ESTIMATION OF CROP WATER REQUIREMENT SATISFACTION INDEX (WRSI) AND CROP COEFFICIENT OF SOYBEAN [*Glycine max (*L.*) Merill.*] CV. MAUS-71 BY USING LYSIMETER.

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B.Sc. (Hons.) Agriculture

MASTER OF SCIENCE

IN

AGRICULTURE

(AGRICULTURAL METEOROLOGY)

DEPARTMENT OF AGRICULTURAL METEOROLOGY,

COLLEGE OF AGRICULTURE, PARBHANI

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PARBHANI- 431 402 (M.S.) INDIA

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BY

PARMESH S BIRADAR

B.Sc. (Hons.) Agriculture

A thesis submitted to

Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani

in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

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2022

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled, **"Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max (L.) Merill.*] cv. MAUS-71 by using Lysimeter."** submitted by me is based on actual work carried out by me under the guidance and supervision of **Kailas. K. Dakhore**. The extent of information derived from the existing literature have been duly cited and referenced. The exciting research work or its any part is not submitted anywhere else for the award of any degree or diploma.

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Date: 30/ 11 / 2022

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This is to certify that the thesis entitled, **"Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max* (L.) *Merill.*] cv. MAUS-71 by using Lysimeter."** submitted by **Pamesh Shivraj Biradar Reg. No: 2020A/23M** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (Agriculture)** in the subject of **AGRICULTURAL METEOROLOGY** submitted to the Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani is a record of bonafide research work carried out by him/her under my guidance and supervision. The thesis or its any part has not previously formed the basis for the award of any degree, diploma or other similar title.

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Date: 30/11/2022

(K. K. Dakhore)
Agrometeorologist
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ABSTRACT The research trial with "Estimation of Crop Water Requirement Satisfaction Index (WRSI) and

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Place: Parbhani

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(Parmesh.S.Biradar)

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ABBREVIATIONS

AICRP	:	All India Co-ordinated Research Project
BSS	:	Bright sunshine hours
DAS	:	Days after sowing
ET_c	:	Actual evapotranspiration
ET_o	:	Potential evapotranspiration
et al.	:	Et alia, and others
etc	:	Et-cetera (and other)
FAO	:	Food and Agricultural Organiazation
Fig.	:	Figure
Temp	:	Temperature
T_{max}	:	Maximum temperature
T_{min}	:	Minimum temperature
K_c	:	Crop Coefficient
K_c ini	:	Crop coefficient at initial stage
K_c mid	:	Crop coefficient at mid stage
K_c end	:	Crop coefficient at end stage
RH	:	Relative Humidity
RH-I	:	Morning humidity
RH-II	:	Afternoon humidity
RH_{mean}	:	Mean Relative humidity
R.F	:	Rainfall
%	:	Percent
RD	:	Rainy Days
^0C	:	Degree Celsius
mm	:	Millimeter
cm	:	Centimeter
G.M	:	Geometric mean
CV	:	Coefficient of variation
SD	:	Standard deviation
Hrs/day	:	Hours per day
i.e.,	:	That is
gm	:	gram
Kg/ha	:	Kilogram per hectare
Km/hr	:	Kilometer per hour
MSL	:	Mean Sea Level
GDD	:	Growing degree days
HTU	:	Helio-thermal units
PTU	:	Photo-thermal Units
HUE	:	Heat Use Efficiency
S	:	Significant
NS	:	Non-significant
VNMKV	:	Vasantrao Naik Marathwada Krishi Vidyapeeth
MW	:	Meteorological Week

THESIS ABSTRACT

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1.	Title of the thesis	:	Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max (L.) Meril*] cv. MAUS-71 by using Lysimeter.
2.	Full name of the Candidate	:	Parmesh.S.Biradar
3.	Full name of the Research Guide	:	Kailas K. Dakhore
4.	Department	:	Agricultural Meteorology
5.	University	:	College of Agriculture, VNMKV, Pabhani- 431402
6.	Degree to be awarded	:	M.Sc. (Agriculture)

ABSTRACT

The research trial with "Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [Glycine max (L.) Merill] cv. MAUS-71 by using Lysimeter." was conducted during the *Kharif* season 2021-22 on the experimental farm of the Department of Agricultural Meteorology, AICRP on Agrometeorology, College of Agriculture, VNMKV, Parbhani, to find out the crop coefficient values of Soybean cv. MAUS-71, the effect of weather parameters on Soybean varieties under different dates of sowing, estimation of crop Water Requirement Satisfaction Index and crop Water Stress Index of soybean. This experiment was carried out in a Split plot design with three replications and 12 treatments, i.e., four sowing dates: D_1 (25th MW), D_2 (26th MW), D_3 (27th MW), and D_4 (28th MW), as well as three Soybean Varieties: V_1 (MAUS-158), V_2 (MAUS-71), and V_3 (JS-335) with spacing of 45 cm x 5 cm. The total number of plots was 36 with the net plot of about 4.5 x 3.6 m^2 and the gross plot was 5.4 × 4.5 m^2. Soybean seeds were sown by drilling method.

The Early sowing crop, D_1 (25th MW) produces maximum Soybean seed yield and have the highest Plant height, number of branches per plant and number of pods per plant than the rest of other sowing date. The amount of soybean seed yield (kg/ha), yield contributing characters and yield attributing factors like seed yield

(gm), stalk yield (Kg/ha), and biological yield (Kg/ha) and harvest index (percent) of the crop decline from D_1 to D_4, i.e., D_1 (25^{th} MW) followed by D_2 (26^{th} MW), then D_3 (27^{th} MW) with D_4 (28^{th} MW) producing the lowest. Among the cultivars, MAUS-158 produces higher yield as well as higher yield attributing characters than MAUS-71 and JS-335, where, JS-335 produces the lowest. The seed yield decline when sowing dates were delayed beyond D_1. Further, D_1 has the highest GDD, PTU, HTU and HUE among other sowing dates and get reduces as the sowing dates were delayed.

During the crop growth period of 2021, the total water requirement of the crop, i.e. ET_c, was 505.70 mm, ranging from 0.5 to 14 mm per day. It was recorded that the highest rate of ET_c (108.2 mm) was seen at grain formation stage of crop growth, indicating an increase in crop water demand during that time frame. The total ET_o (potential evapotranspiration) estimated throughout the crop life cycle was 459.54 mm, using the standard procedure of the FAO Penman-Monteith method.

The crop coefficient (K_c) of the Soybean cv. MAUS-71 (V_2) varied greatly throughout its growth and development phase which increases successively from P1 to P5 (emergence to pod formation) slightly constant at P6 (grain formation) and then decrease from P7 to P10 (pod development to maturity stage), which shows that the pod formation stage has the highest K_c value. The K_c values estimated during initial (0-30 DAS), mid (31-85 DAS), and end (86-110 DAS) stages were 0.67, 1.39 and 0.80, respectively, with the maximum K_c value during mid season stage. The higher K_c values was due to increase in rate of transpiration fully due to canopy with fully develop branches, leaves, maximum plant height and pods which increases crop water demand. Result showed that FAO-56 Irrigation and Drainage paper Allen *et al.*, (1998) overestimated the K_c value of soybean at Parbhani. In terms of K_c values at all stages, Hargreaves method is the only method that differs slightly with the K_c values of P-M method in all stages. This means that the Potential evapotranspiration (ET_o) and crop coefficient (K_c) values can be estimated by Hargreave method in Parbhani location. These two methods have the lowest MAE, MBE and RMSE indicating lowest magnitude of average error.

The Crop Water Requirement Satisfying Index (WRSI) varied with crop stages and is highest during the emergence to flowering stages (99%) then declines during the pod and grain formation stages (70-75%) and rebounds to its highest level during the pod development stage (98%), pod containing full grain stage (100%), dough stage (100%), and maturity stage (98%). The crop's total water demand, or ET_c, over the crop growth period was 505.70 mm, and at all stages of the crop's development, all but the stages of pod formation and grain formation, where a shortage in satisfaction was noted, it was virtually completely satisfied by soil moisture.

As a result of a water shortage, the difference between leaf temperature and air temperature near the leaf was highest at the pod formation stage (4.5 $^{\circ}$C), grain formation stage (4.2 $^{\circ}$C), and maturity stage (4.8 $^{\circ}$C), indicating that the plant was under water stress with CWSI values of 0.98, 0.92 and 1.00 respectively. In contrast, the difference between leaf temperature and air temperature near the leaf was lowest at the remaining majority of plant growth stages, indicating that the plant had access to the ideal amount of water. Higher the difference between leaf temperature and air temperature near the leaf results higher in CWSI values.

Keywords: Crop coefficient, Lysimeter, WRSI, CWSI.

CHAPTER-I

INTRODUCTION

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INTRODUCTION

The Soybean [*Glycine max (L.) Merill*] is a significant food legume and is essential to human survival. Other names for soybean include "miracle crop", and "gold of the century." It has a high proportion of high-quality proteins (35-45%) and edible oil (15-25%) that is rich in important required amino acids. Soybean meal serves as a high-quality source of protein for feed regimens for cattle. It is the most significant seed legume in the world, contributing about 25% of the world's edible oil and around two-thirds of the protein concentrate used in livestock feed. With an average protein content of 40%, a carbohydrate content of 30%, 20% oil content, 9% water content, and 1% ash, it is a significant source of dietary protein for humans. (Nutrient data laboratory 2016)

Soybean is a *kharif* season crop. Soybean was introduced to India long ago through the Himalayan routes and also brought via Burma by traders. Soybean grown about 3 lakhs ha. In India until 1971 but now it occupied over 12.81 million ha in 2021 producing over 12.90 million tons. At present, India ranks fourth in the area with 12.81 million hectares accounting for 9.41% of the world area and fifth in production with 12.90 million tones.

World soybean production in 2020-21 was estimated as 350.72 million tons, a decrease of 17.04 million tons or 4.63% that of previous year. Brazil ranks first in soybean production with 139 million tons followed by United States of America (120.7 million tonnes), Argentina (46.50 million tonnes), China (16.40 million tonnes) and India (12.90 million tonnes) accounting for 32.25, 30.01, 16.56, 4.00 and 3.91 percent of world production respectively. (FAOSTAT. 2021).

In India area under soybean during 2020-21 was 12.81 million hectares Among the states, Madhya Pradesh stood first with 6.50 million ha followed by Maharashtra 4.36 million ha, Rajasthan 1.13 million ha, Karnataka 0.31 million ha, Telangana 0.16 million ha. and Gujarat 0.15 million ha. If we see the production strength of the nation was 12.90 million tonnes during current year. Among the states Maharashtra leads first with 6.20 million tonnes followed by Madhya Pradesh 4.61 million tonnes, Rajasthan 1.09 million tonnes Karnataka 0.38 million tonnes, Telangana 0.24 million tonnes, Gujarat 0.20 million tonnes (Agricultural Statistics at a Glance, GOI 2021).

In Madhyapradesh Ujjain division has highest soybean cultivated area with 19,280 lakh ha, next to this Latur divison in Maharashtra, these two emerged as the largest soybean cultivated area in the country in 2021 *kharif*. (Agricultural Statistics at a Glance, GOI 2021) Especially in Marathawada region soybean is mainly cultivated as rainfed and as well as irrigation given to the crop from June to September and in summer season.

The soybean is grown under warm conditions in the tropics, subtropics and temperate climates. The optimum temperature for germination of soybean seed is 30°C. Soil temperatures of 15.5°C or above favor rapid germination and vigorous seedling growth. Soybean is relatively resistant to low and very high temperatures but growth rates decrease above 35°C and below 18°C. In some varieties, flowering may be delayed at temperatures below 24°C. A temperature of 26 to 30°C appears to be the optimum for most of the varieties. Day length is the key factor in most of the soybean varieties as they are short day plants. (Nimje 2020). In northern India soybean can be planted from third week of June to first fortnight of July. Well drained and fertile loam soils with a pH between 6.0 and 7.5 are most suitable for the cultivation of soybean. Soybeans are susceptible to water logging between emergence and the four leaf stage. However, after this stage soybean has good tolerance to water logging compared to other non-rice crops, which is another reason to grow them. Soybeans, like most legumes, perform nitrogen fixation by establishing a symbiotic relationship with the bacterium Brady Rhizobium japonicum (syn. *Rhizobium japonicum*) (Lindström *et al*. 2010). The temperature 27°C is optimum for nodule formation, more than 35°C effects negatively.

Soybean can grow and get good yield with as little as 180mm of in-crop rain but could expect a 40-60 percent yield decline compared to optimal conditions. The ideal rainfall range is between 450 and 800 mm. Depending on soil type and stored soil moisture; crop failure would be expected if less than 180 mm of rain were received in crop. (Nimje 2020). In India soybean mainly grown under rainfed condition, moisture deficiency during vegetative growth stage reduces rate of plant growth and at flowering stage reduces the quantity of yield. The parameters controlling water requirement of soybean crop are: rainfall (P), Temperature (T), wind speed (WS), cloud cover, actual evapotranspiration (ET), soil moisture (SM), soil water holding capacity (WHC) and water use efficiency (WUE) of crop and many. The present work was undertaken to study the parameters controlling water requirement satisfaction and stress of soybean crop at various phenophases in different soybean by considering ET of the crop.

Irrigation is required to keep the crop well watered when rainfall is insufficient. To acquire the necessary frequency of wetting required to keep the crop stress-free, the mean interval between the future irrigations should be estimated, even in areas where irrigation is not yet built. Reduced crop growth negatively impacts agricultural output when there is a water shortage in the rhizospheric region of the soil. (Zia *et al*. 2021) So, the purpose of irrigation is to maintain a sufficient level of moisture in the root zone so that crop yield is not negatively impacted. However, there is a lot of pressure on water supplies both quantitatively and qualitatively in the current environment of climate change, rapid industrialization, and population growth.

In order to get the highest yield and the most efficient use of water, it is crucial to allocate water resources precisely while taking into account the crop's water needs and accurate information of the soil composition. Agricultural evapotranspiration (ET_c), which takes simultaneous atmospheric water loss from plant transpiration and soil evaporation into account, is often the measure of crop water needs. Energy balance, microclimatological techniques, field water balance and lysimeters are a few of the methods available for the direct determination of ET_c. (Jensen *et al.* 1971) the measurement of reference evapotranspiration and crop coefficients are two examples of indirect approaches, though.

Among all above methods the most accurate and practical method for calculating actual ET_c under field settings is to estimate the water balance in the lysimeter. As a result, the current study goals at to determine the ET_c utilizing the lysimeter water balance method.

The crop coefficient, or K_c, is often calculated experimentally for a particular crop. The K_c values show the combined impact of alterations in leaf area, plant height, crop features, irrigation technique, rate of crop development, crop planting date, degree of canopy cover, soil and climate conditions, and management strategies. (Farahani *et al.* 2007) Each crop will have a unique crop coefficient that will estimate how much water it will require at various phases of growth. The crop coefficient is calculated by measuring the actual and potential crop evapotranspiration at various phases of crop growth using a weighing type field lysimeter. Potential evapotranspiration (PET) can be calculated using the Blaney and Criddle, Thronthwaite, modified Penman, etc. methods. Calculating crop coefficients at various crop growth stages and determining daily crop evapotranspiration help farmers schedule irrigation effectively and use water wisely.

Based on research from the FAO, crop-specific linear yield-reduction functions can be used to connect WRSI to agricultural production. The water stress of a crop throughout a growing season in agriculture is measured by the WRSI as a result of plant and atmospheric demand exceeding the water availability (Woli *et al.* 2012). Frere and Popov originally proposed simplified crop-weather analysis model in 1979 to the United Nations Food and Agriculture Organization (FAO) as a proxy for crop performance, and an indicator of the satisfaction of the crop water requirements in areas of the world where water represents the main constraint for crops (FAO, 1979) An operational monitoring index, the water demand satisfaction index created by Allen *et al.*, in 1998 shows the performance of a crop based on the availability of water during the growing season. The amount is calculated as the seasonal actual crop evapotranspiration (AET) divided by the crop's water requirement (WR). The spatially explicit water requirement satisfaction index (WRSI), which is based on the crop's access to water during a growing season, measures crop performance. Funk *et al*. (2010)

Plant temperature is an indicator of plant water status because stomata close in response to soil water depletion causing a decrease in water uptake and an increase in leaf temperature. Idso *et al*. (1981), precise measurements, particularly canopy temperature, are required to determine the amount of stress. Based on the temperature of the canopy, the surrounding air, and the relative humidity, the crop water stress index (CWSI) has been acknowledged as a reliable predictor of plant water status. The empirical CWSI-e approach, created by Idso *et al*. (1981), and the theoretical

CWSI-t method, created by Jackson *et al*. (1981) have both been extensively utilized and assessed for CWSI calculations. According to the empirical method, there is a connection between the vapor pressure deficit and the canopy-to-air temperature differential (VPD).

By considering above points, the experiment conducted at the farm of Dept. of Agrometeorology, VNMKV, Parbhani, entitled "**Estimation of Crop water requirement satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max (L.) Merill*] cv. MAUS-71 by using Lysimeter**." with following objectives.

1. To find out the crop coefficient values of Soybean cv. MAUS – 71.
2. To study the effect of weather parameters on soybean varieties under different dates of sowing.
3. To computes the Crop water requirement satisfaction index (WRSI) of soybean cv. MAUS – 71.
4. To compute the crop water stress Index (CWSI) of soybean.

CHAPTER-II

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

1. To find out the crop coefficient values of Soybean cv. MAUS – 71.

Allen *et al.* (1998) revised the guidelines for basal crop coefficients for estimating crop water use. They also provided K_c values for several agricultural crops in various places recommending that these values be used in places where local data is unavailable.

Kashyap *et al.* (2001) estimated Crop-coefficients (K_c) for Potato crop at different stages of growth, ET measured with lysimeter and ET_o estimated by various methods. Among all methods the Penman-Monteith equation gave the best result followed by 1982-Kimberly-Penman, Tarc-Radiation and FAO-Blaney-Criddle. The measured values of crop-coefficient for potato crop stages of growth such as initial, crop development, reproductive and maturity were,0.42,0.85,1.27,0.75.

Howell *et al.* (2006) Crop coefficients derived from evapotranspiration measured with large, precise weighing lysimeters at Bushland, And are presented for the major regional irrigated crops like corn, wheat, sorghum, soybean, cotton and alfalfa. The ASCE/EWRI standardized reference evapotranspiration equation for daily weather data for short (*ETos*, grass) and tall (*ETrs*, alfalfa) crops was used as the base. Crop coefficients for both *ETos* and *ETrs* were summarized. They were generally in agreement with Kc values from FAO-56.

Ko *et al.* (2009) determined the growth-stage-specific K_c and crop water use for cotton and wheat at the Texas AgriLife Research field, USA from2005 to 2008. Crop water requirements, K_c determination and comparison to existing FAO K_c values were determined over a 2-year period on cotton and a 3-year period on wheat. Seasonal total amounts of crop water use ranged from 689 to 830 mm for cotton and from 483 to 505mm for wheat. The K_c values determined over the growing seasons varied from 0.2 to 1.5 for cotton and 0.1 to 1.7 for wheat.

Kamble *et al.* (2010) estimated the crop evapotranspiration in soybean crop through lysimeter. From the field study it was seen that the Blaney and Criddle, Thornthwaite and pan evaporation methods did not give correct prediction of PET, due to estimated K_c values and did not give correct estimation at various phenophases. For estimation of PET under Marathwada region at Parbhani condition, the modified Penman method is the most suitable. The total seasonal Actual evapotranspiration (AET) for soybean was found to be 353.59 mm.

Unlu *et al.* (2010) measured ET of irrigated soybean (*Glycine max* L.) directly during the summer of 2009 using weighing lysimeter and ET_0 estimated by BREB method over a growing season in a semi-arid climate of eastern Mediterranean region. Cumulative evapotranspiration totals from the lysimeter and BREB methods were 354 and 405 mm, respectively. The BREB method showed a good performance for daily ET estimation when compared to values measured by lysimeter. This method, with a root mean square error (RMSE) of 0.79 mm d^{-1} and a 0.96 index of agreement, over-estimates lysimetric measurements by 15%.

Pandey *et al.* (2011) developed crop coefficients for black gram, and a comparison is made of single and dual crop coefficient approaches to estimate actual crop evapotranspiration under the climatic conditions of Udaipur, India. Daily measured black gram evapotranspiration data by electronic weighing lysimeter and reference evapotranspiration calculated using standard Penman-Monteith method. The measured values of crop coefficient for the crop were 0.48, 1.18 and 0.33 during initial, mid-season and late-season stages.

Bhandari *et al.* (2012) determined the potential evapotranspiration (PET) of maize, the crop coefficient (K_c) under full water requirement as well as the cause of decrease in maize yield. It was determined that the seasonal PET of maize is about 486.6 mm. The Kc under full water supply was found to be: 0.11, 0.35, 1.51 and 0.34 for initial, development, midseason and the late season stages respectively.

Zhang *et al.* (2013) aimed to estimate the ET_c of winter wheat–summer maize crop sequence in the North China through eddy covariance measurements, to calibrate and validate the SIMDual K_c model, to estimate the basal crop coefficients (K_{cb}). Various indicators have shown the goodness of fit of the model, with estimated values very close to the observed ones and estimate errors close to 0.5 mm d^{-1}. The initial, mid-season and end basal crop coefficients for wheat were 0.25, 1.15 and 0.30, respectively, and those for maize were 0.15, 1.15 and 0.45, thus close to those proposed in FAO56 guidelines.

Babazadeh *et al.* (2013) determined the parameters related to irrigation management in planting soybean in the field, at the Tehran University in Karaj in 2008. Furrow surface irrigation treatments consisted of full irrigation (FI), conventional deficit irrigation treatment at 75 and 50 percent soil moisture deficit compensation (DI75% and DI50%) and partial root drying treatment at fifty percent soil moisture deficit compensation (PRD50%). Results showed that soybean crop coefficients in four stages consisted of initial (K_c ini), developed (K_c adv), middle (K_c mid) and also in final stage (K_c lat) during soybean growth stage was obtained 0.34, 0.7, 1 and 0.44 respectively.

Abedinpour *et al.* (2015) determined growth-stage-specific K_c and compared them to existing FAO K_c values by investigating water use of maize (*Zea mays* L.) at the Water Technology Center Research Field in the Indian Agricultural Research Institute (IARI), New Delhi, India in 2010. The K_c values for the initial, crop development, mid-season, and late stages were 0.40–0.60, 0.70–0.80, 1.1–1.21 and 0.50–0.65, respectively, while the values reported for maize by FAO are 0.3, 1.2, 0.3–0.6 for the initial, mid-season and late stage, respectively.

Farg *et al.* (2012) focuses on estimating the crop coefficient (K_c) and crop evapotranspiration (ET_c) using SPOT-4 satellite data integrated with the meteorological data and FAO-56 approach. Multi linear regression analysis was applied to develop the crop coefficient (K_c) prediction equations for the different growth stages from vegetation indices. The results showed R^2 were 0.82, 0.90 and 0.97 as well as adjusted R^2 were 0.80, 0.86 and 0.96 for developing, mid-season and late-season growth stage respectively.

Prajapati *et al.* (2016) conducted an experiment for two years (2013-14 and 2014-15). Diurnal and temporal variation of soil moisture with depth was monitored using soil moisture sensors at irrigation regimes 1.0 IW/ET_c and 0.8 IW/ET_c. Biodegradable plastic mulch reduced K_c-ini value by 72.26% and 66.54% over control at 1.0 IW/ET_c and 0.8 IW/ET_c respectively. Overestimated adjusted FAO K_c values caused a loss of 78.13mm and 66.54mm of precious water at 1.0 IW/ET_c and 0.8 IW/ET_c respectively.

Mila *et al. (*2016*)* determined K_c values for sunflower (variety BARI Surjomukhi-2) crop during the month of mid-November, 2014 to mid-March, 2015, using a lysimeter at Irrigation and Water Management Division, BARI, Gazipur. Seasonal total ET_c was found as 270.89 mm. The K_c values of sunflower under different ET_o methods for initial, development, mid-season and late season ranged from 0.34 to 0.48, 0.80 to 1.10, 1.06 to 1.55, and 0.27 to 0.36, respectively. Among different methods, P-M method gave relatively higher value than those of other methods and also FAO recommended value.

Mila *et al. (*2016*)* conducted an experiment in order to estimate crop coefficient values of soybean under the local climatic condition at the Irrigation and Water Management Division of Bangladesh Agricultural Research Institute (BARI), Gazipur. An improved crop variety-BARI Soybean-6 was used in this experiment. The seasonal highest cumulative ET_c was 308.43 mm under this treatment. The K_c values of soybean at initial, development, mid-season and late season stages were found as 0.67, 1.46, 1.59 and 0.62, respectively.

Thao *et al.* (2017) developed seasonal ET_c and K_c for sugarbeets grown under surface drip irrigation in the Central Valley of California using WL. During the 2014-2015 and 2015-2016 growing seasons, observed that seasonal ET_c for sugarbeets ranged from 540 mm to 870 mm. Average K_c values generated for the different crop growth stages were: 0.47-0.52 at the end of the initial stage, 0.93-1.26 during midseason and 0.7-0.92 at late season.

Wang *et al.* (2017) proposed a stage-wise Kc variations for winter wheat at each critical phenological stage, for wheat (*Triticum aestivum L.*), at Gucheng Agro-meteorological experimental station in the NCP. Evaluation revealed that the stage-wise method significantly outperformed the FAO method at both daily and critical phenological time scales, with root-mean-square errors in ET_a for the stage-wise method and the FAO method being 0.07 mm. day^{-1} and 0.16 $mm.day^{-1}$, respectively, at the daily time scale, and 0.01 mm. day^{-1} and 0.27 mm. day^{-1} at the critical phenological time scale.

Srinivas (2018) found the K_c values for green gram for different development stages, during *Kharif* the ETc was determined by soil water balance equation and ETo was computed using DSS-ET version 4.1. The seasonal ET_c was found to be 36.83 mm, 86.78 mm, 67.12 mm and 16.52 mm of water calculated for initial, crop development, mid-season and late season stages, respectively. The measured crop coefficient (K_c) values were 0.34, 0.45, 0.57, 0.69, 0.8, 0.99, 1.05, 1.13, 1.1, 1.04, 0.92, 0.66, 0.57, 0.42, 0.37 and 0.17 for the respective each stage of the crop.

Alataway *et al.* (2019) estimated the water requirement, K_c, of potato using non-weighing-type lysimeters in four regions of the Kingdom of Saudi A*Rabi*a (Qassiem, Riyadh, Al-Jouf, and Eastern). The K_c values of potato obtained from the lysimeters were Kc initial (0.58, 0.54, 0.50, and 0.52), K_c middle (1.02, 1.05, 1.13, and 1.10) and K_c end (0.73, 0.74, 0.74, and 0.75) for the Qassiem, Riyadh, Al-Jouf, and Eastern regions, respectively.

Djaman *et al.* (2019) aims to estimate rice seasonal evapotranspiration (ET_a), and to develop rice growth stage specific crop coefficients (K_c) at the Africa Rice research station at Fanaye in Senegal. Rice seasonal ET_a was 841.5 mm in 2014 and 855.4 mm in 2015. The derived rice K_c values varied from 0.77 to 1.51 in 2014 and 0.85 to 1.50 in 2015. Rice K_c values averaged 1.01, 1.31, and 1.12 for the crop development, mid-season and late season growth stages, respectively.

Anda *et al.* (2009) determined Evapotranspiration (ET_a), reference evapotranspiration (ET_0), and seasonal ET_a totals were, for soybean over two growing seasons, at Keszthely, Hungary, the study aimed to document the plant–water response of two soybean varieties (*Sinara*: *Sin*; *Sigalia*: *Sig*). Measured mean ET_a was as much as 10% higher than derived ET_0 rates, causing crop coefficient to exceed 1.0 during flowering. Careful selection of the soybean variety when practicing water-saving management may lead to more efficient variety improvement in a breeding program.

Marek *et al.* (2021) found a K_c value of a short-season soybean variety was planted on 13 June in irrigated weighing lysimeter fields at the USDA-ARS

Conservation and Production Research Laboratory at Bushland, TX. Results showed profitable yields (4,786–4,996 kg ha^{-1}) and although maximum daily K_c values were not different than FAO published values, season length was 24–29 days shorter than for soybean planted in mid-May.

2. To study the effect of weather parameters on soybean varieties under different dates of sowing.

Ram *et al.* (2010) studied the effect of time of sowing on the performance of soybean at Punjab Agricultural University, Ludhiana (Punjab) during *kharif* 2008 and 2009. The highest grain yield (2537 kg/ ha) was recorded in June 5 sown crop which was significantly higher than June 25 sowing (2169 kg/ha) but statistically at par with June 15 sowing (2386 kg/ha) in 2008. The variety SL 744 gave the highest grain yield, which was statistically at par with SL 790 but significantly higher than SL 525.

Ngalamu *et al*. (2013) verified the effects of sowing date on five soybean (Glycine max L. Merrill) genotypes planted at five different planting dates in 2009 and 2010. Early sown crop have maximum height, more number of branches, pods. The highest seed yield of 1.2 t/ha was obtained from sowing carried out on 10th August in 2009, followed by that of 12th July (1.03 t/ha) and 26th July (0.93 t/ha) in 2010, which were the best of the five sowing dates in the two years. Due to presence of appropriate soil moisture, congenial temperature and humidity for its vegetative growth.

Sadeghi *et al.* (2013) Studied the effect of planting date of soybean sown on four sowing dates of April 20, April 30, May 10 and May 20 during the two consecutive crop seasons with Three cultivars, Hill, Sahar and Zan at Kateshal Research Station, Lahijan, northern Iran. Higher numbers of pods per plant and seeds number of main stem pods were produced by April 30 and Sahar cultivar. Similarly maximum seed yield (4176.09kg ha^{-1} and 3219.96 kg ha^{-1}) were produced by April 20, Sahar and April 30, Sahar, respectively.

Yagoub *et al.* (2013) observed in semi-desert region in Sudan that In season 2009/10 S4 (23 -June) and S5 (30-June) obtained the reduced average number days took to attain 50% flowering, attain 50% Pod formation and attain maturity. The S3 (16-June) mid June, recorded the highest average number days took to attain 50%

flowering, attain 50% Pod formation and attain maturity, number of pods/plant, number of seeds/pods and highly significant difference was obtained in weight of pods/plant, weight of seeds/plant, 100seed weight, yield and harvest index parameters.

Jaybhaye *et al.* (2015) showed the effect of sowing date and spacing on growth attributes and yield components of soybean three sowing dates, revealed that the crop sown on 25th MW with spacing 30 x10 cm gave significantly highest number of pods and yield of soybean.

Nath *et al.* (2017) proved that sowing up to 27th MW with variety TAMS 98-21 is optimum for maximizing the yield in the Akola region of Vidarbha. With the record of significant higher seed yield (839 kg ha^{-1}) and biological yield (2773 kg ha^{-1}) than later sowings i.e., 30th MW sowing caused the decreased amount of rainfall and increased maximum temperature regime across the total growing period with consequently lower seed yield (530 kg ha^{-1}).

Naidu *et al.* (2017) conducted an experiment during *Rabi* season 2015-16 Tirupati, to study response of soybean varieties to different sowing times. It was found that September 16th sowing with JS-335 (V4) variety was promising in *Rabi* while compared to other sowing times and varieties.

Sultana *et al.* (2017) studied the influence of sowing dates on physiological quality of soybean variety JS 335 during *kharif*, 2013.Sowings were taken up at weekly interval from July to August. The highest germination percentage (99%), shoot length (18.13 cm), root length (18.56 cm), seedling dry weight (89.0 mg), seedling vigor index-I and II (3607 and 8.81 respectively) and field emergence (91%) were recorded for crop sown in July 2nd week and noticed that sowing date significantly affected the seed quality parameters and seeds from early sowings (July 2nd week sowing) had the good seed quality.

Mukesh Kumar *et al.* (2017) found 15th September to be was the optimum sowing time for Soybean getting higher yield and ‘JS-335’ variety was promising in Coastal AP. on 15th September sown recorded significantly higher seed yield compared to the other combinations.

Kundu *et al.* (2016) studied the effect of sowing date on yield and seed quality of soybean. With four different sowing date *viz.*,18th November, 25th November, 2nd December and 9th December and got significant variations in number of pods plant-^{1}, dry matter accumulation, pods length, number of seeds pod^{-1}, 1000-seed weight, seed yield, Stover yield, biological yield, harvest index, germination percentage, due to different sowing dates.

Jaybhay *et al.* (2018) reported in Western region of Maharashtra sowing of sowing of soybean crop beyond 15th June results in significantly reduced vegetative growth with reduced plant height, number of branches, and number of pods and dry matter accumulation at finally yield. Among three recommended varieties 'RKS 18' performed well.

Serafin-Andrzejewska *et al.* (2021) observed that the sowing date determines the temperature and the day length available for soybean plants, influencing development and yield. Delaying the sowing date by 20 days in relation to the earliest (16–21.04) resulted in the shortening of the length of the vegetative development by 12 days and the shortening of the entire vegetation period by 14 days. The delayed sowing date (06–19.05) under the conditions of south-western Poland (Lower Silesia) contributed to a significant decrease in yield.

3. To compute the Crop Water Requirement Satisfaction Index (WRSI) of soybean.

Victor *et al.* (1988) quantified the crop yield under rainfed conditions, for pearl millet by using concept of WRSI. The relationship between the water requirement satisfaction index and yield was observed to be Y= exp (-18.023 +4.173 In x), indicating the exponential behavior of the yield as affected by the water availability to the crop.

Senay *et al.* (2002) compared between a spatially distributed crop index andp reported yield. Historical sorghum yield data from 1996 -1999 were used to evaluate the performance of a seasonal water requirement satisfaction index (WRSI). WRSI values and reported district yield data were significantly correlated. The WRSI model was particularly successful in capturing the response of the crop during a relatively dry year.

Verdin *et al.* (2002) tested water requirement satisfaction index (WRSI) for maize in Southern Africa. Grids of input variables were obtained from remote sensing estimates of rainfall, meteorological models, and digital soil maps. The spatial WRSI was computed for the 1996–97 and 1997–98 growing seasons. Maize yields were estimated by regression and compared with a limited number of reports from the field for the 1996–97 seasons in Zimbabwe. Agreement at a useful level (r = 0.80) was observed.

