

**SIMULATION OF SOYBEAN GROWTH AND YIELD BY USING
DSSAT MODEL UNDER VARIED ENVIRONMENTAL CONDITIONS
AT PUNE LOCATION**

A thesis submitted to the

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413722, DIST. AHMEDNAGAR,
MAHARASHTRA STATE (INDIA)**

by

**Mr. ARVIND RAMAJI TUPE
(Regn. No. 11/89)**

*in partial fulfillment of the requirements for the degree
of*

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL METEOROLOGY

**DEPARTMENT OF AGRICULTURAL METEOROLOGY,
CENTRE OF ADVANCED FACULTY TRAINING (CAFT) IN
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COLLEGE OF AGRICULTURE, PUNE-411005
MAHATMA PHULE KRISHI VIDYAPEETH, RAHURI
DIST. AHMEDNAGAR (M.S.), INDIA**

(2015)

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CANDIDATE'S DECLARATION

I here by declare that the thesis entitled, **“SIMULATION OF SOYBEAN GROWTH AND YIELD BY USING DSSAT MODEL UNDER VARIED ENVIRONMENTAL CONDITIONS AT PUNE LOCATION”** or part thereof, has not been submitted by me or any other person to any other University or Institute for a Degree or Diploma.

Place : Pune

ARVIND R. TUPE

Date: / /2015

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Professor of Agronomy and
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CERTIFICATE

This is to certify that the thesis entitled, **“SIMULATION OF SOYBEAN GROWTH AND YIELD BY USING DSSAT MODEL UNDER VARIED ENVIRONMENTAL CONDITIONS AT PUNE LOCATION”** submitted to the Faculty of Agriculture, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, District: Ahmednagar, Maharashtra State, in partial fulfillment of the requirement for the degree **DOCTOR OF PHILOSOPHY (AGRICULTURE) in AGRICULTURAL METEOROLOGY**, embodies the results of a piece of bonafide research work carried out by **Mr. Arvind Ramaji Tupe** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or publication in any other form. The assistance and the help received during the course of this investigation and sources of literature referred to have been acknowledged.

Place: Pune

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CERTIFICATE

This is to certify that the thesis entitled, “**SIMULATION OF SOYBEAN GROWTH AND YIELD BY USING DSSAT MODEL UNDER VARIED ENVIRONMENTAL CONDITIONS AT PUNE LOCATION**” submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, District: Ahmednagar, Maharashtra, in partial fulfillment of the requirement for the degree **DOCTOR OF PHILOSOPHY (AGRICULTURE) in AGRICULTURAL METEOROLOGY**, embodies the results of a piece of bonafide research work carried out by **Mr. Arvind Ramaji Tupe**, under the guidance and supervision of **Dr. D. W. Thawal** Professor of Agronomy and Associate Dean, College of Agriculture Pune-5 and that no part of the thesis has been submitted for any other degree or diploma or publication in any other form.

Place : Pune

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(A. R. Tupe)

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(D)**List of Abbreviations**

@	: at the rate
A	: Actual
BSH	: Bright sunshine hours
CD	: Critical difference
CERES	: <u>C</u> rop <u>E</u> nvironment <u>RE</u> sources <u>S</u> ynthesis
cm	: centimetre
cm ²	: Centimetre square
DAS	: Days after sowing
°C	: Degree Celsius
D	: Difference
d	: Day
DAS	: Days after sowing
ET	: Evapotranspiration
EC	: Electrical conductivity
EM	: Emergence
EP	: Evaporation
<i>et al.</i>	: et alia (and others)
etc.	: etcetera
FC	: Field capacity
Fig.	: Figure
FL	: Flowering
FSD	: Full seed development
G	: Gram
GM	: Gross mean
GMR	: Gross monetary return
h	: Hours
ha	: hectare
i.e.	: that is
K	: Potassium
kg	: kilogram
Kg ha ⁻¹	: kilogram per hectare
LAI	: Leaf area index
PM	: Physiological maturity
m	: Metre
m ²	: metre square
MAE	: Mean absolute error
MBE	: Mean bias error
M ha	: Million hectare

mm	: millimetre
mrl	: Metre row length
MT	: Metric tonnes
MW	: Meteorological week
SMW	: Standard meteorological week
N	: Nitrogen
NMR	: Net monetary return
NS	: Non significant
O	: Observed values
$\bar{O}$	: Mean of observed values
P	: Predicted values
P	: Phosphorus
PE	: Per cent error
PF	: Pod formation
PESW	: Plant extracted soil water
PF	: Pod formation
%	: Per cent
/	: per
q	: quintal
r	: Simple
RMSE	: Root mean square error
RDF	: Recommended dose of fertilizer
RF	: Rainfall
RGR	: Relative growth rate
RH	: Relative humidity
Rs.	: Rupees
SD	: Standard deviation
SE(m) $\pm$	: Standard error of mean
SF	: Seed formation
Sig.	: Significant
T	: Treatment
t	: tonnes
Tmax.	: Maximum temperature
Tmin.	: Minimum temperature
V	: Version
Var.	: variety
VG	: Vegetative growth
viz.,	: namely

ABSTRACT

“SIMULATION OF SOYBEAN GROWTH AND YIELD BY USING DSSAT MODEL UNDER VARIED ENVIRONMENTAL CONDITIONS AT PUNE LOCATION”

by

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A field investigation entitled “**Simulation of soybean growth and yield by using DSSAT model under varied environmental conditions at Pune location**” was conducted in ‘D’ division of Agronomy Farm, on the experimental field of Department of Agricultural Meteorology, College of Agriculture, Pune-5 during *kharif* seasons of 2012 and 2013. Four sowing times I FN of June (S_1), II FN of June (S_2), IFN of July (S_3) and II FN of July (S_4) to create different set of environmental conditions for weather variability and three varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) were laid out in Split Plot Design (SPD) with four replications.

The soybean crop was sown in I FN of June (S_1) accumulated higher Growing Degree Days (GDD) and significantly higher biomass and seed yield with maximum heat use efficiency. Subsequent, sowings beyond II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) during 2012 and 2013 encountered higher amount of heat use efficiency and rainfall during vegetative and flowering stage and decreasing trend of heat use efficiency and rainfall across the critical reproductive stage of seed formation to development which consequently resulted in lower seed yield.

Soybean variety, DS-228 (V_3) recorded significantly higher seed yield with maximum heat use efficiency. Subsequent, delay in sowing during II FN of July (S_4) resulted in shortening of the crop growth period and decrease of plant height, dry matter accumulation, leaf area index, yield attributes and harvest index. The growth and yield parameters were recorded the highest in early sown crop I FN of June (S_1), followed by II FN of June (S_2), I FN of July (S_3) and the lowest in II FN of July (S_4) sowing during both years of study.

The climatic factors *viz.*, maximum and minimum temperature ($^{\circ}\text{C}$), morning and evening relative humidity (%), rainfall (mm) and number of rainy days, wind speed (km hr^{-1}), evaporation rate (mm day^{-1}) and bright sunshine (hrs) were played vital role in occurrence and development of pest like *semilooper*, girdle beetle and *spodoptera* on soybean crop. These climatic factors are highly correlated either positively or negatively with the occurrence and development of *semilooper*, girdle beetle and *spodoptera* on soybean crop.

Crop simulation model (CROPGRO-soybean, DSSAT v 4.5) performance in respect of phenological phases *viz.*, anthesis day, first pod day, first seed day, physiological maturity, plant height, leaf area index, seeds per pod, seeds per square meter, threshing percentage and harvest index was found to be highly reliable. The model predicted the reliable seed yield in varieties DS-228 (V_3) and MACS-450 (V_2) during 2013. But the seed yield was slightly overestimated in varieties *viz.*, JS-335 (V_1) and MACS-450 (V_2) during both

the years. Overall, the MBE (mean bias error) values in most of the cases were negative, which indicated that results were slightly under predicted.

Hence, the model performance was found comparatively satisfactory for soybean variety DS-228 (V₃) during *kharif* seasons of 2012 and 2013 under Pune location.

However, the model parameters need further refinement and validation with data of several field experiments conducted under varied environmental conditions.

CHAPTER- I

INTRODUCTION

The present challenges of this country are quite different from the past century. The modern agricultural production factors such as short duration high yielding varieties, hybrid seeds which are highly responsive to irrigation and fertilizer increased the food grain production tremendously to about 260 million tonnes in India. But the production will have to be increased to synchronize with increasing population without more additional increase in inputs. This can be achieved by use of meteorological knowledge for crop production programme along with management practices, Monitoring of climate parameters such as rainfall, maximum temperature and minimum temperature, bright sunshine hours and solar radiation seems to be essential to decide proper time of sowing which influence the crop growth and yield and actual harvesting period to escape the crop from heavy rains. This concept will help for achieving potential yields without additional expenses on inputs (Patil, 2002).

In India, during 2012 and 2013 soybean is grown over an area of 106.9 and 120.3 lakh ha with a production of 126.7 and 129.8 lakh metric tonnes and with an average productivity of 1185 and 1079 kg ha⁻¹, respectively. Madhya Pradesh, Maharashtra and Rajasthan are the major soybean producing states. In Maharashtra, during 2012 and 2013 it was grown over an area of 32.13 and 38.7 lakh ha with total production of 39.5 and 48.5 lakh metric tonnes with an average productivity of 1243 and 1255 kg ha⁻¹, respectively (Anonymous, 2012 and Anonymous, 2013).

Soybean (*Glycine max* (L.) Merrill) has become the miracle of twenty first century. It is paramount importance in human and animal nutrition. It is the cheapest source of high quality protein. Soybean contains 40 to 44 % proteins and 18 to 20 % of excellent edible oil. Soybean has got medicinal value and therefore it is used in preparing antibiotics. Soybean protein is rich in the valuable amino acid lysine (5 %), good amount of minerals and vitamins

(thiamin and riboflavin) and its sprouting grains contain a considerable amount of Vitamin- C (Singh, 1996). In bridging the gap between requirement and availability of proteins soybean assumes a greater importance (Pawar, 2006).

In Maharashtra, mainly the cultivation of soybean is under rainfed condition. It is observed that in most of the years harvesting period of *kharif* soybean is coupled with post monsoon rains resulting into loss of its quality. It is also observed that germination of soybean was considerably affected to the extent of 11 to 20 % (Anonymous 1999). This has alarmed for finding proper time for sowing so as to skip the crop from rains at harvest. Delayed sowing may result in yield reductions to the magnitude of 17-39% (Karmarkar and Bhatnagar, 1995). Delayed sowing of soybean also significantly reduced the protein and oil content (Billore *et al.*, 2000).

The low productivity of soybean both at national and state level is attributed to abiotic (moisture and temperature) and biotic stresses (insect pests and diseases). Among these, insect pests often pose a serious threat to soybean production by increasing cost of cultivation and impairing quality of produce in many ways. Soybean crop is reported to be attacked by about 350 species of insects in many parts of the World (Luckmann, 1971). In India, about 65 insect pests have been reported to attack soybean crop from cotyledon to harvesting stage (Rai *et al.*, (1973), Gangrade, (1962), Adimani, (1976), Mundhe, (1980), Thippaiah, (1997) and Jayappa, (2000).

Defoliators like *Spodoptera litura* (Fab.), *Thysanoplusia orichalcea* (Fab.) damage soybean in early stage and severe defoliation in later stage and thus reducing the photosynthetic capacity of plants, it is major pest of soybean and inflicts severe damage to the crop leading to huge field losses (Adimani, 1976).

Crop simulation model have the potential for its use as a tool in agricultural research directed for better farm performance which simulates duration of crop growth and phasic development, plant morphological development, biomass growth rate and partitioning and yield with reasonable

accuracy. After proper validation, it can become a decision making tool for determination of planting time and amount of fertilizer application, pest and disease management etc. (Hoogenboom *et al.*, 1992).

CERES (Crop Environment Resources Synthesis) Soybean model is one of the dynamic crop growth model. The CERES models were adapted as phenotype. But the model to be used with confidence, it has to be validated for the soil and climatic environment of the area where it could be used. Validation is necessary to test the suitability of the model for the intended purpose. It was reported that application of the CERES- wheat model to yield predictions, the model predicted the grain yield from 80 to 115 % (mean 97.5%) of the observed grain yield (Hundal and Kaur, 1997). Crop models can be used to evaluate crop performance under diverse environment and management scenarios. Crop growth models can be used to predict crop performance in regions where the crop has not been grown before or not grown under optimal conditions. It also facilitates to have pre-harvest estimate of any crop's production. Using crop simulation models, the effects of climate change and climatic variability on crop growth and yield have also been predicted (Lal *et al.*, 1998). Crop simulation modeling for soybean crop has not been attempted in western Maharashtra agro-ecosystem in this regard the present study makes an attempt to use the field experimental data sets to understand the existing crop-weather-management relationships of soybean. Therefore, the present investigation was undertaken with the following specific objectives.

The objectives of present investigation was to use the crop growth model to determine the phenology and productivity pattern across sowing times and cultivars and differential between simulated and observed responses.

- 1) To study the simulation of phenology, growth and yield of soybean crop.
- 2) To validate the optimum sowing time during *kharif* season.
- 3) To determine the population dynamics of pests and diseases in soybean as influenced by different sowing times.

CHAPTER- II

REVIEW OF LITERATURE

This chapter deals with the review of research work done by different scientist on the aspect of growth, productivity, agro-meteorological indices and crop modeling in soybean under varied growing environments. Specific literature on the aforesaid aspects is seldom available. The brief account of literature is classified and presented under different topics to support the findings of the present investigation.

- 2.1 Effect of sowing dates on growth and yield of soybean
- 2.2 Effect of varieties on growth and yield of soybean
- 2.3 Effect of weather parameter on growth and yield of soybean
- 2.4 Crop simulation models
- 2.5 Population dynamics of pests in soybean as influenced by different times of sowing.

2.1 Effect of sowing dates on growth and yield of soybean

Singh *et al.* (1974) conducted an experiment during 1969-70 and observed that delay in planting from 11th June to 21st July reduced the flowering and maturity period, plant height, number of branches but increased the seed weight and yield of soybean crop.

Deshmukh *et al.* (1977) studied response of Clark 63 soybean variety to four dates of planting at Pantnagar and reported that delaying the planting beyond 30th June significantly reduced the number of pods per plant, 100 seed weight, seed yield per plant and seed yield ha⁻¹. However, the protein content of seed increased and oil content decreased with delay in planting.

Arora (1981) conducted field trials at Akola on five sowing dates at one week interval starting from 28th June. It was reported that in soybean crop height and number of leaves per plant were reduced with delay in sowing.

Singh *et al.* (1985) reported that seed yield of soybean cultivar Vls-1 sown at 15 days interval from 15th May to 15th July decreased in the range of 3.29 to 0.61 tonnes per ha with subsequent delay in sowing.

Barik and Sahoo (1989) reported that grain yield was the highest in 10th July sowing followed by 25th June and 25th July sowing which were significantly different from each other. Yield of straw gradually decreased with each delay in sowing time and the harvest index increased significantly from 25th June to 10th July sowing, however, the latter was on par with 25th July sowing. Hence, it was indicated that delayed sowing resulted in higher harvest index.

Jasani *et al.* (1993) conducted an experiment with sowing on 23rd June, 8th July, 23rd July and 7th Aug which produced yields of 1.93, 1.88, 1.48 and 1.18 tonnes ha⁻¹, respectively, indicating decreased seed yield with delayed sowing.

Board and Harvelle (1993) conducted an experiment to study soybean yield components response to light interception gradient during the reproductive period. They concluded that when light interception is increased agronomically through management treatments, such as narrow rows, the effects on yield was noticed during stages R1 to R5 through adjustment in pod number. They reported that LAI and dry matter production and total pod number decreased with decreased light interception.

Jasani *et al.* (1994) conducted an experiment where the crop was sown on 23rd June, 8th July and 7th Aug. They observed that seed yield was the highest with early sowing due to more number of pods per plant and higher test weight which decreased with delay in sowing.

Karmarkar and Bhatnagar (1995) reported in their study that the existence of genotypic variability to suit varied growing conditions including sowing. They concluded that for normal sowing (up to 30th June) under Pantnagar condition, PK-472 was the most suitable variety for higher grain

yield and for late sowing results in significant reduction in grain yield of soybean.

Lingaraju *et al.* (1995) conducted a field experiment with four soybean genotypes and three sowing dates. They observed that second fortnight of June produced significantly higher seed yield over July first and second fortnight which resulted in 31.3 and 28.3 per cent reduction in seed yield, respectively.

Board *et al.* (1997) conducted an experiment to determine the light interception, light use efficiency and leaf area index in soybean. They showed that at the temporal mid point, grain yield declined linearly as light interception decreased from 83 to 50 per cent.

Mahapatra (1998) reported that sowing on 26th June favourably influenced the growth and yield attributes and was found optimum. The seed yield was significantly higher in 26th June sowing compared to sowing on 5th July.

Bhatia *et al.* (1999) noticed that seed yields decreased with delay in sowing. Varieties JS-335, NRC-2 and JS71-05 gave the highest seed yields.

Karad (1999) reported that plant height was the highest in Pb-1 and the lowest in MAUS-55. Similarly, as the sowing was delayed there was reduction in plant height.

Rajput and Shrivastava (1999) observed that maximum seed yield was obtained when the crop was sown on 11th July. There was significant reduction in yield due to delayed sowing with the lowest seed yield under 31st July sown crop.

Growth period of soybean crop from sowing to physiological maturity was shortened as sowing was delayed. Stem weight was decreased by late sowing but seed yield per plant was not significantly affected. Whereas, seed number per pod and harvest index were significantly increased with the late sowing (Park *et al.* 2000).

Billore *et al.* (2000) reported delayed planting significantly reduced the protein and oil content of soybean. The average soybean seed yield decreased linearly by 181.77 kg ha⁻¹ for every 5 days delay in sowing from the normal date (25th June).

Kausale (2000) reported that plant height and number of branches per plant were reduced with delay in sowing.

Krishnamurthy *et al.* (2000) claimed that dry matter production increased with increasing plant age until harvest. It decreased with delay in sowing. Plant height and number of branches was also decreased with delay in sowing.

According to Rajendra Prasad (2002) photoperiodic response dictates the time of sowing for maximum yields in soybean. Early planting gave too great canopy to produce maximum yield, whereas, late sowing resulted in canopy development too restricted for maximum yield.

Hundal *et al.* (2003) reported that leaf area development, dry matter accumulation and seed yield correlated with agro-climatic indices such as growing degrees days, heliothermal units, photo thermal units and heat use efficiency.

Singh and Hundal (2004) reported that early sowing (6th June) resulted in higher LAI and PAR interception than 23rd June sowing. There were non-significant differences in seed yield, seed/straw ratio and 1000 seed weight among dates of sowing and varietal treatments. However, straw yield differences were significant.

Anil kumar *et al.* (2008^a) reported that early sown soybean crop (June 16th) produced more dry matter and also resulted in higher seed and straw yields than late sown crop as they availed more growing degree days.

Jadhao (2009) reported that among different genotypes in soybean crop, genotype JS-335 recorded overall significantly higher plant height, number of branches per plant, dry matter weight per plant, leaf area and leaf area index.

Whereas, earliest sowing during 20th June (25th MW) recorded highest values. There was significant positive correlation between grain yield and biomass production. Total number of pods per plant showed highly significant positive correlation with grain yield as well as biomass production. Harvest index showed highly significant positive correlation with number of pods per plant, grain yield as well as biomass production. Intercepted radiation showed significantly positive correlation with biomass production, grain yield, number of pods per plant and harvest index. Dry matter accumulation per plant exhibited highly significant positive correlation with maximum temperature and significant negative correlation with mean relative humidity.

Mane (2011) reported that plant height, number of branches, leaf area plant⁻¹, leaf area index and dry matter weight plant⁻¹ were significantly superior with early sown crop (26 MW-28th June) and decreased with each delay in sowing (27 MW- 06th July, 28 MW- 13th July and 29 MW- 21st July). Early sown soybean crop (28th June) required more number of days from sowing to maturity than the crop sown later. Significantly higher values for number of pods plant⁻¹, weight of seed plant⁻¹ and seeds pod⁻¹ was obtained due to early sowing (28 June) which was at par with 06th July sowing. Later sowings (13th July and 21st July) decreased these yield components. Hundred seed weight was not significantly influenced due to sowing time. Significantly the highest seed (1847 kg ha⁻¹) was obtained when soybean crop was sown on 28th June. Subsequent 6th July sowing also recorded comparable yield levels. Crop sown on 21st July recorded the lowest seed yield (918 kg ha⁻¹). Similar trend was also observed in terms of biological yield and harvest index.

2.2 Effect of varieties on growth and seed yield of soybean

Katti *et al.* (1970) reported that Bragg, Shelly, Harosoy, Lee, Clark-63 and Wayne started flowering 33 days after sowing. The initiation of flowering was observed at 35, 40 and 64 days after sowing in Hampton, Hill and K-16, respectively. Hill variety produced the highest seed yield followed by K-16. Variety Bragg was intermediate while Hampton was the lowest yielder.

Hanway and Weber (1971) reported that within varieties, rates of dry matter accumulation in different plant parts of soybean were similar from stage 5 to 9. Daily rates of dry matter accumulation in the plant varied among varieties from 88 to 149 kg ha⁻¹ day⁻¹. The rate of dry matter accumulation in seeds of all varieties was similar at 99 kg ha⁻¹ day⁻¹ from 30 days after stage 5 and stage 10. Pods of all varieties increased in weight at a rate of 51 kg ha⁻¹ day⁻¹ from 20 days after 5 to 8 stages.

Diaz *et al.* (1986) reported that in soybean crop the relationship between days to maturity and plant height was most marked. Relationship between pods per plant, seed per pod and 500 seed weight were also important with consequences for yield per plant. Seasonal variation was observed with closeness of association with yield and the characters studied.

Nirmalkumari and Balasubramaniam (1990) conducted an experiment to study the high yielding soybean varieties. They reported that high yielding cultivars recorded high values of specific leaf weight, crop growth rate, harvest index and total dry weight per plant as compared to low yielding ones. Earlier attainment of high CGR and leaf area index was associated with higher seed yield per plant.

Mahajan *et al.* (1993) reported that seed yield per plant positively correlated with seeds per plant, pods per plant, branches per plant, days to 50% flowering, days to maturity and plant height in soybean.

Bhatia *et al.* (1999) observed that seed yield decreased with delay in sowing and varieties JS-335, NRC-2 and JS 71-05 of soybean gave the highest yields.

Jadhao (2009) reported that soybean genotype TAMS-98-21 availed the highest crop duration as 134 days. Genotype JS-335 indicated comparative suitability for sowing time between 25th to 29th MW. There was no much variation in occurrence of particular phenophase due to dates of sowing, in respect of all the genotypes. However, there was variation of 2 to 8 days in total crop period. Among different genotypes, genotype JS-335 recorded overall significantly higher number of pods per plant, grain yield, straw yield

and biological yield. Whereas, the earliest sowing during 20th June (25th MW) recorded overall significantly higher value of these and which was reduced gradually with subsequent delay in sowing. Test weight of seeds was significantly higher in TAMS-38. There was no significant difference in test weight of seeds due to sowing between 25th to 28th MW but there was drastic reduction in respect of sowing in 29th MW.

Singh *et al.* (2010) reported that yield attributes in soybean crop like pods per plant, number of seeds per pod and 100 seed weight decreased with subsequent delay in sowing from 7th June onward during both the seasons.

Mane (2011) reported that variety JS-335 recorded the maximum number of pods plant⁻¹ and seed weight plant⁻¹. Varietal differences as regards number of seeds pod⁻¹ and hundred seed weight were not significant. Soybean variety JS-335 recorded significantly higher seed yield (1725 kg ha⁻¹) over TAMS 98-21 (1374 kg ha⁻¹) and NRC-37 (1303 kg ha⁻¹). Soybean variety TAMS 98-21 recorded the highest biological yield (3301 kg ha⁻¹) which was significantly superior over NRC-37 and at par with JS-335. Similarly, JS-335 was significantly superior over NRC-37 and TAMS-98-21 with the maximum harvest index (53.19%).

2.3 Effect of weather parameters on growth and yield of soybean

Brown and Chapman (1960) conducted an experiment to study available moisture as well as average mean temperature which were correlated with development rate during flowering period. They found that average rate of development per degree temperature during pre-flowering period calculated from equation was nearly the same as that observed in the curve development in field studies. Mean air temperature at lower rates were observed in post flowering period.

Hofstra (1971) studied soybean subjected to day temperature from 18 to 30 °C under controlled green house at high light intensities. Leaf area production reached the maximum at 27 °C to 30 °C, whereas, both maximum dry matter accumulation and stem elongation was highest at 36 °C.

Luxmoore *et al.* (1971) reported that a non-relationship between the incoming radiation and energy received a plane within the crop, indicated that changes in leaf inclination during period of high isolation gave a more open canopy. Measurement of energy 310 to 2750 mm wave band showed that from 65 to 85% of the radiation received at a plane in the crop come from the upper hemisphere and the remaining energy was reflected to the under surface.

Egli and Wardlaw (1980) revealed that soybean were grown at 24/19 °C until beginning seed growth and shifted to 18/13 °C, 24/19 °C, 27/22 °C, 30/25 °C and 32/28 °C (day/night temperature 8 hours day) unit maturity. Air temperature increased from 18/13 °C to 27/22 °C but there was no further change as the temperature increased to 33/28 °C. Excised cotyledons showed a similar growth rate response to temperature. Exposing the plants to high temperature (33/28 °C) during the period which is sensitive to temperature level and not influenced by temperature 21/19 °C to 30/25 °C.

Seddigh and Jolliff (1984) conducted an experiment to study the effect of night temperature on morphology, phenology, yield and yield components of field grown intermediate soybean. They concluded that plant with warmer night accumulated more heat unit than check. Seed weight per plant increased by 37 per cent over the check at 27 °C, by 20 per cent at 16° C and by 23 per cent at 24 °C temperature treatments. The growth of individual seeds appeared to be most responsible of night temperature and increased seed size accounting for the increase in seed yield.

Balkrishnan and Natrajaratnam (1986) studied heat use efficiency under different dates of sowing. They revealed that heat use efficiency was higher in 21st February than in 21st September sowing. Seed yield had positive and significantly associated with heat units availed at flowering and harvest stages.

Jameo (1987) revealed that increasing light intensity from 5000 to 10000 lux, increased photosynthetic rate, leaf area, nodule weight, root and pod dry matter in both the inoculated and non-inoculated (bio-fertilizer) soybean crop.

Melges (1989) conducted that total plant dry matter, leaf, stem, root and pod dry matter accumulation of soybean crop decreased with radiation. Also the seed yields decreased solar radiation and yield were 1.74, 1.81, 1.14 and 0.99 t/ha with 100, 70, 50 and 30 per cent of solar radiation, respectively. However, harvest index was not significantly affected by shedding.

Seed yield increased with late maturity but the percentage of diseased seed increased and the percentage of wrinkled and shrivelled seeds was reduced and hence the percentage of wrinkled and shrivelled seeds get positively correlated with relative humidity while per cent diseased seed follows the reverse pattern (Hatam and Khallil, 1994).

Shrivastava *et al.* (2000) stated that, biomass production of soybean in relation to accumulated heat units has been expressed linear regression.

Veni *et al.* (2003) found that morning relative humidity was the most prominent element throughout crop growth to impact significant and positive correlation with evening relative humidity. The sunshine hours significantly correlated with dry matter production of all four-soybean genotypes.

Tetsuji Oya *et al.* (2004) reported that reproductive development of soybean was retarded by the drought stress and it tend to be retarded less in drought tolerant varieties.

Jadhao (2009) reported that soybean genotype TAMS-38 sown at 20th June (25th MW) recorded highest thermal use efficiency of 0.29 kg/ha/D°C and 0.37 kg/ha/D°C in terms of grain yield and straw yield respectively, and produced highest biological yield of 0.67 kg/ha/D°C when sown during 20th June i.e. 25th MW.

Jadhao (2009) conducted experiment on soybean and reported that the incoming and outgoing solar radiation was found to be on par in all the genotypes during all the phenophases. Crop sown on 20th June recorded higher amount of incoming as well as outgoing solar radiation at top and bottom of the crop during the all phenophases except stage of full size grain seed to

physiological maturity at top of the crop in outgoing radiation. First sowing was done on 20th June (25th MW) the crop recorded significantly highest percentage of light interception during phenological phases of sowing to physiological maturity. Air temperature and relative humidity at morning as well as evening in both genotypes and sowing dates was found to be non-significant differences among at all the phenophases of soybean crop.

Mane (2011) reported that growing degree days (GDD) to reach various phenological stages decreased with each delay in sowing. Overall, early sown crop (28th June) availed highest GDD from sowing to maturity (1695.9 °C days), and the lowest being under 21st July sowing (1508.4 °C days). Thermal use efficiency in terms of seed yield was found to be similar (1.09 kg ha⁻¹ °C day⁻¹) under 26 MW sowing (28th June) and 27 MW sowing (06th July) and it was decreased in the later sowings of 13th July (0.88 kg ha⁻¹ °C day⁻¹) and 21st July (0.61 kg ha⁻¹ °C day⁻¹). Across the total growing period of the soybean crop the rainfall, minimum temperature, relative humidity at evening and GDD showed positive contribution in seed production.

2.4 Crop simulation models

According to Walker and Splinter (1971) mathematical model is defined as a functional relationship between dependent observable plant response such as growth, weight change, photosynthetic change, etc. and the pertinent variable influencing the plant of soybean crop.

Arkin and Dugas (1984) explained the utility of sorghum crop models to develop strategic and to some extent tactical production practices. Because of the spatial variations in weather the use of crop models makes the supportive decisions more rational.

Jefferies *et al.* (1991) reported that if a model is going to have general application, it is necessary to validate it by comparing prediction made by the model with results observed in the field. Validation will show the strength and weakness of a particular model.

According to Kalra and Aggarwal (1994) crop simulation models are effective tools for assessment of growth and yield of crop as well as to suggest optimal resource management options.

Saminova and Porter (1995) reported that the crop simulation models are used widely to predict crop growth and development in studies of the impact of climate change.

Rey *et al.* (1996) reported that the simulating was not skewed. Thus, the model explained well the variation due to planting dates and plant spatial distribution in the field.

According to Wang *et al.* (1997) accurately predicting days to flower in soybean is important because the time between emergence to flowering determines plant size and thus affects dry matter production and final crop yield.

Long-term simulations with recorded weather data showed that soybean was more sensitive to planting date under irrigated conditions than rainfed management in the three studied Galician locations (Ruiz *et al.* 2001).

Jagtap and Jones (2002) reported that the grid-specific yield correction approach can effectively correct bias in simulated yields and accurately predict interannual variability using readily available inputs. Future steps are needed to incorporate procedures that account dynamically for yield susceptibility to pests and diseases. Testing and improvement of the model should continue to realize its potential.

Southworth *et al.* (2002) observed in their study region that as a whole the climate change modeled research could have an overall beneficial effect with mean soybean yield increase of 40% over current levels.

Wolf (2002) reported that changes in climatic variability did not result in a yield change at any site, both with and without irrigation and both for CROPGRO and SOYBEAN models. With irrigation, the change in the coefficient of variation (CV) of seed yield by climate change was nil for both

models, and without irrigation, the change in CV was variable depending on site, climate change scenario and model. The management response analyses showed that the crop variety need not be changed in response to climate change, that the yield increase due to climate change was greater for an advanced sowing date (but only without irrigation), and that irrigation requirements decreased with climate change only in the case of an early sowing date. The uncertainty analyses showed that the yield change due to climate change was practically not affected by the used crop variety and soil type, but that this yield change may become different when a different growth model was applied or a different sowing date was chosen.

Deosthali (2004) reported validation of CROPGRO-soybean model using three sowing dates with three plant densities with a high level of confidence wherein the prediction results indicated that the model is capable of predicting the phenological phases and seed yield reliably.

Pachepsky *et al.* (2004) observed that three cultivars of soybean for different temperatures demonstrated very similar qualitative morphological characteristics; however, the quantitative difference was significant for each cultivar and temperature regime.

Prabhjyot-Kaur *et al.* (2004) revealed that the simulated phenologic events showed deviations of -5 to +10 days for flowering, -3 to +10 days for first pod, -11 to +2 days for full pod and -6 to +4 days for physiological maturity of the crop.

Mall *et al.* (2004) observed that there was a decrease in soybean yield (ranged between 10 and 20%) when the effect of rise in surface air temperature at the time of the doubling of CO₂ concentration was considered. The results obtained on the mitigatory option for reducing the negative impacts of temperature increases indicate that delaying the sowing dates would be favorable for increased soybean yields at all the locations in India.

Sun Hong Min and Li XiaoMing (2007) revealed that leaf is one of the most important organs of soybean. Modeling of soybean leaf structure is useful to the research of its leaf function.

Dogan *et al.* (2007) observed that the reduction in irrigation water resulted in less soybean yield and similar results were obtained from simulations. In general, CROPGRO-Soybean model satisfactorily simulated soybean yields and yield components.

Sadok *et al.* (2007) reported that maximum leaf expansion rate was observed in the absence of stress and of evaporative demand has a genetic variability which is usually smaller than environmental effects.

Anil kumar *et al.* (2008^b) CROPGRO- soybean model validation results under Anand (Gujarat) condition observed that simulated days to various growth stages, phenophases, physiological events viz., 50 per cent flowering, 50 per cent podding, leaf area index, number of seed per pod, biomass, physiological maturity and seed yield with least error. CROPGRO-soybean simulated values of seed and biomass yield of 26th June sowing time at 30 x 5 cm spacing was closer to the observed values of GS-2 cultivar of soybean and was best performance among the other treatment combinations.

Dallacort *et al.* (2008) observed that from the five simulated sowing dates, October 15th and November 1st were considered the best dates for soybean sowing, presenting an average for the four cultivars in the 25 simulations of 2,450 kg ha⁻¹ and 2,303 kg ha⁻¹, respectively. The yield probability analysis proved to be a great tool in decision-making as for the time of sowing of soybean.

According to Banterng *et al.* (2010) CSM – CROPGRO – soybean simulations indicated that the optimum planting dates from June 15th to July 15th produced maximum soybean yield in a rainfed environment. However, the planting date December 15th produced the highest yield under quality irrigation.

Singh *et al.* (2010) reported that deviation varied from -4.47 to -8.95 seeds per pod in 2006 and -5.12 to -8.15 seeds per pod in 2007. The comparison of observed and simulated yield parameters viz., seed and straw yield showed that the model overestimated under all sowing dates. The straw yield was mostly overestimated but it was underestimated when crop sown delayed.

Setiyono *et al.*, (2010) reported that SoySim required just two genotype-specific and two crop management-specific input parameters and yet provides reasonable accuracy in simulating growth and yield under optimum growth conditions across a wide range of sowing dates, plant population, and yield (2.5-6.4 Mg ha⁻¹). Few cultivar-specific parameter input requirements, lack of requirements for specification of key developmental stages, and mechanistic treatment of phenological development, canopy photosynthesis, and seed dry matter accumulation give several advantages to SoySim for use in research and for use as a decision-support tool to evaluate the impact of crop management options on yield potential in favorable environments.

According to Farzad Paknejad *et al.* (2012) CROPGRO model could be used for sowing date management of soybean. Model was successful in the trait simulation (leaf Area Index, leaf Dry Weight, stem dry weight and biomass) evaluated for cv. Williams.

2.5 Population dynamics of pests in soybean as influenced by different dates of sowing

2.5.1 Incidence of major insect pests in soybean

2.1.1 Seasonal incidence of defoliator pests of soybean

Approximately 380 species of insects have been collected from soybean crop from different corners of the World (Luckmann, 1971). A total of 267 insect species were reported from soybean fields in Arkansas (Tugwell *et al.* 1973).

Saxena (1972) observed 32 insect pests and two non-insect pests of soybean in Madhya Pradesh. Singh (1973) reported 56 insect pests and a mite on soybean crop from Pantnagar, Uttar Pradesh.

Rai *et al.* (1973) recorded 24 insect species feeding on soybean in Karnataka, among them maximum damage was done by the larvae of *Lamprosoma indicata* F, *Stomopteryx subsecivella* Zeller, *Diacrisia oblique* Walker and the gelechid shoot borer. About 85 species of insects belonging to six different Orders and a mite on soybean were reported from Madhya Pradesh by Gangrade (1962) and Adimani (1976) recorded 59 insect species belonging to six Orders occurring around Dharwad on soybean in Karnataka. The semilooper, *Thysanoplusia orichalcea* was a pest mainly during *kharif* although it was observed in stray instances during summer also (Mundhe, 1980).

Zag and Kushwaha (1983) reported the population of *S. litura* in cabbage crop to be negatively correlated with average and maximum temperature.

Sontakke and Patro (1991) reported the incidence of about 20 insect pests on soybean in Western Orissa.

The minimum temperature, relative humidity and rainfall proving negative relationship with population of *S. litura* infesting groundnut crop in Junagadh area (Anonymous, 1992).

Field studies were carried out during 1988-89 in Chiplima, Orissa, India, and the *kharif* soybean crop was damaged greater due to insect pests than the *rabi* season crops. Lowest pest incidence and higher yields were recorded with early sowing time (20th June, 5th July, 1st and 15th November) in both *kharif* and *rabi* seasons. Three need-based applications of monocrotophos in *kharif* and two in *rabi* gave satisfactory control of all the insect pests, resulting in increased grain yield of 11.2 and 3.1 q/ha, respectively, as compared to control as reported by Sontakke and Mishra (1994).

The studies on date of sowing carried out at Dharwad also revealed that the higher incidence of *S. litura* with late sown groundnut crop (Patil, 1995).

The incidence of *S. litura* male moths was abundant during the crop season and reached peak from August to September. During the experimental period, temperature and relative humidity played a major role in the population fluctuations. Results of the cumulative data correlation showed that the population of *S. litura* was found to have significant and positive correlation with maximum temperature and sunshine hours whereas minimum temperature, morning vapour pressure, evening vapour pressure and morning RH showed negative correlation. These findings were in concurrence with the reports of Malik and Parihar (1996) and Dhawan and Simwat (1996).

Thippaiah (1997) noticed 34 species of insects on soybean during *kharif* season and 25 species during summer season, in Bangalore, Karnataka. Among these, lepidopteran defoliators, *T. orichalcea*, *S. litura*, *Achaea janata* (Linn.) and *A. lactina* (L.) appeared only during *kharif* season where as *Spilosoma obliqua* (Walker) was noticed during both summer and *kharif* seasons.

The population dynamics of soybean pests and their natural enemies in 3 medium cycle cultivars were surveyed weekly from July to October 1995 in Tocantins State, Brazil using the plant-shaking method. *Anticarsia gemmatilis*, *Hedylepta indicata* [*Omiodes indicata*] and *Chrysodeixis includens* occurred in decreasing order of abundance. *Cerotoma* sp. was the most abundant defoliator beetle found during the extension of cultural development cycle, with population peaks observed close to the reproductive stage. Among the natural enemies collected, *Cicloneda sanguinea*, *Geocoris* sp. and *Lebia* sp. were the most abundant, as reported by Didonet *et al.* (1998).

The population density of some insects associated with soybean was estimated in a field experiment in India in *kharif* 1985 by following simple random sampling and two-stage sampling techniques at three stages of plant growth, 60-64, 86-89 and 98-99 days after sowing, using the ground cloth sampling method. Population densities of *S. obliqua* Walker and *S. litura* (Fab.)

during the crop growth period were maximum around the second half of October. However, density of *T. orichalcea* (Fab.) was higher during the later part of September or early October. Significant correlations were observed between population densities of some insect species as reported by Vinod Kumar *et al.* (1998).

Jayappa (2000) reported 40 and 21 species of insects attacking soybean during *kharif* and summer seasons, respectively in Bangalore, Karnataka. 300 species of insect pests were infesting soybean, of which blue beetle, grey semilooper, green semilooper and stem fly were major insect pests in Madhya Pradesh (Singh *et al.* 2000).

The lepidopteron defoliators like *S. litura*, *T. orichalcea* and *S. obliqua* were observed on the crop from 28 days after growth and caused severe defoliation in Bangalore as reported by Kamala (2000).

Three hundred species of insect pests infesting soybean were reported by Singh *et al.* (2000) of which blue beetle, grey semi looper, green semi looper and stem fly were major insect pests in Madhya Pradesh.

Negoyen Phi-Dieu Huyen (2001) reported that lepidopteron defoliators like *S. litura*, *T. orichalcea* and *L. indicata* were observed from 21 DAG, of which *H. armigera* was a major pest. *S. litura* (Fab.) was seen from 21 to 49 DAG with less incidence (0.12 to 0.5 per plant), *T. orichalcea* was observed from 21 to 77 DAG and population was more at 42 and 49 DAG.

