CROP GROWTH SIMULATION OF MAIZE USING DSSAT MODEL

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B. Tech. (Agril. Engg.)

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(IRRIGATION AND DRAINAGE ENGINEERING)

DEPARTMENT OF IRRIATION AND DRAINAGE ENGINEERING

COLLEGE OF AGRICULTURAL ENGINEERING & TECHNOLOGY

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2021

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BY

SANGALE BHAGWAN BHANUDAS

B. Tech. (Agril. Engg.)

A thesis submitted to
Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
(IRRIGATION AND DRAINAGE ENGINEERING)

DEPARTMENT OF IRRIATION AND DRAINAGE ENGINEERING
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2021

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled, "**CROP GROWTH SIMULATION OF MAIZE USING DSSAT MODEL**", submitted by me is based on the actual work carried out by me under the guidance and supervision of **Dr. UDAY MANOHARRAO KHODKE**. The extent of information derived from the existing literature have been duly cited and referenced. The existing research work or its any part is not submitted anywhere else for the award of any degree or diploma.

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ACKNOWKEDGEMENT

This thesis is the part of my journey in obtaining M. Tech in Irrigation and Drainage Engineering. This thesis has been kept on track and been seen through to completion with the support and encouragement of numerous people including my well-wishers, my family, friends, colleagues, and various institutions. At the end of our thesis, I would like to thank all those people who made this thesis possible and an unforgettable experience for us. It is a pleasant task to express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me.

I avail this opportunity to acknowledge my sincere with respectable regards and immense pleasure, I express my profound sense of gratitude and respect to my Chairman of advisory committee **Dr. U. M. Khodke**, honorable Associated Dean and Principal of college of Agricultural Engineering and Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani, for his inexplicable guidance, fervent support, timely help, fatherly affection, learned counsel, unstinted attention, arduous and meticulous guidance for the work at all stages. I owe a great to them for all the encouragements. His keen interest, patient hearing and constructive criticism have installed in me the spirit of confidence to successfully complete the task and his sympathetic behavior and co-operative nature during the course of present investigation would remain encouraging me forever in my life.

With endless pleasure, I wish to express my indebtedness and deep sense of gratitude to member of the advisory committee, **Dr. H. W. Awari** Associate Professor & Head, Department of Irrigation and Drainage Engineering, college of Agricultural Engineering and Technology for expert opinion and valuable suggestions during the project work and providing all necessary facilities for entire research work.

I am also thankful to the members of the advisory committee **Dr. V. K. Ingle**, Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, VNMKV, Parbhani, **Dr. K. K. Dakhore**, Assistant Professor, Meteorology Department, College of Agriculture, VNMKV, Parbhani for their expound guidance, meticulous care, suggestions and immeasurable guidance which were essential for strengthening the present research work.

I humbly express my wholehearted thanks to **Dr. S. B. Jadhav**, Assistant Professor, Department of Irrigation and Drainage Engineering, College of

Agricultural Engineering and Technology, VNMKV, Parbhani and **Dr. G. D. Gadade,** *Agronomist, AICRP on Irrigation Water Management VNMKV, Parbhani for his advice and moral support. I am specially thankful to* **Balaji Bobade Sir**, *Senior research assistant, Meteorology Department, whose valuable guidance during the project helps me to complete the research work.*

I am very thankful to **Mr. Chandan S. R.** *who helps me directly by providing his experimental data of maize research conducted during 2017-18 for this investigation.*

I will be failing in my duty if I don't acknowledge some of seniors, Mr. Ram More, Mr. Anil Harkal, Mr. Datta Giram, Miss. Ambika Phuphate & Mr. Jaydeep Shewale for their timely help and co-operation.

I wish to extend my gratitude towards my friends, Balaji Jawale, Ramkishan Jadhav, Chalapathi, Kokane Sanket, Krishna Lohkare, Ashutosh Kakade, Shriram Murtadak, Vijay Mane, and Shree Varpe for their support and help.

I am also blessed to have friend like Shubham, Ravi, Achyut, Vaibhav, Bharat & Somnath for their timely help and suggestions during this period.

I avail this opportunity to acknowledge all those who helped & guide me during the course of my research work. This journey would not have been possible without the support of my family. I fail to find suitable words to acknowledge the affection, encouragement and support that I received from family, my beloved father Mr. Bhanudas Tukaram Sangale, mother Mrs. Mandabai and dear brother Dhananjay for their deep love and care throughout my life journey.

I am grateful to all the authorities of university, all teaching and non- teaching staff and those lovely peoples who are part of my life but remain to mention here for their blessing, co-operation and affection from them.

I ever thank one and all including my all-family members and relatives who helped directly or indirectly, visibly and invisibly inspired me a lot.

PLACE : PARBHANI — ***Sangale Bhagwan Bhanudas***

DATE : 03/01/2022 — ***(Reg. No. 2019AE/08M)***

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ABBREVIATIONS USED

Abbreviation		Elaboration
%	:	Percent
/	:	Per
@	:	At the rate
^{0}C	:	Degree centigrade
Agril	:	Agriculture
AICRP	:	All India Co-ordinated Research Project
D	:	Mean deviation
DAS	:	Days after sowing
Dept.	:	Department
DIFF	:	difference
DSSAT	:	Decision Support System for Agrotechnology Transfer
E	:	East
EF	:	Modelling efficiency
Engg	:	Engineering
et al	:	All other
ET_c	:	Estimated reference crop evapotranspiration
ET_o	:	Reference crop evapotranspiration
etc	:	Excetra
Fig.	:	Figure
GM	:	Geometric Mean
ha	:	Hectare
HI	:	Harvest index
IDE	:	Irrigation and Drainage Engineering
i.e.	:	That is
IMD	:	Indian Meteorological Department
K	:	Potassium
Kc	:	Crop coefficient
LAI	:	Leaf area index
m	:	Meter
Max	:	Maximum

ME	:	Maximum error
Mi	:	Measured value
Min	:	Minimum
MSL	:	Mean sea level
mm	:	Millimeter
MZ	:	Maize
n	:	Number of observations
N	:	Nitrogen
N	:	North
Obs	:	Observed
P	:	Phosphorus
P_{eff}	:	Effective rainfall
Pi	:	Predicted value
P_{Tot}	:	Precipitation/ Total rainfall
q/ha	:	Quintal per hectare
R^2	:	Coefficient of determination
RDF	:	Recommended dose of fertilizer
RMSE	:	Root mean square error
RH	:	Relative humidity
SD	:	Standard deviation
SE	:	Standard error
Sim	:	Simulated
Sq	:	Square
VNMKV.	:	Vasantrao Naik Marathwada Krishi Vidyapeeth

THESIS ABSTRACT

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1	Title of the thesis	:	Crop Growth Simulation of Maize Using DSSAT Model
2	Name of candidate	:	Sangale Bhagwan Bhanudas
3	Name of Research Guide	:	U. M. Khodke
4	Department	:	Irrigation and Drainage Engineering
5	College/University	:	College of Agricultural Engineering and Technology, VNMKV, Parbhani.
6	Degree to be awarded	:	M. Tech. (Irrigation and Drainage Engineering)

ABSTRACT

The present project entitled, “Crop Growth Simulation of Maize Using DSSAT Model” carried out during year 2020-2021 at the Department of Irrigation and Drainage Engineering, CAET, VNMKV, Parbhani. The project aimed with specific objectives of calibration of DSSAT model and to study effect of different irrigation and fertigation levels on crop growth and yield attributing parameters with evaluation of performance of the DSSAT model.

Maize (*Zea mays* L.) is an important food and fodder crop which occupies third rank among cereals after wheat and rice in the world. Drip fertigation optimizes the use of water and fertilizers with higher yields, quality produce with increasing water and fertilizer use efficiency. The design of the field experiment was prepared considering split plot design with irrigation levels as the main factor and fertilizer levels as the sub factors. The treatment consisted of three irrigation levels I_1 (1.0 ET_c), I_2 (0.8 ET_c) and I_3 (0.6 ET_c) and five fertilizer levels viz. F_0 (No fertilizer), F_1 (100 % RDF through fertigation), F_2 (75 % RDF through fertigation), F_3 (50 % RDF through fertigation) and F_4 (100 % RDF through soil application) with recommended dose of fertilizers was 150:75:75 kg/ha NPK.

The Decision Support System for Agrotechnology Transfer (DSSAT) is one such software application program that comprises crop simulation models for over 42 crops (as of Version 4.7.5) as well as tools to facilitate effective use of the model to aid farmers in developing long term crop rotational strategies.

The DSSAT model was calibrated by using the data of field experiment conducted on response of maize hybrid to drip irrigation and fertigation levels in post *kharif* season conducted during 2017-18, which includes variety of crop, cropping history, crop management data, soil surface characteristics and soil profile data and daily weather data including total rainfall, maximum and minimum temperature, daily sun shine hours data, relative humidity.

The plots under 100% ETc (I_1) and 100% RDF (F_1) a full irrigation fertilizer treatment of experiment during which crop was almost under non-stress conditions were used to provide necessary information for the calibration of DSSAT. The remaining treatments were used in validating the model. The genetic coefficients of variety DKC- 9149 used in analysis of the model were estimated by repeated reiterations until close match between simulated and observed crop parameters was obtained for all the treatments. Crop parameters such as crop yield, stover yield, biological yield, harvest index and leaf area and leaf area index were estimated.

The CERES Maize model of DSSAT underpredicts grain yield, total biological yields and harvest index of maize under all treatments whereas there is good agreement between observed and simulated results in regards with stover yield and leaf area index of maize. The significant association was observed between predicted and measured values of harvest index and leaf area index with correlation coefficient (0.747) and (0.756) respectively, which indicates that the CERES maize model predicted harvest index and leaf area index of maize fairly well.

Keywords: Calibration, CERES Maize, DSSAT, Genetic Coefficients, Validation.

CHAPTER -I

INTRODUCTION

CHAPTER-I

INTRODUCTION

Maize (*Zea mays* L.) is an important food and fodder crop which occupies third rank among cereals after wheat and rice in the world (Ranum *et al.,* 2014). Maize (*Zea mays L.*), also called corn, is believed to have originated in central Mexico 7000 years ago from a wild grass, and Native Americans transformed it into a better source of food in daily life. Maize contains approximately 72% starch, 10% of protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world, with the United States, China, and Brazil being the top three maize-producing countries in the world, producing approximately 563 of the 717 million metric tons/year. Maize can be processed into a variety of food and industrial products, including starch, protein, sweeteners, beverages, glue, oil, industrial alcohol, pharma, cosmetics and fuel ethanol. In the past 10 years, use of maize for fuel production has been significantly increased, accounting for approximately 40% of the maize production out of total production in the world. Since the ethanol industry absorbs a larger share of the maize crop, higher prices for maize will intensify the competition and could affect maize prices for animal and human consumption. Low production costs, along with the high consumption of maize flour and cornmeal, especially in micronutrient deficient health problems, make this staple food an ideal food vehicle for fortification.

Maize has wider adoptability under varied agro-climatic conditions and it has emerged as one of the most versatile crops. It is cultivated on nearly 150 M ha in 160 countries under diverse conditions of soil, climate, biodiversity and management practices that contribute 36 % (782 MT) in the global grain production. United States of America (USA) is the largest producer of maize contributing nearly 35 % of the total production in the world with highest productivity (> 9.6 T ha^{-1}) almost double than the global average (4.92 T ha^{-1}) whereas the average productivity in India (2.43 T ha^{-1}) is comparatively low. The current cereal-based systems of South Asia are under threat due to multiple challenges of declining water table, escalating energy and fuel prices, shortages of farm labour, deteriorating soil health with overarching effects of climatic variability making farming uneconomical and unattractive. Conservation agriculture (CA) based management practices together with cropping system optimization have demonstrated to produce more with less while restoring, conserving and sustaining natural resources (Farmer's portal., 2012-13).

Maize is the third most important crop after rice and wheat in India in terms of its area coverage and contribution to total food grains production. It is grown in almost all agro-ecological regions of the country, contributing about 22 million tons of grain production from about 9 M ha of land. The production as well as its consumption pattern of maize has dramatically changed in India in the recent past. Bihar, Madhya Pradesh, Rajasthan and Uttar Pradesh were the major maize-producing states, but the southern states especially Andhra Pradesh and Karnataka became the predominant maize-growing states from the last two decades. More recently, Maharashtra and Tamil Nadu are also emerging as very important maize growing States (Kumar *et al*., 2014).

In north-western India, maize (*Zea mays L*.) based systems are being advocated as an alternate to rice-based systems to address the issues of resource degradation particularly water table and climate-change-induced variability in rainfall and temperature, etc. However, targeting maize systems without futuristic best-bet crop management practices suited to production systems and ecologies, may lead to other problems (Yadav *et al*., 2016).

Water is the most important and critical input for agriculture and the demand for efficient use of irrigation water for crops are intensifying in view of changing climate. The ever-increasing demand for irrigation water and its competitions with other sectors is stressing the need to use efficient methods of irrigation that maximizes the water use efficiency (Hess, 1996). The basic information needed to optimize irrigation includes precise knowledge of the relations between water use and crop yield *i.e*. water production functions. Deficit irrigation (DI) has been widely investigated as a valuable strategy where water is the limiting factor in crop cultivation in arid and semiarid regions (Fereres and Soriano, 2007).

Maize is a water demanding crop which requires high amount of water (450-600 mm) as compared to other major crops. With introduction of new hybrids, maize is being cultivated during *rabi* under irrigated conditions because of its higher productivity level. Surface irrigation methods used for irrigating maize crop leads to excess runoff, evaporation, higher leaching levels and deficit soil moisture, thereby the availability of water to the crops remains relatively less. Hence, scheduling irrigation using drip system that reduces the water application losses without reducing the yield is a prime concern as both deficit and excess water supplies could affect maize growth in the tropical climate (Zaidi *et al., 2007*).

Information requirements for agricultural decision making has become essential at all levels due to increased demands for agricultural products and increased pressures on land, water, and other natural resources. The generation of new data through traditional agronomic research methods and its publication are not sufficient to meet these increasing needs. Traditional agronomic experiments are conducted at particular points in time and space, making results site- and season-specific, time consuming and expensive. Hence there is a need to put new data and research findings into formats that are relevant and easily accessible so that they can be used effectively. Under such circumstances the crop growth models can play an important role because of their capacity to take into account limiting factors (soil, weather, water, and fertilizers) dynamically and suggest proper management option. These models are able to describe the behaviour of the real crop by predicting the physiological mechanisms of the crop growth (e.g., phenological development, photosynthesis, dry matter, partitioning, and organogenesis) using mechanistic equations. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics.

The Decision Support System for Agrotechnology Transfer (DSSAT) is one such software application program that comprises crop simulation models for over 42 crops (as of Version 4.7.5) as well as tools to facilitate effective use of the models. The DSSAT was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (IBSNAT, 1993; Tsuji, 1998; Uehara, 1998; Jones *et al*., 1998), to facilitate the application of crop models in a systems approach to agronomic research. The DSSAT is a comprehensive decision support system, which has the capability of predicting the impact of management strategies such as irrigation scheduling and fertilizer management on crop growth and yields. The tools include database management programs for soil, weather, crop management and experimental data, utilities, and application programs. DSSAT and its crop simulation models have been used for a wide range of applications at different spatial and temporal scales. This includes on-farm and precision management, regional assessments of the impact of climate variability and climate change, gene-based modelling and breeding selection, water use, greenhouse gas emissions, and long-term sustainability through the soil organic carbon and nitrogen balances. For applications, DSSAT combines crop, soil, and weather data bases with crop models and application programs to simulate multi-year outcomes of crop management strategies. DSSAT integrates the effects of soil, crop phenotype, weather and management options, and allows users to ask "what if" questions by conducting virtual simulation experiments on a desktop computer in minutes which would consume a significant part of an agronomist's career if conducted as real experiments.

Under such circumstances use of crop growth model like DSSAT for comparison of maize yield under different management practices including deficit irrigation will help to highlight the issues of various management options and efficient irrigation water management in the semi-arid region of Marathwada where there is limited water supply. In view of the above requirement of decision making, the present investigation is planned on **"Crop growth simulation of maize using DSSAT model"** with the following objectives.

Objectives:

1. To study the effect of different drip irrigation and fertigation levels on growth and yield attributing parameters of post monsoon maize.
2. To calibrate the DSSAT model for simulating maize crop growth and yields.
3. To evaluate the performance of DSSAT model in estimating maize growth and yields under different drip irrigation and fertigation levels.

CHAPTER -II

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

Water is precious and the most important input for crop production. Although the major share of water is used in agriculture, but recent developments, industrialization and increase in population is reducing the share of water use in Agriculture. Water resources in the world are either dropping or contaminated by industrial waste discharge. A large cost in agricultural productivity is of fertilizers which are applied into farm to get higher yield. Hence both water and fertilizers are the recent limiting factors to the farmers. Therefore, the present need is to attain maximum production with resourceful use of a drop of water with unit amount of nutrient. Drip irrigation with fertigation optimizes the use of water and fertilizers producing higher yields and quality produce and also achieves higher water and fertilizer use efficiency. The optimized irrigation and fertigation schedules need to be planned in order to provide water and nutrients as and when plants need them.

The available literature on research carried out by various investigators related to the effect of irrigation methods, schedule and fertilizer levels on growth, yield and quality of produce in general with particular reference to maize has been reviewed. Similarly, the research work carried out in past on crop growth simulation in general and crop growth simulation by DSSAT in particular is also presented in this section.

2.1 Response of Maize under Surface Irrigation

2.2 Effect of Irrigation and Fertilization in Maize

2.3 Interaction Effect of Irrigation and Fertilization on Maize

2.4 Drip Irrigation

2.5 Response of Maize under Drip Fertigation

2.6 Crop Growth Simulation

2.7 Crop Growth Simulation Using DSSAT CERES Maize

2.8 Performance of DSSAT in Estimating Maize

2.9 Critiques on the Literature Reviewed

2.1 Response of Maize under Surface Irrigation

Farre and Faci (2009) in their experiment on the effect of deficit irrigation in maize for reducing agricultural water use reported that deficit irrigation or higher interval between irrigations during the grain filling phase did not significantly affect crop growth and yield. Results showed that flowering was the most sensitive stage to water deficit, with reductions in biomass, yield and harvest index. They showed that it was possible to maintain relatively high yields in maize if small water deficits caused by increasing the interval between irrigations were limited to periods other than the flowering stage. Irrigation water use efficiency (IWUE) was higher in treatments fully irrigated around flowering.

Kuscu *et al.* (2016) investigated the relationship between yield and irrigation water applied at different growth stages and determined the most critical stage (s) for maize (*Zea mays* L.) in a sub-humid environment of Turkey. A rainfed (non–irrigated) treatment as the control, full irrigation (VFG) and 15 different irrigation treatments (V, F, G, VF, VG, FG, V75FG, V50FG, V25FG, VF75G, VF50G, VF25G, VFG75, VFG50 and VFG25) with full or limited (25, 50 and 75%) irrigation water, were applied to the hybrid Pioneer 31P41 (Pioneer Seed Company) planted on clay-loam soil, at three critical development stages: vegetative (V), flowering (F), and grain-filling (G). The highest seasonal evapotranspiration (an average of 1133 mm) was measured in the VFG treatment. Limited irrigation applied at different growing stages had different effects on the yield–related characters examined. According to average of two years, the highest grain yield (20.52 t ha^{-1}) and dry matter yield (33.78 t ha^{-1}) were obtained from the VFG and VFG75 treatments, respectively. They confirmed that VFG and VFG75 irrigations are the best choice for maximum yield under the local conditions. The flowering and vegetative were also determined as the most sensitive stages to water deficit of maize.

2.2 Effect of Irrigation and Fertilization in Maize

Khatun *et al.* (2012) in a field experiment at University of Rajshahi showed that irrigation & nitrogen significantly influenced on plant height, leaf area index, total dry matter and crop growth rate. Two irrigations coupled with 130 kg N ha^{-1}

produced maximum cob length (24.93 cm), number of grains cob^{-1} (365.67), grain yield (7.03 t ha^{-1}), stover yield (9.49 t ha^{-1}) and biological yield (16.55 t ha^{-1}) as compared to one irrigation and no irrigation.

Hameedi *et al.* (2015) in his experiment at Abu-Ghraib/ Baghdad on the effect of irrigation intervals and organic fertilizer levels on some growth characteristics, yield and water use efficiency of maize crop (synthetic cultivar 5018) recommended irrigation every 10 days, with application of organic fertilizer (Top_{10}) in 5g L^{-1} foliar applications after 40 and 60 days from planting for maize in semi-arid regions similar to that in Iraq where the research was conducted**.**

Wang *et al.* (2016) conducted a field experiment at Institute of environment and sustainable development in agriculture, China to study the effect of irrigation regimes and nitrogen rates on water use efficiency and nitrogen uptake in maize. The effect of alternate partial root-zone irrigation (PRI) on water use efficiency and nitrogen (N)accumulation compared with deficit irrigation (DI) and full irrigation (FI) were investigated in maize (*Zea mays* L.) grown under three N-fertilization rates (1.5, 3.0, and 6.0 g N pot^{-1}) and moderately and severely water-stressed levels (60 and 40 per cent of soil water holding capacity). The plants were grown in split-root pots and exposed to FI, DI and PRI treatments from the fourth leaf to silking stage. Analysis across the N-fertilization treatments showed that both PRI and DI significantly decreased plant water use as well as plant height, stem girth, leaf area and shoot biomass, leading to similar WUE compared with the FI control. Carbon isotope composition (13C) was highest in PRI plants indicating a fine-tuned long-term stomatal control over gas exchange. Across the N-fertilization rates, full irrigated (FI) plants accumulated significantly greater amount of N than deficit irrigation treatments. Partial root zone irrigation and deficit irrigation plants had similar plant 15N, indicating the similar soil N mineralization. Plant dry biomass, which was linearly associated with plant N uptake, was similar for PRI and DI plants. Both resulted in the equivalent amount of N accumulation in the shoots of PRI and DI plants. It was noted that increased soil moisture level, e.g., from 40 per cent to 60 per cent, showed the tendency of increasing N uptake for PRI plants relative to DI plants. Therefore, in order to facilitate N uptake, soil water availability in the wet soil compartment of PRI treatment should remain at high water levels.

Kuscu and Demir (2013) found that plant height, first ear height, stem diameter, number of ears per plant and net income decreased with decreases in the amount of irrigation, but the effect of soil water deficit on the number of leaves per plant and ear ratio in forage was minor. The highest forage yields were obtained with EI (125 per cent Epan), FI (100 per cent Epan) and DI-75 (75 per cent Epan) treatments. Severe soil water deficit substantially reduced forage yields and net income in both the years. The results showed that full irrigation during the whole growing season is preferable for higher forage yield and net income. However, in regions of water scarcity, farmers should adopt the deficit irrigation (DI-75 = 75 per cent, DI-50 = 50 per cent and DI-25 = 25 per cent Epan) approach to achieve economically sustainable crop production. As an alternative to full irrigation during the entire growing season, the irrigation at a rate of DI-75 per cent Epan can be recommended as optimal level because it achieved irrigation water savings of 25 per cent, an increase of 16 per cent in forage yield irrigation water use efficiency, satisfactory crop morphological characters and an acceptable net income with a yield loss of only approximately 7 per cent compared with full irrigation.