Reddy *et al.* (2003) developed a WRSI values to predict the pod yield of Groundnut, by employing regression techniques, linear regression model. Results revealed that the lower WRSI resulted in reduced yields. The lower values of WRSI ranged between 84 to 88 and corresponding pod yields were between 690 and 990 kg ha^{-1}. Correlation studies between WRSI and pod yield revealed that significantly positive correlation (r=0.92) existed between pod yield and WRSI.

Varshanay *et al.* (2003) found the WRSI value 97%, for the *kharif* season 1998-99 for Pearl millet during (cv. Shradha) with three dates of sowing. The results show that within the sowing dates, the differences in actual rainfall were 38, 18, and 20mm respectively, but WRSI remained at 97% indicating non stress conditions during the year.

Jayasree *et al.* (2008) found impact of moisture stress at different growth phases in maize using Water Requirement Satisfaction Index (WRSI) during *kharif* 2004 at ANGRAU, Rajendranagar. Four "irrigation schedules" *viz*. irrigation as per water requirement, skipping of irrigation at vegetative, flowering stages and rainfed. Reduced yields were recorded when irrigation was withdrawn during reproductive phase. A significant positive correlation between WRSI and yield was observed (r = 0.79).

Senay *et al.* (2003) improved the rangeland WRSI, developed a simple calibration technique that adjusts the K_c values for rangeland monitoring using long-term rainfall distribution and reference evapotranspiration data. The premise for adjusting the K_c values is based on the assumption that a viable rangeland should exhibit above-average WRSI (values >80%) during a normal year.

Rajavel *et al.* (2012) studied Water Requirement Satisfaction Index (WRSI) of tobacco varieties grown during *Rabi* 1979 to 1988 at Rajamundry. The yield of tobacco was linearly and significantly correlated with amount of rainfall, water use and WRSI. The yield of tobacco was linearly and significantly correlated with amount of rainfall, water use and WRSI.

Guled *et al.* (2013) computed crop water requirement satisfaction index (CWRSI) for assessing the sufficiency of crop water requirements and its effect on pod yield of Groundnut during the *Kharif* seasons of 2009 and 2010 with six sowing window combinations with the 3 varieties. The correlation and regression studies revealed that the CWRSI, soil moisture content, AET and rainfall were having highly significant positive correlation during pod development phase and for the entire crop duration.

Mcnally *et al.* (2015) evaluated the possibility and efficiency of replacing the rainfall-derived soil moisture component of a crop water stress index with SMAP data. Over a West Africa domain, the approach is evaluated by comparing the different soil moisture estimates and their resulting Water Requirement Satisfaction Index values from 2000 to 2010. This study highlights how the ensemble of indices performs during wet versus dry years, over different land-cover types, and the correlation with national-level millet yields.

Lalitha *et al.* (2016) Analyzed water balance components for cotton crop in Annur block of Coimbatore district based on the soil information (1:50,000 scale). The water requirement satisfaction index indicated that about 87 per cent of the crop water requirement is satisfied by the soil moisture in the control section irrespective of soil type. The crop will face moisture deficit from 4th to 8th standard weeks which coincide with harvesting stage.

Fenner *et al.* (2017) made an agro climatic zoning of common bean in the Mato Grosso state in the second harvest based on water requirement satisfaction index (WRSI) for the common bean crop, for the three levels of available water capacity of the soils of the state (30, 50 and 75 mm) in 12 sowing periods. Data were entered into ArcGISTM 10.0. After generating the maps, they were clipped to the Mato Grosso State and classified WRSI classes as 1) suitable (WRSI $\geq$ 0.65); 2) restricted (0.55 < WRSI < 0.65) and 3) unsuitable (WRSI ≤ 0.55) for the stage of flowering and grain filling.

Ahmed *et al.* (2017) studied the interconnections between the long-term rainfall variation and the rangeland Water Requirement and Satisfaction Index (WRSI) in Mieso, Jigjiga, and Shinile districts under pastoral conditions of Ethiopia. using MarkSim software, Mann-Kendall's statistical tests, coefficient of variation, LEAP software (version 2.61) The mean annual rainfall anomaly is correlated with the rangeland WRSI. Moreover, the future rainfall trend analysis indicated that variability of rainfall would be expected in between the years 2020–2049, 2040–2069, and 2070–2099.

Tarnavsky *et al.* (2018) introduced WRSI model as to characterize the impact of using deferent rainfall input datasets, ARC2, CHIRPS, and TAMSAT, on key WRSI model parameters and outputs. Found that over half of the variability in yield is explained by water stress when the CHIRPS dataset is used in the WRSI model (R2 = 0.52-0.61 for maize varieties of 120-160 days growing length). Overall, CHIRP Sand TAMSAT show highest skill (R2 = 0.46-0.55 and 0.44-0.58, respectively) in capturing country-level crop yield losses related to seasonal soil moisture.

Sembanan *et al.* (2019) identified the best sowing week for the selected districts of Tamil Nadu Coimbatore for maize and sorghum using WRSI under dryland situation. From the study, it was found out that for sorghum and maize, the elasticity of the identified optimum sowing week was expanded from 35th Meteorological Standard Week (MSW) to 39th standard week for Dindigul, Theni and Namakkal districts.

Masupha *et al.* (2020) Analyzed the drought on rainfed maize production in the Luvuvhu River Catchment was measured using the (WRSI). Computation of WRSI was performed using a crop water balance model in Instat+ software for a 120-day maturing maize crop using nine different planting decades from October to December. Water Requirements Satisfaction Index (WRSI) values corresponding to more intense drought conditions were reflected during the December planting date for all stations. Recommended using October-November as the optimum planting date in the catchment.

Turner *et al.* (2020) assessed the adequacy of the arithmetic mean climatological forecast the Extended WRSI. Use WRSI hind casts of three African regions growing seasons, from 1981-2019; found the Extended WRSI is positively biased, overestimating the actual EOS WRSI by 2-23% in east, west, and southern Africa. The WRSI Outlook can improve our ability to identify agricultural drought and the concomitant need for humanitarian aid.

Tahirou *et al.* (2022) evaluated the hydraulic performance of the Saga hydro-agricultural development in Niger through field data collection which has been compared to data obtained from literature review. The estimation of water requirements for rice was done according to the standard guidelines (FAO) using Cropwat 8.0 software. Results of this study revealed an average percentage of the satisfaction were 73% during the winter season rice crop and 82% in the dry season crop. The average irrigation water requirement was 82% during the dry season and 51% in the winter season.

4. To compute the crop water stress Index (CWSI) of soybean.

Idso *et al.* (1981) foliage--air temperature differentials ($T_f - T_a$) and air vapor pressure deficits (VPD) were conducted on squash, alfalfa, and soybean crops at Tempe and Mesa, Arizona; Manhattan, Kansas; Lincoln, Nebraska; St. Paul, Minnesota; and Fargo, North Dakota. Showed that throughout the greater portion of the daylight period, plots of $T_f - T_a$ vs VPD yield linear relationships for plants transpiring at the potential rate, irrespective of other environmental parameters except cloud cover.

Jackson *et al.* (1981) calculated the crop water stress index (CWSI), was shown to be equal to $1-E/E_p$, the ratio of actual to potential evapotranspiration obtained from the Penman-Monteith equation. Four experimental plots, planted to wheat, received post emergence irrigations at different times to create different degrees of water stress. The CWSI, plotted as a function of time, closely paralleled a plot of the extractable soil water in the 0- to 1.1m zone.

Idso *et al.* (1982) developed a plant water stress index, which employs a radiometric Measurement of foliage temperature and a psychometric measurement of the vapor pressure deficit of the air. The relationship that exists between foliage--air temperature differential and air vapor pressure deficit for the plant in question when it is well watered and transpiring at the potential rate.

Abdul-Jabbar *et al.* (1985) determined the Crop Water Stress Index (CWSI), and to relate CWSI to the ratio of measured evapotranspiration (ET) to potential evaporation (ET_0) and to dry forage yield of alfalfa *(Medicago sativa* L.). The CWSI was then determined for each day at each location on the gradient. Evapotranspiration was calculated for three cutting periods in 1982 using the water balance method at the five locations on the gradient, and Ep was calculated using the Penman equation. Significant relationships ($P<0.01$) were obtained between CWSI and measured E/Ep ($r^2 = 0.85$), and between CWSI and yield ($r^2 = 0.79$).

Jackson *et al.* (1988) reexamined the Crop water stress index, using Canopy temperatures are determined by the water status of the plants and by ambient meteorological conditions. The crop water stress index (CWSI) combines these factors and yields a measure of plant water stress. Two forms of the index have been proposed, an empirical approach as reported by Idso *et al*. (1981), and a theoretical approach reported by Jackson *et al*. (1981). Because it is simple and requires only three variables to be measured, the empirical approach has received much attention in the literature.

Nielsen *et al.* (1990) evaluated irrigation scheduling of soybean (*Glycine max L. Merrill*) with CWSI as computed from measurements of infrared canopy temperature, air temperature, and vapor-pressure deficit. Under deficit-irrigation conditions the relationship between CWSI, soil water content, and leaf water-potential appears to change respective yield.

Yuan *et al.* (2004) evaluated the application of three different forms of CWSI for winter wheat water stress monitoring in the North China Plain (NCP): the Idso empirical model, the Jackson theoretical model, and the new Alves model, The results show that the CWSI based on Jackson's definition and Alves' definition are better than the empirical CWSI for monitoring winter wheat water stress in NCP. Both definitions are useful tools to evaluate winter wheat water stress in NCP, but the CWSI based on Alves' definition is more practical for monitoring winter wheat water stress in NCP.

Erdem *et al.* (2006) determined the relationship between the canopy-air temperature differential and the vapor pressure deficit (VPD), which can be used to quantify the crop water stress index (CWSI) under fully irrigated (100%) and maximum water stress (0%) conditions of trickle irrigated bean. CWSI increased with increased soil water deficit. The yield was directly correlated with seasonal mean CWSI values and the linear equation Y = 2.731 - 2.034. CWSI can be used for yield prediction.

Emekli *et al.* (2007) assessed crop water stress index (CWSI) of Bermuda grass and examined the possibilities of utilization of infrared thermometry to schedule irrigation. Four different irrigation treatments, 100% (I_1), 75% (I_2), 50% (I_3), and 25% (I_4). In addition, a non-irrigated treatment was set up to determine CWSI values. The best visual quality was obtained from I_1 and I_2 treatments. Average seasonal CWSI values were determined as 0.086, 0.102, 0.165, and 0.394 for I_1, I_2, I_3, and I_4 irrigation treatments, it was concluded that the CWSI could be used as a criterion for irrigation timing of Bermuda grass.

Moller *et al.* (2007) investigated the use of thermal imaging for monitoring water stress. Experiments were conducted on a winegrape (*Vitis vinifera* cv.Merlot) vineyard in northern Israel. Irrigation treatments included mild, moderate, and severe stress. Thermal and visible (RGB) images of the crop were taken on four days at midday with a FLIR thermal Imaging system and a digital camera, respectively; CWSI was highly correlated with GL (leaf conductance) and moderately correlated with Ψ (water potential stem). The CWSI-GL relationship was very stable throughout the season.

Anda *et al.* (2009) investigated the CWSI could be used to determine when the irrigation water should be applied to maize under Hungarian changeable weather. Three water treatments were applied: “Ad libitum” watering in lysimeter’s growing chambers, irrigated treatment (use of CWSI), and rainfed control. Final conclusion was that there is no problem in use of CWSI during arid summers, where radiation is undisturbed and the cloudiness does not disturb the canopy temperature sampling. In arid seasons increases in assimilatory surface size and yield of maize in irrigated treatments were between 20–35% and 10–30%, respectively.

Akkuzu *et al.* (2013) investigated the effects of different irrigation treatments on the yield, canopy temperature, and CWSI of olive trees, found that handheld infrared thermometer can be used for stress detection and irrigation scheduling of olive trees. At the olive tree plantation of the Olive Research Station between 2009 and 2010. When the mean CWSI values in the experimental years were examined in terms of the irrigation treatments, the CWSI values ranged from 0 to 0.68 in 2009 and from 0.02 to 0.71 in 2010.

Rud *et al.* (2014) evaluated water status in potato fields for two water-deficit scenarios were tested: a short-term water deficit and a long-term cumulative water deficit. Crop water stress index (CWSI) was calculated, using three forms of minimum baseline temperature: empirical, theoretical and statistical The results indicated a high correlation of CWSI with SC (stomatal conductance) from tuber initiation to maturity based on ground and aerial data ($0.64 \leq R^2 \leq 0.99$). Similar trends of increasing CWSI from well to deficit-irrigated.

DeJonge *et al.* (2015) tried to show six treatments of regulated deficit irrigation in terms of six indices, Canopy temperature was highly correlated with leaf water potential (R^2= 0.895). Canopy temperatures and stress indices were responsive to evapotranspiration based irrigation treatments and all indices showed linear relationship with soil water deficit at high temperatures.

Fattahi *et al.* (2018) determined the Maize (SC-701) irrigation Scheduling, use of leaf temperature in the north of Isfahan, Iran, in the crop year 2013, with five irrigation areas, where the amount of Total Available Water (TAW) was 35, 65, 75, 85, 100% respectively, in four replications. Results revealed that in return of TAW from 35 to 100%, Leaf and air temperature difference (T_l-T_a) reached 4 °C. CWSI rose about three times. CWSI in the day before the irrigation in treatment T1 and T5 were about 0.12 and 0.46, respectively.

Silva *et al.* (2018) determined the water stress index of the tomato crop for industrial processing (Hybrid ‘BRS Sena’) in Southern, Brazil, in 2015 and 2016. Theoretical and empirical methods estimate CWSI similarly in tomato. In the hottest hours of the day, even under adequate soil moisture conditions, the ‘BRS Sena’ tomato showed CWSI above 0.2. CWSI is a good indicator to evaluate the water status of the tomato crop for industrial processing and to recommend the moment of irrigation. The higher the CWSI, the lower the yield of 'BRS Sena' tomato.

Emeribe *et al.* (2013) investigated the applicability of Idso CWSI model in predicting seasonal pattern of water stress in maize over southeastern Nigeria. From analysis CWSI values ranged from 0.54 to 1.0 indicating periods of moderate to maximum water stress. It was observed that CWSI results calculated for maize for the eight climatic stations fall within acceptable range of 0 – 1.0. This buttresses the fact that the Idso empirical CWSI model is a good indicator for maize water stress monitoring in South-eastern Nigeria.

Khorsand *et al.* (2020) evaluated the ability of the crop water stress index to estimate grain yield and water productivity of maize and black gram in the climatic conditions of Urmia (Iran), The highest grain yield for maize and black gram was obtained at crop water stress index values of 0.28 and 0.15, respectively.

Alordzinu *et al.* (2021) examined crop water stress index (CWSI) on tomato growth in two soil types. Idso CWSI proved a strong correlation in estimating the crop water status at R^2 above 0.60 at each growth stage in both soil types. The fruit expansion stage showed the highest correlation at R^2 = 0.8363 in sandy loam and R^2 = 0.7611 in silt loam the CWSI and yield also showed a negative relationship and a strong correlation with R^2 values above 0.95, which indicated that increasing the CWSI had a negative effect on the yield.

Katimbo *et al.* (2022) evaluated the performance of CWSI computation approaches and their sensitivity to changes in soil water depletion under different water stress levels. There were six different approaches. Greater sensitivity and correlation strength to depletion were observed with CWSI-Th and CWSI-EB under severe stress (i.e., D*r,i* > 80%) at deeper soil depths of 1.8 and 2.1 m, producing r2 which ranged from 0.61 to 0.80 (slope: 0.03–0.05) and 0.69–0.79 (slope: 0.03–0.04), respectively.

Appiah *et al.* (2022) determining the viability, efficiency, and swiftness in employing the commercial Workswell WIRIS Agro R infrared camera (WWARIC) in monitoring water stress and scheduling appropriate irrigation regimes in mandarin plants. CWSI (Idso) and CWSI were estimated using the Workswel Wiris Agro R infrared camera (CWSI) and showed a high correlation ($R2 = 0.75$ at $p < 0.05$) in assessing the extent of water stress in mandarin plants.

Zhou *et al.* (2022) proposed a robust strategy to assess crop water status in grapevines. Experiments were performed on Riesling grapevines (Vitis vinfera L.) in southeastern Washington, USA. The results revealed that the proposed algorithm combining thermal and RGB images to determine CWSI can be used for assessing crop water status of grapevines. There was a correlation between CWSI and Ψ leaf with an R-squared value of 0.67 for the measurements in the growing season.

CHAPTER-III

MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

The current research work on "**Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max (L.) Merill*] cv. MAUS-71 by using Lysimeter**." was carried out during *Kharif* season 2021-22.

In this chapter briefly discussed the details of the experimental site, prevailing weather conditions, materials used and techniques adopted during the course of the investigation

3.1 Study approach

In order to meet the objectives, six study approaches were followed:

1. Statistical analysis and data Interpretation
2. Correlation studies
3. Computation of thermal indices
4. Estimation of crop coefficient
5. Computation of crop water requirement satisfying index
6. Computation of the crop water stress index

3.2 Details of the experimental site

3.2.1 Location of the experimental site

The site of the research geographically located at 76^{o}46' E longitude; 19^{o}16' N latitude and 409 m altitude above the mean sea level. The research was carried out at research farm of Department of Agril. Meteorology,VNMKV, Parbhani.

3.2.2 Topography and Soil

The topography of the research field was uniform and well leveled. The soil was well-drained, medium black cotton, clayey in texture, and the depth of soil varied from 2m to 3m.

3.2.3 Agro climatic situation

Parbhani comes under Marathwada region, classified as central maharashtra plateau zone (MH-7) by NARP. An annual basis Parbhani comes under a tropical climate. The rainfall is assured for the *Kharif* season with 804.9 mm and for *Rabi* season with 108.4 mm. hence the region experiences cold dry winter, hot and dry summer, and wet humidity.

3.2.4 Climatic condition during 2021-22

The total rainfall 1710.1 mm received during 2021-22 with 61 rainy days. The Pan Evaporation rate for the year was 1910.1 mm. with average of 5.4 mm/day and the highest and lowest evaporation were 15 mm and 0.2 mm on 27^{th} may and 15^{th} July respectively.

3.3 Experimental materials details

3.3.1 Gravimetric or Weighing type of lysimeter

A. Principle

An isolated block of cropped soil representative of the field is weighted first to determine the quantity of water added by precipitation or irrigation and then after the loss of water by evapotranspiration (ET) is again weighed. The difference of weights in Kg in the two consecutive observations multiplied by conversion factor 0.6 gives the ET in mm.

B. Weighing lysimeter consist of

i. Lysimeter tank
ii. Retaining tank
iii. Dummy tank
iv. Weighing balance.

i. Lysimeter tank

A steel tank contains soil, in which plants are grown. The size of the tank is 1.3×1.3×0.9 mt.

ii. Retaining tank

The retaining tank of 140×140×112.5 cm^3 isolates the lysimeter and weighing bridge from the main field & protects them from the water seepage from the adjoining field.

iii. Dummy tank

A smaller tank of the size 30×30×90 cm^2 is placed in the gap near the head work. This prevents overheating.

iv. Weighing machine

The weighing balance is sensitive having a capacity of 2000 Kg. Its platform size is 120×120 cm^2. The weighing bridge measures weight with accuracy of 200 gm. Observation is taken at 0723 LTM when the wind is calm in the morning; however, rainfall is taken at 0830 IST synoptic hrs.

3.3.2 Infrared thermometer

Principle: - Infrared thermometers employ a lens to focus the infrared light emitting from the object on to a detector known as a thermopile. The thermopile is nothing but thermocouples connected in series or parallel. When the infrared radiation falls on the thermopile surface, it gets absorbed and converts into heat.

The Infrared thermometer was used with the canopy viewed at an angle of 35–45^0 from the horizontal it shows Canopy temperature in ℃ and then viewed at perpendicular to surface got air temperature in ℃. Five plants canopy temperatures were measured in each plot and averaged to determine the plot's canopy temperature. According to some research conclusions, midday canopy temperature is the best indicator to detect the crop water stress Idso *et al*. (1981); Jackson *et al.* (1981), so the midday canopy temperatures obtained from 1200 LMT- 1400 LMT.

3.3.3 Spectroradiometer

The name of the spectroradiometer model is WAVE GO-VIS-50. Wave Go is ideal for applications that require simple, yet highly accurate results when characterizing light sources. The app calculates and displays all the essential metrics for quantifying light and connects the data to a user account via the cloud. Spectral (*i.e.*, wavelength-dependent) radiation is intensity of output from a radiation source (e.g., sun, electric lamp and reflected radiation from a surface of interest) as a function of wavelength. Radiation spectra vary for different radiation sources and conditions. Radiation spectra can be used to characterize radiation sources. Spectrometers measure relative spectral radiation over a specified wavelength range. Spectroradiometer are spectrometers calibrated to output spectral measurements in absolute units (e.g., energy flux density in W m^{-2} nm^{-1} or photon flux density in µmol m^{-2} s^{-1} nm^{-1}).

3.3.4 Leaf area meter

Leaf area is an important agronomical parameter as it is related to plant growth, photosynthetic capacity. Leaf area meters are scientific instrument that are specially designed to measure the area of leaves. The non portable SYSTRONICS leaf area meter 211 was used to find out the leaf area.

Working principle: It works on photometric technology. The leaf is placed between a light source and a photocell, the reduction in photocell output due to the presence of leaf then given a measure of leaf area. The transmission of light through the leaves is source of error and an attempt to minimize this is usually made by fitting magenta filter between the leaf and the photocell to absorb any green light passing through the leaf.

3.4 Experimental detail

Crop	: Soybean **[** *Glycine max (L.) Merill*]
Design	: Split Plot Design
Replication	: Three
Total number of plots	: 36
Spacing	: 45 cm × 5 cm
Plot size	: Gross- 5.4 m × 4.5 m
	: Net - 4.5 m × 3.6 m
Fertilizer recommended	: 30:60:30 NPK kg ha^{-1}As per recommendation
Year of experiment	: 2021
Location	: Farm of Dept. Agrometeorology, VNMKV, Parbhani.

Treatment details:

Main plot:		**Sub plot:**	
Date of sowing:	1) D_1–25 SMW	**Varieties:**	V_1 - MAUS – 158
	2) D_2- 26 SMW		V_2 - MAUS - 71
	3) D_3–27 SMW		V_3 - JS – 335
	4) D_4–28 SMW		

Plate 3.1 Gravimetric or Weighing type of lysimeter containing soybean MAUS-71.

Plate 3.2 Leaf area meter **Plate 3.3 Infrared thermometer**

Plate 3.4 Spectroradiometer model is WAVE GO-VIS-50.

Plate 3.5 Radiation measuring sensors in lysimeter plot.

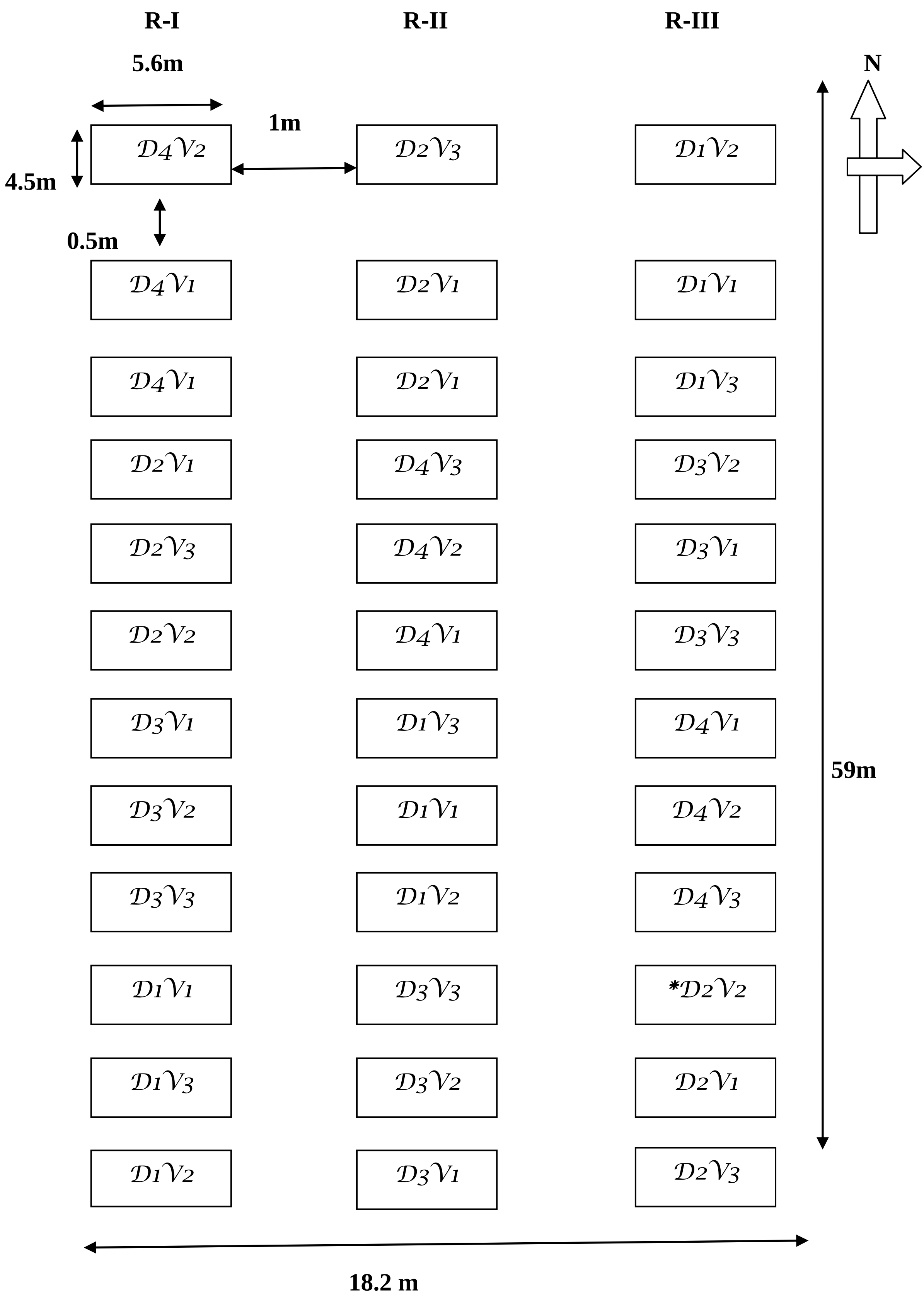

Fig 3.1 Layout of Research plot

Gross plot size: 5.4 m x 4.5 m

Net Plot size: 4.5 m ×3.6 m

Main Plots: Date of sowing: - D_1: 21June, D2: 28 June, D3: 05 July, D4: 12 July

Sub Plots: Variety: - V_1: MAUS-158, V_2: MAU 26 S-71 **Lysimeter (*),** V_3: JS-335

3.5 Cultural operations

3.5.1 Plouhing, harrowing and cleaning

The field was ploughed up to 30 cm depth with a tractor-drawn MB Plough, followed by 2-3 cross harrowing was done to break the clods to get good tilth condition before sowing of the crop. The field was cleaned by collecting the crop residues of last season.

3.5.2 Layout

The treatment details and symbols used are represented in the plan of the layout were shown in Fig. 3.1. After field preparation the layout was done and plots were prepared with the help of measuring tape, nylon rope and pegs.

3.5.3. Sowing

The sowing was done with drilling method. The seeds of soybean varieties V_1-MAUS-158, V_2 - MAUS-71, and V3- JS-335 were drilled with row to row and plant to plant spacing of 45 × 5 cm during 4 different meteorological weeks 25^{th} SMW (21-06-2020), 26^{th} SMW (28-06-2020), 27^{th} SMW (05-07-2020) and 28^{th} SMW (12-07-2020).

3.5.4 Fertilizer application

Fertilizer applied at rate of 30:60:30 NPK kg ha^{-1} as per the recommendation of package of practice given by VNMKV.Parbhani. By using complex fertilizer *viz*. DAP (Diammonium phosphate) for N and P_2O_5, MOP for potassium.

3.5.5 Intercultural operations

i. Thinning and gap filling

A Thinning operation was carried out one week after the emergence of seedling when a sufficient amount of moisture was available in the soil. Gap filling was done by dibbling the soybean seeds where seeds did not emerge.

ii. Weeding and spraying herbicide

To reduce the crop weed competition for water and nutrient three times hand weeding, once spraying of herbicide Quizalofop ethyl 5% at the dose of 0.75ml/lit. were carried out during the season.

iii. Irrigation management

Irrigation given for two times with sprinkler irrigation system during intermediate dry spell of crop season.

3.5.6 Plant protection measures

Spraying of insecticides has done with Monochrotophose at the dose of 1.5ml/lit for two times to control *Spodoptera litura* infestation and soil drenching of Chloropyriphos 50 EC at dose of 2ml/lit for two times to destroy the white grub (*Holotrichia consangunea*).

3.5.7 Harvesting and threshing

Harvesting and threshing was done by manually.

3.6 Meteorological observations

At the Central Meteorological Observatory, AICRP on Agril. Meteorology Farm VNMKV, Parbhani. The daily meteorological observations were recorded including weather parameters like rainfall, maximum and minimum temperature, relative humidity, wind speed, rate of evaporation, and bright sunshine hours. The observations were taken regularly at a given standard time to perform a proper analysis process.

3.6.1 Soil moisture percentage

The soil moisture percentage was calculated by collecting soil samples from different depths i.e., 0-15 cm, 15-30 cm, and 30-45 cm, from each plot of 50 gm, weighed and kept in an oven for drying at 105^{o}C for 24 hours then weigh the dry weight of the collected sample.

To Convert the of dry weight into volumetric content using the following formula-

$$\text{Moisture percentile} = \frac{W_1 - W_2}{W_2} \times 100$$

Where, W_1 - Weight of moist soil sample (g)

W_2 - Weight of oven-dry soil sample (g)

3.7 Biometric observations

By adopting the schedule in Table 3.2. The biometric observations were recorded and used for generating yield attributes *viz*., number of pods plant^{-1}, seed yield plant^{-1}, grain yield plot^{-1} and test weight of seeds of each plot.

Table 3.1: Dates of agronomical and cultural practices carried out during the experimental period 2021-22.

Sr. No	Particulars	Frequency	Date of operations
A) Pre sowing cultural operations			
1	Ploughing	1	25-04-2021
2	Harrowing	1	07-06-2021
3	Cleaning of field	1	09-06-2021
4	Layout of experiment	1	15-06-2021
B) Sowing operations			
1	Sowing	1	D_1 21-06-2021 D_2 28-06-2021 D_3 05-07-2021 D_4 12-07-2021
2	Fertilizer application	1	At the time of sowing.
C) Intercultural operations			
1	Hand weeding	3	D_1, D_2, D_3, D_4 12-07-2021 D_2 & D_4 22-08-2021 D_3 & D_1 24-08-2021
2	Irrigation	2	D_1, D_2, D_3, D_4 03-07-2021 & 08-08-2021
D) Plant protection measures			
1	Spraying of Insecticides	2	29-07-2021, 21-08-2021
2	Spraying Herbicide	1	28-07-2021
3	Soil drenching	2	09-08-2021, 16-08-2021
E) Harvesting		1	D_1 08-10-2021 D_2 12-10-2021 D_3 17-10-2021 D_4 20-10-2021

Table 3.2: Schedule of biometric observations

Sr.No	Particulars	Frequency	DAS	Sampling Index
A) Pre-harvest studies				
1	Emergence count	1	08	Net plot
2	Final plant stand	1	At harvest	Net plot
3	Height of plant (cm)	7	15, 30, 45,60,75,90, 105 and at harvest.	Five plants plot^{-1}
4	Number of branches plant^{-1}	6	30,45,60,75,90, 105 and at harvest	Five plants plot^{-1}
5	Leaf area	7	15, 30, 45,60,75,90, 105 and at harvest.	Five plants plot^{-1}
6	Number of pods plants^{-1}	4	60,75,90, 105 and at harvest	Five plants plot^{-1}
7	Dry matter (g) plant^{-1}	6	15, 30, 45,60,75,90, 105 and at harvest.	Five plants plot^{-1}
8	Days required to 50% flowering	1	At flowering stage.	Net Plot
9	Days required to 50% Pod formation	1	At flowering stage.	Net Plot
10	Days required to maturity	1	At maturity stage.	Net Plot
B) Post-harvest studies				
1	Weight of seeds (g plot^{-1})	1	At harvest	Five plants plot^{-1}
2	Weight of pods(g plot^{-1})	1	At harvest	Five plants plot^{-1}
3	Grain yield plot^{-1}	1	At harvest	Net plot
5	Straw yield plot^{-1}	1	At harvest	Net plot
6	Test weight (1000 seeds)	1	At harvest	Composite samples from each net plot
7	Harvest Index (%)	1	At harvest	Composite samples

				from each net plot

3.7.1 Sampling technique

Five plants from each net plot were selected randomly, labeled tags were tied on selected plants, bamboo pegs were also fixed near the observational plants and observations were recorded periodically on these plants.

3.7.2 Pre-harvest studies

3.7.2a Emergence count

When complete emergence was noticed, the counting percentage of all the plants that emerged out was recorded from each net plot on 8 days after sowing this is called the emergence count.

3.7.2b Final plant count

The final count per net plot was recorded when the crop was fully matured and ready for harvest. The counting percentage of all plants from each net plot was recorded at harvest.

3.7.3 Growth studies

3.7.3a Plant height (cm)

The plant height was measured from the base of the plant to the base of the fully opened leaf at the apex. It was recorded from 15 DAS to harvest and at harvest at 15 days intervals from five observational plants.

3.7.3b Number of branches plants^{-1}

The total number of branches was recorded from 15 DAS to harvest at 15 days intervals from five observational plants from each net plot. An average number of branches per plant were worked out by dividing the total number by five.

3.7.3c Leaf area in cm^{-2}

The leaf area was measured by uprooting plant that selected randomly from each plot detached all the leaves of the plant and kept in leaf area meter and taken readings. It was recorded from 15 DAS to harvest and at harvest at 15 days intervals.