Patil (2002) reported that soybean was attacked by 48 phytophagous insect species, among these the seedling borers, *M. sojae* Zehnter, *Obereopsis brevis* Swed, leaf eating caterpillar *S. litura* (Fab.) and pod borer, *Cydia ptychora* Meyrick were key pests during *kharif*. Whereas, leaf miner, *A. modicella*, white fly, *Bemisia tabaci* Genn and leaf hopper, *Ambrasca biguttula biguttula* Ishida were major pests during summer.

The studies on date of sowing was conducted at Dharwad also revealed that the incidence of *S. litura* with late sown ground nut crop (Patil, 1995), and same thing was reported on soybean (Patil, 2002).

An experiment was carried out at the experimental station of the University of Tocantins in Gurupi, Brazil to determine the population fluctuation of soybean pests. Among defoliating caterpillars, *A. gemmatilis* (Hub.) and *Cydia includens* were the most abundant. Among the defoliating beetle complexes, *Cerotoma arcuata* (Oliv.) was the most abundant, with population peaks near the reproductive stage as reported by Didonet *et al.* (2003).

Thanki *et al.* (2003) reported that the outbreak of this pest occurs due to resistance to insecticide, favourable weather conditions, cyclonic weather and heavy rainfall after a long dry spell. The *S. litura* damage assessment was done by counting the total number of leaves and the number of affected leaves and the percentage was worked out.

Sastawa *et al.* (2004) reported that the number of insect defoliators and pod sucking bugs were significantly higher in soybean sown on 31st July in 2001 and on 28th August in 2002. Grain yields were higher in early sown soybean in 2001 compared to 2002.

Sailaja Rani *et al.* (2006) reported that Minimum temperature, morning and evening relative humidity and rainfall exhibited non-significant and negative relationship with population of *S. litura* infesting onion crop in Guntur area of Andhra Pradesh.

Meena and Sharma (2006) reported the minimal larval population of 1.42 larvae per mrl in early sown crop (25th June), followed by mid sown crop and late sown crop which recorded 1.67 and 1.87 larvae per mrl, respectively, at udaipur, Rajasthan.

Madrap *et al.* (2007) recorded the seasonal incidence of insect pests of soybean during *Kharif* season at Parbhani. The studies revealed that the

infestation of leaf miner and semilooper was less during the season. However, infestation of *S. litura* and girdle beetle was more up to 6.8 and 5.6 per cent, respectively.

Maximum larval population of *S. litura* and *T. orichalcea* (7.80, 12.00, 12.80 and 6.50, 6.20 and 8.60 larvae/mrl, respectively) were noticed on the crop sown on 08-06-06, 27- 06-06 and 08-06-06 dates, respectively. Early sown crop recorded lower incidence of *S.litura*, *T. orichalcea* and *S. obliqua* compared to that of late sown crop as reported by Harish (2008).

Joshi and Patel (2010) also observed non-significant relationship between the insect pest population and the ambient weather.

Selvaraj *et al.* (2010) reported that infestation of bollworms in bhendi crop to be positively correlated with maximum temperature and dewfall.

Sinha and Netam (2013) reported the early sown crop had least infestation by girdle beetle and highest grain yield. The girdle beetle attack increased in the subsequent dates of sowing. Among four different dates of sowing, crop sown on 4th July revealed minimum infestation by girdle beetle with 2.07 to 2.63 girdle beetle infested plants per meter row length, whereas maximum infestation by girdle beetle was recorded on crop sown on 4th August with 6.01 to 6.20 infested plants per meter row length. Based on the observations of sowing of soybean in the first week of July is most appropriate as it escapes the damage by girdle beetle to a larger extent. The maximum grain yield was obtained from the crop sown on 4th July i.e. 2320 and 2240 kg/ha from varieties NRC-37 and Bragg. It was followed by the yield obtained in crop sown on 14th and 24th July. The crop sown on 4th August recorded least yield i.e. 1748 and 1826 kg/ha from the two varieties NRC-37 and Bragg, respectively.

Netam *et al.* (2013) reported that the Girdle beetle, *O. brevis*, tobacco caterpillar, *S. litura*, green semilooper, *C. acuta*, whitflies, *B. tabaci* and jassids, *E. kerri* were observed as the major pest on soybean variety JS-93-05. The peak activity of girdle beetle (3.2 damaged plants/m row) and

lepidopterous larvae (5.0 larvae/m row) was recorded during last week of August and that of sucking pests (4.4 insects/plant) during third week of September.

Two species of lady bird beetle, *C. septumpunctata* and *M. sexmaculata* and two predatory spiders- Lynx spider and golden predatory spider were found predating mainly on jassids and whiteflies. A predatory pentatomid bug, *E. furcellata* was noticed sucking the body sap of lepidopterous larvae. There existed a positive but non-significant co-relation between caterpillar pests and predators ($r = 0.545$) and between sucking pests and predatory fauna ($r = 0.798$), respectively reported by Netam *et al.* (2013)

CHAPTER- III

MATERIALS AND METHODS

The present investigation entitled “Simulation of soybean growth and yield using DSSAT model under varied environmental conditions at Pune location” in *kharif* seasons of 2012 and 2013 was conducted to validate the growth and development sub-routine of CERES-Soybean model during *kharif* season under field conditions. The details about materials used and methods adopted during investigation are given in this chapter.

3.1 Details of experimental materials

3.1.1 Experimental site

The present experiment was laid out in ‘D’ division of Agronomy Farm, at the experiment field of Department of Agricultural Meteorology. College of Agriculture Pune-5 during *kharif* seasons of 2012 and 2013. It is located on 18° 32` N latitude and 73° 51` E longitude.

3.1.2 Soil

The topography of the experimental field was well leveled and uniform. The soil of this plot was Vertisol (medium black) clayey in texture. The field was well drained having depth more than 90 cm. Representative samples were collected to know the chemical properties of the soil from depth 0-30 cm and 0-90 cm. Data regarding physico-chemical properties (Table 3.1 A) and physico-constants (Table 3.1 B) of the experimental field alongwith analytical method used for estimation are given below.

The bulk density of soil was determined by core sampler method (Dastane, 1972). The drained upper limit of plant extractable soil water were determined by pressure membrane extractor technique at 1/3rd bar and 15 bar pressure by compression machine, and the mechanical analysis of soil was done by Bouyoucos hydrometer method (Black, 1965)

Table 3.1 (A) Physico-chemical properties of soil

Sr. No.	Particulars	Observation	Analytical method adopted
A	Physical		
1.	Coarse Sand (%)	4.56	Bouyoucos hydrometer method (Page <i>et al.</i> 1982)
2.	Fine Sand (%)	25.67	
3.	Silt (%)	16.69	
4.	Clay (%)	45.44	
5.	Organic Carbon	0.30	Rapid titration (Jackson, 1973)
6.	Oven dry moisture	3.61	-----
7.	Textural class	Clayey	Textural Triangle
B	Chemical composition		
1.	pH (soil: water, 1:2.5)	8.1	pH meter (Jackson, 1973)
2.	EC	0.84	EC meter (Jackson, 1973)
3.	CaCO ₃	7.78	-----
4.	Mg	11.71	-----
5.	N (kg ha ⁻¹)	212.20	Alkaline permagnate method (Subbiah and Asijia, 1956)
6.	P (kg ha ⁻¹)	23.86	Olsen P method (Olsen <i>et al.</i> 1954)
7.	K (kg ha ⁻¹)	360.0	Flame photometry (Hanway and Heidal, 1967)

Table 3.1 (B) Physico-constants of soil at different depth

Method of Determination	Pressure plate apparatus		Field method	Core sampler
Depth (cm)	LL* (cm ³ cm ⁻³)	DUL* (cm ³ cm ⁻³)	SATW* (cm ³ cm ⁻³)	Bulk density (g cc ⁻¹)
0 - 5	0.197	0.42	0.55	1.20
5 - 15	0.196	0.40	0.54	1.19
15 - 30	0.192	0.39	0.52	1.20
30 - 45	0.191	0.38	0.52	1.22
45 - 60	0.189	0.37	0.51	1.26
60 - 75	0.180	0.37	0.51	1.27
75 - 90	0.178	0.36	0.50	1.27

* LL- Lower level, DUL-Drained upper level, SATW- Saturated soil water content in layer L.

3.2 Climatic condition

The climatic conditions of the location are described under the following heads.

3.2.1 General climate

The location of the site i.e. Pune is on the Eastern side of the Western Ghats and Agro-climatically it comes under the Plain Zone of Maharashtra state.

Geographically, Pune is situated at 18° 32' N latitude and 73° 51' E longitude. The altitude of the Pune is 557.7 m above mean sea level. The average annual rainfall of the place is 670.0 mm. Out of the total rainfall, about 75 per cent is received through Southwest monsoon during the month of June to September, while remaining rainfall is received during the post monsoon months (Oct-Nov). From December to May, there is dry spell period with abundant sunshine and clear sky. The highest value of temperature ranges is between 34°C to 44°C, during the months of April and May, while the lowest value ranges between 6°C to 10°C in the months of December and January. The annual average maximum and minimum temperatures are 32.0°C and 18.2°C, respectively.

The annual average morning relative humidity (RH-I) recorded at 7.30 hrs is 71 per cent while annual average afternoon relative humidity (RH-II) recorded at 14.30 hrs is 46 per cent. The peak wind velocity is in the month of July and the least in the month of December. The annual mean wind velocity ranges between 2.7 and 9.2 km hr⁻¹ with an average insolation of 20.50 MJ m⁻² d⁻¹.

3.2.2 Climatic condition during experimental period (*kharif*, 2012 and 2013)

In order to get an idea about the climatic conditions prevailing during the period of the present investigation, the meteorological data recorded on the important weather parameters during the cropping season are presented in Table 3.2 and graphically depicted in Fig. 1 to 6. The meteorological data were obtained from the Department of Agricultural Meteorology and Centre of

Advanced Faculty Training (CAFT) in Agricultural Meteorology, College of Agriculture, Pune-5.

Weather during crop period

Actual rainfall during June 2012 to March 2013 was 514.6 mm which was received in 40 rainy days. The mean maximum and minimum temperature during the crop growth period ranged between 26.6 °C to 35.8 °C and 12.3 °C to 24.9 °C, respectively. Morning and evening relative humidity during the crop period ranged between 70 % to 95 % and 33 % to 86 %, respectively. The highest (95 %) morning RH was recorded during 40 SMW where as the lowest (33 %) evening RH was observed during 46 SMW. The bright sunshine hours were the highest 10.5 hrs recorded in 22 SMW. (Table 3.2)

During 2013-14, actual rainfall during June 2013 to March 2014 was 767.7 mm which was received in 51 rainy days. The mean maximum and minimum temperature during the crop growth period ranged between 24.8 °C to 35.7 °C and 12.2 °C to 24.3 °C, respectively. Morning and evening relative humidity during the crop growth period ranged between 69 % to 92 % and 31 % to 88 %, respectively. The highest (92 %) morning RH was recorded during 30 SMW where as the lowest (31 %) evening RH was observed during 46 SMW. The bright sunshine hours were the highest 9 hrs recorded during 22 SMW. (Table 3.2)

3.3 Cropping history of the experimental field

The cropping history of the experimental field previous four years is presented in Table 3.3

Table 3.3 Cropping history of experimental field

Year	Crop cultivated		
	<i>Kharif</i>	<i>Rabi</i>	Summer
2008-09	Soybean	Wheat	Fallow
2009-10	Soybean	Wheat	Fallow
2010-11	Soybean	Wheat	Fallow
2011-12	Soybean	Wheat	Fallow
2012-13	Present investigation		
2013-14	Present investigation		

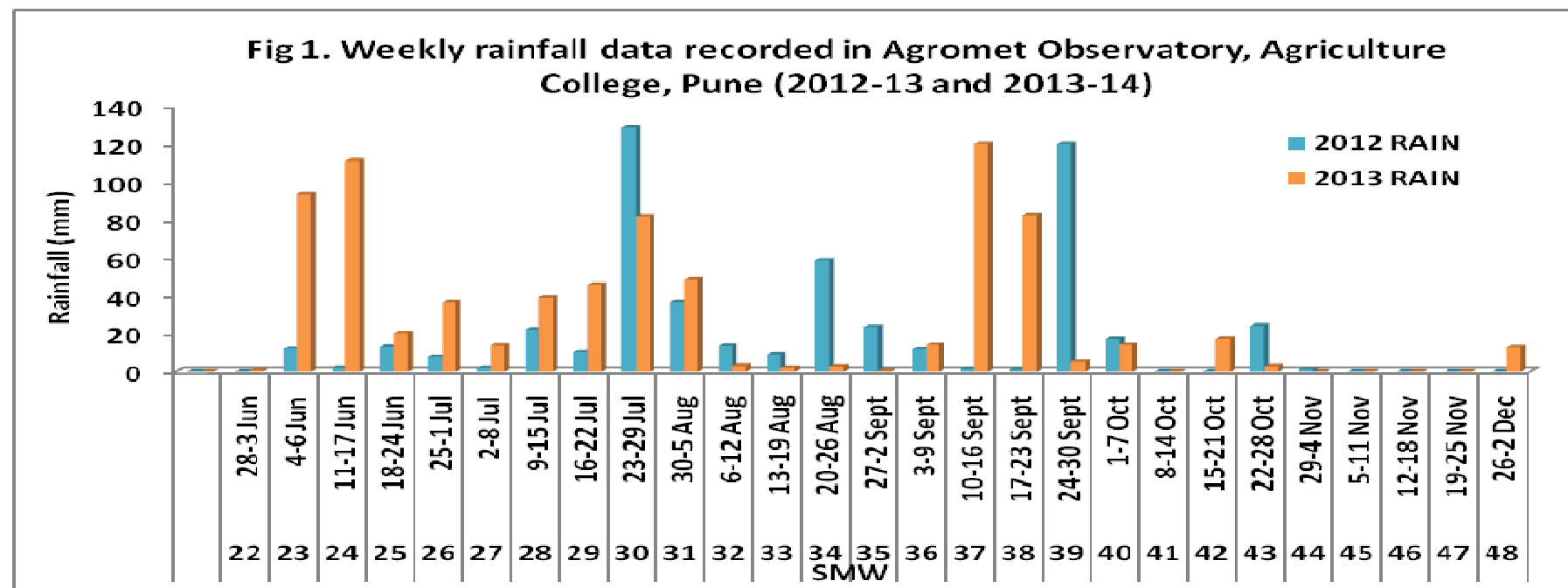
**Table 3.2 Weekly weather data during crop growth period recorded in Agromet Observatory, Agriculture College Pune
(2012-13 and 2013-14)**

SMW	DATE	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
		Tmax °C	Tmax °C	Tmin °C	Tmin °C	R H I (%)	R H I (%)	R H II (%)	R H II (%)	W S km h ⁻¹	W S km h ⁻¹	RAIN (mm)	RAIN (mm)	R D	R D	Epan (mm)	Epan (mm)	B S S (hrs)	B S S (hrs)
22	28-3 Jun	35.8	35.7	23.6	24.3	70	69	34	40	12.0	10.0	0.0	0.8	0	0	10.4	9.9	10.5	9.0
23	4-6 Jun	33.8	33.1	24.9	22.7	73	84	56	55	9.1	5.6	12.0	93.5	2	4	7.3	4.8	6.3	4.3
24	11-17 Jun	33.5	28.6	23.1	22.8	76	85	52	74	8.7	7.6	2.1	111.2	0	4	6.9	3.1	7.1	1.4
25	18-24 Jun	31.8	29.2	23.7	22.7	74	83	54	69	13.6	8.5	13.0	20.1	1	1	9.2	4.4	7.4	4.5
26	25-1 Jul	31.8	27.8	23.2	22.3	81	88	55	78	9.7	8.2	7.4	36.6	1	4	6.8	2.6	5.6	1.3
27	2-8 Jul	30.7	28.1	23.0	22.3	85	89	69	76	8.5	8.2	2.1	13.8	0	2	5.8	3.7	3.3	2.7
28	9-15 Jul	30.5	26.9	22.7	21.9	81	87	60	79	9.3	9.1	22.3	39.2	4	3	6.2	2.6	4.6	1.6
29	16-22 Jul	29.3	26.2	22.8	21.8	86	91	73	88	9.7	8.7	10.0	45.8	1	5	4.5	2.3	2.8	0.1
30	23-29 Jul	28	25.7	23.0	21.7	85	92	77	88	12.3	8.4	129.1	81.9	7	7	4.4	2.6	1.3	0.4
31	30-5 Aug	26.6	26.2	21.8	21.4	87	89	86	86	11	8.5	36.6	48.3	4	5	2.7	2.3	1.1	2.4
32	6-12 Aug	27.7	27.7	22.1	21.4	88	86	80	72	10.1	8.2	13.6	2.9	2	0	3.8	3.6	2.4	3.4
33	13-19 Aug	28.4	28.4	21.6	22.0	86	88	70	60	9.2	8.6	8.7	2.1	1	0	4.2	4.3	6.7	4.6
34	20-26 Aug	29.0	28.2	21.6	21.7	85	84	64	67	7.4	11.2	58.7	2.7	3	0	4.9	4.8	6.0	4.0
35	27-2 Sept	28.8	29.1	22.3	20.1	89	87	78	59	5.5	6.5	23.6	0.4	3	0	4.9	4.9	3.7	5.1
36	3-9 Sept	27.3	29.9	22.0	17.5	91	87	86	62	5.5	6.1	11.6	14.1	1	2	2.4	5.7	2.4	6.2
37	10-16 Sept	27.4	30.8	21.0	21.4	89	94	74	62	5.8	2.6	1.4	120.2	0	6	4.0	3.5	2.9	4.3
38	17-23 Sept	29.5	28.8	20.6	21.4	86	88	61	69	5.3	6.6	1.1	82.5	0	2	4.0	3.6	4.9	3.6
39	24-30 Sept	30.8	24.8	20.1	18.5	89	74	60	58	4.2	5.2	120.2	4.8	5	1	4.6	3.7	7.4	3.0
40	1-7 Oct	30.5	26.6	21.4	18.6	95	77	70	53	2.3	3.7	17.2	14.1	2	2	3.2	4.3	3.8	6.3

41	8-14 Oct	31.9	26.3	19.8	17.7	88	75	40	50	2.0	5.3	0.0	0.0	0	0	4.9	3.6	7.7	6.6
42	15-21 Oct	31.7	28.2	16.9	17.7	86	78	36	40	2.0	2.1	0.1	17.2	0	1	5.1	4.0	8.4	6.2
43	22-28 Oct	30.5	27.8	19.8	17.4	84	87	52	43	2.5	1.7	24.2	2.8	2	1	4.0	4.1	4.0	6.6
44	29-4 Nov	30.0	27.9	16.5	15.9	89	76	42	43	2.2	1.6	1.2	0.0	0	0	4.5	4.2	6.6	7.5
45	5-11 Nov	32.1	26.4	16.2	13.4	88	78	36	35	2.1	1.6	0.0	0.0	0	0	4.5	4.0	9.0	6.9
46	12-18 Nov	30.2	25.5	13.4	10.9	90	80	33	31	1.9	1.6	0.0	0.0	0	0	4.6	3.9	8.9	7.9
47	19-25 Nov	30.0	27.3	12.3	12.2	91	80	36	33	1.8	1.3	0.0	0.0	0	0	4.3	3.5	8.8	7.8
48	26-2 Dec	31.6	26.6	14.3	14.5	92	81	37	33	1.8	1.7	0.0	12.7	0	1	3.7	3.2	8.0	7.3

Tmax= Maximum temperature, Tmin= Minimum Temperature, RH I = Relative Humidity (Morning), RH II = Relative Humidity (Evening), WS= Wind Speed,

RAIN= Rainfall, RD= Rainy Days, Epan= Evaporation, BSS= Bright Sun Shine Hours



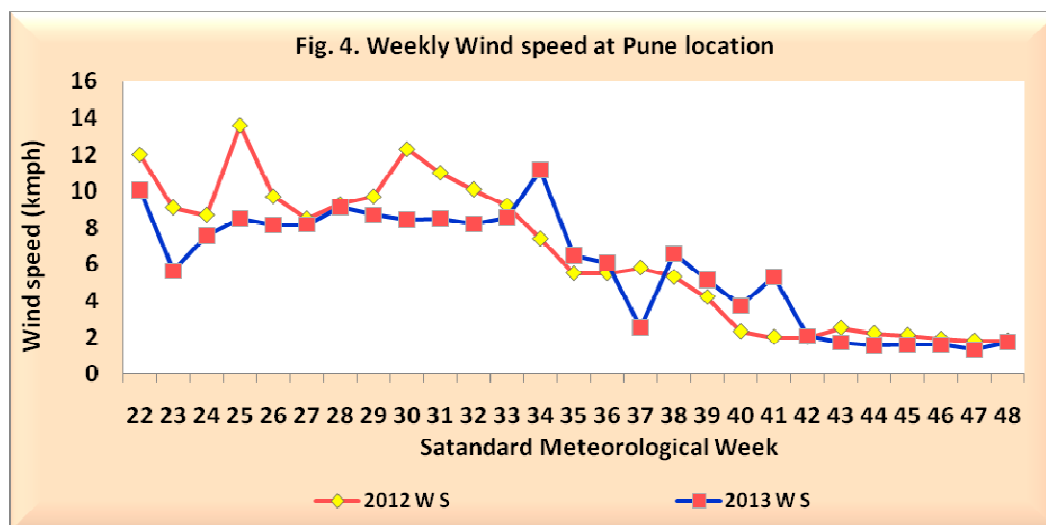
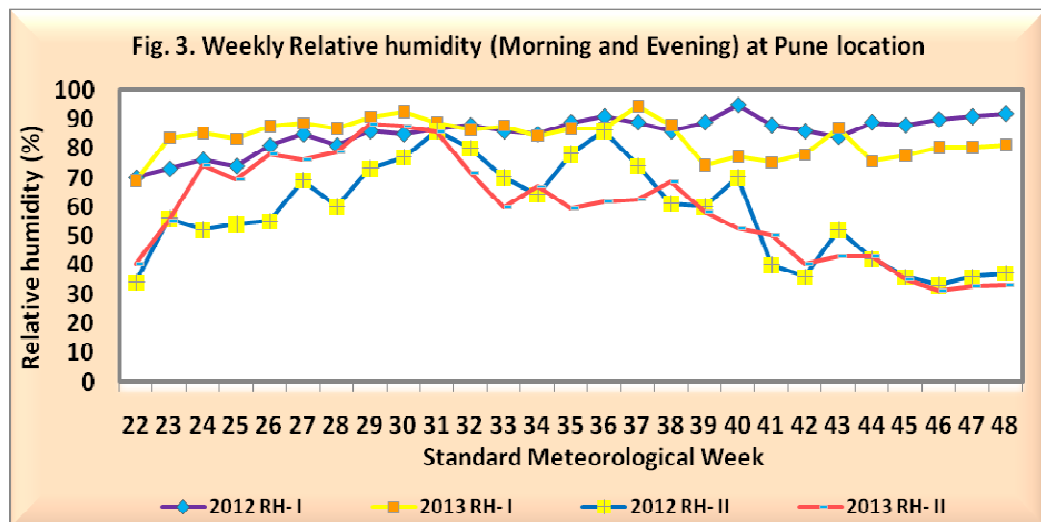
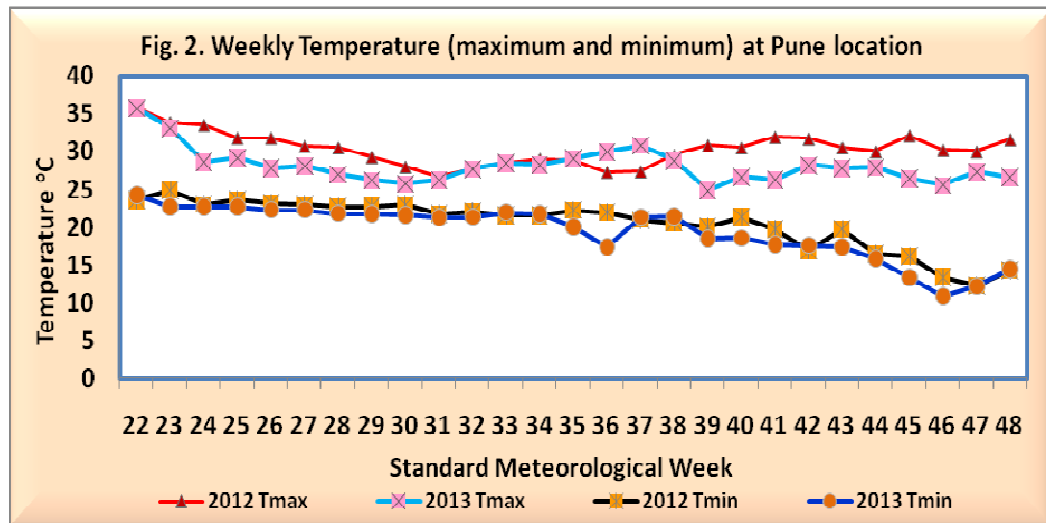


Fig.5. Weekly Pan evaporation at Pune location

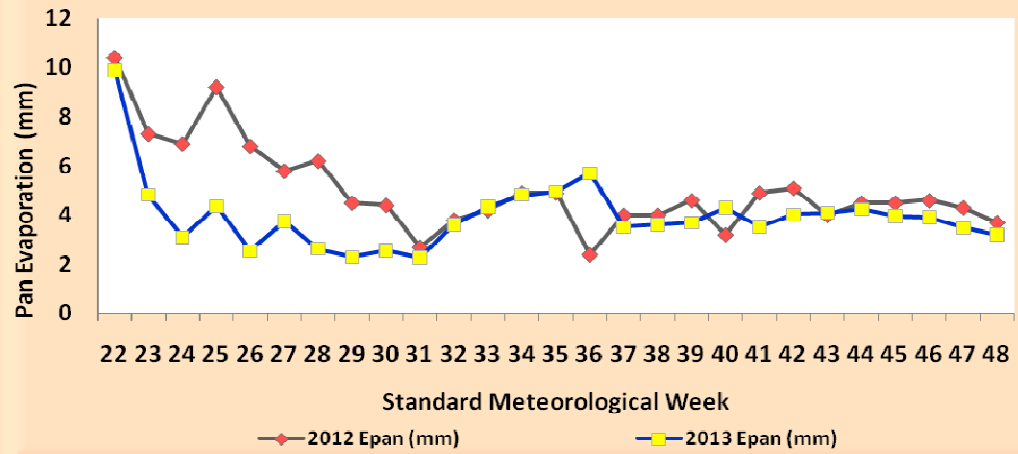
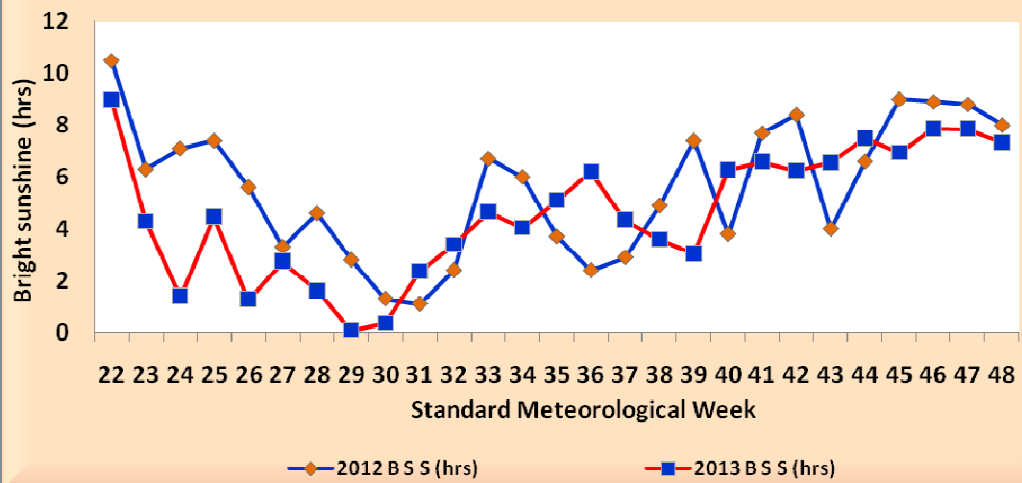


Fig. 6. Weekly bright sunshine hours at Pune location



3.4 Experimental details

3.4.1 Treatments and Layout

The experiment was laid out in a Split Plot Design (SPD) with four sowing dates (fortnight interval) in the month of June and July, which were replicated four times during *kharif* season. The treatment details along with the symbols used in the plan are presented in Table 3.4.

3.4.2 Details of layout and treatments

1. Name of crop : Soybean (*Glycine max.* [L.] Merrill)
2. Experimental Design : Split Plot Design (SPD)
3. Plot Size : a) Gross : 4.0 x 3.6 m²
b) Net : 3.0 x 2.7 m²
4. Total No. of Treatments : 12 (Twelve)
5. Total No. of Replications : 4 (Four)
6. Total No. of Plots : 48
7. Spacing : 45 cm x 5 cm
8. Seed rate : 75 kg ha⁻¹
9. Fertilizer dose : 50: 75: 00 kg NPK ha⁻¹
P₂O₅ through single super phosphate and Nitrogen through urea.
10. Seasons : *Kharif* 2012-13 and 2013-14
11. Method of sowing : Dibbling

Table 3.4 Treatments Details

Treatment	
	A) Main plots: Sowing time (S)
S₁	First Fortnight of June
S₂	Second Fortnight of June
S₃	First Fortnight of July
S₄	Second Fortnight of July
	B) Sub plots: Variety (V)
V₁	JS- 335
V₂	MACS-450
V₃	DS-228 (Phule Kalyani)

3.5 Details of field operations

The details of cultural operations undertaken during the course of present experimentation are given in Table 3.5.

Table 3.5 Details of cultural operations

Sr. No	Particulars	Frequency	Implement used	Dates of operations (2012)	Dates of operations (2013)
A	Preparatory tillage				
1.	Ploughing	1	Iron plough	10-06-2012	07-06-2013
2.	Harrowing	2	Harrow	11-06-2012	10-06-2013
3.	Layout of experiment	1		12-06-2012	11-06-2013
B	Sowing				
1.	Sowing of seed by dibbling	1	Manually	15-06-2012 30-06-2012 13-07-2012 30-07-2012	18-06-2013 29-06-2013 12-07-2013 30-07-2013
C	Manures and fertilizer application				
1.	Basal dose i.e. full N + full P ₂ O ₅	1	Manually	15-06-2012 30-06-2012 13-07-2012 30-07-2012	18-06-2013 29-06-2013 12-07-2013 30-07-2013
D	Intercultural operation				
1.	Hand weeding	1	Manually	16-07-2012 25-07-2012 22-08-2011	01-07-2013 15-07-2013 16-08-2013
2.	Hoeing	2	Blade hoe	09-08-2012	
E	Plant protection measures				
1.	Chloropyrifos	1	Knapsack sprayer	03-07-2012 15-08-2012	17-07-2013 13-08-2013
F	Harvesting and threshing				
1.	Harvesting	At maturity in respective sowing	Manually	27-09-2012 to 15-11-2012	12-10-2013 to 10-11-2013
2.	Threshing and winnowing	—,—	Manually	03-10-2012 to 25-11-2012	21-10-2013 to 15-11-2013

3.5.1 Preparation of land and layout of experiment

The land was ploughed with tractor drawn plough followed by harrowing and stubble collection. These operations were carefully followed so as to get a good seed bed. The experiment was laid out as per the plan of layout (Fig. 7).

3.5.2 Fertilizer application

Recommended dose of N and P_2O_5 was applied @ 50:75 kg N:P ha⁻¹ through urea (46% N) and single super phosphate (16%, P_2O_5), respectively, at the time of sowing.

3.5.3 Seed and sowing

The certified seed of soybean variety JS-335 and MACS-450 was purchased from market and certified seed of DS-228 variety was obtained from ARS, Kasabe Digra, MPKV, Rahuri on gratice. The rainfed sowing of soybean crop was carried out as per the treatment (Table 3.4). Seeds were sown to maintaining 45 cm spacing between rows and at the time of thinning expected plant stand was achieved maintaining plant to plant distance of 5 cm. As required gap filling was done on 6th and thinning on 10th day after sowing so as to maintain intra plant spacing of 5 cm.

3.5.4 Intercultural operations

3.5.4.1 Weeding and hoeing

Hoeing and hand weeding were done to keep the crop weed free and to keep the soil loose and porous for good aeration, moisture conservation and better establishment of root system. The schedule of intercultural operations undertaken is mentioned in Table 3.5.



Plate 1. (a)



Plate 1. (b)

Plate 1 (a and b). General view of experimental plot



Plate 2. Soybean crop condition at 40 DAS



Plate 3. Soybean crop condition at 60 DAS

3.5.4.2 Plant protection

Plant protection measures were undertaken as per the necessity to protect the crop from semilooper and *Spodoptera litura* incidence. Spraying of Chloropyriphos 25% @ 20 ml per 10 litres of water was undertaken.

3.6 Harvesting

The crop was harvested when it was completely matured. First the borderlines were separated before harvest of plants from net plot. The plants were cut close to the ground level and tied it in bundles. After labeling properly, the bundles were taken to threshing yard. After complete drying (3-5 days), the produce from each net plot was threshed; winnowed, cleaned separately and seed weight was recorded for each net plot.

3.7 Biometric observations

The various biometric observations were recorded treatment wise on randomly selected five soybean plants from each net plot during the course of investigation. The details of observations recorded and their frequency is presented in Table 3.6. The techniques followed for recording each observation are described separately wherever necessary.

Table 3.6 Details of biometric observations

Sr. No.	Particulars	Frequency	Days after sowing
Soybean			
a. Pre harvest observations: (Biometric observations)			
1.	Initial and final plant population count	1	After emergence and at harvest
2.	Plant height (cm)	4	20,40,60 and 80 DAS
3.	Number of branches per plant	4	20,40,60 and 80 DAS
4.	Number of leaves per plant	4	20,40,60 and 80 DAS
5.	Leaf area per plant	2	40 and 60 DAS
6.	Leaf area index	2	40 and 60 DAS
7.	Dry matter accumulation per plant (g)	4	20,40,60 and 80 DAS

b. Post harvest observations: (Yield attributes and yield)			
1.	Number of pods per plant	1	At harvest
2.	Seeds weight per plant (g)	1	At harvest
3.	Number of seeds per pod	1	At harvest
4.	Test weight (g)	1	At harvest
5.	Dry matter partitioning (g)	1	At harvest
6.	Grain yield (q ha^{-1})	1	At harvest
7.	Biological yield (q ha^{-1})	1	At harvest
8.	Harvest index (%)	1	At harvest
c. Meteorological observations:			
1.	Relative humidity and air temperature	7	At Phenophases
2.	Radiation intensity	7	At Phenophases
3.	Radiation interception (%)	7	At Phenophases
4.	Thermal units and thermal requirement	7	At Phenophases
	Thermal units(TU)	7	At Phenophases
	Thermal requirement	7	At Phenophases
	Heliothermal units (HTU)	7	At Phenophases
5.	Thermal use efficiency (TUE)	7	At Phenophases
d. Insect pest and disease occurrence during growth period			

3.7.1 Plant count

After crop emergence, plant population was measured at 10 days after sowing final plant stand of the crop was recorded at harvest.

3.7.2 Plant height

For measurement of plant height, five plants from net plot were randomly selected and labeled for taking observations. Height of plant was measured from the ground to the tip of the terminal at an interval of 20 days till 80 DAS and means were worked out.

3.7.3 Number of branches per plant

The number of branches from the randomly selected five plants was counted at harvest and average was worked out.

3.7.4 Leaf area (plant⁻¹)

The leaves from the plant sample for dry matter study were used for estimating the leaf area. The leaves of sampled plants were removed and grouped in small, medium and large leaves and leaf area of representative leaf in each group was scanned through laser area meter (model CI 203, CID Inc. USA.) and multiplied by number of functional leaves in each group. The leaf area readings obtained in cm².

3.7.5 Leaf area index (LAI)

Leaf area index was calculated treatment wise as shown below-

$$\text{LAI} = \frac{\text{Leaf area plant}^{-1} (\text{cm}^2)}{\text{Land area plant}^{-1} (\text{cm}^2)}$$

3.7.6 Dry matter accumulation (plant⁻¹)

Randomly selected one plant was uprooted from each treatment net plot and the root portion of the plant was cut from ground level. The aerial portion of the plant was kept in brown paper bag and sun dried for 48 hours and then placed in hot air oven at a regulated temperature of 65 °C till constant dry matter weight was obtained. The observation on dry matter was taken periodically per plant.

3.8 Crop phenology

Phenological observations on occurrence of different phenophase, were taken in order to know the number of days required from emergence for initiation of different phenophase and its duration and from it total duration from emergence to physiological maturity.

3.9 Yield attributes

Important yield attributing characters were studied after the harvest of the crop.

3.9.1 Number of pods (plant⁻¹)

The number of pods was counted on five samples plants and the average number of pods per plant was worked out.

3.9.2 Seed weight (plant⁻¹)

After shelling of pods from sample plants the seed weight was recorded from this per plant seed weight was worked out.

3.9.3 Number of Seeds (pod⁻¹)

Pods were collected from the sampled plants, seeds were separated and counted and calculate mean number of seeds per pod.

3.9.4 Test weight (g)

From the seed produce in each net plot randomly 100 seeds were counted and weighed to get the test weight.

3.9.5 Seed yield

After the harvest, the plants were tied in bundles and were air dried for about 8-10 days. Then produce was threshed and seed produce from each net plot was weighed to record seed yield per net plot and then yield in quintal per hectare was calculated.

3.9.6 Biological yield

The plants from net plot were uprooted and tied into bundles. The bundles were dried in the sun and their weight was recorded before threshing as per treatments. From this biological yield per hectare was worked out.

3.9.7 Harvest index (HI)

The economic yield (seed yield) was divided by respective biological yield and the relationship expressed as percentage as indicated below.

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

3.10 Population dynamics of insect pests

Weekly insects counts were recorded from 10 randomly selected plants in each plot. Field observation of insect pest population was recorded during the cool hours of the day (7.00 to 9.30 am and 4.00 to 6.00 pm). The data on pod damage was calculated from 50 pods sample randomly from each treatment. From this mean pod damage was calculated.

3.10.1 Leaf eating caterpillars

Observations on larval population of leaf eating caterpillar, *S. litura* was made at three randomly selected spots of one meter row in each treatment leaving border rows. Larval counts were made by shaking the plant gently over a white cloth placed between the rows. Average number of caterpillars found meter⁻¹ row length (mrl) was worked out.

3.11 Micrometeorological observations

3.11.1 Growing degree days (GDD)

Temperature is a major environmental factor that determines the rate of plant development. The temperature requirement and range of optimum temperature varied with species and genotype. The thermal response of genotype can be quantified by using the heat unit or thermal time concept. There is high probability of successfully predicting the development of black gram by heat unit.

Thermal time or growing degree days were calculated according to the equation.

$$\text{GDD} = [(T_{\text{max.}} + T_{\text{min.}})/2 - T_b]$$

Where,

GDD	=	Growing degree days
T _{max.}	=	Daily maximum temperature of i th day (°C)
T _{min.}	=	Daily minimum temperature of i th day (°C)
T _b	=	Base temperature of soybean (10°C)

3.11.2 Radiation intensity and interception

During photosynthesis, plants use energy in the region of electromagnetic spectrum from 400-700 nm. The radiation in this range, referred to as PAR (Photosynthetically Active Radiation) can be measured in energy units of quanta (photons) per unit time per unit surface area.

Various component of PAR i.e, incoming (PAR_o), intercepted (IPAR), transmitted (TPAR), and reflected (RPAR) were measured with the help of line quantum sensor, which specially averages radiation over its one meter length and thus minimizes the error, was used. It was connected to the (LI-1000) data logger. The sensor was leveled and always held horizontal during measurements. All measurements were made around solar noon between 1130 to 1300 to eliminate effects of solar elevation (Sivakumar and Virmani, 1984). The measurements were made at phenological stages. PAR_o was measured by keeping the line quantum sensor facing up above the top of the canopy. Whereas TPAR was measured by placing line quantum sensor above the ground across the rows. IPAR was calculated using the equation (Gallo and Daughtry, 1986).

$$IPAR = PAR_o - TPAR$$

Total reflected PAR by canopy and soil (RPAR_c) was measured by inverting the line quantum sensor and holding it above the canopy across the rows. And that reflected by soil (RPAR_s) was measured by inverting line quantum sensor and holding it 15 cm above the soil across the rows. RPAR by canopy was determined by using equation.

$$RPAR = RPAR_c - RPAR_s$$

APAR was worked out by adopting the equation,

$$APAR = (PAR_o + RPAR_s) - (TPAR + RPAR_c) \text{ (Gallo and Daughtry, 1986).}$$

3.12 Details of instruments

3.12.1 LI-191 SA Line Quantum Sensor

The LI-191 sensor is designed for measuring PAR (Photo synthetically Active Radiation) in applications where the radiation is to be measured in

spatially non-uniform canopies (such as within canopies). To achieve this, the sensor features a sensing area that is one meter in length. The LI-191 SA has quantum (photon) response through the wave length range of 400 to 700 nm for PPFD (Photosynthetic Photon Flux Density) as generally preferred for PAR measurements, and has an output in units of mole.

