J.T. 2003. DSSAT Cropping System Model. *European Journal of Agronomy*. 18: 235-265.

Kosgasago, H. 2006. Effect of planting dates and densities on yield and yield components of short and ultra growth period of maize. *Ph. D Thesis*. University of Pretoria. 57-59.

Kumar, M and Singh, M. 1999. Effect of nitrogen and phosphorous levels of yield and nutrient uptake in maize (*Zea mays L*.) under rainfed condition of Nagaland. *Crop Research*. 25(1): 46-49.

Leela, P.R, Sreenivas, G and Reddy, R.D. 2014. Application of CSM-CERES-Maize model to define a sowing window and nitrogen rates for rainfed maize in semi-arid environment. *International Journal of Bio resource and Stress Management*. 5(2): 181-185.

Leong, S.K and Ong, C.K. 1983. The influence of temperature and soil water deficit on the development and morphology of groundnut (*Arachis hypogea*). *Journal of Experimental Botany*. 34: 1551-1561.

Madhavi, K. 2007. Nutrient management for maize groundnut cropping systems under normal and late sown conditions. *Ph.D. Thesis*, ANGRAU, Hyderabad.

Majumder, D., Kingra, P.K and Kukal, S.S. 2016. Canopy temperature and heat use efficiency of spring maize under modified soil microenvironment. *Annual J ournal of gricultural Research*. 37(3): 225-235.

Martin, M and Williams II. 2008. Sweet corn growth and yield responses to planting dates of the north central united states. *Horticultural science*. 43(6): 1775-1779

Matrorilli, M., Katerji, N., Ben Nouna, B. 2003. Using the CERES –Maize model in semi arid Mediterranean environment. Validation of three revised versions. *European Journal of Agronomy*. 19: 125-134.

Muchow, R.C. 1989. Comparative productivity of maize, sorghum and pearmillet in a semi arid tropical environment. 1: Yield potential. *Field Crops Research*. 20(3): 191-205.

Murthy, K.K., Bommegowda, A., Jagannath, M.K., Enugopal, N., Ramachandra Prasadh, T.V., Jayaram, G., Raghunath, G and Rajasekhar, B.G. 1973. Investigations on the structure of yield in cereals –maize and sorghum. *Paper presented at the ICAR Annual Workshop on maize research.* G.B. Pant University of Agriculture and Technology, Patnagar.

Nafnizer, E.D. 1994. Corn planting date and plant population. *Journal of production Agriculture*. 7: 62-69.

Nahar, K., Hasanuzzaman, M. and Majumder, R.R. 2010. Effect of low temperature stress in transplanted rice varieties mediated by different planting dates. Acadian Journal of Plant Science. 2(3): 132-138.

Namakka, A., Abubakar, I.U., Sadik, L.A., Sharifai, A.I and Hassas, A.H.2008. Effect of sowing date and nitrogenlevel on yield and yield components of two extra early maize varieties (Zea mays. L) in Sudan Savannah region of Nigeria. *Journal of Agricultural and Biological Science*. 3(2):1-5.

Narcico, G., Ragni, P and Venturi, A. 1992. Agrometeorological aspects of crops in Italy, Spainand Greece: A summary of duram wheat, barley, maize, rice, sugarbeet, sunflower, soybean, rapeseed, potato, tobacco, cotton, olive and grape. *Publication EUR14214 EN of the office publications of the European Communities*. Series of Agriculture Luxumberg.

Nielsen, R.L., Tomison, P.R., Brown, G.A., Holter, A.L., Wells, J. and Wuethrick, K. L. 2002. Delayed planting effects on flowering and grain maturation of dent corn. *Agronomy Journal.* 94 : 549-558.

Olsen, S.R., Cole, C.V., Waterable, F.S and Dean, L.A. 1954. Estimation of [hosphorous in soils by extraction with sodium bicarbonate. United States Department of Agriculture.939.

Pandey, I.B., Pandey, R.K., Dwivedi, D.K and Singh. R.S. 2010. Phenology, heat unit requirement and yield of wheat (*Triticum aestivum)* varieties under different crop growing environment. *Indian Journal of Agricultural Sciences*. 80: 136-140.

Pathak, A.N and Tiwari, K.N. 1972. Chemical composition and nutrient uptake of maize in relation to nitrogen and sowing dates. *Indian Journal of Agricultural Research*. 6(2): 147-150.

Piper, C.S. 1996. *Soil and Plant Analysis*. Academic press, New York. 368.

Rahman, M.M. Hampton, J.G and Hill, M.J. 2006. Soyabean seed yield as effected by sowing in a cool environment. *Journal of New Seeds*. 7: 1-5.