3.7.3d Normalized Difference Vegetation Index (NDVI)

Calculation of the Normalized Difference Vegetation Index (NDVI), which is available on the-fly, comes first. In addition, NDVI is often used around the world to monitor drought, forecast agricultural production, and assist in forecasting fire zones and desert offensive maps. Farming apps, like Crop Monitoring, integrate NDVI to facilitate crop scouting and give precision to fertilizer application and irrigation, among other field treatment activities, at specific growth stages.

NDVI is calculated in accordance with the formula:

NDVI = (NIR-RED / NIR+RED)

Where,

NIR – reflection in the near-infrared spectrum

RED – reflection in the red range of the spectrum

This index defines values from -1.0 to 1.0, basically representing greens, where negative values are mainly formed from clouds, water and snow, and values close to zero are primarily formed from rocks and bare soil

3.7.3e Number of pods plants^{-1}

Numbers of pods plant^{-1} from five observational plants were counted at 15-day intervals from 60 DAS to harvest and the average worked was out.

3.7.3f Dry matter accumulation (g plant^{-1})

One plant from each net plot was randomly selected at biweekly intervals to determine total dry matter accumulation. Plant roots were removed, and shoot parts were sun dried before being dried in a hot air oven at around 650^{o}C. It was weighed again and again until the constant weights were achieved.

3.7.3g Days required to 50% flowering

Number of days required for the 50 % flowering was recorded by counting the number of plants having flowers in whole net plot.

3.7.3h Days required to 50% pod formation

Number of days required for pod formation was recorded by counting the number of plants having pods in whole net plot.

3.7.3i Days required to maturity

The number of days necessary for 90% grain maturity was recorded and used to calculate days to maturity.

3.7.4 Post-harvest observations

The plants selected for biometric observations were used for generating the data on yield attributes *viz*., seed yield plant^{-1}, straw yield plot^{-1}, and biological yield.

3.7.4a Weight of pods plant^{-1} (g)

Five observational plants from each net plot were harvested separately and pods were separated weighed using electric weighing balance.

3.7.4b weight plant^{-1} (g)

The separated pods were threshed manually and seeds were collected, weighed using electric weighing balance.

3.7.4c Test weight (g)

Weight of thousand grains was recorded from the grain samples drawn randomly from the cleaned produce obtained from each of the net plot using electric balance and expressed in grams.

3.7.4d Seed yield (Kg ha^{-1})

Net plot plants were harvested collected grains carefully; weighed using balance expressed in kg and then converted this net plot yield for hectare.

3.7.4e Straw yield (Kg ha^{-1})

After net plot grain collection remaining straw was weighed, expressed in kg and converted into hectare.

3.7.4f Biological yield (Kg ha^{-1})

The biological yield was calculated by adding the seed yield and straw yield.

3.7.4g Harvest Index (%)

It is the per cent of economic yield to the biological yield. The harvest index reflects the production of assimilated distribution between economical and total biomass.

The harvest index was calculated by using the formula-

$$\text{Harvest Index} = \frac{\text{Total seed yield (Kg/ha)}}{\text{Total biological yield (Kg/ha)}} \times 100$$

3.8 Phenological stage observations:

The day on which, five of the observational plants attained any particular phenological stage was recorded. There were 10 phenological stages recorded from sowing to harvesting of the soybean crop.

3.9 Statistical analysis and interpretation of data

Panse and Sukhatme (1967) given technique of ANOVA using this analysis of variance and significance were determined. The data recorded were statistically analyzed with the help of a computer.

3.10 Correlation studies

The simple correlation between weather parameters i.e., Rainfall, Maximum temperature, Minimum temperature, Relative humidity, Evaporation, Bright sunshine hours, and Wind velocity on the development of soybean crop was estimated to know the correlation between these weather parameters and seed yield of different date of sowing and variety was estimated.

The procedure and formula described by Snedecor and Cochran (1968) were adopted and significance was tested.

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x)(\Sigma y)}}$$

Where,

r – Correlation coefficient

x – Independent variable (attributes)

y – Dependent variable (yield).

3.11 Computation of Thermal indices

3.11.1 Growing degree days (GDD)

The daily GDD worked out by taking the daily average temperature (T_{max} + T_{min})/2 and subtracting the base temperature of the crop soybean 10℃ from the daily average temperature.

The resulting number is the number of heat units accumulated for the day. The method typically used for calculating accumulated heat units for each stages of the crop is expressed by the following formula Freeland *et al*. (2004).

$$GDD(°C\ day\ hrs) = \Sigma\frac{[T_{max} + T_{min}]}{2} - T_{base}$$

Where,

GDD - Growing degree days

T_{max} - Maximum temperature

T_{min} – Minimum temperature

T_{base} – Base temperature

3.11.2 Helio-thermal units (HTU)

The HTU is the product of GDD and the mean daily hours of bright sunshine. The method typically used for calculating accumulated Helio-thermal units for each stages of the crop. The Helio-thermal units for each day are calculated by the following equation Srivastva and Tyagi, (2011).

$$HTU\ (°C\ day\ hrs) = GDD \times BSS$$

Where,

HTU – Helio-thermal units

GDD - Growing degree days

BSS – Bright sunshine hours (Actual).

3.11.3 Photo-thermal unit (PTU)

The photo thermal unit is the product between heat units or GDD and day length. The sum of the photothermal units for each phenophase was worked out by using the following formula-

$$Photo\text{-}thermal\ Units\ (°C\ day\ hrs) = (GDD \times D)$$

Where,

GDD- Growing degree days

D – Day length in hour

3.11.4 Heat Use Efficiency (HUE)

Heat Use Efficiency represents the amount of soybean seed yield produced per unit of Growing Degree Days (GDD). It indicates the efficiency of crop to utilize the available heat energy. It is also represented by thermal time used efficiency (TTUE). It was calculated by using the following formula:

$$\text{HUE} = \frac{seed\ \ yield\ (kg/ha)}{\sum GDD}$$

Where,

$\sum GDD$ = cumulative Growing Degree Days.

3.12 Estimation of crop coefficient

Crop coefficient (K_c) is defined as the ratio of crop evapotranspiration to that of reference evapotranspiration which computed over a reference grass surface of standard height with no scarcity of available water Allen *et.al*. (1998).

The concept of crop coefficient (K_c) was introduced by Jensen (1968) and further developed by other researchers.

$$\text{Kc} = \frac{\text{ETc}}{\text{ETo}}$$

Where,

ET_c - Actual crop evapotranspiration mm day^{-1}

ET_o – Reference crop evapotranspiration mm day^{-1}

3.12.1 Estimation of crop evapotranspiration

Crop evapotranspiration was calculated by using daily observations of a mechanical weighing type of lysimeter. Lysimeter readings were taken regularly at 7.23 AM in which the sowing of MAUS-71 (V_2) on 26^{th} MW was done. The equation for calculating of ET_c Srivastava and Tyagi (2011) is as follows,

ET_c (mm) = Difference in weight of two consecutive lysimeter observation in Kg × 0.6 + rainfall (mm).

3.12.2 Estimation of reference evapotranspiration

3.12.2a Penman-Monteith Method:

The FAO Penman-Monteith method was used to calculate reference evapotranspiration (ET_o). The Penman-Monteith equation has been recommended as a standard method of ET_o estimation around the world in FAO Irrigation and Drainage Paper 56 Allen *et al*. (1998), with the reference surface defined as a hypothetical grass surface with an assumed height of 0.12 m, surface resistance of 70s/m and albedo of 0.23, which closely resembles evaporation from extensive green grass of uniform height, actively growing and adequately watered. The FAO Penman-Monteith method is given as:-

$$ETo = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T_a + 273}\,u_2(es - e_a)}{\Delta + \gamma\,(1 + 0.34\,u^2)}$$

Where,

ET_o = 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_a = Mean daily air temperature at 2m height (^0C),

u_2 = Wind speed at 2m height

es = Saturation vapour pressure (kPa),

e_a = Actual vapour pressure (kPa),

$es - e_a$ = Saturation vapour pressure deficit (kPa),

Δ = Slope vapour pressure curve (kPa $^0C^{-1}$),

γ = Psychrometric constant (kPa$^0C^{-1}$),

Each parameter needed for the FAO Penman-Monteith model was calculated using the mean values of weather parameters (T_{max}, T_{min}, RH-I, RH-II, Rn and u_2), altitude and latitude using a programme developed in MS Excel as follows:

Mean daily temperature (T_a)

The mean daily temperature was calculated using the mean values of daily maximum and minimum air temperatures in degrees Celsius (^0C).

$$T_a = \frac{T_{max} + T_{min}}{2}$$

Where,

T_a = Mean daily air temperature (^0C)

T_{max} = Maximum daily air temperature (^{0}C)

T_{min} = Minimum daily air temperature (^{0}C)

Wind Speed (u_2)

The average daily wind speed in metres per scond (m/s) measured at 2 metres above ground level is expected, but the observed wind speed data was measured in Kilometres per hours (km/hr) at 3 metres above ground leavel. The wind speed was adjusted for height and unit conversion according to the following equation:

$$u_2 = u_z \frac{4.87}{\ln(67.8\,h - 5.42)} \times \frac{5}{18}$$

Where,

u_2 = wind speed at 2 m above the ground surface (m s^{-1})

u_z = measured wind speed at Z m above the ground surface (km hr^{-1})

h = height of the measurement above the ground surface (m).

Atmospheric pressure (P)

The pressure exerted by the weight of the earth's atmosphere is known as Atmospheric Pressure (P). According to the Ideal Gas Law, the standard atmosphere conditions of temperature was assumed at 20^{0}C and P was 1 atm but here P was calculated in kPa at a particular elevation as:

$$P = 101.3\left(\frac{293 - 0.0065z}{293}\right)^{5.26}$$

Where,

P = atmospheric Pressure (kPa)

z = elevation above mean sea level (m)

Psychrometric Constant (γ)

The following formulae were used to measure the values of **γ** as a function of altitude.

$$\gamma = \frac{c_p\,P}{\varepsilon\lambda} = 0.665 \times 10^{-3}\,P$$

Where,

γ = Psychrometric constant (kPa ^{0}C^{-1})

P = Atmospheric pressure (kPa)

λ = Latent heat of Vaporization, 2.245 MJ kg^{-1} $^{0}C^{-1}$ (at $20^{0}C$)

C_p = Specific heat at constant pressure = 1.013 x 10^{-3} (MJ kg^{-1} $^{0}C^{-1}$

ε = Ratio of molecular weight of water vapour to dry air = 0.622

Slope of saturation vapour pressure (Δ)

The slope of the relationship between saturation vapour pressure (Δ) and temperature is required to calculate evapotranspiration.

$$\Delta = \frac{4098\left[0.6108\ exp\left(\frac{17.27\ T_a}{T_a + 237.3}\right)\right]}{(T_a + 237.3)^2}$$

Where,

Δ = Slope of saturation vapour pressure curve at air temperature Ta (kPa $^{0}C^{-1}$)

Ta = Mean daily air temperature (^{0}C)

exp(..) = 2.7183 (base of natural logarithm)

Saturation vapour Pressure (e_s) derived from air temperature

The following formula is used to measure the Saturation vapour Pressure based on air temperature:

$$e_{(T_{max})} = 0.6108 \exp\left[\frac{17.27 \times T_{max}}{T_{max} + 237.3}\right]$$

$$e_{(T_{min})} = 0.6108 \exp\left[\frac{17.27 \times T_{min}}{T_{min} + 237.3}\right]$$

Where,

T_{max} = maximum daily air temperature (^{0}C).

T_{min} = minimum daily air temperature (^{0}C).

For a day, week or month, the mean saturation vapour pressure was calculated as the average between the saturation vapour pressure at the mean daily maximum and the minimum air temperature for that period.

$$e_s = \frac{e_{(T_{max})} + e_{(T_{min})}}{2}$$

Where,

e_s = Saturation vapour pressure (e_s) derived from air temperature (kPa)

Actual vapour pressure (e_a) derived from relative humidity

The following formula is used to measure the actual vapour pressure based on relative humidity:

$$e_a = \frac{e_{(T_{min})}\frac{RH_{max}}{100} + e_{(T_{max})}\frac{RH_{min}}{100}}{2}$$

Where,

e_a = Actual vapour pressure (kPa)

$e_{(T_{min})}$ = Saturation vapour pressure at daily minimum air temperature (kPa)

$e_{(T_{max})}$ = Saturation vapour pressure at daily maximum air temperature (kPa)

RH_{max} = Maximum Relative Humidity (%)

RH_{min} = Minimum Relative Humidity (%).

Vapour pressure deficit ($e_s - e_a$)

The vapour pressure deficit is the difference between the saturation (e_s) and the actual vapour pressure (e_a) for a given period of time.

Extraterrestrial Radiation (R_a)

Extraterrestrial solar radiation (R_a) is the amount of solar radiation received at the top of the earth's atmosphere on the horizontal surface. The solar constant is the amount of radiation touching a surface perpendicular to the sun's rays at the top of the earth's atmosphere and its value is 0.082 MJ m^{-2} min^{-1} or 1.94 cal cm^{-2} min^{-1} or 1370 Wm^{-2}. The extraterrestrial radiation for each day of the year and for different latitudes was estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24\,(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)]$$

Where,

R_a = Extraterrestrial radiation (MJ m^{-2} day^{-1})

G_{sc} = Solar constant (0.082 MJ m^{-2} min^{-1})

d_r = Inverse relative Earth-sun distance (radian)

ω_s = Sunset hour angle (radian)

φ = Latitude (radian)

δ = Solar declination (radian)

Conversion degrees of Latitude to radians

The latitude (φ) expressed in radians of Northern hemisphere is positive while that of Southern hemisphere is negative. The following formula was used to translate decimal degrees to radians:

$$\varphi \text{ (radian)} = \frac{\pi}{180}\ \varphi \text{ (decimal degree)}$$

Inverse relative earth-sun distance (d_r)

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{265} J\right)$$

Solar declination (δ)

$$\delta = 0.409 \sin\left[\frac{2\pi}{265} J - 1.39\right]$$

Where,

J = Julian day/Number of the day in the year between 1(1st January) and 365 or 366 (31st December).

Sunset hour angle(ω_s)

$$\omega_s = \arccos[-\tan\varphi \tan\delta]$$

Where,

φ = Latitude (radian)

δ = Solar declination (radian)

Hours of Daylight (N)

The number of daylight hours or the maximum probable duration of sunlight N is calculated as follows:

$$N = \frac{24}{\pi}\omega_s$$

Where,

ω_s = Sunset hour angle (radian)

N = Hours of sunlight or maximum probable duration of sunlight.

Short wave radiation/solar radiation (Rs)

The solar radiation Rs computed with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine hours as:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

Where,

R_s = Short wave radiation (MJ m^{-2} day^{-1})

n = Actual duration of sunshine (hours)

N = Maximum probable duration of sunlight or daylight hours (hours)

n/N = Relative sunshine duration

R_a = Extraterrestrial radiation (MJ m^{-2} day^{-1})

a_s = Regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n=0)

$a_s + b_s$ = Fraction of extraterrestrial radiation reaching the earth on clear days (n=N).

The value of a_s = 0.25 and b_s= 0.50 were taken in present computation.

Clear sky solar radiation (R_{so})

For computing the net long wave radiation, the measurement of clear sky radiation (R_{so}) was needed, when n = N

$$R_{so} = (a_s + b_s)\, R_a$$

Where,

R_{so} = Clear sky solar radiation (MJ m^{-2} day^{-1})

$a_s + b_s$ = Fraction of extraterrestrial radiation reaching the earth on clear days (n=N).

Net short wave radiation (R_{ns})

Net shortwave radiation is a term used to describe the amount of energy emitted. The balance between incoming and reflected solar radiation yielded the following net solar radiation as follows:

$$R_{ns} = (1 - \alpha)\, R_s$$

Where,

R_{ns} = Net short wave radiation (MJ m^{-2} day^{-1})

α = Albedo or canopy reflection coefficient (0.23 for the hypothetical grass reference crop (diamensionless))

R_s = Incoming solar radiation (MJ m^{-2} day^{-1}).

Net longwave radiation (R_{nl})

Stefan-Boltzmann law states that the rate of longwave radiation emission is proportional to the fourth power of the absolute temperature of the surface.

Longwave radiation is absorbed and emitted by water vapour, clouds, carbon dioxide and particulates. Due to the importance of humidity and cloudiness in calculating the net outgoing flux of long wave radiation, the Stefan-Boltzmann theorem was corrected by these two considerations when estimating the net outgoing flux as:

$$R_{nl} = \sigma \left[\frac{T_{max}.K^4 + T_{min}.K^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\,\frac{R_s}{R_{so}} - 0.35\right)$$

Where,

R_{nl} = Net outgoing longwave radiation (MJ m^{-2} day^{-1}).

σ = Stefan-Boltzmann constant (4.903×10^{-9} MJ K^{-4} m^{-2} day^{-1}).

T_{max}.K= Maximum absolute temperature during the 24 hour period (K = ^{0}C + 273.16)

T_{min}.K = Minimum absolute temperature during the 24 hour period (K = ^{0}C + 273.16)

e_a = Actual vapour pressure (kPa)

$\frac{R_s}{R_{so}}$ = Relative short wave radiation.

R_s = Short wave radiation (MJ m^{-2} day^{-1})

R_{so} = Clear sky solar radiation (MJ m^{-2} day^{-1})

The expression$\left(0.34 - 0.14\sqrt{e_a}\right)$ reflects the adjustment for humidity, and the expression $(1.35\ Rs/Rso\ - 0.35)$ reflects the adjustment for cloudiness in the above formulation.

Net radiation (R_n)

The difference between the incoming net shortwave radiation(R_{ns}) and the outgoing longwave radiation (R_{nl}) is known as the net radiation (R_n) and it was calculated as follows:

$$R_n = R_{ns} - R_{nl}$$

Where,

R_n = Net radiation (MJ m^{-2} day^{-1})

Soil heat flux density (G)

Since soil heat flux is minimal in comparison to Rn, G was set to zero (0) for the normal ten-day cycle measurement. The magnitude of the soil heat flux under the grass reference surface is so minimal that it can be neglected.

$$\boldsymbol{G_{day} \approx 0}$$

3.12.2b. FAO Modified penman method

Doorenbos and Pruitt (1975) developed a method for estimating ETo from a grass surface of 8-15 cm height and not short of water supply instead of a water surface after certain modifications such as adding shortwave reflection coefficient 0.25 for grass and 0.05 for water, wind function in aerodynamic to the Penman method. The FAO Penman method has been updated and is given as:

$$ETo = C\left[\frac{\Delta}{\Delta + \gamma} \times R_n + \frac{\gamma}{\Delta + \gamma} \times (0.27)(1 - 0.1u_2)(e_s - e_a)\right]$$

Where,

C = Correction/calibration factor

Δ = Slope of saturation vapour pressure (kPa/^{0}C)

γ = Psychrometric constant (kPa/^{0}C)

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

u_2 = Wind speed at 2m height (m/s)

$(e_s - e_a)$ = Saturation vapour pressure deficit (kPa).

3.12.2c. Hargreaves method

Hargreaves method is dependent on the air temperature and radiation. The formula is as follows:

$$ETo = 0.0023\, R_A T_d^{\,0.5}(T_m + 17.8)$$

Where,

R_A = Extraterrestrial radiation(mm/day).

T_d = Temperature differential, i.e., the difference between the maximum and minimum temperature (^{0}C)

T_m = Mean temperature (^{0}C)

3.12.2d. Makkink method

Makkink (1957) developed a condensed version of the Priestley-Taylor method for grasslands in Holland. The difference is that instead of using net radiation, the Makkink method uses incoming short wave radiation (Rs) and temperature. The following is the given equation:

$$ETo = 0.65 \frac{\Delta}{\Delta + \gamma}(R_s - G)$$

Where,

Δ = Slope of saturation vapour pressure (kPa/^{0}C)

γ = Psychrometric constant (kPa/^{0}C)

R_s = Solar radiation (MJ m^{-2} day^{-1})

G = Ground heat flux (MJ m^{-2} day^{-1}).

3.12.2e. Turc method

Turc method uses only two parameters, i.e., average daily radiation and temperature and they are expressed as:

$$ETo = 0.013(23.88 \times R_s + 50)T_a(T_a + 15)^{-1}$$

Where,

R_s = Solar radiation (MJ m^{-2} day^{-1})

T_a = Mean air temperature (^{0}C)

3.12.2f. Hargreaves-samani method

Hargreaves-samani (1985) proposed an equation dependent on air temperature, the difference between maximum and minimum air temperature, and extraterrestrial solar radiation for calculating ETo. The formula is as follows:

$$ETo = 0.0023(T_m + 17.8)R_a\sqrt{T_d}$$

Where,

T_m = Mean temperature (^{0}C)

R_a = Extraterrestrial radiation (mm/day).

T_d = Temperature differential, i.e., the difference between the maximum and minimum temperature (^{0}C).

3.12.2g. Priestley-Taylor method

Priestley-Taylor (1972) proposed an equation for calculating reference evapotranspiration (ETo) that only requires net radiation and temperature. This is the radiation-driven component of the penman equation which is written as:

$$ETo = \frac{\alpha\Delta}{\lambda\Delta + \gamma}(R_n - G)$$

Where,

α = Calibration factor, assuming values of 1.26

Δ = Slope of saturation vapour pressure (kPa/^{0}C)

λ = Latent heat of vapourization (J/kg)

γ = Psychrometric constant (kPa/^{0}C)

R_n = Net solar radiation (MJ m^{-2} day^{-1})

G = Soil heat flux (MJ m^{-2} day^{-1}).

3.12.2h. Christian method

Christiansen (1968) developed the empirical formula for estimating evapotranspiration based on the climatic data, when accurate determined pan evaporation data are not available. The formula is as follows:

$$ETo = 0.755E_{pan} \times C_T \times C_W \times C_H \times C_S$$

Where,

E_{pan} = Pan evaporation (mm/day)

C_T = Temperature coefficient

C_W = Wind velocity coefficient

C_H = Humidity coefficient

C_S = Solar radiation coefficient

3.12.2i Hargreaves method

Hargreaves developed a method in 1985 to estimate evapotranspiration is an empirical relation based on air temperature and radiation. (Bsanagouda R.F., 2016). The Hargreaves method is given by-

$$ET_o = 0.0023RA\,T_d 0.5\,(T_m + 17.8)$$

Where,

ET_o – Reference evapotranspiration (mm day^{-1})

RA – Extra-terrestrial radiation (mm day^{-1})

T_d – Difference between maximum and minimum temperature (°C)

T_m – Mean temperature (°C)

3.12.2j. Modified Penman method

Doorenbos and Pruitt (1975) recommended a method after some modification like adding short wave reflection coefficient 0.25 for grass and 0.05 for water, wind function in aerodynamic to the Penman method for estimation of ET_o from a grass surface of 8 to 15 cm height and not short of water supply instead of water surface. The modified FAO Penman method is given as-

$$ET_o = C\,[\,\Delta + \gamma \times R_n + \gamma\Delta + \gamma \times (0.27)(1 - 0.1u_2)(e_s - e_a)$$

Where,

ET_o - Reference evapotranspiration (mm day^{-1})

Δ - Slope of saturation vapour pressure (KPa °C^1)

γ – Psychrometric constant (KPa °C^1)

R_n – Net radiation (mm day^{-1})

u_2 – Wind speed at 2m height

e_s-e_a – Difference between saturated vapour pressure an actual vapour pressure of air (KPa)

C – Correction /calibration factor.

3.13 Error analysis

The statistical parameters like average error (AE), mean absolute error (MAE), mean bias error (MBE), and root mean square error (RMSE) *etc*. were used to test the performance of different methods used for estimation of ET_c. following formulae were used to calculate this analysis.

$$AE\,(\%) = \frac{ETo - ETc}{ETc} \times 100$$

$$\text{MAE (mm)} = \frac{\sum_{i=1}^{N}[\text{ETo} - \text{ETc}]}{N}$$

$$\text{MBE (mm)} = \frac{\sum_{i=1}^{N}[\text{ETo} - \text{ETc}]}{N}$$

$$\text{RMSE (mm)} = \sqrt[2]{\frac{\sum_{i=1}^{N}[\text{ETo} - \text{ETc}]^2}{N}}$$

3.14 Computation of Crop water requirement satisfying index (WRSI)

Frere and Popov originally proposed simplified crop-weather analysis model in 1979 to the United Nations Food and Agriculture Organization (FAO) as a proxy for crop performance, and an indicator of the satisfaction of the crop water requirements in areas of the world where water represents the main constraint for crops (FAO, 1979). The WRSI is an indicator of crop performance based on the availability of water to the crop during a growing season. Studies by the FAO (Doorenbos and Pruitt, 1977; FAO, 1986) given formula,

$$\text{WRSI} = \frac{\sum \text{AETc}}{\sum \text{PETc}} 100$$

Where,

PETc denotes crop specific potential evapotranspiration after an adjustment is made to the reference crop PET by the use of appropriate crop coefficients (K_c). Gabriel B.*et al.* (2003)

The water requirement of the crop (PET_c) at a given time in the growing season is calculated by multiplying standard reference crop PET by K_c:

$$PET_c = K_c \, PET$$

The criterion proposed by Rajavel *et al*. (2012) was adopted to categorize the WRSI.

WRSI (%)	Description
95-100	Good
80-94	Average
50-79	Poor
< 50	Failure

3.15 Computation of the crop water stress Index

CWSI computed using empirical method. According to the Idso's definition Idso *et al*. (1981), the CWSI can be expressed:

$$CWSI = \frac{(T_c - T_a) - D_2}{D_1 - D_2} \qquad (1)$$

Where,

D_1 = maximum canopy and air temperature difference for a stressed crop (the maximum stressed baseline), Jackson *et al.* (1981)

D_2 = lower limit canopy and air temperature difference for a well watered crop (the non-water-stressed baseline),

T_c = measured canopy surface temperature (◦C),

T_a = air temperature (◦C).

3.15.1Thermal data acquisition

The Infrared thermometer was used with the canopy viewed at an angle of 35–45^0 from the horizontal it shows Canopy temperature in ℃ and then viewed at perpendicular to surface got air temperature in ℃. Five plants canopy temperatures were measured in each plot and averaged to determine the plot's canopy temperature. According to some research conclusions, midday canopy temperature is the best indicator to detect the crop water stress Idso *et al*. (1981); Jackson *et al*. (1977), so the midday canopy temperatures obtained from 1200 LMT - 1400 LMT. As the same time ,air temperature (T_a) was also captured with the surrounding temperature in an alternating manner to relate the canopy temperature with surrounding temperature. The plants for the data acquisition were the same as used for biometric observations and these were sampled at the completion of each growth stage.

3.15.2 Canopy and air Temperature difference (T_c-T_a)

Difference between the canopy and air temperature was calculated as soon as the measurements of these temperatures were finished at corresponding Phenoplogical stages Average of (T_c-T_a) was calculated to represents single value for each stage and thus, stage –specific values were obtained.

3.15.3 Determination of lower boundary (D_2)

The lower bound indicates the lowest limit below which no value of T_c-T_a will occur. It was obtained from the given formula. Jackson *et al*. (1988)

$$(T_c - T_a) = \frac{r_a R_n}{\rho C_p} * \frac{\gamma(1+\frac{r_c}{r_a})}{\Delta+\gamma(1+\frac{r_c}{r_a})} - \frac{e_s - e_a}{\Delta+\gamma(1+\frac{r_c}{r_a})} \quad (2)$$

Where,

r_a = Aerodynamic resistance (s m^{-1})

R_n = Net radiation (594.6 W m^{-2})

ρ =Density of air (1.28 kg m^{-3})

C_p = Heat capacity of air (700 J kg^{-1} °C^{-1})

γ = Psychometric constant (54 Pa °C^{1})

VPD = vapor pressure deficit (K Pa)

Δ = Slope of the saturated vapor pressure-temperature difference between leaf and air. (P °C^{-1})

By setting r_c=0 in the above Equation (2) which represents the condition of wet plants behaving as a free water surface for the transpiration (Jackson *et al*.1988) we get:

$$(T_c - T_a) = \frac{r_a R_n}{\rho C_p} * \frac{\gamma}{\Delta+\gamma} - \frac{e_s - e_a}{\Delta+\gamma} \quad (3)$$

3.15.4 Determination of upper boundary (D_1)

The D_1 maximum canopy and air temperature difference for a stressed crop can be found by allowing the canopy resistance r_c to increase without bound as $r_c = \infty$, (Jackson.*et al*.1988).

$$T_c - T_a = \frac{r_a R_n}{\rho C_p}. \quad (4)$$

Vapor pressure deficit (VPD)

The VPD (kPa) was calculated on daily basis using dry bulb and wet bulb temperatures with the help of whriling psychrometer and hygrometeric tables for the field conditions. It was figured out as follow

$$VPD = (e_s - e_a)$$

Where,

e_s = Saturation vapor pressure (kPa) for given air temperature (T_a).

e_a = Actual vapor pressure (kPa) at same T_a

Net radiation (R_n)

The stress index would simply need ab=n anticipated amount of net radiation, excluding the situations when low vapor pressure deficit dominates Fritschen *et al*. (1967). Hence, an estimated value of 594.6Wm^{-2} was taken for calculating lower and upper boundaries.

Aerodynamic resistance (r_a)

The resistance term r_a was estimated by measuring T_c-T_a and R_n of soybean as fully senesced, nature stage in order to attain the condition with no available soil water. It was followed by solving Eq. (4) to obtain value r_a. Jackson *et al*. (1988).

Calculation of Δ

As the proposed study is based on irrigated crop, the temperature difference (T_c-T_a) will be large vapor pressure deficits, hence a superior consideration is to calculate Δ at (T_c+T_a)/2 Jackson *et al*. (1988).the average value of temperatures is sufficient for solving Eq.(3).

CHAPTER-IV

RESULTS AND DISCUSSION

CHAPTER - IV

RESULT AND DISCUSSION

In this chapter data recorded during the experiment have been analyzed by using proper statistical and mathematical methods. Results and discussion were given under the following headings.

4.1 Weather conditions during crop growing season 2021

4.2 Weather parameters during crop growth period as per the different dates of sowing

4.3 Pre-harvest studies

4.4 Growth studies

4.5 Post harvest studies

4.6 Thermal Indices

4.7 Correlation studies

4.8 Estimation of Crop coefficient of soybean cv.MAUS-71

4.9 Estimation of Crop water requirement satisfying index of soybean cv.MAUS-71

4.10 Computation of the crop water stress Index of soybean.

4.1 Weather conditions during crop growing season 2021

The weather data during the experiment was recorded at Meteorological Observatory, Department of Agricultural Meteorology, VNMKV, Parbhani.

The weather conditions prevailing during the crop growing season *i.e.*, *kharif* 2021-22 are mentioned in Table 4.1 and illustrated graphically in Fig. 4.1 to 4.4 by plotting various meteorological elements averaged over standard meteorological weeks. The weather elements comprised rainfall, maximum and minimum air temperature, relative humidity; bright sunshine hours, evaporation, and wind speed are all discussed below.

Table 4.1: Mean weekly weather data during crop growing season 2021-22

Week	RF	Temperature ^{0}C		Humidity (%)		EVP (mm)	BSS (Hrs.)	WS (Kmph)
		Max	Min	RH1	RH2			
25	9.7	32.7	19.6	86	57	4.7	5.5	5.4
26	35.3	32.9	23.3	84	57	4.6	5.6	5.2
27	41.1	33.4	23.8	82	54	5.3	5.9	4.2
28	389.7	29.7	22	96	78	1.1	2.4	3.7
29	126.7	30.1	22.6	92	73	3	5.7	4.1
30	9.9	30.5	21.4	89	65	3.4	4.5	5.3
31	1.4	30.9	21.6	84	63	3.3	2.7	5.8
32	2.3	33.1	22.5	84	52	4.9	6.2	4.2
33	48.5	29.4	22.2	89	70	3.6	4.7	4.6
34	5.9	30.6	22.4	92	64	3.1	5.2	2.9
35	48.8	30.0	22.7	78	59	3	3.4	2.8
36	233.1	28.2	21.8	94	78	1.6	3.9	3.3
37	44.4	30.9	22	90	69	3.4	6.6	4.3
38	48.6	30.9	22.3	98	71	4	5.1	3.7
39	133.9	28.9	21.8	94	75	1.6	2.2	3.6
40	112.9	32.7	22.4	94	59	3.5	7.3	2.4
41	3.0	33.0	21.2	92	46	4.4	7.8	2.3
42	45.8	31.1	19.6	89	48	4.2	7.0	2.9
Total	**1341**							
Mean		**31.1**	**22.0**	**90**	**63**	**3.5**	**5.1**	**3.9**

4.1.1 Rainfall (mm day^{-1})

The data on Table 4.1 shows total rainfall received during the crop growing season was 1341.0 mm. against 773.0 mm average *kharif* season rainfall. 25th MW (21th June) received 9.6 mm of rainfall with this sowing of soybean seed was done as D_1. 26th MW (28th June) received 35.3 mm of rainfall; soil got optimum soil moisture and sowing done as D_2. D3 sowing was done on 27th MW (5th July) which received 41.1 mm of rainfall, and 28th MW (12th July) received 389.7 mm rainfall but excess water was drained out and done sowing as D_4. During four weeks of time period good soil moisture was available for sufficient germination of seed and emergence of the soybean crop. Further rainfall with 41.1 mm and 389.7 mm was received during 27th and 28th MW respectively, which results in good growth and development of seedlings. The highest rainfall received of 389.7 mm and 233.1 mm was received in 28th MW and 36th MW was favorable for proper germination and pod development of soybean crop. During 30, 31, 32 MW a short dry spell was found with rainfall of 13.6 mm.

4.1.2 Air Temperature (℃)

Air temperature prevalent during crop growing season represented in table 4.1 and graphically represented in Fig. 4.4. The data showed the average maximum and minimum temperature ranged between 31.1℃ to 21.6℃.