Vora *et al.* (2017) conducted a field experiment at Junagadh, South Saurastra in *kharif* 2012 to study the effect of nitrogen N (60, 80, 100 and 120 kg ha^{-1}) and phosphorus P (40, 50 and 60 kg P2O5 ha^{-1}) on yield and yield attributes of maize. The results revealed that the application of 120 kg N ha^{-1} recorded the maximum plant height (165.28 cm), cob girth (15.05 cm), number of cobs per plant (1.49), cob length (17.87 cm), dry matter accumulation (153.09 g $plant^{-1}$), number of grains per cob (283.19), 100 grain weight (26.70 g), grain yield (4905 kg ha^{-1}), biological yield (13382 kg ha^{-1}), stover yield (8478 kg ha^{-1}), net return Rs (39228 ha^{-1}) and BCR (3.14) and the lowest values were recorded under 60 kg N ha^{-1}. In the same manner all growth parameters were influenced by different levels of phosphorus application. With the application of 60 kg P_2O_5 ha^{-1}, growth characteristics, yield attributes, and yield characteristics were better while under 40 kg P_2O_5, the lowest values of these growth and yield characteristics were recorded. They recommended application of nitrogen at the rate of 120 kg N ha^{-1} and phosphorus at 40 kg P2O5 ha^{-1} for production and net returns.

2.3 Interaction Effect of Irrigation and Fertilization on Maize

Negy *et al*. (2002) conducted an experiment at the Látókép experimental station of the Center for Agricultural Sciences, Debrecen University, during 1999 and 2002, to study the effect of irrigation on maize yield. They reported that the yield increasing effect of fertilization can be reliably detected with small and medium doses, but at higher doses a plateau section is reached, where it is not worth applying more nutrients. Irrigation has positive correlation with fertilization which means that if the water supply of the plant declines, less fertilizer is needed for safe production. The two factors (irrigation and fertilization) have to be increased or decreased at the same time. They reported that in un-irrigated treatments, 90 kg/ha nitrogen and the related phosphorus and potassium are enough, while in irrigated treatments this should be 120 kg/ha.

2.4 Drip Irrigation

Drip irrigation is one of the latest innovations for applying water to row planted, widely spaced crops, especially in the water scarce areas (Bucks and Davis, 1986). There can be considerable saving of water in drip irrigation since water can be applied more frequently almost precisely and directly in the root zone without wetting the entire area. Drip irrigation system is being advocated to maximize yield and quality of produce because of precise application of water and fertilizers.

There have been remarkable advantages of drip irrigation over surface irrigation which have been reported in past studies, such as enhancement in water use efficiency (50-95 per cent), fertilizer use efficiency (fertilizer saving of 30 per cent) and better yields (40-100 per cent); and quality products in addition to reduction in tillage requirements, weed growth, reduction in occurrence of pest and diseases, less labour requirements (Bucks *et al*., 1982) and encouraging effects on yield, water saving and increasing the irrigation performance (Phene and Howell, 1984). The additional advantage of drip irrigation is efficient use of saline or poor-quality water for crop production (Goldberg and Shmueli, 1970).

2.5 Response of Maize under Drip Fertigation

Earlier studies have reported amount of fertilizer saving, and increase in yield and fertilizer use efficiency of different crops under drip fertigation as compared to conventional methods. Increased yields, improvement in quality of the produce, water and nutrient expense efficiencies are the advantages of the drip fertigation. The literature pertaining to the response of maize under drip fertigation is presented in this section.

Sampathkumar and Pandian (2014) conducted a field research at ACRI, Coimbatore in 2007 to assess the impact of different drip fertigation levels. The experiment included four fertigation frequency (once every 6, 9, 12, and 15 days), two fertilizer levels (100 and 150 per cent RDF), surface irrigation with 100 per cent RDF, and absolute control (no fertilizer). The use of 150 per cent RDF once every 6 days resulted in a considerably greater grain yield (8,957 kg ha^{-1}) than the use of 100 per cent RDF (7,915 kg ha^{-1}). According to the findings of this study, hybrid maize production can be increased by applying drip fertigation with 150 per cent RDF applied once every 6 days.

Ibrahim *et al.* (2016) conducted field experiment in a split-plot design with four irrigation levels (0.6, 0.8, 1.0, and 1.2) and two fertigation periods (RDF in 60 and 80 per cent of the irrigation time) and control treatment that represented conventional maize irrigation and fertilisation in the studied area. They observed that the increase in amount of irrigation water used and the time between fertiliser applications resulted in higher vegetative growth and yield. The treatments with 1.2 and 0.6 crop evapotranspiration had the best and lowest grain yields, respectively The treatment with 0.8 crop evapotranspiration and fertiliser application in 80 per cent of irrigation time had the maximum water productivity (1.631 kg m^{-3}) and conserved 27 per cent of irrigation water.

Bibe *et al.* (2017) conducted a field experiment in kharif season at Parbhani during 2015-16 to study the response of irrigation and fertigation management on growth and yield of maize. The experiment was set up in a split plot design with twelve treatments, three drip irrigation levels as the main plot (0.6 x P.E, 0.8 x P.E, 1.0 x P.E) and four fertilizer levels as sub plot treatments (100 per cent RDF, 75 per cent RDF and 50 per cent RDF through fertigation and 100 per cent RDF as soil application), replicated three times. It was found that grain yield was significantly higher (8845.43 kg/ha) with irrigation at 1.0 PE (I1) over the 0.6 PE (I3) and comparable with 0.8 PE (I2). The fertilizer at the rate of 100 per cent RDF through drip (F1) recorded significantly highest growth parameters.

Latkar *et al*. (2017*)* conducted experiment in rabi season to determine suitability of irrigation method, fertilizer approaches and levels of soil ameliorant to sweet corn. Sweet corn grown under drip irrigation noticed significantly higher green cob, fodder and total biomass (1.67, 1.73 and 3.40 t/ha, respectively) with increment of 10.78, 4.05 and 7.35 per cent, respectively over check basin method of irrigation. Application of soil test-based fertilizer requirement of N, P, K and micronutrients (Cu, Zn, B and Mn) had significantly highest green cob yield (2.05 t/ha) and increment was 71.66, 13.27 and 5.97 per cent over control, recommended dose of fertilizer and soil test based fertilizer requirement of NPK, respectively. However, corn ameliorated with 50 per cent lime requirement recorded the highest green cob and fodder yield (1.67 and 1.74 t/ha, respectively) with increment in the magnitude of 10.40 per cent and 6.03 per cent, respectively over lime control and 25 per cent lime requirement.

Kiran *et al.* (2019) conducted a field experiment at Water Technology Centre, PJTSAU, Hyderabad during Rabi season to assess the influence of drip fertigation of nitrogen, potassium and microbial consortium. Results showed that fertigation with 100 per cent RD N and K recorded higher plant height, number of leaves plant^{-1}, and dry matter over 75 per cent RD N and K at all development phases, except at 30 DAS. Whereas microbial consortium (MC) showed significantly greater growth characteristics, such as plant height, leaf number plant^{-1}, and dry matter at 60, 90, and harvest. Similarly, yield (grain and stover) was highest with MC bio fertigation five times and three times, respectively, which was comparable to MC soil application and superior to no MC treatment.

Rani and Mariappan (2019) conducted field experiment at TNAU in Kharif seasons of 2008 and 2009 to study the impact of drip irrigation and fertigation levels on maize. The experiment was set up in a split plot design with two irrigation regimes: M1- irrigation via drip at 75 per cent PE once every 3 days, and M2 - irrigation via drip at 100 per cent PE once every three days as the main plot and eight fertigation levels as the sub plot. Results showed that drip irrigation at 100 per cent PE once every 3 days resulted in considerably better maize grain yields than irrigation at 75 per cent PE. Drip fertigation with P through water soluble fertiliser at 150 per cent RDF (225: 112.5: 112.5) resulted in considerably greater grain production.

Lakshmi *et al.* (2020) studied the impact of different levels of irrigation & fertilizers on hybrid maize at Agricultural Research Institute, Rajendranagar. Two different treatments in randomized block design were used in which first treatment consisted of five irrigation levels as drip irrigation at 60 per cent, 80 per cent, 100 per cent, 120 per cent E pan and surface irrigation IW/CPE- 1.0 applied whereas second treatment consisted of four nitrogen levels viz., N1: 120 kg ha^{-1}, N2: 160 kg ha^{-1}, N3: 200 kg ha^{-1}, N4: 240 kg ha^{-1}. The results showed that the drip irrigation with 120 per cent E pan, which was comparable to 100 per cent E pan, significantly improved crop performance in terms of growth parameters such as plant height, LAI, and dry matter production, and both were superior to drip irrigation with 80 and 60 per cent E pan, and also surface irrigation. Nitrogen at a rate of 240 kg ha^{-1} resulted in considerably greater growth parameters, yield characteristics, green cob and fodder production, but it was on par with 200 kg ha^{-1}, and both were superior to 160 and 120 kg N ha^{-1}.

Ramulu *et al.* (2020) conducted field experiments at Rajendranagar, Hyderabad in rabi seasons of 2008-09 to 2010-11 to enhance maize grain production and water productivity by determining the appropriate irrigation plan and fertiliser amount using drip fertigation. Surface furrow irrigation at 1.0 IW/CPE, drip irrigation at 0.7, 1.0, and 1.2 Epan, and three fertigation levels (150, 100, and 75 per cent NPK RDF) were used as major treatments. The results revealed that increases in irrigation water supply and fertiliser level (NPK) boosted maize grain production. The maximum and minimum grain yields were achieved using drip fertigation with Epan of 1.2 and 0.7, respectively. The use of 150 per cent RDF (NPK) resulted in a better grain production than the lower NPK dosage (75 per cent and 100 per cent RDF). It is observed that the drip fertigation strategy at 1.0 Epan conserved 22 per cent of the water as compared to surface irrigation.

2.6 Crop Growth Simulation

Crop growth simulation modelling can help to understand the dynamics of maize crop growth and yield (Boote *et al*., 1989). Based on the understanding of biological processes, data availability and experimental conditions, there can be more than one modelling approach to describe the experimental phenomenon.

Crop simulation models are key components to test the advances in agricultural technology so as to predict crop responses for present and future climatic changes. These models are being used widely to estimate the crop production potential, transfer of agro-technologies, assist strategic decisions and forecast real-time yields (Bannayan and Crout, 1999). Whereas according to (Sivarajan, 2011), crop simulation models involve the mathematical function of various crop physiological factors such as photosynthesis, respiration and relative growth rate to describe the crop growth changes under various climatic and environmental conditions. Sometimes the model becomes complicated as it needs several detailed inputs for simulation and makes the calibration process tedious to perform.

Kiniry and Jones (1986) simulated growth parameters of the corn with the daily time step from sowing to maturity on the basis of physiological processes determined by the crop response to soil and environmental conditions. They reported that the CERES-Maize model allows the quantitative determination of growth and yield parameters of corn.

The EPIC, ALMANAC, WOFOST, CROPSYST, ADEL and CERES-Maize models have been successfully used to simulate maize crop growth and yield. The SORKAM, SorModel and SORGF models are being used to address specific tasks of sorghum crop management whereas CERES – pearl millet model, CROPSYST, PmModels have been used to study the suitability and yield simulation of pearl millet genotypes across the globe. Similarly, the two most common growth models used in application for cotton are the GOSSYM (Mckinion *et al*, 1989) and COTONS models. On the same analogy the PNUTGRO (Boote *et al*, 1989) for groundnut, CHIKPGRO for chick pea, WTGROWS for wheat, SOYGRO for soybean, BEANGRO (Hogenboom *et al*, 1994) for beans and QSUN for sunflower have been used to meet the requirements of farmers, scientists and decision makers. (Oteng-Darko *et al.,* 2013).

Hoogenboom *et al.* (1994) developed a Decision Support System for Agrotechnology Transfer (DSSAT), which integrates various crop simulation models for grain legumes, cereals, vegetables and oilseeds with weather, soil and experimental databases. (Ma *et al.* 2002) evaluated three models RZWQM, CROPGRO and CERES-MAIZE for response of water stress and showed weaknesses and strength of each model. They concluded that the application of model to conditions such as water amount, irrigation methods, and weather depends on the model. The study in general, showed that RZWQM and CROPGRO simulated ET equally well however, response of model to irrigation was better in case of RZWQM. As far as the water quality is concerned, RZWQM performed better while for crop yield performance of CROPGRO was superior, depending on the method of irrigation. (Jagtap and Jones. 2002) calibrated CROPGRO model for prediction of regional yield and production under different management options. (Collino *et al*. 2002) used DSSAT CROPGRO model to describe the physiological responses of different peanut varieties to water stress.

DSSAT is a decision support system that is designed to aid farmers in developing long term crop rotational strategies. Fifteen crop stimulation models (CERES: wheat, maize, rice, sorghum, millet, barley, sunflower, sugarcane, chickpea, tomato and pasture; SOYGRO, PNUTGRO, BEANGRO, SUBSTOR-potato) are accessible in DSSAT. The crop models are developed to assess the influence of weather and management practices (cultivar selection, sowing time, plant population, initial condition, irrigation water, nitrogen schedule, mulching etc.) on crop growth and development on daily basis. The significant feature of DSSAT is the development of standards for data collection and formats for data acquisition and exchange. This allows any crop model of the family to share and access common soils and weather data. Multiple season simulation provides cumulative probability analysis for risk management. The models include: CERES-Barley, CERES-Maize, CERES-Millet, CERES-Rice, CERES-Sorghum and CERES-Wheat. (CERES= Crop Environment Resource Synthesis) (Oteng-Darkoet *et al.*, 2013). It includes various analysis programs to apply the crop models for decision making related to short and long term practical and strategic planning.

DSSAT has modules that allow users to build model input files for spatial simulations across predefined management zones, calibrate the models to simulate historic spatial yield variability and crop response to environmental and management variations (Thorp *et al*., 2008).

2.7 Crop Growth Simulation Using DSSAT CERES Maize

Steiner *et al.* (1991) used CERES crop growth simulation model for Maize, sorghum and winter wheat grown at Bushland, Texas to predict evapotranspiration and crop growth parameters like, leaf area index and total dry matter accumulation under water stress, and suggested that the model prediction needs evaluation of model for other crops under moderate stress conditions.

Asadi and Clemente (2003) simulated nitrate leaching, nitrogen uptake, corn yield and soil moisture content using the CERES-Maize model in the central region of Thailand using two years experimental data (1999-2000) for the validation. Throughout the season, the soil was irrigated and fertigated with a sprinkler irrigation method with fertigation levels of 0, 100, 150, and 200 kg N ha^{-1}, with three replications in randomized complete block layout for each. Ceramic cups were used to assess nitrate leaching, and the gravimetric method was used to determine soil moisture content. Site data, daily weather data, soil properties, soil initial conditions, irrigation and fertiliser management, and crop performance data were all used as inputs to the model. The equation Ys=1.058Yo with R^2 =0.97 for grain yield, Ys=0.7396Yo with R^2 =0.86 for nitrate leaching, and Ys=1.1103Yo with R^2 =0.99 for total N uptake represented the relationship between experimental (Yo) and simulation (Ys) results. They concluded that `the effects of N and irrigation management on maize yield, nitrate leaching and N uptake under irrigated tropical conditions could be significantly simulated.

Panda *et al.* (2004) conducted a field experiment for three years using CERES-Maize with five irrigation treatments as 10 per cent (T1), 30 per cent (T2), 45 per cent (T3), 60 per cent (T4) and 75 per cent (T5) maximum allowable depletion of available soil water. Under water scarcity conditions. The observed and simulated results revealed that plant extractable soil water depletion of more than 45 per cent of ASW must be managed to avoid even during non-critical growth stages to achieve high water use efficiency and net return.

Manuela *et al.* (2007) evaluated the CSM-CERES-Maize model with experimental data obtained during three field experiments in Piracicaba, SP, Brazil to simulate the yield of Maize. The CSM-CERES-Maize model was found to be capable of accurately simulating phenology and grain yield for the four hybrids, with a normalised RMSE of less than 15 per cent. Analysis showed that a delayed planting decreases average yield of 55 per cent for the rainfed and 21 per cent for the irrigated conditions for all hybrids.

López-cedrón *et al.* (2008) estimated the biomass and grain yield by using CSM–CERES–Maize model with the default ET option (PT) for irrigated (IR) and rainfed (RF) treatments. The model underpredicted mean biomass by 4228 kg ha^{-1} (RMSE=5027) and mean grain yield by 3323 kg ha^{-1} (RMSE=3728) in rainfed treatments. Because of underpredicted mean seed number (2479 estimated seeds m^{-2} vs 3900) measured, the model predictions of mean harvest index (HI) of rainfed treatments were always low (0.360 estimated vs. 0.490 measured). where simulations projected earlier effects of water deficit on biomass accumulation and grain mass were observed and in both IR, and RF treatments, crop phases were correctly predicted.

According to Pereira *et al.* (2010) the CERES-Maize model was proven as a decent tool for simulation of agronomic characteristics in maize hybrids in tropical conditions. Similarly, under tropical conditions, (Lyanda *et al.* 2014) used the DSSAT CERES Maize model to identify the potential zones for the production of maize hybrids in Nigeria by covering six sites all over the country.

He *et al.* (2012) used DSSAT CERES-Maize model to identify the effect of different irrigation and nitrogen levels on maize. In single factor simulations, a total of 24 irrigation schedules, 21 N fertiliser levels, 30 N application splits, and 20 N application rates per split were systematically evaluated. Then, in a multifactor evaluation, a set of 324 management scenarios comprised of 6 irrigation timing/amount and 54 N fertiliser application strategies chosen in earlier single factor explorations were examined. Results showed that the frequency of irrigation had a significant impact on maize yield. Corn growth suffered water stress and the simulated yield was lowered when irrigation events were triggered when the maximum allowed depletion (MAD) of soil water content was greater than 60 per cent. Above 168 kg N ha^{-1} the increase in yield reached zero. Splitting N fertiliser applications had no effect on yield whether N was applied during the small-leaf or large-leaf stage; however, the least quantity of N leaching occurred when no N was applied during the small-leaf stage. When application rates were reduced from 100 to

70 kg N ha^{-1} each fertigation event, simulated yield increased, but only modestly when application rates were less than 70 kg N ha^{-1} per fertigation. Smaller application rates per fertigation significantly reduced N leaching, specifically at rates less than 70 kg N ha^{-1}. Six potential Best Management Practices were chosen from 324 management scenarios to maximise production while reducing N leaching.

Yang *et al.* (2013) simulated long-term continuous maize growth from 1990 to 2007 in Gongzhuling, North-East China using three stages of N treatments: no N (N0), 165 kg N ha^{-1} from synthetic fertilizer (N165), and 50 kg N ha^{-1} from synthetic fertilizer plus 115 kg N ha^{-1} from farmyard manure (N50) (N165M). The maize yield in the N0 treatment was significantly lower in both measured and simulated results. After 2003, maize yields in N165M treatments were higher than in N165 treatments. Weather had an impact on maize yields, particularly during drought years. They concluded that in long-term field conditions, the DSSAT CENTURY-based model is a valuable tool for simulating soil nitrogen dynamics and predicting soil organic carbon sequestration.

Sampathkumar *et al*. (2013) conducted field experiment at ACRI, Coimbatore from 2007 to 2009 for cotton -maize by using seven levels of drip irrigation. Among the different irrigation treatments. The treatments were 1) CDI_{100}-Conventional drip irrigation (CDI) at 100% ETc once in three days (throughout the cropping period, full irrigation) 2) ADI_{100-50}-100 and 50% of ETc as full and deficit in alternate cycle (alternate deficit irrigation (ADI) at 100% ETc, mild deficit) 3) ADI_{100-0}–100% ETc in alternate irrigation cycle (CDI at 50% ETc once in six days, severe deficit) 4) CDI_{80}–Conventional drip irrigation (CDI) at 80% ETc once in three days (throughout the cropping period, mild deficit) 5) ADI_{80-40}-80 and 40% of ETc as deficit irrigation in alternate cycle (ADI at 80% ETc, mild deficit)6) ADI_{80-0}-80% ETc in alternate irrigation cycle (CDI at 40% ETc once in six days, severe deficit); SUR-Surface irrigation (Furrow), the response of crops to water stress indicated that growth, yield parameters and crop yield were higher in mild water deficit (ADI at 100 per cent ETc once every three days) whereas plant height, LAI, and dry matter production were found to increase with alternate deficit irrigation (ADI_{100-50} and ADI_{80-40}).

Liu *et al.* (2014) simulated maize growth, maize yield, soil water content and soil nitrogen concentration by using DSSAT CERES-Maize model. They concluded that the DSSAT model could simulate measured grain yield, above-ground biomass, leaf area index, soil water content and soil inorganic nitrogen concentration with significant agreement.

Cavero *et al*. (2014) evaluated the impact of cover crop–maize rotations on N leaching for a range of soil types and irrigation managements during a 14 years rotation in La Violada watershed, Spain using DSSAT model. The model accurately simulated total maize N content in maize after fallow and after various cover crops (RMSE = 25 kg N ha^{-1}), adequately simulated N leaching reductions with cover crops. Thus, the model could be used to study different management scenarios that would be difficult to investigate under field conditions.

Araya *et al.* (2015) evaluated the performance of the DSSAT CSM-CERES-Maize and APSIM-maize models to predict the maize yield in Ethiopia. They reported that both crop models fairly reproduced observations for time to anthesis, time to physiological maturity and crop yields, with values for the index of agreement of 0.86, 0.80 and 0.77 for DSSAT, and 0.50, 0.89 and 0.60 for APSIM. The results show the significant root mean square errors were, moderate for days to anthesis 1.3 and 3.7 days, respectively, for DSSAT and APSIM, also for time to physical maturity 4.5 and 3.1 days, and yield 1.1 and 1.2 tons respectively for DSSAT and APSIM models. Days to anthesis (DSSAT: 2.4-2.3 per cent and APSIM: 0-6 per cent) and days to maturity (DSSAT: 0.6-4.4 per cent; APSIM: 1.9-3.3 per cent) had modest deviations from observed values, but yield (DSSAT: 18.5-21.2 per cent; APSIM: 19.1-37.1 per cent) had comparatively high deviations. Thus, the comparative study shows that the DSSAT has shown closer results than that of APSIM model.

Kisekka *et al.* (2016) used CERES-Maize model in DSSAT-CSM v4.6 to determine the best plant-available water threshold for irrigation to maximise net returns, the impact of percentage soil water depletion at planting on yield, seasonal transpiration, water productivity, extractable soil water at maturity, and net returns and the impact of late irrigation season termination on extractable soil water at physiological maturity, yield, and net returns at Kansas Agricultural Experiment Station. The results showed that the calibrated model was able to forecast end-of-season grain production with satisfactory accuracy (NSE > 0.9, 0.13 per cent RMSE 0.19), indicating that it might be used to evaluate various management techniques for irrigating maize in southwest Kansas with limited water.

Yakoub *et al.* (2017) assessed the skills of two maize models in DSSAT, CERES-Maize and CSM-IXIM, to simulate growth, grain production, and crop N requirement under high-yielding environments. They also examined an alternative method to estimate crop N demand to enhance the accuracy of overall model estimates.

Liu *et al.* (2017) studied the effect of low nitrogen input on wheat yield under a wheat-maize rotation by using DSSAT 4.6 model. Before wheat and maize planting, two treatments were used: N_0 (no nitrogen application) and N_{150} (150 kg nitrogen ha^{-1}), with phosphorus (P) and potassium (K) basal fertilisers added as 75 kg P_2O_5 ha^{-1} and 37.5 kg K_2O ha^{-1}, respectively. N application (N_{150}) increased wheat yield compared to no N application (N_0), as per model simulation and field measurements.