Where,

$$1\mu\text{ mol m}^{-2}\text{s}^{-1} = 1\mu\text{E m}^{-2}\text{s}^{-1} = 6.02 \times 10^{17} \text{ photon m}^{-2}\text{s}^{-1}$$

The LI-191 SA Line Quantum sensor, which spatially averages radiation over its one meter length, minimize the errors and allows one to easily make many measurements in a short period of time. The sensor was connected to the LI-1000 data logger.

Since the sensing area is a flat acrylic diffuser, the response of given angle of incidence is fairly constant, as the azimuth angle around the sensor is varied. It is specified at less than $\pm$ at a 45° angle of elevation for 360° sensor rotation.

Specifications

Absolute calibration	: $\pm 10\%$ traceable to NBS. The LI-191 SA is calibrated under natural daylight, clear conditions, via transfer calibration using a reference LI-191SA Line Quantum Sensor. Transfer error is $\pm 5\%$. (Including the $\pm 10\%$).
Sensitivity	: Typically $3\mu\text{A}$ per $1000 \mu\text{mol m}^{-2}\text{s}^{-1}$
Linearity	: Maximum deviation of 1% up to $10000 \mu\text{mol m}^{-2}\text{s}^{-1}$
Stability	: $< \pm 2\%$ changes over a one year period
Response time	: $10\mu\text{s}$
Temperature dependence	: $\pm 0.15\%$ per $^\circ\text{C}$ maximum
Cosine correction	: Acrylic diffuser
Azimuth	: At 45° elevation $< \pm 2\%$ error over 360°
Sensitivity area	: $1 \text{ m L} * 12.7 \text{ mm W}$ ($39.4'' * 0.50''$)
Detector	: High proof anodized aluminum case with acrylic diffuser and stainless steel hardware.
Size	: $116 \text{ L} * 2.54 \text{ W} * 2.5 \text{ cm D}$ ($45.5'' * 1.0''$)
Weight	: 1.8 kg (4.0 lb)
Cable length	: 3.1 m (10.0 ft)

3.12.2 LI-1000 Data Logger

The LI-1000 Data Logger is a 10 channel data logger that functions both as a data logging device and a multichannel, auto ranging meter. The electronics of the LI-1000 have been optimized for highly accurate measurement of LI-1000 radiation sensors, which have a current signal. The LI-1000 is also well suited to measure low impedance voltage sensors such as thermocouples and sensors with a pulsed output (tipping bucket rain gauges, etc.,). A wide variety of other sensors for environmental and industrial test and measurement can also be measured with the LI-1000.

Specifications

Analog inputs: Eight total analog inputs configured as voltage or current channels

Current inputs: Eight channels; two seal BNC connector and six channels accessed directly through 37p in D connector or by connecting the 1000-05 Terminal Block or the 1000-10 Thermocouple Terminal Block.

Voltage inputs: Six signal ended channels accessed directly through 37 pin D connector or by connecting the 1000-05 Terminal Block, Thermocouple Terminal Block 1000-06 AC Terminal Block, channel 1 and 2 can also be configured for voltage measurement by placing an input impedance resistor in the sensor cable.

Pulse counting inputs: Two pulse counting channels switch closure to ground (200 Hz); external signal driving (1 KHz).

Analog to Digital converter

Type	:	Voltage to frequency
Resolution	:	14 bits (1 part in 16,000)
Scan rate	:	4 channels per second, (200 ms integration time for 50 or 60 Hz noise rejection)
Voltage	:	$\pm 0.3\%$ of full scale reading (25°C), $\pm 0.55\%$ (0 to 55°C)

Current	:	$\pm 0.2\%$ of full scale reading (25°C), $\pm 0.45\%$ (0 to 55°C)
Temp. Coefficient	:	$\pm 0.01\%$ of reading per °C
Linearity	:	0.05%
Normal mode rejection	:	> 60 dB at 50 or 60 Hz voltage input noise (25°C)
Typical	:	$\pm 2.5 \mu$
Max. 60 sec. Ave.	:	$\pm 5 \mu V$
Typical	:	$\pm 0.4 \mu$
Max. 60 sec. Ave.	:	$\pm 0.8 \mu V$ current input noise (25 °C)
Typical	:	± 25 picoamps
Max. 60 sec. Ave.	:	± 50 picoamps
Typical	:	± 4 picoamps
Max. 60 sec. Ave.	:	± 8 picoamps

Theory of operation

For measurement of radiation by Line Quantum Sensor following commands are given

I	ON	V	Multiplier (-107.99)
II	INST MODI	VI	Label-UM
III	CH 1	VII	Ave. 1 minute
IV	Range A		

3.12.3 Vaisala HM34 Relative humidity and temperature indicator

The pocket sized Vaisala HM34 meter was used to measure fast and conveniently relative humidity and temperature. The instrument includes HOLD button which allows the user to retain an RH and temperature measurement until it has been noted. If no buttons are pressed for three minutes, the unit automatically switches itself off. This automatic POWER-OFF function prevents the possibility of accidental discharge of the HM34's battery.

The HM34 meter incorporates Vaisala's HUMICAP®H sensor, which is accurate, durable and insensitive to dust and most chemical contaminants. Both humidity and temperature sensors are housed in an extendable probe that retracted back into the rugged plastic casing for storage, creating a compact and easy to carry device.

Each unit includes

1. 9 V battery
2. Attached probe
3. 0.2 µm protective membrane filter
4. Carrying case

Specifications

Relative humidity

Range	:	0 to 100%
Accuracy	:	±2% (0 to 90% RH)
Resolution	:	0.1% RH
Temperature dependence	:	±0.02% RH/°F (±0.04% RH/°C)
Sensor type	:	HUMICAP®H
Response time	:	10 sec. with membrane filter 15 sec. with sintered filter 5 sec. with plastic filter

Temperature

Range	:	- 4 to + 140 °F (- 20 to + 60 °C)
Accuracy	:	± 0.5 °F (0.3 °C)
Resolution	:	0.1 °F (0.1 °C)
Temperature dependence	:	±0.02% °F/ °F (±0.02% °C/ °C)
Sensor type	:	Pt 100 IES 751 1/3 Class B

General

Display	:	3 ½ digit LCD
Weight	:	250 g

Size	:	6.3" x 2.2" x 1.1" (160 x 57 x 27 mm)
Power supply	:	9 V battery
Battery life	:	50 hrs.
Hold function	:	to hold of displayed value
Power off	:	automatic, after 3 minutes

3.13 Statistical Analysis

The experimental data collected during the course of investigation were statistically analyzed with split plot design programme on computer by adopting standard statistical techniques of analysis of variance (Gomez and Gomez, 1984). Wherever, the results were significant, critical differences at $P = 0.05$ levels were calculated for comparison of treatment means. Data on interaction effects are presented wherever found significant. The data on treatment effects are presented suitably in appropriate tables and graphically depicted in figures.

Correlation study was done in order to explore the relationship between various weather variables and final seed yield of soybean crop. Correlation coefficients between seed yield and weather variables were worked out.

The experimental data were subjected to the statistical analysis. Insect numbers transformed in to $\sqrt{n+1}$ value where 'n' is number of insect.

3.14 Description of CROPGRO-Soybean (DSSAT v 4.5) model

CROPGRO-Soybean model (Hoogenboom *et al.*, 1994; Boote *et al.*, 1998) embedded in the Decision Support Systems for Agro-technology Transfer (DSSAT Vol. 3; Tsuji *et al.*, 1994, Hoogenboom *et al.*, 2010) is a process-oriented dynamic and generic crop simulation model. The model operates on a daily time step. It can simulate crop growth and development of four different legumes (soybean, peanut, common bean, chickpea). A description of the processes in CROPGRO is provided by Boote *et al.*, (1998).

The CROPGRO-Soybean model reasonably predicts growth and yield in various subtropical and temperate locations.

In the present study, the data for evaluating the CROPGRO-Soybean simulation model came from experimental study that involved different sowing management and varieties (Table 3.4). The experiments were conducted during the *kharif* seasons 2012 and 2013. Detailed observations on phenology and crop growth and yield measurements were made in individual treatment.

The genetic coefficients for the soybean varieties JS-335, MACS-450 and DS-228 were determined with the GLUE coefficient estimator embedded in the DSSAT v 4.5 model using data collected during the experiment. The goodness-of-fit between the predicted and measured variable was examined and the coefficient was decreased (increased), until the fit between the predicted and measured variable is good. To run the model genetic coefficients are required variety wise to distinguish its phasic development uniquely. These genetic coefficients are related to the photothermal days required to attain phenological events and dry matter accumulation. Genetic coefficients are used to simulate the response of various cultivars to weather and management conditions. These coefficients allow the same soybean crop growth model to predict differences in development, growth and yield among cultivars when planted in the same environment as well as the differences in the behavior of a single cultivar when planted in different environments (Boote *et al.* 1998).

Input data files of CROPGRO soybean model were used as per the IBSNAT standard input and output formats and file structure (Uehara, 1990). Model requires daily weather inputs and soil parameters at various profile depths and details of management practices.

3.14.1 Data inputs to the model

To run a simulation, input files were created as follows -

- (1) .SBX (Crop management data)
- (2) .SBT (Experimental data)
- (3) .WTH (weather)
- (4) .SOL (Soil data)

3.14.2 Output parameters

Some of the output parameters that model simulates are as follows-

- (1) Julian day of anthesis
- (2) Julian day of first pod
- (3) Julian day of first seed
- (4) Julian day of physiological maturity
- (5) Plant height (m)
- (6) Maximum LAI
- (7) Seeds per pod
- (8) Seeds per m⁻²
- (9) Seed yield
- (10) By product (Straw yield)
- (11) Threshing %
- (12) Harvest index

3.14.3 Calibration of the model

Calibration of model involves adjusting certain model parameters or relationships to make the model work for any desired location. The field experimental data was used for model calibration. Crop parameters such as phenological development, leaf area index, canopy height, by product and yield were estimated. The genetic coefficients of varieties (JS-335, MACS-450 and DS-228) used in the analysis of the model were estimated by repeated iterations until a close match between simulated and observed phenology and yield was obtained in these treatments. Hence, model was calibrated to simulate phenology, LAI, seed yield and straw yield (byproduct) accurately.

3.14.4 Validation of the model

Before any model can be used with confidence, adequate validation or assessment of the magnitude of the errors that may result from its use should be performed. Model validation, in its simplest form is a comparison between simulated and observed values. Several statistical measures are available to evaluate the association between predicted and observed values. The measures used in this study are indicated below-

RMSE	$[\sum (P_i - O_i)^2 / n]^{1/2}$
PE	RMSE / O $\times 100$
MAE	$\sum (P_i - O_i) / n$
MBE	$(\sum (P_i - O_i)) / n$
D	$1 - [\sum (P_i - O_i)^2 / \sum (P_i^2 + O_i^2)]$

Where,

P_i = simulated, O_i = observed, $P'_i = P_i - P$, $O'_i = O_i - O$

MAE and RMSE indicate the magnitude of the average error. MBE describes the direction of the error bias. A negative MBE occurs when predictions are smaller in value than observations. A simple way of expressing the error is to express root mean square error as percentage of mean of observed value i.e. Percentage error (PE). PE is ratio of RMSE to mean observed value expressed as percentage. If the PE is less than ten percent the predictions is acceptable. The Degree of agreement (D) is used mainly to determine the relative superiority of models; it can be used as a descriptive parameter of model performance. The more (D) approaches unity (1), the more accurate the model is.

$$PE = \frac{RMSE}{\bar{O}} \times 100$$

Besides the above test criteria, error per cent was also calculated in different treatment under study to express the deviation more scientifically.

This is as follow:

$$\text{Error \%} = \{(\text{Predicted} - \text{Observed}) / \text{Observed}\} * 100$$

The entire procedure as described above was carried out for the purpose of fulfilling the objectives of this investigation and pertinent results are described in the next chapter.

3.15 Instrumentation

3.15.1 Pressure membrane extractor

Pressure membrane extractor catalogue No. 1000 was used to measure the field capacity (FC) i.e. drained upper limit and Permanent Wilting Point (PWP) i.e. drained lower limit of plant extractable soil water.

Working principle

After the extractor has been loaded with samples and bolts tightened, the valve at the manifold is opened to admit compressed gas only to the extractor chamber. When extraction has sufficiently progressed so that the samples are firm, as indicated above, the valve supplying air to the diaphragm chamber is then opened. The extraction chamber line should be opened vented slightly at the exhaust valve on the mercury differential regulator to allow the diaphragm to move down in contact with the soil and to take care of excess pressure that is brought about in the extraction chamber during this downward motion. The exhaust valve is closed as soon as air is heard to bubble past the mercury in the U tube.

When soil sample reaches equilibrium in one extractor and is ready to remove, manifold exhaust valve for the diaphragm chamber is opened first to exhaust air from behind the diaphragm. The manifold exhaust valve for the extraction chamber is now opened to exhaust air from the extraction chamber. The extraction may now be opened as above and the soil samples remove. We can use 6-10 soil samples at a time for extraction. Sample may be removed any time after 48 hours from the commencement extraction.

One-third bar pressure was used for determining the drained upper limit, whereas fifteen bar pressure was used for getting the value of PWP i. e. lower limit.

3.15.2 LI-3100 Leaf Area Meter

The LI-COR model LI-3100 leaf area meter is an instrument capable of measuring the area of non-transparent samples. The LI-3100 is available with area sensing resolutions of 1.0 mm². Both 1.0 and 0.1 mm² areas, sensing resolution can be provided on the same instrument. The LI-3100 consists of a

transparent belt conveyer mechanism, an object illumination lamp and area scanning, counting and displaying unit.

Theory of operation

Samples are placed between the guides on the lower transparent belt and allowed to pass through the LI-3100. As sample travel under the fluorescent light source, the projected image is reflected by a system of three mirrors to a solid state-scanning camera within the rear housing.

An adjustable press roller flattens the curled leaves and feeds them properly between the transparent belts. This makes it possible to accurately measure leaf area of small grasses, legumes, cereals, aquatic plants and similar type of leaves.

As the sample pass under the light source, the area in cm² is displayed on the LED display system. Calibration is done by measuring a standard area disk and turning the calibration screw near the display.

CHAPTER- IV

RESULTS AND DISCUSSION

In view with the object of the research project entitled “Simulation of soybean growth and yield by using DSSAT model under varied environment conditions at Pune location”, the various observations recorded during the course of investigation and data collected thereof have been duly analyzed and presented in this chapter under suitable heads. The results are discussed briefly in this chapter supported with sound reasoning and appropriate evidences.

4.1 Plant population

The data pertaining to initial plant population of the soybean crop after complete emergence and final plant population at harvest stage of the crop are presented in Table 7.

4.1.1 Initial plant population

The average initial plant population 4.27 and 4.32 lakh ha⁻¹ and the average final plant population 4.17 and 4.27 lakh ha⁻¹ was recorded during the year 2012 and 2013, respectively.

Sowing times

During the year 2012 and 2013, the data on initial plant population recorded at 10 DAS revealed that the differences due to various sowing times were found to be non-significant.

Varieties

The treatment differences due to different varieties were found to be non-significant at 10 DAS, during the year 2012 as well as 2013.

Interactions

Interaction effects between sowing times and varieties were also found to be non-significant during both the years.

Table 7. Mean Initial and final plant population (ha ⁻¹) as influenced by sowing times and varieties (2012 and 2013)				
Treatment	Number of plants (ha ⁻¹)			
	Initial plant population	Final plant population	Initial plant population	Final plant population
	Lakh ha ⁻¹		Lakh ha ⁻¹	
	2012		2013	
A) Sowing times				
S ₁ (I FN of June)	4.42	4.21	4.43	4.36
S ₂ (II FN of June)	4.38	4.18	4.41	4.33
S ₃ (I FN of July)	4.20	4.16	4.25	4.24
S ₄ (II FN of July)	4.11	4.14	4.19	4.15
S. Em ±	0.08	0.33	0.10	0.26
C.D. at 5%	NS	NS	NS	NS
B) Varieties				
V ₁ (JS-335)	4.18	4.15	4.20	4.18
V ₂ (MACS-450)	4.23	4.18	4.33	4.26
V ₃ (DS-228)	4.41	4.19	4.43	4.37
S. Em ±	0.09	0.30	0.06	0.20
C.D. at 5%	NS	NS	NS	NS
Interaction (AxB)				
S. Em ±	0.18	0.61	0.13	0.41
C.D. at 5%	NS	NS	NS	NS
GM	4.27	4.17	4.32	4.27

4.2 Growth Studies

4.2.1 Plant height (cm)

The mean plant height (cm) as influenced by different treatment recorded periodically are presented in Table 8 and 9 and graphically depicted in Fig. 8 and 9. The mean plant height increased as the crop advanced in age. The mean plant height increased from 16.97 cm to 56.88 cm and 16.55 cm to 58.82 cm at 20 DAS and 80 DAS during the year 2012 and 2013, respectively. The rate of increase in plant height was the maximum between 40 to 60 DAS. Subsequently the rate of increase was slow towards 80 DAS.

Sowing times

The mean plant height was significantly influenced throughout the crop growth period by different growing environments created through different sowing times. The maximum mean plant height (42.67 and 43.93 cm) was recorded with I FN of June (S₁) sowing, whereas II FN of July (S₄) produced least plant height (35.82 and 36.57 cm) at all stages of crop growth during the year 2012 and 2013, respectively.

During 2012, the mean plant height recorded from 20 DAS to 80 DAS showed significant difference between I FN of June (S₁) (42.67 cm), II FN of June (S₂) (41.74 cm) and I FN of July (S₃) (39.52 cm) were significantly superior over II FN of July (S₄) (35.82 cm). The treatment I FN of June (S₁) proved statistically superior at 60 DAS and II FN of June (S₂) and I FN of July (S₃) at par with I FN of June (S₁) treatments, whereas II FN of July (S₄) (47.76 cm) was significantly lowest during the period.

During 2013, the differences in plant height due to various dates of sowing were significant at all the fortnightly dates of sowing. I FN of June (S₁) sowing dates had recorded significantly higher plant height than other dates of sowing, but it was at par with II FN of June (S₂) sowing date at 20 and 60 DAS and in I FN of July (S₃) at 40 and 80 DAS. The decline trend was observed in case of mean plant height as the sowing delayed.

The reason for increased plant height in early sowing may be due to the enhanced vegetative growth of soybean crop with favourable weather conditions, particularly rainfall and hence soil moisture regime throughout the growing period that facilitated better shoot growth. Singh *et al.* (1974), Arora (1981), Karad (1999), Kausale (2000), Rajendra Prasad (2002) and Mane (2011) were also reported the similar results.

Varieties

The mean plant height differences due to varieties were significant at all stages of crop growth during the year 2012 and 2013. It could be observed that

at all the stages of growth variety MACS-450 (V_2) was recorded significantly higher plant height (42.72 and 44.14) as compared to DS-228 (V_3) (39.71 and 40.41) and JS-335 (V_1) (37.21 and 37.83). The Variety DS-228 (V_3) (52.85 and 53.60) was statistically at par with JS-335 (V_1) (48.46 and 49.71) except at 60 DAS, whereas, it was significantly more over JS-335 (V_1) (48.46 and 49.71) during both the years. The superior performance of MACS-450 (V_2) (42.72 and 44.14) compared to other two varieties in terms of plant height could be mainly due to inherent genetic characteristics of the varieties with better growth and extending capacity of the shoot. Similar results were reported by Mahajan *et al.* (1993).

Interactions

Interaction effects were found to be non-significant at all the stages of plant growth.

Table 8. Mean plant height (cm) as influenced periodically by sowing times and varieties (2012)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2012				
S_1 (I FN of June)	17.85	36.02	56.34	60.48	42.67
S_2 (II FN of June)	17.51	34.53	55.35	59.55	41.74
S_3 (I FN of July)	16.59	33.92	51.54	56.04	39.52
S_4 (II FN of July)	15.91	28.15	47.76	51.47	35.82
S. Em $\pm$	0.37	0.97	1.76	1.43	-
C.D. at 5%	1.20	3.12	5.63	4.57	-
B) Varieties					
V_1 (JS-335)	15.98	30.03	48.46	54.36	37.21
V_2 (MACS-450)	17.55	36.33	56.92	60.08	42.72
V_3 (DS-228)	16.67	33.11	52.85	56.21	39.71
S. Em $\pm$	0.46	1.20	1.32	1.36	-
C.D. at 5%	1.35	3.50	3.86	3.98	-
Interaction (AxB)					
S. Em $\pm$	0.92	2.40	2.64	2.72	-
C.D. at 5%	NS	NS	NS	NS	-
GM	16.97	33.15	52.75	56.88	39.94

Table 9. Mean plant height (cm) as influenced periodically by sowing times and varieties (2013)					
Treatment	Days after sowing				
	20 DAS	40 DAS	60 DAS	80 DAS	Mean
A) Sowing times	2013				
S ₁ (I FN of June)	18.23	36.43	58.59	62.48	43.93
S ₂ (II FN of June)	16.79	35.12	56.27	61.30	42.37
S ₃ (I FN of July)	16.04	34.67	52.46	58.47	40.41
S ₄ (II FN of July)	15.14	28.82	48.85	53.47	36.57
S. Em $\pm$	0.54	1.16	1.80	1.46	-
C.D. at 5%	1.75	3.70	5.76	4.69	-
B) Varieties					
V ₁ (JS-335)	15.40	29.96	49.71	56.24	37.83
V ₂ (MACS-450)	17.71	38.01	58.80	62.02	44.14
V ₃ (DS-228)	16.54	33.30	53.60	58.21	40.41
S. Em $\pm$	0.35	1.06	1.41	1.34	-
C.D. at 5%	1.03	3.10	4.13	3.93	-
Interaction (AxB)					
S. Em $\pm$	0.71	2.13	2.83	2.69	-
C.D. at 5%	NS	NS	NS	NS	-
GM	16.55	33.76	54.04	58.82	40.79

4.2.2 Number of branches (plant⁻¹)

The mean number of branches plant⁻¹ were recorded at different growth stages of soybean. It was 2, 7, 8 and 7 numbers during 2012 and 2, 7, 8 and 8 numbers during the year 2013 at 20, 40, 60, 80 DAS, respectively. The relevant data is presented in Table 10 and 11 with Fig.10 and 11.

Sowing times

The mean number of branches plant⁻¹ increased with advancement in the age of the soybean crop. The mean maximum number of branches plant⁻¹ was 8 at 60 to 80 DAS. The rate of increase was comparatively high during 40 to 80 DAS and slow thereafter. At 60 DAS, the plant attained maximum mean number of branches (7.98) and (8.34) during 2012 and 2013, respectively.

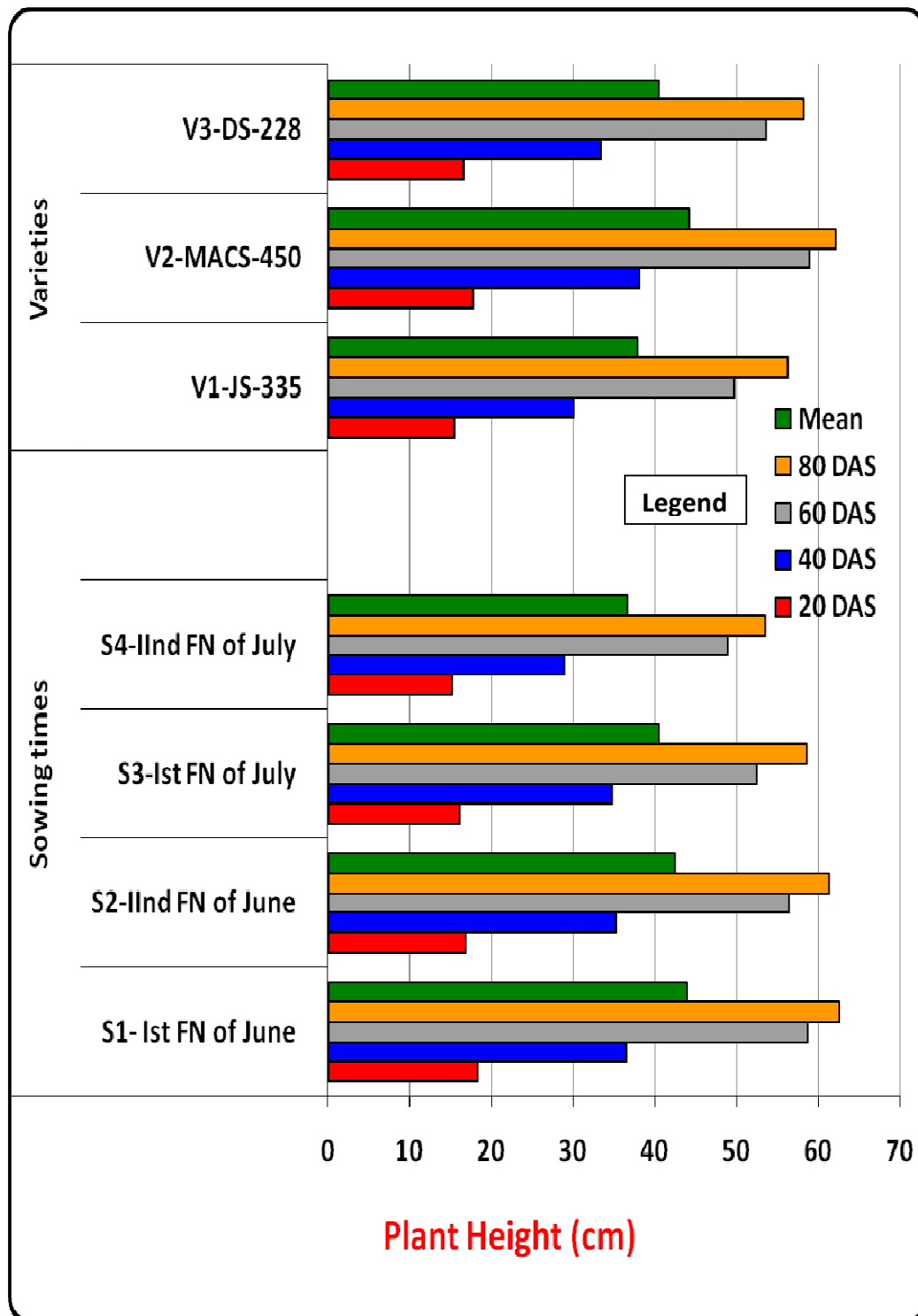


Fig.8. Mean plant height (cm) as influenced periodically by sowing times and varieties (2012)

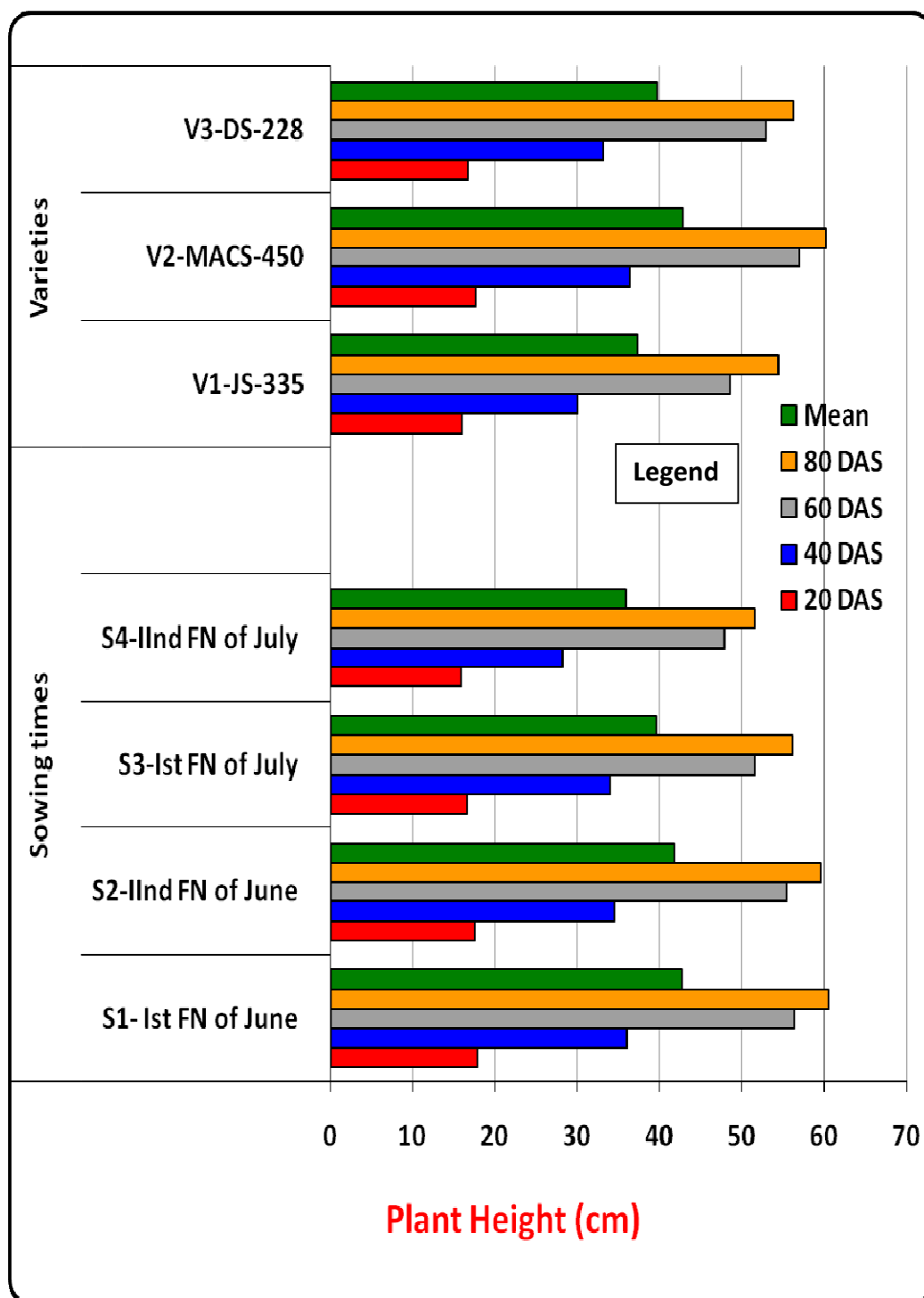


Fig.9. Mean plant height (cm) as influenced periodically by sowing times and varieties (2013)

The differences in mean number of branches plant⁻¹ due to various dates of sowing were non-significant at all the fortnightly dates of sowing. I FN of June (S₁) sowing date had recorded higher mean number of branches plant⁻¹ (6.36 and 6.76) than other dates of sowing. There was a declining trend observed in mean number of branches plant⁻¹ as the sowing delayed during both the year. The reason for increased mean number of branches plant⁻¹ in early sowing may be the enhanced vegetative development of crop due to the favourable weather conditions, particularly favourable rainfall and hence soil moisture regime throughout the growing period that facilitated better shoot growth. Singh *et al.* (1974), Arora (1981), Karad (1999), Kausale (2000), Rajendra Prasad (2002) and Mane (2011) were reported similar results.

Varieties

The differences due to varieties on the mean number of branches plant⁻¹ were non-significant at all the growth stages of soybean crop. During the year 2012 and 2013, it could be observed that at all the growth stages of variety MACS-450 (V₂) were recorded higher number of branches plant⁻¹ (6.17 and 6.50) as compared to DS-228 (V₃) (6.01 and 6.33) and JS-335 (V₁) (5.86 and 6.32). The superior performance of MACS-450 (V₂) compared to other two varieties in terms of number of branches plant⁻¹ could be mainly due to inherent genetic characteristic of the varieties with better growth and extending capacity of the shoot. Similar results was reported by Krishnamurthy *et al.* (2000).

Interaction

The mean number of branches plant⁻¹ was significantly influenced due to sowing times with varieties interactions at 40 DAS during 2012 (Table 10 a). The sowing time S₁ with variety V₃ (S₁V₃) was significantly superior (7.650) over rest of the treatments except S₁V₂ and S₂V₂ which found to be at par with each other. Similarly, mean number of branches plant⁻¹ was significantly influenced by treatment interactions at 40 and 80 DAS during 2013 (Table 11 a and b), sowing S₁ with variety V₃ (S₁V₃) was significantly superior (7.90) over rest of the treatments except S₁V₂ (7.75) and S₂V₂ (7.25) which found to be at

par with each other at 40 DAS and sowing S_2 with variety V_3 (S_1V_3) was significantly superior (9.25) over rest of the treatments except S_1V_2 and S_2V_2 which found to be at par with each other at 80 DAS.

Table 10. Mean number of branches (plant⁻¹) as influenced periodically by sowing times and varieties (2012)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2012				
S_1 (I FN of June)	2.25	7.27	8.42	7.50	6.36
S_2 (II FN of June)	2.17	6.72	8.00	7.38	6.07
S_3 (I FN of July)	2.08	6.50	7.86	7.16	5.90
S_4 (II FN of July)	2.04	6.27	7.63	7.03	5.74
S. Em $\pm$	0.17	0.23	0.34	0.32	-
C.D. at 5%	NS	NS	NS	NS	-
B) Varieties					
V_1 (JS-335)	2.13	6.50	7.73	7.09	5.86
V_2 (MACS-450)	2.09	6.88	8.29	7.44	6.17
V_3 (DS-228)	2.19	6.69	7.91	7.26	6.01
S. Em $\pm$	0.16	0.12	0.22	0.20	-
C.D. at 5%	NS	NS	NS	NS	-
Interaction (AxB)					
S. Em $\pm$	0.32	0.24	0.45	0.40	-
C.D. at 5%	NS	0.69	NS	NS	-
GM	2.14	6.69	7.98	7.27	6.02

Table 10 a. Mean number of branches (plant⁻¹) as influenced periodically by interactions between sowing times and varieties at 40 DAS (2012)				
A) Sowing times	B) Varieties			Mean
	V_1 (JS-335)	V_2 (MACS-450)	V_3 (DS-228)	
S_1 (I FN of June)	6.650	7.500	7.650	7.267
S_2 (II FN of June)	6.250	7.000	6.900	6.717
S_3 (I FN of July)	6.800	6.300	6.400	6.500
S_4 (II FN of July)	6.300	6.700	5.800	6.267
Mean	6.500	6.875	6.688	
S. Em $\pm$	0.24			
C.D. at 5%	0.69			

Table 11. Mean number of branches (plant⁻¹) as influenced periodically by sowing times and varieties (2013)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2013				
S ₁ (I FN of June)	2.50	7.52	8.83	8.20	6.76
S ₂ (II FN of June)	2.42	6.97	8.38	8.09	6.46
S ₃ (I FN of July)	2.33	6.75	8.25	7.67	6.25
S ₄ (II FN of July)	2.25	6.60	7.88	7.46	6.05
S. Em $\pm$	0.11	0.23	0.23	0.22	-
C.D. at 5%	NS	NS	NS	NS	-
B) Varieties					
V ₁ (JS-335)	2.38	6.81	8.50	7.58	6.32
V ₂ (MACS-450)	2.44	7.13	8.54	7.89	6.50
V ₃ (DS-228)	2.31	6.94	7.98	8.10	6.33
S. Em $\pm$	0.13	0.11	0.22	0.15	-
C.D. at 5%	NS	NS	NS	NS	-
Interaction (AxB)					
S. Em $\pm$	0.26	0.23	0.45	0.30	-
C.D. at 5%	NS	0.67	NS	0.89	-
GM	2.38	6.96	8.34	7.88	6.39

Table 11 a. Mean number of branches (plant⁻¹) as influenced periodically by interaction between sowing times and varieties at 40 DAS (2013)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	6.90	7.75	7.90	7.51
S ₂ (II FN of June)	6.50	7.25	7.15	6.96
S ₃ (I FN of July)	7.05	6.55	6.65	6.75
S ₄ (II FN of July)	6.80	6.95	6.05	6.60
Mean	6.81	7.12	6.93	
S. Em $\pm$	0.22			
C.D. at 5%	0.67			

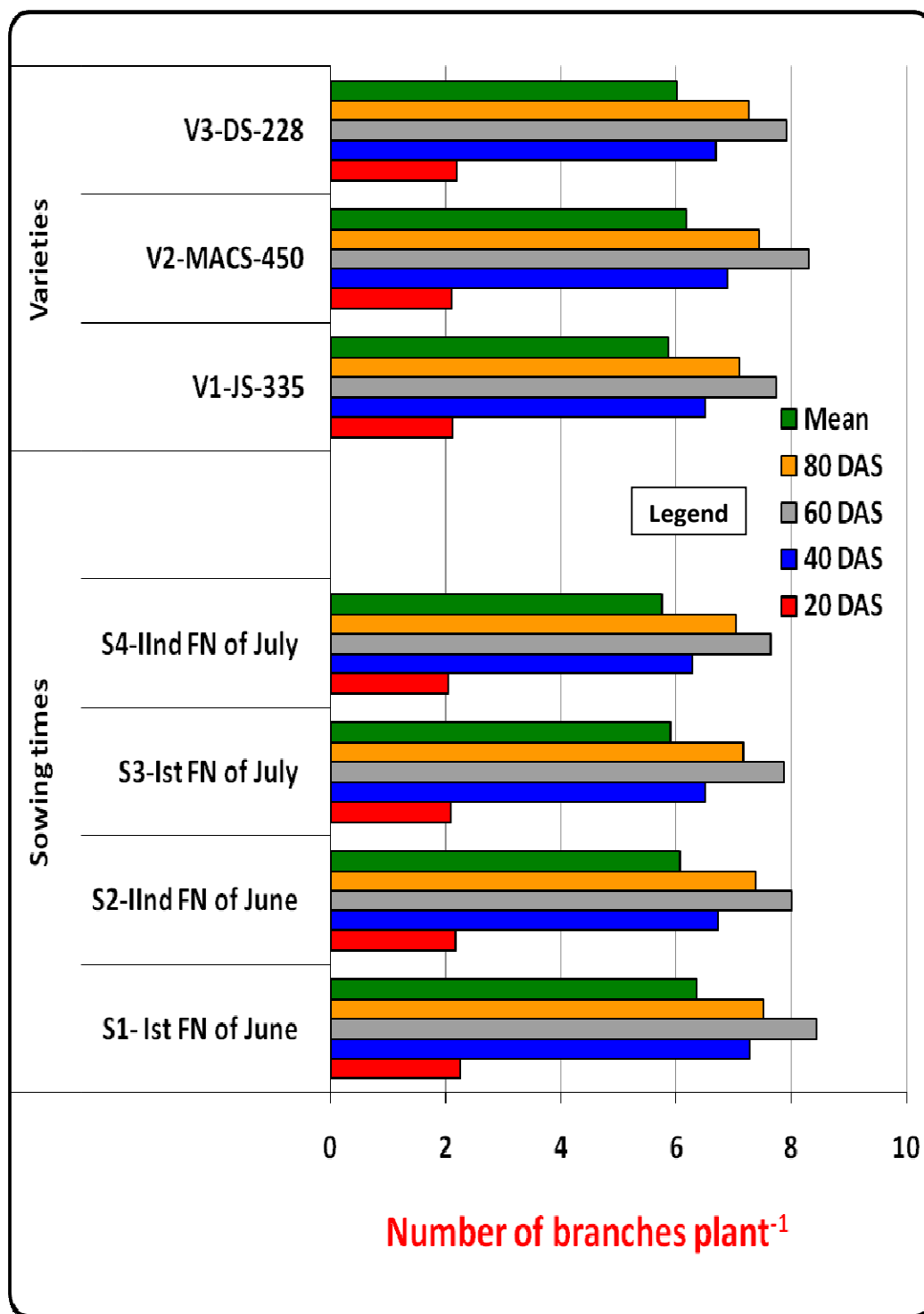


Fig.10. Mean number of branches (plant^{-1}) as influenced periodically by sowing times and varieties (2012)

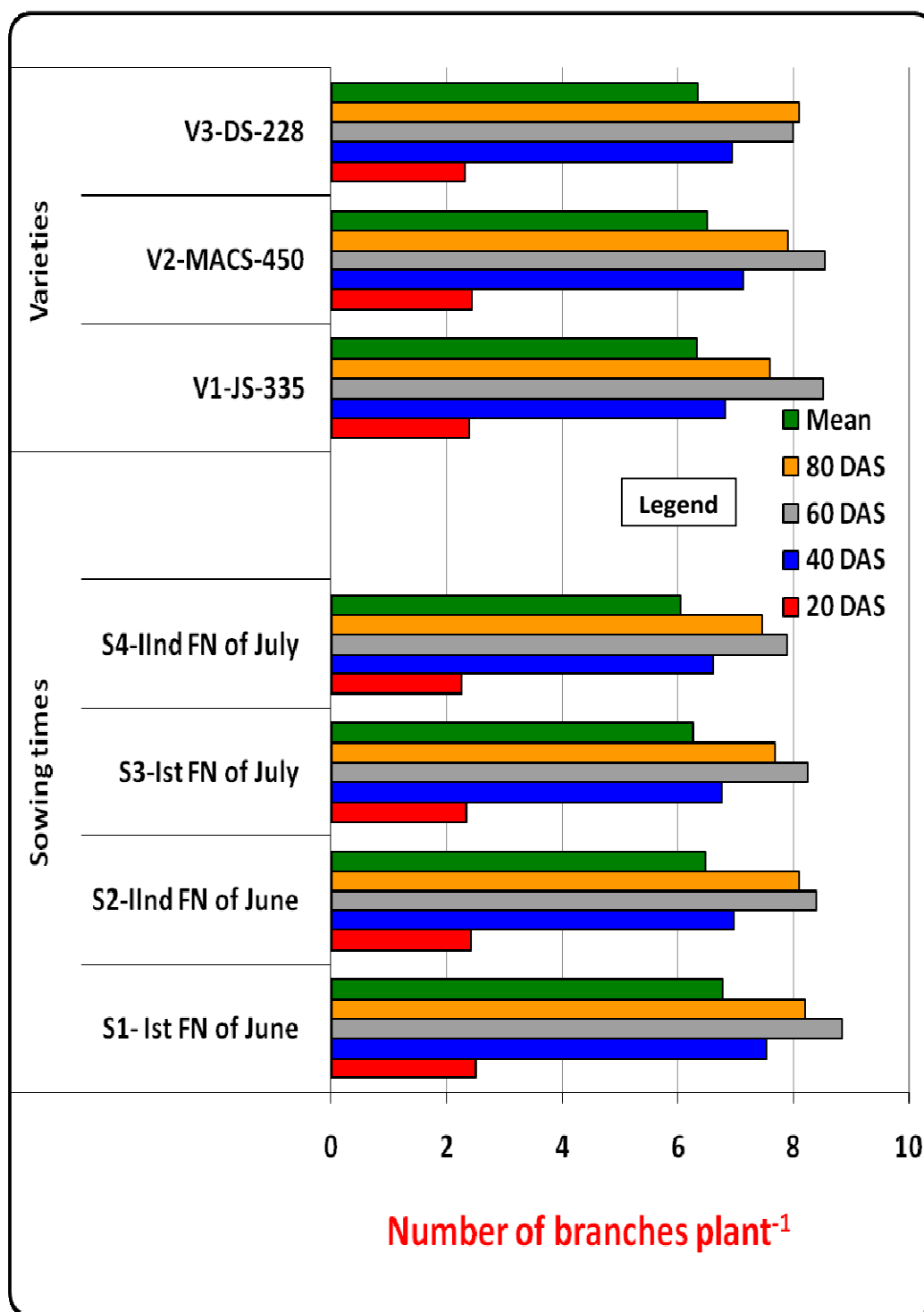


Fig.11. Mean number of branches (plant⁻¹) as influenced periodically by sowing times and varieties (2013)

Table 11 b. Mean number of branches (plant⁻¹) as influenced periodically by interaction between sowing times and varieties at 80 DAS (2013)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	8.25	9.05	8.03	8.44
S ₂ (II FN of June)	7.25	8.51	9.25	8.33
S ₃ (I FN of July)	8.25	7.25	8.25	7.91
S ₄ (II FN of July)	7.53	7.71	7.85	7.70
Mean	7.82	8.13	8.34	
S. Em ±	0.30			
C.D. at 5%	0.88			

4.2.3 Number of functional leaves (plant⁻¹)

The data on mean number of leaves plant⁻¹ were recorded at different growth stages of soybean. It was 3.10, 12.14, 16.61 and 11.20 numbers during 2012 and 3.35, 12.21, 16.88 and 11.64 numbers during the year 2013 at 20, 40, 60, 80 DAS, respectively. The relevant data is presented in Table 12 and 13 with Fig.12 and 13.