The highest maximum temperature i.e., 33.4 ℃, and lowest maximum temperature of 28.2 ℃ was recorded during 27th and 25th MW respectively with mean of growing season maximum temperature was 31.1℃ against seasonal normal of 32.4℃. The highest minimum and lowest minimum temperature i.e., 23.8 ℃ and 19.6 ℃ was recorded during 27th MW and 42nd MW respectively and the mean of 22 ℃ against 22.6℃ of seasonal normal minimum temperature. There was considerable variation in the range of minimum temperature during the crop growing season.

4.1.3. Relative humidity (%)

The mean relative humidity of morning (RH-I) and afternoon (RH-II) hours during the crop growing season was 89 % and 63 % respectively, during crop season RH-I ranged from 77% to 98% and RH-II ranged from 45 % to 78%. Data was presented in Table 4.1 and graphically plotted in Fig. 4.3.

4.1.4 Evaporation (mm day^{-1})

The evaporation rate during the crop growing season ranged from 1.1 to 5.6 mm day^{-1} where the lowest and highest evaporation rate was recorded during 28th MW and 27th MW respectively, the mean evaporation of 3.5 mm was recorded during the growing period of the crop against 5.4 mm of seasonal normal evaporation. Continuous rainfall and low temperature within a week decreased the evaporation rate. The data shown in Table 4.1 and graphically illustrated in Fig.4.5.

4.1.5 Bright sunshine hours (hrs day^{-1})

As per the data shown in table 4.1 the mean BSS during crop growing season (25th to 42rd MW) ranges from 2.2 to 7.8 hrs day^{-1} and is plotted graphically in Fig. 4.5. The maximum BSS of 7.8 hrs day^{-1} was observed during 41st MW while the minimum BSS of 2.2 hrs day^{-1} was recorded during 39th MW. The seasonal bright sunshine hour was 5.6 hrs day^{-1} but during this season falls to 5.1 hrs day^{-1}.

4.1.6 Wind velocity (km hr^{-1})

The data on weekly mean wind velocity during the crop growing period was presented in Table 4.1 which ranged from 2.3 to 5.8 km hr^{-1} with the mean wind speed of 3.9 Km hr^{-1} during the crop growth. Seasonal normal wind speed was 6.8Km hr^{-1} but for this season got lower wind velocity was observed to be helpful for the decrease in evapotranspiration (ET) rate and illustrated graphically in Fig. 4.5**.**

4.2 Weather parameters during crop growth period as per the dates of sowing.

The average data of weather parameters recorded according to each phenophases wise on different dates of sowing during crop growing season for different dates of sowing (D_1, D_2, D_3 and D_4). The weather data includes rainfall, rainy days, maximum temperature and minimum temperature, relative humidity, evaporation, bright sunshine hours, and wind speed which are presented in Table 4.3, 4.4, 4.5 and 4.6. for D_1, D_2, D_3 and D_4, respectively.

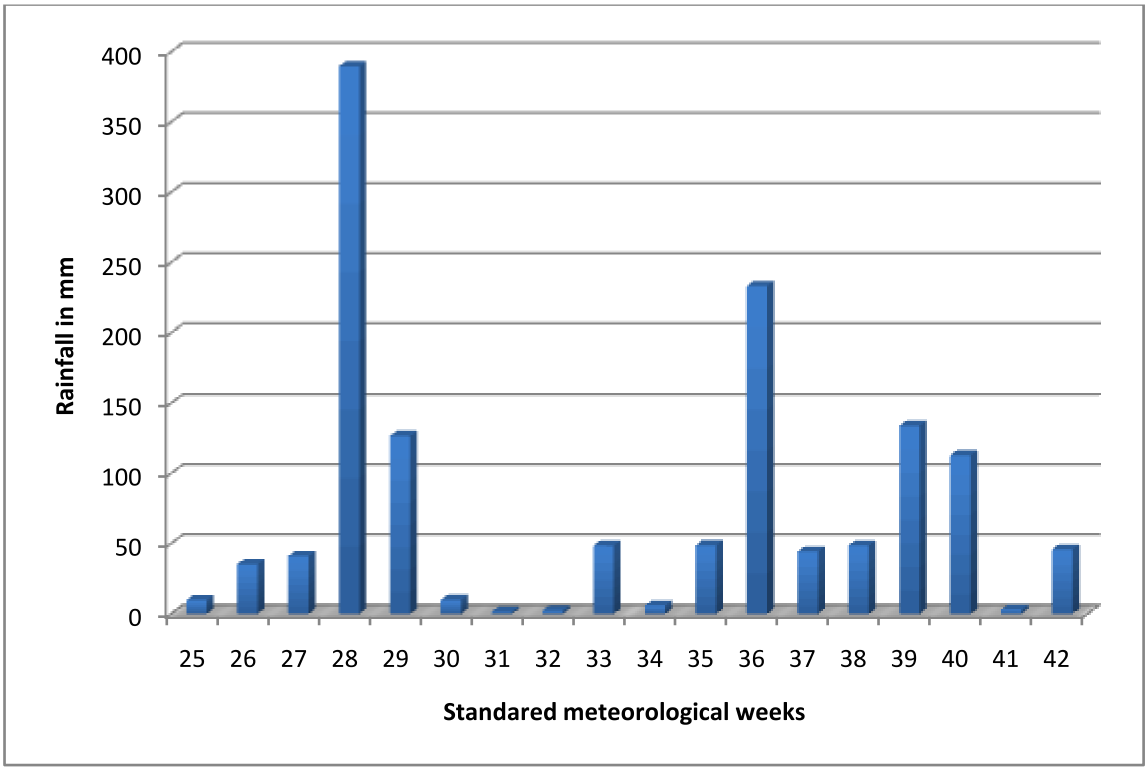

Fig. 4.1: Weekly rainfall (mm) during crop growing season during the year 2021.

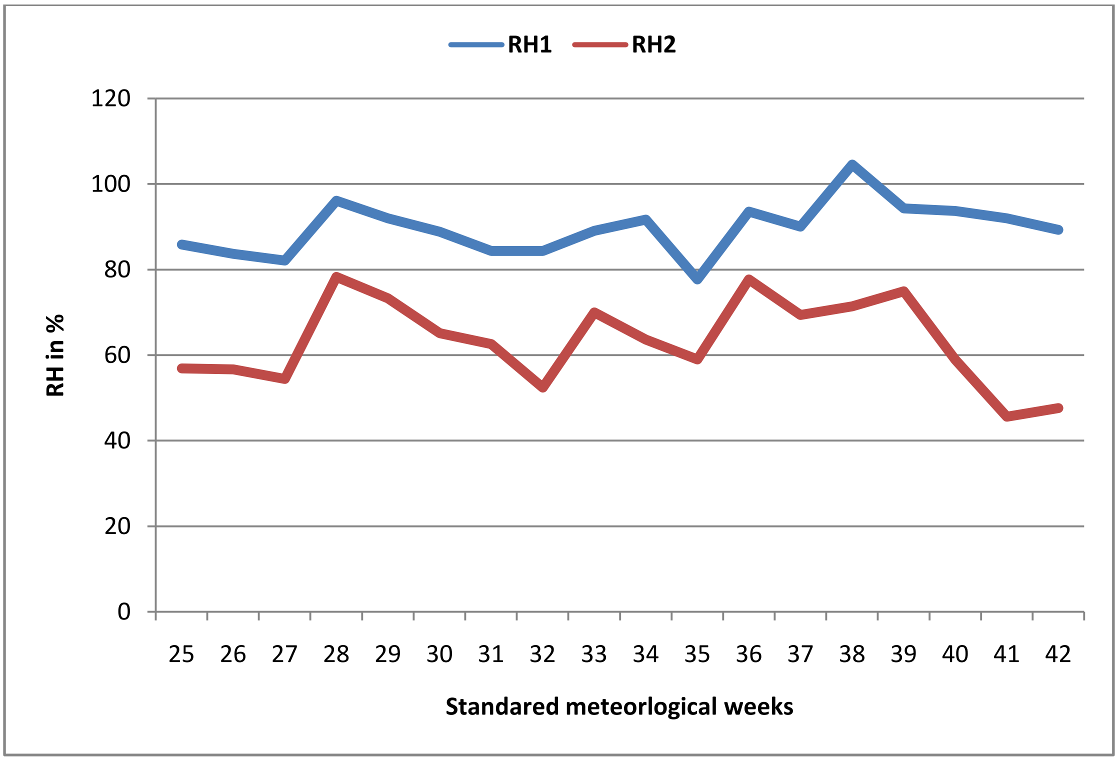

Fig. 4.3: Weekly mean RH in % during crop growing season during the year 2021.

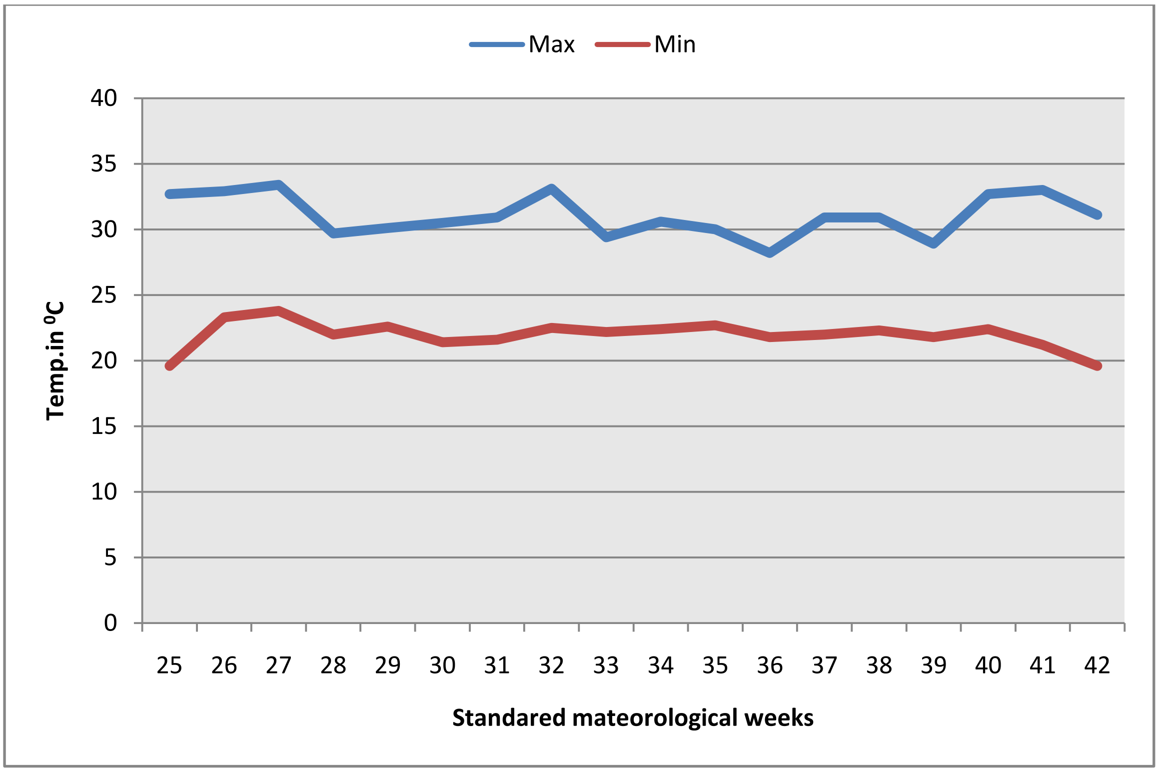

Fig. 4.4: Weekly mean Temperature in ^{0}C during crop growing season during the year 2021.

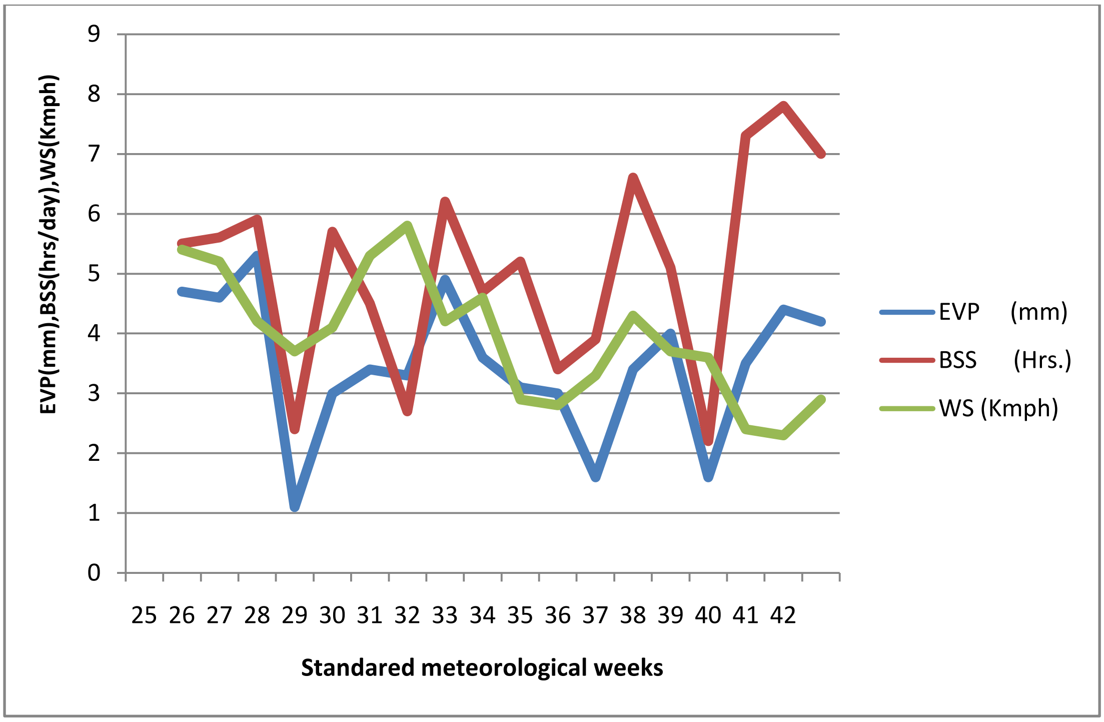

Fig. 4.5: Weekly mean EVP in mm, BSS in hrs, WS in Kmph during crop growing season during the year 2021.

Table 4.3: Phenophases wise average weather condition prevailed during D_1 (25^{th} SMW).

Weather parameters	Phenophage Stages in D_1 (25^{th} SMW)											
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**Total**	**Mean**
RF(mm)	6.1	133.3	348.0	120.9	0.3	2.3	57.6	323.1	69.8	16.2	**1077.6**	
T_{max} (℃)	32.9	32.8	30.2	30.0	30.2	33.1	29.5	29.6	30.7	31.1		**31.0**
T_{min} (℃)	20.0	23.5	22.3	21.4	21.5	22.5	22.4	22.0	22.2	22.3		**22.0**
T_{mean} (℃)	26.5	28.1	26.2	25.7	25.9	27.8	25.9	25.8	26.5	26.7		**26.5**
RH_{max}(%)	84	85	94	90	85	84	92	92	92	94		**89**
RH_{min}(%)	58	58	75	68	66	51	70	73	65	65		**65**
RH_{mean}(%)	71	71	85	79	75	67	81	82	79	79		**77**
EVP (mm)	5.8	4.6	2.9	3.4	3.1	5.5	2.8	3.0	3.9	3.1		**3.8**
BSS (hrs)	6.4	5.1	5.1	4.0	1.9	7.0	4.0	4.6	4.5	5.2		**4.8**
WS (kmph)	5.7	4.3	3.9	5.4	6.2	4.5	3.4	3.7	3.5	3.0		**4.4**

Table 4.4: Phenophases wise average weather condition prevailed during D_2 (26^{th} SMW).

Weather parameters	Phenophage Stages in D_2 (25^{th} SMW)											
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**Total**	**Mean**
RF (mm)	34.8	432.0	135.4	1.4	2.3	49.2	287.1	114.2	197.1	31.5	**1285**	
T_{max} (℃)	33.0	31.6	30.1	31.3	33.3	29.1	29.6	30.8	29.7	32.9		**31.1**
T_{min} (℃)	23.2	22.9	21.8	21.7	22.7	22.2	22.4	22.1	22.0	22.1		**22.3**
T_{mean} (℃)	28.1	27.2	25.9	26.5	28.0	25.6	26.0	26.4	25.8	27.5		**26.7**
RH_{max}(%)	87	90	90	85	84	90	92	91	95	93		**90**
RH_{min}(%)	58	66	70	62	50	72	69	66	71	54		**64**
RH_{mean}(%)	73	78	80	73	67	81	81	79	83	74		**77**
EVP (mm)	4.0	3.8	3.7	3.4	5.2	3.2	3.1	3.7	2.1	4.1		**3.6**
BSS (hrs)	5.9	4.2	5.2	3.2	6.7	4.1	4.2	5.6	3.9	7.2		**5.0**
WS (kmph)	4.0	3.7	5.2	5.5	4.0	4.5	3.1	3.9	3.4	2.3		**4.0**

Table 4.5: Phenophases wise average weather condition prevailed during D_3 (27^{th} SMW).

Weather parameters	Phenophage Stages in D3 (27^{th} SMW)											
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**Total**	**Mean**
RF(mm)	41.1	516.4	11.3	1.3	1.0	54.4	113.2	213.4	183.2	160.7	**1296**	
T_{max} (℃)	33.2	29.9	30.1	31.9	33.2	28.7	29.9	30.6	29.4	32.4		**30.9**
T_{min} (℃)	23.8	22.3	21.9	22.0	22.7	22.1	22.7	22.0	22.0	21.5		**22.3**
T_{mean} (℃)	28.5	26.1	26.0	26.9	27.9	25.4	26.3	26.3	25.7	26.9		**26.6**
RH_{max}(%)	88	94	90	85	82	93	91	91	95	92		**90**
RH_{min}(%)	59	76	70	59	48	75	66	69	73	54		**65**
RH_{mean}(%)	73	85	80	72	65	84	78	80	84	73		**77**
EVP(mm)	5.1	2.9	3.1	4.0	5.9	1.9	3.7	3.8	2.2	4.2		**3.7**
BSS(hrs)	6.8	4.0	4.2	4.6	7.5	2.7	5.3	5.4	2.9	7.0		**5.0**
WS(kmph)	3.8	3.9	4.9	5.0	4.5	3.6	3.1	3.9	3.5	2.5		**3.9**

Table 4.6: Phenophases wise average weather condition prevailed during D_4 (28th SMW).

Weather parameters	Phenophage Stages in D4 (28th SMW)											
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**Total**	**Mean**
RF(mm)	311.1	135.4	1.4	1.3	48.5	46.7	285.5	182.5	115.9	45.8	**1173.1**	
T_{max} (℃)	29.8	30.1	30.9	33.0	26.7	30.3	29.7	29.9	32.8	31.8		**30.5**
T_{min} (℃)	21.9	21.8	21.6	22.4	22.0	22.5	22.0	22.1	22.5	19.4		**21.8**
T_{mean} (℃)	25.9	25.9	26.3	27.7	24.4	26.4	25.8	26.0	27.6	25.6		**26.2**
RH_{max}(%)	96	90	84	81	96	91	92	93	94	90		**91**
RH_{min}(%)	73	70	63	48	87	66	72	69	57	44		**65**
RH_{mean}(%)	84	80	74	64	91	79	82	81	75	67		**78**
EVP(mm)	1.0	3.4	3.3	6.2	1.2	3.3	2.4	2.8	3.6	4.6		**3.2**
BSS(hrs)	3.5	5.2	2.7	7.5	1.5	4.5	4.9	3.6	7.2	7.7		**4.8**
WS(kmph)	3.4	5.2	5.8	5.1	4.1	3.2	3.7	3.6	2.4	2.7		**3.9**

P_1- Emergence stage, P_2- Seedling stage, P_3- Branching stage, P_4- Flowering stage, P_5- Pod formation stage, P_6- Grain formation stage P_7- Pod development stage, P_8- Pod containing full-size grain, P_9- Dough stage, P_{10}- Maturity.

4.3 Pre-harvest studies

4.3.1. Emergence count and final plant stand (percent)

The emergence count was recorded 8 days after sowing and the final plant stand was recorded at harvesting time.

Table 4.7: Mean emergence count and final plant stand (%) of soybean crop as influenced by different treatments.

Treatments	Germination count in %	Final plant stand in %
Date of sowing	89.4	87.2
D2- 26th SMW	88.8	86.7
D3-27th SMW	85.7	84.5
D4-28th SMW	81.3	81.2
S.E. m±	0.97	0.50
C.D. @ 5%	3.37	1.73
Variety		
V1- MAUS-158	87.7	86.1
V2- MAUS-71	86.8	85.2
V3-JS-335	84.4	83.4
S.E. m±	0.83	0.41
C.D. @ 5%	2.50	1.24
Interaction (D × V)		
S.E. m±	1.67	0.83
C.D. @ 5%	NS	NS
G.M.	86.3	84.9

4.3.1.1 Effect of sowing dates

It was calculated in percentage and found that D_1 has the highest emergency count of 89.4 percent with the final count of 87.2 percent, followed by D_2 having emergence count of 88.8 percent with final count of 86.7 percent, D_3 having emergence count of 85.7 percent with final count of 84.5 percent and D_4 having emergence count of 81.3 percent with final count of 81.2 percent, respectively as shown in table 4.7 and fig.4.6. Kundu *et al.* (2016) got similar results of germination and final plant stand of different dates of sowing.

4.3.1.2 Effect of varieties

The emergence count and final plant stand of three different varieties were recorded and found that V_1 has the highest emergence count of 87.7 percent with final count of 86.1 percent, followed by V_2 having emergence count of 86.8 percent with final count of 85.2 percent and then V_3 having the lowest emergence count of 84.4 per cent with final count of 83.4 per cent.

4.3.1.3 Interaction

According to data from Table 4.7, the result was concluded that the emergence count and final plant stand was not significantly affected with the dates of sowing, different hybrid and their interaction.

4.4. Growth Studies

This study includes the collection of data that explains the daily growth and development of different varieties of crop in responses to different dates of sowing and varieties as well as comparison of growth and development between varieties in 15 days interval from the first day of observation until harvest.

4.4.1. Plant height (cm)

This data was collected from 15 DAS at 15 days interval up to 105 DAS and at harvest as shown in Table 4.8 and illustrated in Fig. 4.8 and fig. 4.9 to find the impact of different sowing dates and varieties on plant height by measuring the height of crop in cm. According to data, it was found that the plant height of soybean crop gradually increases from 15 DAS till harvest but peak increase at 45 DAS and the geometric mean plant height at 15 days interval from 15 DAS till harvest was 5.4, 10.5, 21.2, 24.9, 27.2, 28.8, 29.1 and 29.1cm, respectively, with mean plant height at harvest was the highest (29.1cm).

4.4.1.1. Effect of sowing dates

The plant height data was then taken for statistical analysis to determine the effect of sowing dates on plant height. According to data from Table 4.8 and Fig. 4.8 it was found that D_1 has the maximum plant height of 32.7 cm, followed by D_2 of 31.3 cm, D_3 of 27.4 cm and D_4 of 25.1 cm, respectively. As a result, the varied dates of sowing were found to have statistically significant effects on plant height, with the

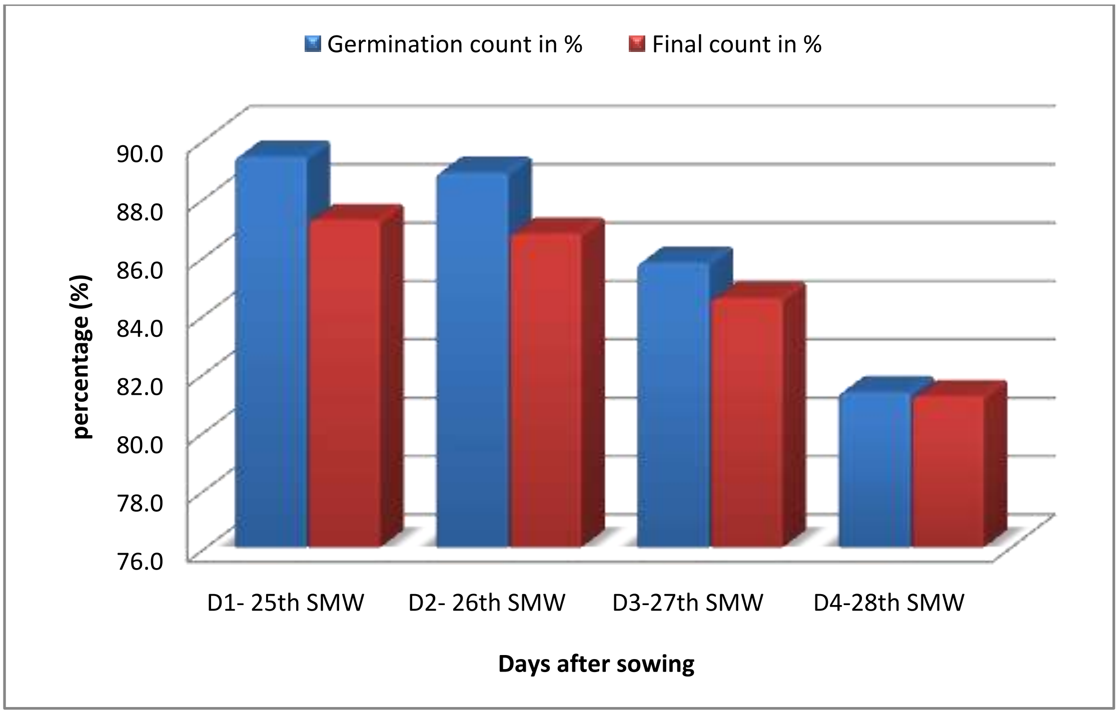

Fig 4.6: Mean emergence count (%) and final count (%) as influenced by various dates of sowing.

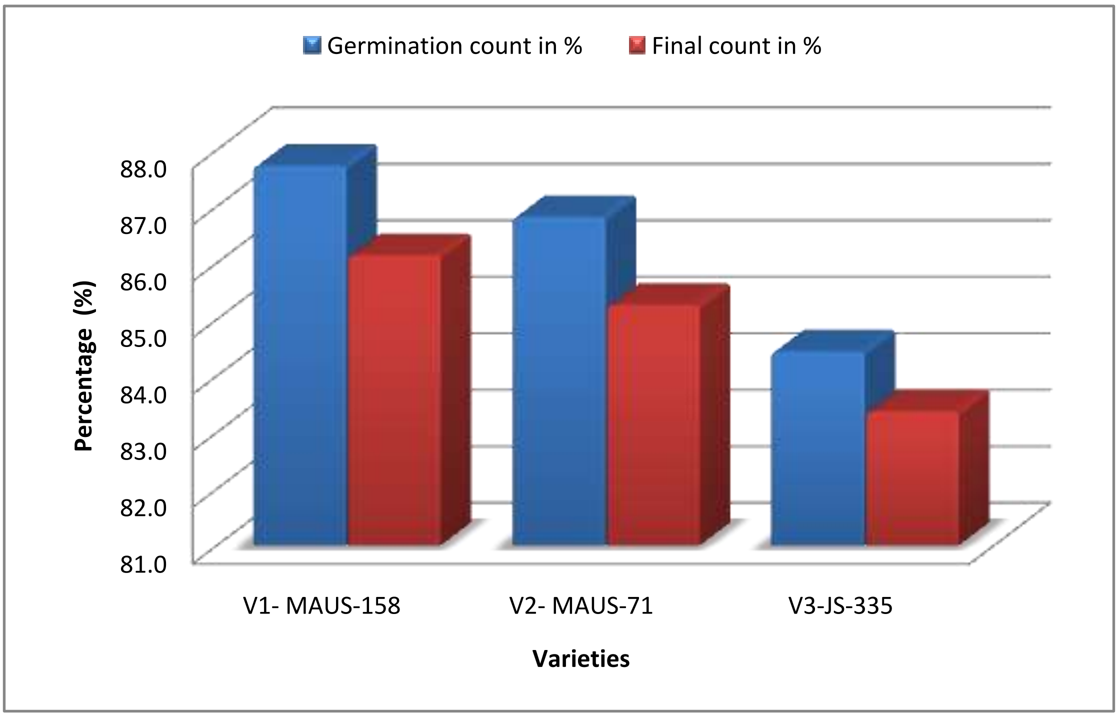

Fig 4.7: Mean emergence count (%) and final count (%) as influenced by different varieties.

early sowed crop (D_1) growing taller than the late sowed crops (D_4) and showed significantly at par with (D_2). This is due to the fact that the early sowed crop received good rainfall and optimum moisture to aid in the crop's growth and development. This similar result was reported by Serafin-Andrzejewska *et al.* (2021) and Jaybhay *et al.* (2018) that the plant height was significantly influenced due to delay in sowing dates and maximum plant height was observed in early sowing dates and decreases in late sowing dates.

Table 4.8: Mean height plant^{-1} as influenced by various treatments.

Treatments	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
Date of sowing								
D1- 25th SMW	6.01	12.1	25.6	29.5	31.9	32.3	32.7	32.7
D2- 26th SMW	5.42	11.9	24.1	27.6	29.5	31.2	31.3	31.3
D3-27th SMW	5.31	10.2	20.0	22.8	25.3	27.2	27.4	27.4
D4-28th SMW	4.84	7.9	15.1	19.7	22.3	24.3	25.1	25.1
S.E. m±	0.25	0.43	0.65	1.17	1.28	0.97	1.02	1.02
C.D. @ 5%	NS	1.47	2.26	4.05	4.44	3.37	3.52	3.52
Varieties								
V1- MAUS-158	5.71	12.5	22.7	25.9	28.6	30.5	30.5	30.5
V2- MAUS-71	5.54	9.95	21.0	25.3	27.7	29.0	29.3	29.3
V3-JS-335	5.12	9.07	19.9	23.4	25.4	26.8	27.4	27.4
S.E. m±	0.17	0.48	0.55	0.64	0.76	0.88	0.78	0.78
C.D. @ 5%	NS	1.45	1.64	1.90	2.28	2.64	2.34	2.34
Interaction (D × V)								
S.E. m±	0.34	0.97	1.09	1.27	1.52	1.76	1.56	1.56
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	5.45	10.5	21.2	24.9	27.2	28.8	29.1	29.1

4.4.1.2. Effect of varieties

The plant height was statistically significant from 30 DAS till harvest, among different treatments of varieties, V_1- MAUS-158 (30.5 cm) was found to be the tallest than V_2- MAUS-71(29.3cm) and V_3- JS-335(27.4 cm). Jaybhay *et al.* (2018) also found maximum height of variety 'RKS 18'.

4.4.1.3. Interaction effect

The interaction effect of different dates of sowing and varieties during crop growth period was nonsignificant with plant height.

4.4.2 Mean number of branches per plant

This data was taken 30 days after sowing at 15-day intervals up to 105 days after sowing, and at harvest as presented in Table 4.9 and illustrated in Fig. 4.10 and 4.11, to determine the impact of different sowing dates and varieties on number of branches per plant by counting the number of branches of each plant from five observational plants from each net plot. According to data, the number of branches of the soybean crop continuously grows from 30 DAS till harvest from 30 DAS to harvest, the geometric mean number of branches per plant at 15 days interval was 0.93, 1.61, 3.01,3.36, 3.92, 4.29 and 4.29, with the mean number of branches at harvest was the highest (i.e., 4.29).

4.4.2.1 Effect of sowing dates

The data Mean number of branches was presented in Table 4.9 and Fig. 4.10. D_1 had the maximum number of branches per plant with 4.48, followed by D_2 with 4.26, D_3 with 4.08 and D4 with 3.52. As a result, the varied dates of sowing were found to have statistically significant effects on number of branches per plant, with the early sowed crop (D_1) having higher rate of branching than the late planted crops (D_4) and showed significantly at par with (D_2). This is due to that the early sowed crop exposed to good amount of soil moisture, sunlight, humidity and temperature to aid in the crop's vegetative growth and development. Ngalamu *et al.* (2013) also reported that the early sown crop has a greater number of branches due to presence of appropriate soil moisture, congenial temperature and humidity for its vegetative growth.

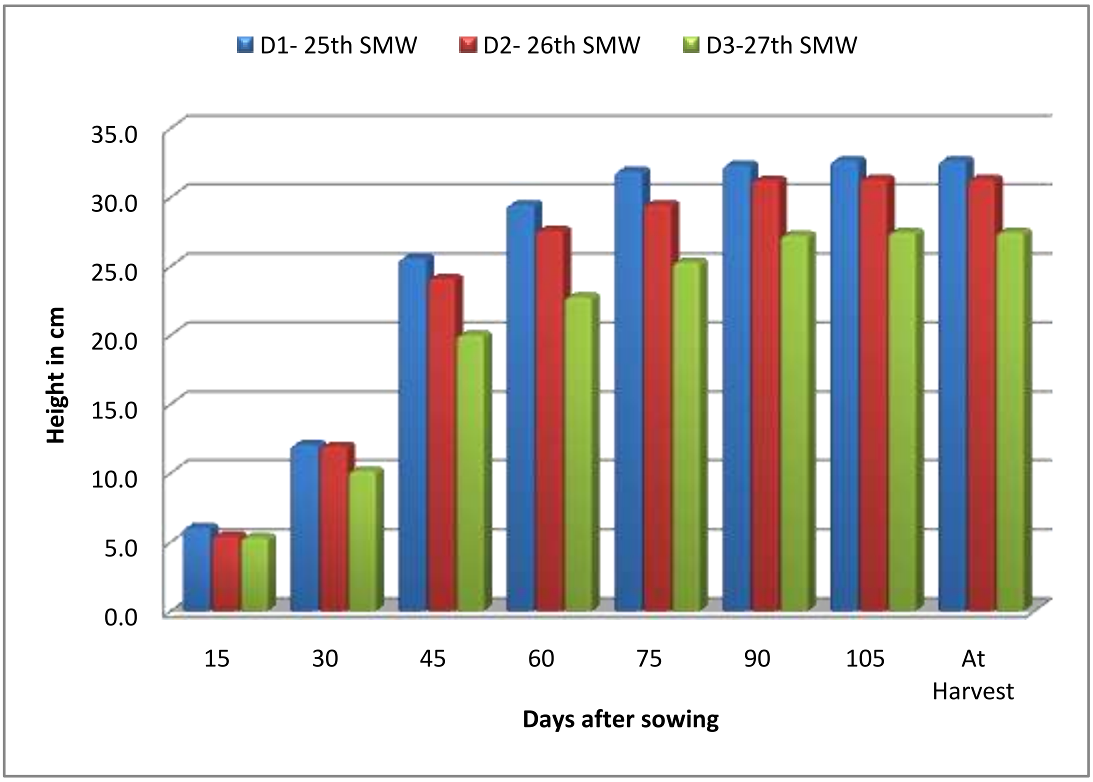

Fig 4.8: Mean plant height (cm) as influenced by different sowing dates.