Babel *et al.* (2018) assessed the performance of DSSAT-CERES model for Maize (Zea mays) at Himalayan region of India. The calibration and validation of model was done based on the combination of different irrigation and farm manure application rates. Results showed that as compared to filed experimental data, the DSSAT-CERES underestimated yield by 0.2 per cent, total aboveground biomass by 1.7 per cent and overestimated LAI by 0.5 per cent. Based on the results they concluded that, the DSSAT-CERES model can be suitable for higher altitudes in the Himalayan region of India.

Hammad *et al.* (2018) simulated maize experiment with a total of 15 treatments using a split plot design and a combination of three irrigation regimes (full irrigation, water deficit at vegetative and reproductive stages) and five nitrogen (N) rates ranging from 100 to 300 kg N ha^{-1}. Based on 35 years of historical daily weather data, the simulations were run using CERES-Maize model. The results showed that the model correctly estimated soil moisture content during the growing season (R^2 = 0.98). The mean percentage differences (MPD) for the number of grains per ear, leaf area index (LAI), and total dry matter (TDM) were 5.98 per cent, 11.4 per cent, and 4.85 per cent respectively. The normalised root mean square error (nRMSE) for grain yield was 10.4 per cent. Study revealed that the model can be used to determine the optimum water and nitrogen requirements for maize production.

Venkatesan and Pazhanivelan (2018) used DSSAT CERES-Maize model to simulate yield of maize spatially and validated it by comparing with observed data during kharif 2017 under Ariyalur and Perambalur districts. They used DSSAT required datasets of crop growth and management, daily weather data and soil data. The simulated yield was validated using the observed data from farmers' fields. The agreement between DSSAT simulated and observed yield was 90.4 per cent with R^2 and RMSE of 0.502 and 538.6 $kgha^{-1}$ respectively. Their results indicated that maize yield can be estimated spatially using the DSSAT crop simulation model.

Tovihoudji (2019) used the CSM CERES-Maize model to simulate maize response to different levels of fertilizer applications. He observed the significant agreement between observed yield and simulated yield with minimum RMSE 12 per cent for grain yield & 8 per cent for biomass yield.

Fayaz *et al.* (2020) conducted field experiment during 2015 and 2016 to evaluate maize growth and yield by using CERES-Maize model at three planting dates viz., 22nd May, 30th May and 8th June and four different nitrogen levels applied viz., 80 kg N ha^{-1} (N1), 120 kg N ha^{-1} (N2), 160 kg N ha^{-1} (N3) and 200 kg N ha^{-1}. They simulated the maize growth and yield in various agro-climatic zones of Kashmir valley at fixed dates with variable nitrogen levels and at constant nitrogen levels with variable dates of sowing., Simulated maize tests revealed that sowing of maize on May 30th with 160 kg N ha^{-1} (N3) produced the highest LAI, biological yield, and grain yield.

Ren *et al.* (2020) studied the maize yield response to the N fertilizer application and planting density by using the DSSAT (version 4.7) Maize model and showed that optimal N application amount increases linearly as the planting density increases. For simulated and actual maize yields, the root mean square error, normalised root mean square error, and index of agreement were 1,171 (kg ha^{-1}), 12 per cent, and 0.84 per cent, respectively. The potential yield was 15.58 t ha^{-1} whereas the yields of 11.43, 11.06, 10.33, and 7.95 t ha^{-1} were obtained using the super-high-yield cultivation pattern, optimal nutrient and density management pattern, simulated farmer's practice cultivation pattern, and actual farmer's practice respectively.

Song and Jin (2020) evaluated the CERES-Maize model on the basis of phenology date, leaf area index (LAI), aboveground biomass, kernel weight, yield, and soil water content. Data was collected during 2013 to 2015 on maize planting to maturity in the Guanzhong Plain, China, under both water stress and full irrigation conditions. They significantly simulated maize growth and yield in the water limited regions and observed that water stress during the seedling stage damaged photosynthetic membrane and reduced the chlorophyll content in the leaf.

Attia *et al.* (2021) calibrated and evaluate the DSSAT model for maize in arid regions of Middle East and North Africa. The 1st experiment was conducted during 2011 and 2012 growing seasons and included three ET-based irrigation treatments each year of replacing 100 %, 80 %, and 60 % ET for the total water amounts of 625, 500, and 375 mm, respectively. The 2nd field experiment was carried out in 2007 and 2008 growing seasons and there were 12 irrigation treatments in each season consisting of four irrigation frequencies and three ET replacement levels of 100 %, 80 %, and 60 % ET nested within irrigation frequency treatments. The amounts of water applied by different irrigation treatments ranged from 596 mm for 100 % ET to 357 mm for 60 % ET. In 2005 and 2006, there were two experiments that are referred to as the 3rd and 4th experiments. The 3rd experiment had four irrigation frequency treatments ranging from irrigating once in two days (high frequency) to once in five days (low frequency) and the 4th experiment had three ET based irrigation levels each year representing 100 %, 80 %, and 60 % ET replacements for total water amounts of 595, 476 and 357 mm, respectively. The total number of treatments from the four experiments were 44 treatments They found that the model accurately simulates maize phenology, growth, and yield, as well as evapotranspiration and soil water content. The output variables of yield and soil fertility were also found to have a substantial relationship. Through interactions with other inputs, maize residue retention considerably affected simulations of cumulative N mineralization, soil organic content (SOC) %in 0.2 m depth, and cumulative soil CO_2 efflux, i.e., total-order sensitivity index (STi) > 0.05. When compared to no application, compost application enhanced grain production by 13 per cent, soil organic carbon stock by 5 per cent, and cumulative soil CO_2 efflux by 95 per cent.

Bai and Gao (2021) simulated three years field experimental data from 2014 to 2016 for maize at Jilin Province, China using DSSAT model. They revealed that the DSSAT model significantly simulated the crop growth and development of maize under drip irrigation and rain-fed methods. The model was calibrated initially using crop yield, soil moisture, phenological phases, and N content data, and good agreement was achieved between the simulated and observed data during the calibration and validation. The normalised root mean square error (nRMSE) for grain yield was 1.45 per cent during the calibration period and 1.61 per cent during the validation period. In the experimental results for 2016, the total amount of N fertiliser schedule was 198 kg/ha, which were slightly higher than the traditional schedule (187.5 kg/ha), but the yield of maize in the suggested N fertiliser schedule was upregulated by 7 to 9per cent compared to the conventional N fertilisation schedule. They concluded that the drip irrigation is superior to rain-fed irrigation, and the optimal N fertilisation schedule can boost the economic benefits up to 8.4 to 12.4 per cent.

Rugira *et al.* (2021) determined the suitable irrigation management and optimum sowing dates to ensure the stability of spring maize production using DSSAT CERES-Maize Model at the Loess Plateau (Northern China). The model was calibrated using the full irrigation treatment for the growing seasons 2017–2019, with crop data, such as plant phenological phases, above ground biomass, crop yield, and leaf area index. The calibrated results showed very good consistency between observed and simulated data with nRMSE value ranging from 0.77per cent to 21.6per cent. The calibrated model's performance was evaluated using field values of crop yield, above ground biomass, LAI, soil water quality, and water usage efficiency. The model evaluation was found to be significant, with suitable nRMSE varying from 1.9 per cent to 25.3 per cent. Study indicated that, in the event that rainfall is inadequate to meet the crops' water demands, maize yields can be raised by using irrigation and changing the sowing date.

2.8 Performance of DSSAT in Estimating Maize Yields

Liu *et al.* (2011) characterized maize yield and nitrogen dynamics in a 50-year maize production study at Woodslee, Ontario, Canada with DSSAT CERES-Maize model. Continuous maize with fertilisation (CC-F) and continuous maize without fertilisation (CC-NF) treatments were chosen for long-term maize yield simulations using a sequential model (1959–2008). Near-surface soil mineral N and cumulative soil nitrate loss were fairly well simulated by the CERES-Maize model in the CC-F treatment, with n-RMSE = 62 and 29 per cent, respectively.

Sivarajan (2011) analysed the capability of the DSSAT model in simulating crop responses and the sensitivity of the model output to input parameters with spatial attention to the determinants of the model response to the practice of conservation agriculture.

Anothai *et al.* (2013) tested the CSM–CERES–Maize model's ability to simulate the effect of various irrigation levels on maize (Zea mays L.) under semi-arid conditions, growth and development, evapotranspiration, and soil water content. Irrigation treatments included 100, 85, 70, 55, and 40 per cent of full crop water requirements, respectively. Bowen ratio-energy balance (BREB) instrumentation was used to calculate daily evapotranspiration (ET). The ET approach had a normalised root mean square error of less than 10.2 per cent for grain yield and 36.8 per cent for final biomass, while the FAO-56 PM approach had a normalised root mean square error of 12.1 per cent for grain yield and 26.0 per cent for final biomass. With both ET approaches, the model could simulate daily and seasonal ET to within 12 per cent of calculated ET. They find rational agreement between the simulated and observed water content for all four soil depths of the six irrigation treatments which were derived from both ET approaches.

Malik and Dechmi (2019) evaluated the DSSAT model by using field data during the 2015-16 season in Spain. Crop and soil type data from 54 plots of farmers' fields were used for model calibration and evaluation during the 2015 and 2016 irrigation seasons. Two irrigation scenarios were applied in eight soil types based on the current irrigation applied by farmers and the optimum irrigation adjusted to crop requirement. The applied irrigation revealed that the potential reduction in the seasonal irrigation depth for maize-SS (short-season maize) (27 per cent), maize-LS (long season maize) (18 per cent). The study shows that the, DSSAT model demonstrated good performance among maize, wheat, barley and sunflower crops.

Worou *et al*. (2019) predicted yield of maize variety Massongo for the time periods of 1980–2010 (historical) and 2021–2050 (2030s, near future) across 8 agronomic practices including the fertilizer input rates recommended by the national extension services (28 kg N, 20 kg P, and 13 kg K ha^{-1}). The performance of the crop model DSSAT 4.6 for maize was first evaluated using on-farm experimental data that encompassed two seasons in the Sudano-Sahelian zone in six contrasting sites of Central West Burkina Faso. The efficiency of the crop model was evidenced by reliable simulations of total above ground biomass and yields after calibration and validation. The root-mean-square error (RMSE) of the entire dataset for grain yield was 643 kg ha^{-1} and 2010 kg ha^{-1} for total aboveground biomass. Three regional climate change projections for Central West Burkina Faso indicate a decrease in rainfall during the growing period of maize. All the three scenarios project that the decrease in rainfall is to the tune of 3-9 per cent in the 2030s under RCP4.5 in contrast to climate scenarios produced by the regional climate model GCM ICHEC-EC-Earth which predicted an increase of rainfall of 25 per cent under RCP8.5. Simulations using the CERES DSSAT model revealed that maize yields without fertilizer show the same trend as with fertilizer in response to climate change projections across RCPs. Under RCP4.5 with output from the climate model ICHEC-EC-Earth, yield can slightly increase compared to the historical baseline on average by less than 5 per cent. In contrast, under RCP8.5, yield is increased by 13–22 per cent with the two other climate models in fertilized and non-fertilized plots, respectively. Nevertheless, the average maize yield will stay below 2000 kg ha−1 under nonfertilized plots in RCP4.5 and with recommended mineral fertilizer rates regardless of the RCP scenarios produced by ICHEC-EC-Earth. Giving the fact that soil fertility improvement alone cannot compensate for the adverse impact of future climate on agricultural production particularly in case of high rainfall predicted by ICHEC-EC-Earth, it is recommended to combine various agricultural techniques and practices to improve uptake of nitrogen and to reduce nitrogen leaching such as the splitting of fertilizer applications, low-release nitrogen fertilizers, agroforestry and any other soil and water conservation practices.

2.9 Critiques on the Literature Reviewed

Past studies on surface irrigation to maize reported that identification of most critical stage such as flowering and applying full irrigation during that stage is the best option in order to get better yields and higher water use efficiency. Studies also showed that use of deficit irrigation or increasing irrigation interval during grain filling stage of maize does not much affect crop growth and yields. Accumulation of N fertilizers in plants was higher under full irrigation treatment than deficit or partial irrigation. Some studies reported that yield increase can be detected only under small and medium amount of fertilizer doses, whereas at higher doses a plateau is reached where it is not worth applying more nutrients. In drip irrigation it is possible to apply small amounts of water and fertilizers more frequently. The literature reviewed in the previous sections clearly demonstrated that drip irrigation even in close growing crops improves the yield, enhance the quality of produce, and gives higher water and fertilizer use efficiency.

Some studies were also focused on effect of irrigation and fertigation levels on maize growth yields. The moisture distribution studies revealed that under optimum drip irrigation level there is sufficiency of moisture in the crop root zone resulting in to higher yields thereby increasing the irrigation water use efficiency. The application of fertilizers through micro irrigation also improved the quality of produce with enhancement in the nutrient uptake, higher fertilizer use efficiency and saving in fertilizers. The findings also indicated the positive effects of interaction between irrigation and fertigation on growth, yield and quality of crop produce. All these studies indicated that the maize growth and yield is better in full irrigation and fertigation treatments. However, there is scope to reduce the water and fertilizer amount slightly without affecting much yields.

The review also reveals that most studies on drip fertigation used drip irrigation schedule based on pan evaporation without considering crop coefficient and fertigation levels. The literature demonstrates that irrigation scheduling based on ETc seems to be more precise although have not been studied earlier due to absence of required meteorological data. Hence the concept of irrigation scheduling based on ETc needs to be used for precise water management under drip irrigation.

Crop Water productivity (CWP) needs to be increased under the situation where population is increasing with the decrease in share of irrigation water. This requires a decision support system at local level before the start of crop season to predict the crop yields in response to water and fertilizer and predict crop responses for present and future climatic changes under various crop management options. Crop growth simulation models can act as decision support system in evaluating the effects of various crop management options including water and fertilizer deficits on sustainable crop yield. Although, literature shows the availability of crop simulation models for simulating crop growth and yield predictions under varying crop management options in general, they have not been specifically tested for most important cereal crop like maize under semi-arid conditions of Marathwada.

A Decision Support System for Agrotechnology Transfer (DSSAT), developed by Hoogenboom *et al.* (1994) integrates various crop simulation models for grain legumes, cereals, vegetables and oilseeds with weather, soil and experimental databases. The CERES-Maize model of DSSAT was proven as efficient tool for simulation of agronomic characteristics in maize hybrids in tropical conditions. However, there is a need to test DSSAT for semi-arid regions of Marathwada where there is lot of potential for maize cultivation. After calibration and validation, the model could be used to predict the maize crop yields under various limiting factors including water and fertilizers in the region.

Thus, there is need for a systematic simulation study to evaluate the effect of irrigation and fertigation levels on growth and yield of maize to explore the various management options.

CHAPTER -III

MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the experimental details, material used and methods followed during the present investigation entitled 'Crop growth simulation of maize using DSSAT model'.

3.1 Experimental Site and Data

The field experiment was conducted during post monsoon season of the year 2017-18 (Sept 8 to Dec 29, 2017) at AICRP on Irrigation Water Management, Vasantrao Naik Marathwada Agricultural University, Parbhani. The geographical location of the experimental site (Parbhani) is 76^0 47' E longitude and 19^0 16' N latitude with an altitude of 409 m above mean sea level (MSL). The observations recorded during this experiment conducted by Chandan (2018) have been used for simulation studies of present investigation.

3.2 Weather and Climate

The weather prevailing at Parbhani can be categorized as tropical and semi-arid on annual basis whereas within the seasons it can be classified as sub-humid to humid in monsoon, semiarid in winter and arid in summer season. The region falls in an assured rainfall agro-climatic zone with average annual precipitation of 889 mm mainly concentrated during June to September from South West monsoon. The daily mean maximum temperature varies between 29.9^0C in winter (December) to 41.7^0C in summer (May). The mean minimum temperature varies from 10.2^0C to 26.4^0C during winter (January) and summer (May), respectively. The minimum and maximum relative humidity varies between 15 to 63 and 33 to 100 per cent, respectively.

The daily weather data during field experimental period was collected from the IMD recognized meteorological laboratory of VNMKV Parbhani adjacent to the field where crop experiments were conducted. The prevailing weather with the major values of meteorological parameters during the experimental period after sowing till the harvest is shown in Table 3.1.

Table 3.1: Ranges of micro weather parameters during experimental period

Parameter		Experimental period (September - December, 2017)
Air temperature (^oC)	Max	36.0
	Min	5.6
	Mean	23.8
Relative humidity(^oC)	Max	100
	Min	15
	Mean	61.0
Wind speed (kmph)	Max	8.0
	Min	1.3
	Mean	3.0
Actual sunshine(h)	Max	10.2
	Min	0.0
	Mean	7.7
Precipitation (mm)	Total	334.9

The daily values of important meteorological parameters for the period of experimentation are presented in Appendix-A and depicted in Fig. 3.1 through 3.5.

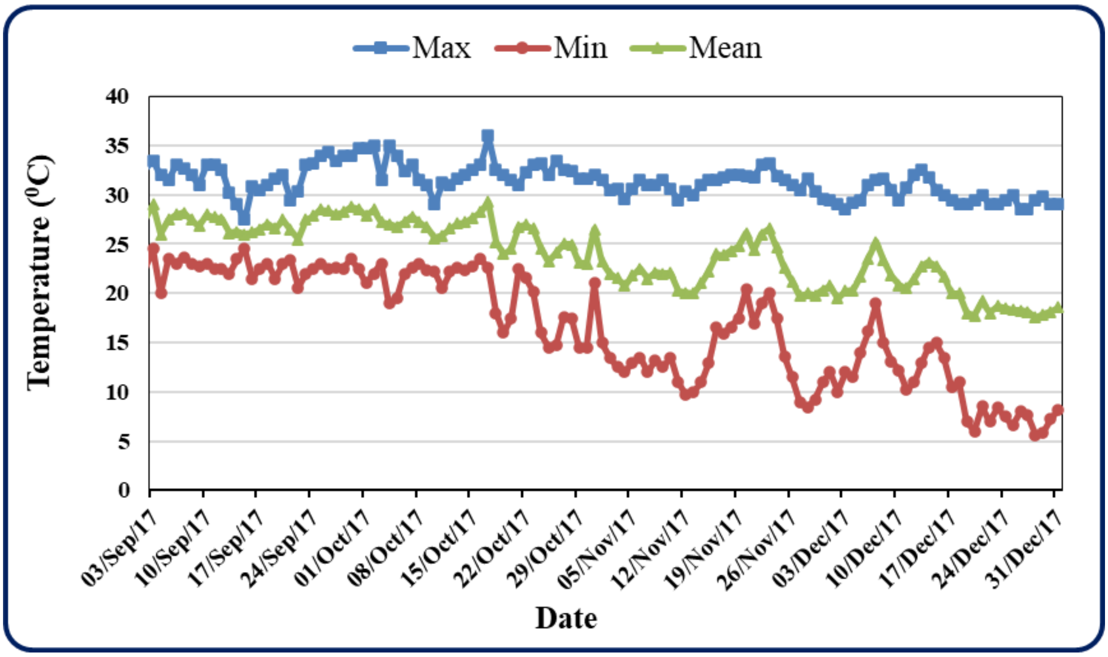

Fig. 3.1: Variation of daily temperature during the experimental period

During the field experiment the mean air temperatures were between 18-29^{0}C adequate for the growth of maize (Doorenbos *et al.*, 1979). The temperatures generally were low to moderate after 4th November suitable for the growth of maize. However there after the temperature decreased around 20^{0}C and reaches minimum on 28th December 2017. The exceptionally high difference in maximum and minimum daily temperatures was observed after 1st November 2017 (Fig.3.1).

In general, the mean relative humidity was higher at the beginning of the crop period due to rains which is suitable for the initial growth of crop (Fig. 3.2).

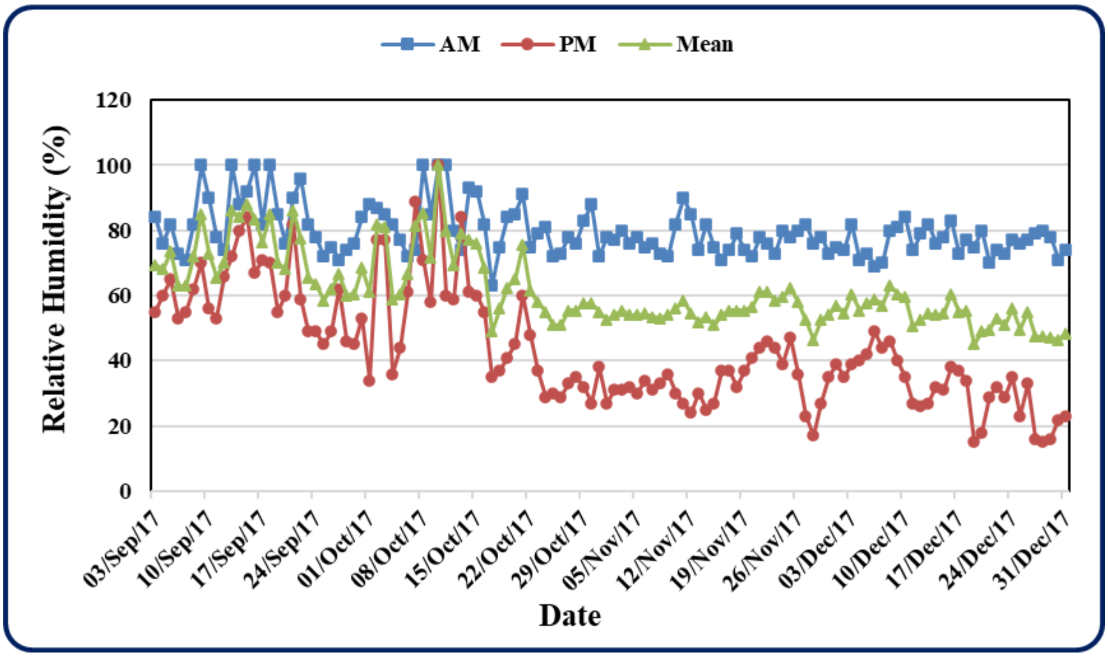

Fig. 3.2: Variation of daily relative humidity during the experimental period

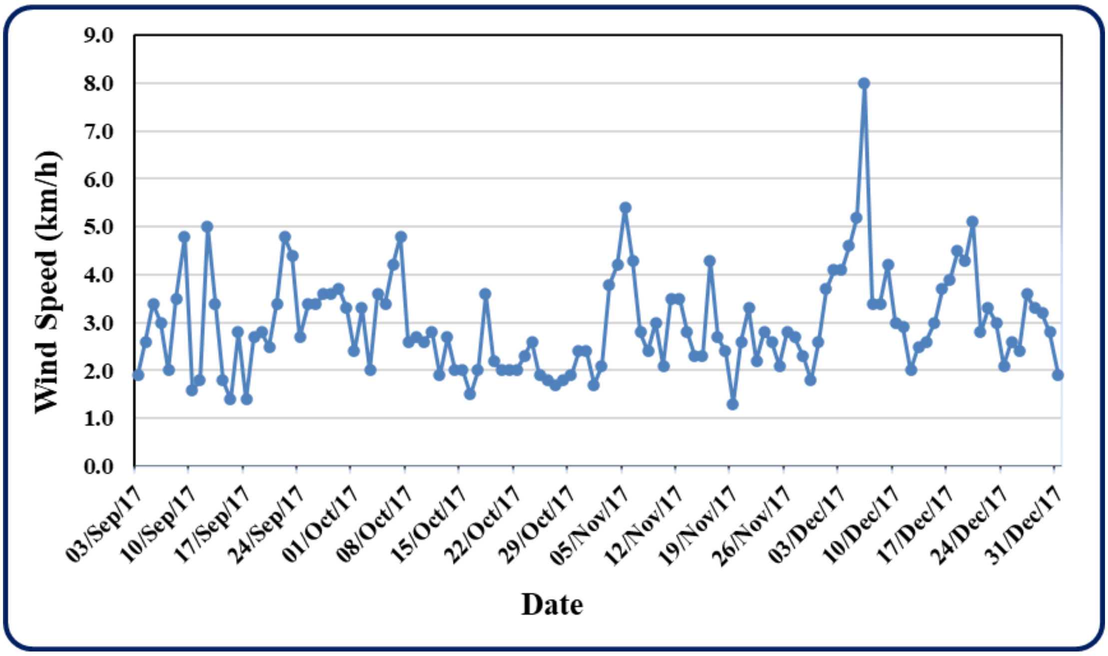

Fig. 3.3: Variation of daily average wind speed during the experimental period

While the average wind velocity during the experimental period was well within the limit (3.0 km/hr), it varied between 1.3 to 8.0 km/hr and did not reach above 8.0 km/hr (Fig. 3.3).