Sowing times

The mean number of functional leaves plant⁻¹ was significantly influenced throughout the crop growth period due to different growing environment created through different sowing times. The maximum number of leaves plant⁻¹ was recorded with I FN of June (S₁) sowing (11.77 and 12.03) whereas II FN of July (S₄) produced least number of leaves plant⁻¹ (9.54 and 9.72) at all stages of crop growth during the year 2012 and 2013, respectively.

During 2012, the mean number of leaves plant⁻¹ recorded from 40 DAS to 80 DAS showed significant difference between I FN of June (S₁), II FN of June (S₂) and I FN of July (S₃) were significantly superior over II FN of July (S₄). Sowing time I FN of June (S₁) proved statistically superior over sowing II FN of July (S₄) and par with II FN of June (S₂) and I FN of July (S₃) during 40,

60 and 80 DAS whereas II FN of July (S₄) was significantly lowest during the period.

During 2013, the differences in mean number of leaves plant⁻¹ due to various dates of sowing were significant at all fortnightly dates of sowing. I FN of June (S₁) sowing date had recorded significantly higher number of leaves plant⁻¹ (13.34 and 18.39) than other times of sowing but it was at par with II FN of June (S₂) and I FN of July (S₃) sowing dates at 40 and 80 DAS and except 60 DAS. There was a declined trend observed in mean number of leaves plant⁻¹ as the sowing delayed.

The reason for increased mean number of leaves plant⁻¹ in early sowing may be enhanced vegetative development of crop due to the favourable weather condition, particularly favourable rainfall and hence soil moisture regime throughout the growing period that facilitated better shoot growth. Singh *et al.* (1974), Arora (1981), Karad (1999), Kausale (2000), Rajendra Prasad (2002) and Mane (2011) reported similar results.

Varieties

The differences due to varieties on the mean number of leaves plant⁻¹ were significant at 40 to 80 DAS. During the year 2012 and 2013, it could be observed that at all the stages of growth variety MACS-450 (V₂) (11.35 and 11.62) recorded significantly higher number of leaves plant⁻¹ as compared to DS-228 (V₃) (10.93 and 11.14) and JS-335 (V₁) (10.02 and 10.30). The superior performance of MACS-450 (V₂) (11.35 and 11.62) compared to other two varieties in terms of number of leaves plant⁻¹ could be mainly due to inherent genetic characteristic of the varieties with better growth and extending capacity of the shoot. Similar results are reported by Krishnamurthy *et al.* (2000).

Interaction

The mean number of leaves plant⁻¹ was not significantly influenced by treatment interaction.

Table 12. Mean number of leaves (plant⁻¹) as influenced periodically by sowing times and varieties (2012)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2012				
S ₁ (I FN of June)	3.32	13.24	18.14	12.37	11.77
S ₂ (II FN of June)	3.13	12.83	17.67	12.07	11.43
S ₃ (I FN of July)	2.99	11.52	16.23	10.57	10.33
S ₄ (II FN of July)	2.97	10.99	14.40	9.81	9.54
S. Em $\pm$	0.10	0.54	0.85	0.57	-
C.D. at 5%	NS	1.73	2.71	1.82	-
B) Varieties					
V ₁ (JS-335)	3.02	11.25	15.38	10.42	10.02
V ₂ (MACS-450)	3.16	12.83	17.45	11.94	11.35
V ₃ (DS-228)	3.13	12.35	16.99	11.25	10.93
S. Em $\pm$	0.04	0.36	0.56	0.38	-
C.D. at 5%	NS	1.06	1.63	1.10	-
Interaction (AxB)					
S. Em $\pm$	0.09	0.73	1.12	0.76	-
C.D. at 5%	NS	NS	NS	NS	-
GM	3.10	12.14	16.61	11.20	10.76

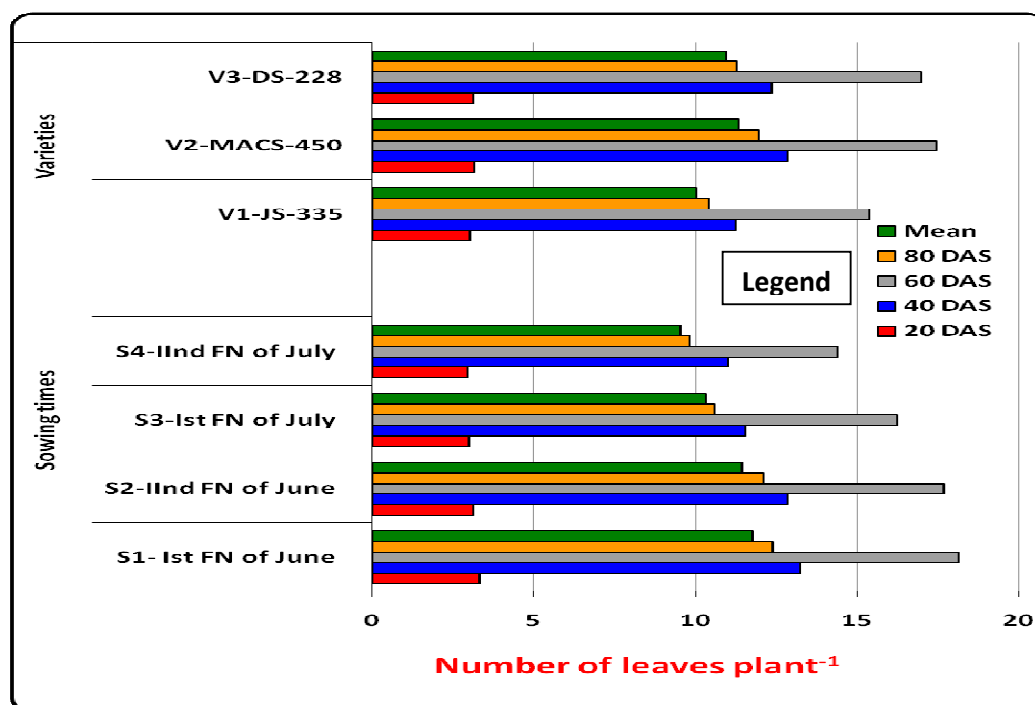


Fig.12. Mean number of leaves (plant⁻¹) as influenced periodically by sowing times and varieties (2012)

Table 13. Mean number of leaves (plant ⁻¹) as influenced periodically by sowing times and varieties (2013)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2013				
S ₁ (I FN of June)	3.54	13.34	18.39	12.87	12.03
S ₂ (II FN of June)	3.38	12.91	17.84	12.57	11.68
S ₃ (I FN of July)	3.30	11.61	16.73	10.98	10.65
S ₄ (II FN of July)	3.19	10.99	14.56	10.14	9.72
S. Em $\pm$	0.10	0.52	0.65	0.59	-
C.D. at 5%	NS	1.66	2.07	1.87	-
B) Varieties					
V ₁ (JS-335)	3.33	11.31	15.63	10.92	10.30
V ₂ (MACS-450)	3.38	12.89	17.83	12.38	11.62
V ₃ (DS-228)	3.35	12.43	17.18	11.63	11.14
S. Em $\pm$	0.05	0.36	0.49	0.39	-
C.D. at 5%	NS	1.04	1.44	1.13	-
Interaction (AxB)					
S. Em $\pm$	0.10	0.71	0.99	0.77	-
C.D. at 5%	NS	NS	NS	NS	-
GM	3.35	12.210	16.88	11.64	11.02

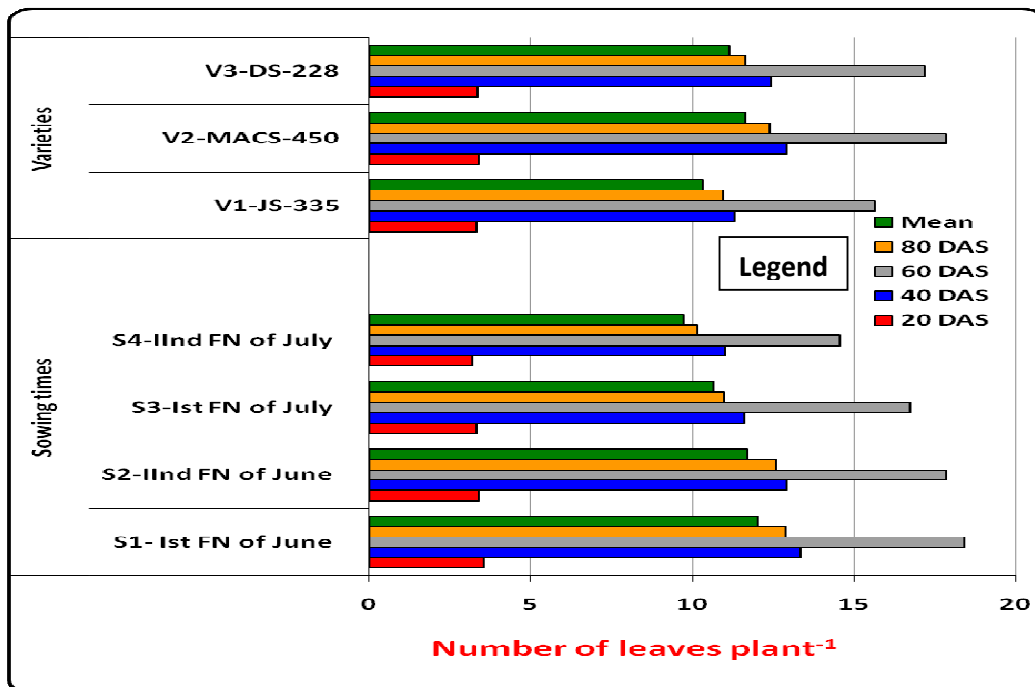


Fig.13. Mean number of leaves (plant⁻¹) as influenced periodically by sowing times and varieties (2013)

4.2.4 Leaf area plant⁻¹

Data in respect of leaf area plant⁻¹ as influenced periodically by different treatments are presented in Table 14 and 15 and graphically depicted in Fig.14 (a) and 15 (a). The leaf area plant⁻¹ expanded from 602.9 to 964.4 cm² and 633.2 to 997.3 cm² at 40 to 60 DAS during 2012 and 2013, respectively. The observation stage was coincided with flowering phase at 40 DAS and pod formation stage at 60 DAS.

Sowing times

Among the four times of sowing during the experimentation it was observed that significantly higher leaf area plant⁻¹ was recorded at early sowing times i.e I FN of June (S₁) followed by other sowing times. The lowest leaf area was recorded by last sowing time i.e. II FN of July (S₄).

During 2012, leaf area recorded plant⁻¹ showed that sowing times I FN of June (S₁) produced significantly higher leaf area over the rest of the treatments, except that it was at par with II FN of June (S₂) and I FN of July (S₃) at 40 DAS. Sowings I FN of July (S₃) and II FN of July (S₄) were statistically equal while II FN of June (S₂) was at par with I FN of July (S₃) at 40 DAS. Whereas, sowing time I FN of June (S₁) produced significantly higher leaf area over the rest of treatments, except that it was at par with II FN of June (S₂) at 60 DAS. During 2013, recorded leaf area plant⁻¹ was showed that sowing time I FN of June (S₁) produced significantly higher leaf area over the rest of the treatments; sowings I FN of July (S₃) and II FN of July (S₄) were statistically equal while I FN of July (S₃) was at par with II FN of July (S₄) at 40 DAS. Sowing II FN of July (S₄) recorded significantly lowest leaf area. While, sowing times I FN of June (S₁) produced significantly higher leaf area over the rest, except that it was at par with II FN of June (S₂) and I FN of July (S₃) at 60 DAS and II FN of July (S₄) treatments were recorded significantly lowest leaf area over the rest of the treatments.

This was due to better growth and regeneration capacity of plants under favourable weather and soil moisture regime prevailed across earlier sown

growing period and a sort of inadequacy situation in terms of soil moisture and weather regime in late sown crop consequently causing greater leaf area in early sown crop, which decreased in later sowings as a consequence of lower leaf number and perhaps reduced leaf expansion. The results are in conformity with the findings reported by Arora (1981) and similar results were reported by Hofstra (1971) and Mane (2011).

Varieties

Different varieties had significant influence on the leaf area production plant^{-1} . During the years 2012 and 2013, It could be observed that at 40 and 60 DAS the growth of MACS-450 (V_2) was recorded significantly higher leaf area plant^{-1} as compared to DS-228 (V_3) and JS-335 (V_1), whereas, variety DS-228 (V_3) it was at par with variety JS-335 (V_1) at 40 DAS. The superior performance of MACS-450 (V_2) was compared to other two varieties in terms of leaf area plant^{-1} could be mainly due to inherent genetic characteristic of the varieties with better growth and extending capacity of the shoot. The differences observed could be attributed more to the inherent genetic potential of the varieties in terms of leaf production. Similar results were reported by Hundal *et al.* (2003).

Interaction

The leaf area plant^{-1} was not significantly influenced due to treatment interaction.

Table 14. Leaf area plant⁻¹ (cm²) and Leaf area index as influenced periodically by sowing times and varieties (2012)						
Treatment	Leaf area plant⁻¹ (cm²)			Leaf area index		
	Days after sowing			Days after sowing		
	40 DAS	60 DAS	Mean	40 DAS	60 DAS	Mean
A) Sowing times	2012			2012		
S ₁ (I FN of June)	684.1	1043.6	863.9	3.09	4.62	3.86
S ₂ (II FN of June)	628.1	1001.1	814.6	2.92	4.44	3.68
S ₃ (I FN of July)	583.1	941.3	762.2	2.72	4.02	3.37
S ₄ (II FN of July)	516.2	871.5	693.8	2.45	3.33	2.89
S. Em ±	34.6	27.8	-	0.12	0.25	-
C.D. at 5%	110.7	89.1	-	0.38	0.80	-
B) Varieties						
V ₁ (JS-335)	573.0	916.5	744.7	2.61	3.82	3.22
V ₂ (MACS-450)	629.8	1037.5	833.7	2.97	4.40	3.69
V ₃ (DS-228)	605.9	939.1	772.5	2.80	4.08	3.44
S. Em ±	15.0	23.5	-	0.09	0.16	-
C.D. at 5%	43.8	68.8	-	0.27	0.46	-
Interaction (AxB)						
S. Em ±	30.0	47.1	-	0.18	0.32	-
C.D. at 5%	NS	NS	-	NS	NS	-
GM	602.9	964.4	783.6	2.80	4.10	3.45

Table 15. Leaf area plant⁻¹ (cm²) and Leaf area index as influenced periodically by sowing times and varieties (2013)						
Treatment	Leaf area plant⁻¹ (cm²)			Leaf area index		
	Days after sowing			Days after sowing		
	40 DAS	60 DAS	Mean	40 DAS	60 DAS	Mean
A) Sowing times	2013			2013		
S ₁ (I FN of June)	710.3	1077.8	894.0	3.31	4.65	3.98
S ₂ (II FN of June)	658.1	1020.7	839.4	3.08	4.52	3.80
S ₃ (I FN of July)	611.4	988.0	799.7	2.94	4.35	3.65
S ₄ (II FN of July)	552.9	902.6	727.7	2.64	3.64	3.14
S. Em ±	14.4	36.0	-	0.11	0.20	-
C.D. at 5%	46.3	115.3	-	0.36	0.65	-
B) Varieties						
V ₁ (JS-335)	609.2	940.6	774.9	2.82	3.98	3.40
V ₂ (MACS-450)	662.0	1090.8	876.4	3.15	4.61	3.88
V ₃ (DS-228)	628.3	960.4	794.4	3.00	4.28	3.64
S. Em ±	13.2	43.9	-	0.08	0.13	-
C.D. at 5%	38.5	128.2	-	0.24	0.38	-
Interaction (AxB)						
S. Em ±	26.4	87.8	-	0.16	0.26	-
C.D. at 5%	NS	NS	-	NS	NS	-
GM	633.2	997.3	815.2	2.99	4.29	3.64

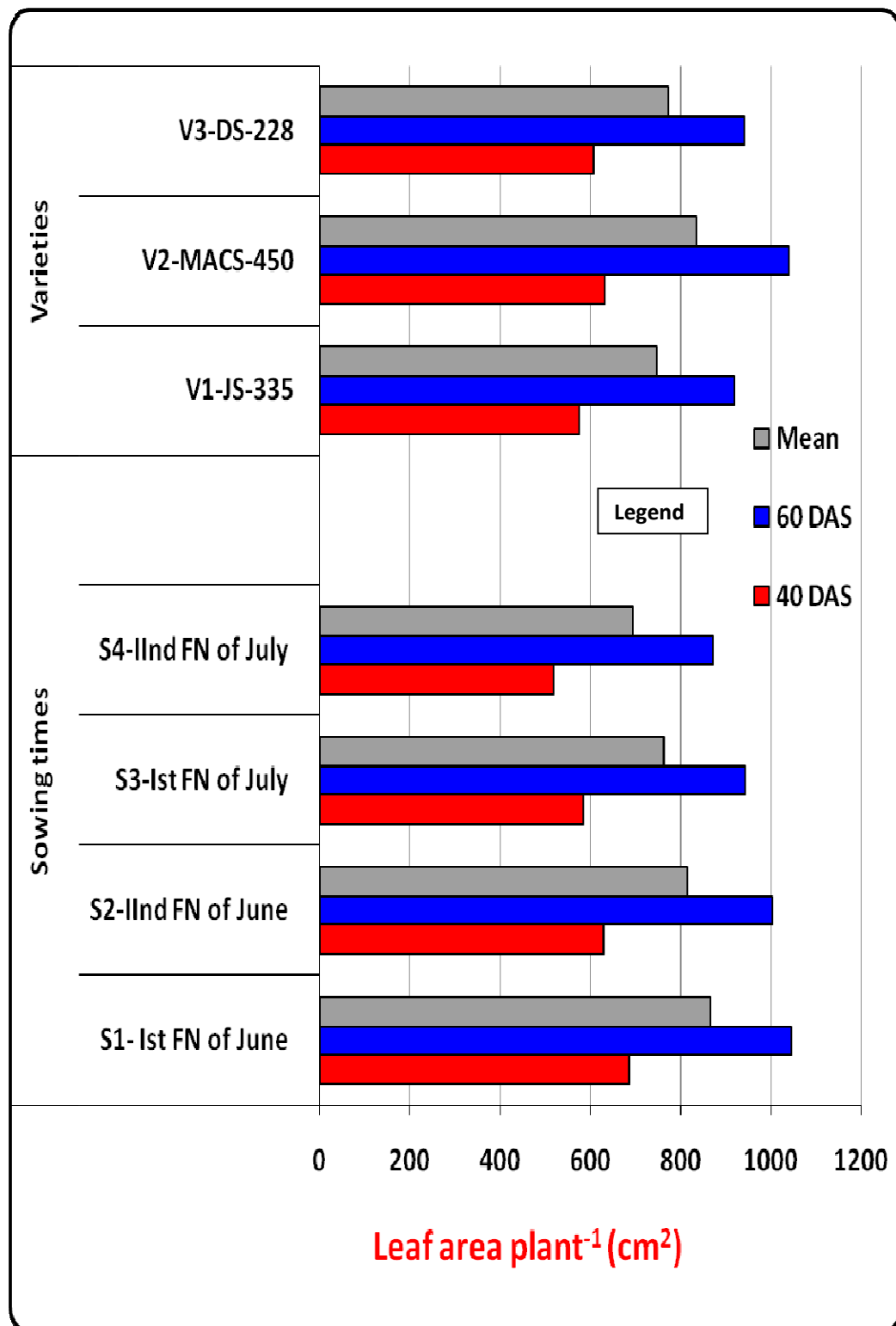


Fig.14 a. Leaf area plant⁻¹ (cm²) as influenced periodically by sowing times and varieties (2012)

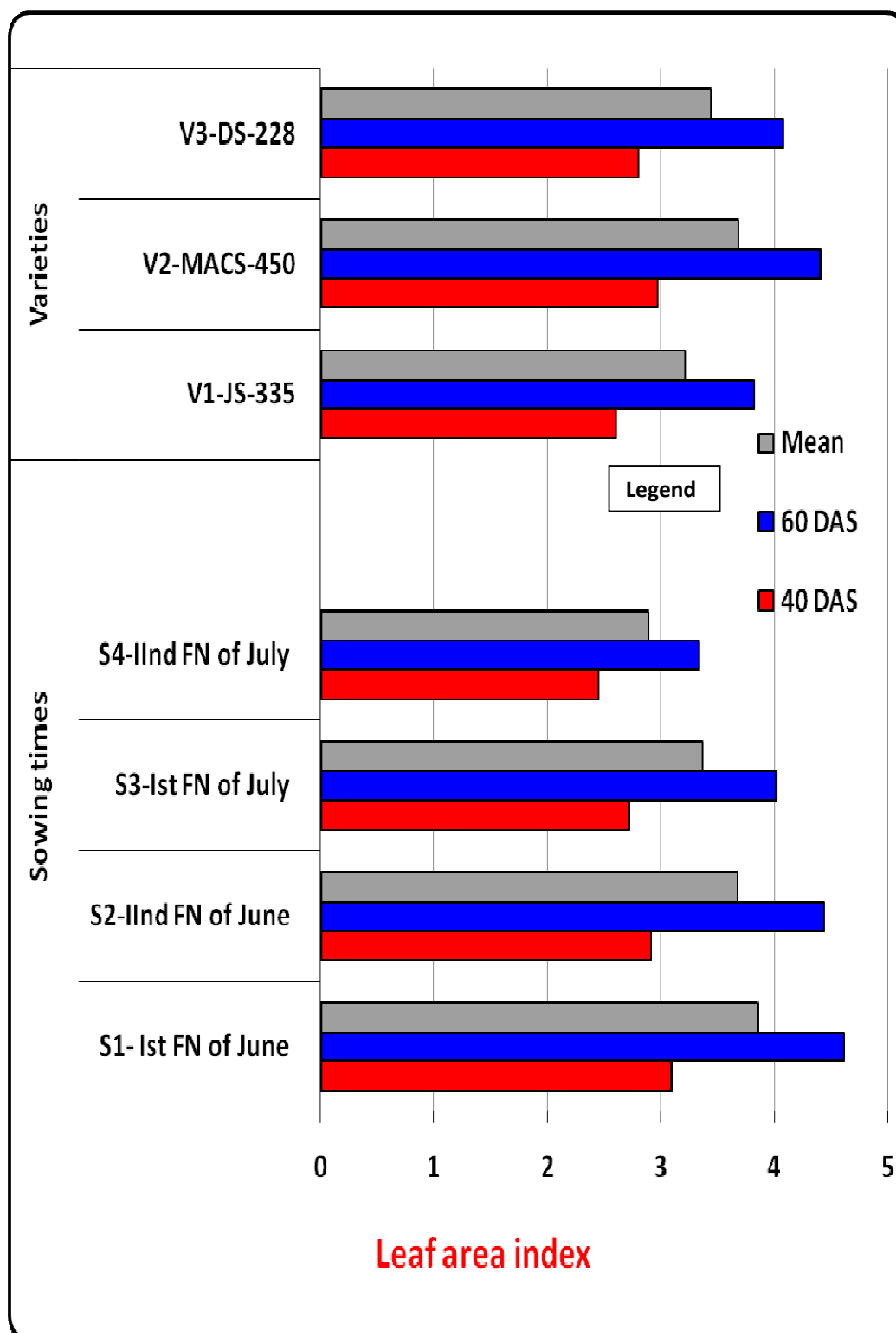


Fig.14 b. Leaf area index as influenced periodically by sowing times and varieties (2012)

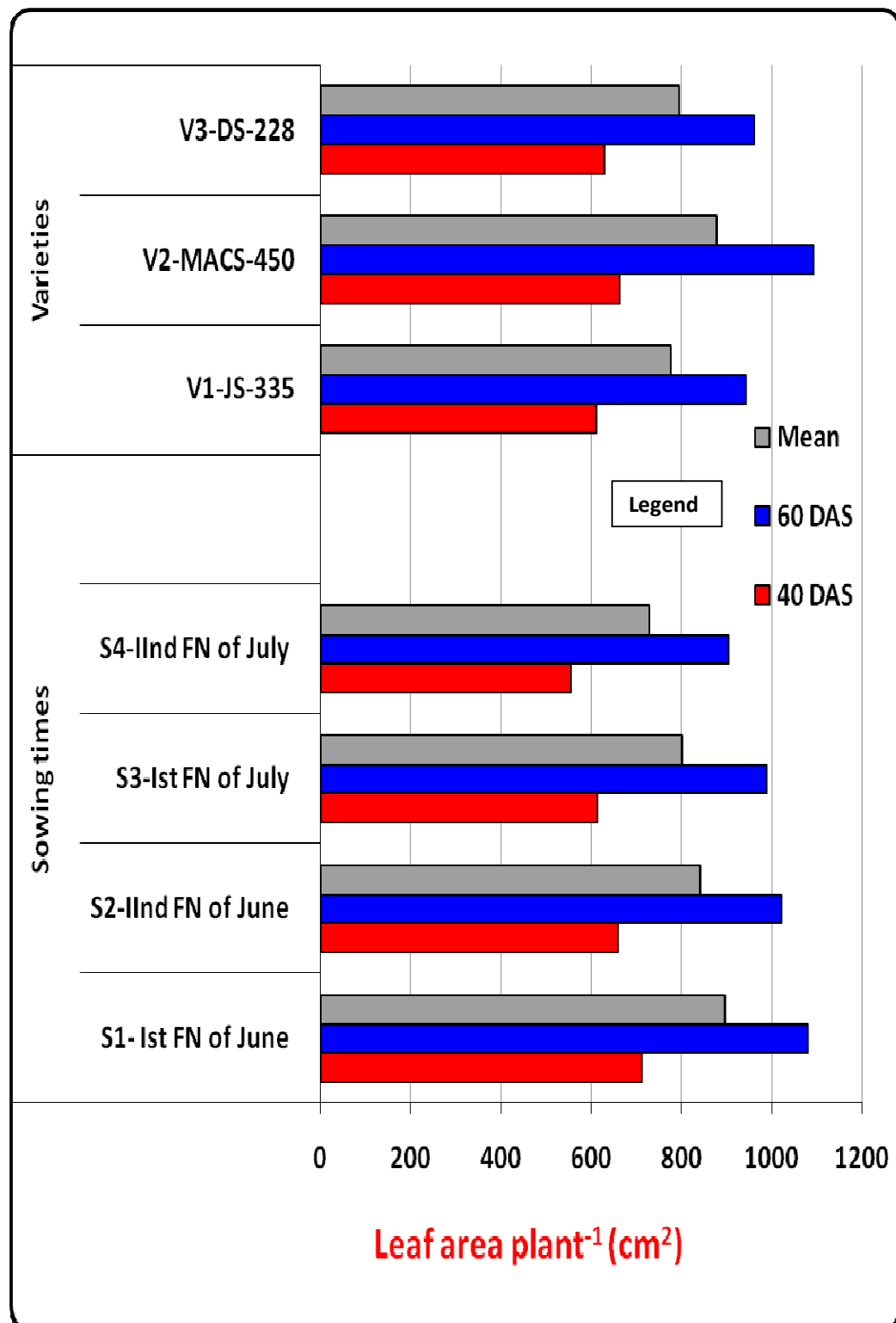


Fig.15 a. Leaf area plant⁻¹ (cm²) as influenced periodically sowing times and varieties (2013)

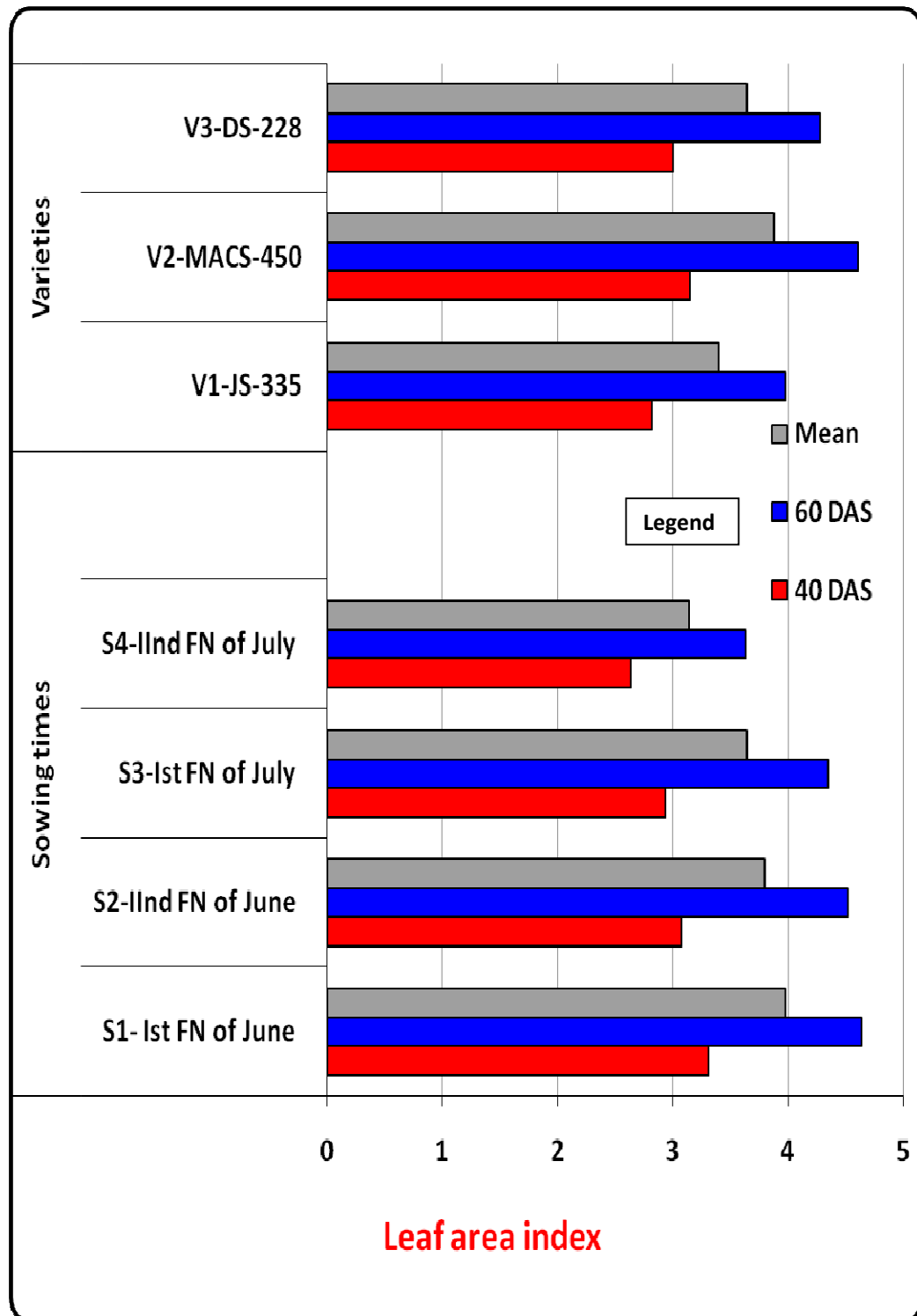


Fig.15 b. Leaf area index as influenced periodically by sowing times and varieties (2013)

4.2.5 Leaf area index

Data in respect of leaf area index as influenced periodically by different treatments are presented in Table 14 and 15 and graphically depicted in Fig.14 (b) and 15 (b). The mean leaf area index increased 2.80 to 4.10 and 2.99 to 4.29 from 40 to 60 days stage during 2012 and 2013, respectively. These stages coincided with flowering phase and pod formation stage in soybean crop.

Sowing times

During 2012, sowing time I FN of June (S_1) being at significantly superior than II FN of July (S_4) and it was at par with II FN of June (S_2) and I FN of July (S_3) at 40 and 60 DAS, it was produced significantly higher leaf area index. Whereas, leaf area index in sowing times II FN of June (S_2) and I FN of July (S_3) proved equal at 40 and 60 DAS.

During 2013, leaf area index in sowing time I FN of June (S_1) was significantly superior than sowing times I FN of July (S_3) and II FN of July (S_4) but it was at par with sowing time II FN of June (S_2) at 40 DAS, it was also significantly superior than II FN of July (S_4) and at par with II FN of June (S_2) and I FN of July (S_3) at 60 DAS. In early sown crop greater leaf area with higher leaf area index, which was decreased in later sowings as a consequence of reduced leaf area. The findings were in agreement with Rajendra Prasad (2002), Singh and Hundal (2004) and Mane (2011).

Early sowing promotes the higher leaf area which reflects in higher leaf area index which has a practical significance in higher accumulation of light which might be beneficial in dry matter accumulation. Similar results were reported by Board *et al.* (1997).

Board and Harvelle (1993) also reported that LAI and dry matter production were decreased with light interception.

Varieties

Different varieties had significant influence on the leaf area index. Variety MACS-450 (V_2) recorded significantly higher leaf area index as

compared to DS-228 (V_3) and JS-335 (V_1) and it was at par with DS-228 (V_3) at 40 and 60 DAS during 2012. During 2013, variety MACS-450 (V_2) was recorded significantly higher leaf area index than variety JS-335 (V_1) but at par with variety DS-228 (V_3) at 40 DAS. Whereas, leaf area index of variety MACS-450 (V_2) was highly significant superior than varieties DS-228 (V_3) and JS-335 (V_1) by and large leaf area index of variety DS-228 (V_3) were at par with variety JS-335 (V_1) at 60 DAS.

Interaction

Leaf area index was not significantly influenced by treatments interaction.

4.2.6 Weight of dry matter accumulation (DMA) plant⁻¹(g)

The accumulation of dry matter (DMA) plant⁻¹ (g) is probably the best index of growth put forth by the crop. Relevant data to this character recorded at various stages are presented in Table 16 and 17 and graphically depicted in Fig. 16 and 17.

During the crop growing period, increase in dry matter weight was continuous up to last observed stage (80 DAS). The rate of increase was slow up to 40 days stage. Thereafter, it accelerated most between 40 and 60 days stage and then further till 80 days stage.

Sowing times

Sowing times influenced dry matter weight significantly. At all the stages of observations the dry matter weight plant⁻¹ showed decreasing trend with late sowings (S_1 to S_4). During 2012, sowing time of I FN of June (S_1) accumulated significantly higher dry matter weight plant⁻¹ compared to late sowings II FN of July (S_4). However, it was statistically at par with sowing times II FN of June (S_2) and I FN of July (S_3) at 20 and 40 DAS. At 60 DAS sowing time I FN of June (S_1) accumulated significantly higher dry matter weight plant⁻¹ as compared to late sowings II FN of June (S_2) and it was also statistically at par with I FN of July (S_3) and II FN of July (S_4) at 60 DAS. Sowing of I FN of June (S_1) accumulated significantly higher dry matter weight plant⁻¹ as compared to late sowings II FN of June (S_2), I FN of July (S_3) and II

FN of July (S_4). Sowing of II FN of July (S_4) recorded the least dry matter accumulation.

Dry matter production during 2013, sowing of I FN of June (S_1) accumulated significantly higher dry matter weight plant⁻¹ as compared to late sowings II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) at 20 DAS, and it was also accumulated significantly higher dry matter weight plant⁻¹ as compared to late sowings I FN of July (S_3) and II FN of July (S_4) at 40, 60 and 80 DAS. However, it was statistically at par with sowing II FN of June (S_2) at 40, 60 and 80 DAS. Sowing of II FN of July (S_4) was recorded the least dry matter accumulation. This could be attributed due to comparatively less favourable weather conditions and soil moisture regime encountered along the growing period by later sown crop that decreased the dry matter accumulation (DMA). Besides, growth period of the crop also decreased with each successive delay in sowing which was also caused reduction in dry matter accumulation in late sowings. This corroborates the findings of Park *et al.* (2000) Hundal *et al.* (2003) and Anil kumar *et al.* (2008^a).