Rajesh, K., Deshmukh, R., Verma, N and Kaushik, D. 2015. Phenological growth and yield of wheat in relation to agrometeorological indices under different sowing dates. *Plant Archives*. 15: 81-87.

Rajput, R.P. 1980. Response of soyabean crop to climate and soil environment *Ph. D thesis.* Indian Agricultural Research Institute, Pusa, New Delhi.

Ramawat, N., Sharma, H.L and Kumar, R. 2012. Simulation, Validation and application of CERES-Maize model yield maximization of maize in north western Himalayas. *Applied Ecology and Environmental Research*. 10(3): 303-318.

Rao, A.S., Singh, N.L., Joshi and Ramakrishna, Y.S. 2000. Evapo-transpiration, water and radiation utilization of clusterbean (*Cyampsis tetragonoloba*). *Indian Journal of Agricultural Sciences*. 70 (1): 149-153.

Rao, K.L and Padmaja, M. 1994. Nitrogen requirement of maize (Zea mays) types. *Journal of Research.* APAU. 22: 151.

Reynolds, M.P and White, J.W. 2002. A physiological perspective on modeling temperature response in wheat and maize crops. In : White, J.W (ed) modeling temperature response in wheat and maize proceedings of a workshop CIMMYT, EL Batan, Mexico.2001 CIMMYT, Mexico city. 17-18.

Ritchie, J.T and Godwin, D.C. 1989. Description of soil water balance. In: Virmani, S.M., Tandon, H.L.S., Alagarswamy, G. (Eds.) – *Modeling the growth and development of sorghum and pearlmillet.* ICRISAT, Research bulletin 12. Andhra Pradesh, India. 14-16.

Ritchie, J.T. 1998. Soil water balance and plant water stress. In: Tsuji, G.Y., Hoogenboom, G., Thornton, P.K. (Eds.) – Understanding options for Agricultural Production. Kluver Academic Publishers, Dordrect, The Netherlands. 41-58.

Roman Paoli, E., Welsh, S.M and Vanderlip, R.L. (2000). Comparing genetic coefficients estimation methods using the CERES–Maize model. *Agricultural systems. 65: 1*28-152.

Rouanet, G. 1987. *The Tropical Agriculturalist-Maize*. Macmillan Press Ltd London and Basingstoke. Chapter 1: 1-14.

Shekh, A.M and Rao, B.B. 1996. Crop growth modeling possibilities and limitation: An Indian perspective. In *Climate Variability and Agriculture,* Eds. Abrol, Y.B., Gadgil, S., and Pant, G.B., Narosa Publishing house, New Delhi. 356-374.

Shrestha, U., Amgain, L.P., Bahadur, T.K., Dahal, K.R and Shrestha, J. 2016. Effect of sowing dates and maize cultivars in growth and yield of maize along with their Agro-climatic indices in Nawalprarasi.*Nepal Journal of Agricultural Research*. 3(1): 57-62.

Sikdar, S. 2009. Accumulated heat unit and phenology of wheat cultivars as influenced by late sowing heat stress conditions. *Journal of Agricultural Rural Development*. 7: 57-64.

Singh, A.K., Balasuramaniyan, K.K., Baxla, R., Tripathi, A.K and Mishra, P.N. 2010. Validation of CERES-Maize model growth, yield attributes and yield of kharif maize for NPEZ of eastern U. P. *Journal of Agrometeorology.* 12(1): 118-120.

Snedcor, G.W and Cochron, W.G. 1967. Statistical Methods oxford and IBH Publishing company, Parklane, Calcutta, 172-177.

Sprague, G.F and Dudley, J.W. 1998. *Corn and Corn Improvement*. 3rd Edition. American Society of Agronomy, Inc. Madison, U.S. 578-638.

Srinivasulu, A., Karuna, G.S., Chandrika, V and Reddy, D.S. 2008. Performence of maize genotypes under varied time of sowing under rainfed conditions in southern agroclimatic zone of Andhra Pradesh. *Agricultural Science Digest*. 28 (3): 233-234.

Stewart, D.W., Dwyer, L.M. and Carrigan, L.M. 1998. Phenological temperature response of maize. *Agronomy Journal*. 90 : 73-79.

Subbaiah, B.V and Asija, G.L. 1956. A rapid procedure of estimation of available nitrogen in soils. *Current Science*. 65(7): 477-480.

Sulochana, Solanki, N.S., Dhewa, J.S and Bajia, R. 2015. Effect of sowing dates on growth, phenology and agrometeorological indices for maize varities. *An International Quarternaly Journal of Life sciences.* 10 (3): 1339-1343

Thavapraash, N., Jagannath, R., Velayudham, K and Guruswamy, L. 2007. Seasonal influence on phenology and accumulated heat units in relation to yield of baby corn. *International Journal of Agricultural Research*. 2(9): 826-831.