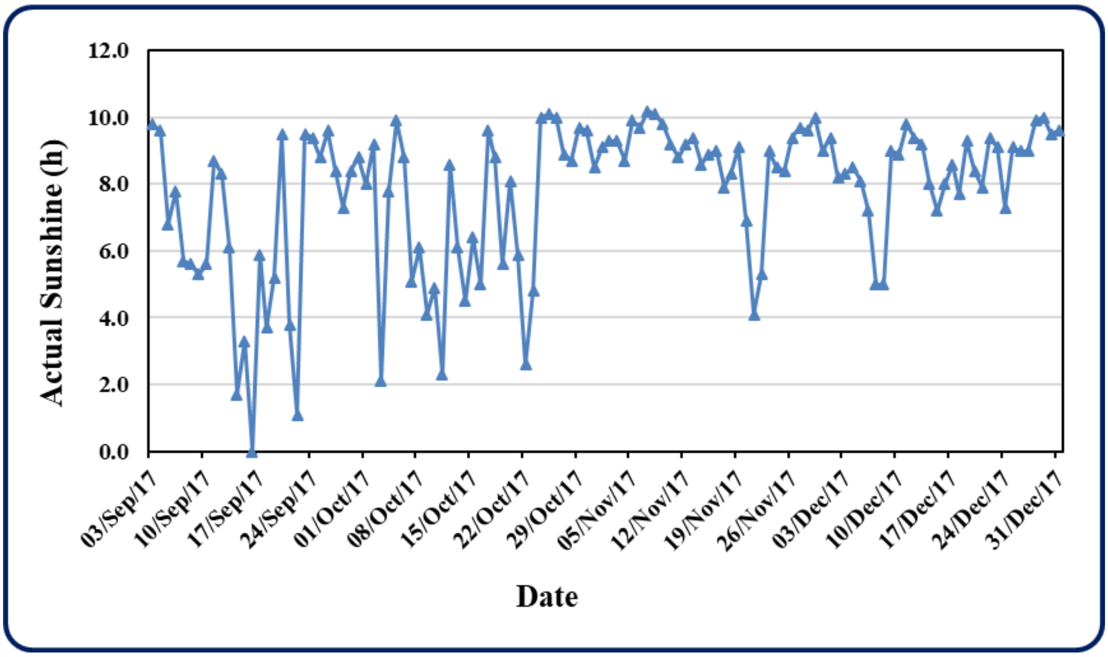

Fig. 3.4: Variation of daily actual sunshine hours during the experimental period

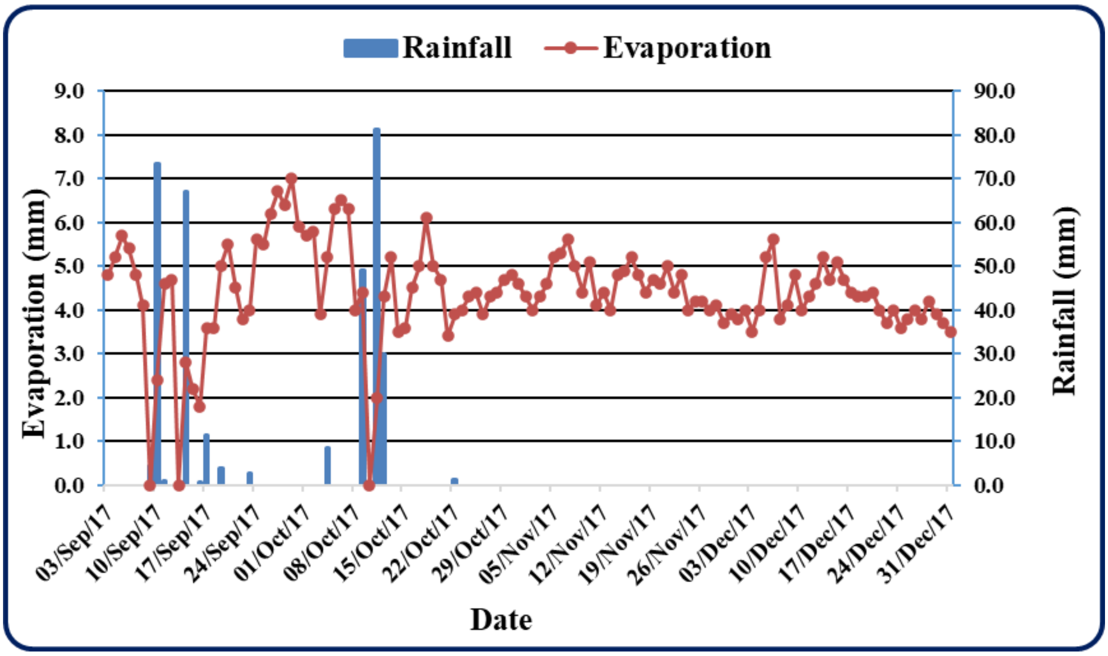

Fig. 3.5: Variation of daily rainfall and evaporation during the experimental period

The actual sunshine hours for the experimental period varied significantly with the maximum value of 10.2 hours (Table 3.1). Except during 45 DAS, the actual sunshine hours remained around 8 to 10.0 hrs, which was sufficient for better growth of crop (Fig. 3.4).

The daily measured evaporation by USWB Class-A pan and rainfall during the experimental period is shown in Fig. 3.5. The major rainfall events above 60 mm occurred thrice in the initial period after sowing on 9th September, 13th September and on 10th October, respectively which have reduced the possibility of irrigation during that period. However, thereafter there was no rainfall during rest of the crop growth period. The pan evaporation was well within 3 to 7 mm till the harvesting. The values of pan evaporation were further compared and used for irrigation scheduling of the maize crop.

3.3 Soil Characteristics of Experimental Plot

Soil of the experimental plot was vertisol (deep black), clayey in texture and having the uniform depth up to 1.20 m. The experimental plot had 0.2 percent slope (along the lateral) and 0.5 percent in west to east direction (along the submain). The random soil samples were collected from the different places in the experimental plot for 0-15 and 0-30 cm depth with the help of screw auger using standard procedure (Sacheti, 1985) and composite layer wise representative sample were made. The soil was air dried ground and sieved through 2 mm sieve. The physico-chemical properties of soil were determined by adopting the standard methods and procedures.

3.4 Cropping History

The cropping history of the experimental plot for the preceding three years is given in Table 3.2.

Table 3.2: Cropping history of the experimental plot

Sr. No.	**Year**	**Post monsoon**	***Rabi***	**Summer**
1	2014-2015	Fallow	Dhaincha	Groundnut
2	2015-2016	Post *monsoon* Maize	----------	Groundnut
3	2016-2017	Post *monsoon* Maize	Cabbage	Fallow
4	2017-2018	Post *monsoon* Maize		

3.5 Crop

Maize is usually grown throughout the year in all seasons which requires a warm and slightly moist climate. The required optimum temperature range is between 15 to 35^0 C. The high temperatures above 35°C and below 12°C do not suit maize cultivation. Maize (*Zea mays L.)* a late *kharif* season hybrid variety DKC-9149 was selected for the present field experiment. The growing period of maize was 112 days (between 100 to 120 days).

3.6 Experimental Details

As per the cropping history the experimental plot was fallow during summer season. Before sowing the plot was deeply ploughed and well pulverized with a tractor-operated plough followed by harrowing with spring tooth harrow. The tractor-operated rotavator was also used to crush the clods followed by planking to level the field and to bring soil in good tilth.

The drip irrigation system was laid out as per the layout plan. Field experiment comprising of drip irrigation levels as the main factor and fertigation levels as sub factor in split plot design with three replications was planned. The treatment details are summarized below:

Experimental Treatments

a) Main (Drip Irrigation levels)

I_1 - Irrigation with 1.0 ETc depth

I_2 - Irrigation with 0.8 ETc depth

I_3 - Irrigation with 0.6 ETc depth

b) Sub (Fertilizer levels)

Recommended dose of fertilizer (RDF) = 150:75:75; N: P_2O_5:K_2O kg ha^{-1}

F_0 - (Control) No fertilizer

F_1 - 100% RDF through fertigation

F_2 - 75% RDF through fertigation

F_3 - 50% RDF through fertigation

F_4 - 100% RDF through soil application

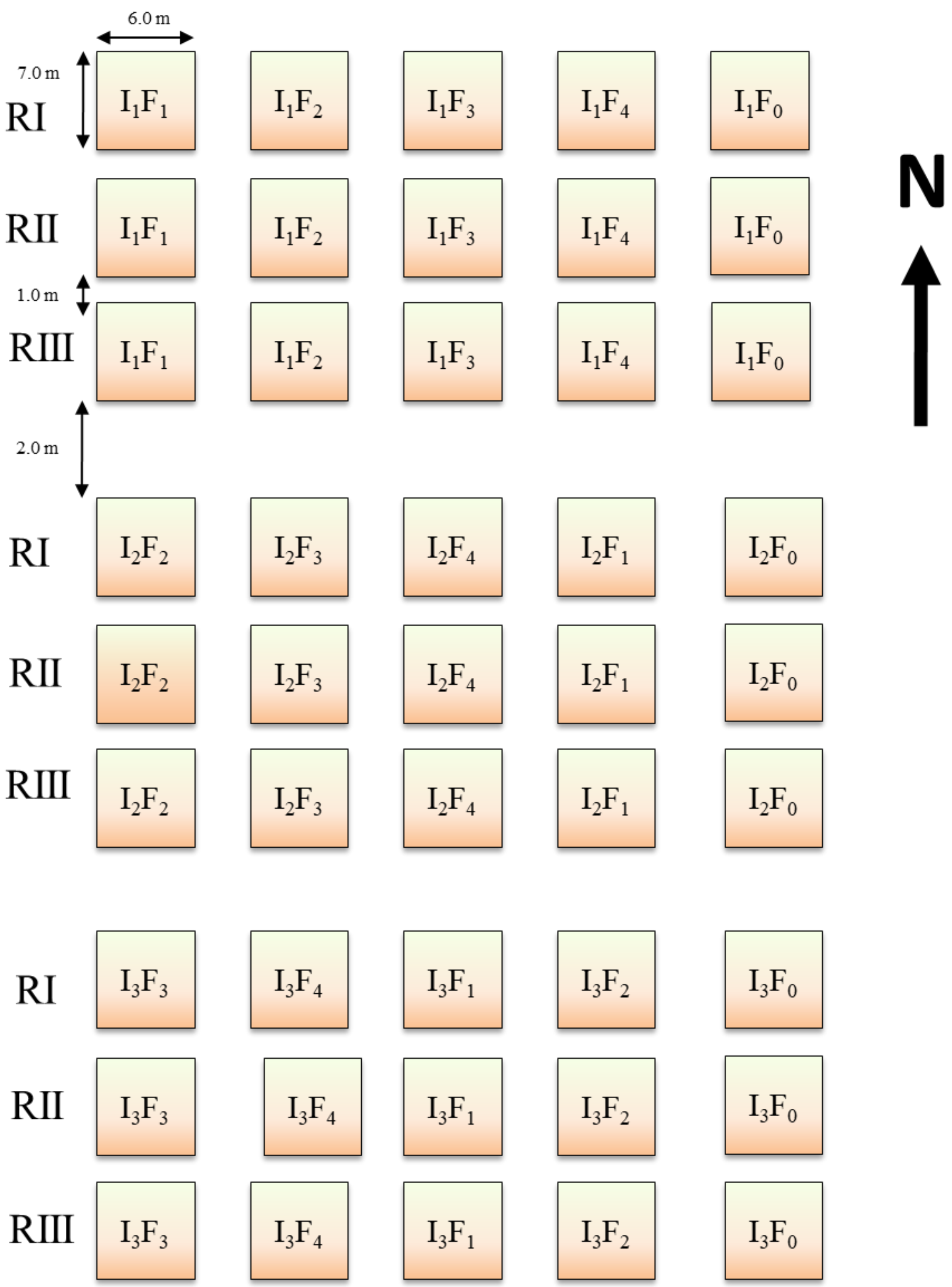

Fig. 3.6 Layout of experimental plot

Details of experimental layout

1.	Name of Crop	:	Maize
2.	Experimental Design	:	Split Plot Design
3.	Plot Size: A) Gross	:	7.0 × 6.0 m^2
	B) Net	:	3.6 × 4.4 m^2
4.	Number of Treatments	:	8
5.	Number of Replications	:	3
6.	Number of Plots	:	45
7.	Spacing	:	75- 45x15 cm
8.	Method of Sowing	:	Dibbling
9.	Fertilizer Dose	:	150:75:75; N: P_2O_5:K_2O kg ha^{-1}

Each plot was of 7.0 x 6.0 m with the net plot size of 3.6 m × 4.4 m. Dry seeds of hybrid maize variety DKC-9149 were used for the sowing. Sowing was done on 8th November 2017 on paired row with a strip of 75 cm between pairs. The inter-row spacing was 45 cm whereas intra-row spacing was 15 cm. A buffer strip of 1 m and 2 m was kept between two adjacent plots and within replications, respectively. Irrigation was not applied immediately after sowing since there was an occurrence of rainfall.

3.7 Field Operations

The schedule of various field operations carried out during the experiment is presented in Table 3.3.

Intercultural operations

In order to maintain optimum and uniform plant population in each plot the gap filling was done on 10th day after sowing whereas the thinning was done at 20th day after sowing. The intercultural operations including two hand weeding at an interval of 28 days and earthling up at 58 DAS were carried out. Hand weeding was done to keep the crop weed free whereas the earthing up was done to keep the soil loose and porous for suitable aeration, moisture conservation and better establishment of crop root system.

Table 3.3: Schedule of field operations carried out in the experimental plot

Sr. No.	Operations	Frequency	Date of operation
1	Ploughing	1	27/08/2017
2	Harrowing	1	02/09/2017
3	Clod crushing and Cleaning	1	04/09/2017
4	Field layout	1	06/09/2017
5	Layout of drip irrigation system	1	06/09/2017
6	Sowing	1	08/09/2017
7	Gap filling	1	18/09/2017
8	Thinning	1	28/09/2017
9	Hand-hoeing	1	08/10/2018
10	Earthing up	1	08/10/2017
11	Hand weeding	2	05/10/2017 05/11/2017
12	Plant protection: Spraying of insecticides	2	06/10/2017 31/10/2017
13	Irrigation	Alternate day	As per treatment
14	Fertigation	As per treatment	As per treatment
15	Harvesting	1	29/12/2017

Plant protection

The first spraying with Detametherin 1% + trizophos 35 EC (Tridel) 10ml/10liters of water was done in early stages of crop at 28 DAS to protect it from *Jassids* and white fly. The second spraying was done at 53 DAS using Detametherin 1% + trizophos 35 EC (Tridel) (10ml/10liter of water) to protect the crop from leaf hopper sucking pest, the stem borer and cob borer.

Harvesting and threshing

Crop was harvested when almost all the cobs were dried and plants turned yellowish in color. The border rows ware removed first and then harvesting of net plot was completed. The harvested produce was dried in sun for 2 to 3 days in the respective plot and then it was threshed with thresher. The treatment wise weight of biomass and seed per plot after threshing were recorded.

3.8 Drip Irrigation Setup

Drip irrigation system was installed according to the plan of experiment shown (Fig. 3.6) using 16 mm inline laterals with emitters of 2.4 lph discharge spaced at 40 cm. Separate valve arrangement was provided for scheduling of irrigation and fertilizers to the individual plots. The drip irrigation system consisted of main, submain laterals, control valve, filter, pressure gouges and venturi applicator for fertilizer application.

Pump and pipeline: A horizontal open well submersible pump (5 HP) coupled with an electric motor was used for pumping water from the open well. Well water was diverted to the field through 75 mm pipe main and three separate HDPE sub mains of 63 mm with control valves were connected to main to distribute water to the individual plots.

Laterals: The inline laterals of 16 mm diameter having 2.4 lph dripper discharge and 0.4 m dripper spacing were connected to sub main with the help of grommet take off. End plugs were used to close the ends of laterals. The control valve was fitted before venturi and filtration unit to bypass the water and at sub main to divert the water to respective plots during irrigation and fertigation.

Filtration unit: Filtration unit consisted of screen and disc filter of 25 m^3h^{-1} capacity installed after pumping and fertigation unit, respectively. The filters were periodically cleaned to avoid the clogging of the system. Pressure gauges were fitted at the control unit for monitoring the fertigation and filtration unit. The inlet and outlet pressures were adjusted with the help of control and bypass valves at each location.

Fertigation unit: For the fertigation, Venturi applicator was connected to the system before filtration unit to apply the fertilizer through drip system. Venturi works on the principle of pressure difference and this pressure difference was created with the help of control valves fitted to the main line and excess water was by-passed to the well**.**

3.9 Irrigation Scheduling

Drip irrigation system was run at 1.0 kg cm^{-2} operating pressure. Irrigation water was applied through drip irrigation system at an alternate day as per the irrigation levels at 0.6, 0.8 and 1.0 times ETc throughout the growing season. The daily crop evapotranspiration was estimated using crop coefficient and reference crop evapotranspiration using the following equation.

$$ETc = Kc. ETo \qquad .... (3.1)$$

Where,

ETc - crop evapotranspiration [mm d^{-1}],

Kc - crop coefficient [dimensionless],

ETo - reference crop evapotranspiration [mm d^{-1}].

For estimation of reference crop evapotranspiration (ETo), daily meteorological data as collected from the meteorological observatory located adjacent to experimental plot was used. The reference crop evapotranspiration was estimated using the FAO Penman-Montieth equation (Allen *et al.*, 1998):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad .... (3.2)$$

Where,

ETo- Reference evapotranspiration (mm day^{-1}),

Rn - Net radiation at the crop surface (MJ m^{-2} day^{-1}),

G - Soil heat flux density (MJ m-2 day^{-1}),

T -Mean daily air temperature at 2 m height (°C),

u_2 -Wind speed at 2 m height (m s^{-1}),

es - Saturation vapour pressure (KPa),

ea-Actual vapour pressure (KPa),

(es-ea) -Saturation vapour pressure deficit (KPa),

Δ -Slope vapour pressure curve (KPa °C^{-1}),

γ -Psychrometric constant (KPa °C^{-1})

3.9.1 Crop Coefficient

The crop coefficient varies according to crop type, growth stages and varying local climatic conditions. Hence, stage wise crop coefficients of maize derived from FAO 56 was modified as per the climatic parameters of Parbhani by following the standard procedure and guidelines suggested in (Allen *et al.*, 1998). The modified crop coefficients developed for Parbhani (Chandan, 2018) were used for estimation of daily crop water requirement.

3.9.2 Volume of irrigation water

Volume of water to be applied per plant through drip irrigation was estimated on the basis of ETc and area covered per plant for each treatment. Based upon the discharge capacity of the drippers, drip system was operated for a particular time so as to apply a given volume of water per plant.

The volume of water to be applied according to irrigation level per plot or strip was calculated by using the equation below:

$$V = \mathrm{ETc} \times \mathrm{A} \qquad \text{…. (3.3)}$$

Where,

V= Volume of water to be applied (liter/day/plot)

ETc= crop evapotranspiration (mm d^{-1}),

A= Area of the plot or strip (m^2).

Similarly, the time of operation of drip system (t) for each run for the particular plot or strip was calculated by using the following equation:

$$\mathrm{t} = \frac{\mathrm{V}}{\mathrm{q} \times \mathrm{Ne}} \times 60 \qquad \text{…. (3.4)}$$

Where,

t = Time of operation of system, min

V = Volume of water to be applied (liter/day/plot)

q = Average emitter discharge, lph

Ne = Number of emitters per plot

3.9.3 Effective rainfall (mm)

The effective rainfall depends on number of parameters. But as a general rule for soils, smaller quantum of rainfall is more effective and larger ones less. This is true because smaller quantum can be easily accommodated in the soil but once the soil reaches its field capacity, no more rains can be stored and are transformed into run off. Effective rainfall was estimated using USDA-SCS equation as:

$$P_{eff} = P_{Tot} \times \frac{125 - 0.2\, P_{Tot}}{125} \qquad \text{.... (3.5)}$$

Where,

P_{Tot} = Precipitation (mm)

P_{eff} =Effective rainfall (mm)

The treatment wise irrigation water applied during the crop growing season is presented in Appendix-B.

3.10 Fertilizers and Manures

The recommended dose of the fertilizer for maize i. e. 150:75:75 NPK kg/ha was used in the experiment. For soil application (treatment F_4) the source of major nutrients NPK used in the experiment was in the form of urea (46 per cent N) applied in two splits, 50% each at the time of sowing and at 30 DAS, whereas single superphosphate (16 per cent P_2O_5) and potassium nitrate (60 per cent K_2O) were applied once at the time of sowing. Under drip fertigation, NPK were applied through fertilizers of different grades (Urea, 46:0:0, Mono Ammonium Phosphate; 12:61:00 and Potassium Nitrate, 13:0:45) in 8, 4 and 8 splits, respectively at an interval of 10, 20, 30, 40, 50, 60, 70 and 80 DAS as per the planned schedule. The fertigation schedule used in the experiment is shown in Table 3.4.

Table 3.4: Schedule of fertilizer application during the crop growth period

(For 100 per cent recommended dose of fertilizers)

Time of application	Per cent of fertilizer dose Applied through soil			Percent of fertilizer dose applied through fertigation		
	N	P	K	N	P	K
At sowing	50	100	100	-	-	-
10 DAS	-	-	-	12.5	25	12.5
20 DAS	-	-	-	12.5	25	12.5
30 DAS	50	-	-	12.5	25	12.5
40 DAS	-	-	-	12.5	25	12.5
50 DAS				12.5		12.
60 DAS	-	-	-	12.5	-	12.5
70 DAS	-	-	-	12.5	-	12.5
80 DAS	-	-	-	12.5	-	12.5

The amount of major nutrients (NPK) applied under different treatments is calculated during the crop growing season is presented in Appendix-C.

3.11 Crop Growth and Yield Parameters

Crop growth observations such as plant height, total number of functional leaves and leaf area per plant (leaf area index) were recorded by randomly selecting five plants. These plants were properly labelled and growth parameters were monitored on them in net plot area. The crop growth parameters were recorded on plants at regular intervals (15 days) viz. 30, 45, 60, 75 and 90 DAS and at the time of harvest.

The observations at harvest include number of cobs per plant, weight of cob per plant, weight of spindle per plant, weight of husk per plant, total grain, stover yield, biological yield and harvest index per plot.

3.11.1 Plant Height

The plant height was measured from the base of plant to the longest point with the help of scale and an average value was worked out for each treatment at regular intervals (15 days) viz. 30, 45, 60, 75 and 90 DAS and at the time of harvest.