Varieties

Differences in dry matter weight plant⁻¹ due to varieties were significantly differed at all the observed stages. During 2012 across all the stages variety MACS-450 (V_2) was produced significantly higher dry matter weight plant⁻¹ than JS-335 (V_1) and DS-228 (V_3) at 20 and 40 DAS. The latter two varieties were statistically at par with each other at 20 and 40 DAS. The variety MACS-450 (V_2) was produced significantly higher dry matter weight plant⁻¹ than JS-335 (V_1) and by and large variety DS-228 (V_3) was at par with variety MACS-450 (V_2) at 60 and 80 DAS. During 2013, variety MACS-450 (V_2) was produced significantly higher dry matter weight plant⁻¹ than JS-335 (V_1) and DS-228 (V_3) and latter two varieties were statistically at par with each other at all the stages. However, JS-335 (V_1) recorded significantly lower dry matter weight plant⁻¹ than MACS-450 (V_2) and DS-228 (V_3) at all the growth stages. The differential dry matter accumulation among varieties may mainly be attributed to their genetic potential rather than the effect of external weather

Table 16. Total dry matter accumulation plant ⁻¹ (DMA) (g) as influenced periodically by sowing times and varieties (2012)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2012				
S ₁ (I FN of June)	0.59	5.25	14.62	16.05	15.34
S ₂ (II FN of June)	0.52	4.73	14.09	14.90	14.50
S ₃ (I FN of July)	0.51	4.54	12.75	13.47	13.11
S ₄ (II FN of July)	0.37	3.94	11.52	11.93	11.73
S. Em ±	0.04	0.23	0.35	0.32	-
C.D. at 5%	0.15	0.75	1.11	1.03	-
B) Varieties					
V ₁ (JS-335)	0.44	4.26	11.97	13.38	12.68
V ₂ (MACS-450)	0.57	5.04	14.43	15.11	14.77
V ₃ (DS-228)	0.48	4.54	13.34	13.76	13.55
S. Em ±	0.01	0.16	0.43	0.47	-
C.D. at 5%	0.05	0.48	1.26	1.38	-
Interaction (AxB)					
S. Em ±	0.03	0.33	0.86	0.94	-
C.D. at 5%	NS	NS	NS	NS	-
GM	0.50	4.62	13.25	14.09	13.67

Table 17. Total dry matter accumulation plant ⁻¹ (DMA) (g) as influenced periodically by sowing times and varieties (2013)					
Treatment	Days after sowing				Mean
	20 DAS	40 DAS	60 DAS	80 DAS	
A) Sowing times	2013				
S ₁ (I FN of June)	0.63	5.50	15.09	16.64	15.87
S ₂ (II FN of June)	0.55	5.00	14.70	15.57	15.13
S ₃ (I FN of July)	0.53	4.72	13.09	14.14	13.61
S ₄ (II FN of July)	0.40	4.19	11.69	12.27	11.98
S. Em ±	0.01	0.20	0.35	0.58	-
C.D. at 5%	0.04	0.63	1.12	1.88	-
B) Varieties					
V ₁ (JS-335)	0.55	4.43	12.29	13.89	13.09
V ₂ (MACS-450)	0.57	5.40	15.55	15.93	15.74
V ₃ (DS-228)	0.52	4.72	13.09	14.13	13.61
S. Em ±	0.01	0.15	0.46	0.47	-
C.D. at 5%	0.04	0.44	1.36	1.37	-
Interaction (AxB)					
S. Em ±	0.02	0.30	0.93	0.94	-
C.D. at 5%	NS	NS	NS	NS	-
GM	0.53	4.85	13.64	14.65	14.15

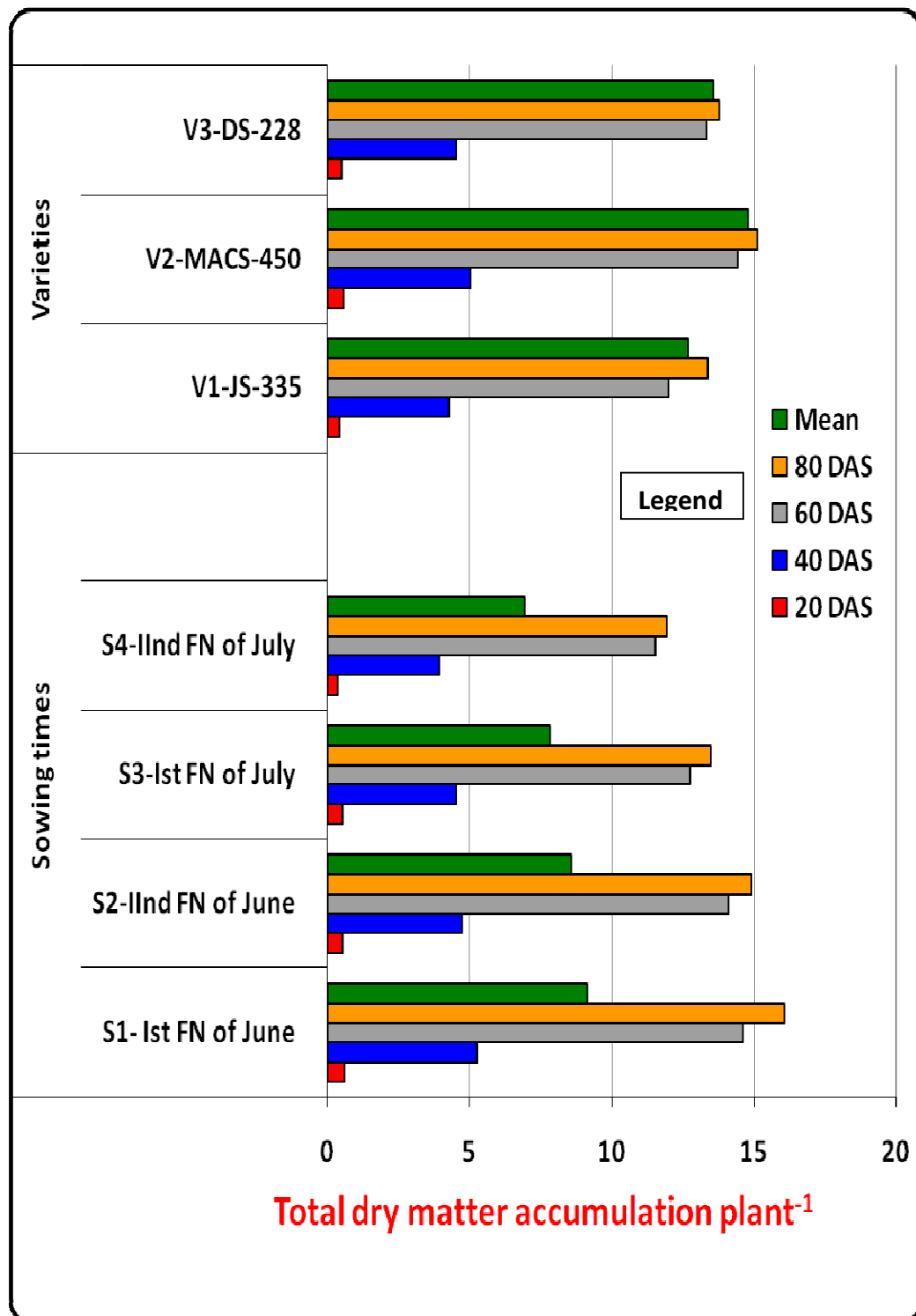


Fig.16. Total dry matter accumulation plant⁻¹ (DMA) (g) as influenced periodically by sowing times and varieties (2012)

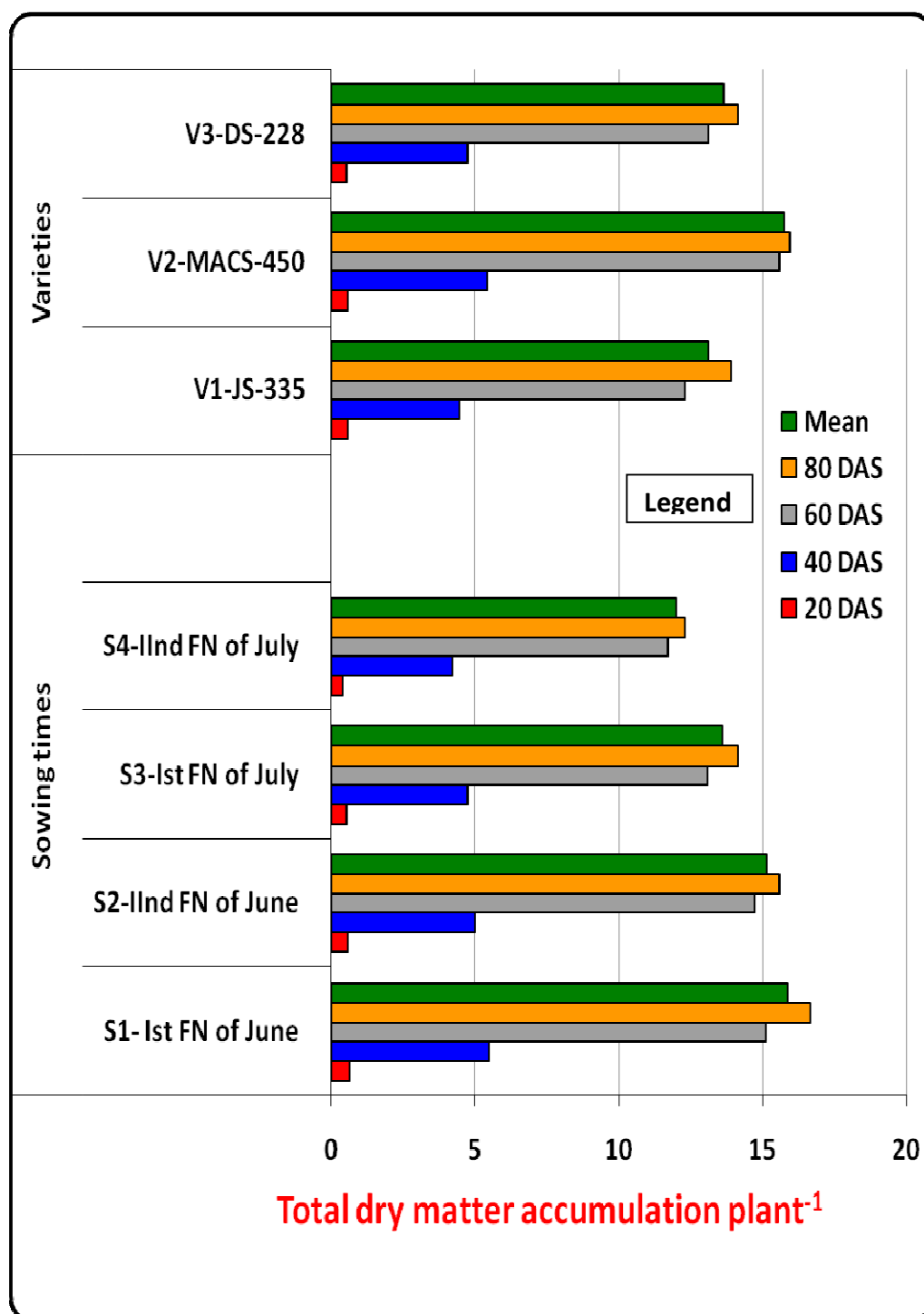


Fig.17. Total dry matter accumulation plant⁻¹ (DMA) (g) as influenced periodically by sowing times and varieties (2013)

parameters which prevailed more or less in similar range along the growing period of varieties. All the genotypes has a definite genetic make up which reflects in dry matter accumulation. More or less similar results have been reported by Hanway and Weber (1971).

Interaction

Total dry matter accumulation was not significantly influenced by treatments interaction.

4.2.7 Dry matter partitioning by stem, grain and stover of soybean (g) at sowing times and varieties (2012 and 2013)

The data on mean dry matter distribution pattern into various plant parts at harvest are presented in Table 18 and 19 and graphically presented in Fig.18 and 19.

It was evident from the data that contribution to total dry matter at harvest by stover was about 1.58 and 1.69 (g), contribution of stem was 4.87 and 5.64 (g) and contribution of grain was 5.27 and 5.47 (g) respectively, during 2012 and 2013.

Partitioning of dry matter in the different plant parts differed significantly due to various environmental conditions during 2012 and 2013.

Sowing times

In grain mean dry matter accumulation was more with I FN of June (S_1) sowing during 2012 and 2013, hence, it was significantly superior over all other treatments in respect of production of dry matter in grain.

Sowing I FN of June (S_1) being significantly superior over rest of the treatments during 2012 and 2013 but sowing II FN of June (S_2) during 2013 was found to be at par with rest of the treatments in respect of dry matter accumulation in stem during both the seasons.

Mean dry matter accumulation in stover was more with sowing I FN of June (S_1) and it was on par with sowing II FN of June (S_2) during 2012. During 2013, sowing I FN of June (S_1) was found to be significantly superior over

sowing I FN of July (S_3) and II FN of July (S_4) but at par with sowing II FN of June (S_2).

Varieties

Higher dry matter accumulation in stem found to be in variety MACS-450 (V_2) followed by DS-228 (V_3) during 2012 and 2013. However, variety DS-228 (V_3) accumulated maximum dry matter in grain during 2012 and 2013, variety MACS-450 (V_2) being on par with JS-335 (V_3).

Total dry matter production per plant and its accumulation in different parts of plant is the manifestation of the magnitude and persistence of photosynthetic capacity of the plant and its translocation to different parts.

Interaction

Mean dry matter accumulation (g) in grain was significantly influenced by treatments interaction between sowing times and varieties at harvest during 2012 (Table 18 a), treatment S_1V_3 was significantly superior over rest of the treatments, similarly, during 2013 (Table 19 a), treatment S_1V_3 was significantly superior over rest of the treatments except S_1V_2 which was found to be at par with rest of the treatments.

Similarly, mean dry matter accumulation (g) in stover was significantly influenced by treatment interaction between sowing times and varieties at harvest during 2012 (Table 18 b), treatment S_1V_1 was significantly superior over rest of the treatments except S_1V_2 and S_2V_2 which found to be at par with each other. However, during 2013 (Table 19 b), treatment S_1V_1 was significantly superior over rest of the treatments except S_2V_2 which was found to be at par with each other.

Table 18. Mean dry matter partitioning (g) by stem, grain and stover of soybean (g) at sowing times and varieties (2012) at harvest			
Treatment	Days after sowing		
	2012		
A) Sowing times	Stem	Grain	Stover
S ₁ (I FN of June)	6.22	7.60	1.84
S ₂ (II FN of June)	5.41	5.71	1.59
S ₃ (I FN of July)	4.20	4.17	1.49
S ₄ (II FN of July)	3.65	3.61	1.40
S. Em ±	0.19	0.14	0.09
C.D. at 5%	0.61	0.44	0.28
B) Varieties			
V ₁ (JS-335)	4.59	4.88	1.56
V ₂ (MACS-450)	5.20	5.31	1.58
V ₃ (DS-228)	4.82	5.63	1.60
S. Em ±	0.05	0.10	0.07
C.D. at 5%	0.13	0.30	NS
Interaction (AxB)			
S. Em ±	0.09	0.20	0.13
C.D. at 5%	NS	0.60	0.39
GM	4.87	5.27	1.58

Table 18 a. Mean dry matter partitioning (g) in grain as influenced by interactions between sowing times and varieties at harvest (2012)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	7.03	7.52	8.25	7.60
S ₂ (II FN of June)	4.33	6.04	6.74	5.70
S ₃ (I FN of July)	4.75	3.96	3.78	4.16
S ₄ (II FN of July)	3.39	3.71	3.73	3.61
Mean	4.88	5.31	5.62	
S. Em ±	0.20			
C.D. at 5%	0.59			

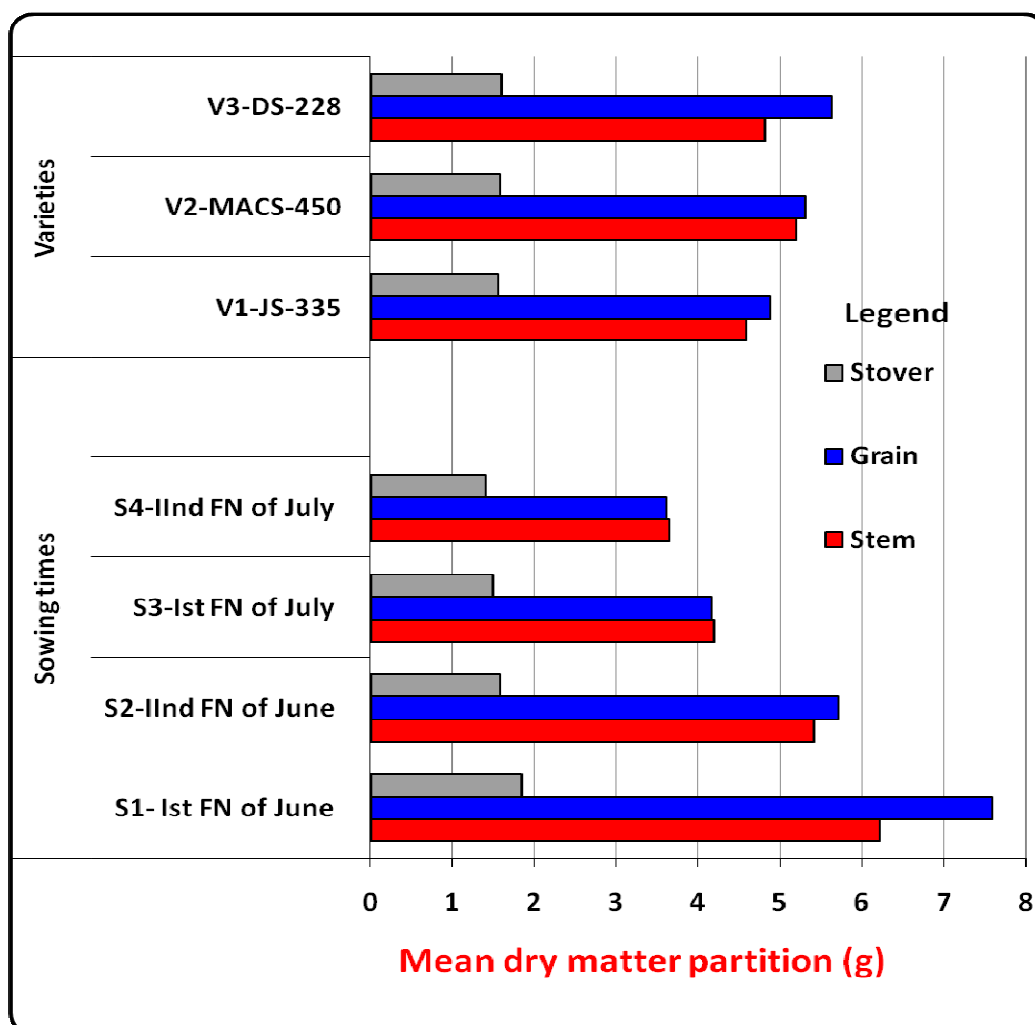


Fig.18. Mean dry matter partitioning (g) by stem, grain and stover of soybean (g) by sowing times and varieties (2012)

Table 18 b. Mean dry matter partitioning (g) in stover as influenced by interactions between sowing times and varieties at harvest (2012)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	2.10	1.75	1.65	1.83
S ₂ (II FN of June)	1.37	1.84	1.56	1.59
S ₃ (I FN of July)	1.37	1.49	1.60	1.48
S ₄ (II FN of July)	1.40	1.24	1.57	1.40
Mean	1.56	1.58	1.59	
S. Em $\pm$	0.13			
C.D. at 5%	0.39			

Table 19. Mean dry matter partitioning (g) by stem, grain and stover of soybean (g) at sowing times and varieties (2013) at harvest

Treatment	Days after sowing		
	2013		
A) Sowing times	Stem	Grain	Stover
S ₁ (I FN of June)	6.86	7.77	1.92
S ₂ (II FN of June)	6.22	6.02	1.69
S ₃ (I FN of July)	5.01	4.32	1.66
S ₄ (II FN of July)	4.46	3.76	1.48
S. Em $\pm$	0.20	0.14	0.07
C.D. at 5%	0.64	0.45	0.23
B) Varieties			
V ₁ (JS-335)	5.28	5.22	1.67
V ₂ (MACS-450)	6.01	5.46	1.69
V ₃ (DS-228)	5.63	5.73	1.70
S. Em $\pm$	0.06	0.10	0.06
C.D. at 5%	0.18	0.28	NS
Interaction (AxB)			
S. Em $\pm$	0.12	0.19	0.11
C.D. at 5%	NS	0.56	0.33
GM	5.64	5.47	1.69

Table 19 a. Mean dry matter partitioning (g) in grain as influenced by interactions between sowing times and varieties at harvest (2013)

A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	7.43	7.67	8.22	7.77
S ₂ (II FN of June)	4.98	6.19	6.89	6.02
S ₃ (I FN of July)	4.90	4.11	3.93	4.31
S ₄ (II FN of July)	3.54	3.86	3.88	3.76
Mean	5.21	5.46	5.73	
S. Em $\pm$	0.19			
C.D. at 5%	0.55			

Table 19 b. Mean dry matter partitioning (g) in stover as influenced by interactions between sowing times and varieties at harvest (2013)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	2.26	1.90	1.80	1.99
S ₂ (II FN of June)	1.52	1.96	1.79	1.75
S ₃ (I FN of July)	1.66	1.77	1.75	1.73
S ₄ (II FN of July)	1.52	1.39	1.74	1.55
Mean	1.74	1.76	1.77	
S. Em ±	0.11			
C.D. at 5%	0.33			

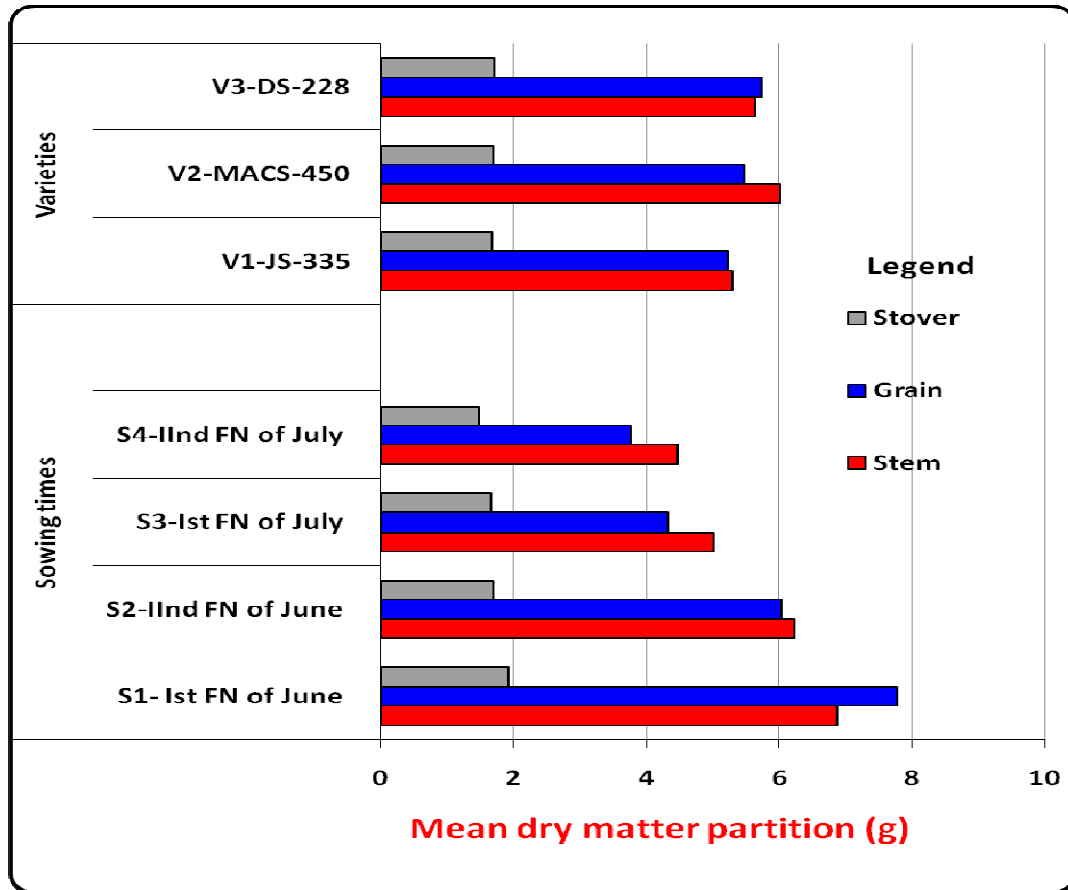


Fig.19. Mean dry matter partitioning (g) in stem, grain and stover of soybean (g) by sowing times and varieties (2013)

4.3 Yield attributes studies

4.3.1 Number of pods plant⁻¹

Data on total number of pods plant⁻¹ under various treatments are enumerated in Table 20 and graphically shown in Fig.20 (a and b). Mean total number of pods plant⁻¹ was 40.81 and 43.02 during 2012 and 2013 respectively.

Sowing times

Sowing times was significantly influenced the number of pods plant⁻¹. During 2012 sowing of I FN of June (S₁) was recorded significantly higher number of pods plant⁻¹ compared to late sowings of II FN of July (S₄), while it was at par with II FN of June (S₂) and I FN of July (S₃). Sowings of II FN of June (S₂) and I FN of July (S₃) were significantly at par with each other. The lowest number of pods plant⁻¹ was recorded by sowing II FN of July (S₄) (37.58). Similarly, during 2013 sowing of I FN of June (S₁) was recorded significantly higher number of pods plant⁻¹ as compared to sowings of II FN of June (S₂) and I FN of July (S₃) and II FN of July (S₄) and lowest number of pods plant⁻¹ was recorded by II FN of July (S₄) (40.42). The above results are in conformity with the findings reported by Barik and Sahoo (1989), Jasani *et al.* (1994), Park *et al.* (2000), Singh *et al.* (2010) and Mane (2011).

Varieties

The variety DS-228 (V₃) was recorded the maximum number of pods plant⁻¹ (43.06 and 47.13) that was significantly more over varieties MACS-450 (V₂) (40.00 and 41.56) and JS-335 (V₁) (39.38 and 40.38). The latter two treatments were at par with each other during both the year i.e. 2012 and 2013. Similar results were reported by Katti *et al.* (1970).

Interaction

Number of pods plant⁻¹ was not significantly influenced by treatments interaction.

4.3.2 Seed weight plant⁻¹

Data pertaining to mean seed weight plant⁻¹ (g) as influenced by different treatments are given in the Table 20 and graphically shown in Fig. 20 (a and b). Mean seed weight per plant was 7.54 and 8.51 g during 2012 and 2013 respectively.

Sowing times

Mean seed weight plant⁻¹ was significantly influenced due to different sowing times. During 2012 maximum seed weight plant⁻¹ was recorded by sowing of I FN of June (S₁) (8.73 g). It was significantly superior over sowings I FN of July (S₃) and II FN of July (S₄) and at par with sowing II FN of June (S₂). Sowings of I FN of July (S₃) and II FN of July (S₄) were significantly at par with each other. The lowest seed weight plant⁻¹ was recorded by sowing time of II FN of July (S₄) (6.38 g).

Similarly, during 2013 sowing of I FN of June (S₁) recorded significantly maximum seed weight plant⁻¹ (9.59 g) as compared to sowings of II FN of June (S₂), I FN of July (S₃) and II FN of July (S₄). Sowings of II FN of June (S₂) and I FN of July (S₃) were at par with each other and seed weight plant⁻¹ was recorded by II FN of July (S₄) (7.55 g).

Varieties

The variety DS-228 (V₃) recorded the maximum seed weight plant⁻¹ (8.19 g) that was the significantly superior over MACS-450 (V₂) and JS-335 (V₁). The latter two treatments were at par with each other and minimum seed weight plant⁻¹ was recorded by JS-335 (V₁) (7.19 and 7.89 g) during both the year i.e. 2012 and 2013.

Interaction

Seed weight plant⁻¹ was not significantly influenced by treatments interaction.

Table 20. Yield attributes at harvest as influenced by sowing times and varieties (2012 and 2013)								
Treatment	Number of pods plant⁻¹	Seed weight plant⁻¹ (g)	Number of seeds pod⁻¹	100 seed weight (g)	Number of pods plant⁻¹	Seed weight plant⁻¹ (g)	Number of seeds pod⁻¹	100 seed weight (g)
A) Sowing times	2012				2013			
S ₁ (I FN of June)	43.25	8.73	2.74	9.87	45.58	9.59	2.93	9.93
S ₂ (II FN of June)	41.67	8.00	2.69	9.64	43.67	8.74	2.88	9.78
S ₃ (I FN of July)	40.75	7.07	2.41	9.56	42.42	8.14	2.75	9.64
S ₄ (II FN of July)	37.58	6.38	2.26	8.54	40.42	7.55	2.53	8.84
S. Em ±	1.09	0.30	0.11	0.07	0.38	0.23	0.09	0.17
C.D. at 5%	3.49	0.95	0.37	0.24	1.21	0.75	0.29	0.53
B) Varieties								
V ₁ (JS-335)	39.38	7.19	2.31	8.94	40.38	7.89	2.55	9.08
V ₂ (MACS-450)	40.00	7.25	2.48	9.23	41.56	8.13	2.71	9.36
V ₃ (DS-228)	43.06	8.19	2.79	10.03	47.13	9.49	3.06	10.21
S. Em ±	0.89	0.23	0.11	0.09	0.44	0.20	0.07	0.17
C.D. at 5%	2.60	0.66	0.33	0.27	1.29	0.59	0.20	0.50
Interaction (AxB)								
S. Em ±	1.78	0.45	0.23	0.18	0.88	0.40	0.14	0.34
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS
GM	40.81	7.54	2.53	9.40	43.02	8.51	2.77	9.55

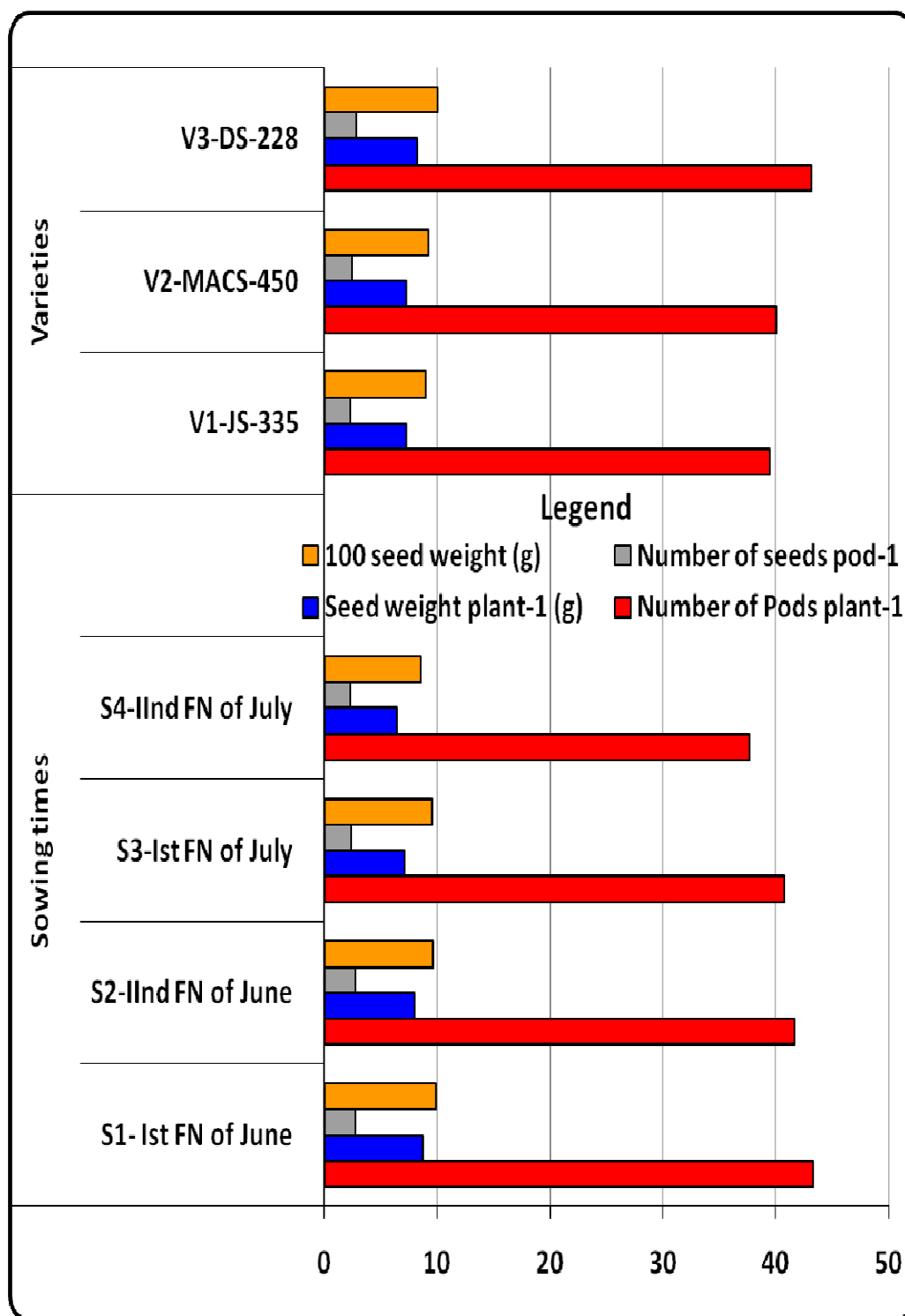


Fig. 20 a. Yield attributes at harvest as influenced by sowing times and varieties (2012)

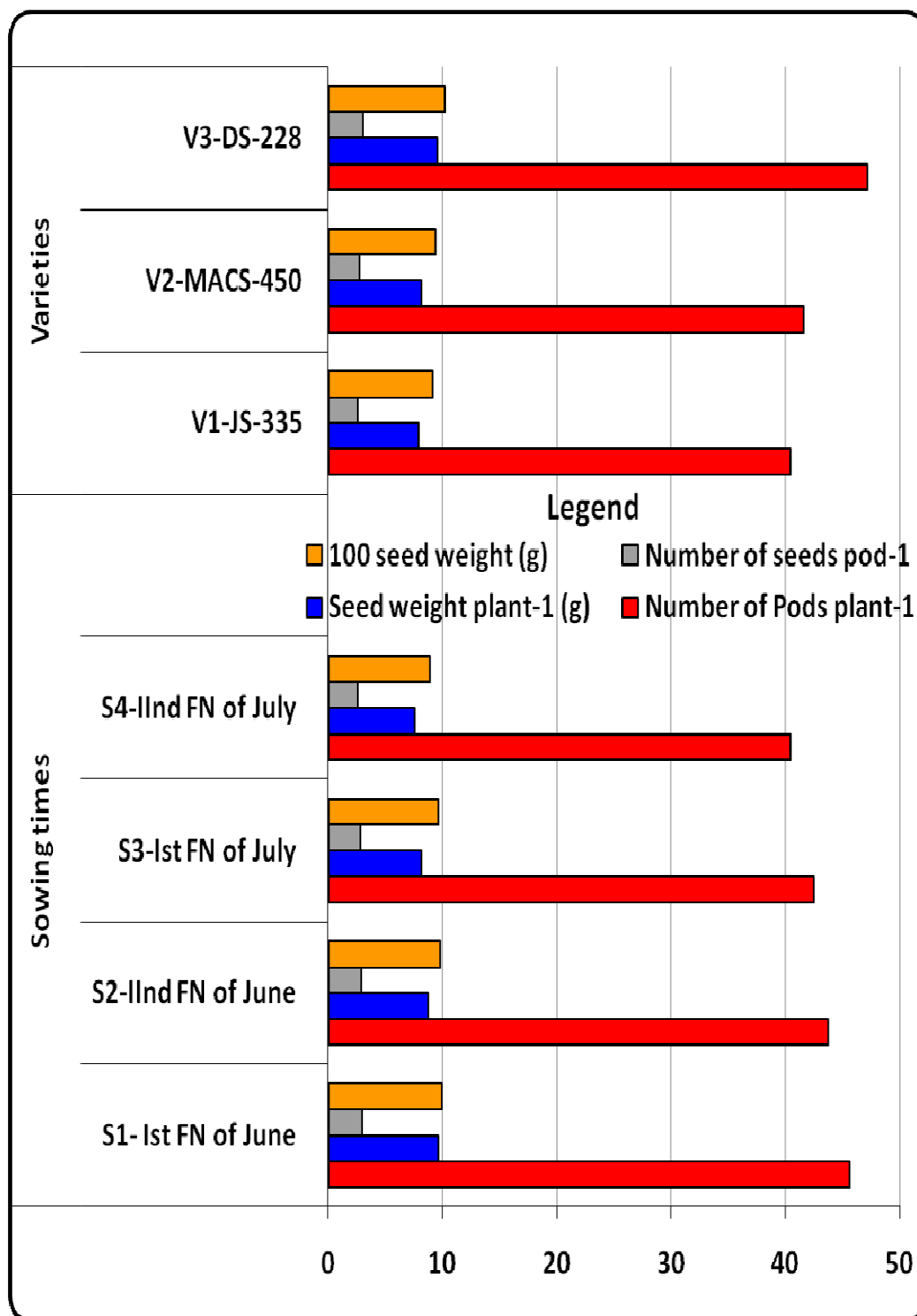


Fig. 20 b. Yield attributes at harvest as influenced by sowing times and varieties (2013)

4.3.3 Number of seeds pod⁻¹

Data pertaining to mean number of seeds pod⁻¹ as influenced by different treatments are given in the Table 20 and graphically shown in Fig. 20 (a and b). Mean seeds plant⁻¹ was 2.53 and 2.77 during 2012 and 2013, respectively.

Sowing times

Differences in mean number of seeds pod⁻¹ observed among different sowing times were significant.

During 2012, sowing I FN of June (S₁) was recorded the maximum number of seeds pod⁻¹ (2.74) and being at par with sowings II FN of June (S₂) and I FN of July (S₃), whereas, II FN of June (S₂) was significantly superior over II FN of July (S₄) and at par with I FN of July (S₃) sowings. The lowest number of seeds pod⁻¹ was recorded by II FN of July (S₄) (2.26) of sowing.

Similarly, during 2013 sowing I FN of June (S₁) was recorded the maximum number of seeds pod⁻¹ (2.93) and being at par with II FN of June (S₂) and I FN of July (S₃), whereas II FN of June (S₂) was significantly superior over II FN of July (S₄) and at par with I FN of July (S₃) sowings. The lowest number of seeds pod⁻¹ was recorded by II FN of July (S₄) (2.53) sowing. On the contrary Park *et al.* (2000) reported that seed number per pod was significantly increased with the late sowing.

Varieties

Differences in number of seeds pod⁻¹ due to different varieties were significant. variety DS-228 (V₃) recorded maximum seeds pod⁻¹ (2.79) at par with MACS-450 (V₂) (2.48) and it was significantly higher than JS-335 (V₁) during 2012, whereas, variety DS-228 (V₃) was recorded maximum seeds pod⁻¹ (3.06) that was significantly superior over MACS-450 (V₂) and JS-335 (V₃) during 2013. Lower number of seeds pod⁻¹ was recorded in variety JS-335 (V₁) during both the years i.e. 2012 and 2013.

Interaction

Number of seeds pod^{-1} was not significantly influenced by treatments interaction.

4.3.4 Hundred seeds weight (g)

Hundred seeds weight (g) under various treatments is presented in Table 20 and Fig. 20 (a and b). Average 100 seeds weight was observed to be 9.40 and 9.55 g during 2012 and 2013, respectively.

Sowing times

Differences in hundred seeds weight observed among different sowing times were significant. Numerically, the maximum hundred seeds weight was recorded by sowing I FN of June (S_1) (9.40 and 9.93 g) and the minimum hundred seeds weight was recorded by II FN of July (S_4) (8.54 and 8.84 g) during the year 2012 and 2013, respectively. Delayed sowings recorded significantly lower 100 seeds weight.

During 2012, sowing of I FN of June (S_1) was recorded the maximum hundred seeds weight (9.87 g) and being at par with sowing II FN of June (S_2), it was also was significantly superior over I FN of July (S_3) and II FN of July (S_4) of sowings. Hundred seeds weight of sowing times I FN of July (S_3) and II FN of July (S_4) were significantly at par with each other. The lowest hundred seed weight (8.54 g) was recorded by II FN of July (S_4).

Similarly, during 2013 sowing of I FN of June (S_1) was recorded the maximum hundred seeds weight (9.93 g) and being at par with sowings II FN of June (S_2) and I FN of July (S_3), whereas II FN of June (S_2) was significantly superior over II FN of July (S_4) and at par over I FN of July (S_3). The lowest maximum hundred seeds weight (8.84 g) was recorded by II FN of July (S_4). Similar result reported by Singh *et al.* (2010).