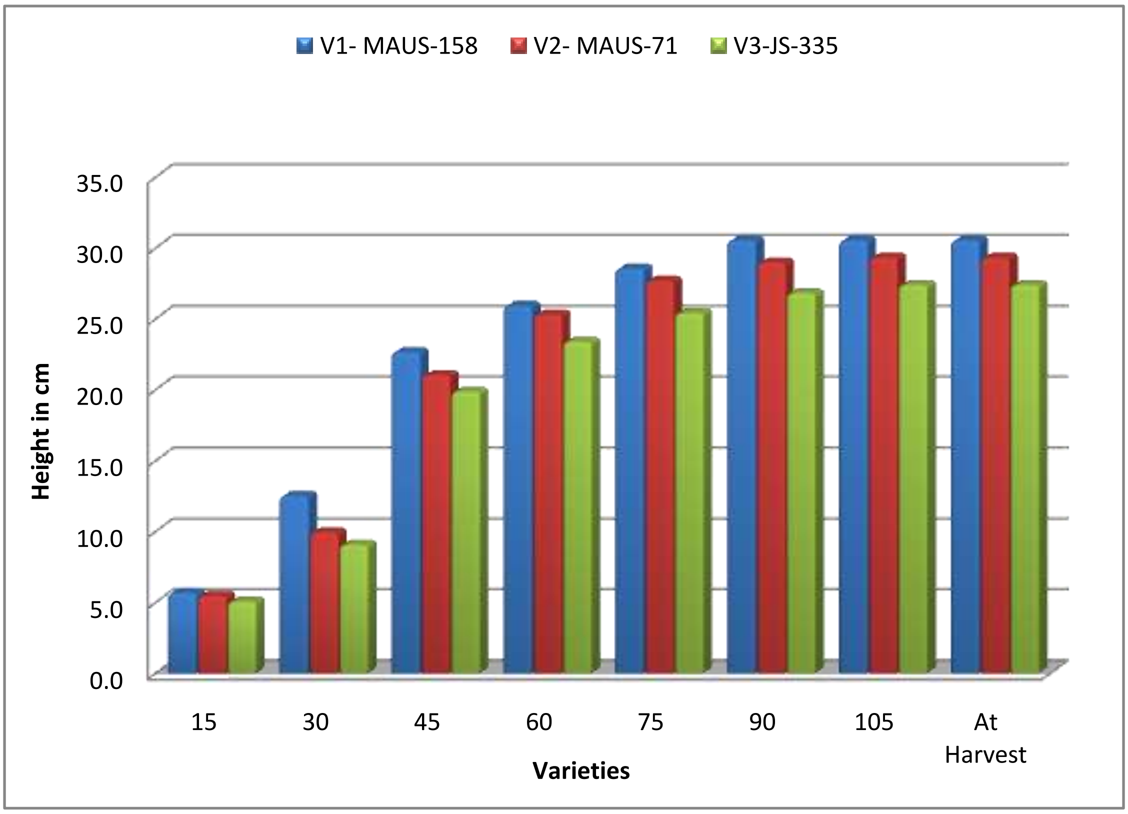

Fig 4.9: Mean plant height (cm) as influenced by different varieties.

Table 4.9: Mean number of branches as influenced by different dates of sowing and varieties of sowing.

Treatments	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
Date of sowing							
D_1- 25th SMW	1.09	2.00	3.56	4.08	4.31	4.48	4.48
D_2- 26th SMW	0.96	1.97	3.41	3.64	4.07	4.26	4.26
D_3-27th SMW	0.88	1.33	2.96	3.09	3.83	4.08	4.08
D_4-28th SMW	0.78	1.14	2.10	2.61	3.46	3.52	3.52
S.E. m±	0.06	0.07	0.11	0.12	0.16	0.11	0.11
C.D. @ 5%	NS	0.23	0.38	0.40	0.54	0.38	0.38
Varieties							
V_1- MAUS-158	1.02	1.89	3.28	3.49	4.09	4.43	4.43
V_2- MAUS-71	0.94	1.56	3.01	3.42	3.97	4.13	4.13
V_3-JS-335	0.82	1.38	2.73	3.16	3.69	3.69	3.69
S.E. m±	0.06	0.05	0.07	0.09	0.11	0.11	0.11
C.D. @ 5%	NS	0.14	0.21	0.26	0.32	0.34	0.34
Interaction (D ×V)							
S.E. m±	0.11	0.09	0.14	0.18	0.21	0.23	0.23
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS
G.M.	0.93	1.61	3.01	3.36	3.92	4.29	4.29

4.4.2.2 Effect of Varieties

Different soybean varieties had a significant impact on mean number of branches per plant from 45 Days after sowing to harvest. Among different treatments of varieties V_1, i.e., MAUS-158 (4.43) was found to have higher rate of branching during crop growth period as compare to other varieties, V_2, i.e., MAUS-71 (4.13) and V_3, i.e., JS-335 (3.69).

4.4.2.3 Interaction

The interaction effects of different dates of sowing and varieties during crop growth period was nonsignificant with mean number of branches per plant.

4.4.3 Mean Leaf area (cm^{-2}) per plant

The data as shown in Table 4.10 and depicted Fig.4.12 and 4.13, was taken 15 days after sowing at intervals of 15-days up to harvest. After sowing, and at harvest to determine the impact of different sowing dates and varieties on leaf area per plant by measuring leaf area of each plant from 5 observational plants from each net plot.

Table 4.10: Average Leaf area plant^{-1} of soybean as influenced by different treatments.

Date of sowing	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
D1- 25th SMW	39.0	66.1	171.8	241.1	314.4	265.1	147.3	54.4
D2- 26th SMW	38.1	65.1	170.9	239.0	310.3	262.8	146.1	50.7
D3-27th SMW	34.7	59.8	160.3	228.0	298.3	239.9	133.2	48.3
D4-28th SMW	31.0	54.0	151.6	213.8	277.0	216.6	113.1	29.3
S.E. m±	0.89	2.03	1.78	1.87	2.23	0.66	2.14	1.00
C.D. @ 5%	3.07	7.04	6.16	6.46	7.73	2.28	7.42	3.66
Variety								
V1- MAUS-158	37.4	64.8	166.3	233.0	305.5	250.8	138.3	51.0
V2- MAUS-71	36.1	63.1	164.7	234.3	303.4	248.9	136.4	48.9
V3-JS-335	33.7	55.9	160.0	224.2	291.2	238.5	130.1	37.2
S.E. m±	0.81	1.89	1.61	1.65	1.96	0.49	1.92	1.00
C.D. @ 5%	2.42	5.68	4.84	4.95	5.89	1.45	5.76	2.96
Interaction (D × V)								
S.E. m±	1.61	3.79	3.23	3.30	3.93	0.97	3.84	1.9
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	35.7	61.3	163.6	230.5	300.0	246.1	134.9	45.7

This data was collected from 15 DAS at 15 days interval up to 105 DAS and at harvest as shown in table 4.10 and illustrated in fig. 4.12 and fig. 4.13 to find the impact of different sowing dates and varieties on leaf area by measuring the height of crop in cm^{-2}. According to data, it was found that the leaf area of soybean crop gradually increases from 15 DAS till 75 DAS ($300cm^2$) and then decrease gradually becomes 45.7 cm^2 at harvest stage and geometric mean leaf area at 15 days

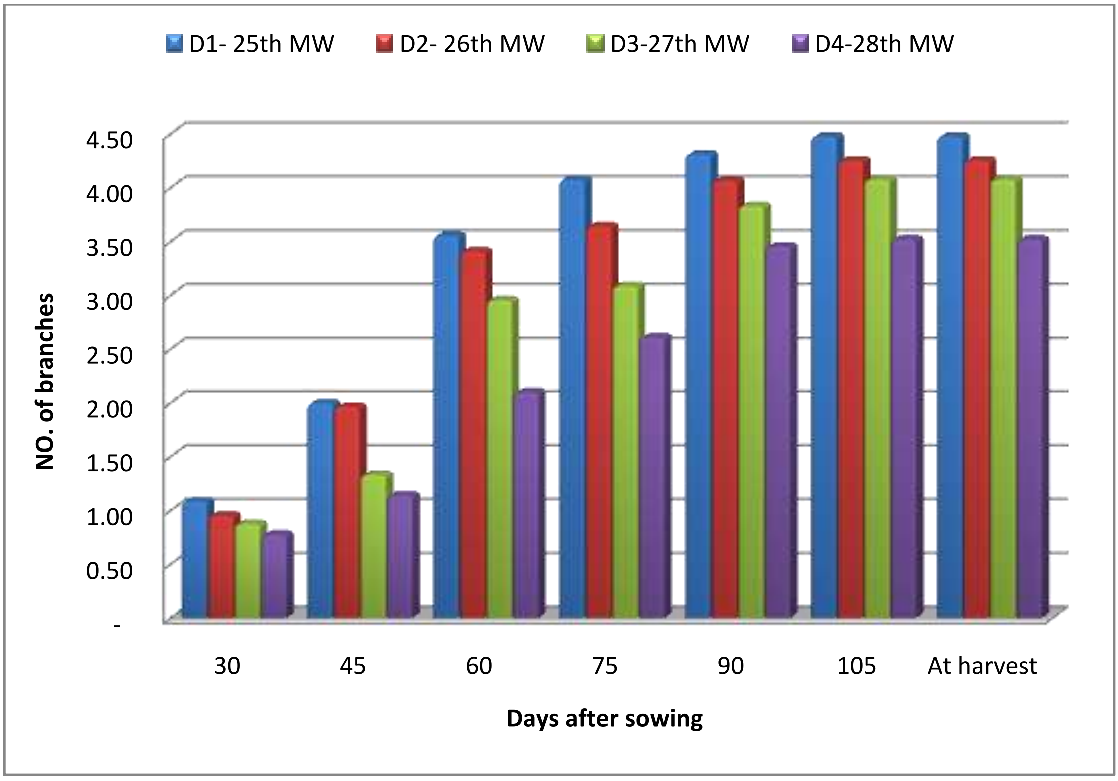

Fig 4.10: Mean no. of branches as influenced by different dates of sowing.

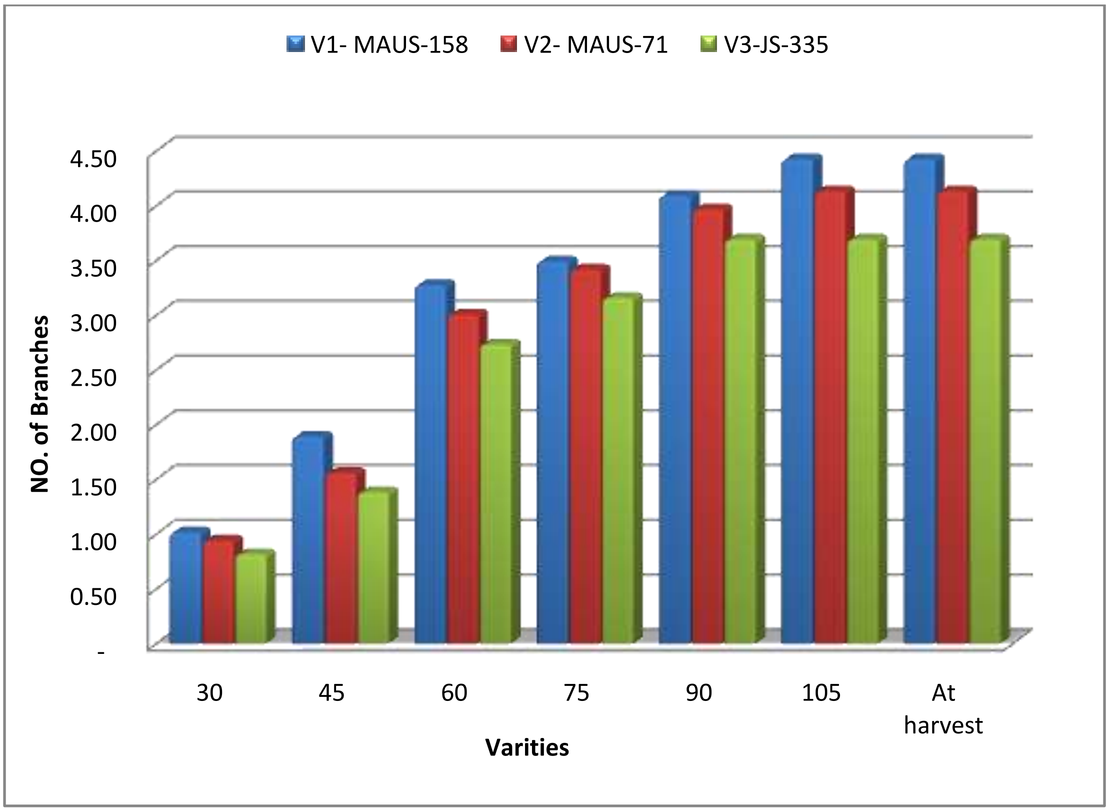

Fig 4.11: Mean no. of branches as influenced by different varieties.

interval from 15 DAS till harvest was 35.7, 61.3, 163.6, 230.5, 300.0, 246.1, 134.9 and 45.7 cm^{-2}.

4.4.3.1. Effect of sowing dates

The leaf area data was then taking for statistical analysis to determine the effect of sowing dates on leaf area. According to data from Table 4.10 and Fig. 4.12 it was found that D_1 has the maximum leaf area of 314.4 cm^{-2}, followed by D_2 of 310.3 cm^{-2}, D_3 of 298.3 cm^{-2} and D4 of 277.0 cm^{-2} at 75 DAS respectively. As a result, the varied dates of sowing were found to have statistically significant effects on leaf area, with the early sowed crop (D_1) growing with maximum canopy than the late sowed crops (D_4) and showed significantly at par with (D_2). This is due to the fact that the early sowed crop received good rainfall and optimum moisture to aid in the crop's growth and development. This similar result was reported by Gitelson *et al*. (2014) that the leaf area was significantly influenced due to delay in sowing dates and maximum leaf area was observed in early sowing dates and decreases in late sowing dates.

4.4.3.2. Effect of varieties

The leaf area was statistically significant from 15 DAS till harvest, among different treatments of varieties, V_1- MAUS-158 (305.5 cm^{-2}) was found to be the maximum than V_2- MAUS-71 (303.4 cm^{-2}) and V_3- JS-335 (291.2 cm^{-2}).

4.4.3.3. Interaction effect

The interaction effect of different dates of sowing and varieties during crop growth period was nonsignificant with leaf area.

4.4.4 Mean NDVI per plant

The data as shown in Table 4.11 and depicted Fig.4.14 and 4.15 was taken 15 days after sowing at intervals of 15-days up to harvest. After sowing, and at harvest to determine the impact of different sowing dates and varieties on NDVI per plant by measuring spectral wave length of each plant from 5 observational plants from each net plot.

Table 4.11: Average NDVI plant^{-1} of soybean as influenced by different treatments.

Treatments	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
Date of sowing								
D1- 25th SMW	0.21	0.30	0.58	0.67	0.75	0.84	0.54	0.34
D2- 26th SMW	0.21	0.28	0.57	0.66	0.73	0.83	0.53	0.33
D3-27th SMW	0.14	0.20	0.45	0.56	0.65	0.76	0.45	0.23
D4-28th SMW	0.10	0.17	0.33	0.43	0.55	0.61	0.38	0.21
S.E. m±	0.04	0.02	0.02	0.01	0.02	0.03	0.02	0.01
C.D. @ 5%	0.01	0.01	0.05	0.04	0.07	0.11	0.05	0.02
Variety								
V1- MAUS-158	0.18	0.26	0.52	0.61	0.70	0.80	0.51	0.30
V2- MAUS-71	0.16	0.23	0.48	0.59	0.68	0.77	0.48	0.28
V3-JS-335	0.15	0.22	0.44	0.55	0.63	0.70	0.44	0.26
S.E. m±	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.01
C.D. @ 5%	0.01	0.01	0.03	0.03	0.05	0.07	0.04	0.02
Interaction (D × V)								
S.E. m±	0.04	0.04	0.02	0.02	0.03	0.05	0.03	0.01
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	0.17	0.24	0.48	0.58	0.67	0.76	0.48	0.28

4.4.4.1. Effect of sowing dates

The NDVI data was then took for statistical analysis to determine the effect of sowing dates on NDVI. According to data from table 4.11 and fig. 4.14 it was found that D_1 has the maximum NDVI of 0.84, followed by D_2 of 0.83, D_3 of 0.76 and D4 of 0.61, at 90 DAS respectively. As a result, the varied dates of sowing were found to have statistically significant effects on NDVI, with the early sowed crop (D_1) growing with maximum canopy than the late sowed crops (D_4). This similar result was reported by Gitelson *et al*. (2014) that the NDVI was significantly influenced due to delay in sowing dates and maximum NDVI was observed in early sowing dates and decreases in late sowing dates.

4.4.4.2. Effect of varieties

The NDVI was statistically significant from 15 DAS till harvest, among different treatments of varieties, V_1- MAUS-158 (0.78) was found to be the maximum than V_2- MAUS-71 (0.77) and V_3- JS-335 (0.70).

4.4.4.3. Interaction effect

The interaction effect of different dates of sowing and varieties during crop growth period was nonsignificant with NDVI.

4.4.5 Mean number of Pods per plant

The data as shown in Table 4.12 and depicted Fig.4.16 and 4.17, was taken 60 days after sowing at intervals of 15-days up to harvest. According to data, the number of pods of soybean crop continuously grows from 60 DAS till harvest.

Table 4.12: Average number of pods plant^{-1} of soybean as influenced by different treatments.

Treatments	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
Date of sowing					
D1- 25th SMW	12.1	23.4	29.1	31.5	31.5
D2- 26th SMW	11.9	22.4	27.3	30.4	30.4
D3-27th SMW	9.82	18.6	20.8	25.3	25.3
D4-28th SMW	6.23	12.8	16.0	17.2	17.2
S.E. m±	0.37	0.81	1.02	0.92	0.92
C.D. @ 5%	1.28	2.78	3.52	3.20	3.20
Varieties					
V_1- MAUS-158	11.3	20.4	24.8	28.3	28.3
V_2- MAUS-71	10.3	19.5	23.2	26.3	26.3
V_3-JS-335	8.45	17.9	21.9	23.8	23.8
S.E. m±	0.27	0.48	0.56	0.66	0.66
C.D. @ 5%	0.82	1.44	1.69	1.99	1.99
Interaction (D × V)					
S.E. m±	0.55	0.96	1.13	1.33	1.33
C.D. @ 5%	NS	NS	NS	NS	NS
G.M.	10.0	19.3	23.3	26.1	26.1

From 60 DAS to harvest, the geometric mean number of pods per plant was 10, 19.3, 23.3 and 26.1 with the mean maximum number of bolls at harvest was the highest (i.e., 26.1).

4.4.5.1 Effect of sowing dates

According to data from Table 4.12 and Fig. 4.16 D_1 had the maximum number of pods per plant which was 31.5 followed by D_2 which was 30.4, D_3 which was 25.3 and D_4 which was 17.2. As a result, varied dates of sowing were found to have statistically significant effects on number of Pods per plant, with D_1 attained most pods per plant while late sowed crops (D_4) attained least while D_1 shows significantly at par with D_2. This is due to the fact that late sowed crop received less rain and dry weather during the flowering stage and pod formation stages, that results in flower drop and less number in pod formation. Jaybhaye *et al.* (2015) reported crop sown on 25th SMW gave significantly highest number of pods and yield of soybean.

4.4.5.2 Effect of varieties

Different varieties had a significant impact on mean number of pods per plant from 60 Days after sowing to harvest. Among different treatments of varieties V_1, i.e., MAUS-158 was found to attain more pods (28.3) during crop growth period compare to other varieties, V_2, i.e., MAUS-71 (26.3) and V_3, i.e., JS-335 (23.8).

4.4.5.3 Interaction

The interaction effects of different dates of sowing and varieties during crop growth period was nonsignificant with mean number of pods per plant**.**

4.4.6 Mean dry matter accumulation per plant (g)

The recorded data on mean total dry matter content per plant grew gradually at all growth phases of the soybean crop, as shown in Table 4.13 and illustrated in Fig. 4.18 and 4.19. The rate of increase in total dry matter accumulation was gradual from seedling to pod formation stage and then quickly increased between pod formation and dough stage it was the peak at the phase of flowering, pod formation, and pod development, the average total dry matter production per plant was 23.3g.

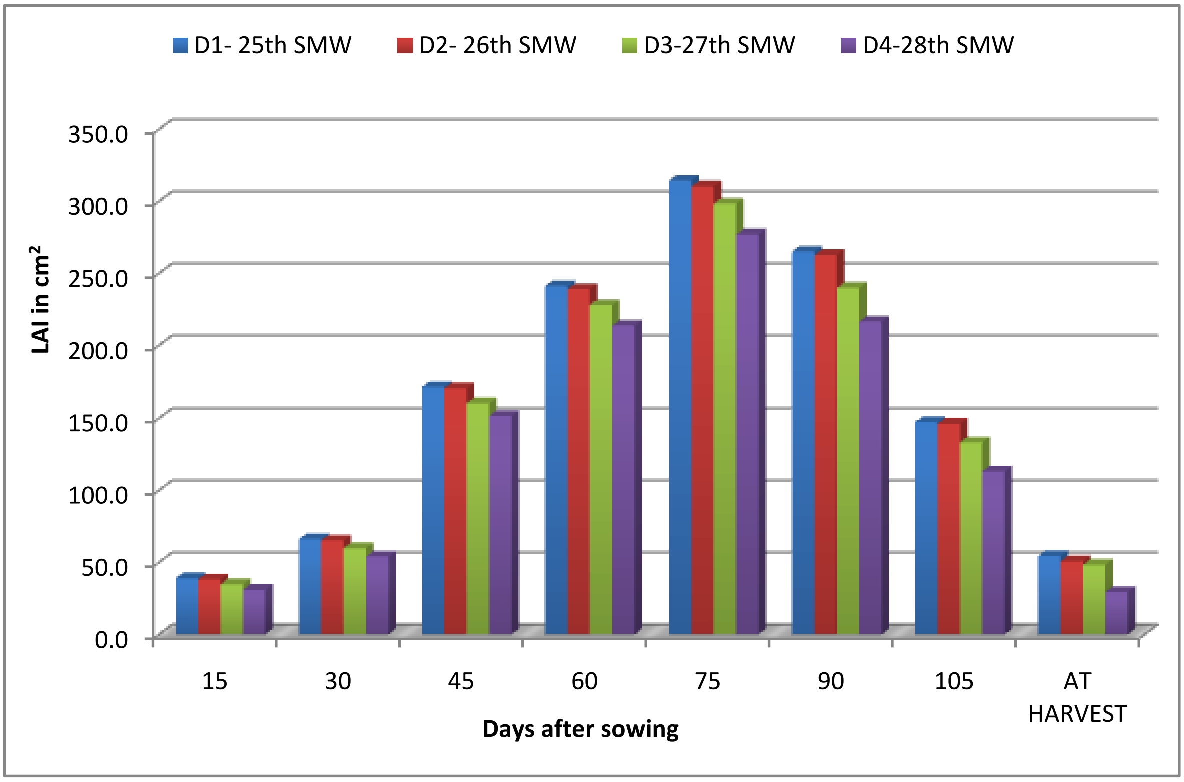

Fig 4.12: Mean Leaf area as influenced by different dates of sowing.

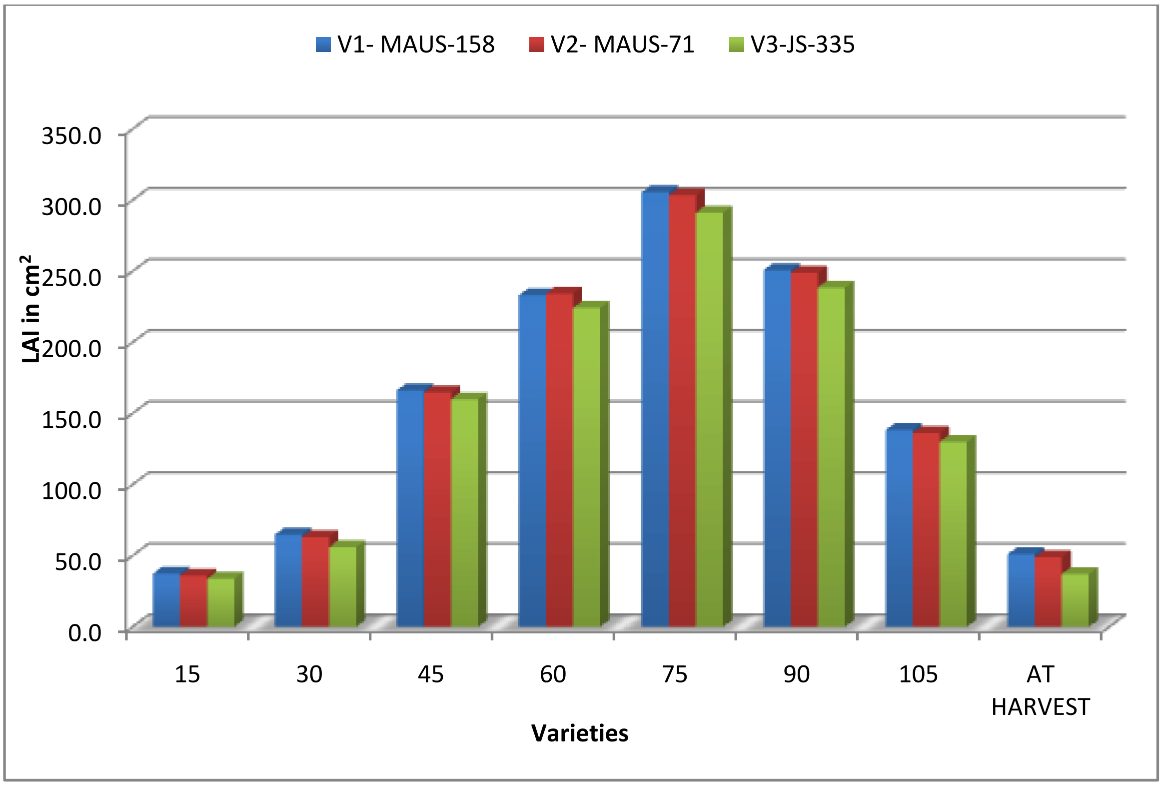

Fig 4.13: Mean leaf area as influenced by different varieties.

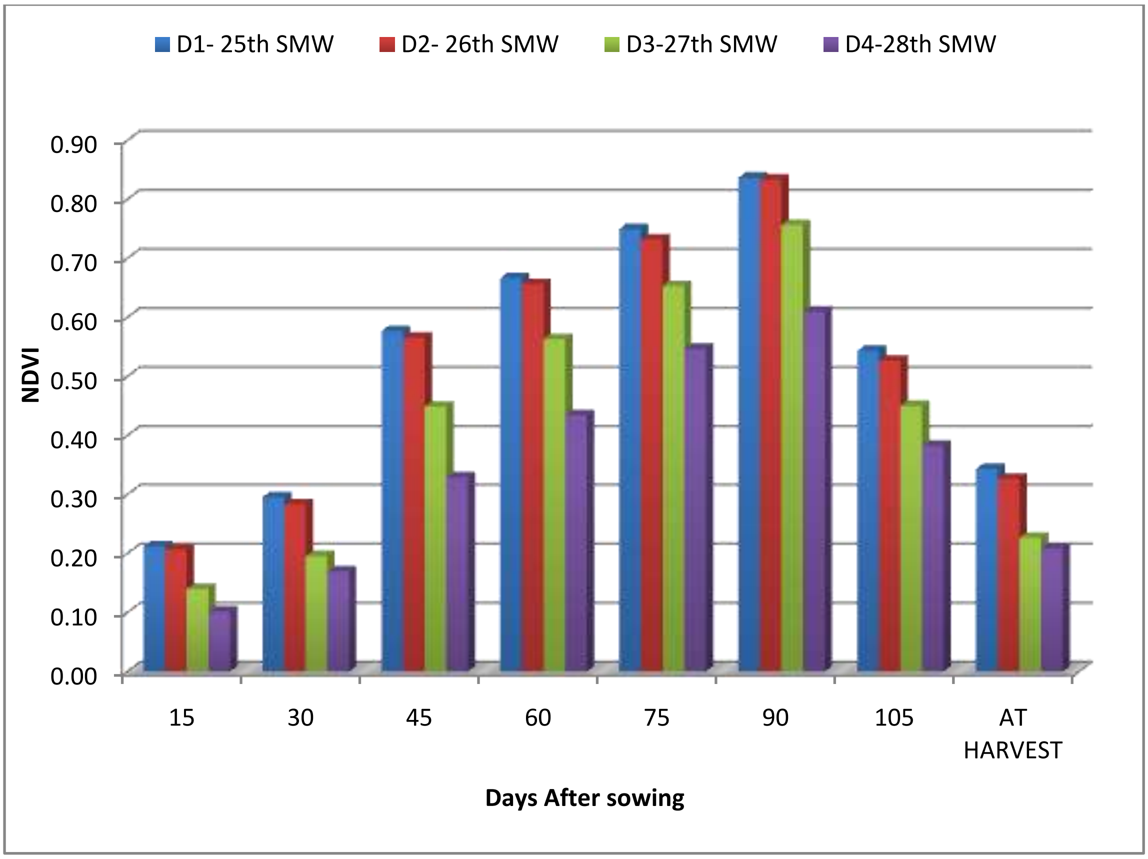

Fig 4.14: Mean NDVI as influenced by different dates of sowing.

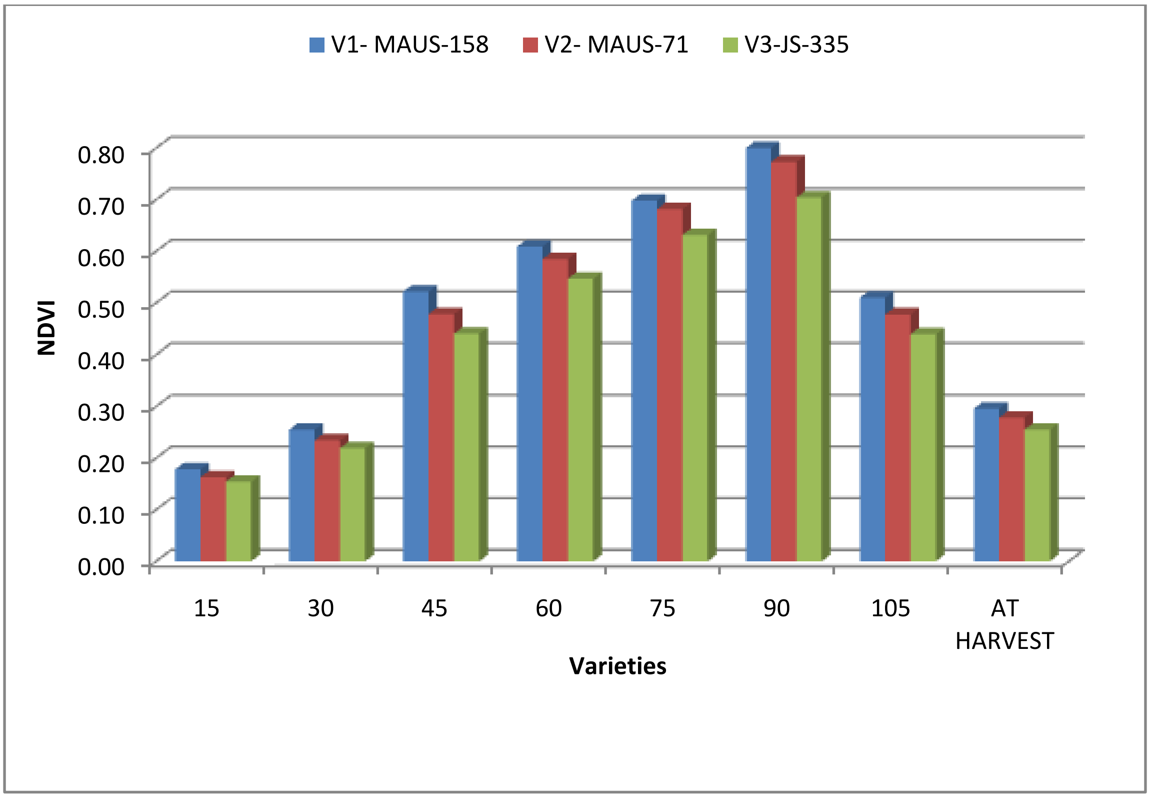

Fig 4.15: Mean NDVI as influenced by different varieties.

Table 4.13: Mean dry matter (g) plant^{-1} of soybean as influenced by different treatments.

Treatments	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At Harvest
Date of sowing								
D1- 25th MW	1.40	5.10	16.0	19.8	21.2	24.6	26.5	26.5
D2- 26th MW	1.20	4.86	15.6	18.8	20.5	24.0	25.7	25.7
D3-27th MW	1.19	4.54	13.4	15.1	17.1	20.1	22.1	22.1
D4-28th MW	0.98	4.01	12.2	13.2	14.3	17.1	18.8	18.8
S.E. m±	0.08	0.20	0.38	0.54	0.64	0.66	0.67	0.67
C.D. @ 5%	NS	0.68	1.31	1.71	1.9	2.02	2.15	2.15
Varieties								
V1- MAUS-158	1.32	4.89	15.0	17.8	19.3	22.9	24.4	24.4
V2- MAUS-71	1.14	4.68	14.5	16.9	18.5	21.6	23.6	23.6
V3-JS-335	1.12	4.31	13.5	15.4	17.0	19.9	21.8	21.8
S.E. m±	0.06	0.15	0.38	0.44	0.45	0.47	0.51	0.51
C.D. @ 5%	NS	0.44	1.13	1.2	1.13	1.34	1.62	1.62
Interaction (D × V)								
S.E. m±	0.12	0.29	0.75	0.85	0.74	0.85	1.12	1.12
C.D. @ 5%	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	1.19	4.63	14.3	16.7	18.3	21.5	23.3	23.3

4.4.6.1 Effect of sowing dates

At all growth stages, sowing dates had a significant impact on total dry matter production per plant. The early sowing, D_1 had the largest mean total dry matter accumulation (26.5 g/plant), whereas the D_4 sowing had the lowest (18.8 g/plant). Where D_1 and D_2 were significantly at par with each other. It could be because delayed sowing (D_3 and D_4) provides low soil moisture to the crop during flowering and pod formation stages than early sowing (D_1 and D_2). These findings support those of Ram *et.al.* (2010), who found that early sowings produced much more dry matter than late sowings due to a lower availability of soil moisture, relative humidity, and high temperature, all of which reduce dry matter accumulation.