3.11.2 Leaf Area Index (LAI)

The leaves from each plant were picked up for dry matter studies and categorized into three categories viz. small, medium and large. The grade wise leaves were counted and their frequency was recorded. The representative sample of each of those grades was observed for linear measurement of maximum length and breadth and then leaf area was calculated by following formula.

$$A = L \times B \times N \times F$$

Where,

A : Leaf area per plant (cm^2)

L : Maximum length of leaf (cm)

B : Maximum breadth of leaf (cm)

N : Number of functional leaves

F : Leaf area constant (conversion factor = 0.797)

Total leaf area (cm^2) was estimated by summation of leaf area of each group multiplied by leaf area constant.

Leaf area index is the measure of crop growth per unit area since the crop yield is to be assessed per unit of area instead of per plant. Therefore, leaf area existing on one plant was considered as leaf area produced on unit ground area (actual area of plant). The measure is known as leaf area index (LAI) and was calculated using equation (Watson, 1952):

$$\text{LAI} = \frac{\text{Leaf area per plant } (\text{cm}^2)}{\text{Ground area } (\text{cm}^2)}$$

3.11.3 Dry matter production

The individual plant from the respective net plot was picked up at time of every observation. Firstly, the roots of plant were removed and the plant was chopped in to pieces and kept in the labeled brown paper bag treatment-wise. The plants were dried first in the sunlight followed by drying in the thermostatically controlled oven at 60^0C until constant weight was obtained. The final constant weight was recorded as dry matter (g/plant).

3.11.4 Grain and Stover yield

The cobs obtained from all plants of net plot were dried. These cobs were dehusked and shelled by maize sheller. The grains were dried and weighed and thus grain yield (kg) per net plot was recorded.

Weight of cobs per plant

Weight of cobs after removal from plant was taken on analytical balance.

Stover yield per plot

Stover yield obtained from net plot was recorded after sun drying for 6 to 8 days.

Spindle weight per plot

Spindle weight per plot was recorded by removing the grains from all the cobs of a plot.

Biological yield per plot

The weight of dry produce of stover along with cobs of the respective plot was taken as biological yield per plot.

3.11.5 Harvest index

The harvest index was calculated by using the following formula and expressed as percentage.

$$\mathrm{H.I}(\%) = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.12 Crop Growth Simulation

Crop growth simulation is a formal way to represent the quantitative knowledge about how a crop grows in interaction with its environment. Various crop growth simulation models are being used for simulating the crop growth for assessing the impact of weather parameters, water deficit and other conditions like soil on crop growth and yield including yield forecasting. These models include DSSAT, Aqua-Crop, EPIC, Info-Crop, CropWat and Crop-Syst etc. For the present study DSSAT Model is used for simulating the maize crop growth under varying irrigation and fertilizer levels.

3.12.1 The DSSAT

The Decision Support System for Agrotechnology Transfer (DSSAT) is one such software application program that comprises crop simulation models for over 40+ crops (as of DSSAT Version 4.7.5) as well as tools to facilitate effective use of the models. The DSSAT was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project. DSSAT includes improved application programs for seasonal, spatial, sequence and crop rotation analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate variability, climate change, soil carbon sequestration, and precision management. Its initial development was motivated by a need to integrate knowledge about soil, climate, crops, and management for making better decisions about transferring production technology from one location to others where soils and climate differed (IBSNAT, 1993; Uehara and Tsuji, 1998).

3.12.2 DSSAT file structure

The DSSAT model has its own format of organize different files such as input, output and experiment data files.

3.12.2.1 Experiment Input files

The crop models of DSSAT require daily weather data, soil surface and profile information, and detailed crop management as input. To create experimental input file, the different Input files such as weather and soil, crop and cultivar are required. For present experiment the crop code used in DSSAT v4.7.5 for Maize is MZ.

3.12.2.2 Crop management and experimental data (field experiments) file

Experimental data including irrigation and fertigation treatment as par combinations used to create experimental input file. It also requires data related to experimental conditions including field characteristics, soil analysis data, initial soil water, seed bed preparation, cultivars, planting geometries, irrigation, fertilizer, organic amendment, tillage, chemical application, harvest and simulation control options. Experimental file is referred as FILEX for specific experiment. For this experiment (MUPA1701.MZX) is created to run the experiment for first trial considered for the treatment (I_1F_1: I_1-Irrigation with 1.0 ETc depth and F_1-100% RDF through fertigation).

3.12.2.3 Weather data file

The model requires daily weather data for the duration of the crop growing season. The weather data (daily basis) such as minimum and maximum temperature, precipitation or rainfall, total solar radiation or sunshine hours, relative humidity and average daily wind speed was collected from IMD recognized meteorological laboratory of VNMKV Parbhani to create weather file (VNPB.WTH).

3.12.2.4 Soil data file

The data related to soil profile, soil water, soil nitrogen and root growth characteristics, soil taxonomic classification, soil texture and other descriptive data of the experimental site were used to create the soil file (PARBHANI SOIL.SOL). The soil data was obtained after physical and chemical analysis of soil samples of experimental plots The data in the soils file are arranged so that entries need to be made only for the aspects simulated.

3.12.2.5 Genetic Coefficients input file

Crop and cultivar file contains three files, FILEC as cultivar/variety coefficients for particular crop species, and model. FILEE as ‘ecotype’ for particular crop species and FILEG contains crop (species) specific coefficients for a particular model (CERES-Maize model for maize). The crop genetic coefficients for the maize hybrid DKC-9149 were derived from genotype coefficient, which includes physiological processes such as development, growth and photosynthesis for the individual crop variety. The model run these coefficients on the basis of following factors:

P1- Thermal time from seedling emergence to the end of the juvenile phase (expressed in growing degree days above a base temperature of 8 $^{\circ}$C) during which plant is not responsive to changes in photoperiod.

P2- Extent to which development (expressed as days) is delayed for each hour increase in photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).

P5- Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 $^{\circ}$C).

G-2- Maximum possible number of kernels plant^{-1}.

G-3- Kernel filling rate during the linear grain filling stage under optimum conditions (mg day^{-1}).

PHINT (Phyllochron interval)- The interval in thermal time (degree days) between successive leaf tip appearances.

Rani *et al*., (2016) calibrated and validated Ceres-Maize model (DSSAT v 4.5) for maize hybrid variety (Dekalb Super 900M) which is closely related to DKC-9149 variety used in the present investigation. Hence the genetic coefficients of the Dekalb Super 900M are modified and used for maize variety DKC-9149 in present investigation.

3.12.2.6 Output files

There are 22 output files created after running each simulation for the experiment with specific model (CERES-Maize). The two main output files namely; OVERVIEW.OUT contains overview of inputs and major crop soil variables where as SUMMARY.OUT contains summary information of crop and soil input and output variables. In addition, model provides output files containing detailed simulation results, simulated seasonal growth and development, water balance, nitrogen balance, phosphorous balance and soil water balance. These output files can be overwritten by starting new simulation run for the specific experiment.

3.12.3 DSSAT model inputs

The weather files were created for the field experiment following the procedure suggested in the user manual. Information regarding longitude, latitude, elevation, average air temperature and daily input data of solar radiation, maximum and minimum air temperatures and rainfall was stored in the weather file FILEW. The soil profile of experimental site (0-65 cm) was divided into six horizons characterized by five sets of field averaged soil characteristic data, which were ultimately stored in the file SOIL.SOL. The data consisted of depth-wise physical and chemical properties of soil including soil texture, moisture contents at permanent wilting point, field capacity and saturation, electrical conductivity, pH, total nitrogen and organic carbon content, etc. The morphological and physiological characteristics and genotype specific inputs required for simulation were stored in genotype file MZCER047CUL. These genotype inputs for maize variety Dekalb Super 900M were modified and used for variety DKC-9149 for the simulation.

Experiment file FILEX was created with twelve combinations of three irrigation levels and four fertigation levels using all available inputs. Under each combination the information on cultivar, fields (weather and soil identifiers), soil analysis, planting, irrigation, fertilizer, tillage, environment and harvest was given. Modified FAO-56 method was selected under method for evaporation due to unavailability of daily dew point temperature data, which otherwise is essential for FAO modified Penman method to be used in the model.

3.13 Calibration of model

Calibration of model comprises of adjusting some of the model parameters and relationships to make the model work efficiently for specific location under varied environmental conditions. For the present experiment, detailed field investigation data of late kharif season of 2017-18 for maize hybrid variety DKC-9149 were used for model calibration. Crop parameters such as crop yield, stover yield, biological yield, harvest index and leaf area index were estimated. The genetic coefficients of variety DKC- 9149 used in analysis of the model were estimated by repeated reiterations until close match between simulated and observed crop parameters was obtained for all the treatments.

3.14 Validation of the model

Validation of model is nothing but comparison between simulated and observed values of the specific parameters. The model was validated to check the accuracy of model simulations using the data recorded for field investigation during 2017 kharif season of maize. Firstly, model was validated for single treatment (I_1F_1 : I_1 - Irrigation with 1.0 ETc depth and F_1 - 100% RDF through fertigation) and then it was validated for the other treatments with observed yields and growth parameters.

During calibration and validation of model, various statistical parameters were used to evaluate the association between predicted and observed values (Loague and Green, 1991). These include coefficient of determination (R^2), mean deviation (D), root mean square error (RMSE) and maximum error (ME) which are determined by the following equations:

$$D = \frac{\sum_{i=1}^{n} | P_i - M_i |}{n} \qquad \ldots (1)$$

$$RMSE = \left[\frac{\sum_{I=1}^{n} (P_i - M_i)^2}{n} \right]^{1/2} \qquad \ldots (2)$$

$$ME = \max |P_i - M_i| \,_{i=1}^{n} \qquad \ldots (3)$$

Where,

Pi - predicted value

Mi - measured value

n - number of observations

3.15 Data Analysis

The data of field experiment conducted on response of maize hybrid to drip irrigation and fertigation levels in post *kharif* season conducted during 2017-18 were collected. This includes data on initial soil properties, irrigation schedules, fertigation schedules, plant protection and management of crop, crop and yield attributing characters during the entire crop growth period. The daily weather data was collected from the IMD recognized meteorological laboratory of VNMKV Parbhani adjacent to the field where crop experiment was conducted. The design of the field experiment was prepared considering split plot design with irrigation levels as the main factor and fertilizer levels as the sub factors.

The data was statistically analyzed by “Analysis of variance” method (Panse and Sukhatme, 1967) and the ‘F’ test of significance was used for testing the null hypothesis in order to determine whether the observed treatment effects were real and discernible from chance effects. Whenever the results were found to be significant, (‘F’ test) critical difference (CD) was worked out at five per cent probability level and the values furnished. The treatment differences that were not significant were denoted by “NS”. Statistical analysis was carried out using a standard statistical software for the comparison between the treatment means of growth and yield attributes using F test, standard error of means and the critical differences (CD). The observed data was compared with the model simulated outputs using various statistical parameters.

CHAPTER -IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The present investigation entitled "Crop growth simulation of maize using DSSAT model" is carried out in the Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, VNMKV Parbhani. The field experiment was conducted on response of drip irrigation and fertigation levels on growth and yield attributes of post *monsoon* maize during 2017. The experiment was comprised of treatments with three irrigation levels based on crop evapotranspiration viz.1.0, 0.8 and 0.6 of ETc (crop evapotranspiration) and four fertilizer levels based on recommended dose of fertilizers viz., F_1 (100% RDF), F_2 (75% RDF) and F_3 (50% RDF), F_4 (100% RDF through soil application), F_0 (No fertilizers). The observations on growth and yield characteristics of maize were periodically recorded throughout the experimental period. The observed data of field experiment is used for the crop growth simulation.

The data on weather parameters, soil and growth and yield attributes for post monsoon maize during the experimental period (September – December 2017) was collected and used for simulating the crop growth using DSSAT model.

4.1 Soil Properties

The physical and chemical composition of surface soil (0-30 cm) of the experimental plot is shown in Table 4.1. Data shows that the soil was clayey in texture, low in nitrogen, and rich in phosphorus and potassium.

Among the fertility constituent organic carbon was 0.51 per cent. Soil was slightly alkaline in reaction (pH 7.69) with high base saturation. The moisture content at -0.33 and 1.5 MPa was 33.28 and 17.85 per cent, respectively. The bulk density of soil was 1.40 Mg m^{-3}. The available water storage capacity of surface soil (mm/m depth) was 216 mm.

Table 4.1: Soil characteristics of the experimental site

Sr. No.	Particulars	Value
1.	Particle size distribution	
	i) Coarse sand, %	9.35
	ii) Fine sand, %	4.15
	iii) Silt, %	30.00
	iv) Clay, %	54.00
	v) Textural class	Clayey
2.	Chemical composition	
	i) Organic carbon, %	0.51
	ii) Available nitrogen, kg ha^{-1}	155.5
	iii) Available phosphorus, kg ha^{-1}	11.8
	iv) Available potash, kg ha^{-1}	411.9
	v) Soil Ph	7.69
	vi) Electrical conductivity (dS m^{-1} at 20^0C)	0.90
3.	Soil moisture constants	
	i) Field capacity, per cent	33.28
	ii)Permanent welting point, per cent	17.85
	iii) Bulk density, Mg m^{-3}	1.40
	iv) Available WHC (mm/m depth)	216.0

4.2 Plant height

Data on height of plant as influenced by different irrigation and fertigation levels during the growth period are presented in Table 4.2

Data presented in Table 4.2 indicate that mean plant height of post *monsoon* maize was increased progressively at every period of observation of crop growth till maturity. The increase in plant height was slow in the initial stage up to 30 days. During 30 to 45 DAS the increase in plant height was gradual whereas sudden increase in pant height was observed during 46 to 60 DAS. Thereafter the increase in plant height again became gradual during 61 to 90 days and there was practically no increase in plant height after 90 days till the harvest.

The recorded mean plant height at 30, 45, 60, 75, 90 DAS and at harvest were 54.47, 115.44, 212.02, 252.40, 256.58, and 257.24 cm, respectively. The effect of irrigation and fertigation level on the mean plant height of post *monsoon* maize was significant at all growth stages.

Table 4.2: Effect of irrigation levels and fertigation levels on mean plant height

Treatment	Height of plant (cm)					
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
Irrigation levels						
I_1 - Irrigation at 1.0 ETc	60.74	123.25	227.22	259.90	263.54	264.16
I_2 - Irrigation at 0.8 ETc	51.56	111.85	214.11	250.75	257.43	258.52
I_3 - Irrigation at 0.6 ETc	50.71	112.44	198.51	248.61	250.18	250.89
S.E ±	0.86	0.32	1.46	0.77	0.86	1.06
C.D at 5%	3.36	1.24	5.75	3.02	3.37	4.14
Fertigation levels						
F_0 (Control): No fertilizer	49.49	94.33	171.40	224.50	229.33	230.36
F_1 : 100% RDF through drip	61.99	129.07	235.21	267.73	272.25	272.49
F_2 : 75% RDF through drip	56.06	124.69	228.84	261.42	266.84	267.00
F_3 : 50% RDF through drip	50.73	112.44	208.89	253.89	256.46	257.22
F_4 : 100% RDF through soil	53.40	118.71	222.05	257.89	260.37	262.22
S.E ±	1.05	1.10	1.85	1.60	1.53	1.65
C.D at 5%	3.06	3.21	5.39	4.68	4.47	4.81
Interaction (I x F)						
S.E ±	1.82	1.91	3.20	2.78	2.65	2.86
C.D at 5%	NS	NS	NS	NS	NS	NS
GM	54.47	115.44	212.02	252.40	256.58	257.24

4.2.1 Effect of irrigation and fertigation levels on plant height

Data in Table 4.2 indicate that the application of irrigation through drip at 1.0 ETc (I_1) recorded significantly higher plant height of post *monsoon* maize over rest of the irrigation levels at 30, 45, 60,75, 90 DAS and at harvest whereas the lower plant height was noticed under irrigation level of 0.6 ETc (I_3).

Fertigation levels through drip irrigation significantly increased the plant height of post *monsoon* maize at 30, 45, 60, 75, 90 DAS and at harvest where 100% RDF through drip (F_1) is proved to be significantly superior treatment in regards to plant height of post *monsoon* maize, followed by 75 % RDF through drip (F_2). The lower plant height was observed under F_0 (No fertilizer) throughout the observation period.

4.2.2 Interaction effect on plant height

The plant height of post *monsoon* maize was not influenced significantly by the interaction effects of irrigation and fertigation levels throughout the observation period.

4.3 Number of functional leaves per plant:

Table 4.3 Effect of irrigation and fertigation levels on mean number of functional leaves per plant

Treatment	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
Irrigation levels						
I_1 – Irrigation at 1.0 ETc	6.73	8.93	11.84	13.49	13.97	13.09
I_2 – Irrigation at 0.8 ETc	6.66	8.57	11.36	13.29	13.57	12.84
I_3 – Irrigation at 0.6 ETc	6.15	7.61	10.67	13.07	13.51	12.51
S.E ±	0.14	0.02	0.06	0.02	0.09	0.04
C.D at 5%	NS	0.07	0.22	0.10	0.34	0.16
Fertigation levels						
F_0 (Control): No Fertilizer	6.02	7.21	9.98	12.60	13.11	12.04
F_1 : 100% RDF through drip	6.80	9.13	11.99	13.76	14.21	13.33
F_2 : 75% RDF through drip	6.72	8.82	11.71	13.49	13.89	13.00
F_3 : 50% RDF through drip	6.47	8.24	11.27	13.16	13.36	12.66
F_4 : 100% RDF through soil	6.56	8.43	11.51	13.42	13.87	13.04
S.E ±	0.22	0.10	0.09	0.07	0.10	0.09
C.D at 5%	NS	0.30	0.27	0.19	0.30	0.25
Interaction (I x F)						
S.E ±	0.38	0.18	0.16	0.11	0.18	0.15
C.D at 5%	NS	NS	NS	NS	NS	NS
GM	6.51	8.36	11.23	13.26	13.66	12.78

Data presented in Table 4.3 indicate that the number of functional leaves per plant was influenced by different irrigation and fertigation levels throughout the observation period of post *monsoon* maize except at 30 DAS.

Data in Table 4.3 reveal that the mean number of functional leaves per plant was increased progressively till 90 DAS of the crop, thereafter decline in number of functional leaves was observed after 90 DAS due to leaf senescence. The mean number of functional leaves per plant at 30, 45, 60, 75 and 90 days after sowing were 6.51, 8.36, 11.23, 13.26, 13.66, and 12.78 respectively.

4.3.1 Effect of irrigation and fertigation levels on number of leaves per plant

Data presented in Table 4.3 indicate that the irrigation levels significantly influenced number of functional leaves per plant of post *monsoon* maize throughout the growth period of crop. The number of functional leaves per plant under 1.0 Etc (I_1) irrigation level was significantly higher as compared to 0.6 ETc (I_3) and was at par with 0.8 ETc (I_2) at 45 and 90 DAS and at harvest. The lowest mean number of functional leaves per plant was noticed in irrigation at 0.6 ETc (I_3) at 45, 60, 75, 90 DAS and at harvest (Table 4.3) throughout the observation period.

Fertigation levels through drip irrigation significantly increased the mean number of functional leaves of post *monsoon* maize at 45, 60, 75, 90 DAS and at harvest where 100% RDF through drip (F_1) has shown significantly higher number of functional leaves of post *monsoon* maize among all the fertigation levels followed by 75 % RDF through drip (F_2). The lowest number of functional leaves was observed under F_0 (No fertilizer) throughout the observation period.

4.3.2 Interaction effect on number of leaves

The interaction effects of irrigation and fertigation levels on number of leaves of post *monsoon* maize was not significant throughout the observation period.

4.4. Leaf Area (LA)

The data on leaf area per plant of post *monsoon* maize as affected by different irrigation and fertigation levels is presented in Table 4.4. The leaf area per plant was found to increase with growth stage till 90 DAS whereas it was decreased from 90 DAS to harvest.

Table 4.4: Effect of irrigation and fertigation levels on leaf area per plant

Treatment	Leaf area (cm^2)					
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
Irrigation levels						
I_1 – Irrigation at 1.0 ETc	3470	7038	9413	10881	10986	9581
I_2 – Irrigation at 0.8 ETc	2919	6214	8519	10059	10114	8916
I_3 – Irrigation at 0.6 ETc	2755	5393	7755	9407	9437	8449
S.E ±	58.27	49.20	158.41	116.74	121.43	11.13
C.D at 5%	224.85	193.16	621.88	458.29	476.70	43.70
Fertigation levels						
F_0 (Control): No fertilizer	2689	4845	7021.97	8613	8388	7446
F_1 :100% RDF through drip	3390	7242	9625.79	11076.	11238	9898
F_2 : 75% RDF through drip	3126	6231	8938.82	10605	10628	9520
F_3 : 50% RDF through drip	2990	5931	8412.84	9902	10102	8603
F_4 : 100% RDF through soil	3046	6826	8813.09	10384	10539	9443
S.E ±	76.59	144.44	155.77	191.01	168.22	120.51
C.D at 5%	223.57	421.61	454.70	557.55	491.01	351.77
Interaction (I x F)						
S.E ±	132.67	250.18	269.81	330.84	291.36	208.74
C.D at 5%	NS	NS	NS	NS	NS	NS
GM	3048	6128	8527	10046	10115	8916

4.4.1 Effect of irrigation and fertigation levels on leaf area per plant

The leaf area of plant was significantly influenced due to irrigation levels throughout the observation period. The leaf area per plant under I_1(1.0ETc) irrigation level was significantly higher as compared to irrigation levels I_2 (0.8ETc) and I_3(0.6ETc) throughout the observation period.

Data indicate that the effect of fertigation levels on leaf area per plant (cm^2) of maize was significantly influenced due to different fertigation levels. The leaf area per plant in fertigation level F_1(100% RDF through drip) was significantly higher over other fertigation levels viz., F_4(100% RDF through soil application), F_3 (50% RDF through drip) throughout the observation period and was at par with F_2 (75% RDF through drip) at 75 DAS and at harvest. The lower leaf area per plant was observed in F_0 (No fertilizer) throughout the growth period of post *monsoon* maize.

4.4.2 Interaction effect on leaf area per plant

Interaction effect of irrigation and fertigation did not reach to the level of significance with respect to leaf area per plant of post *monsoon* maize at all stages of growth and at harvest.

4.5 Leaf Area Index

The leaf area index of post monsoon maize as influenced by different irrigation and fertigation levels during the growth period are presented in Table 4.4.

Similar to number of leaves, the leaf area index of post *monsoon* maize increased progressively during every observation period of crop growth till 90 DAS. However, the leaf area index during 90 DAS to harvest was decreased in all the treatments.

Table 4.5: Effect of irrigation and fertigation levels on leaf area index

Treatment	Leaf area index					
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	At harvest
Irrigation levels						
I_1 – Irrigation at 1.0 ETc	2.57	5.21	6.97	8.06	8.14	7.10
I_2 – Irrigation at 0.8 ETc	2.16	4.60	6.31	7.45	7.49	6.60
I_3 – Irrigation at 0.6 ETc	2.04	4.00	5.74	6.97	6.99	6.26
Fertigation levels						
F_0 (Control): No fertilizer	1.99	3.59	5.20	6.38	6.21	5.52
F_1 : 100% RDF through drip	2.51	5.36	7.13	8.20	8.32	7.33
F_2 : 75% RDF through drip	2.32	5.06	6.62	7.86	7.87	7.05
F_3 : 50% RDF through drip	2.21	4.39	6.23	7.33	7.48	6.37
F_4 : 100% RDF through soil	2.26	4.62	6.53	7.69	7.81	7.00
GM	2.26	4.60	6.34	7.49	7.54	6.65

4.5.1 Effect of irrigation and fertigation levels on leaf area index

The results indicate that leaf area index was influenced due to irrigation levels throughout the observation period. In general, LAI showed slightly increasing trend with each increased level of irrigation throughout the observation period from 0.6 ETc to 1.0 ETc. The leaf area index under I_1 (1.0ETc) irrigation level was higher as compared to I_2 (0.8ETc) and I_3 (0.6ETc) throughout the observation period.