Overall data revealed that gradual reduction in test weight of seed with subsequent delay in sowing which is attributed to reduce soil moisture status and increased disease incidence during grain development stage. Higher day

temperature may partly contribute to lowered test weight of seed in delayed sowing. However, this was true beyond 3rd sowing date. Results agree with those reported by Singh (1973) Deshmukh *et al.* (1977), Singh *et al.* (2010) and Mane (2011).

Varieties

Differences in test weight (100 seed weight due to different varieties were significant. Significantly higher test weight (100 seed weight) were recorded by variety DS-228 (V₃) (10.03 and 10.21 g) followed by MACS-450 (V₂) (9.23 and 9.36 g) and JS-335 (V₁) (8.94 and 9.08 g) during both the year.

Variety DS-228 (V₃) recorded maximum test weight (100 seed weight) and at par over MACS-450 (V₂) and significantly higher than JS-335 (V₁) during 2012. Similar trend was observed during 2013. Whereas, 100 seed weight were recorded by DS-228 (V₃) during both the year. The higher test weight over the next lower which is mainly by the genetic characters. Similar finding were reported by Singh *et al.* (1974), Diaz Carrasco *et al.* (1986) and Singh *et al.* (2004)

Interaction

Hundred seeds weight (g) was not significantly influenced by treatments interaction.

4.3.5 Seed yield (q ha⁻¹)

The data on seed yield (q ha⁻¹) as influenced by different treatments are presented in Table 21 and graphically illustrated in Fig. 21 a. Mean seed yield of soybean was 19.45 and 26.71 q ha⁻¹ recorded during 2012 and 2013, respectively.

Sowing times

Different sowing times had a profound influence on the seed yield. Significantly highest seed yield (22.87 q ha⁻¹) in 2012 was obtained when crop was sown I FN of June (S₁), but significantly superior over II FN of June (S₂), I FN of July (S₃) and II FN of July (S₄), it was followed by II FN of June (S₂), I

FN of July (S_3). Crop sown on II FN of July (S_4) recorded the lowest seed yield (15.47 q ha^{-1}). Lowest grain yield was recorded during 2012 under II FN of July (S_4) when sowing taken on. Similar trend were observed during 2013, significantly highest seed yield (29.79 q ha^{-1}) was obtained when crop was sown I FN of June (S_1), but significantly superior over II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4), it was followed by II FN of June (S_2), I FN of July (S_3). The mean values were higher when the crop was sown on I FN of June (S_1) during both the years for all vegetative and reproductive attributes indicating that earlier sowing enabled the crop to express the inherent potential to the maximum as compared to later sowings. Other authors (Mahapatra (1998), Rajendra Prasad (2002), Anil kumar *et al.* (2008^a) have noted similar decisive effect of sowing times on soybean growth and development and reported reductions in various morpho-physiological attributes with delayed sowing due to reduced soil moisture regime increase disease incidence and less favourable weather variables. Early sowing in soybean has accumulated higher photosynthates due to higher LAI which helped in higher accumulation of dry matter and varies yield components, which ultimately resulted in higher grain yield. Similar results were observed by Singh *et al.* (1985) Jasani *et al.* (1993) Hatam and Khallil (1994), Rajput and Shrivastava (1999) and Jadhao (2009).

Varieties

During the year 2012 and 2013 the results were highly consistent. During 2012, Soybean variety DS-228 (V_3) recorded significantly higher seed yield (23.50 q ha^{-1}) over MACS-450 (V_2) (19.46 q ha^{-1}) and JS-335 (V_1) (15.38 q ha^{-1}) but MACS-450 (V_2) were at par over variety JS-335 (V_1). Similar trend of grain yield were observed during the year 2013, DS-228 (V_3) recorded significantly higher seed yield (29.04 q ha^{-1}) over MACS-450 (V_2) (26.70 q ha^{-1}) and JS-335 (V_1) (24.38 q ha^{-1}) but MACS-450 (V_2) were at par over Varieties JS-335 (V_1). DS-228 (V_3) had recorded higher per cent over MACS-450 (V_2) and JS-335 (V_1). Differences in yield among the varieties might be due to genetic potential of the genotypes. Higher grain yield in DS-228 (V_3)

might be due to higher light interception also. Similar result were reported by Lingaraju *et al.* (1995), Board *et al.* (1997), Bhatia *et al.* (1999) and Jadhao (2009).

Interaction

During the year 2012 (Table 21 a) interaction between sowing times and varieties found to be significant. Combination S₁V₃ found to be significantly superior over rest of the treatment. However, interaction effects were found to be statistically non-significant during year 2013.

4.3.6 Straw yield (q ha⁻¹)

The data on straw yield (q ha⁻¹) as influenced by different treatments are presented in Table 21 and graphically illustrated in Fig 21 a. Mean straw yield of soybean was 27.70 and 35.30 q ha⁻¹ recorded during 2012 and 2013, respectively.

Sowing times

Different sowing times had a profound influence on the straw yield. Straw yield during the year 2012 was found to be non significant however, during the year 2013 sowing I FN of June (S₁) was found to be significantly superior over rest of the treatment in straw yield (32.63 q ha⁻¹). Lower straw yield was recorded during 2013 under II FN of July (S₄) when sowing taken on. The mean values were higher when the crop was sown on I FN of June (S₁) during both the years for all vegetative and reproductive attributes indicating that earlier sowing enabled the crop to express the inherent potential to the maximum as compared to later sowings. Other authors (Mahapatra (1998), Rajendra Prasad (2002), Anil kumar *et al.* (2008^a) have noted similar decisive effect of sowing times on soybean growth and development and reported reductions in various morpho-physiological attributes with delayed sowing due to reduced soil moisture regime and less favourable weather variables. Early sowing in soybean has accumulated higher photosynthates, which helped in higher accumulation of dry matter, which ultimately resulted in higher grain yield. Similar results were observed by Singh *et al.* (1985) Jasani *et al.* (1993) Hatam and Khallil (1994), Rajput and Shrivastava (1999) and Jadhao (2009).

Varieties

During the years 2012 and 2013 the results were highly consistent. Straw yield during the year 2012 was found to be non significant however, during the year 2013 soybean variety MACS-450 (V_2) (35.75 q ha^{-1}) recorded significantly higher straw yield followed by variety DS-228 (V_3) (35.26 q ha^{-1}) lowest straw yield was recorded in variety JS-335 (V_1) (31.90 q ha^{-1}). Differences in yields might be due to genetic potential of the genotypes. Similar result were reported by Lingaraju *et al.* (1995), Board *et al.* (1997), Bhatia *et al.* (1999) and Jadhao (2009).

Interaction

Interaction effects were found to be statistically non-significant for straw yield during both the years.

4.3.7 Biological yield (q ha^{-1})

The data as regards to biological yield (q ha^{-1}) as influenced by different treatments are presented in Table 21 and graphically shown in Fig.21 b. The mean biomass yield of soybean was 53.75 and 52.10 q ha^{-1} during the year 2012 and 2013, respectively.

Sowing times

In general biological yield decreased with later sowings from I FN of June (S_1) to II FN of July (S_4) but sowing I FN of June (S_1) were significantly superior over II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4). Crop sown on II FN of July (S_4) recorded the lowest biological yield (47.86 q ha^{-1}) during 2012.

During the year 2013, sowing I FN of June (S_1) was recorded significantly highest biological yield as compare to all the treatments but sowing times II FN of June (S_2) and I FN of July (S_3) was at par with each other. Lowest biological yield (48.33 q ha^{-1}) was recorded in II FN of July (S_4). Progressive significant decreased in biological yield was noticed with successive later sowings I FN of June (S_1) and II FN of July (S_4). Similar results were recorded by Bhatia *et al.* (1999). The results are in line with the findings of Barik and Sahoo (1989) and Jadhao (2009).

Varieties

Differences in biological yield due to different varieties were significant. During the year 2012 and 2013 the results were highly consistent. Soybean variety DS-228 (V_3) recorded significantly higher biological yield (58.76 q ha^{-1}) over MACS-450 (V_2) (55.21 q ha^{-1}) and JS-335 (V_1) (47.21 q ha^{-1}) but MACS-450 (V_2) were at par over variety JS-335 (V_1) during the year 2012.

Biological yield were observed during the year 2013, DS-228 (V_3) recorded significantly higher biological yield (54.02 q ha^{-1}) over MACS-450 (V_2) (53.02 q ha^{-1}) and JS-335 (V_1) (49.09 q ha^{-1}). Early sowing in soybean has accumulated higher photosynthates which helped in higher accumulation of dry matter which ultimately resulted in higher grain yield which resulted in higher biological yield.

Interaction

Interaction effect of sowing times with varieties had significant influence on biological yield. During the year 2012 (Table 21 b) interaction due to sowing times with varieties found to be significant. Combination S_1V_3 found to be significantly superior over rest of the treatment. However, interaction effects were found to be statistically non-significant during year 2013.

4.3.8 Harvest index

The data on harvest index presented in Table. 21 and graphically shown in Fig. 21 b. indicated that the mean harvest index (%) was 35.70 and 51.27 per cent during 2012 and 2013, respectively.

Sowing times

Sowing times had significant influence on the harvest index; which in general decreased with successive later sowings during year 2012 and 2013. Sowing on I FN of June (S_1) recorded significantly highest harvest index (38.44%) over to sowing I FN of July (S_3) and II FN of July (S_4), whereas sowing II FN of July (S_4) recorded the lowest harvest index (32.33%). As such I FN of June (S_1) and II FN of June (S_2) sowings were statistically at par during year 2012.

Similarly, during 2013 sowing on I FN of June (S_1) recorded significantly highest harvest index (54.58%) over to sowings I FN of July (S_3) and II FN of July (S_4). As such I FN of June (S_1) and II FN of June (S_2) sowings were statistically at par. Whereas, sowing II FN of July (S_4) recorded the lowest harvest index (48.86%) during year 2012. Higher harvest index in earlier sown crops could be due to comparatively better translocation efficiency. The above results in conformity with Barik and Sahoo (1989), whereas, Park *et al.* (2000) reported that harvest index significantly increased with the late sowing.

Varieties

Differences in harvest index due to different varieties were found to be statistically significant. During year 2012, variety DS-228 (V_3) was significantly superior over MACS-450 (V_2) and JS-335 (V_1) by recording maximum harvest index (39.99%). Variety MACS-450 (V_2) was found significantly superior over JS-335, which was recorded the minimum harvest index i.e. (32.53%). The finding shows better translocation efficiency of DS-228 (V_3) compared to MACS-450 (V_2) and JS-335 (V_1). Whereas similar trend was observed during 2013, variety DS-228 (V_3) was significantly superior over MACS-450 (V_2) and JS-335 (V_1) by recording maximum harvest index (53.60%). Variety MACS-450 (V_2) was found significantly superior over JS-335 (V_1), which recorded the minimum harvest index i.e. (49.66%). Variety DS-228 (V_3) recorded overall significantly highest harvest index which may be attributed to the higher grain yield recorded under this variety. These results are in comparison with Nirmalkumari and Balasubramaniam (1990) and Jadhao (2009).

Interaction

Interaction effect of sowing times with varieties had significant influence on harvest index (%). During the year 2012 (Table 21 c) interaction due to sowing times with varieties found to be significant. Combination S_2V_3 found to be significantly superior over rest of the treatments except S_1V_3 , S_3V_3 and S_2V_2 which found to be at par with each other. However, interaction effects were found to be statistically non-significant during year 2013.

Table 21. Seed, straw, biological yield (pooled) and harvest index as influenced by sowing times and varieties (2012 and 2013)

Treatment	Seed yield (q ha ⁻¹)		Pooled	Straw yield (q ha ⁻¹)		Pooled	Biological yield (q ha ⁻¹)		Pooled	Harvest index (%)		Mean
	2012	2013		2012	2013		2012	2013		2012	2013	
A) Sowing times												
S ₁ (I FN of June)	22.87	29.79	26.33	28.63	36.62	32.63	59.48	54.58	57.03	38.44	54.58	46.51
S ₂ (II FN of June)	21.39	27.74	24.56	28.49	34.69	31.59	56.08	54.04	55.06	38.13	51.33	44.73
S ₃ (I FN of July)	18.06	25.69	21.87	26.71	33.52	30.12	51.58	51.43	51.51	35.01	49.95	42.48
S ₄ (II FN of July)	15.47	23.61	19.54	26.97	32.38	29.68	47.86	48.33	48.09	32.33	48.86	40.60
S. Em $\pm$	0.21	0.27	0.15	1.24	0.56	0.85	0.53	1.42	0.74	0.60	1.19	
C.D. at 5%	0.68	0.85	0.47	NS	1.81	NS	1.70	4.54	2.35	1.91	3.82	
B) Varieties												
V ₁ (JS-335)	15.38	24.38	19.88	27.34	31.90	29.62	47.28	49.09	48.19	32.53	49.66	41.10
V ₂ (MACS-450)	19.46	26.70	23.08	28.88	35.75	32.31	55.21	53.02	54.11	35.25	50.37	42.81
V ₃ (DS-228)	23.50	29.04	26.27	26.89	35.26	31.07	58.76	54.18	56.47	39.99	53.60	46.80
S. Em $\pm$	0.23	0.24	0.16	0.59	0.57	0.44	0.58	0.75	0.43	0.47	0.68	
C.D. at 5%	0.68	0.69	0.46	NS	1.65	1.29	1.70	2.19	1.05	1.37	1.97	
Interaction (AxB)												
S. Em $\pm$	0.46	0.47	0.31	1.18	1.13	0.40	1.16	1.50	0.86	0.94	1.35	
C.D. at 5%	1.35	NS	0.91	NS	NS	NS	3.40	NS	NS	2.74	NS	
GM	19.45	26.71	23.08	27.70	34.30	31.00	53.75	52.10	52.92	35.70	51.27	43.49

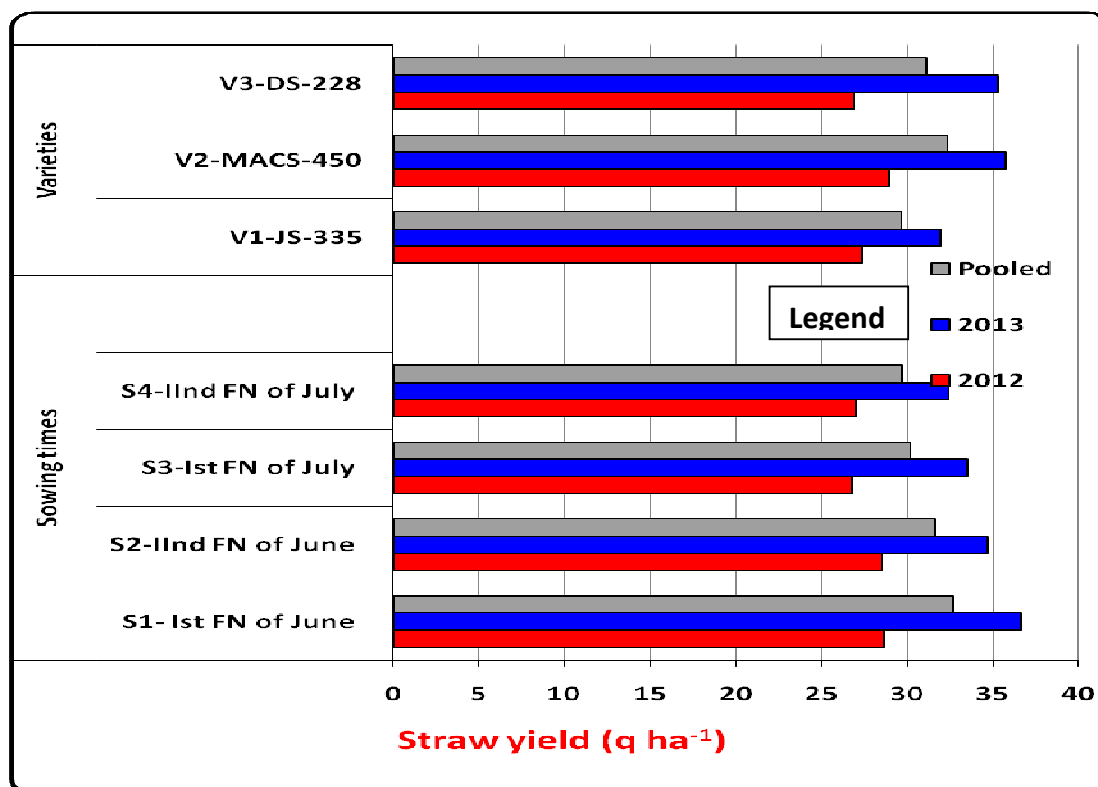
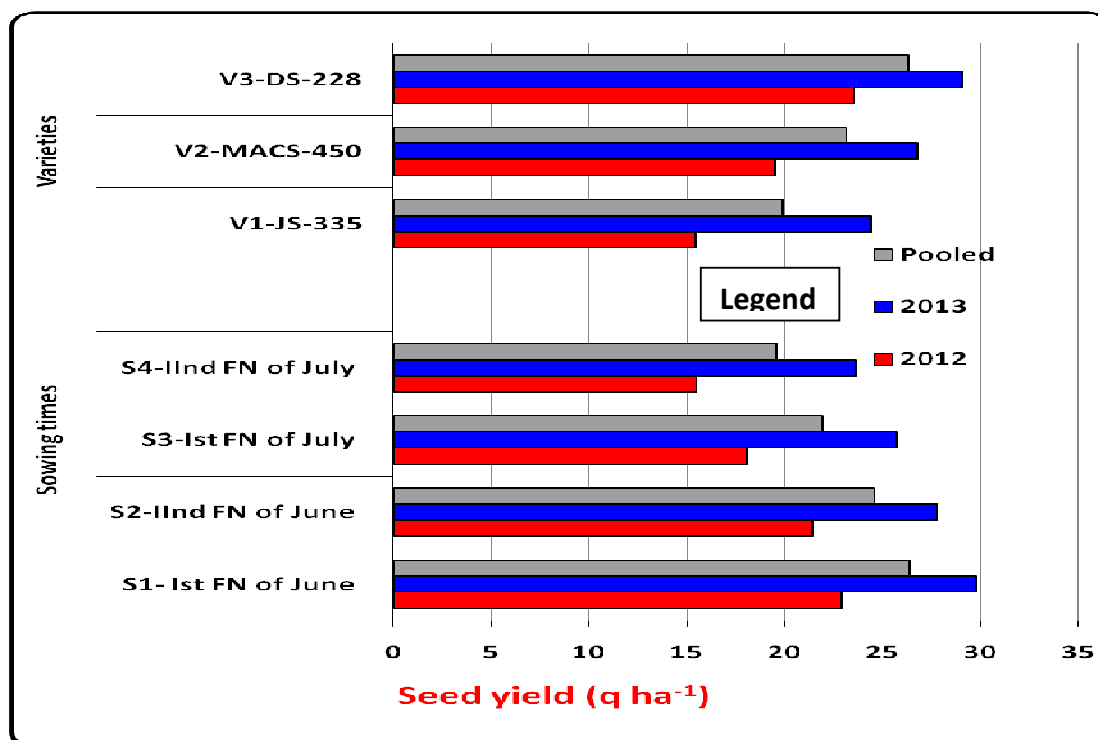


Fig. 21 a. Seed and straw yield (pooled) as influenced by sowing times and varieties (2012 and 2013)

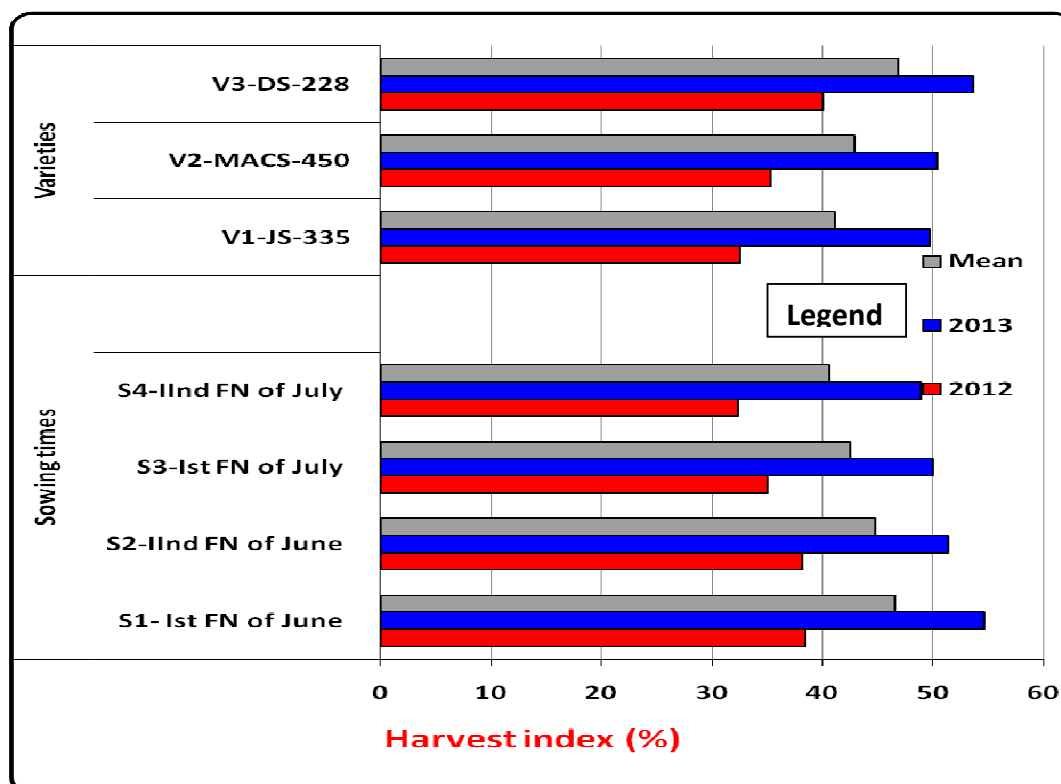
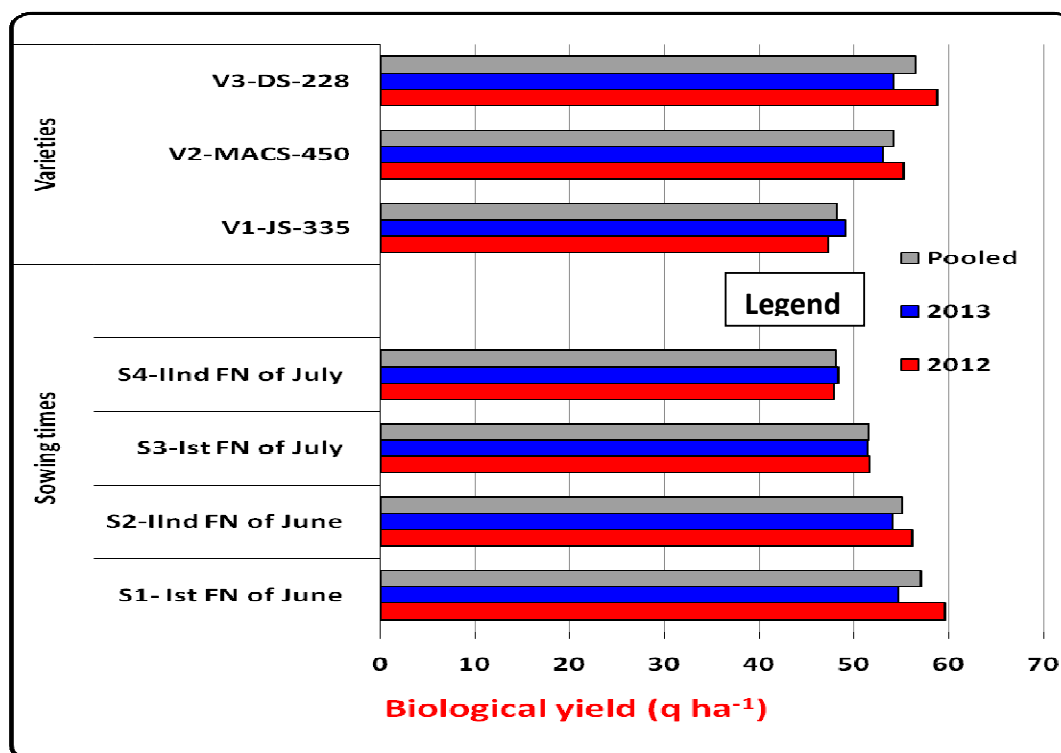


Fig. 21 b. Biological yield (pooled) and harvest index as influenced by sowing times and varieties (2012 and 2013)

Table 21 a. Mean seed yield as influenced by interactions between sowing times and varieties (2012)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	18.06	23.54	26.99	22.86
S ₂ (II FN of June)	15.69	23.59	24.87	21.38
S ₃ (I FN of July)	14.70	17.22	22.25	18.05
S ₄ (II FN of July)	13.07	13.48	19.87	15.47
Mean	15.38	19.45	23.49	
S. Em $\pm$	0.46			
C.D. at 5%	1.35			

Table 21 b. Mean biological yield as influenced by interactions between sowing times and varieties (2012)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	50.16	61.68	66.60	59.48
S ₂ (II FN of June)	48.56	60.10	59.56	56.07
S ₃ (I FN of July)	46.47	52.73	55.53	51.58
S ₄ (II FN of July)	43.94	46.30	53.32	47.85
Mean	47.28	55.20	58.75	
S. Em $\pm$	1.16			
C.D. at 5%	3.39			

Table 21 c. Mean harvest index as influenced by interactions between sowing times and varieties (2012)				
A) Sowing times	B) Varieties			Mean
	V ₁ (JS-335)	V ₂ (MACS-450)	V ₃ (DS-228)	
S ₁ (I FN of June)	36.07	38.19	40.52	38.26
S ₂ (II FN of June)	32.42	39.26	41.73	37.80
S ₃ (I FN of July)	31.63	32.70	40.00	34.78
S ₄ (II FN of July)	29.59	29.00	37.28	31.96
Mean	32.43	34.78	39.88	
S. Em $\pm$	0.93			
C.D. at 5%	2.73			

4.4 Agro-meteorological indices

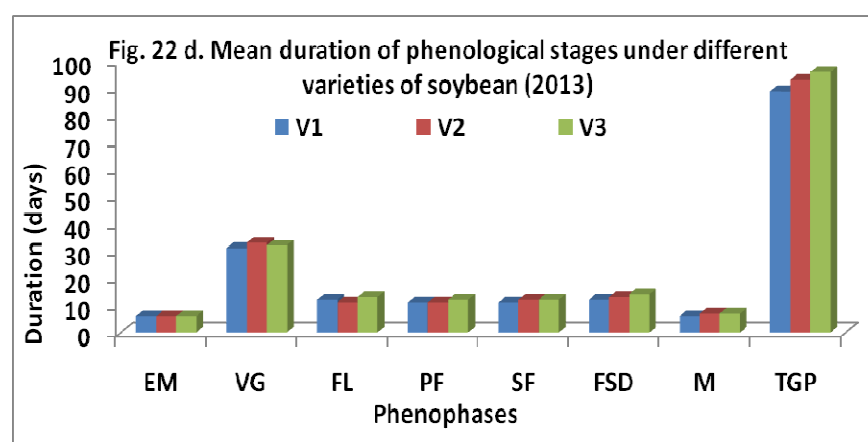
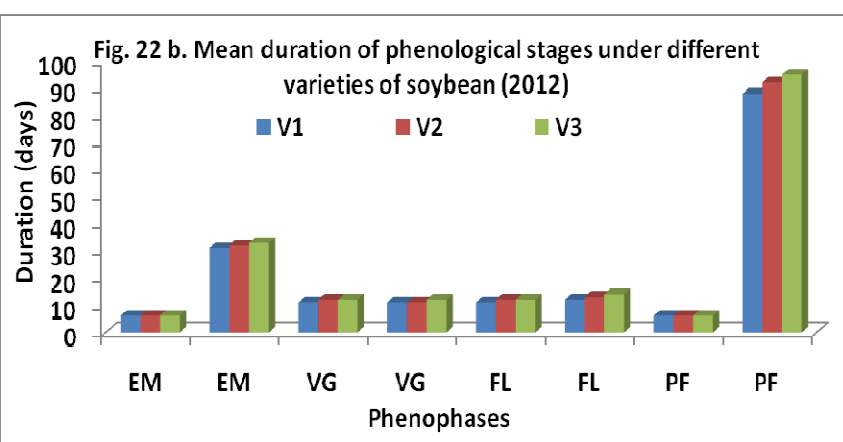
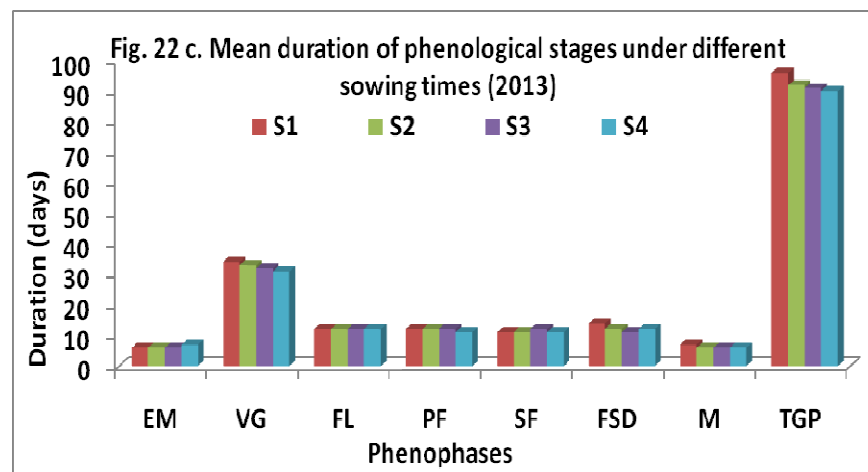
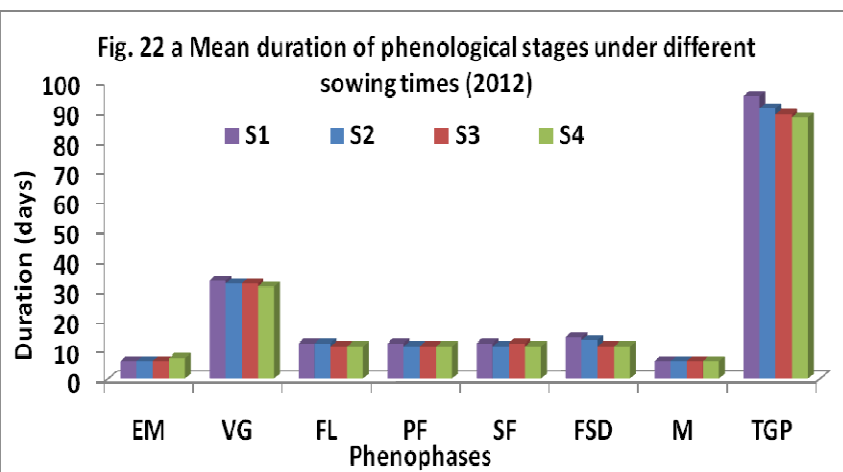
4.4.1 Crop Phenology

Phenological observations on occurrence of different phenophase of crop were recorded and its duration in days as counted from the date of emergence under different treatments was presented in Table. 22 and graphically shown in Fig. 22 a b c and d.

The development of phenophase is most essential component of the study of crop weather relationship of soybean crop and crop weather models, which can be used to specify the most appropriate rate and time of the specific development phase for maximization of crop yield. Soybean is basically a short day plant, determinate in habit with specific stages of development responsive to changing growing environment. Time of overlap of vegetative and reproductive growth is lesser in determinate type than indeterminate type. In these experiments, number of days taken to achieve different phenophases in soybean (Table 22) showed that number of days for different phenological stages decreased with successive delayed sowings. However, as regards emergence the germination across all the four sowings took place in 6 to 7 days with uniform optimum plant stand. Further, early sowing I FN of June (S_1) required more number of days for attaining various phenological stages reaching maturity in 95 and 96 days during 2012 and 2013 respectively. Subsequent three sowings took 91, 89, 88 and 92, 91 and 90 days for maturity respectively. This was due to decreased duration of each phenophase in response to the weather variables in each of the successive delayed sowing. The maturity period averaged was more in variety DS-228 (V_3) (95 and 96 days) followed by MACS-450 (V_2) (92 and 93 days) and JS-335 (V_1) (88 and 89 days) during 2012 and 2013. This was more due to inherent genetic characteristics of the variety rather than any other interacting factor.

Table 22. Mean duration (days) of phenological stages as influenced by sowing times and varieties (2012 and 2013)

Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S ₁ (I FN of June)	6	6	33	34	12	12	12	12	12	11	14	14	6	7	95	96
S ₂ (II FN of June)	6	6	32	33	12	12	11	12	11	11	13	12	6	6	91	92
S ₃ (I FN of July)	6	6	32	32	11	12	11	12	12	12	11	11	6	6	89	91
S ₄ (II FN of July)	7	7	31	31	11	12	11	11	11	11	11	12	6	6	88	90
B) Varieties																
V ₁ (JS-335)	6	6	31	31	11	12	11	11	11	11	12	12	6	6	88	89
V ₂ (MACS-450)	6	6	32	33	12	11	11	11	12	12	13	13	6	7	92	93
V ₃ (DS-228)	6	6	33	32	12	13	12	12	12	12	14	14	6	7	95	96
GM	6	6	32	32	12	12	11	12	12	11	13	13	6	6	91	92
*EM-Emergence, VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity TGP-Total Growing Period																



4.4.2 Rainfall distribution

Rainfall during total growth period (emergence to physiological maturity) and its distribution across various phenophase of soybean under different treatments is presented in Table 23 and depicted in Fig.23 a b c and d.

Sowing times

Overall, during the year 2012, rainfall during total growth period was erratic in I FN of June (S_1) and II FN of June (S_2) sowing it was much less than remaining sowing i.e. 353.8 and 333.0 mm respectively but it was more during crop sown in I FN of July (S_3) and II FN of July (S_4) i.e. 433.6 and 422.9 mm respectively as compare to first and second sowing. However, during the year 2013, higher amount of rainfall (636.3 mm) during the total growing period was received, which decreased with each delayed sowing date. Rainfall across the growing period (emergence to physiological maturity) was more or less similar in the second two sowings II FN of June (S_2) (459.9 mm), and I FN of July (S_3) (455.1mm) but it was least (312.6mm) in sowing II FN of July (S_4).

Total rainfall received across the emergence to vegetative stages during 2012 and 2013 at sowing I FN of June (S_1), II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) was 61.4, 178.8, 216.9 and 252.3 mm, while 311.3, 232.7, 216.3 and 60.2 mm respectively. The growing period from pod formation to full seed development sowings I FN of June (S_1), II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) received 152.4, 113.0, 121.4 and 122.7 mm and 108.6, 219.9, 235.7 and 109.7 mm rainfall, respectively. Besides the differential physiological response of the crop to sowing times, subdued/ sub-optimal rainfall activity and consequent suboptimal soil moisture across the pod formation to seed development phase is a common feature under later sowings (S_3 and S_4) as compared to earlier sowing in the year 2013. Across the flowering phase the crop encountered comparatively more amount of rainfall in later sowings (S_1 -130.2 mm, S_2 -40.7 mm, S_3 -41.6 mm, S_4 -30.2 mm) during 2012 and (S_1 -93.1 mm, S_2 -5.0 mm, S_3 -3.1 mm, S_4 - 139.9 mm) in 2013.

Overall, rainfall during different phenophases of the reproductive stage *viz.*, flowering, pod formation and full seed development was quite well during both the year.

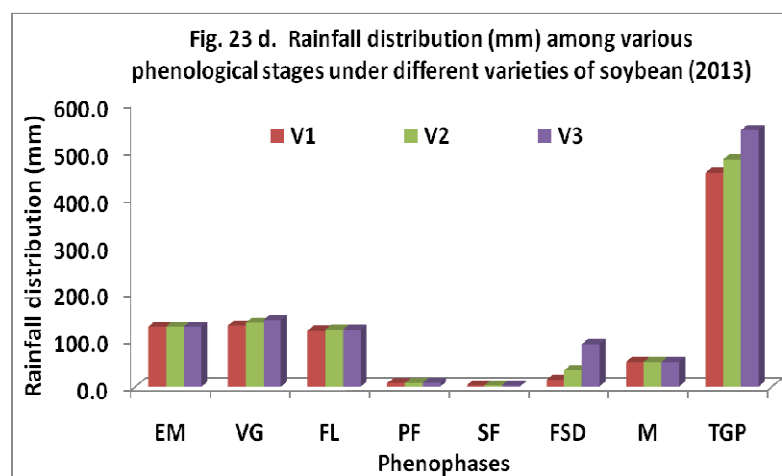
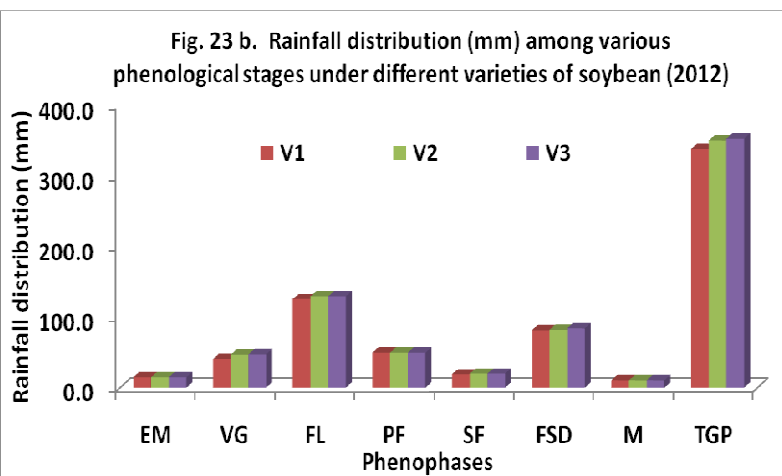
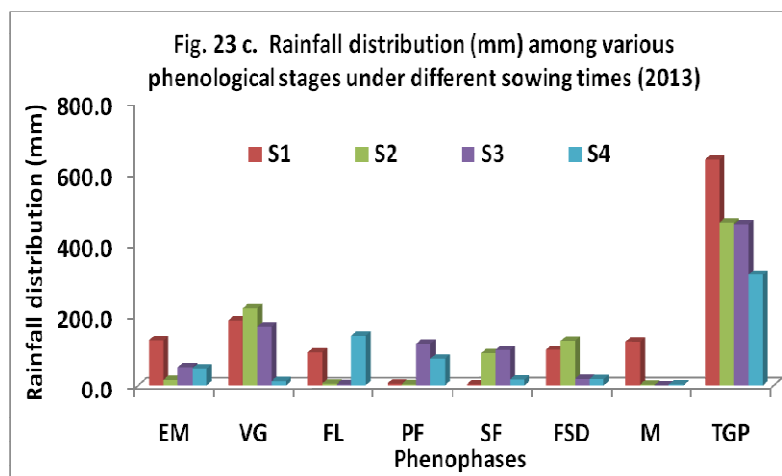
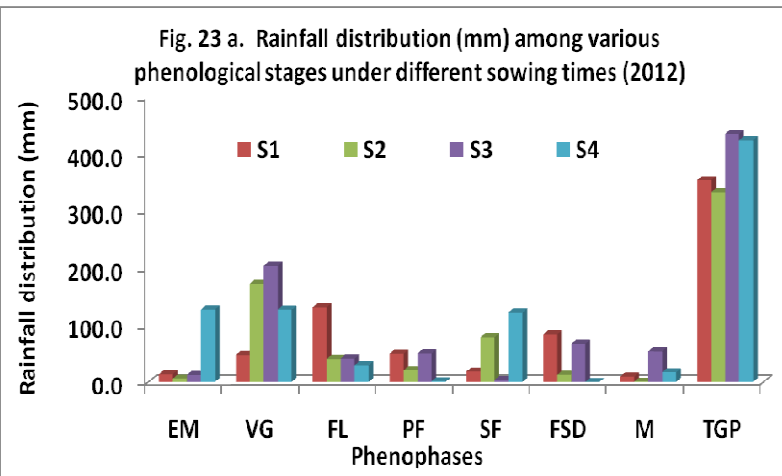
As such in the present study earlier sown crop received fairly adequate amount and distribution of rainfall across the critical growing period by and large in the later sowings, decreased amount of rainfall at the respective stages might had a progressive and cumulative inadequacy effect carried across the growing period till seed development stage.

Varieties

Total rainfall received during the crop growing period varied slightly in response to the total growth duration of varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) i.e. (339.7 mm), (351.2 mm), (353.8 mm) during 2012 and (454.0 mm), (481.5 mm), (544.7 mm) during 2013. Slight variation observed in the rainfall amount across the phenophase of the varieties was due to differences in duration of respective Varieties being slightly more under DS-228 (V_3) as compared to MACS-450 (V_2) and JS-335 (V_1).