4.4.6.2 Effect of Varieties

Table 4.13 shows that varieties had a significant impact on mean total dry matter production per plant at all growth stages, with V_1- MAUS-158 (24.4 g/plant) producing much more and pods per plant than V_2- MAUS-71 (23.6 g/plant) and V_3- JS-335 (21.8 g/plant).

4.4.6.3 Interaction

The interaction of different sowing dates and verities had no significant effect on the mean dry matter accumulation per plant (g).

4.4.7 Number of days required to 50% flowering, 50% Pod formation, and maturity

The results on the average number of days necessary for soybean to attain 50% flower, 50% pod formation, and maturity as a result of various treatments are summarized in Table 4.14.

Table 4.14: Days required to 50% flowering, Days required to 50% Pod formation, Days required to maturity.

Treatments	Days required to 50% flowering	Days required to 50% Pod formation	Days required to maturity
Date of sowing			
D_1- 25th SMW	46.4	55.9	105.8
D_2- 26th SMW	44.7	54.2	105.1
D_3-27th SMW	40.4	52.8	97.1
D_4-28th SMW	34.8	49.9	93.8
S.E. m±	1.14	1.16	0.94
C.D. @ 5%	3.95	4.02	3.25
Varieties			
V_1- MAUS-158	44.3	54.8	102.7
V_2- MAUS-71	41.8	53.5	100.8
V_3-JS-335	38.7	51.3	97.9
S.E. m±	0.93	0.89	0.80
C.D. @ 5%	2.78	2.68	2.39
Interaction (D ×V)			
S.E. m±	1.85	1.79	1.59
C.D. @ 5%	NS	NS	NS
G.M.	41.6	53.2	100.4

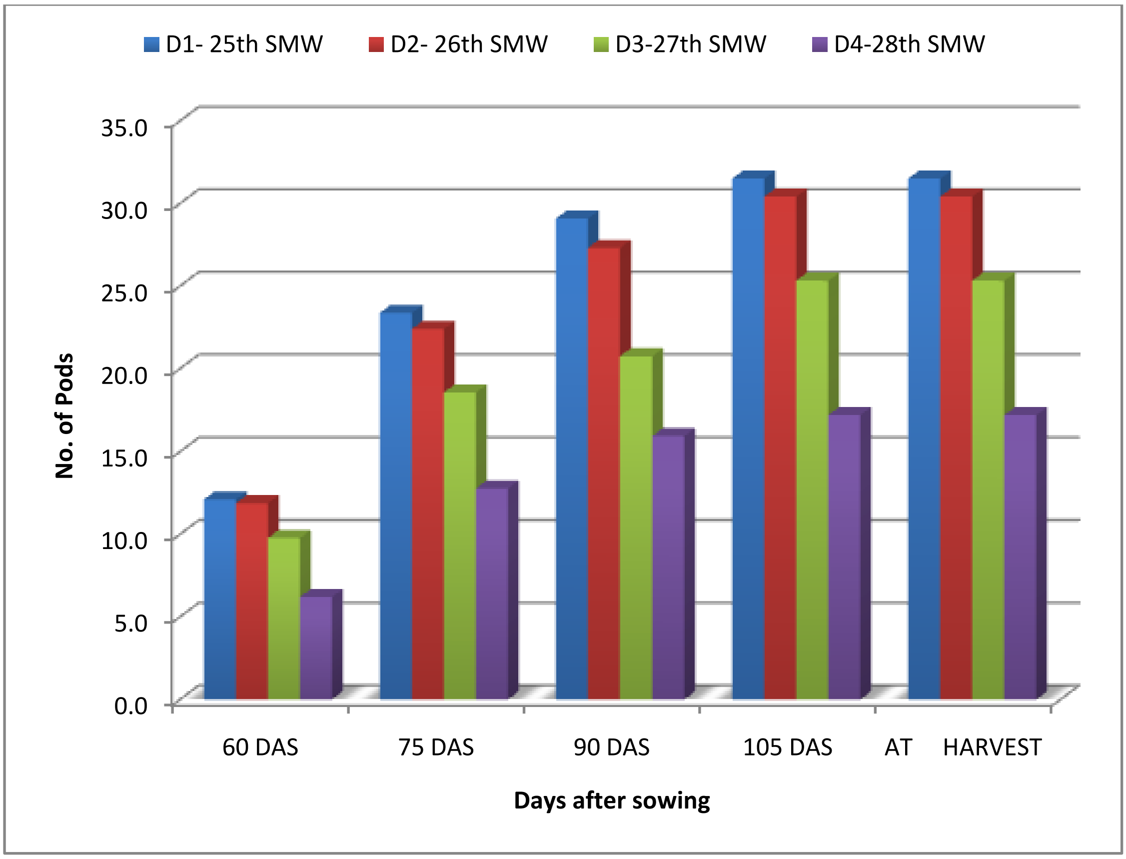

Fig 4.16: Mean No. of Pods as influenced by different dates of sowing.

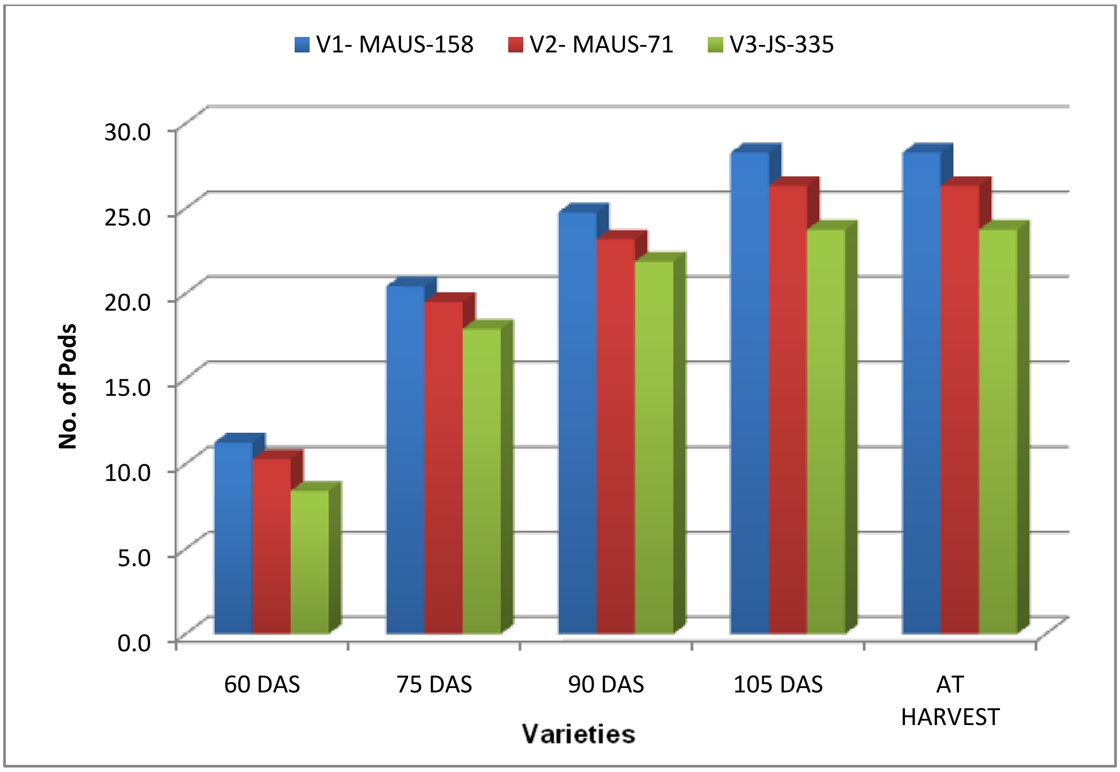

Fig 4.17: Mean No. of Pods as influenced by different varieties.

4.4.7.1 Effect of sowing dates

The average number days took to attain 50% flowering varied from each other with respect to treatments. D_1 took 46.4 and D_2 took 44.7 days, D_3 took 40.4 days and D_4 took 34.8. The average days took to attain 50% pod formation varied from each other with respect to treatments. D_1 took 55.9 and D_2 took 54.2 days, D_3 took 52.8 days and D_4 took 49.9 and the average days took to attain maturity varied from each other with respect to treatments. D_1 took 105.8 and D_2 took 105.1 days, D_3 took 97.1 days and D_4 took 93.8. Yagoub *et al.* (2013) recorded similar results that delayed sowing crops will attain early flowering, pods and maturity than early sowing one.

4.4.7.2 Effect of varieties

The average number of days taken by different varieties for the 50% flowering, 50% Pod formation and maturity were, V_1 (MAUS-158) took 44.3, 54.8, and 102.7 days respectively, V_2 (MAUS-71) took 41.8, 53.5 and 100.8 respectively and V_3 (JS-335) took 38.7, 51.3 and 97.9 respectively and to as shown in table 4.14. is found that V_1 (MAUS-158) took maximum days to attained the 50% flowering, 50% Pod formation and maturity followed by V_2 (MAUS-71) and which is the highest number of days necessary for flowering while V_2 (MAUS-71) and V_3 (JS-335).

4.4.7.3 Interaction

The interaction of different sowing dates and varieties had no significant effect on the mean number of days required for 50% flowering, 50% pod formation and maturity.

4.5 Post-harvest studies

These studies discuss that after harvest of the crop to record the data that are relevant to yield attributing characters like mean weight of seeds, pods per plant (gm plant^{-1}) and test weight (gm). This data was presented in Table 4.15 and seed yield (kg/ha), straw yield (kg/ha), biological yield (kg/ha) and Harvest index (in percent).

4.5.1 Mean weight of seeds, pods per plant (g plant^{-1}) and test weight (g)

The weights of seeds per plant, pods per plant, and test weight of soybean yield recorded in gram per plant was presented in Table 4.15. with grand mean of 3.65, 6.24 and 110.1 g per plant respectively.

Table 4.15: Mean weight of seeds (g plant^{-1}), the weight of pods (g plant^{-1}), and test weight (g) as influenced by different treatments

Treatments	Weight of seeds plant^{-1}	Weight of pods plant plant^{-1}	Test weight
Date of sowing			
D_1- 25th SMW	4.57	7.37	119.7
D_2- 26th SMW	4.36	7.04	118.4
D_3-27th SMW	3.27	5.92	106.3
D_4-28th SMW	2.43	4.63	95.8
S.E. m±	0.14	0.24	2.22
C.D. @ 5%	0.47	0.83	7.68
Varieties			
V_1- MAUS-158	4.08	6.56	113.3
V_2- MAUS-71	3.63	6.30	111.9
V_3-JS-335	3.25	5.9	104.9
S.E. m±	0.08	0.09	1.98
C.D. @ 5%	0.23	0.28	5.94
Interaction (D ×V)			
S.E. m±	0.15	0.18	3.96
C.D. @ 5%	NS	NS	NS
G.M.	3.65	6.24	110.1

4.5.1.1 Effect of sowing dates

There are significant effects between different sowing dates and seed weight of seeds per plant, weight of pods per plant, and test weight. Where the maximum weight of seeds, pods weight per plant and test weight were recorded in D_1 (25th MW) with weight of 4.57, 7.37, g/plant 119.7 g/1000 seeds respectively than those sown on D_2 (26th MW) with weight of 4.36, 7.04 g/plant and 118.4 g/1000 seeds respectively, D_3 (27th MW) with weight of 3.27, 5.92 gm/plant and 106.3 g/1000 seeds and D_4 (28th MW) with weight of 2.43, 4.63 g/plant and 95.8 g/plant g/1000 seeds. Where both D_1 & D_2 showed significantly at par to each another. Jaybhaye *et al.* (2015) and Nath *et.al.* (2017) reported that the earlier sowing crops produce higher seed weight of seeds per plant, weight of pods per plant and test weight because more radiation and

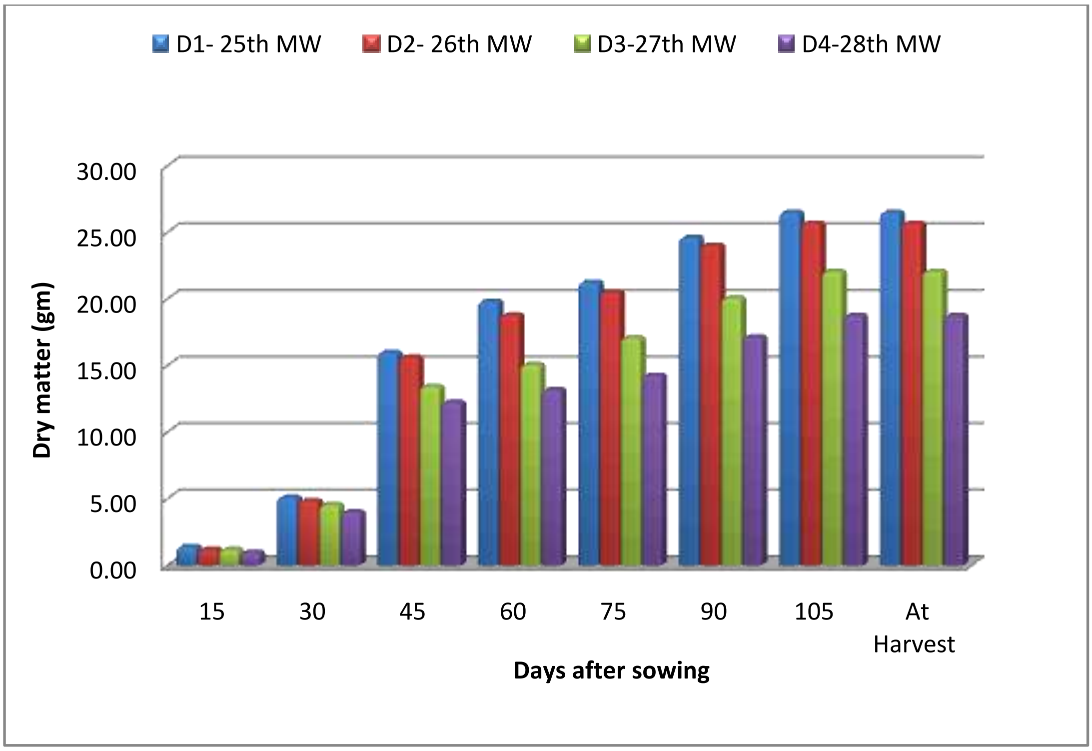

Fig 4.18: Mean Dry matter as influenced by different dates of sowing.

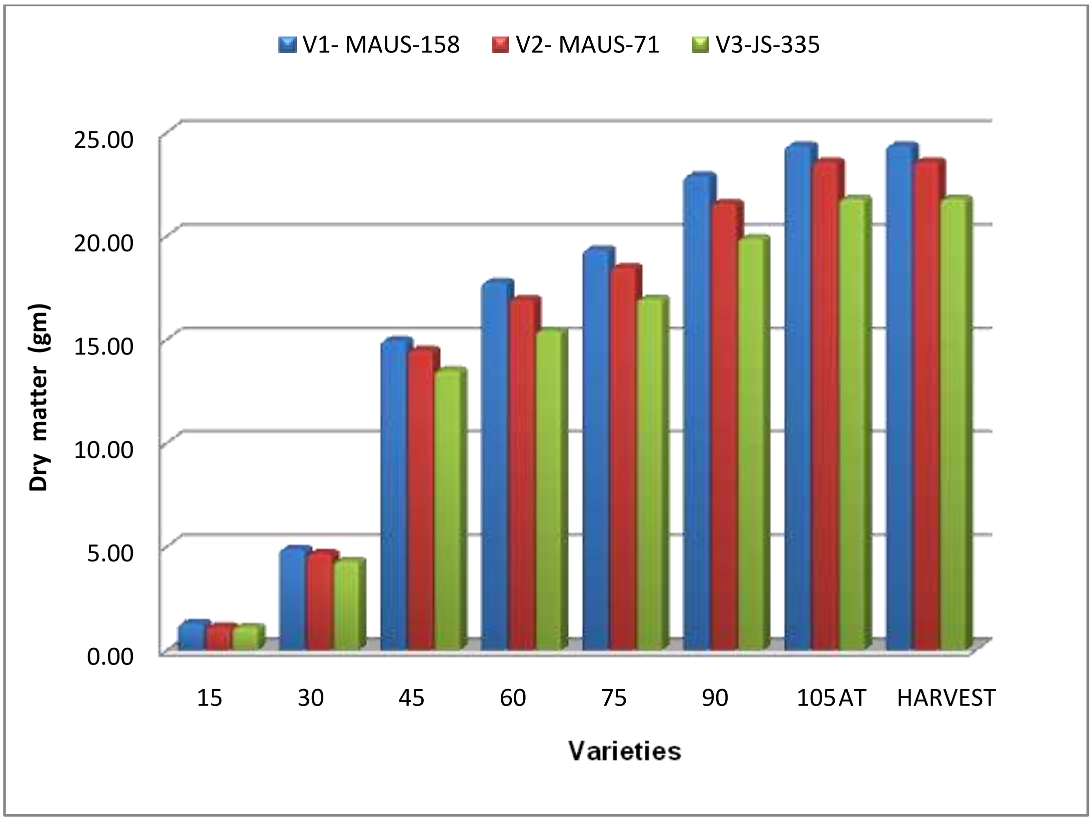

Fig 4.19: Mean Dry matter as influenced by different varieties.

heat resources were obtained for the earlier sowing dates to attain a greater number of seeds and pods.

4.5.1.2 Effect of varieties

Different varieties have significant effects on seed, pod per plant and test weight (g/plant) where among variety, V_1 (MAUS-158) have a maximum seed, pod per plant and test weight of 4.08, 6.56 g/plant and113.3 g/1000 seeds than those of V_2 (MAUS-71) with weight of 3.63, 6.30 gm/plant and 111.9 g/1000 seeds and V_3 (JS-335) weight of 3.25, 5.9 g/plant and 104.9 g/1000 seeds.

4.5.1.3 Interaction

The interaction between different sowing dates and varieties had no significant effect on seed, pod weight per plant and test weight.

4.5.2 Seed yield (kg ha^{-1})

The soybean seed yield recorded in kg per hector was presented in Table 4.16 with average weight of seed yield of 1446.4 kg per ha. Which is illustrated in Fig. 4.20 and Fig. 4.21.

4.5.2.1 Effect of sowing dates

There is significant effect between different sowing dates and seed yield in kg per ha where the maximum seed yield was recorded on D_1 (25^{th} SMW) with yield of 1852 kg/ha than those sown on D_2 (26^{th} SMW) with yield of 1758.6 kg/ha, these two shows significantly at par to one another, While D_3 (27^{th} SMW) with yield of 1273.6 kg/ha and D_4 (28^{th} SMW) with yield of 900.7 kg/ha. The low yield is because of very high rain fall at early stages of late sowing crops, faced water logging situation that results in stunted growth and mortality of plants at early crop growth stages of D_3 and D_4. Sadeghi *et al.* (2013), Grassini *et.al.* (2015) and Jaybhaye *et al.* (2016) reported that the earlier sowing crop use more heat resources and optimum moisture was available which produced higher seed yield and biomass become maximum.

Table 4.16: Mean seed yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}), and harvest index (%) as influenced by various treatments.

Treatments	Seed yield Kg ha^{-1}	Straw yield Kg ha^{-1}	Biological yield Kg ha^{-1}	Harvest index %
Date of sowing				
D1- 25th MW	1852.8	4257.7	6110.5	43.5
D2- 26th MW	1758.6	4107.4	5865.9	42.8
D3-27th MW	1273.6	3445.0	4718.6	37.0
D4-28th MW	900.7	2781.0	3681.6	32.4
S.E. m±	60.0	109.3	155.2	-
C.D. @ 5%	207.5	378.3	537.0	-
Variety				
V1- MAUS-158	1636.5	3842.7	5479.2	42.6
V2- MAUS-71	1434.7	3731.6	5166.3	38.4
V3-JS-335	1268.1	3368.9	4637.0	37.6
S.E. m±	33.7	100.3	134.0	33.5
C.D. @ 5%	100.9	300.8	390.5	
Interaction (D × V)				
S.E. m±	67.3	200.7	260.5	-
C.D. @ 5%	NS	NS	NS	-
G.M.	1446.4	4047.8	5494.2	38.8

The yield in the year 2021 was lower as compared to the previous year in spite of growing on the same location, this might be due to the fact that the different weather conditions exposed by crop growth phenophases from last year but the first and second dates of sowing yield normally whereas in third and fourth dates of sowing over rainfall cause water logging situation during their early stages of crop leads to less germination and plant population, which could potentially cause direct yield losses. Average temperature of 24–30^{0}C was favored for growth and

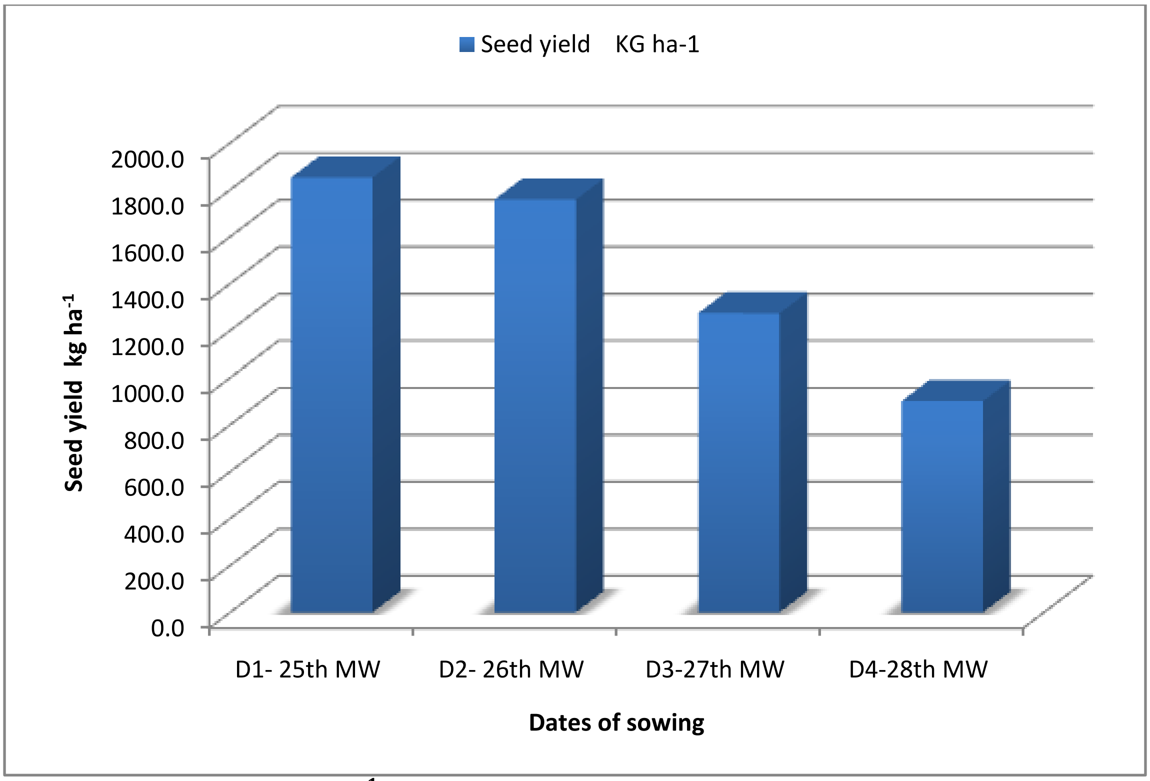

Fig 4.20: Seed yield (kg ha^{-1}) as influenced by different dates of sowing.

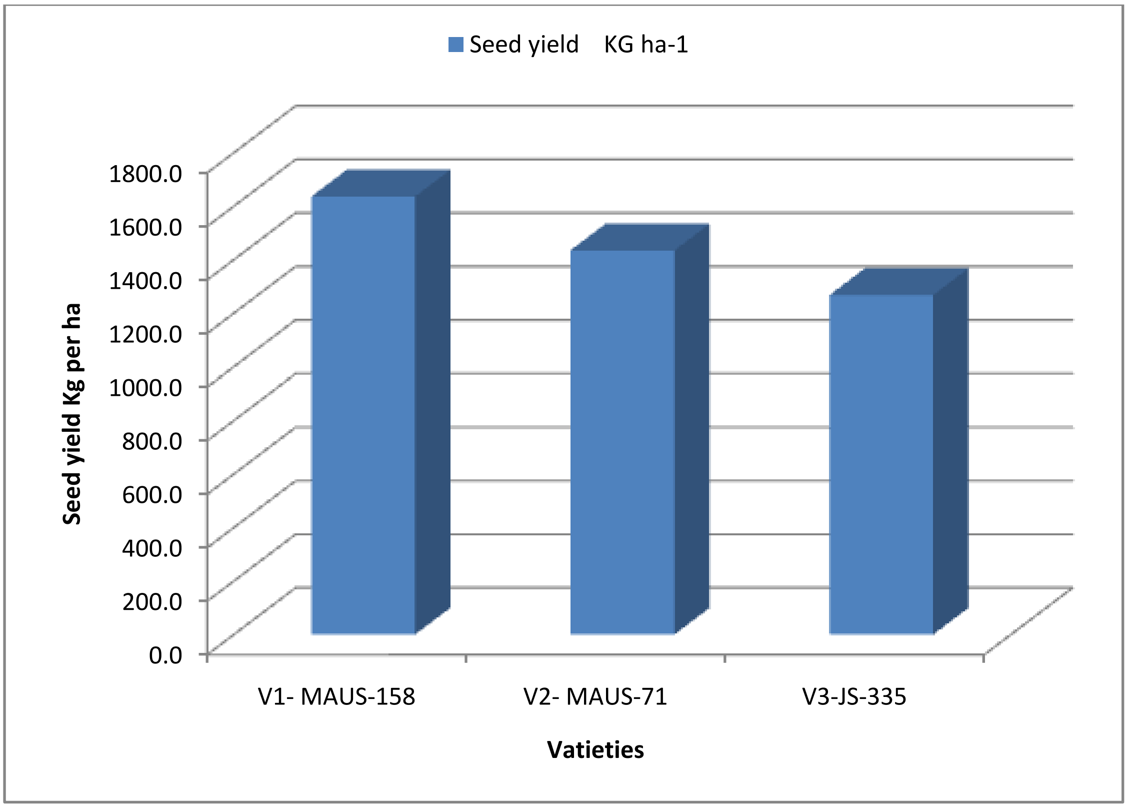

Fig 4.21: Seed yield (Kg per ha) as influenced by different varieties.

development of crop. The average relative humidity was ranges from 63 to 89 percent during *kharif* 2021 which leads to high insect pest infestation in vegetative stages of late sown soybean crop. An average evaporation rate of 3.6 mm/day during crop growing period shows less evaporation with average wind speed of 3.9 km/hrs.

4.5.2.2 Effect of varieties

Different varieties have a significant effect on seed yield (kg/ha) where among varieties, V_1 (MAUS-158) have a maximum seed yield of 1636.5 kg/ha than those of V_2 (MAUS-71) 1434.7 (kg/ha) and V_3 (JS-335) producing the minimum seed yield of 1268.1 (kg/ha).

4.5.2.3 Interaction

The interaction between different sowing dates and verities had no significant effect on seed yield in kg/ha.

4.5.3 Straw yield (kg/ha)

The straw yield recorded in kilogram per hectare was presented in Table 4.16 with average yield of 4047.8 kg per ha.

4.5.3.1 Effect of sowing dates

There is significant effects between different sowing dates and straw yield in kilogram per ha where the maximum straw yield was recorded on D_1 (25^{th} SMW) with yield of 4257.7 kg/ha than those sown on D_2 (26^{th} SMW) with yield of 4107.4 kg/ha, with significant at par to each other's. D_3 (27^{th} SMW) with yield of 3445 kg/ha and D_4 (28^{th} SMW) with yield of 2781 kg/ha. Norwal and Maik, (1986) also reported same results that a reduction in biological yield due to delayed planting.

4.5.3.2 Effect of varieties

Different varieties have a significant effect on straw yield (kg/ha) where among varieties, V_1 (MAUS-158) have a maximum seed yield of 3842.7 kg/ha than those of V_2 (MAUS-71) 3731.6 (kg/ha) and V_3 (JS-335) producing the minimum straw yield of 3368.9 (kg/ha).

4.5.3.3 Interaction

The interaction between different sowing dates and verities had no significant effect on straw yield in kg/ha.

4.5.4 Biological yield (kg/ha)

The Biological yield recorded in kilogram per hectare was presented in Table 4.16 with average yield 5494.2 kg/ha.

4.5.4.1 Effect of sowing dates

There is significant effect between different sowing dates and biological yield in Kg/ha, where the maximum biological yield was recorded on D_1 (25th SMW) with yield of 6110.5 kg/ha than those sown on D_2 (26th SMW) with yield of 5865.9 kg/ha, with significant at par to each other's. D_3 (27th SMW) with yield of 4718.6 kg/ha and D4 (28th SMW) with yield of 3681.6 kg/ha. The lack of complete canopy closure in late plantings could be attributed to less time being available for vegetative growth. Nagalamu (2012) was observed where later planted soybean required fewer total days to reach maturity. The fewer days for later sowing to reach maturity can be attributed to the shortening of day length throughout the growing season.

4.5.4.2 Effect of varieties

Different varieties have a significant effect on biological yield (kg/ha) where among varieties, V_1 (MAUS-158) have a maximum biological yield of 5479.2 kg/ha than those of V_2 (MAUS-71) 5166.3 (kg/ha) and V_3 (JS-335) producing the minimum biological yield of 4637 (kg/ha).

4.5.4.3 Interaction

The interaction between different sowing dates and verities had no significant effect on biological yield in kg/ha.

4.4.5 Harvest index (%)

The Harvest index recorded in per cent was presented with the average harvest index was 38.8 % recoded.

4.5.5.1 Effect of sowing dates

There is significant effect between different sowing dates and harvest index in per cent where the maximum harvest index was recorded on D_1 (25th SMW) with 43.6 % than those sown on D_2 (26th SMW) with 43.4 % both shows significant at par to each other's. D_3 (27th SMW) with 37.6 % and D_4 (28th SMW) with 32 %. Naidu *et al.* (2017) revealed that harvest index is affected by planting date. Early planting date results in higher harvest index which was contradictory with the present findings.

4.5.5.2 Effect of varieties

Different varieties have a significant effect on harvest index (percent) where among varieties, V_1 (MAUS-158) have a maximum harvest index of 42.6 % than those of V_2 (MAUS-71) 38.4 %t (kg/ha) and V_3 (JS-335) producing the minimum harvest index of 37.6 %.

4.5.5.3 Interaction

The interaction between different sowing dates and verities had no significant effect on harvest index %.

4.6 Thermal Indices

4.6.1 Growing degree days (GDD)

The data on GDD during each phenophase was recorded with the base temperature of 10^0C and presented on Table 4.17. According to the data, the general mean of accumulated GDD of different sowing dates from each phenophases (i.e., P1 to P10) of soybean crop was about 2704.8 ^{0}C day. Result showed that there was a significant effect between different sowing dates and Growing Degree Days of soybean at each phenophases where the early sown crop, D_1 (25^{th} SMW) have the maximum accumulated GDD of 2822.6 ^{0}C day than D_2 (26^{th} SMW) of 2741.6 ^{0}C day, D_3 (27^{th} SMW) of 2699.8 ^{0}C day with the least accumulated GDD by late sown crop D_4 (28^{th} SMW) of 2555.5 ^{0}C day which showed a decreasing trend from D_1 to D_4. Singh *et al.* (2007) reported similar results that early sowing crops have maximum no of degree days than late sowing.

4.6.2 Helio-thermal unit (HTU)

The Helio-thermal unit (HTU) of the crop was mainly dependent on the bright sunshine hours and GDD of the crop. This data was calculated for each phenophases of different sowing dates and presented in Table 4.18. It showed that there is significant effect between different dates of sowing and Helio-thermal unit of soybean where the maximum HTU for total crop life cycle was recorded during first date of sowing, D_1 (25^{th} SMW) of 14,741 ^{0}C day hrs, followed by D_2 (26^{th} SMW) with value of 13,186 ^{0}C day hrs, then comes the D_3 (27^{th} SMW) of 12,722 ^{0}C day hrs and the least HTU was recorded during D_4 (28^{th} SMW) of 12,268 ^{0}C day hrs. The value of HTU of D_1 was highest. However, due to much bright sunshine hours received during the growth period than of the D_2, D_3 and D_4. Narwal *et al.* (1986) also got maximum HTU in early sowing crops than latter.

4.6.3 Photo thermal unit (PTU)

This data on Photo Thermal Unit was calculated using GDD and the length of the day (12 hrs) to determine the heat energy used by crop during the day which was presented in table 4.19. Results revealed that the different sowing dates has a significant effect on photo thermal Unit of soybean at each phenophases, where the early sown crop, D_1 (25^{th} SMW) have the maximum total PTU of 33871.0^{0}C day hrs than D_2 (26^{th} SMW) of 33,289 ^{0}C day hrs, D3 (27^{th} SMW) of 32,398 ^{0}C day hrs with the least accumulated GDD by late sown crop D_4 (28^{th} SMW) of 31,565 ^{0}C day hrs which showed a decreasing trend from D_1 to D_4. Suryakala *et al.* (2020) also observed highest PTU in early sowing chickpea crop than delayed one.