The effect of fertigation levels on leaf area index of maize was affected due to different fertigation levels in which fertigation level F_1 (100% RDF through drip) showed higher LAI over other fertigation levels viz., F_2 (75% RDF through drip), F_4 (100% RDF through soil application) and F_3 (50% RDF through drip). The lowest leaf area index was observed in F_0 (No fertilizer) throughout the growth period.

4.6 Yield Attributes of Maize

Yield data *viz*., grain yield (q/ha), fodder yield (q/ha), spindle yield (q/ha), husk yield (q/ha) and biological yield of post *monsoon* maize as influenced by different treatments are presented in Table 4.6.

4.6.1 Grain yield

Data on total grain yield per hectare of post *monsoon* maize was influenced by different irrigation and fertigation levels.

4.6.1.1 Effect of irrigation and fertigation levels on grain yield

Data presented in Table 4.6 reveal that irrigation through drip at 1.0 ETc produced significantly higher grain yield (84.57 q/ha) of post *monsoon* maize as compared to 0.6 ETc (I_3), however it was at par with irrigation at 0.8 ETc (81.01 q/ha).

4.6.1.2 Effect of irrigation and fertigation levels on grain yield

The effect of fertigation levels on grain yield of post *monsoon* maize was also significant. The grain yield of post *monsoon* maize showed increasing trend with the increase in fertigation levels. Significantly higher grain yield of maize (92.46 q/ha) was observed in fertigation treatment F_1 (100% RDF; 150:75:75 NPK kg ha^{-1}) through drip as compared to F_3 (77.46 q/ha), F_4 (81.48 q/ha) and F_0 (60.32 qha^{-1}) whereas it was comparable with F_2 (75 % RDF through drip) (91.35 q/ha). The significantly lowest grain yield (60.32 q/ha) of post *monsoon* maize was observed under fertigation level F_0 (No fertilizer).

4.6.1.3 Interaction effect on grain yield

The grain yield of post *monsoon* maize was not influenced significantly by the interaction effects of irrigation and fertigation levels.

4.6.2 Husk and spindle yield

The data furnished in Table 4.6 also reveal that the husk weight and spindle yield(q/ha) of post *monsoon* maize was influenced significantly by different irrigation and fertigation levels.

4.6.2.1 Effect of irrigation levels on husk yield and spindle yield

Data reveal that among all the irrigation levels, irrigation at 1.0 ETc (I_1) recorded significantly higher husk and spindle yield (11.42 and 18.00 q/ha, respectively) than irrigation at 0.6 ETc (I_3) and was comparable with irrigation at 0.8 ETc (I_2).

4.6.2.2 Effect of fertigation levels on husk yield and spindle yield

Similarly, the fertigation level F_1(100% RDF through drip) recorded significantly higher husk and spindle yield (12.08 and 18.45q/ha) as compared to other fertigation levels. This was followed by fertigation level F_2 (75% RDF through drip), fertigation levelF_4(100% RDF through soil application) and fertigation level F_3 (50% RDF through drip). The lowest husk yield and spindle yield (q/ha) was recorded under F_0 (7.26 and 11.27q/ha) in which no fertilizers were applied.

4.6.2.3 Interaction effect on husk yield and spindle yield

The husk yield and spindle yield(q/ha) of post *monsoon* maize was not influenced significantly by the interaction effects of irrigation and fertigation levels.

4.6.3 Fodder yield

Data on fodder yield (q/ha) as influenced by different irrigation and fertigation levels is presented in Table 4.6.

4.6.3.1 Effect of irrigation levels on fodder yield

Data in Table 4.6 indicate that different irrigation levels significantly influenced the average fodder yield of post *monsoon* maize and were increased significantly with subsequent increase in irrigation level. Irrigation level I_1**(**1.0 ETc) showed significantly highest fodder yield (106.63 q/ha) as compared to I_2 (101.37 q/ha) and I_3 (94.21 q/ha).

4.6.3.2 Effect of fertigation levels on fodder yield

The effect of fertigation levels on fodder yield was also significant. Data in Table 4.6 show that the fertigation level F_1 (100% RDF through drip) has produced significantly higher fodder yield (116.72 q/ha) as compared to other fertigation levels. This was followed by fertigation level F_2 (111.01q/ha), and F_4 (102.61q/ha) and F_3 (97.44q/ha). The lowest fodder yield was recorded under F_0 (75.91q/ha) in which no fertilizers were applied.

4.6.3.3 Interaction effect on fodder yield

The fodder yield of post *monsoon* maize was not influenced significantly by the interaction effects of irrigation and fertigation levels throughout the observation period.

4.6.4. Biological yield

Data on biological yield (q/ha) which is the summation of all biological parts of post *monsoon* maize per hectare as influenced by different irrigation and fertigation levels is also presented in Table 4.6.

4.6.4.1 Effect of irrigation levels on biological yield

The data presented in from Table 4.6 indicated that irrigation levels significantly influenced the biological yield (q/ha) of post *monsoon* maize. The irrigation level I_1 (1.0 ETc) showed significantly higher biological yield (220.62q /ha) over irrigation level I_3 (192.71q/ha) and I_2 (208.83 q/ha).

Table 4.6: Mean grain, spindle, husk, fodder, biological yield (q/ha) and harvest index of maize as influenced by various levels of irrigation and fertigation

Treatment	Grain yield(q/ha)	Husk weight (q/ha)	Spindle weight (q/ha)	Fodder yield (q/ha)	Biological yield (q/ha)	Harvest index
Irrigation levels						
I_1 - Irrigation at 1.0 ETc	84.57	11.42	18.00	106.63	220.62	38.33
I_2 - Irrigation at 0.8 ETc	81.01	10.50	15.95	101.37	208.83	38.79
I_3 - Irrigation at 0.6 ETc	76.27	8.98	13.25	94.21	192.71	39.58
S.E ±	0.63	0.04	0.34	0.90	1.91	-
C.D at 5%	2.46	0.16	1.34	3.54	7.5	-
Fertigation levels						
F_0(Control) : No fertilizer	60.32	7.26	11.27	75.91	154.76	38.98
F_1 : 100% RDF through drip	92.46	12.08	18.45	116.72	239.71	38.57
F_2 : 75% RDF through drip	91.35	11.17	16.26	111.01	229.79	39.75
F_3 : 50% RDF through drip	77.46	9.95	15.19	97.44	200.04	38.72
F_4 : 100% RDF through soil	81.48	11.05	17.49	102.61	212.63	38.32
S.E ±	0.92	0.18	0.40	1.41	2.91	-
C.D at 5%	2.69	0.53	1.18	4.12	8.52	-
Interaction (I x F)						
S.E ±	1.59	0.32	0.70	2.45	5.06	-
C.D at 5%	NS	NS	NS	NS	NS	-
GM	80.49	101.18	15.48	100.47	206.62	38.96

4.6.4.2 Effect of fertigation levels on biological yield

The effect of fertigation levels on biological yield (q/ha) was significant where the fertigation level F_1 (100% RDF through drip) has produced significantly higher biological yield (239.71 q/ha) as compared to other fertigation levels. This was followed by fertigation level F_2 (229.79 q/ha) and F_4 (212.63 q/ha) where 75% RDF through drip and 100% RDF through soil, respectively were applied. The lowest biological yield was recorded under F_0 (154.76 q/ha) in which no fertilizers were applied.

4.6.4.3 Interaction effect on biological yield

The biological yield of post *monsoon* maize was not influenced significantly by the interaction effects of irrigation and fertigation levels.

4.7 Simulating Maize Crop Growth

This section describes the simulation of maize crop growth and yield under different irrigation and fertilizer management scenarios. The measured and recorded data of field experiment of post monsoon season for maize hybrid variety DKC-9149 under three drip irrigation levels viz., I_1 - Irrigation with 1.0 ETc depth; I_2 - Irrigation with 0.8 ETc depth and I_3- Irrigation with 0.6 ETc depth and four fertigation levels viz., F_1 - 100% RDF through fertigation; F_2 - 75% RDF through fertigation; F_3 - 50% RDF through fertigation and F_4 - 100% RDF through soil application were used. The treatment combination of I_1 F_1 (irrigation at 1.0 ETc and application of 100% RDF through fertigation) was used to calibrate the DSSAT 4.7.5 model, since the plots under this treatment had negligible water and nutrient stress during the entire crop growth period.

For the present experiment, detailed field investigation data of late kharif season of 2017-18 for maize were used for DSSAT 4.7.5 model calibration. The filed investigation data of other treatment combinations were used for the validation of model. The descriptions of model presented in section 3.12.

4.7.1 Calibration of CERES maize

The CERES Maize model, a component of DSSAT v4.7.5 was calibrated using the standard calibration procedure (Boote, 1999). The use of CERES Maize was aimed at studying the effect of irrigation and fertilizer levels on crop growth. Therefore, the measured data well-watered (I_1 irrigation schedule) and well fertilized (F_1) treatment of field experiment were used for calibration of CERES Maize. The measured soil physical and chemical parameters pertaining to surface soil layer was given as input to the model. The observed maize crop data on the various growth parameters viz., grain yield, stover yield, temporal variation of LAI and biological yield at harvest were compared with the simulated ones during calibration.

Table 4.7: Estimated values of genetic coefficients for hybrid maize cultivar DKC-9149

Sr. No.	Genetic coefficient code	Definition of genetic coefficient	Pre-assigned range	Calibrated value
1	P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in growing degree days above a base temperature of 8ºC) during which plant is not responsive to changes in photoperiod.	5 - 450	275
2	P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).	0 - 2	0.8
3	P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8ºC).	580 - 999	950
4	G-2	Maximum possible number of kernels $plant^{-1}$.	248 - 990	820
5	G-3	Kernel filling rate during the linear grain filling stage under optimum conditions (mg day^{-1}).	5 – 16.5	7.98
6	PHINT (Phyllochron interval)	The interval in thermal time (degree days) between successive leaf tip appearances.	39 - 49	48

The file containing genotype coefficients (MZCER047CUL.) was used to estimate the genetic coefficients for maize cultivar DKC -9149. The final set of genetic coefficients was obtained by the best-fit method. The range of genetic coefficients shown in Table 4.7 is based on the cultivars, which were tested by modelers across the world (Boote et al., 1998a). Except, PHINT the calibrated values for all other genetic coefficients for the cultivar were within the prescribed range.

During calibration, simulated results pertaining to the plant height, grain yield, stover yield, biological yield, harvest index and LAI closely matched with the observed data. The measured data was found to be in close agreement with the simulated values and hence, the present calibrated parameters were accepted.

The measured and simulated values of different crop parameters for all the treatments are presented in the succeeding sections.

4.7.2 Model validation

The DSSAT CERES-Maize model was validated using the independent data set collected during the field investigation of late kharif season (2017-18) for maize hybrid variety DKC-9149. The corresponding results are summarized as follows,

4.7.2.1 Grain Yield

The scattergrams and regression analysis of the measured and CERES Maize predicted values of grain yield for all the treatment combinations is depicted in Fig. 4.1. The uniform clustering of the measured and predicted yield around the 1:1 line and the fairly good correlation coefficient (0.735) indicate that the CERES maize model slightly underpredicted grain yield. The statistical parameters related to grain yield shown in Table 4.9 indicate that the prediction of grain yield by the model is quite good. The RMSE and absolute percentage deviations (%D) between the predicted and measured values were within acceptable range.

Table 4.8: Treatment wise observed and simulated maize grain yield (q/ha)

Grain yield q/ha		
Treatment	Observed	Simulated
I_1 - Irrigation at 1.0 ETc	84.57	86.42
I_2 - Irrigation at 0.8 ETc	81.01	76.86
I_3 - Irrigation at 0.6 ETc	76.27	69.44
F_1 : 100% RDF through drip	92.46	84.34
F_2 : 75% RDF through drip	91.35	83.98
F_3 : 50% RDF through drip	77.46	71.09
F_4 : 100% RDF through soil	81.48	78.69

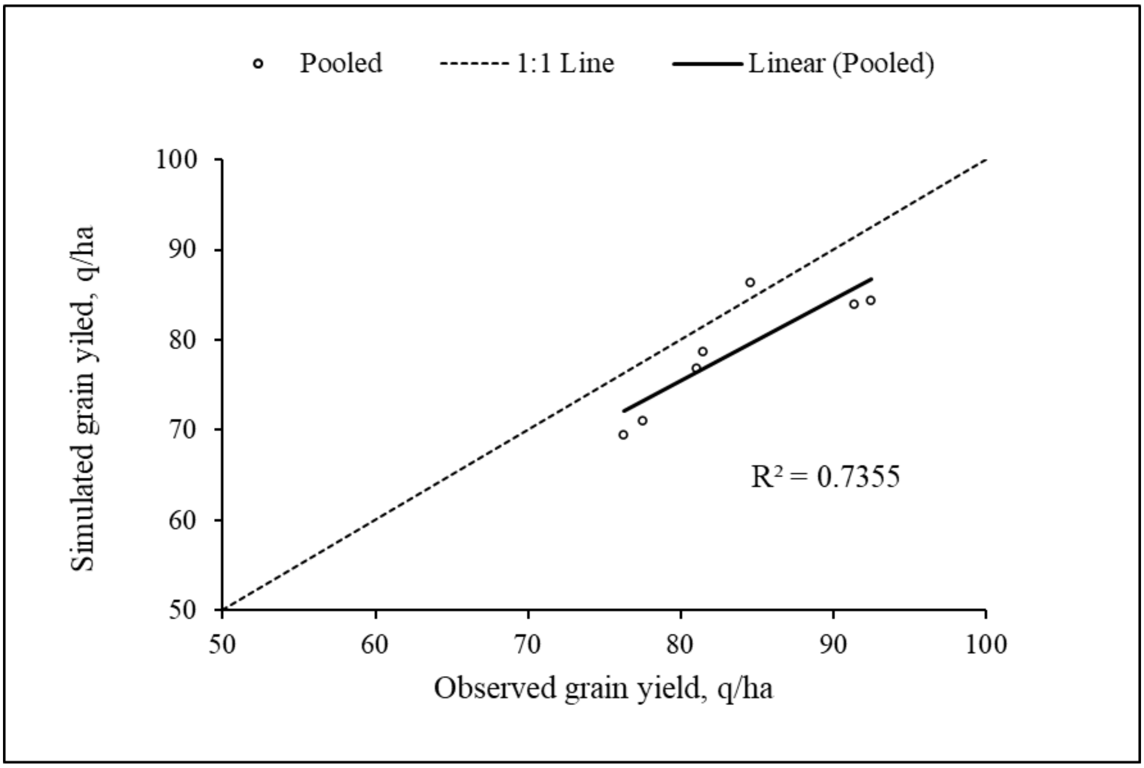

Fig. 4.1: Comparison between observed and simulated grain yield under different treatments

Table 4.9: Test criteria for evaluation of model with respect to grain yield

Parameters	Value
n	7
R^2	0.735
D	1.16
RMSE	5.81
ME	8.12
EF	0.03

4.7.2.2 Stover Yield

The scattergrams and regression analysis of the measured and CERES Maize predicted values of stover yield for all the treatment combinations is depicted in Fig. 4.2. The uniform clustering of the measured and predicted yield around the 1:1 line and the fairly good correlation coefficient (0.801) indicate that the CERES maize model predicted stover yield fairly well. The statistical parameters related to grain yield shown in Table 4.11, show that the prediction of stover yield by the model is well. The RMSE and absolute percentage deviations (%D) between the predicted and measured values were within acceptable range.

Table 4.10: Treatment wise observed and simulated stover yield (q/ha)

Stover yield q/ha		
Treatment	Observed	Simulated
I_1 - Irrigation at 1.0 ETc	113.69	118.51
I_2 - Irrigation at 0.8 ETc	107.96	111.32
I_3 - Irrigation at 0.6 ETc	99.95	100.66
F_1 : 100% RDF through drip	116.28	124.34
F_2 : 75% RDF through drip	112.36	105.24
F_3 : 50% RDF through drip	98.05	87.13
F_4 : 100% RDF through soil	102.11	101.92

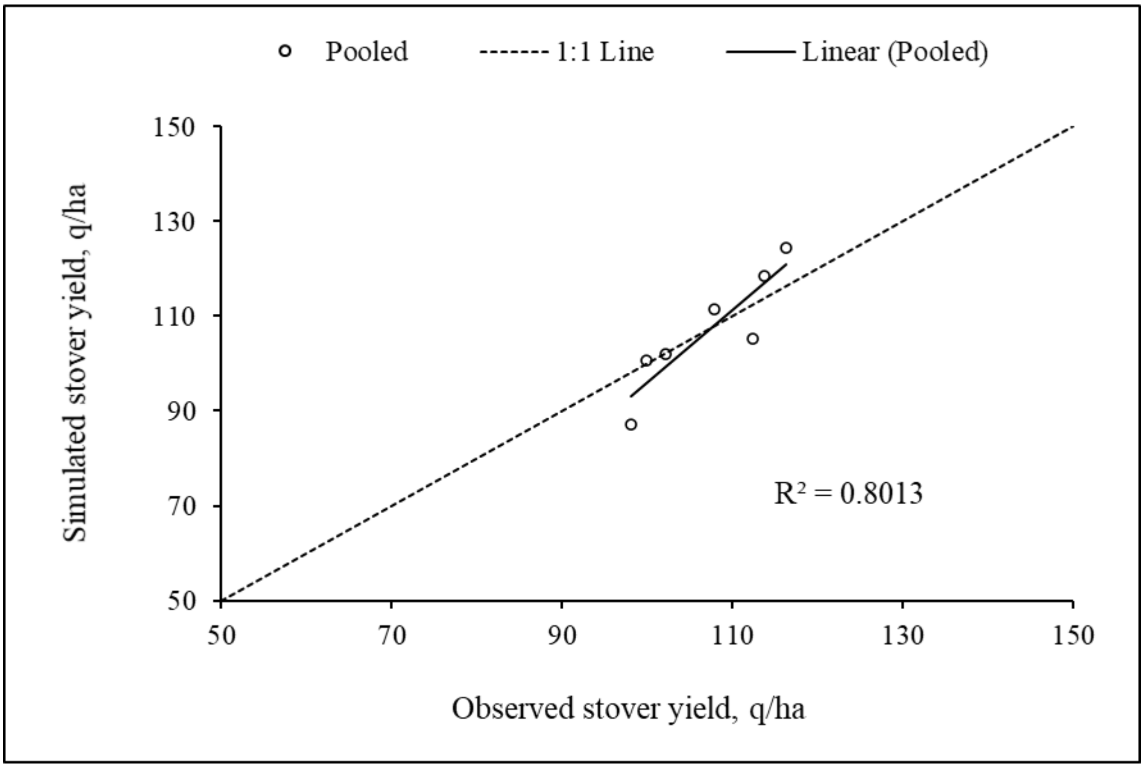

Fig. 4.2: Comparison between observed and simulated stover yield under different treatments

Table 4.11: Test criteria in evaluation of model with respect to stover yield

Parameters	Value
n	7
R^2	0.801
D	1.56
RMSE	6.21
ME	10.92
EF	0.14

4.7.2.3 Biological Yield

The scattergrams and regression analysis of the measured and CERES Maize predicted values of biological yield for all the treatment combinations is depicted in Fig. 4.3. The uniform clustering of the measured and predicted yield around the 1:1 line and the fairly good correlation coefficient (0.756) indicate that although the CERES maize model slightly under predicted biological yield of maize. There is good agreement between observed and simulated values according to statistical parameters related to biological yield shown in Table 4.13. The RMSE and absolute percentage deviations (%D) between the predicted and measured values were within acceptable range.

Table 4.12: Treatment wise observed and simulated biological yield (q/ha)

Biological yield q/ha		
Treatment	Observed	Simulated
I_1 - Irrigation at 1.0 ETc	220.62	203.92
I_2 - Irrigation at 0.8 ETc	208.83	187.20
I_3 - Irrigation at 0.6 ETc	192.71	174.15
F_1 : 100% RDF through drip	239.71	221.63
F_2 : 75% RDF through drip	229.79	216.27
F_3 : 50% RDF through drip	200.04	175.44
F_4 : 100% RDF through soil	212.63	219.40

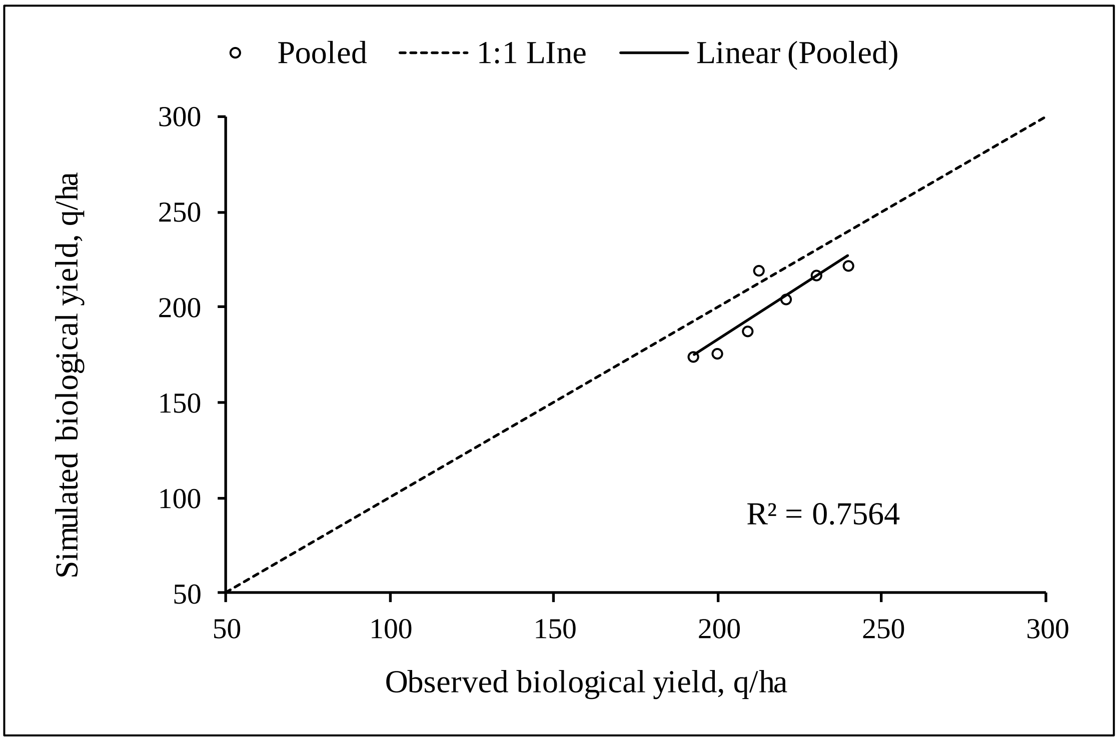

Fig. 4.3: Comparison between observed and simulated biological yield under different treatments

Table 4.13: Test criteria in evaluation of model with respect to biological yield

Parameters	Value
n	7
R^2	0.756
D	3.51
RMSE	17.94
ME	24.60
EF	0.28

4.7.2.4 Harvest Index

The scattergrams and regression analysis of the measured and CERES Maize predicted values of harvest index for all the treatment combinations is depicted in Fig. 4.4. The uniform clustering of the measured and predicted yield around the 1:1 line and the fairly good correlation coefficient (0.746) indicate good match between observed and predicted harvest index of maize. There is good agreement between observed and simulated values according to statistical parameters related to harvest index as shown in Table 4.15. The RMSE and absolute percentage deviations (%D) between the predicted and measured values were within acceptable range.