Table 23. Rainfall distribution (mm) among various phenophases of soybean under sowing times and varieties (2012 and 2013)

Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S ₁ (I FN of June)	14.0	127.3	47.4	184.0	130.2	93.1	49.6	5.0	19.1	3.0	83.6	100.6	9.9	123.8	353.8	636.8
S ₂ (II FN of June)	6.4	15.3	172.4	217.4	40.7	5.0	21.4	3.1	78.5	90.8	13.1	126.0	0.5	2.3	333.0	459.9
S ₃ (I FN of July)	12.7	51.8	204.2	164.5	41.6	3.1	50.1	117.9	3.7	99.7	67.6	18.1	53.7	0.0	433.6	455.1
S ₄ (II FN of July)	126.2	48.3	126.1	11.9	30.2	139.9	1.4	75.4	121.3	16.6	0.0	17.7	17.7	2.8	422.9	312.6
B) Varieties																
V ₁ (JS-335)	14.0	127.3	41.1	129.7	126.1	119.2	49.6	7.7	18.2	2.8	80.8	14.4	9.9	52.9	339.7	454.0
V ₂ (MACS-450)	14.0	127.3	47.0	135.4	130.2	120.8	49.6	7.7	19.1	2.8	81.4	34.6	9.9	52.9	351.2	481.5
V ₃ (DS-228)	14.0	127.3	47.4	141.7	130.2	120.8	49.6	8.1	19.1	2.8	83.6	91.1	9.9	52.9	353.8	544.7
GM	28.8	89.2	97.9	140.7	89.9	86.0	38.8	32.1	39.9	31.2	58.6	57.5	15.9	41.1	369.7	477.8
*EM-Emergence, VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity TGP-Total Growing Period																



4.4.3 Air temperature regime

The data in Table 24 (a and b) and depicted in Fig. 24 (a and b) shows the mean air temperature regime, both maximum temperature and minimum temperature, experienced by the crop across different growth stages as well as over the total growing period during 2012 and 2013. During 2012, it was observed that mean maximum temperature regime showed decreased slightly from emergence (30.6°C) to vegetative stage (29.7°C). Then it was approximately same from vegetative (29.7°C) to reproductive stage i.e. seed formation (29.1°C). Mean maximum temperature decreased from seed formation (29.1°C) to physiological maturity (28.7°C). Highest mean maximum temperature was faced by emergence stage (30.6°C). Mean minimum temperature showed decreased from 23.3 to 20.5°C across emergence to physiological maturity stage. However, during 2013, It was observed that mean maximum temperature regime showed decreased slightly from emergence (27.7°C) to vegetative stage (27.4°C). Then it was approximately same from vegetative (27.7°C) to reproductive stage i.e. seed formation (28.9°C). Mean maximum temperature increased from seed formation (28.9°C) to physiological maturity (30.3°C). Highest mean maximum temperature was faced by maturity stage (30.3°C). Mean minimum temperature showed decreased from 22.1 to 21.1°C across emergence to physiological maturity stage. Similar results were recorded by Brown and Chapman (1960), Egli and Wardlaw (1980) and Jadhao (2009).

Sowing times

During the year 2012, Maximum (32.2°C to 26.6°C) and minimum (24.0°C to 21.8°C) temperature regime experienced by the crop during emergence stage showed decrease with later sowings (S_1 to S_4). From vegetative to pod formation stage maximum and minimum temperature regime experienced by the crop showed more or less similar temperature regime across I FN of June (S_1) to II FN of July (S_4). Across seed formation stage (SF) and seed development stage (FSD) maximum temperature regime increased from I

FN of June (S_1) to II FN of July (S_4) sowings, whereas the minimum temperature regime reduced from I FN of June (S_1) to II FN of July (S_4) sowings. Maximum temperature averaged across the total growing period of the crop showed more or less similar values (29.0 to 29.4 $^{\circ}$ C) under different sowings. Minimum temperature over the total growing period (20.5 $^{\circ}$ C to 22.2 $^{\circ}$ C) showed slight decline across the sowings.

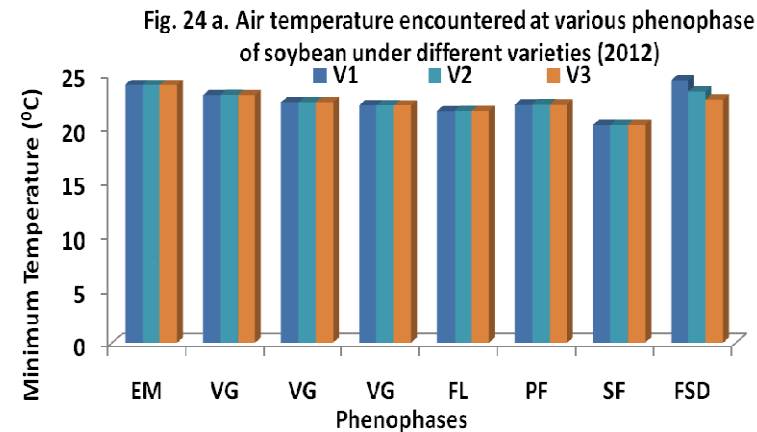
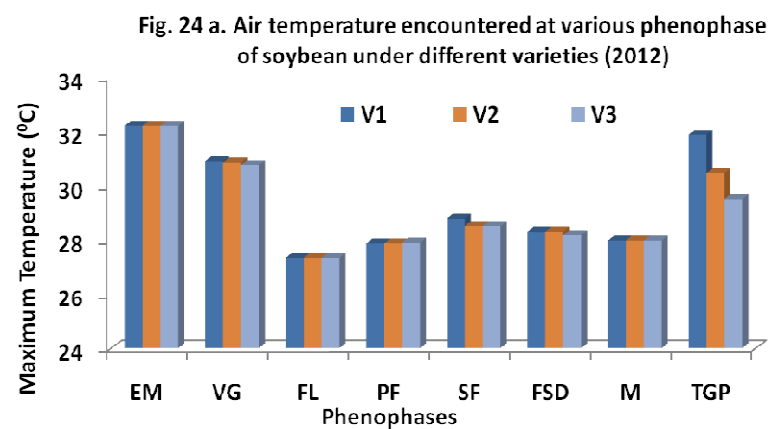
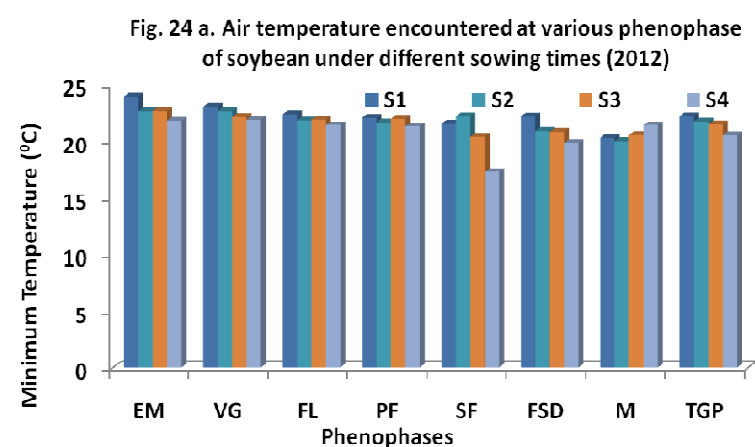
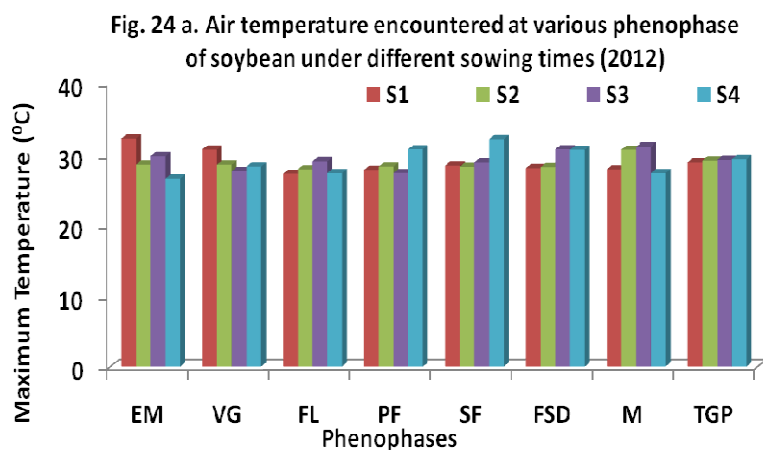
During the year 2013, Maximum (28.3 $^{\circ}$ C to 26.4 $^{\circ}$ C) and minimum (21.4 $^{\circ}$ C to 22.3 $^{\circ}$ C) temperature regime experienced by the crop during emergence stage showed decrease with later sowings (S_1 to S_4). From vegetative to pod formation stage maximum and minimum temperature regime experienced by the crop showed more or less similar temperature regime across I FN of June (S_1) to II FN of July (S_4). Across seed formation stage (SF) maximum temperature regime increased from I FN of June (S_1) to II FN of July (S_4) sowings and same trend was observed in seed development stage (FSD) except I FN of June (S_1) sowing, whereas the minimum temperature regime reduced from I FN of June (S_1) to II FN of July (S_4) sowings except during seed development stage (FSD). Maximum temperature averaged across the total growing period of the crop showed more or less similar values (28.4 to 29.6 $^{\circ}$ C) under different sowings. Minimum temperature over the total growing period (21.0 $^{\circ}$ C to 21.6 $^{\circ}$ C) showed slight decline across the sowings.

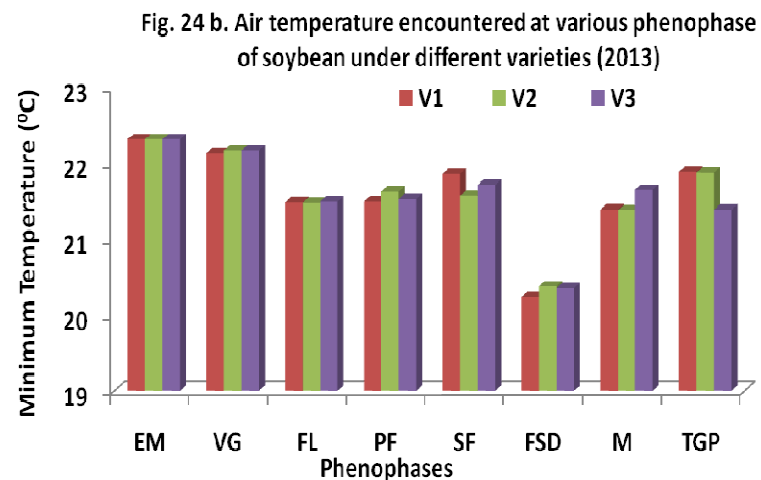
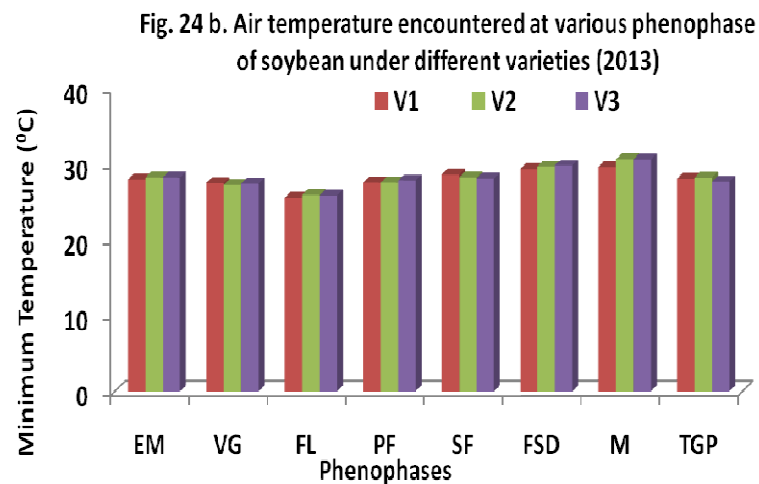
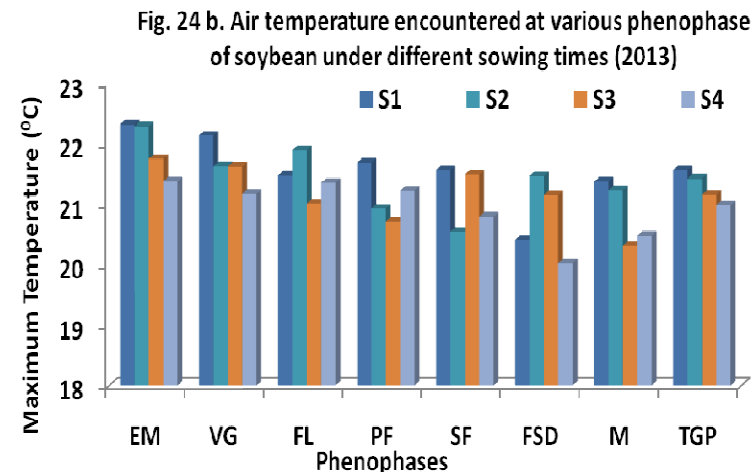
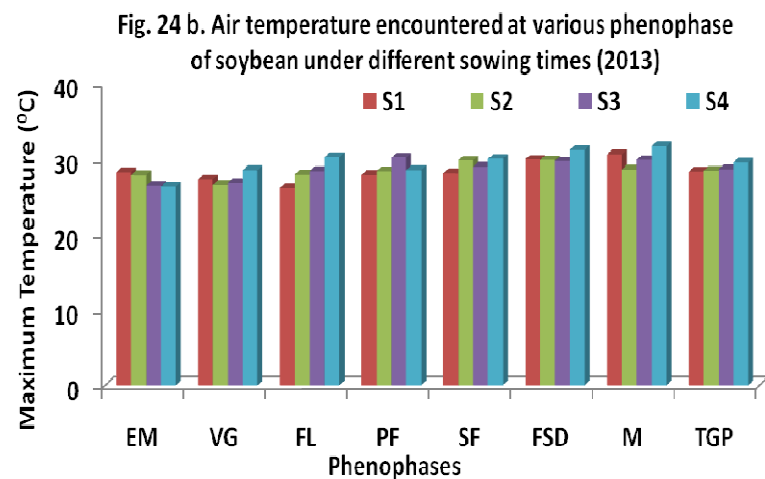
Varieties

Among the varieties, the maximum and minimum temperature regime did not vary much and remained more or less similar at most of the observed phenophase and when averaged over total growing period of the crop during both the year 2012 and 2013.

Table 24 a. Air temperature (⁰ C) regime encountered during soybean phenophases under sowing times and varieties (2012)																
Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn
A) Sowing times																
S ₁ (I FN of June)	32.2	24.0	30.7	23.0	27.3	22.4	27.9	22.1	28.5	21.5	28.2	22.2	28.0	20.3	29.0	22.2
S ₂ (II FN of June)	28.7	22.6	28.7	22.6	28.0	21.8	28.4	21.7	28.4	22.2	28.3	20.9	30.7	20.0	29.2	21.7
S ₃ (I FN of July)	29.8	22.7	27.7	22.1	29.1	21.9	27.4	22.0	29.0	20.4	30.8	20.8	31.1	20.5	29.3	21.5
S ₄ (II FN of July)	26.6	21.8	28.4	21.9	27.4	21.4	30.8	21.3	32.1	17.3	30.7	19.8	27.4	21.4	29.4	20.5
B) Varieties																
V ₁ (JS-335)	32.2	24.0	30.9	23.0	27.3	22.4	27.9	22.1	28.8	21.5	28.3	22.2	28.0	20.3	31.8	24.4
V ₂ (MACS-450)	32.2	24.0	30.8	23.0	27.3	22.4	27.9	22.1	28.5	21.5	28.3	22.2	28.0	20.3	30.5	23.3
V ₃ (DS-228)	32.2	24.0	30.7	23.0	27.3	22.4	27.9	22.1	28.5	21.5	28.2	22.2	28.0	20.3	29.5	22.6
GM	30.6	23.3	29.7	22.7	27.7	22.1	28.3	21.9	29.1	20.9	29.0	21.5	28.7	20.5	29.8	22.3

Table 24 b. Air temperature (⁰ C) regime encountered during soybean phenophases under sowing times and varieties (2013)																
Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn
A) Sowing times																
S ₁ (I FN of June)	28.3	22.3	27.4	22.1	26.2	21.5	28.0	21.7	28.2	21.6	30.0	20.4	30.7	21.4	28.4	21.6
S ₂ (II FN of June)	27.9	22.3	26.6	21.6	28.0	21.9	28.4	20.9	29.9	20.6	29.9	21.5	28.7	21.2	28.5	21.4
S ₃ (I FN of July)	26.5	21.8	26.9	21.6	28.4	21.0	30.3	20.7	29.0	21.5	29.8	21.2	30.0	20.3	28.7	21.2
S ₄ (II FN of July)	26.4	21.4	28.6	21.2	30.3	21.4	28.6	21.2	30.1	20.8	31.3	20.0	31.8	20.5	29.6	21.0
B) Varieties																
V ₁ (JS-335)	28.1	22.3	27.6	22.1	25.6	21.5	27.6	21.5	28.7	21.9	29.4	20.2	29.7	21.4	28.2	21.9
V ₂ (MACS-450)	28.3	22.3	27.4	22.2	26.0	21.5	27.6	21.6	28.3	21.6	29.7	20.4	30.8	21.4	28.3	21.9
V ₃ (DS-228)	28.3	22.3	27.5	22.2	25.9	21.5	27.9	21.5	28.2	21.7	29.9	20.4	30.7	21.7	27.8	21.4
GM	27.7	22.1	27.4	21.9	27.2	21.5	28.4	21.3	28.9	21.4	30.0	20.6	30.3	21.1	28.5	21.5
*EM-Emergence, VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity, TGP-Total Growing Period, Mx- Maximum air temperature, Mn-Minimum air temperature																





4.4.4 Relative humidity regime

Data regarding relative humidity regime (morning-RHI and evening-RH-II) encountered by the crop across different phenophase during the year 2012 and 2013 are presented in Table 25 and Fig. 25 (a and b). It was observed that mean morning relative humidity remained between 75% to 89% and 86% to 90% and mean evening relative humidity remained between 20% to 34% and 60 % to 79% respectively during all phenophase of crop. Similar results were recorded by Brown and Chapman (1960), Egli and Wardlaw (1980) and Jadhao (2009).

Sowing times

During the year 2012, at emergence stage morning and evening relative humidity more from I FN of June (S_1) to II FN of July (S_4). Morning and evening relative humidity was approximately same for all four sowing times (S_1 to S_4) at vegetative stage except I FN of June (S_1) sowing time. During pod formation, seed formation and full seed development stage morning and evening relative humidity decreased from I FN of June (S_1) to later sowing times. During seed formation stage (SF) maximum evening relative humidity was 93% under sowing times II FN of July (S_4) followed by II FN of June (S_2) (90%), I FN of July (S_3) and II FN of July (S_4) (86%). Across seed development stage (FSD) maximum evening relative humidity was 91% under sowing times I FN of July (S_3) followed by I FN of June (S_1)(90%), II FN of June (S_2) (88%) and II FN of July (S_4) (85%). Averaged across the total growing period, morning relative humidity show increasing trend from I FN of June (S_1) to II FN of July (S_4) sowing times however, in evening relative humidity it was show decreasing trend.

During the year 2013, at emergence stage morning and evening relative humidity was more or less equal except II FN of June (S_2) from I FN of June (S_1) to II FN of July (S_4) sowing times. During pod formation, seed formation and full seed development stage morning and evening relative humidity decreased from II FN of June (S_2) to later sowing times except I FN of June

(S₁) sowing times. During seed formation stage (SF) maximum evening relative humidity was 92% under sowing times II FN of June (S₂) followed by I FN of June (S₁) (89%), I FN of July (S₃) and II FN of July (S₄) (88%). Across seed development stage (FSD) maximum evening relative humidity was 91% under sowing times S₃ followed by S₁ (90%), II FN of June (S₂) (88%) and II FN of July (S₄) (85%). Averaged across the total growing period, morning relative humidity show more or less equal except I FN of June (S₁) sowing from all sowing times however, in evening relative humidity show decreasing trend.

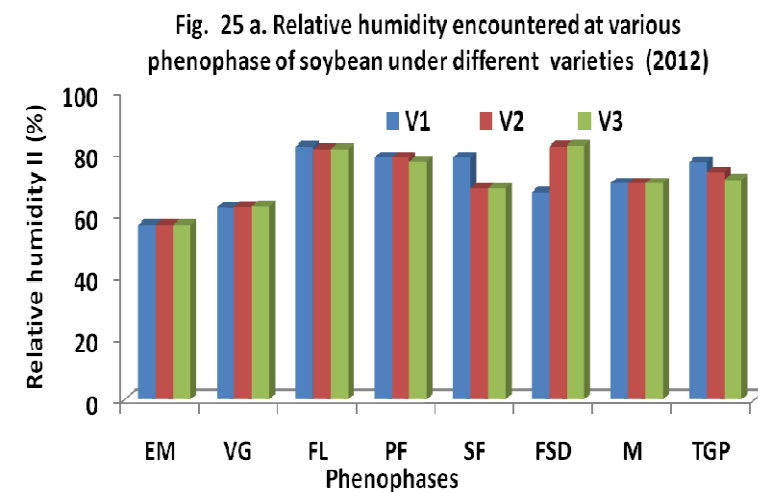
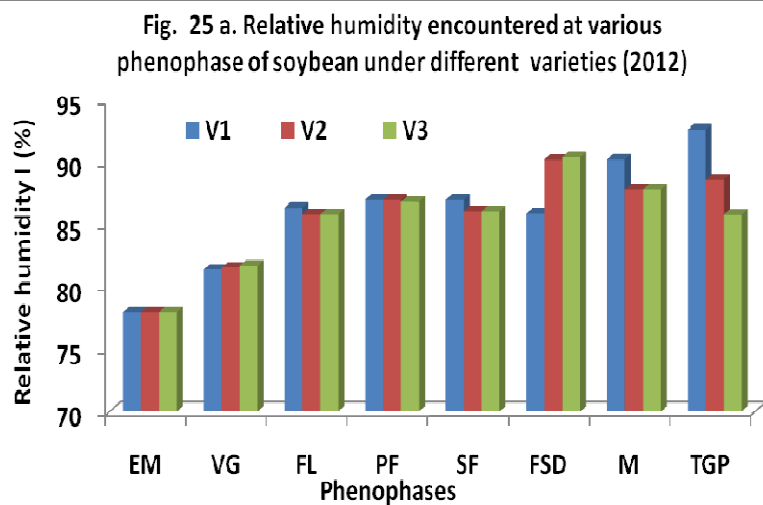
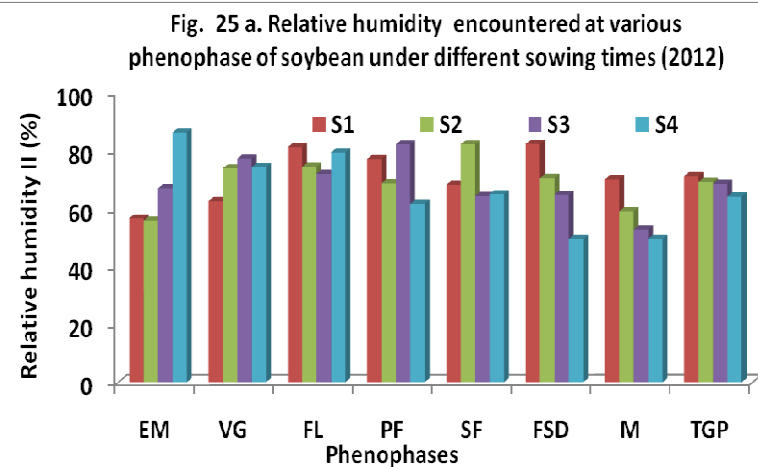
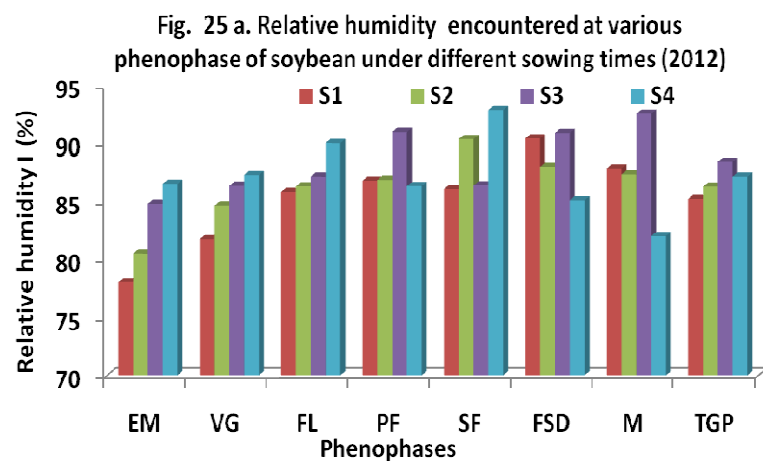
Varieties

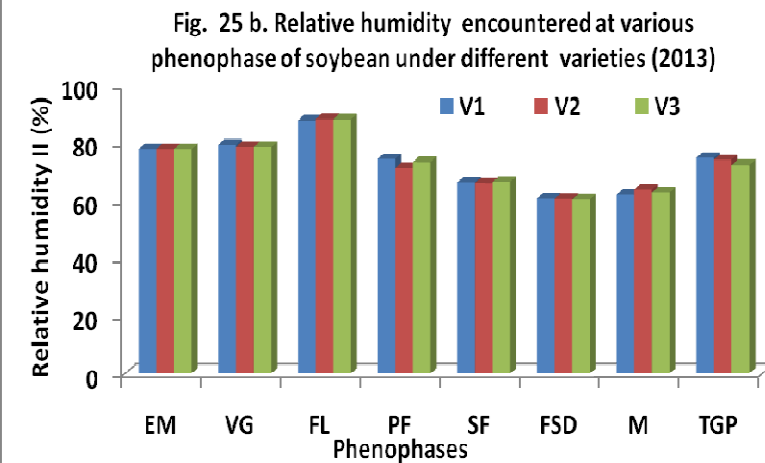
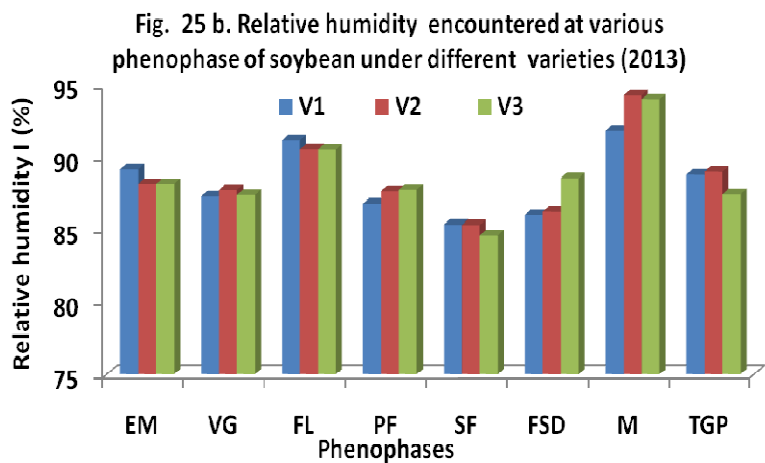
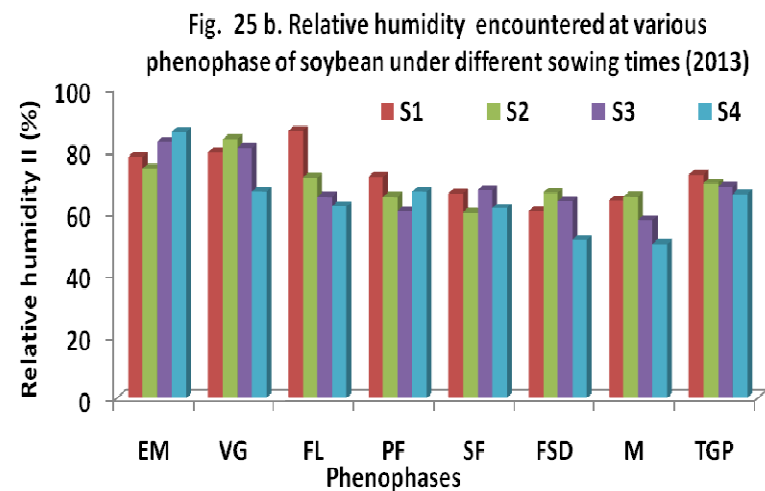
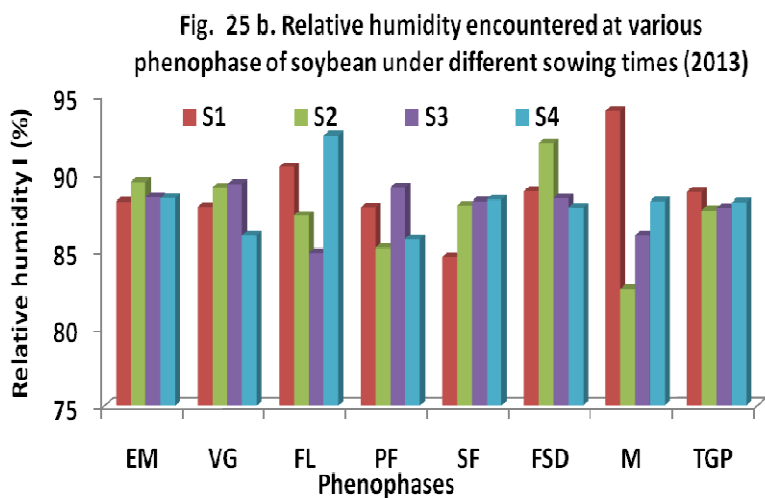
Among the varieties, morning and evening humidity regime did not show marked variation and remained more or less similar at the observed phenophase and across the total crop growing period during the year 2012 and 2013.

It is very clear that sowing dates and genotype receives more or less similar relative humidity during the entire growth phases of soybean crop during the experimentation. Lower amount of relative humidity recorded at top as well as bottom in evening. These findings are in accordance with those of Veni *et al.* (2003).

Table 25 a. Relative humidity (%) regime encountered during soybean phenophases under sowing times and varieties (2012)																
Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II
A) Sowing times																
S ₁ (I FN of June)	78	57	82	63	86	81	87	77	86	68	90	82	88	70	85	71
S ₂ (II FN of June)	81	56	85	74	86	75	87	69	90	82	88	71	87	59	86	69
S ₃ (I FN of July)	85	67	86	77	87	72	91	82	86	64	91	65	93	53	88	69
S ₄ (II FN of July)	87	86	87	74	90	79	86	62	93	65	85	50	82	50	87	64
B) Varieties																
V ₁ (JS-335)	78	57	81	62	86	82	87	78	87	78	86	67	90	70	93	77
V ₂ (MACS-450)	78	57	82	62	86	81	87	78	86	68	90	82	88	70	89	74
V ₃ (DS-228)	78	57	82	63	86	81	87	77	86	68	90	82	88	70	86	71
GM	81	62	84	68	87	79	87	75	88	71	89	71	88	63	88	71

Table 25 b. Relative humidity (%) regime encountered during soybean phenophases under sowing times and varieties (2013)																
Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		TGP	
	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II	RH-I	RH-II
A) Sowing times																
S ₁ (I FN of June)	88	78	88	79	90	86	88	71	85	66	89	60	94	64	89	72
S ₂ (II FN of June)	89	74	89	83	87	71	85	65	88	60	92	66	83	65	88	69
S ₃ (I FN of July)	88	83	89	81	85	65	89	60	88	67	88	64	86	57	88	68
S ₄ (II FN of July)	88	86	86	66	92	62	86	66	88	61	88	51	88	50	88	66
B) Varieties																
V ₁ (JS-335)	89	78	87	79	91	88	87	74	85	66	86	61	92	62	89	75
V ₂ (MACS-450)	88	78	88	79	91	88	88	71	85	66	86	61	94	64	89	74
V ₃ (DS-228)	88	78	87	79	91	88	88	73	85	66	89	60	94	63	87	72
GM	89	79	88	78	90	78	87	69	86	65	88	60	90	61	88	71
*EM-Emergence, VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity, TGP-Total Growing Period, RH-I= Relative humidity (morning), RH-II=Relative humidity (afternoon)																





4.5 Radiation intensity

4.5.1 Photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident on soybean phenophases under sowing times and varieties (2012 and 2013)

Data collected on photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident at top of the crop at 12.00 hrs in afternoon at various phenophases are presented in Table 26 and 27 and Fig.26 and 27.

Sowing times

During the year 2012 (Table 26) the mean value of incident PAR were 1209.4, 1369.0, 1165.5, 1133.3, 1019.2 and 752.7 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly the highest incident PAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases.

Similar trend of observation was recorded during the year 2013 (Table 27) as compared to the year 2012. The mean value of incident PAR were 1043.9, 1212.86, 1239.6, 1193.7, 1085.95 and 847.2 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest incident PAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases. Lower accumulation of solar radiation indicated decreased seed yield of the crop. Similar results were reported by Melges *et al.* (1989) and Jadhao (2009).

Varieties

During year 2012 (Table 26) among all the varieties, MACS-450 (V_2) (1388.5 $\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum PAR values at flowering stage followed by variety JS-335 (V_1) (1385.0 $\mu \text{ mol m}^{-2}\text{s}^{-1}$). Higher amount of incident PAR was recorded at top of the crop during the vegetative and flowering stage but it was in decreasing trend due to decrease in vegetation cover in pod formation seed formation full seed development and maturity.

Table 26. Photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident on soybean phenophases under sowing times and varieties (2012)						
Treatment	PARo					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	1252	1433	1288	1161	1066	784
S ₂ (II FN of June)	1239	1387	1195	1150	1013	762
S ₃ (I FN of July)	1225	1329	1095	1127	1004	739
S ₄ (II FN of July)	1119	1326	1082	1093	992	724
B) Varieties						
V ₁ (JS-335)	1222	1385	1162	1128	1018	713
V ₂ (MACS-450)	1223	1353	1164	1130	999	766
V ₃ (DS-228)	1124	1388	1088	1168	1020	729
GM	1209	1369	1165	1133	1019	752
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

Table 27. Photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident on soybean phenophases under sowing times and varieties (2013)						
Treatment	PARo					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	1108	1314	1290	1219	1141	875
S ₂ (II FN of June)	1062	1245	1272	1209	1088	850
S ₃ (I FN of July)	1004	1150	1250	1177	1062	837
S ₄ (II FN of July)	1001	1141	1144	1168	1050	825
B) Varieties						
V ₁ (JS-335)	1059	1216	1253	1197	1087	871
V ₂ (MACS-450)	1028	1210	1254	1180	1062	825
V ₃ (DS-228)	1043	1211	1149	1243	1070	844
GM	1043	1212	1239	1193	1085	847
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

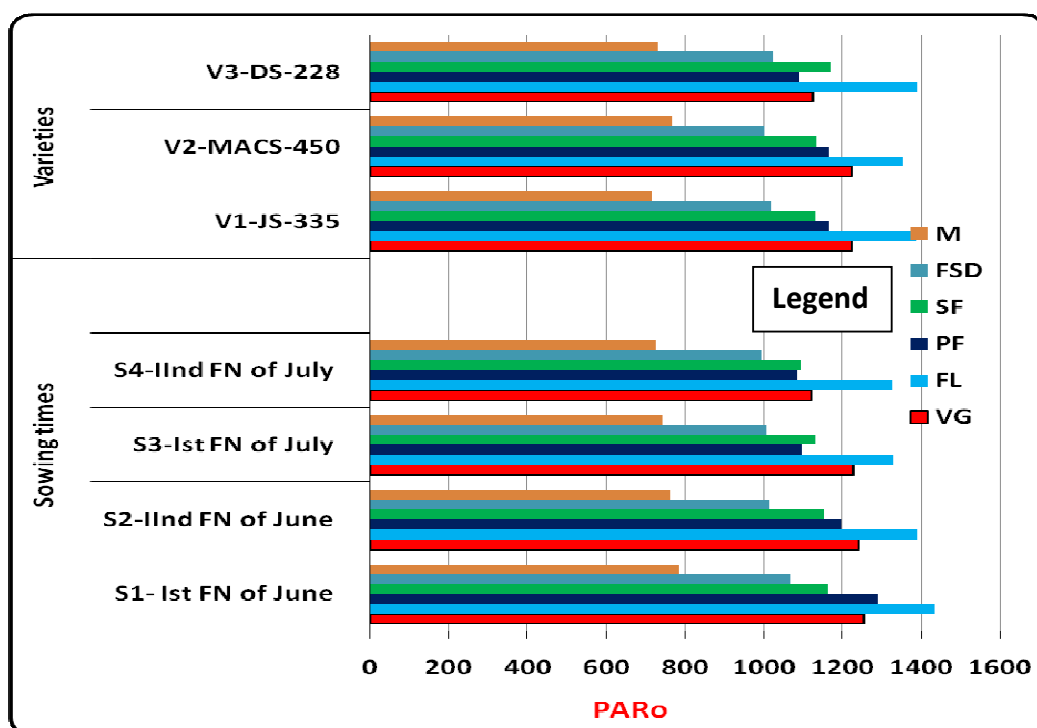


Fig.26. Photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident on soybean phenophases under sowing times and varieties

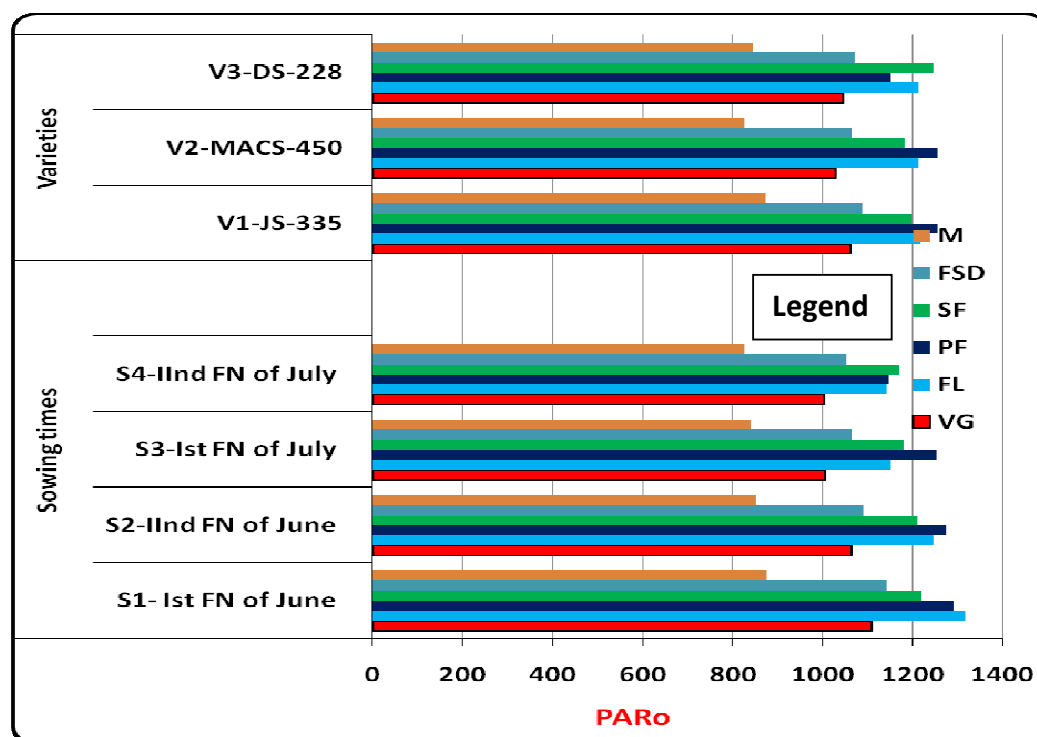


Fig.27. Photosynthetically active radiation (PARo) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) incident on soybean phenophases under sowing times and varieties (2013)

During year 2013 (Table 27) among all the variety, MACS-450 (V_2) ($1254.1 \mu \text{ mol m}^{-2} \text{ s}^{-1}$) recorded maximum PAR values at pod formation stages which were followed by variety JS-335 (V_1) ($1253.2 \mu \text{ mol m}^{-2} \text{ s}^{-1}$). The incident radiation was generally depends upon the weather condition of the day. The low incident radiations were observed when cloudy condition remained while recording the observations.

Similar results were reported by Melges (1989), Jadhao (2009) and Paulo *et al.* (2010).