Thomison, P. 2010.Has cool weather hurt corn yield? In: C.O.R.N Newsletter. The Ohio State University.

Tojosoler, C.M, Paulo, C.S and Hoogenboom. 2000. Application of the CSM-CERES-Maize model for planting date evaluation and yield forecasting for maize grown off-season in a subtropical environment. *European Journal of Agronomy*. 27: 165-177.

Tollennaar, M and Hunter, R.B. 1983. A photoperiod and temperature sensitive period for leaf number of maize. *Journal of crop science*. 23(3): 457- 460.

Tollennaar, M. 1989. Genetic improvement in grain yield of commercial hybrids grown in Ontario from 1959-1988. Crop Science. 29: 1365-1371.

Tripathi, S.M and Shrivastava, R.S. 2004. Effect of variety, sowing time and integrated nutrient management on growth yield attributes and yield of summer maize (*Zea mays* L.). *Annals of Agriculture*. 25(1): 155-158.

Walkley, A and Black, C.A. 1934. Estimation of organic carbon by chromic acid titration method. *Soil Science*. 37: 29-38.

Wallace, H.A and Bressman, E.N. Corn and Corn Growing. John Wiley and sons, Newyork.

Waong, M., Laux, P and Kunstmann, H. 2015. Adaptations to climate change: The impacts of optimized planting dates on attainable maize yields under rainfed conditions. *Agriculture and Forest meteorology*. 205:23-39.

Warrington, I.J and Kanemasu, E.T. 1983. Corn growth response to temperature and photoperiod, I seedling emergence, tassel initation and anthesis. *Agronomy Journal.* 75: 749-754.

Watson, D.J. 1952. The physiological basis of variation in yield. *Advances in Agronomy*. 6: 103-109.

Williams, M.M and Lindqiut, J.L. 2007. Influence of planting date and weed interference on sweet corn growth and development. *Agronomy Jurnal*. 99: 1066-1072.

Williams, M.M. 2008. Sweet corn growth and yield response to planting dates of the North Central United states. *Hort Science*. 43(6): 1775-1779.

Willmott, C.J., Ackleson, S.G., Feddema, J.J., Klink, K.K., Legates, J. and Rowe, C.M. 1985. Statistics for evaluation and comparison of models. *Journal of Geophysical Research of Oceans*. 90: 8995-9005.

Wilson, D. R., Muchow, R. C. and Murgatroyd, C. J. 1995. Model analysis temperature and solar radiation limitation to maize potential productivity in a cool climate. *Field Crops Research.* 43 : 1-18.

www.Indiastat.com. 2014

www.timeanddate.com.

Yusafzai, H.K. Arif, R. Ahmad, R, Khan, N. 2002. Effect of sowing dates on maize cultivars. *National Agricultural Research Centre*.

Zaker, S., Aminpanah, H, Homayoon, D. 2014. Effect of planting date and nitrogen rate on yield and quality of forage corn. *Agriculture and Forestry*. 60(2): 193-206.

Zheng G., Liangzhi Goa and Ximei Xue. 2005. Study on the simulation model for maize phenology.

Bhushal, T.N and Jagdish, T. 2016. Effect of weather years and climatic parameters on yield of maize varieties. *Nepal Journal of Science and Technology*. 11: 17-24.

Jaliya, M.M., Falaki, A.M., Mahmud, M and Sani, M.Y. 2008. Effect of sowing date and NPK fertilizer rate on yield and yield components of quality protein maize (*Zea mays* L.). *Journal of Agricultural and Biological Science*. 3(2): 23-29.

Karthikeyan, R. 2002. Identification of potential season and sowing window for irrigated COH 3 hybrid maize (*Zea mays* L.) and validation of CERES maize model. Ph.D Thesis, Tamil Nadu Agricultural University, Coimbatore.

Muchow and Carberry, 1989. Comparative productivity of maize, sorghum and pearmillet in a semi-arid tropical environment. 1: Yield potential. *Field Crops Research*. 20(3): 191-205.

Hanway, J.J. 1962. Corn growth and composition in relation to soil fertility: I. Growth of different plant parts and relation between leaf weight and grain yield. *Agronomy Journal*. 54: 145-148.

Thakur, N., Kumar, R., Prakash, J., Sharma, J.K., Nageswar, S and Lata, S. 2000. Evaluation of elite maize genotype (*Zea mays* L.) for nutritional traits. *Electronic Journal of Plant Breeding*. 6(1): 350-354.