Table 4.14: Treatment wise observed and simulated harvest index

Harvest index		
Treatment	Observed	Simulated
I_1 - Irrigation at 1.0 ETc	38.33	37.99
I_2 - Irrigation at 0.8 ETc	38.79	38.69
I_3 - Irrigation at 0.6 ETc	39.58	39.11
F_1 : 100% RDF through drip	38.57	38.88
F_2 : 75% RDF through drip	39.75	40.34
F_3 : 50% RDF through drip	38.72	39.01
F_4 : 100% RDF through soil	38.32	38.35

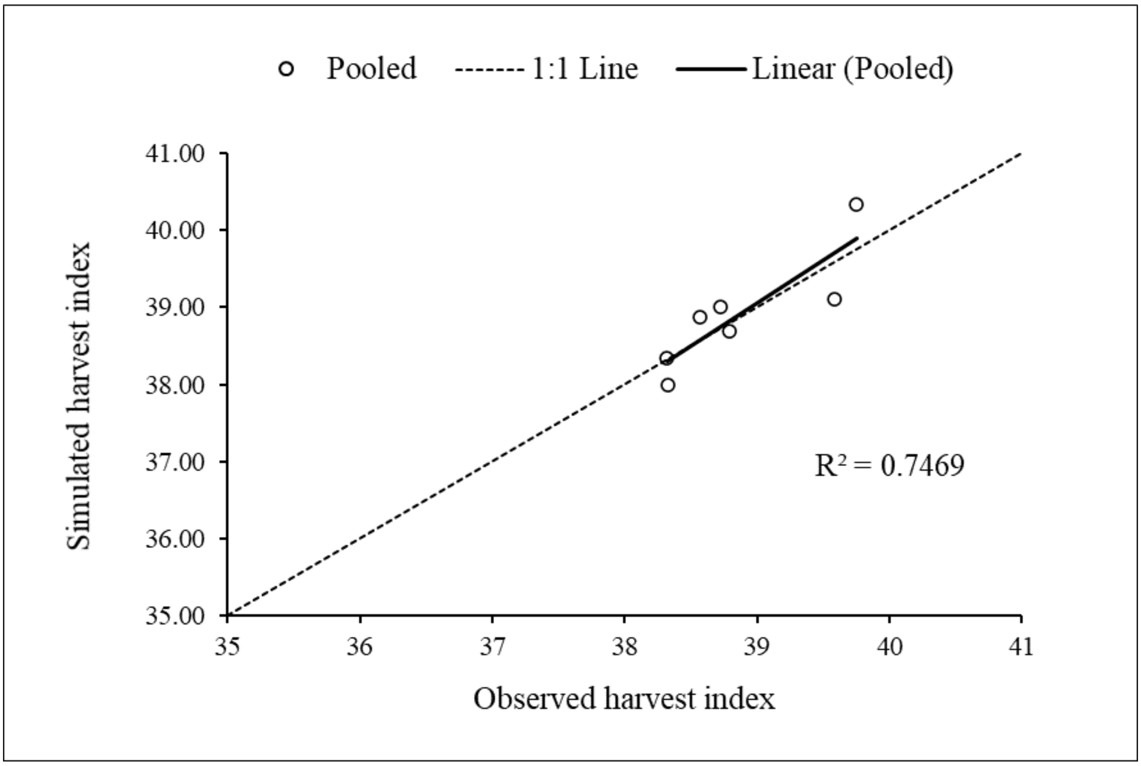

Fig. 4.4: Comparison between observed and simulated harvest index under different treatments

Table 4.15: Test criteria in evaluation of model with respect to harvest index

Parameters	Value
n	7
R^2	0.746
D	0.13
RMSE	0.61
ME	0.92
EF	0.23

4.7.5 Leaf Area Index

The scattergrams and regression analysis of the measured and CERES Maize predicted leaf area index at harvest for all the treatment combinations is depicted in Fig. 4.5. The uniform clustering of the measured and predicted leaf area index around the 1:1 line and the fairly good correlation coefficient (0.715) indicate that the CERES maize model predicted leaf area index of maize at harvest fairly well. There is good agreement between observed and simulated values according to statistical parameters related to leaf area index is shown in Table 4.17. The RMSE and absolute percentage deviations (%D) between the predicted and measured values were within acceptable range.

Table 4.16: Treatment wise observed and simulated leaf area index

Leaf area index		
Treatment	Observed	Simulated
I_1 - Irrigation at 1.0 ETc	7.1	6.88
I_2 - Irrigation at 0.8 ETc	6.6	6.65
I_3 - Irrigation at 0.6 ETc	6.26	6.10
F_1 : 100% RDF through drip	7.33	6.89
F_2 : 75% RDF through drip	6.95	7.00
F_3 : 50% RDF through drip	6.37	6.49
F_4 : 100% RDF through soil	7	6.66

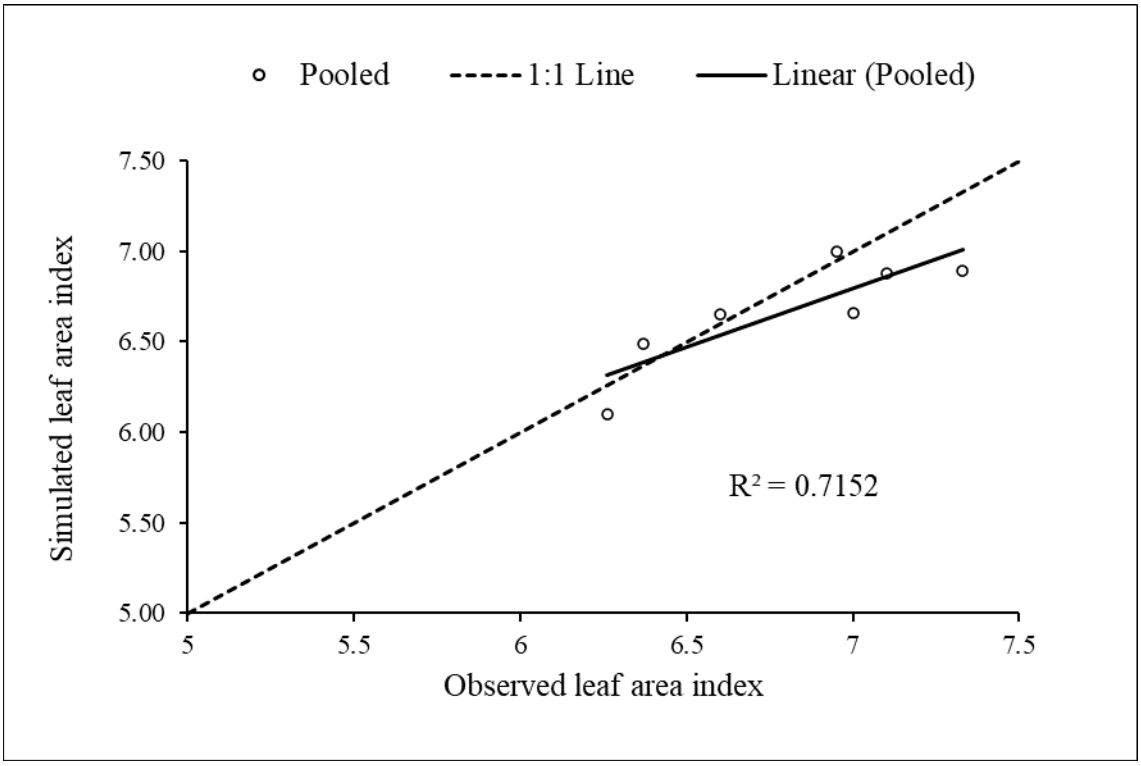

Fig. 4.5: Comparison between observed and simulated leaf area index under different treatments

Table 4.17: Test criteria in evaluation of model with respect to leaf area index

Parameters	Value
n	7
R^2	0.715
D	0.06
RMSE	0.24
ME	0.44
EF	0.59

4.8 Water Use Efficiency

The drip irrigation was scheduled at an alternate day with 1.0 ETc, 0.8 ETc and 0.6 ETc and the actual depth of water applied was measured. The data regarding observed irrigation and total water applied, and water use efficiency is presented in Table 4.18.

It is obvious that among the irrigation schedules the drip irrigation schedule of 0.6 ETc (I_3) gave the highest water use efficiency of 19.27 kg/ha-mm whereas lowest WUE (16.58 kg/ha-mm) was observed under 1.0 ETc irrigation schedule under drip irrigation (I_1).

Table 4.18: Observed water use efficiency of post *monsoon* maize as influenced by different irrigation levels

Treatments	Yield of maize (q/ha)	Irrigation water applied (mm)	Eff. Rainfall (mm)	Total Water use (mm)	Water use efficiency (kg/ha-mm)
I_1 - Irrigation at 1.0 ETc	84.64	288.40	222	510.40	16.58
I_2 - Irrigation at 0.8 ETc	81.01	230.72	222	452.72	17.89
I_3 - Irrigation at 0.6 ETc	76.13	173.04	222	395.04	19.27

During simulation, the input of irrigation water applied and weather data was given treatment wise for the DSSAT CERES Maize mode. The water use efficiency estimated from the simulated results under various drip irrigation levels is also compared with observed water use efficiency in Table 4.19.

Table 4.19: Comparison of estimated observed and simulated water use efficiency

Drip irrigation levels	Yield of maize (q/ha)		Total Water use (mm)		Water use efficiency (kg/ha-mm)	
	Obs	Sim	Obs	Sim	Obs	Sim
I_1 - Irrigation at 1.0 ETc	84.64	86.42	510.40	576.2	16.58	15.00
I_2 - Irrigation at 0.8 ETc	81.01	76.86	452.72	527.7	17.89	14.57
I_3 - Irrigation at 0.6 ETc	76.13	69.44	395.04	479.8	19.27	14.47

The data shows that there is difference in observed and simulated grain yield as well as water use efficiency. This difference is because of the variation in observed and simulated total water use. Higher values of total water use and lower values of water use efficiency in simulations is because of the calculations of effective rainfall by model.

4.9 Total Fertilizer Use Efficiency

The additional maize grain yield under each treatment due to application of fertilizer were estimated by deducting the grain yield obtained under control treatment (no fertilizer) from the yield obtained in each treatment. The total fertilizers used under different treatments are the total of NPK used under that treatment. The total fertilizer use efficiency thus calculated is presented in Table 4.20.

The data indicate that the highest total fertilizer use efficiency (14.31 kg/kg fertilizer used) was observed in I_1F_2 combination. This is because the yields were comparatively higher and the fertilizers used were slightly lower resulting into higher fertilizer use efficiency. The fertigation level F_2 (75% RDF through drip) gave highest total fertilizer use efficiency under all irrigation levels as compared to other fertigation levels. The fertilizer use efficiency under F_4 (100% RDF through soil application) is the lowest among all fertilizer levels.

Table 4.20: Observed total fertilizer use efficiency of maize under different treatments

Treatments	Total fertilizer use efficiency kg/ kg of fertilizer used			
	F_1 :100% RDF through drip	F_2 :75% RDF through drip	F_3 :50% RDF through drip	F_4 :100% RDF through soil
I_1 - Irrigation at 1.0 ETc	12.10	14.31	11.61	8.98
I_2 - Irrigation at 0.8 ETc	10.87	14.27	13.28	7.51
I_3 - Irrigation at 0.6 ETc	10.61	13.68	10.28	5.33

4.10 Soil Moisture

The moisture content could not be monitored during the experiment. However, during simulation studies, in order to assess the depth and time variation of soil moisture the soil layer was divided in different layers viz., 0-5, 5-15, 15-30, 30-42 and 42-65 cm. The simulations were run under different treatments and simulated. The temporal variation of soil water content after sowing in each treatment is presented in this section. The variation of soil moisture during the crop growth under treatment I_1F_1 is presented in Fig. 4.6.

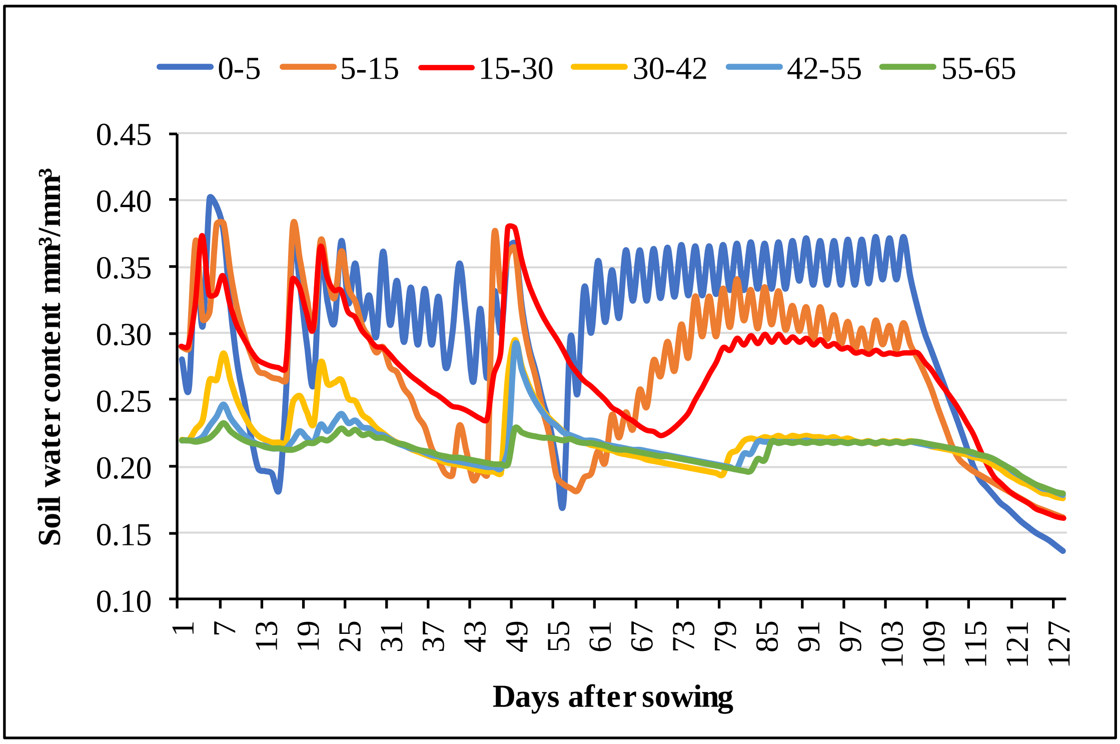

Fig. 4.6: Temporal variation of soil water content under treatment (I_1F_1) 1.0 ET_c and 100% RDF through drip irrigation

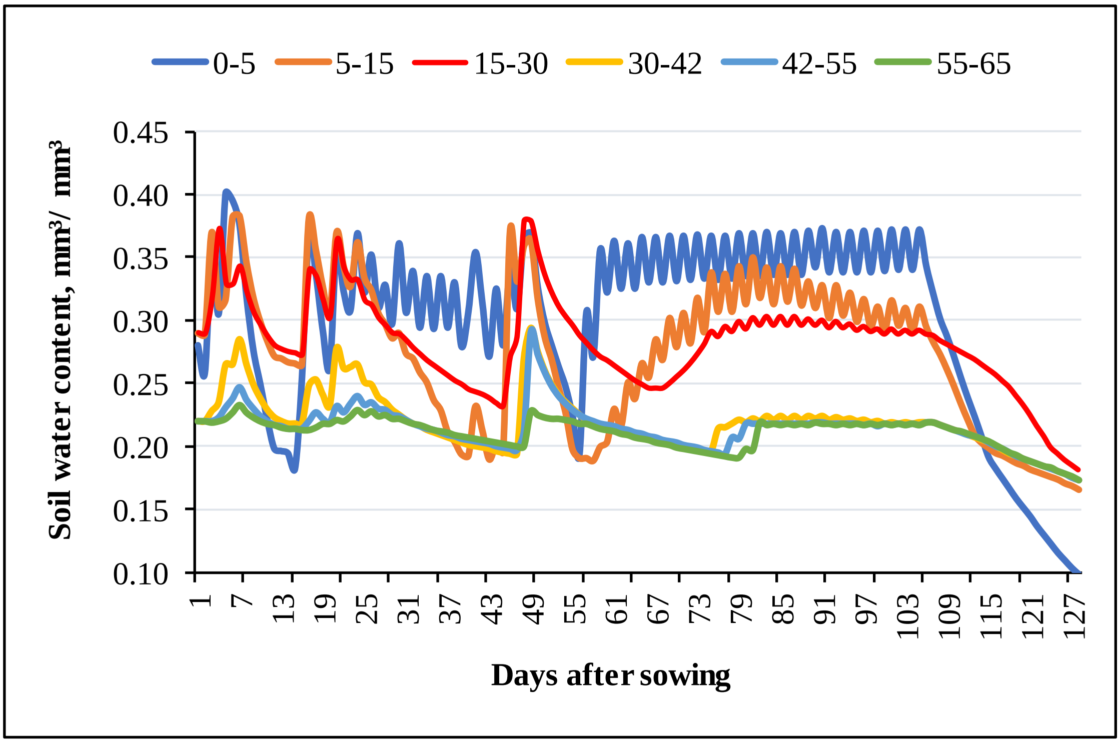

Fig.4.7: Temporal variation of soil water content under treatment (I_1F_2) 1.0 ET_c and 75% RDF through drip irrigation

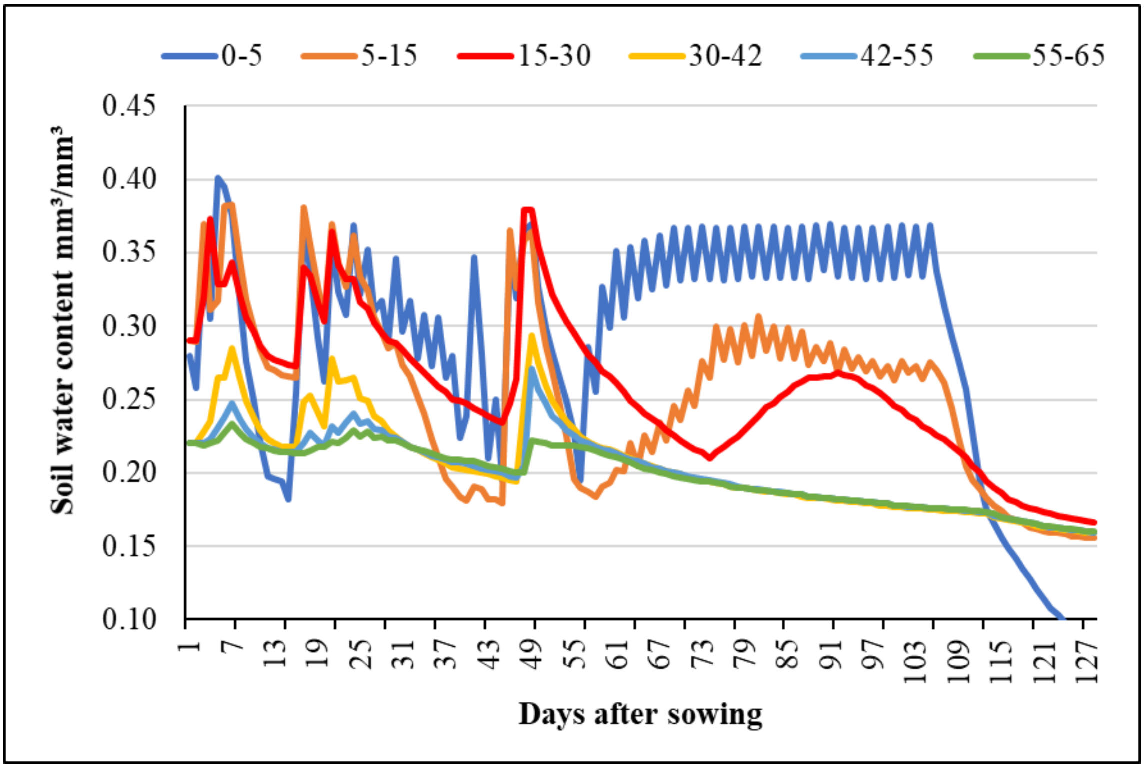

Fig.4.8: Temporal variation of soil water content under treatment (I_2F_2) 0.8 ET_c and 75% RDF through drip irrigation

The temporal variation of soil moisture under different treatments is presented in Fig. 4.7 for treatment I_1F_2, Fig. 4.8 for treatment I_2F_2 and Fig. 4.9 for treatment I_3F_3. These figures reveal that in general the soil moisture if not obscured by rainfall experienced a cyclic temporal variation. The amplitude of this cyclic variation was higher in upper (0-5, 5-15 and 15-30 cm) than lower (30-42 and 55-65 cm) soil layers. The cyclic variation in soil moisture in the soil layer 42-55 cm represents clearly the deep percolation in this layer after occurrence of rainfall or application of irrigation.

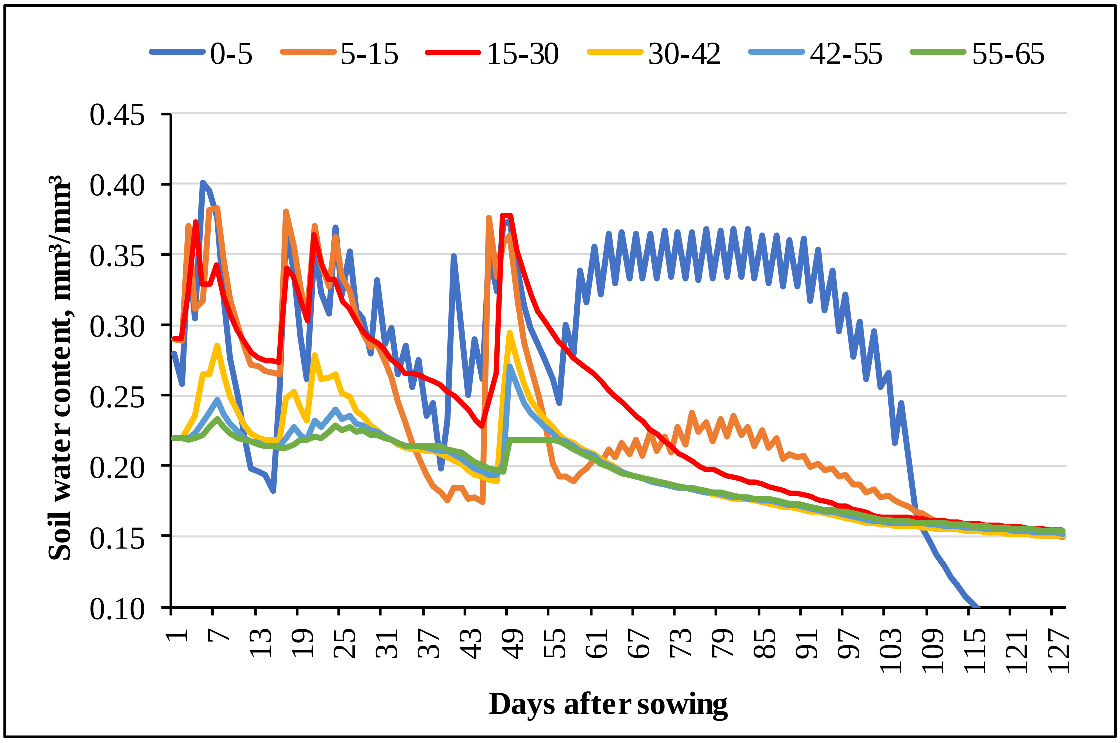

Fig. 4.9: Temporal variation of soil water content under treatment (I_3F_3) 0.6 ET_c and 50% RDF through drip irrigation

In general, observed soil moisture variation in the upper soil layers was due to moisture extraction and evaporation from the top soil to cope up with the atmospheric evaporative demands. Under I_1, moisture extraction was limited to 15-30 cm depth while under I_2 it was sometimes from 42-55 cm depth. The above results thus imply that, the temporal variation of soil moisture in upper layers (0-42 cm) was mainly due to evaporative demands of atmosphere and water input through irrigation or rainfall whereas in lower layers (42-55 cm) it was due to occurrence of unusual rainfall and subsequent drainage in the subsoil layer. The soil water in the soil layer 55-65 cm remains stable throughout the growth period with slight declining trend at the end of theseason.