4.6.4 Heat use efficiency (HUE)

The Heat Use Efficiency of soybean estimated using seed yield and accumulated GDD of particular date of sowing and observed that D_1 (25^{th} SMW) has highest HUE with the value of 0.66 Kg/ha degree days^{-1} slightly more than D_2, with the value of 0.64, while D3 and D_4 has lowest of 0.47 and 0.35 Kg/ha degree days^{-1} respectively, due to early sown crops took a greater number of days to complete life cycle compared to late sown. This shows similar with results with Devi *et al*. 2019. The data illustrated in table 4.20.

Table 4.20 Heat use efficiency of different sowing dates of soybean during *Kharif* season 2021

Sr. No.	Particular	D_1 (25^{th} SMW)	D_2 (26^{th} SMW)	D_3 (27^{th} SMW)	D_4 (28^{th} SMW)
	Yield (Kg/ha)	1852.8	1758.6	1273.6	900.7
	Phenophase	**GDD (ºC day)**			
1	Emergence stage	122.4	102.4	103.8	145.1
2	Seedling stage	411.9	425.8	355.4	301.3
3	Branching stage	278.5	301.3	249.5	173.9
4	Flowering stage	195.3	228.5	178.6	268.0
5	Pod formation stage	119.3	130.0	157.7	87.5
6	Grain formation stage	322.6	195.2	218.6	306.4
7	Pod development stage	379.1	484.3	305.5	403.6
8	Pod containing full-size grain	428.3	413.0	410.3	353.7
9	Dough stage	201.6	196.6	272.5	266.3
10	Maturity stage	363.8	264.8	448.1	249.9
Accumulated GDD (ºC day)		**2822.6**	**2741.6**	**2699.8**	**2555.5**
HUE (Kg/ha/ºC degree day)		**0.66**	**0.64**	**0.47**	**0.35**

Table 4.17 Phenophase wise GDD required for different sowing dates of soybean during *Kharif* season 2021.

Date of Sowing	Phenophases										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	TOTAL
D_1	122.4	411.9	278.5	195.3	119.3	322.6	379.1	428.3	201.6	363.8	**2822.6**
D_2	102.4	425.8	301.3	228.5	130.0	195.2	484.3	413.0	196.6	264.8	**2741.6**
D_3	103.8	355.4	249.5	178.6	157.7	218.6	305.5	410.3	272.5	448.1	**2699.8**
D_4	145.1	301.3	173.9	268.0	87.5	306.4	403.6	353.7	266.3	249.9	**2555.5**
MEAN	**118.4**	**373.6**	**250.8**	**217.6**	**123.6**	**260.7**	**393.1**	**401.3**	**234.2**	**331.6**	**2704.8**

Table 4.18 Phenophase wise HTU required for different sowing dates of soybean during *Kharif* season 2021

Date of Sowing	Phenophases										TOTAL
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
D_1	783	2095	1413	776	829	1145	2121	2583	912	2084	**14741**
D_2	604	1785	1567	731	676	800	2019	2323	769	1912	**13186**
D_3	585	1677	1498	714	815	781	1911	2223	703	1855	**12762**
D_4	501	1567	1472	687	729	750	1885	2171	684	1822	**12268**
MEAN	**618**	**1781**	**1488**	**727**	**762**	**869**	**1984**	**2325**	**767**	**1918**	**13239**

Table 4.19 Phenophase wise PTU required for different sowing dates of soybean during *Kharif* season 2021

Date of Sowing	Phenophases										
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	TOTAL
D_1	1468	4942	3341	2344	1431	3871	4549	5140	2419	4365	**33871**
D_2	1348	4729	3235	2261	1380	3762	4431	5076	2379	4298	**32899**
D_3	1246	4265	2994	2143	1892	2623	3665	4923	3270	5377	**32398**
D_4	1141	3615	2886	3216	1749	2277	3443	4844	3196	5199	**31565**
MEAN	**1301**	**4388**	**3114**	**2491**	**1613**	**3133**	**4022**	**4996**	**2816**	**4810**	**32683**

D_1-25th SMW, D_2- 26th SMW, D_3-27^{h} SMW, D_4- 28th SMW

4.7 Correlation studies between weather parameters and soybean seed yield.

The correlation study was done to find the relationship between two variables, i.e., seed yield different of soybean varieties and Weather Parameter at different phenological stage. It is presented in Table 4.21, 4.22 and 4.23.

4.7.1 Variety MAUS-158 (V_1)

According to data from Table 4.21, it was found that during sowing to emergence stage (P1), maximum temperature (0.705), evaporation (0.788), BSS (0.645) and wind speed (0.899) were positively significance, whereas, rainfall (-0.811), RH-I (-0.908), and RH-II (-0.784), were negatively significance, During seedling stage (P2), maximum temperature (0.944), and evaporation(0.829) were positively significance whereas, minimum temperature (-1.00), RH-I (-0.720), and RH-II (-0.801), were negatively significance, During Branching stage (P3) maximum temperature (0.715), RH-I (0.907), RH-II (0.929), BSS (0.901) and wind speed (0.845) were positively significance whereas, minimum temperature (-0.843) negatively significance. During Flowering stage (P4) rainfall (0.786), RH-I (0.934), and RH-II (0.951) and wind speed (0.799) were positively significance, whereas, maximum temperature (-0.989), minimum temperature (-0.986) evaporation (-0.849) and BSS (-0.805) were negatively significance. During Pod formation (P5) wind speed (0.738) was positively significance whereas rainfall (-0.757) and RH-I (-0.611) were negatively significance. During Grain formation (P6) rainfall (0.752), maximum temperature (0.600), RH-I (0.842) evaporation (0.701), BSS (0.660) and wind speed (0.953) were positively significance, whereas, RH-II (-0.603) was negatively significance. During Pod development stage (P7), RH-I (0.651) was positively significance, whereas BSS (-0.844) and maximum temperature (-0.667) were negatively significance. During Pod contending full size grain (P8) no significance effect of any weather parameter has seen. During Dough stage (P9) wind speed (0.766) was only positively significance. And during maturity stage (P10) RH-I (0.975), and RH-II (0.948) were positively significance, whereas, minimum temperature (-0.880,) evaporation (-0.925) and BSS (-0.860) were negatively significance. Similar results were observed by Kumar *et al*. (2008).

4.7.2 Variety MAUS-71 (V_2)

According to data from Table 4.22, it was found that during sowing to emergence stage (P1) RH-I (0.691), evaporation (0.670), BSS (0.649) and wind speed

(0.815) were positively significance, whereas, rainfall (-0.767) was negatively significance, During seedling stage (P2) maximum temperature (0.916), RH-I (0.664) and evaporation (0.788) were positively significance whereas, minimum temperature (-0.956), and RH-II (-0.753), were negatively significance, During Branching stage (P3) rainfall (0.828), minimum temperature (0.911), RH-I (0.891), and RH-II (0.871), and BSS (0.790) were positively significance whereas, evaporation (-0.626) and wind speed (-0.948) were negatively significance. During Flowering stage (P4) rainfall (0.672), RH-I (0.902), RH-II (0.911), and BSS (0.692) were positively significance, whereas, maximum temperature (-0.948), minimum temperature (-0.769) and evaporation (-0.796) were negatively significance. During Pod formation (P5) wind speed (0.751) was positively significance whereas rainfall (-0.753) and RH-I (-0.689) were negatively significance. During grain formation (P6) maximum temperature (0.876), evaporation (0.933), BSS (0.896) and wind speed (0.789) were positively significance, whereas, rainfall (-0.945), RH-I (-0.995) and RH-II (-0.883) were negatively significance. During pod development stage (P7) RH-I (0.767) was positively significance Whereas BSS (-0.939) was negatively significance. During Pod contending full size grain (P8) BSS (0.592) and wind speed (0.572) were positively significance whereas, rainfall (-0.587), and RH-I (-0.625) was negatively significance. During Dough stage (P9) wind speed (0.769) was only positively significance whereas minimum temperature (-0.765), minimum temperature (-0.647) and evaporation (-0.610) were negatively significance. And during maturity stage (P10) RH-II (0.847) was positively significance, whereas, minimum temperature (-0.869), RH-I (-0.927), evaporation (-0.841) and BSS (-0.569) were negatively significance. Borowska, *et al.* (2021) reported same results.

4.7.3 Variety JS-335 (V_3)

According to data from Table 4.23, it was found that during sowing to emergence stage (P1) wind speed (0.658) was positively significance, whereas, RH-I (-0.732) was negatively significance, During seedling stage (P2), maximum temperature (0.786), minimum temperature (0.809) and evaporation (0.815) were positively significance whereas, RH-I (-0.672), and RH-II (-0.706), were negatively significance, During branching stage (P3) rainfall (0.660), RH-I (0.751), and RH-II (0.769), were positively significance whereas, maximum temperature (-0.991) evaporation (-0.752) and wind speed (-0.623) were negatively significance. During flowering stage (P4) RH-II (0.626) was positively significance, whereas, minimum temperature (-0.591) and BSS (-0.581) were negatively significance. During pod formation (P5) wind speed (0.597) was positively significance whereas rainfall (-0.758) was negatively significance. During grain formation (P6) wind speed (0.762) was positively significance. During pod development stage (P7) maximum temperature (0.923), evaporation (0.797), BSS (0.967) were positively significance, whereas RH-I (-0.887) and RH-II (-0.749) were negatively significance. During pod contending full size grain (P8) wind speed (-0.949) was negatively significance. During dough stage (P9) there is any significance of weather parameters. And during maturity stage (P10) minimum temperature (0.719), and RH-I (0.873), were positively significance, whereas, evaporation (-0.659) was negatively significance. Shah *et al*. (1989) also got similar results.

Table 4.21: Correlation between Soybean Seed yield and weather parameters of different phenophases of V_1- MAUS-158

	Phenophase of V_1- MAUS-158									
Weather Parameter	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
RF (mm)	-0.811**	-0.091	0.189	0.786**	-0.757**	0.752**	-0.531	0.471	-0.288	-0.467
Tmax	0.705*	0.944**	- 0.715**	-0.989**	0.413	0.600*	-0.667*	0.193	0.465	0.272
Tmin	-0.494	-1.000**	-0.843**	-0.986**	-0.365	-0.177	-0.345	-0.000	-0.451	-0.880**
RH I	-0.908**	-0.720**	0.907**	0.934**	-0.611*	0.842**	0.651*	-0.322	-0.404	0.975**
RH II	-0.784**	-0.801**	0.929**	0.951**	-0.427	-0.603*	-0.036	0.387	0.352	0.948**
EVP (mm)	0.788**	0.829**	-0.106	-0.849**	0.273	0.701*	0.082	0.067	0.135	-0.925**
BSS (hrs)	0.645*	-0.003	0.901**	-0.805**	-0.008	0.660*	-0.844**	0.433	-0.462	-0.860**
WS (Kmph)	0.899**	-0.523	- 0.845**	0.799**	0.738**	0.953**	-0.333	0.066	0.766**	0.350

*Significant at 5 percent (0.567) ** significant at 1 percent (0.708)

P_1- *Emergence stage* P_2- *Seedling stage*

P_3- *Branching stage* P_4- *Flowering stage*

P_5- *Pod formation stage* P_6- *Grain formation stage*

P_7- *Pod development stage* P_8- *Pod containing full-size grain*

P_9- *Dough stage* P_{10}- *Maturity stage*

Table 4.22: Correlation between Soybean Seed yield and weather parameters of different phenophases of V_2- MAUS-71

Weather Parameter	Phenophase of V_2- MAUS-71									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
RF(mm)	-0.767**	-0.018	0.828**	0.672*	0.753**	-0.945**	-0.560	-0.587*	-0.050	0.510
Tmax	0.406	0.916**	-0.037	-0.948**	0.437	0.876**	-0.548	0.132	-0.647*	-0.064
Tmin	-0.458	-0.956**	0.911**	-0.769**	-0.331	0.217	0.527	-0.492	-0.765**	-0.869**
RH I	0.691*	0.664*	0.891**	0.902**	-0.689*	-0.995**	0.767**	-0.625*	-0.007	-0.927**
RH II	-0.377	-0.753**	0.871**	0.911**	-0.503	-0.883**	0.115	0.348	0.565	0.847**
EVP (mm)	0.670*	0.788**	-0.626*	-0.796**	0.521	0.933**	-0.036	0.489	-0.195	-0.841**
BSS (hrs)	0.649*	0.102	0.790**	0.692*	0.311	0.896**	-0.939**	0.592*	-0.610*	-0.569*
WS (Kmph)	0.815**	-0.218	-0.948**	0.174	0.751**	0.789**	-0.471	0.572*	0.769**	0.090

** Significant at 5 percent (0.567)* *** significant at 1 percent (0.708)*

P_1- *Emergence stage*
P_2- *Seedling stage*
P_3- *Branching stage*
P_4- *Flowering stage*
P_5- *Pod formation stage*
P_6- *Grain formation stage*
P_7- *Pod development stage*
P_8- *Pod containing full-size grain*
P_9- *Dough stage*
P_{10}- *Maturity stag*

Table 4.23: Correlation between Soybean Seed yield and weather parameters of different phenophases of V_3- JS-335

	Phenophase of V_3- JS-335									
Weather Parameter	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
RF(mm)	-0.470	-0.242	0.660*	0.470	-0.758**	0.099	-0.055	-0.265	-0.209	0.219
Tmax	0.503	0.786*	-0.991**	-0.549	0.529	0.222	0.925**	-0.320	0.029	-0.106
Tmin	-0.282	0.809**	0.507	-0.591*	-0.186	-0.136	-0.244	0.515	-0.184	0.719**
RH I	-0.732*	-0.672*	0.751**	0.555	-0.562	-0.382	-0.887**	0.019	-0.447	0.873**
RH II	-0.566	-0.706*	0.769**	0.626*	-0.409	-0.231	-0.749**	0.325	-0.093	0.483
EVP (mm)	0.484	0.815**	-0.752**	-0.560	0.236	0.223	0.797**	-0.233	0.601*	-0.659*
BSS (hrs)	0.543	0.547	0.079	-0.581*	-0.175	0.131	0.967**	-0.062	0.126	-0.306
WS (Kmph)	0.658*	-0.314	-0.623*	0.490	0.597*	0.762**	0.312	-0.949**	0.463	0.138

* Significant at 5 percent (0.567) ** significant at 1 percent (0.708)

P_1- *Emergence stage* P_2- *Seedling stage*

P_3- *Branching stage* P_4- *Flowering stage*

P_5- *Pod formation stage* P_6- *Grain formation stage*

P_7- *Pod development stage* P_8- *Pod containing full-size grain*

P_9- *Dough stage* P_{10}- *Maturity stage*

Table 4.2: Soil moisture percentage (%) of Soybean in different sowing dates at different depth.

	D1			**D2**			**D3**			**D4**		
DAS	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**
At sowing	29.87	29.20	28.53	18.48	24.22	23.6	26.90	26.10	26.90	26.10	30.72	26.10
7 DAS	18.34	24.07	23.60	26.74	28.53	26.26	26.42	27.55	25.00	24.22	23.60	22.10
14DAS	27.23	30.21	26.26	26.58	27.39	26.10	24.22	23.92	22.70	**RF**	**RF**	**RF**
21 DAS	26.58	27.88	26.42	22.85	23.76	22.70	**RF**	**RF**	**RF**	21.21	20.92	19.05
28 DAS	21.65	24.07	22.70	**RF**	**RF**	**RF**	19.90	21.21	21.36	17.51	17.23	21.95
35 DAS	**RF**	**RF**	**RF**	20.92	21.95	24.84	16.69	18.20	20.05	26.26	20.34	21.95
42 DAS	20.63	21.80	23.61	16.82	16.96	20.63	26.26	18.20	20.92	29.87	26.10	27.18
49 DAS	18.34	18.76	20.65	26.58	18.48	20.77	29.37	26.42	27.39	13.77	15.61	12.23
56 DAS	26.10	18.48	20.48	29.2	26.42	27.55	12.99	14.42	12.74	21.80	24.22	24.38
63 DAS	28.70	27.06	27.55	13.25	13.51	14.53	21.36	24.22	23.15	23.60	24.07	21.21
70 DAS	13.25	13.51	14.03	22.4	24.53	23.6	22.70	24.22	20.05	19.90	20.34	22.85
77 DAS	22.40	24.69	22.40	22.25	23.46	20.92	18.76	20.34	24.22	24.22	26.10	29.70
77 DAS	22.25	20.34	20.05	21.21	20.92	24.53	24.38	26.42	28.87	24.07	31.75	33.16
84 DAS	20.92	21.21	23.61	26.58	25.94	28.87	24.69	29.70	34.41	21.21	23.92	25.31
91 DAS	26.74	29.87	29.53	25.16	30.55	28.70	21.21	23.30	23.76	31.75	32.80	33.51
98 DAS	26.90	29.03	29.20	21.21	23.46	22.40	33.16	32.98	33.51	20.19	21.21	22.85
105 DAS	21.95	23.15	22.85	32.98	37.69	36.45	20.19	21.21	24.22	17.51	20.34	24.07
109 DAS	33.69	34.05	33.16	21.65	20.48	22.7	18.91	21.21	24.07	17.51	21.36	24.37

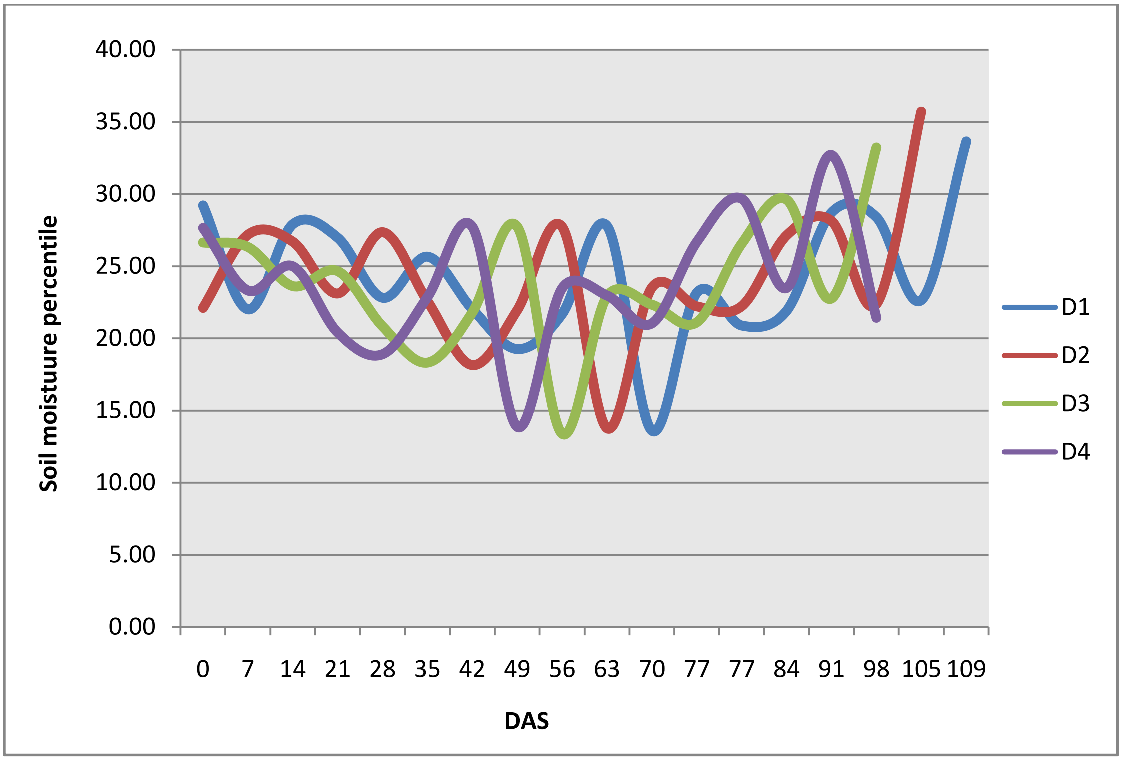

Fig.4.2: Soil moisture percentile (%) of Soybean at different sowing dates at sowing.

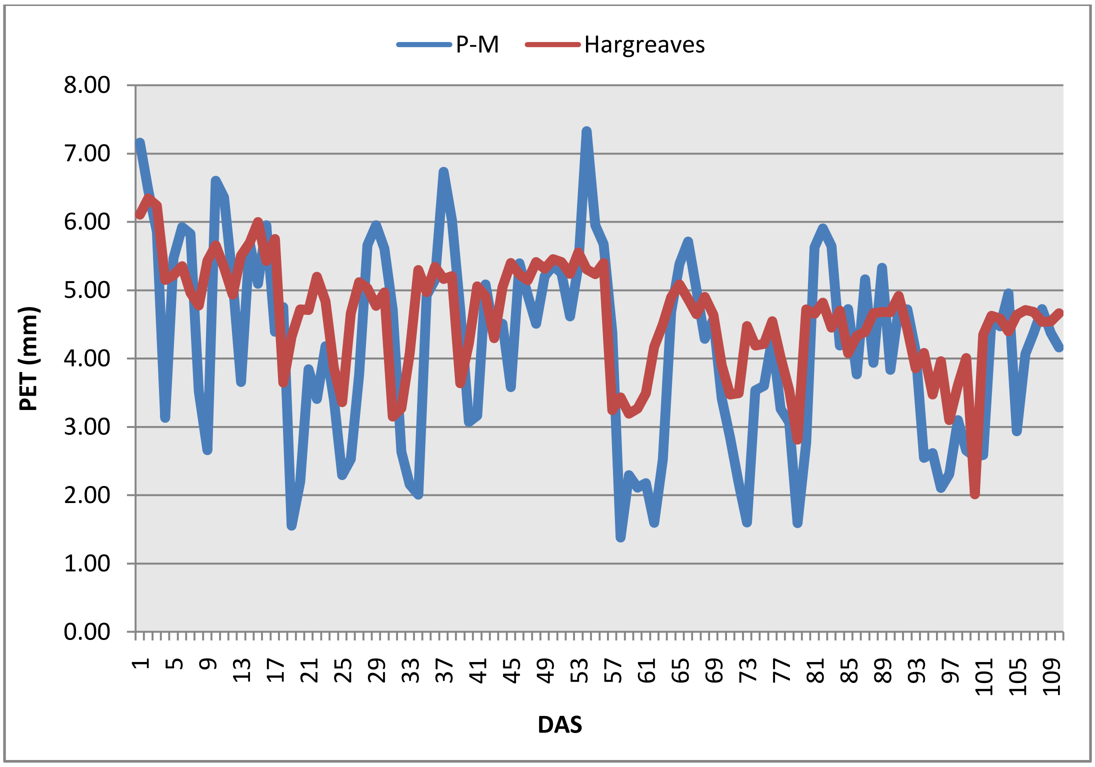

Fig 4.24: Comparison of estimated K_c values and K_c values of Hargreaves methods.

4.8 Crop coefficient of soybean cv. MAUS-71

The crop coefficient (K_c) of soybean estimated by computing crop water requirement was determined using the guidelines from FAO Irrigation and Drainage Paper No. 56 given by Allen *et al.* (1998). The crop coefficient values were calculated as the ratio of crop evapotranspiration (ET_c) and the potential evapotranspiration (ET_o) for the entire life cycle of the crop. The crop coefficient was calculated in three stages (i.e., initial, mid-stage and late stage) as recognized internationally where the duration of each stage depends on the length of the growing period of the particular crop and climate. The crop growth stage was different from one crop to other. In Soybean, the general crop coefficient suggested by FAO-56 was 0.50, 1.15 and 0.50-1.0 for initial, mid and end stage, respectively. K_c values were calculated as suggested by Allen *et al.* (1998)

$$K_c = \frac{ETc}{ETo}$$

Table 4.24: Phenophase wise Rainfall, AET, and PET in (mm) of Soybean cv. MAUS-71

Crop stages	Rainfall	AET	PET
Emergence stage	6.1	14.3	28.1
Seedling stage	133.3	38.1	69.3
Branching stage	348	43.0	45.4
Flowering stage	120.9	45.9	34.3
Pod formation stage	1.4	47.0	30.0
Grain formation stage	2.3	108.2	63.1
Pod development stage	57.6	78.3	52.4
Pod containing full- grain stage	323.1	66.4	64.9
Dough stage	69.8	28.9	29.9
Maturity stage	226.4	40.6	51.9

Actual Evapotranspiration (ET_c)

The actual evapotranspiration of the crop was recorded daily throughout their life cycle by using mechanical weighing type field lysimeter. According to the data presented in Table 4.24 and Fig. 4.22, the total actual evapotranspiration till harvest was 505.7 mm. Jadhav *et al.* (2010) reported that the seasonal total amount of actual evapotranspiration was 353.9 mm of soybean, the data when estimated in stage wise ranging from 14.8 to 108.2 mm. It was recorded that the highest rate of ET_c was seen at grain formation stage. This is due to the fact that more canopies were present during that stage which transpires more water from the plant along with evaporation from the surface. Srinivas *et al.* (2018) also reported that the ET_c during middle stage was higher because of fully developed crop canopy and high evaporative demand. Ko *et al.* (2006) also report that highest actual evapotranspiration (ET_c) was recorded during grain formation stage due to presence of highest crop canopy that result in higher crop water demand. The rate of ET_c is decreasing at end stages in spite of receiving good amount of rainfall because in these stages, it has attended the stage maturity. In ET_c curve, the fluctuation is regulated by crop growth and development. The crop water use decreases in the late season stage, which was due to cessation of leaf growth. Allen *et al.* (1998).

Potential Evapotranspiration (ET_o)

Potential Evapotranspiration (ET_o) was estimated daily using the standard method of Penman-Monteith method as recommended by FAO expert for the calculation of crop water requirement Allen *et al*. (1998). The daily weather data was used as the input for calculating ET_o in FAO P-M method. The total ET_o recorded was about 459.44 mm during the entire life period of crop. In ET_o curve as depicted in Fig. 4.30, the fluctuation is regulated by weather parameter values. According to Table 4.22, it is observed that ET_o in stage wise ranged from 28.1 to 69.3 mm during the entire crop life period. The rate of ET_o is lesser than ET_c (actual Evapotranspiration) during the Flowering stage to Pod containing full- grain stage which indicated that the crop water requirement is more during that period. It was also found that the ET_o is more during initial and end stage of crop. This might be because of high evaporation rate during initial where vegetation cover is very less, whereas, during late stage, it decreases because of leaf senescence or the growth of leaves have stop that leads to reduction of actual evapotranspiration (ET_c) rate compared to Potential Evapotranspiration (ET_o). Karam *et al*. (2005) reported that the ET_o maximum during the initial crop growth stage due to higher evaporative demand of the atmosphere and transpiration demand of plant, whereas the decline in the end stage was due to maturity and senescence of leaf and to the completion of grain formation and filling thereby limiting transpiration.

Table 4.25: Crop coefficient (K_c) values at different stages of Soybean cv. MAUS-71

Crop stages	K_c
Emergence stage	0.5
Seedling stage	0.5
Branching stage	0.9
Flowering stage	1.3
Pod formation stage	2.0
Grain formation stage	1.9
Pod development stage	1.4
Pod containing full-grain stage	1.0
Dough stage	0.9
Maturity stage	0.8

According to the data presented in Table 4.25 The crop coefficient (K_c) values vary with stages of the crop which was 0.5 at emergence and seedling stage, at branching stage 0.9, at flowering 1.3, at pod formation stage 2.0, at grain formation stage1.9, at pod development stage1.4, at pod containing full-grain stage 1.0, at dough stage 0.9 and at maturity stage 0.8. At initial stages K_c values were low due to less crop canopy cover of plant small water requirement by the crop at branching onwards crop water requirement increases up to pod formation stage, then again decreases at maturity stages due to less transpiration demand. Kumar *et al*. (2015) reported that excessive growth at mid stages of crop shows higher values of crop coefficient (K_c).

4.26: Comparison of estimated crop coefficient (K_c) values and FAO-56 K_c values

Stages of crop	DAS	Estimated K_c values	FAO-56 K_c values
Initial stage	1 to 30	0.67	0.50
Mid stage	31 to 85	1.39	1.15
End stage	85 to 110	0.80	0.5-1.0

The crop coefficient (K_c) values of FAO-56 were estimated in three crop stage wise according to number of days after sowing Allen *et al.* (1998), therefore, for comparison, it is important to estimate the measured K_c values in three stage wise accordingly with FAO-56, i.e., initial (0-30 DAS), mid stage (31-85) and end stage (86-110 DAS). According to the data presented in table 4.26, the K_c values of

Soybean cv. MAUS-71 estimated during initial, mid and end stage was 0.67, 1.39 and 0.80, respectively, with the maximum K_c values during mid-season stage. This might be due to fully developed canopy cover during mid stage with fully develop branches, leaves, maximum plant height and leaf area which increases crop water demand. Alataway *et al.* (2019) reported that the K_c values during initial stage was relatively low because the evapotranspiration at this stage depended on the evaporation from the soil, as the crop has no ground cover whereas the Kc values during mid-season stage was higher due to maximum evapotranspiration rate by fully develop crop, at the end stage, the K_c values declined steadily due to maturity and senescence of the leaves. Djaman *et al.* (2019) also reported that the highest K_c values obtained during mid stage was due to maximum evapotranspiration (ET_c) whereas the decline in the end stage was due to maturity and senescence of leaf and to the completion of grain formation and filling thereby limiting transpiration. Results are quite similar with the report of Mark *et al.* (2021), Shang *et al.* (2012) that the crop coefficient (K_c) during mid-season stage was at the maximum than the rest of the stage. The result also shown that the estimated K_c values of soybean cv. MAUS-71 were higher in all three stages as compared to those K_c values suggested in FAO-56 Irrigation and Drainage Paper Allen *et al*. (1998).

. **Table 4.27: Stage wise crop coefficients of soybean by using different methods**

Methods	Initial	Mid	End
P-M	**0.65**	**1.39**	**0.80**
Hargreaves	**0.57**	**1.29**	**0.80**
J-H Method	1.80	1.97	1.16
Christiansen	1.49	2.53	1.50
Pan evaporation	2.88	2.38	2.24
FAO 24 radiation	1.37	1.54	1.00
FAO modified p.	1.01	2.40	1.29
Makkink	1.10	1.28	0.75
Turc	1.35	3.41	1.73
Priestley-Taylor Method	1.19	1.33	0.81
H-S Method	0.23	0.53	0.33

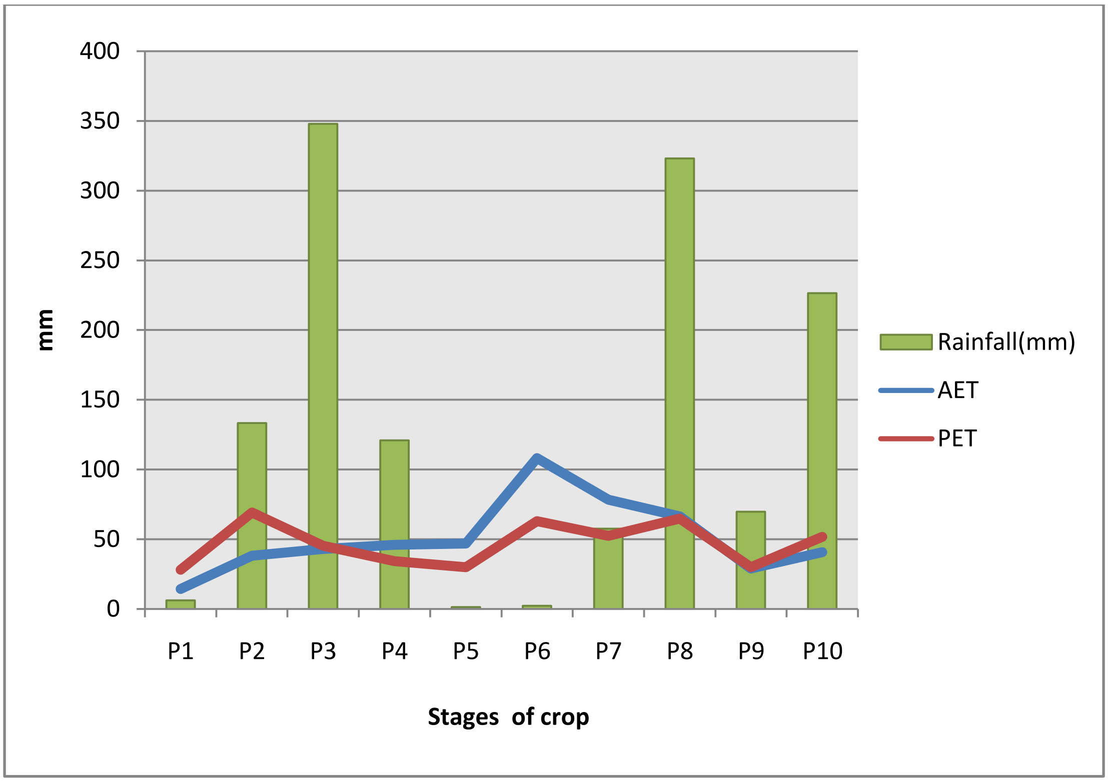

Fig. 4.22: Phenological stage wise total rainfall, ET_c, ET_o (mm) recorded during *Kharif* season 2021 at Parbhani.