CHAPTER -V

SUMMARY AND CONCLUSIONS

CHAPTER V

SUMMARY AND CONCLUSIONS

Maize is a water demanding crop requiring high amount of water as compared to other major crops and is being cultivated in *rabi* under irrigated conditions because of its higher productivity level. Use of surface irrigation for maize has few limitations such as excess runoff, evaporation, higher leaching levels and deficit soil moisture, thereby the availability of water to the crops remains relatively less. Hence, scheduling irrigation using drip system that reduces the water application losses without reducing the yield is a prime concern. Under such situation, drip fertigation is the most suitable option, which can efficiently use and save water and fertilizer in addition to increase in the area along with increasing productivity. Research on drip irrigation conducted so far in India and abroad has shown that this method leads not only the appreciable saving of water but also returns in achieving higher crop yields as compared to surface irrigation method. Maize has a great potential in Marathwada and the area under maize cultivation has tremendously increased in the region.

Information requirements for agricultural decision making has become essential at all levels due to increased demands for agricultural products and increased pressures on land, water, and other natural resources. The generation of new data through traditional agronomic research methods and its publication are not sufficient to meet these increasing needs. Under such circumstances the crop growth models can play an important role because of their capacity to take into account limiting factors (soil, weather, water, and fertilizers) dynamically and suggest proper management option.

The DSSAT is a comprehensive decision support system, which has the capability of predicting the impact of management strategies such as irrigation scheduling and fertilizer management on crop growth and yields.

In pursuit of the above considerations, a comprehensive field investigation and study was conducted on ‘Crop growth simulation of maize using DSSAT model’. The experiment was conducted to study the effect of different drip irrigation and fertigation levels on growth and yield attributing parameters of maize. The investigation was consisted of calibration and validation of CERES Maize model of

DSSAT to estimate maize yields under different drip irrigation and fertigation levels of post monsoon maize.

The field experiment was conducted during late kharif (September to December 2017) on maize hybrid variety DKC-9149. The experiment comprised of three levels of drip irrigation as main factor and five levels of fertigation levels as sub factor in spilt plot design. Drip irrigation levels included I_1 (1.0 ETc), I_2 (0.8 ETc), I_3 (0.6 ETc) whereas fertigation levels were F_1 (100% RDF), F_2 (75% RDF) and F_3 (50%RDF) through drip irrigation F_4(100% RDF) through soil application. For comparison one level F_0 with no fertilizer was also included. These treatments were replicated thrice. The recommended dose fertilizer was 150:75:75 kg/ha N:P_2O_5:K_2O.

Experimental plot size of maize was sown in post monsoon season on plots of size 7.0 x 6.0 cm each in paired row planting at spacing of 30 x 45 - 75 cm. Drip irrigation under treatments I_1, I_2 and I_3 was scheduled at an alternate day as desired in the treatments based on crop evapotranspiration. The fertilizers were applied in splits through irrigation water in F_1, F_2 and F_3 treatments while in F_4 fertilizers were applied conventionally through soil application. Water soluble fertilizers of grade 0:52:34, urea and 0:0:50 were used for fertigation whereas for soil application urea, single super phosphate (SSP) and muriate of potash (MOP) were used as fertilizer source. In drip fertigation soluble fertilizers in the form of nitrogen, phosphorous and potassium were applied in 8, 4 and 8 splits, respectively whereas in soil applications P and K were applied as basal dose and nitrogen in 2 equal splits at the time of sowing and 30 days after sowing.

5.1 Crop Growth Parameters and Yield Attributes

The weather data was collected from IMD recognized VNMKV observatory and used for estimation of reference crop evapotranspiration using FAO 56 Penman Monteith equation. Crop coefficient for maize was developed based on the previous of plant height and climatic conditions using standard procedure mentioned in FAO 56. Cultural operations and plant protection measures were taken up as and when required during different stages crop growth. The crop growth parameters viz. plant height (cm), number of functional leaves, leaf area, leaf area index, dry matter of plant (g/plant) were measured from 30 days after sowing at 15 days’ interval till harvest. The observations related to yield attributes viz. number of cobs per plant, weight of cobs/plant, husk weight (g), spindle weight, total grain yield (q/ha), fodder yield (q/ha) and total biological yield were taken at harvest.

5.2 Crop Growth Simulation

The crop growth simulation model CERES Maize of DSSAT was used to simulate the maize growth and yield parameters. It requires data related to experimental conditions including field characteristics, soil analysis data, initial soil water, seed bed preparation, cultivars, planting geometries, irrigation, fertilizer, organic amendment, tillage, chemical application, harvest and simulation control options. The model requires daily weather data such as minimum and maximum temperature, precipitation or rainfall, total solar radiation or sunshine hours, relative humidity and average daily wind speed for the duration of the crop growing season in the form of weather file. The data related to soil profile, soil water, soil nitrogen and root growth characteristics, soil taxonomic classification, soil texture and other descriptive data of the experimental site is required.

The plots under 100% ETc (I_1) and 100% RDF (F_1) a full irrigation fertilizer treatment of experiment during which crop was almost under non-stress conditions were used to provide necessary information for the calibration of DSSAT. The remaining treatments were used in validating the model. The genetic coefficients of variety DKC- 9149 used in analysis of the model were estimated by repeated reiterations until close match between simulated and observed crop parameters was obtained for all the treatments. Crop parameters such as crop yield, stover yield, biological yield, harvest index and leaf area and leaf area index were estimated. The results of the field investigation and the simulation studies are summarized below.

Conclusions:

Based on the results of the present investigation following conclusions are drawn.

1. The irrigation and fertilizer levels significantly influence the growth parameters of post monsoon maize viz., plant height, number of functional leaves, leaf area and LAI throughout the observation period.
2. Drip irrigation scheduled at alternate day with 1.0 ETc depth gives significantly higher grain and stover yield of post *monsoon* maize. However,

irrigation depth of 0.8 ETc also results comparable yields with 58 mm saving in water.

3. Drip fertigation at 100% RDF (150:75:75 NPK kg ha^{-1}) applied in spilt doses gives significantly higher grain and stover yield of maize which is comparable with 75 % RDF (113:57:57 NPK kg ha^{-1}) through drip with 25% saving in fertilizers.
4. The higher water use efficiency was observed in drip irrigation level 0.6 ETc followed by 0.8 ETc. The maximum WUE was noticed in 100% RDF (150:75:75 NPK kg ha-1) through drip irrigation followed by 75% RDF through drip.
5. The drip irrigation with 0.8 ETc depth and fertigation at 75% RDF (113:57:57 NPK kg ha^{-1}) results in highest total fertilizer use efficiency (14.31 kg/kg fertilizer used). The fertilizer use efficiency under F_4 (100% RDF) where fertilizers are applied conventionally through soil gives the lowest total fertilizer use efficiency.
6. The CERES Maize model of DSSAT underpredicts grain yield, total biological yields and harvest index of maize under all treatments whereas there is good agreement between observed and simulated results in regards with stover yield and leaf area index of maize.
7. The significant association was observed between predicted and measured values of harvest index and leaf area index with correlation coefficient (0.746) and (0.715) respectively, which indicates that the CERES maize model predicted harvest index and leaf area index of maize fairly well.
8. The DSSAT model simulated layer wise temporal variation of soil water content fairly well. The simulated water use efficiencies were less as compared to observed water use efficiency.
9. CERES-Maize model can be used as a research tool to predict the maize yields under variable agronomic and climatic conditions.

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LITERATURE CITED

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APPENDIX

APPENDIX-A

Weather data for the experimental period at Parbhani

Date	RF	Temperature ^{o}C		Humidity (%)		Average Humidity (%)	EVP (mm)	BSS (Hrs.)	WS (Kmph)
		Max	Min	AM	PM				
1-Sep-17	0.0	31.8	20.0	82	55	69	5.0	10.6	2.6
2-Sep-17	0.0	32.6	22.5	88	60	74	4.0	8.0	2.3
3-Sep-17	0.0	33.5	24.5	84	55	70	4.8	9.8	1.9
4-Sep-17	0.0	32.0	20.0	76	60	68	5.2	9.6	2.6
5-Sep-17	0.0	31.5	23.5	82	65	74	5.7	6.8	3.4
6-Sep-17	0.0	33.0	23.0	73	53	63	5.4	7.8	3.0
7-Sep-17	0.0	32.7	23.7	71	55	63	4.8	5.7	2.0
8-Sep-17	4.5	32.0	23.0	82	62	72	4.1	5.6	3.5
9-Sep-17	73.4	31.0	22.7	100	70	85	OF	5.3	4.8
10-Sep-17	1.0	33.0	23.0	90	56	73	2.4	5.6	1.6
11-Sep-17	0.0	33.0	22.5	78	53	66	4.6	8.7	1.8
12-Sep-17	0.0	32.6	22.5	74	66	70	4.7	8.3	5.0
13-Sep-17	67.0	30.2	22.0	100	72	86	OF	6.1	3.4
14-Sep-17	0.0	29.0	23.5	88	80	84	2.8	1.7	1.8
15-Sep-17	0.8	27.5	24.5	92	84	88	2.2	3.3	1.4
16-Sep-17	11.4	30.9	21.5	100	67	84	1.8	0.0	2.8
17-Sep-17	0.0	30.5	22.5	82	71	77	3.6	5.9	1.4
18-Sep-17	4.0	31.0	23.0	100	70	85	3.6	3.7	2.7
19-Sep-17	0.0	31.7	21.5	85	55	70	5.0	5.2	2.8
20-Sep-17	0.0	32.0	23.0	76	60	68	5.5	9.5	2.5
21-Sep-17	0.0	29.5	23.4	90	82	86	4.5	3.8	3.4
22-Sep-17	2.6	30.4	20.6	96	59	78	3.8	1.1	4.8
23-Sep-17	0.0	33.0	22.0	82	49	66	4.0	9.5	4.4
24-Sep-17	0.0	33.2	22.5	78	49	64	5.6	9.4	2.7
25-Sep-17	0.0	34.0	23.0	72	45	59	5.5	8.8	3.4
26-Sep-17	0.0	34.3	22.5	75	49	62	6.2	9.6	3.4
27-Sep-17	0.0	33.4	22.6	71	62	67	6.7	8.4	3.6
28-Sep-17	0.0	34.0	22.5	74	46	60	6.4	7.3	3.6
29-Sep-17	0.0	34.0	23.5	76	45	61	7.0	8.4	3.7
30-Sep-17	0.0	34.7	22.5	84	53	69	5.9	8.8	3.3
1-Oct-17	0.0	34.7	21.0	88	34	61	5.7	8.0	2.4
2-Oct-17	0.0	35.0	22.0	87	77	82	5.8	9.2	3.3
3-Oct-17	8.5	31.5	23.0	85	77	81	3.9	2.1	2.0
4-Oct-17	0.0	35.0	19.0	82	36	59	5.2	7.8	3.6
5-Oct-17	0.0	34.0	19.5	77	44	61	6.3	9.9	3.4
6-Oct-17	0.0	32.4	22.0	72	61	67	6.5	8.8	4.2
7-Oct-17	0.0	33.0	22.6	74	89	82	6.3	5.1	4.8
8-Oct-17	49.1	31.5	23.0	100	71	86	4.0	6.1	2.6
9-Oct-17	0.0	31.0	22.4	85	58	72	4.4	4.1	2.7

10-Oct-17	81.2	29.0	22.2	100	100	100	off	4.9	2.6
11-Oct-17	30	31.2	20.5	100	60	80	2.0	2.3	2.8
12-Oct-17	0.0	31.0	22.2	80	59	70	4.3	8.6	1.9
13-Oct-17	0.0	31.6	22.6	74	84	79	5.2	6.1	2.7
14-Oct-17	0.0	32.0	22.4	93	61	77	3.5	4.5	2.0
15-Oct-17	0.0	32.5	22.8	92	60	76	3.6	6.4	2.0
16-Oct-17	0.0	33.0	23.5	82	55	69	4.5	5.0	1.5
17-Oct-17	0.0	36.0	22.6	63	35	49	5.0	9.6	2.0
18-Oct-17	0.0	32.5	18.0	75	37	56	6.1	8.8	3.6
19-Oct-17	0.0	32.0	16.0	84	41	63	5.0	5.6	2.2
20-Oct-17	0.0	31.5	17.5	85	45	65	4.7	8.1	2.0
21-Oct-17	1.4	31.0	22.5	91	60	76	3.4	5.9	2.0
22-Oct-17	0.0	32.3	21.6	75	48	62	3.9	2.6	2.0
23-Oct-17	0.0	33.0	20.2	79	37	58	4.0	4.8	2.3
24-Oct-17	0.0	33.2	16.0	81	29	55	4.3	10.0	2.6
25-Oct-17	0.0	32.0	14.5	72	30	51	4.4	10.1	1.9
26-Oct-17	0.0	33.5	14.7	73	29	51	3.9	10.0	1.8
27-Oct-17	0.0	32.5	17.6	78	33	56	4.3	8.9	1.7
28-Oct-17	0.0	32.4	17.5	76	35	56	4.4	8.7	1.8
29-Oct-17	0.0	31.7	14.5	83	32	58	4.7	9.7	1.9
30-Oct-17	0.0	31.6	14.5	88	27	58	4.8	9.6	2.4
31-Oct-17	0.0	32.0	21.0	72	38	55	4.6	8.5	2.4
1-Nov-17	0.0	31.5	15.0	78	27	53	4.3	9.1	1.7
2-Nov-17	0.0	30.5	13.5	77	31	54	4.0	9.3	2.1
3-Nov-17	0.0	30.6	12.5	80	31	56	4.3	9.3	3.8
4-Nov-17	0.0	29.6	12.0	76	32	54	4.6	8.7	4.2
5-Nov-17	0.0	30.6	13.0	78	30	54	5.2	9.9	5.4
6-Nov-17	0.0	31.5	13.5	75	34	55	5.3	9.7	4.3
7-Nov-17	0.0	31.0	12.0	76	31	54	5.6	10.2	2.8
8-Nov-17	0.0	31.0	13.2	73	33	53	5.0	10.1	2.4
9-Nov-17	0.0	31.5	12.5	72	36	54	4.4	9.8	3.0
10-Nov-17	0.0	30.6	13.5	82	30	56	5.1	9.2	2.1
11-Nov-17	0.0	29.5	11.0	90	27	59	4.1	8.8	3.5
12-Nov-17	0.0	30.4	9.7	85	24	55	4.4	9.2	3.5
13-Nov-17	0.0	30.0	10.0	74	30	52	4.0	9.4	2.8
14-Nov-17	0.0	31.0	11.0	82	25	54	4.8	8.6	2.3
15-Nov-17	0.0	31.5	13.0	75	27	51	4.9	8.9	2.3
16-Nov-17	0.0	31.5	16.5	71	37	54	5.2	9.0	4.3
17-Nov-17	0.0	31.8	15.9	74	37	56	4.8	7.9	2.7
18-Nov-17	0.0	32.0	16.6	79	32	56	4.4	8.3	2.4
19-Nov-17	0.0	32.0	17.5	74	37	56	4.7	9.1	1.3
20-Nov-17	0.0	31.9	20.4	72	41	57	4.6	6.9	2.6
21-Nov-17	0.0	31.8	17.0	78	44	61	5.0	4.1	3.3
22-Nov-17	0.0	33.0	19.0	76	46	61	4.4	5.3	2.2
23-Nov-17	0.0	33.2	20.0	73	44	59	4.8	9.0	2.8
24-Nov-17	0.0	31.9	17.4	80	39	60	4.0	8.5	2.6
25-Nov-17	0.0	31.5	13.6	78	47	63	4.2	8.4	2.1
26-Nov-17	0.0	31.0	11.5	80	36	58	4.2	9.4	2.8

27-Nov-17	0.0	30.5	9.0	82	23	53	4.0	9.7	2.7
28-Nov-17	0.0	31.6	8.4	76	17	47	4.1	9.6	2.3
29-Nov-17	0.0	30.4	9.2	78	27	53	3.7	10.0	1.8
30-Nov-17	0.0	29.6	11.0	73	35	54	3.9	9.0	2.6
1-Dec-17	0.0	29.5	12.0	75	39	57	3.8	9.4	3.7
2-Dec-17	0.0	29.0	10.0	74	35	55	4.0	8.2	4.1
3-Dec-17	0.0	28.5	12.0	82	39	61	3.5	8.3	4.1
4-Dec-17	0.0	29.2	11.5	71	40	56	4.0	8.5	4.6
5-Dec-17	0.0	29.5	14.0	73	42	58	5.2	8.1	5.2
6-Dec-17	0.0	31.0	16.1	69	49	59	5.6	7.2	8.0
7-Dec-17	0.0	31.5	19.0	70	44	57	3.8	5.0	3.4
8-Dec-17	0.0	31.7	15.0	80	46	63	4.1	5.0	3.4
9-Dec-17	0.0	30.5	13.1	81	40	61	4.8	9.0	4.2
10-Dec-17	0.0	29.5	12.2	84	35	60	4.0	8.9	3.0
11-Dec-17	0.0	30.8	10.2	74	27	51	4.3	9.8	2.9
12-Dec-17	0.0	32.0	11.0	79	26	53	4.6	9.4	2.0
13-Dec-17	0.0	32.5	13.0	82	27	55	5.2	9.2	2.5
14-Dec-17	0.0	31.8	14.5	76	32	54	4.7	8.0	2.6
15-Dec-17	0.0	30.5	15.0	78	31	55	5.1	7.2	3.0
16-Dec-17	0.0	30.0	13.5	83	38	61	4.7	8.0	3.7
17-Dec-17	0.0	29.5	10.5	73	37	55	4.4	8.6	3.9
18-Dec-17	0.0	29.0	11.0	77	34	56	4.3	7.7	4.5
19-Dec-17	0.0	29.0	7.0	75	15	45	4.3	9.3	4.3
20-Dec-17	0.0	29.5	6.0	80	18	49	4.4	8.4	5.1
21-Dec-17	0.0	30.0	8.5	70	29	50	4.0	7.9	2.8
22-Dec-17	0.0	29.0	7.0	74	32	53	3.7	9.4	3.3
23-Dec-17	0.0	29.0	8.4	73	29	51	4.0	9.1	3.0
24-Dec-17	0.0	29.5	7.5	77	35	56	3.6	7.3	2.1
25-Dec-17	0.0	30.0	6.6	76	23	50	3.8	9.1	2.6
26-Dec-17	0.0	28.5	8.0	77	33	55	4.0	9.0	2.4
27-Dec-17	0.0	28.6	7.6	79	16	48	3.8	9.0	3.6
28-Dec-17	0.0	29.5	5.6	80	15	48	4.2	9.9	3.3
29-Dec-17	0.0	29.8	5.9	78	16	47	3.9	10.0	3.2
30-Dec-17	0.0	29.0	7.2	71	22	47	3.7	9.5	2.8
31-Dec-17	0.0	29.0	8.2	74	23	49	3.5	9.6	1.9

APPENDIX-B

Irrigation water applied during the growth period of maize based on irrigation levels

No	DAS	Date	1.0ETc	0.8ETc	0.6ETc
0	12	20-Sep-17	3.91	3.13	2.34
1	14	22-Sep-17	2.77	2.22	1.66
2	16	24-Sep-17	4.77	3.82	2.86
3	18	26-Sep-17	5.05	4.04	3.03
4	20	28-Sep-17	4.68	3.74	2.81
5	22	30-Sep-17	4.87	3.9	2.92
6	24	02-Oct-17	5.31	4.25	3.19
7	28	06-Oct-17	7.65	6.13	4.59
8	41	19-Oct-17	6.69	5.35	4.01
9	43	21-Oct-17	5.7	4.57	3.42
10	45	23-Oct-17	6.43	5.14	3.86
11	47	25-Oct-17	8.41	6.73	5.05
12	49	27-Oct-17	7.91	6.34	4.75
13	51	29-Oct-17	8.25	6.6	4.95
14	53	31-Oct-17	9.13	7.3	5.48
15	55	02-Nov-17	8.36	6.68	5.01
16	57	04-Nov-17	9.47	7.58	5.68
17	59	06-Nov-17	11.36	9.1	6.82
18	61	08-Nov-17	9.65	7.72	5.79
19	63	10-Nov-17	10.28	8.22	6.17
20	65	12-Nov-17	10.4	8.32	6.24
21	67	14-Nov-17	8.7	6.96	5.22
22	69	16-Nov-17	9.5	7.6	5.7
23	71	18-Nov-17	8.75	7	5.25
24	73	20-Nov-17	7.46	5.97	4.47
25	75	22-Nov-17	6.82	5.45	4.09
26	77	24-Nov-17	8.17	6.53	4.9
27	79	26-Nov-17	7.19	5.74	4.31
28	81	28-Nov-17	6.9	5.52	4.14
29	83	30-Nov-17	6.48	5.19	3.89
30	85	02-Dec-17	7.27	5.82	4.36
31	87	04-Dec-17	6	4.8	3.59
32	89	06-Dec-17	6.84	5.47	4.1

APPENDIX-C

Amount of NPK applied in kg/ha for 100 % RDF (F_1 Treatments)

DAS	N	P	K
10	19	19	9
20	19	19	9
30	19	19	9
40	19	19	9
50	19	0	9
60	19	0	9
70	19	0	9
80	19	0	9

Amount of NPK applied in kg/ha for 75% RDF (F_2 Treatments)

DAS	N	P	K
10	14	14	7
20	14	14	7
30	14	14	7
40	14	14	7
50	14	0	7
60	14	0	7
70	14	0	7
80	14	0	7

Amount of NPK applied in kg/ha for 50% RDF (F_3 Treatments)

DAS	N	P	K
10	9	9	5
20	9	9	5
30	9	9	5
40	9	9	5
50	9	0	5
60	9	0	5
70	9	0	5
80	9	0	5

Amount of NPK applied in kg/ha for 100% RDF through soil (F_4 Treatments)

DAS	N	P	K
At sowing	75	75	75
30	75	-	-

CURRICULUM VITAE

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Academic qualification

Course/ Degree	Name of college/Institute	University/ Board	Year of passing	Percentage (%)/ CGPA	Class/ Grade
SSC	Harinarayan Swami Vidhyalaya Karhewadi	Aurangabad	2013	81.45%	First class
HSC	S. B. E. S College of Science and Technology, Aurangabad	Aurangabad	2015	60.31%	First class
B. Tech (Agricultural Engineering)	Aditya College of Agril. Engg. and Tech. Beed	VNMKV., Parbhani	2019	78.01%	First class

Place: Parbhani

Date : 03/ 01 /2022

Signature of the candidate

Sangale Bhagwan Bhanudas