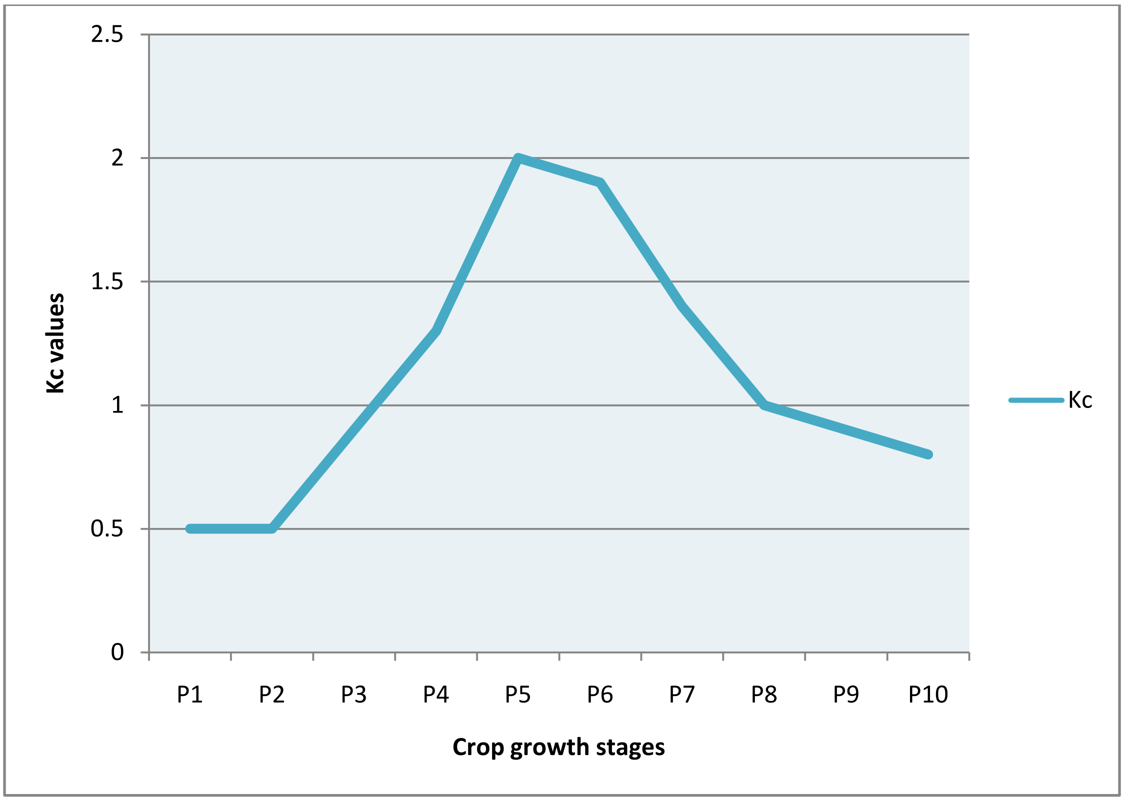

Fig 4.23: Stage wise calculated crop coefficients of soybean cv. MAUS-71.

Table 4.28: Stage wise actual ET (ET_c) and estimated ET (ET_o) of soybean by different methods with its average error

PET computation methods	Initial stage (1-30 DAS)	Mid stage (31-85 DAS)	End stage (112 - 155 DAS)	TOTAL
AET	84.6	332.6	88.5	505.7
P-M	**132.4 (56.5 %)**	**227.6 (-31.6%)**	**99.42 (12.3%)**	**459.4 (12.4%)**
Hargreaves	**148.0 (75%)**	**248.9 (-25.1%)**	**109.9 (-24.2%)**	**506.9 (24.7%)**
J-H Method	107.2 (26.8%)	172.4 (-48.2%)	88.4 (0.0%)	368.1 (-7.1%)
Christiansen	94.4 (-11.7%)	150.9 (-54.6%)	70.5 (-20.2%)	315.9 (-21.1%)
Pan evaporation	83.4 (-1.4%)	130.7 (-60.7%)	58.1 (-34.3%)	272.2 (-32.1%)
FAO 24 radiation	126.0 (49%)	207 (-37.7%)	105.2 (18.9%)	438.2 (-10.1%)
FAO modified p.	93.8 (11%)	155.3 (-53.3%)	78.1 (-11.6%)	327.4 (-18.0%)
Makkink	170.6 (101.7%)	279.9 (-15.8%)	142.7 (61.2%)	593.2 (49.0%)
Turc	80.6 (-4.7%)	134.9 (-59.4%)	67.9 (-23.2%)	283.5 (-29.1%)
Priestley-Taylor	156.1 (84.5%)	257.6 (-22.5%)	130.8 (47.8%)	544.6 (36.6%)
H-S Method	362.7 (328.8%)	609.9 (83.4%)	269.3 (204.4%)	1242.1 (205%)

Table 4.29: Error analysis of ET_c estimation by different methods

Parameters	MAE (mm)	MBE (mm)	RMSE(mm)
P-M	**-0.42**	**0.42**	**4.41**
Hargreave	**0.79**	**-0.79**	**8.32**
J-H Method	-1.25	1.25	13.1
Christiansen	-1.72	1.72	18.1
Pan evaporation	-2.12	2.12	22.3
FAO-24 radiation	-0.61	0.61	6.41
FAO modified p.	-1.62	1.62	17
Turc	-2.02	2.02	21.2
H-S Method	6.69	-6.69	70.2

4.7.4 Comparison of potential evapotranspiration (ET_o) and crop coefficient (K_c) of soybean cv. MAUS-71 derived from different methods

According to the data presented in table 4.28 and 4.29, the Potential evapotranspiration (ET_o) was estimated by different method along with their average error. Result showed that Hargreave-samani method recorded the highest total ET_o of 1242.1 mm whereas Pan evaporation method recorded the lowest total ET_o of 272.2 mm during the seasonal growth period of crop. The estimated ET_o for different method was also evaluated in terms of error analysis and the result revealed that ET_o estimated by P-M method and FAO-24 radiation have the lowest MAE, MBE and RMSE indicating lowest magnitude of average error.

The crop coefficient (K_c) is the ratio of AET to PET. It clearly means that it is the value which represents the canopy development and radiation trapping, in the course of crop development (Kamble *et al.* 2010). The crop coefficient estimated by different method which is presented in table 4.28, showed that the estimated K_c values of the mid-season stage was higher than the rest of the stages in all the method which was caused by evapotranspiration of maximum vegetation cover and their metabolism. According to result, the Kc_{in} and, Kcmid values of FAO modified (1.01, 2.40 and 1.29), Makkink (1.10,1.28 and0.75), Turc (1.35, 3.41 and 1.73), Priestley-Taylor (1.19, 1.13 and 0.81), Christiansen (1.49,1.97 and 1.16), overestimated the Kc_{in} ,Kc_{mid} and Kc_{end} of PM method, respectively, whereas, Kc_{in}, Kc_{mid} and Kc_{end} of Hargreave (0.57, 1.29 and 0.80), and Hargreave-samani (0.23, 0.53 and 0.33) underestimated that of PM method (0.5, 1.13 and 0.80) at all stages, respectively. Hargreaves method is the only method that differs slightly with the K_c values of PM method in all stages. This means that the Potential evapotranspiration (ET_o) and crop coefficient (K_c) values can be estimated by Hargreave method in Parbhani location. Similar results were reported by Dakhar (2021).

4.9 Estimation of Crop Water Requirement Satisfying Index (WRSI) of Soybean cv. MAUS-71

Frere and Popov originally proposed simplified crop-weather analysis model in 1979 to the United Nations Food and Agriculture Organization (FAO) as a proxy for crop performance, and an indicator of the satisfaction of the crop water requirements in areas of the world where water represents the main constraint for crops (FAO, 1979). The WRSI is an indicator of crop performance based on the availability of water to the crop during a growing season. Studies by the FAO Doorenbos and Pruitt, (1977); FAO, (1986) given formula,

$$\text{WRSI} = \frac{\sum \text{AETc}}{\sum \text{PETc}} * 100$$

Where,

PET_c denotes crop specific potential evapotranspiration after an adjustment is made to the reference crop PET by the use of appropriate crop coefficients (K_c). Senay *et al.* (2003)

The water requirement of the crop (PET_c) at a given time in the growing season is calculated by multiplying standard reference crop PET by K_c:

$$PET_c = K_c PET$$

Table 4.30: Crop Water Requirement Satisfying Index (WRSI) values at different stages of Soybean cv. MAUS-71

STAGES	AET	PET	WRSI %
Emergence stage	14.3	28.1	99
Seedling stage	38.1	69.3	100
Branching stage	43.0	45.4	100
Flowering stage	45.9	34.3	99
Pod formation stage	47.0	30.0	70
Grain formation stage	108.2	63.1	75
Pod development stage	78.3	52.4	98
Pod containing full-grain stage	66.4	64.9	100
Dough stage	28.9	29.9	100
Maturity stage	40.6	51.9	98

Table 4.30 shows that the Crop Water Requirement Satisfying Index (WRSI) varies with stages of the crop which was 99 % at emergence, at seedling stage 100 %, at branching stage 100 %, at flowering 99 %, at pod formation stage 70 %, at grain formation stage 75 %, pod development stage 98 %, at pod containing full-grain stage 100 %, at dough stage 100 % and at maturity stage 98%. At initial and end stages WRSI values were more than 100 % due to maximum soil moisture available to the crop whereas at Pod formation stage and Grain formation stage WRSI values shows lowest as 75% and 70% respectively due to increase in crop water requirement at those stages because of maximum level of transpiration demand with short of water supply to crop. Reddy *et al.* (2003) reported that short supply of water at mid stages of crop growth shows lower values of Crop Water Requirement Satisfying Index (WRSI).

The criterion proposed by Rajavel *et al.*, (2012) was adopted to categorize the WRSI.

WRSI (%)	Description
95-100	Good
80-94	Average
50-79	Poor
< 50	Failure

According to the above-mentioned parameters, several phonological stages were subjected to various water supply levels during the crop growth period. Except for the pod formation stage and grain formation stage, where each stage falls under the "Good class of WRSI" category because the WRSI values were at 100%, the pod formation stage and grain formation stage, where the WRSI values were less than 100%, i.e., 75% and 70%, respectively, fall under the "Poor class of WRSI," which denotes insufficient water supply to the crop, which results in a decrease in pod and seed weight and a lower yield. Varshneya *et al*. (2003) also reported same results that short of water supply results in decrease of Crop Water Requirement Satisfying Index (WRSI) values.

4.10 Computation of the Crop Water Stress Index (CWSI)

CWSI computed using empirical method. According to the Idso's definition Idso *et al.* (1981), the CWSI can be expressed:

$$CWSI = \frac{(T_c - T_a) - D_2}{D_1 - D_2} \quad (1)$$

Where,

D_1 = maximum canopy and air temperature difference for a stressed crop (the maximum stressed baseline), Jackson *et al.* (1981),

D_2 = lower limit canopy and air temperature difference for a well-watered crop (the non-water-stressed baseline),

T_c = measured canopy surface temperature (◦C),

T_a = air temperature (◦C).

4.10.1 Canopy and air Temperature difference (T_c-T_a)

Difference between the canopy and air temperature was calculated as soon as the measurements of these temperatures were finished at corresponding

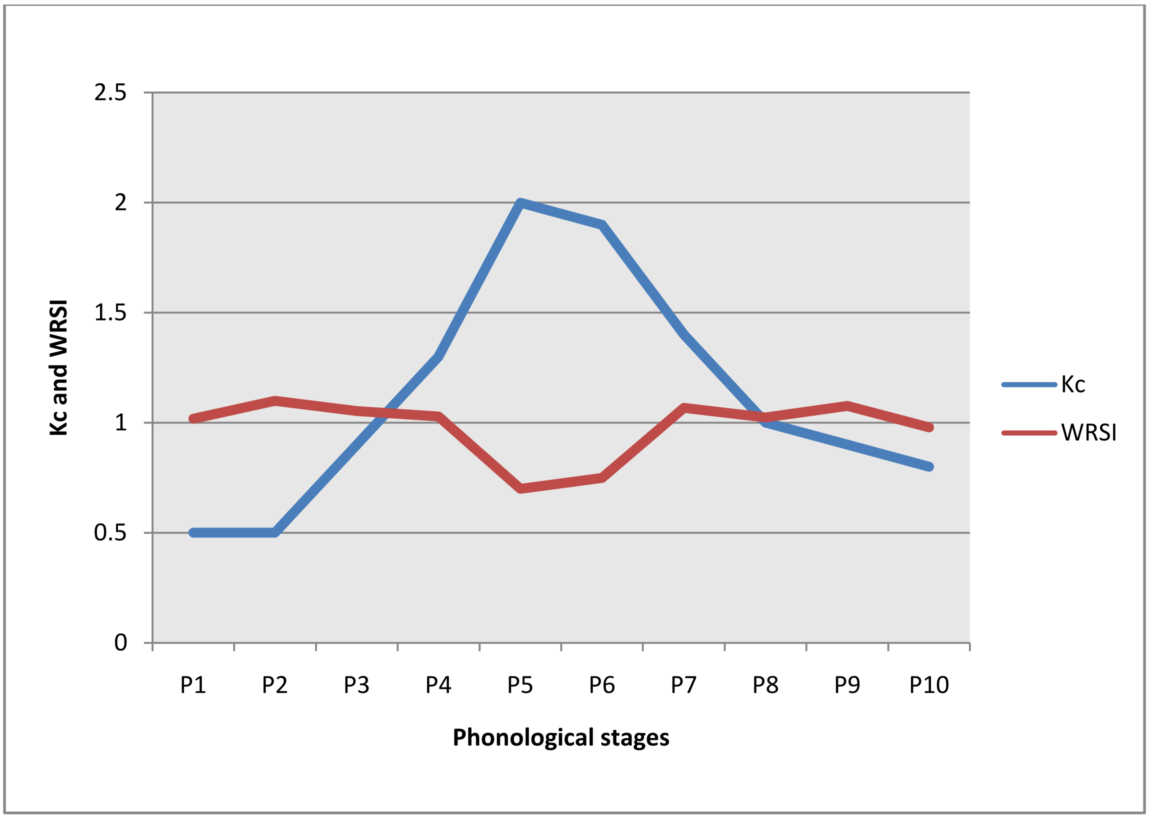

Fig 4.25: Comparison of estimated K_c and WRSI at different stages of the soybean cv. MAUS-71.

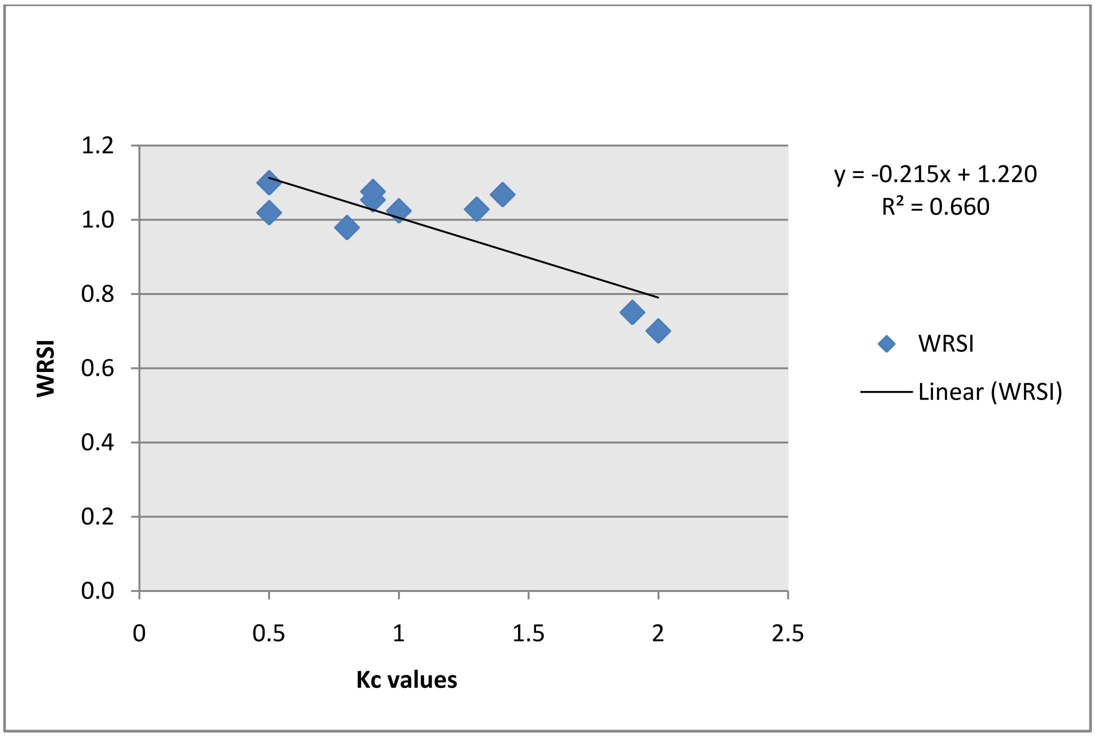

Fig 4.26: Linear regression between K_c values and WRSI values.

Phenoplogical stages Average of (T_c-T_a) was calculated to represents single value for each stage and thus, stage –specific values were obtained.

4.10.2 Determination of lower boundary (D_2)

The lower bound indicates the lowest limit below which no value of T_c-T_a will occur. It was obtained from the given formula. (Jackson *et al*.1988).

$$(T_c - T_a) = \frac{r_a R_n}{\rho C_p} * \frac{\gamma(1+\frac{r_c}{r_a})}{\Delta+\gamma(1+\frac{r_c}{r_a})} - \frac{e_s - e_a}{\Delta+\gamma(1+\frac{r_c}{r_a})} \quad (2)$$

Where,

r_a = Aerodynamic resistance (s m^{-1})

R_n = Net radiation (594.6 W m^{-2}),

ρ =Density of air (1.28 kg m^{-3}),

C_p = Heat capacity of air (700 J kg^{-1} $°C^{-1}$),

γ = Psychometric constant (54 Pa $°C^{-1}$),

VPD = vapor pressure deficit (K Pa),

Δ = Slope of the saturated vapor pressure-temperature difference between leaf and air. (P $°C^{-1}$)

By setting r_c=0 in the above Equation (2) which represents the condition of wet plants behaving as a free water surface for the transpiration (Jackson *et al*.1988) we get:

$$(T_c - T_a) = \frac{r_a R_n}{\rho C_p} * \frac{\gamma}{\Delta+\gamma} - \frac{e_s - e_a}{\Delta+\gamma} \quad (3)$$

4.10.3 Determination of upper boundary (D_1)

The D_1 maximum canopy and air temperature difference for a stressed crop can be found by allowing the canopy resistance r_c to increase without bound as $r_c = \infty$, (Jackson.*et al*.1988).

$$T_c - T_a = \frac{r_a R_n}{\rho C_p} \quad (4)$$

Table 4.31: Crop Water Stress Index (CWSI) values at different stages of Soybean cv. MAUS-71

Crop stages	Rainfall	(T_c-T_a) °C	CWSI
Emergence stage	6.1	1.2	0.29
Seedling stage	133.3	1.8	0.42
Branching stage	348	1.4	0.33
Flowering stage	120.9	1.5	0.35
Pod formation stage	1.4	4.5	0.98
Grain formation stage	2.3	4.2	0.92
Pod development stage	57.6	2.1	0.48
Pod containing full-grain stage	323.1	2.5	0.56
Dough stage	69.8	2	0.46
Maturity stage	226.4	4.8	1.00

As shown in Table 4.31, which demonstrates a linear relationship with the amount of moisture available to the plant in the soil, the difference between the temperature of the leaf and the temperature of the air close to the leaf varied at each stage. Difference between leaf temperature and air temperature near the leaf at emergence stage 1.2°C, seedling stage 1.8°C, branching stage 1.4°C, flowering stage 1.5°C, pod formation stage 4.5°C, grain formation stage 4.2°C, pod development stage 2.1°C, pod containing full-grain stage 2.5°C, dough stage 2.0°C, and maturity stage 4.8°C. Due to low moisture availability from low rainfall at those stages, the higher value of CWSI, 1.00, was recorded at the phases of maturity, 0.98 pod formation, and 0.92 grain formation, whereas the lower values were obtained at the other stages. As a result of the plants' increased water shortage, the CWSI score is higher. The difference between the temperature of the leaf and the temperature of the air is near in the early stages because there is a significant quantity of rainfall received, and CWSI values were lower. Emeribe *et al.* (2019) reported that CWSI values ranged from 0.54 to 1.0 indicating periods of moderate to maximum water stress. Khorsand *et al.* (2020) reported that the lowest water stress in maize and black gram was found at crop water stress index values of 0.28 and 0.15 respectively. Rud *et al.* (2014) found similar results that high correlation of CWSI with SC (stomata conductance) from tuber initiation to maturity ($0.64 \leq R^2 \leq 0.99$). Similar trends of increasing CWSI from well to deficit-irrigated.

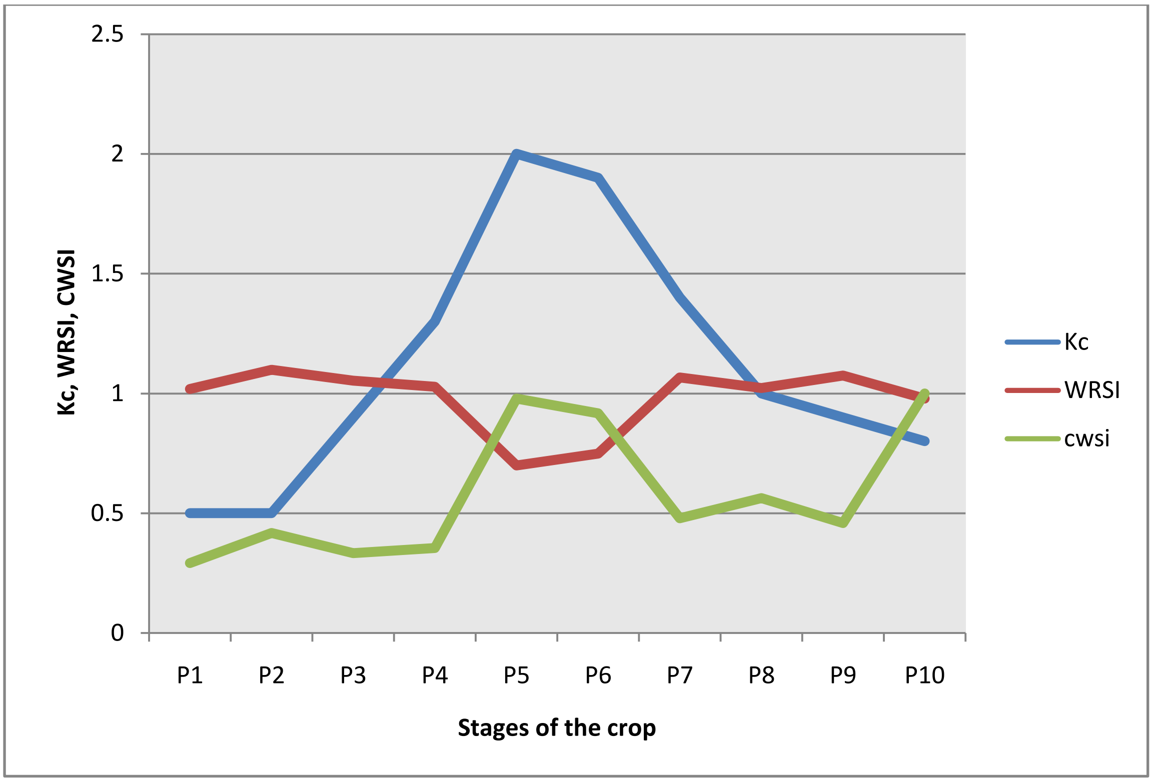

Fig 4.27: Comparison of estimated K_c, WRSI and CWSI at different stages of the soybean cv. MAUS-71.

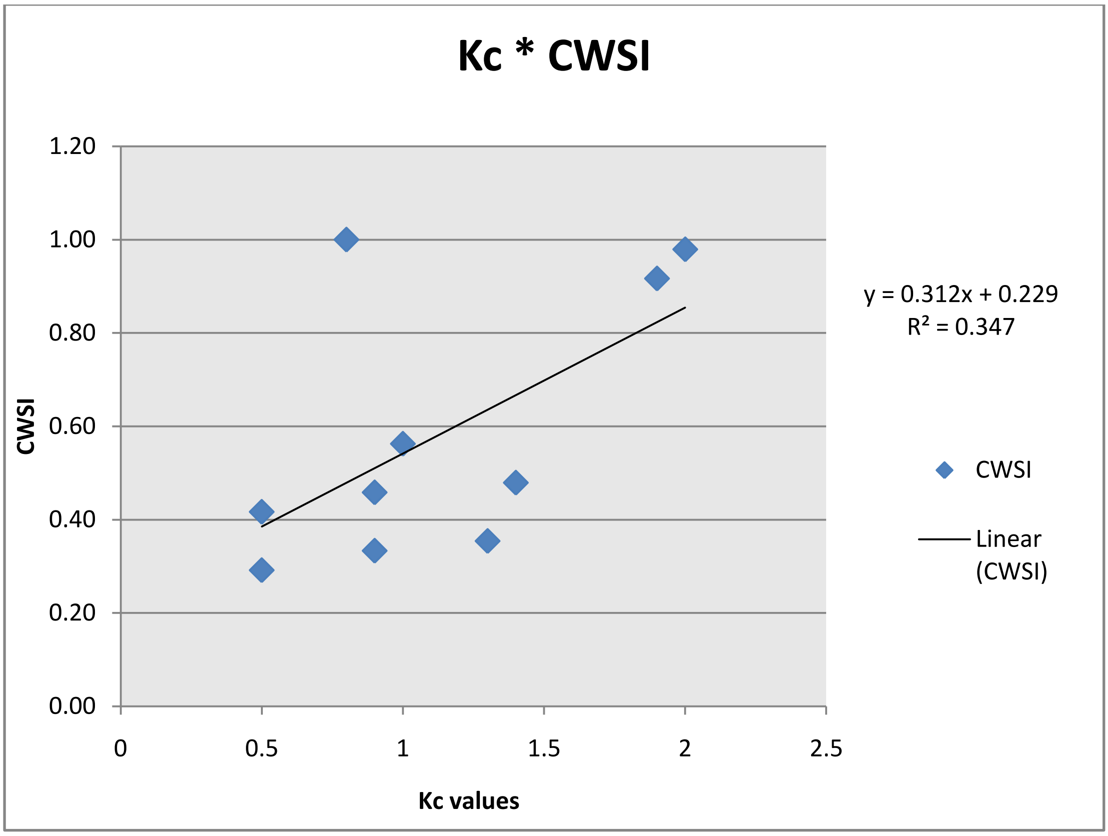

Fig 4.28: Linear regression between K_c values and CWSI values.

CHAPTER-V

SUMMARY AND CONCLUSIONS

CHAPTER-V

SUMMARY AND CONCLUSION

This chapter contains a quick summary of the study's findings and conclusions. During the *Kharif* season of 2021-22, on the experimental farm of the Department of Agricultural Meteorology, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, a field experiment titled “Estimation of Crop Water Requirement Satisfaction Index (WRSI) and Crop Coefficient of Soybean [*Glycine max (L.) Merill*] cv. MAUS-71 by using Lysimeter.” was conducted.

The water requirement of crop varies at different stages and weather variables affect the crop at different growth stages and throughout their life cycle. Therefore, this study is important to decide the critical growth stages of the crop. The aim of this study was to acquire the necessary frequency of wetting required to keep the crop stress-free, the mean interval between the future irrigations by determining the crop evapotranspiration using a mechanical weighing type field lysimeter in the semi-arid region of Parbhani and Potential evapotranspiration (ET_o) using FAO Penman-Monteith method; to determine the effect of weather parameters on crop growth, development, and yield of soybean varieties under various sowing dates throughout the crop life cycle and to estimate Crop Water Requirement Satisfaction Index. Along these two this study aims to compute Crop Water Stress Index (CWSI) values of Soybean by measuring leaf temperature and air temperature near to the leaf using infrared thermometer.

To achieve the goal of this experiment, the experiment was set up in a split plot design with three replications, where, three varieties (i.e., MAUS-158, MAUS-71 and JS-335) in the sub plot were sown in four sowing dates i.e., 25th SMW (D_1), 26th SMW (D_2), 27th MW (D_3), and 28th SMW (D_4) in the main plot. The findings are summarised below.

5.1. To find out the crop coefficient values of Soybean cv. MAUS-71

During the crop growth period of 2021, the total water requirement of the crop, i.e. ET_c, was 505.70 mm, ranging from 0.5 to 14 mm per day. It was recorded that the highest rate of ET_c (108.2 mm) was seen at grain formation stage of crop growth, indicating an increase in crop water demand during that time frame. The total

ET_o (potential evapotranspiration) estimated throughout the crop life cycle was 459.54 mm, using the standard procedure of the FAO Penman-Monteith method.

The crop coefficient (K_c) of the Soybean cv. MAUS-71 (V_2) varied greatly throughout its growth and development phase which increases successively from P1 to P5 (emergence to pod formation) slightly constant at P6 (grain formation) and then decrease from P7 to P10 (pod development to maturity stage), which shows that the pod foemation stage has the highest K_c value. The K_c values estimated during initial (0-30 DAS), mid (31-85 DAS), and end (86-110 DAS) stages were 0.67, 1.39 and 0.80, respectively, with the maximum K_c value during mid season stage. The higher K_c values was due to increase in rate of transpiration fully due to canopy with fully develop branches, leaves, maximum plant height and pods which increases crop water demand. Result showed that FAO-56 Irrigation and Drainage paper (Allen *et al.*, 1998) overestimated the K_c value of soybean at Parbhani.

In terms of K_c values at all stages, Hargreaves method is the only method that differs slightly with the K_c values of P-M method in all stages. This means that the Potential evapotranspiration (ET_o) and crop coefficient (K_c) values can be estimated by Hargreave method in Parbhani location. These two methods have the lowest MAE, MBE and RMSE indicating lowest magnitude of average error.

5.2. Effect of weather parameters on Soybean varieties under different dates of sowing.

In terms of emergence count and final plant stand, D_1 (25^{th} MW) had the highest mean emergence count and final plant stand, than D_2 (26^{th} MW), D_3 (27^{th} MW), and D_4 (28^{th} MW). Among the verities, V_1 (MAUS-158) had the highest mean emergence count and final plant stand, than V_2 (MAUS-71) and V_3 (JS-335). Different planting dates, different types, and their interactions had no effect on the mean emergence count and final plant stand.

The growth character like plant height, number of branches/plant, pods/plant and dry matter/plant and number of days required to 50% flowering, 50% Pod formation, and maturity were significantly influenced by different sowing dates and different varieties at all stages of the crop.

D_1 (25^{th} MW) had the highest seed yield per plant was (4.57 gm/plant), soybean seed yield per ha (1852.8 kg/ha), straw yield per ha (4257.7 kg/ha), biological yield per ha (6110.5 kg/ha) and harvest indexes (43.5 percent) among all the sowing dates. Among the varieties, MAUS-158 (V_1) produced the highest seed yield per plant (4.08 gm/plant), soybean seed yield per ha (1636.5 kg/ha), straw yield per ha (3842.7 kg/ha), biological yield per ha (5479.2 kg/ha) and harvest index (42.6 percent), whereas, JS-335 (V_3) produced the lowest.

The crop weather relationship was summarised as rainfall was positively correlated with soybean seed yield at P3, P4, and P5 stages and negatively correlated at P1, P6 and P8 stages in all varieties. Maximum temperature was positively affected with seed yield, but lowest temperature was negatively correlated at all stages. At the P5, P6, P8, and P10 stages RH-I was negatively correlated and positively correlated at P1, P2, P3, P4 and P7 stages, whereas, RH-II was positively correlated at P3, P4, and P10 stages and negatively correlated at P4 and P6 stages. Evaporation was positively correlated at stage P1, P2, and P6 stages and negatively correlated in P3, P4, and P10 stages, whereas BSS was positively correlated at P1, P3, P4, P6 and P8 stages negatively correlated at P7, P8 and P10 stages. The wind speed was positively correlated at stage P1, P5, P6, P8 and P9 but negatively correlated at stage P3.

5.3. To compute the Crop Water Requirement Satisfaction Index (WRSI) of soybean.

The Crop Water Requirement Satisfying Index (WRSI) varied with crop stages and is highest during the emergence to flowering stages (99%) then declines during the pod and grain formation stages (70-75%) and rebounds to its highest level during the pod development stage (98%), pod containing full grain stage (100%), dough stage (100%), and maturity stage (98%). The crop's total water demand, or ET_c, over the crop growth period was 505.70 mm, and at all stages of the crop's development, all but the stages of pod formation and grain formation, where a shortage in satisfaction was noted, it was virtually completely satisfied by soil moisture.

5.4 To compute Crop Water Stress Index (CWSI) of Soybean.

As a result of a water shortage, the difference between leaf temperature and air temperature near the leaf was highest at the pod formation stage (4.5 ˚C), grain formation stage (4.2 ˚C), and maturity stage (4.8 ˚C), indicating that the plant was under water stress with CWSI values of 0.98, 0.92 and 1.00 respectively. In contrast, the difference between leaf temperature and air temperature near the leaf was lowest at the remaining majority of plant growth stages, indicating that the plant had access to the ideal amount of water. Higher the difference between leaf temperature and air temperature near the leaf results higher in CWSI values.

CONCLUSION

The crop coefficient values for soybean crop differ from one location to another. At Parbhani, the predicted K_c values for the beginning (0-30 DAS), mid (31-85 DAS), and end (86 - 110 DAS) stages of Soybean cv. MAUS-71 were 0.67, 1.39 and 0.80, respectively. During the *Kharif* season of 2021, the total crop water demand or ET_c, was 505.70 mm. With the highest crop canopy cover, the maximum actual evapotranspiration rate was found between pod formation and grain formation stage with 108.2mm indicating a high crop water demand. Hargreaves approach is ideally suited for the Parbhani location if climatological data is insufficient for the estimate of potential evapotranspiration and crop coefficients temperature based.

When compared to other sowing dates, soybean sown on the 25^{th} SMW (D_1) was shown to be the most favourable in terms of all growth and yield contributing factors, seed yield, straw yield, and biological yield and Harvest index. For the most part, MAUS-158 (V_1) performed well over MAUS-71 (V_2) and JS-335 (V_3) in terms of growth and yield. The yield attributes like plant height, number of branches per plant, pods per plant and mean dry matter per plant was higher in the early sown crop (25^{th} SMW) than the late sown crop (28^{th} MW) during the crop growth season. Similarly, among the varieties, MAUS-158 produces more yield attributes than MAUS-71 and JS-335.

The Crop Water Requirement Satisfying Index (WRSI) was found maximum at all stages except at pod formation and grain formation stages of the crop growth and development due to water insufficient water availability.

Crop Water Stress Index (CWSI) was found maximum at pod formation and grain formation stages of the crop growth and development due to water stress as a result of maximum difference between leaf temperature and air temperature near the leaf.

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Academic Qualification

Course /Degree	**Name of College / Institute**	**University / Board**	**Year of passing**	**Percentage (%) / CGPA**	**Class / Grade**
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