4.5.2 Reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2012 and 2013)

Data collected on reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) from top of the crop at 12.00 hrs in afternoon at various phenophases are presented in Table 28 and 29 and Fig. 28 and 29.

Sowing times

During the year 2012 (Table 28) the mean value of RPAR were 453.1, 432.0, 411.6, 408.8, 351 and 336.3 ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest RPAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases.

Similar trend of observation was recorded during the year 2013 (Table 29) as compared to the year 2012. The mean value of RPAR were 447.3, 435.9, 430.1, 385.4, 418.0 and 371.4 ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly the highest RPAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases. Lower accumulation of solar radiation indicated decreased seed yield of the crop. Similar results were reported by Melges (1989) and Jadhao (2009).

Varieties

During the year 2012, among all the varieties, DS-228 (V_3) ($456.3 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum RPAR values at all the stages followed by variety MACS-450 (V_2) ($453.3 \mu \text{ mol m}^{-2}\text{s}^{-1}$). Higher amount RPAR was recorded at top of the crop during the vegetative and flowering stage but it was in decreasing trend due to decrease in vegetation cover in pod formation seed formation full seed development and maturity (Table 28).

During the year 2013, among all the variety, MACS-450 (V_2) ($455.2 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum RPAR values at vegetative and flowering. The RPAR was generally depends upon the weather condition of the day. The low incident radiations were observed when cloudy condition remained while recording the observations (Table 29).

Similar results were reported by Melges (1989), Jadhao (2009) and Paulo *et al.* (2010).

4.5.3 Transmitted photosynthetically active radiation (TPAR) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2012and 2013)

Data collected on transmitted photosynthetically active radiation (TPAR) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) from bottom of the crop at 12.00 hrs in afternoon at various phenophases are presented in Table 30 and 31and Fig.30 and 31.

Sowing times

During the year 2012, the mean value of TPAR were 907.1, 863.1, 892.2, 905.0, 912.4 and 996.1 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest TPAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases. (Table 30)

Table 28. Reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)						
Treatment	RPAR					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	470	452	432	443	392	350
S ₂ (II FN of June)	454	452	424	413	367	341
S ₃ (I FN of July)	447	428	412	401	346	330
S ₄ (II FN of July)	442	397	379	379	304	325
B) Varieties						
V ₁ (JS-335)	450	436	413	405	370	347
V ₂ (MACS-450)	453	423	416	424	326	341
V ₃ (DS-228)	456	437	363	363	360	321
GM	453	432	412	409	352	336
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

Table 29. Reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)						
Treatment	RPAR					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	469	468	451	425	425	399
S ₂ (II FN of June)	461	446	437	401	425	366
S ₃ (I FN of July)	449	426	417	379	412	363
S ₄ (II FN of July)	410	404	415	337	410	358
B) Varieties						
V ₁ (JS-335)	447	430	423	403	387	378
V ₂ (MACS-450)	452	455	430	359	437	381
V ₃ (DS-228)	397	388	437	394	430	352
GM	447	436	430	385	418	371
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

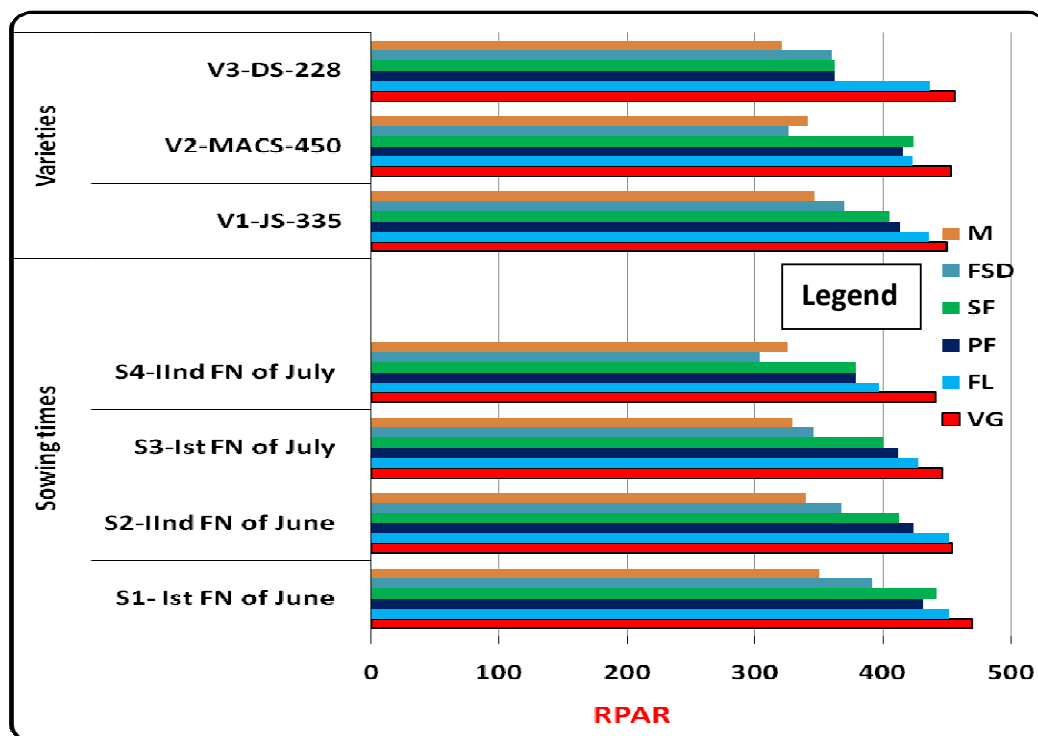


Fig.28. Reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)

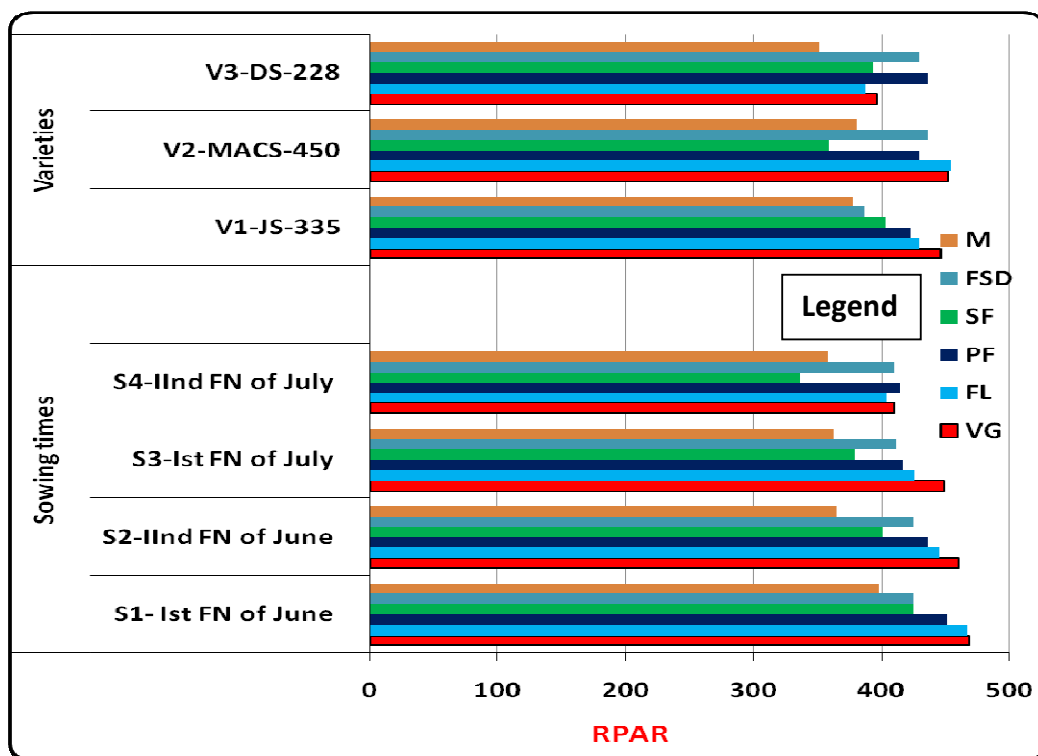


Fig.29. Reflected photosynthetically active radiation (RPAR) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)

Similar trend of observation was recorded during the year 2013 (Table 31) as compared to the year 2012. The mean value of TPAR were 888.8, 824.0, 919.3, 927.9, 1018.2 and 1029.0 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest RPAR was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenophases. Lower accumulation of solar radiation indicated decreased seed yield of the crop. Similar results were reported by Melges (1989) and Jadhao (2009).

Varieties

During the year 2012 (Table 30) among all the varieties, MACS-450 (V_2) ($1026.0 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum TPAR values at maturity followed by variety DS-228 (V_3) ($993.3 \mu \text{ mol m}^{-2}\text{s}^{-1}$). Higher amount TPAR was recorded at bottom of the crop during maturity, it was in increasing trend due to decrease in vegetation cover in seed formation to maturity. During the year 2013 (Table 31) among all the variety, JS-335 (V_1) ($1078.7 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum TPAR values at maturity followed by variety MACS-450 (V_2) ($1040.4 \mu \text{ mol m}^{-2}\text{s}^{-1}$). The TPAR was generally depends upon the weather condition of the day. The low incident radiations were observed when cloudy condition remained while recording the observations.

Similar results were reported by Melges (1989), Jadhao (2009) and Paulo *et al.* (2010).

4.5.4 Reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2012 and 2013)

Data collected on reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) from bottom of the crop at 12.00 hrs in afternoon at various phenophases are presented in Table 32 and 33 and Fig.32 and 33.

Table 30. Transmitted photosynthetically active radiation (TPAR) ($\mu\text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)						
Treatment	TPAR					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	939	895	912	940	948	1039
S ₂ (II FN of June)	931	892	906	927	922	1028
S ₃ (I FN of July)	886	844	886	878	894	978
S ₄ (II FN of July)	873	824	866	876	886	940
B) Varieties						
V ₁ (JS-335)	894	883	900	920	935	949
V ₂ (MACS-450)	910	860	908	874	923	1026
V ₃ (DS-228)	918	835	863	903	879	993
GM	907	864	892	905	912	996
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

Table 31. Transmitted photosynthetically active radiation (TPAR) ($\mu\text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)						
Treatment	TPAR					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	920	858	945	957	1060	1073
S ₂ (II FN of June)	917	846	931	944	1045	1039
S ₃ (I FN of July)	869	804	911	903	1003	1019
S ₄ (II FN of July)	849	788	891	909	965	986
B) Varieties						
V ₁ (JS-335)	908	810	931	939	976	1079
V ₂ (MACS-450)	885	827	933	906	1040	1023
V ₃ (DS-228)	860	835	888	928	1018	986
GM	889	824	919	928	1018	1029
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

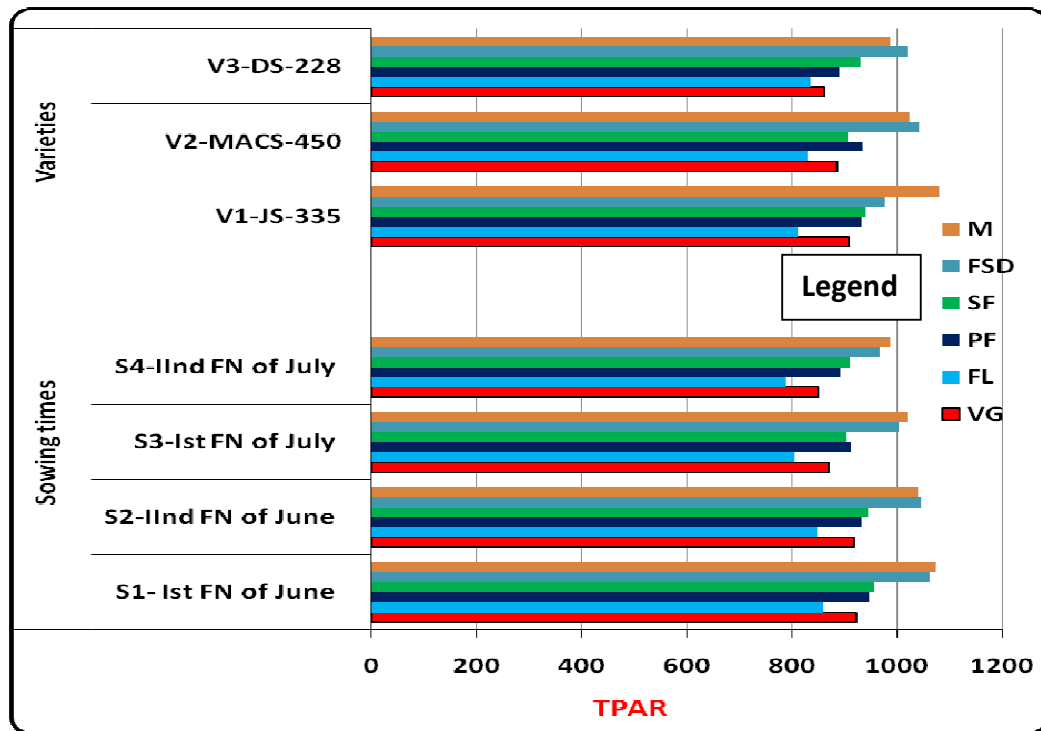


Fig. 30. Transmitted photosynthetically active radiation (TPAR) ($\mu \text{mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)

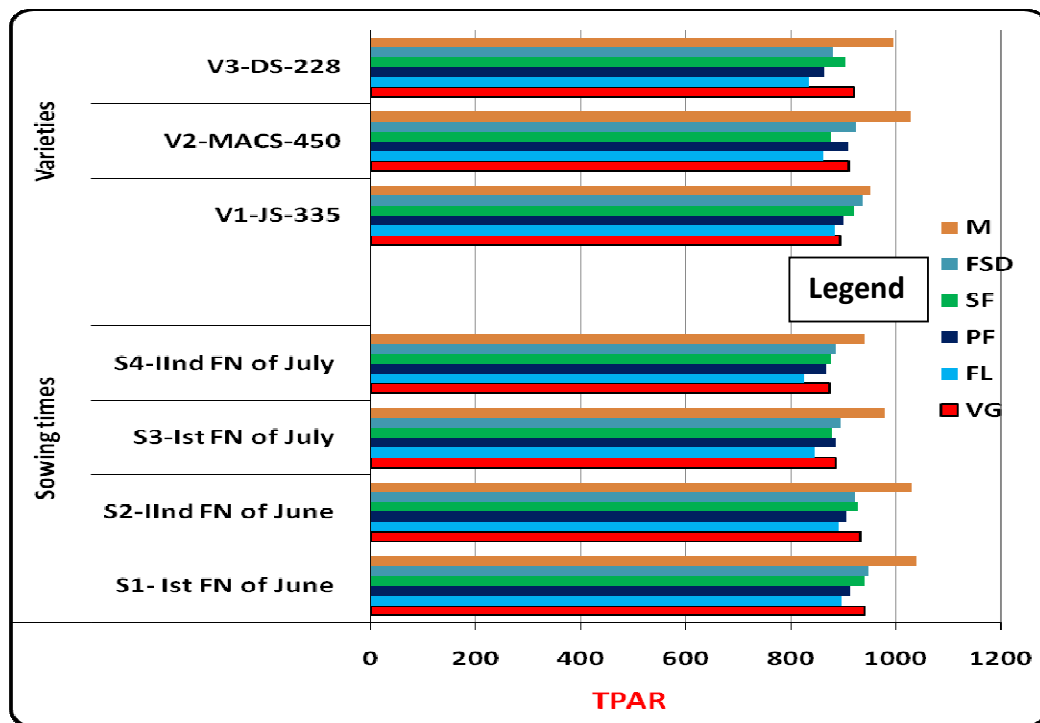


Fig. 31. Transmitted photosynthetically active radiation (TPAR) ($\mu \text{mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)

Sowing times

During the year 2012, the mean value of RPARs were 281.3, 292.3, 299.4, 317.3, 359.5 and 371.5 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest RPARs was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenopheses (Table 32).

Similar trend of observation was recorded during the year 2013 (Table 33) as compared to the year 2012. The mean value of RPARs were 306.3, 321.5, 331.8, 348.7, 365.1 and 378.3 ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded at vegetative, flowering, pod formation, seed formation, full seed development and maturity, respectively. Significantly highest RPARs was recorded in crop sown on I FN of June (S_1) and lowest in sowing II FN of July (S_4) during all the phenopheses. Lower accumulation of solar radiation indicated decreased seed yield of the crop. Similar results were reported by Melges (1989) and Jadhao (2009).

Varieties

During the year 2012, among all the varieties, JS-335 (V_1) ($373.5 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum RPARs values at maturity followed by variety MACS-450 (V_2) ($371.9 \mu \text{ mol m}^{-2}\text{s}^{-1}$). Higher amount RPARs was recorded at bottom of the crop during maturity; it was in increasing trend due to decrease in vegetation cover in seed formation to maturity (Table 32).

During the year 2013, among all the variety, JS-335 (V_1) ($393.2 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum RPARs values at maturity followed by variety MACS-450 (V_2) ($384.1 \mu \text{ mol m}^{-2}\text{s}^{-1}$). The RPARs was generally depends upon the weather condition of the day. The low incident radiations were observed when cloudy condition remained while recording the observations (Table 33).

Similar results were reported by Melges (1989), Jadhao (2009) and Paulo *et al.* (2010).

Table. 32. Reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)						
Treatment	RPARs					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	301	310	318	328	391	398
S ₂ (II FN of June)	283	301	305	326	364	389
S ₃ (I FN of July)	280	294	294	319	356	360
S ₄ (II FN of July)	261	271	280	296	327	340
B) Varieties						
V ₁ (JS-335)	281	304	303	329	352	374
V ₂ (MACS-450)	292	303	300	328	358	372
V ₃ (DS-228)	218	216	297	241	369	370
GM	281	292	299	317	360	372
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

Table 33. Reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)						
Treatment	RPARs					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	326	336	353	368	389	401
S ₂ (II FN of June)	308	326	343	358	378	396
S ₃ (I FN of July)	305	321	340	338	353	376
S ₄ (II FN of July)	286	296	321	330	341	340
B) Varieties						
V ₁ (JS-335)	306	335	348	347	357	393
V ₂ (MACS-450)	317	334	353	352	366	384
V ₃ (DS-228)	243	241	266	347	372	358
GM	306	322	332	349	365	378
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

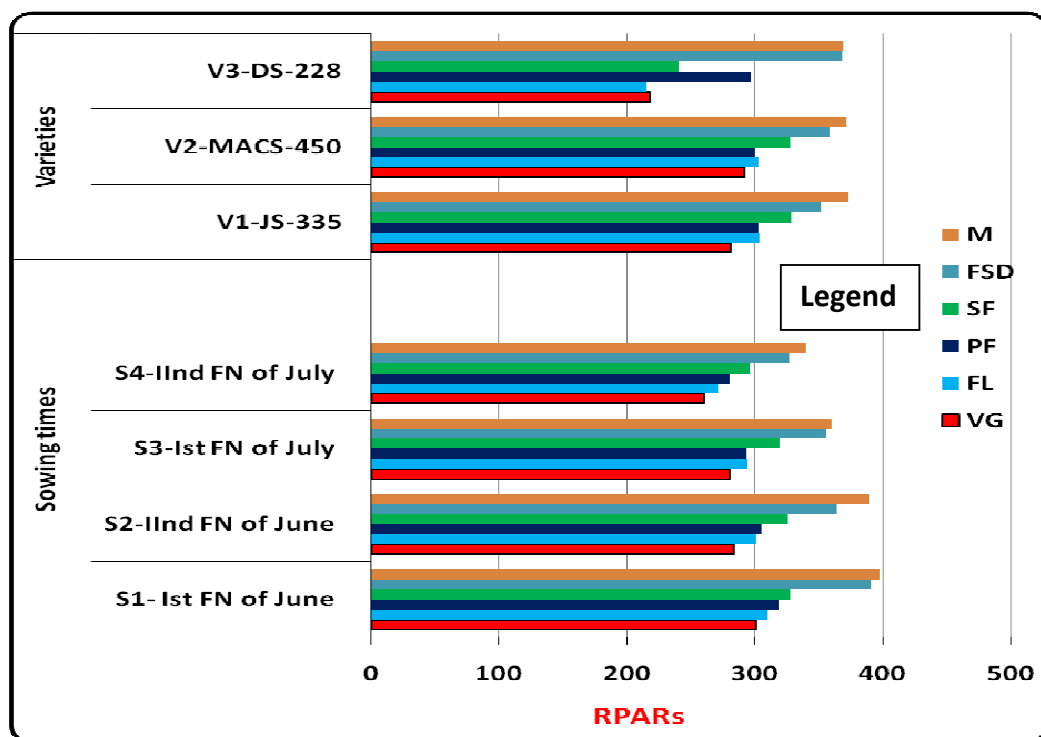


Fig.32. Reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2012)

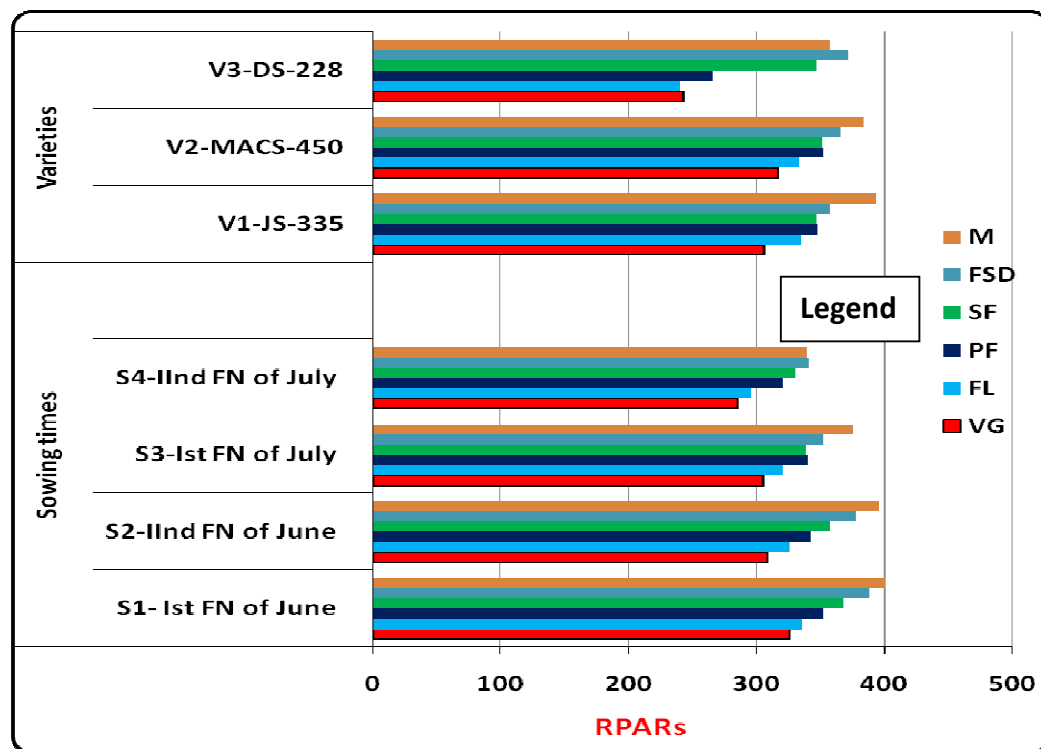


Fig.33 .Reflected (soil) photosynthetically active radiation (RPARs) ($\mu \text{ mol m}^{-2} \text{ s}^{-1}$) by soybean phenophases under sowing times and varieties (2013)

4.6 Radiation interception

Data in respect of radiation interception as influenced by different sowing times and varieties at different phenophases are presented in Table 34 and 35 and Fig 34 and 35 for the year 2012 and 2013.

Sowing times

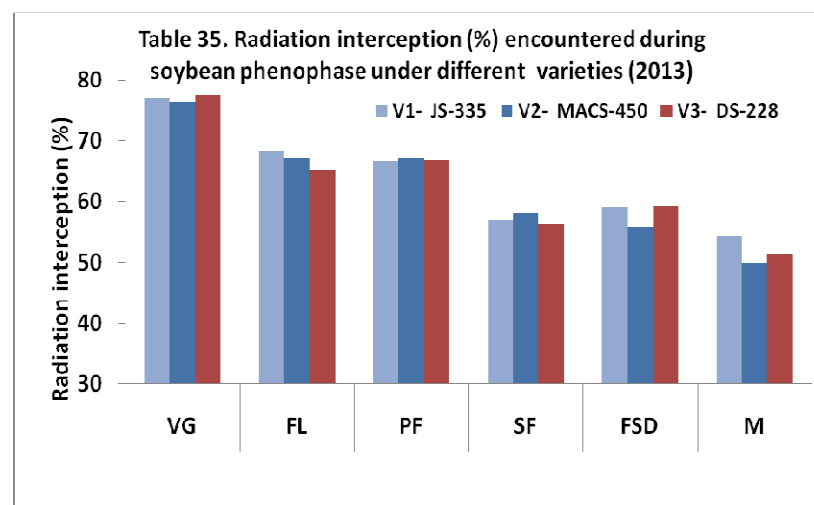
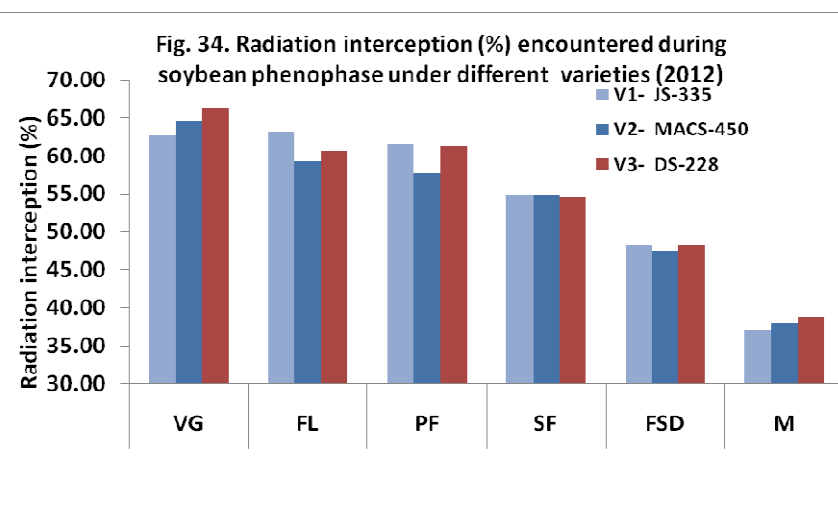
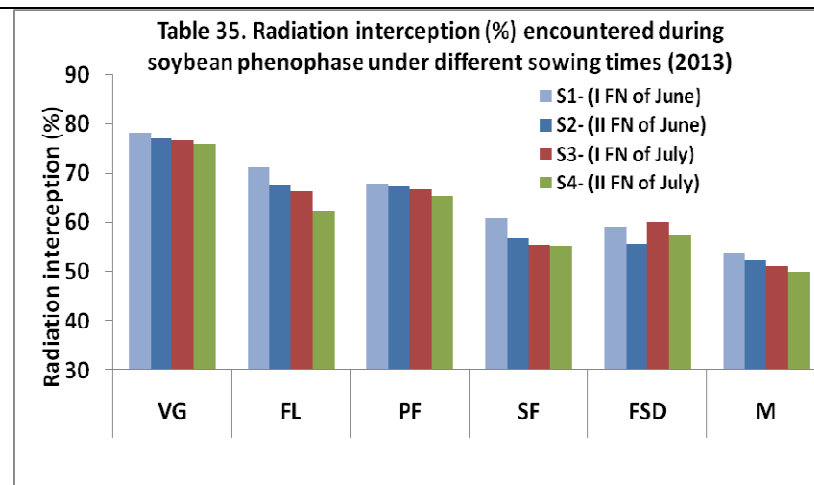
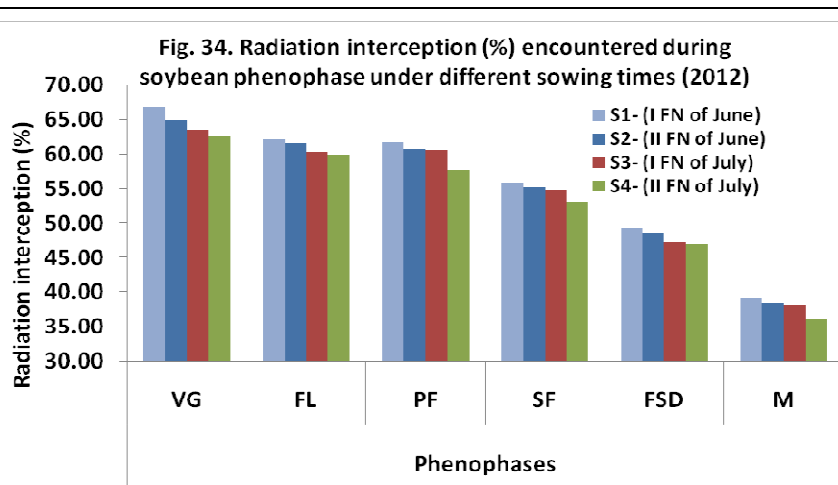
During the year 2012, it was observed from the data presented in Table 34 that the highest percentage of radiation interception was recorded in the crop sown I FN of June (S_1) followed by all other sowing times in various phenological stages of soybean crop and the lowest percentage of radiation interception was recorded in the crop sown during II FN of July (S_4). It was observed that, the general mean percentage of radiation interception was found highest at vegetative stage (64.43%), it was constant at flowering pod formation stage (60.97 and 60.18%) respectively, and thereafter the per cent radiation interception declined till the harvest maturity.

During the year 2013, it was observed from the data presented in Table 35 that the highest percentage of radiation interception was recorded in the crop sown during I FN of June (S_1) followed by all other sowing times in various phenological stages of soybean crop and the lowest percentage of radiation interception was recorded in the crop sown during II FN of July (S_4). It was observed that, the general mean percentage of radiation interception was found highest at vegetative stage (76.99%), it was constant at flowering pod formation stage (66.87 and 66.82 %), respectively, and thereafter the per cent radiation interception declined till the harvest maturity. Similar results were recorded by Singh and Hundal (2004).

During the year 2012 and 2013, comparatively it is observed that the radiation interception was higher in the year 2013 than the year 2012.

Table 34. Radiation interception (%) encountered during soybean phenophases under sowing times and varieties (2012)						
Treatment	Radiation interception (%)					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	66.84	62.11	61.67	55.92	49.29	39.29
S ₂ (II FN of June)	64.91	61.59	60.70	55.13	48.45	38.45
S ₃ (I FN of July)	63.47	60.25	60.60	54.80	47.15	37.99
S ₄ (II FN of July)	62.48	59.93	57.75	53.10	46.99	36.16
B) Varieties						
V ₁ (JS-335)	62.61	63.02	61.52	54.84	48.26	37.01
V ₂ (MACS-450)	64.56	59.19	57.76	54.83	47.42	38.05
V ₃ (DS-228)	66.11	60.70	61.25	54.53	48.23	38.85
GM	64.43	60.97	60.18	54.74	47.97	37.97
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						

Table 35. Radiation interception (%) encountered during soybean phenophases under sowing times and varieties (2013)						
Treatment	Radiation interception (%)					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S ₁ (I FN of June)	78.32	71.31	67.83	60.95	59.04	53.77
S ₂ (II FN of June)	77.07	67.62	67.38	56.78	55.58	52.42
S ₃ (I FN of July)	76.61	66.29	66.63	55.49	60.17	51.08
S ₄ (II FN of July)	75.95	62.28	65.44	55.32	57.34	50.02
B) Varieties						
V ₁ (JS-335)	77.05	68.30	66.66	57.01	59.08	54.27
V ₂ (MACS-450)	76.44	67.10	67.08	58.05	55.84	49.81
V ₃ (DS-228)	77.48	65.22	66.72	56.35	59.17	51.39
GM	76.99	66.87	66.82	57.14	58.03	51.82
<i>*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity</i>						



Varieties

Data in Table 34 and 35 revealed that the highest percentage of radiation interception was recorded in the variety DS-228 (V_3) as compared to the varieties MACS-450 (V_2) and JS-335 (V_1) at vegetative and full seed development stage during both the years. This is attributed to higher canopy development in early sowing, as it evident from higher dry matter production in this genotype. Similar results were recorded by Board and Harvelle (1993); Jameo (1987), Board *et al.* (1997) and Jadhao (2009)

4.7 Growing degree day

Data regarding phenophases wise growing degree days (GDD) and total growing degree days availed by different sowing times and genotypes are presented in Table 36 and depicted in Fig. 36 (a and b) for the year 2012 and 2013. The accumulated growing degree days to reach various growth stages showed variation among the different sowing times and varieties. The accumulated growing degree days were reasonably higher during reproductive stage (FL-FSD) as compared to vegetative stage (VG).

Among the reproductive phenophases, seed development phase availed higher growing degree days

Sowing times

During the year 2012, accumulated growing degree days (thermal units) to reach various growth stages differed among the different sowing times. The early sown crop I FN of June (S_1), accumulated highest growing degree days (1515.1 $^{\circ}\text{C day}$) to reach various phenophases which decreased with successive delayed sowing. First sowing I FN of June (S_1) availed higher GDD during emergence phase compared to II FN of June (S_2), I FN of July (S_3), II FN of July (S_4). During subsequent phenophases also early sown crop (S_1) accumulated highest growing degree days to reach various phenophases which decreased with successive later sowing (S_2 to S_4). Across the total growing period (emergence to physiological maturity) of the crop the highest heat units

were accumulated by sowings I FN of June (S_1) (1515.1 °C day) followed by II FN of June (S_2) (1414.6 °C day), I FN of July (S_3) (1353.9 °C day) and II FN of July (S_4) (1292.0 °C day). However, similar trend observed during the year 2013, the early sown crop I FN of June (S_1) accumulated highest growing degree days (1439.6 °C day) to reach various phenophases which decreased with successive delayed sowing. First sowing I FN of June (S_1) availed higher GDD during emergence phase compared to that in II FN of June (S_2), I FN of July (S_3), II FN of July (S_4). During subsequent phenophases also early sown crop I FN of June (S_1) accumulated highest growing degree days to reach various phenophases which decreased with successive later sowing (S_2 to S_4). Across the total growing period (emergence to physiological maturity) of the crop the highest heat units were accumulated by I FN of June (S_1) (1439.6 °C day) followed by I FN of July (S_3) (1377.7 °C day), II FN of June (S_2) (1372.7 °C day), and II FN of July (S_4) (1366.7 °C day). Similar results were reported by Shrivastava *et al.* (2000), Seddigh and Jolliff (1984), Upendrashankar *et al.*, (1996) and Jadhao (2009).

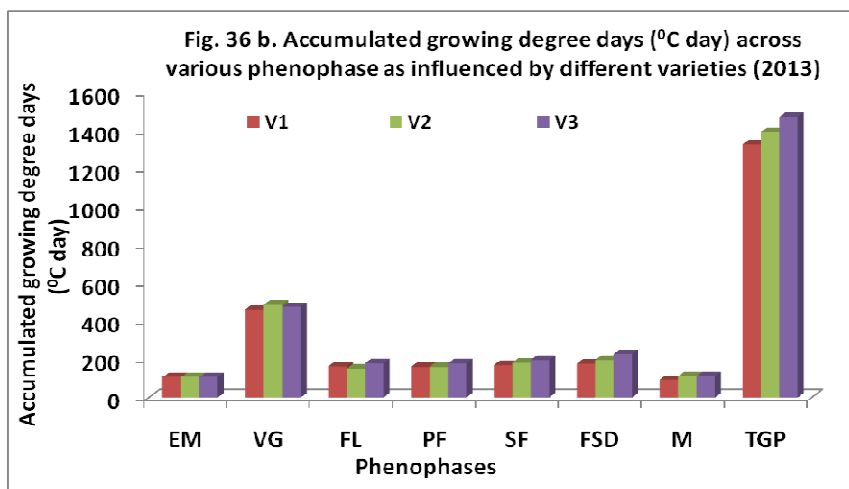
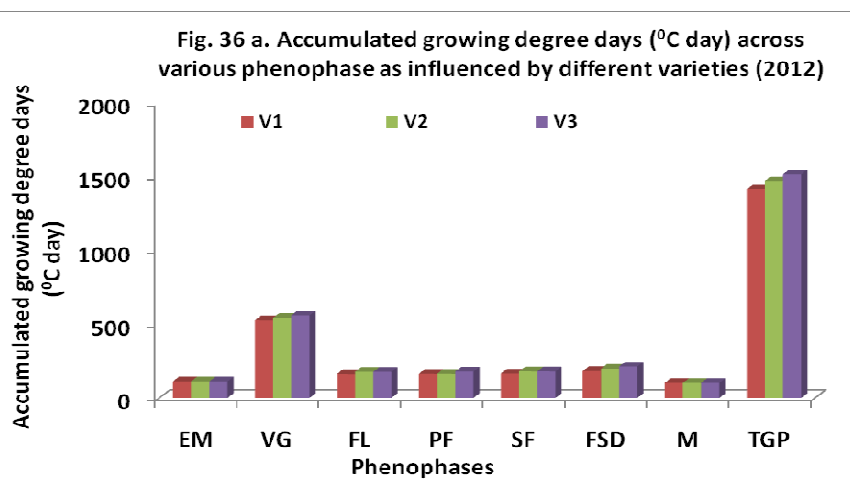
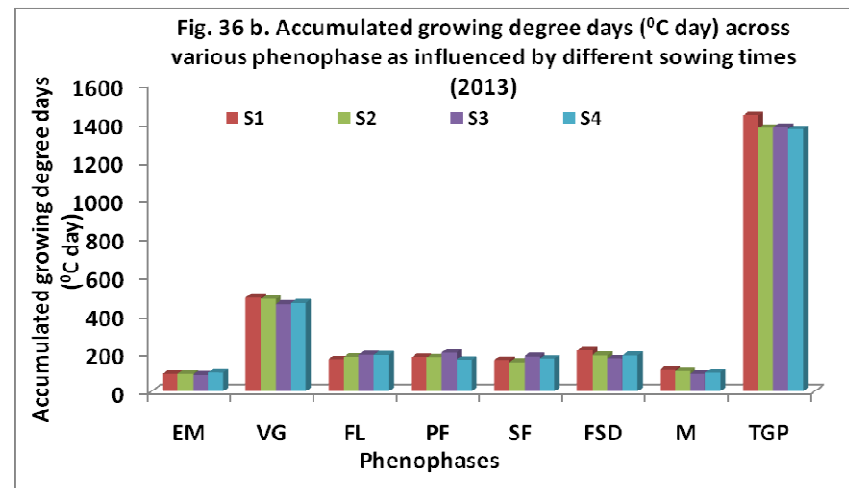
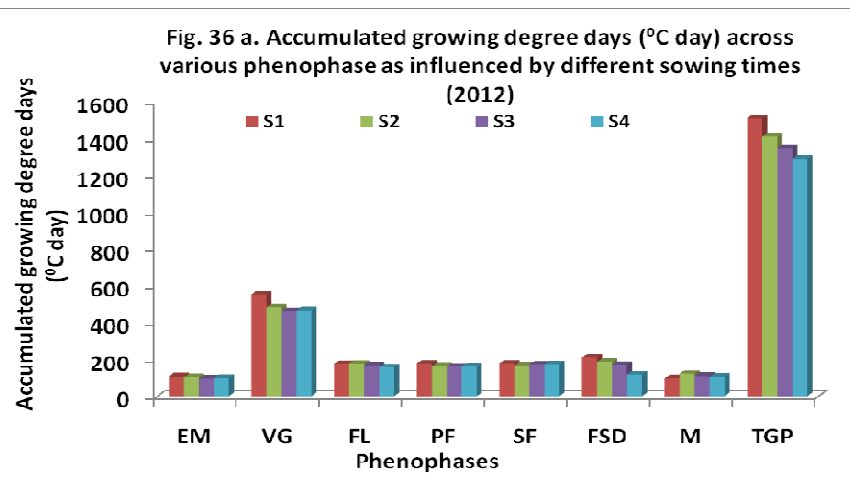
Varieties

During the years of 2012 and 2013, amongst the varieties, in respect of GDD availed across vegetative and reproductive phases, by and large DS-228 (V_3) availed more number of GDD followed by MACS-450 (V_2), JS-335 (V_1). During emergence all genotypes availed same number of GDD. Comparatively longer duration of each respective phenophases and total growth duration of the crop in the respective sowing times and Varieties caused higher accumulation of GDD. Similar results were reported by Shrivastava *et al.* (2000), Seddigh and Jolliff (1984), Upendrashankar *et al.* (1996) and Jadhao (2009).

Table 36. Accumulated growing degree days ($^{\circ}\text{C day}$) across various phenophases as influenced by sowing times and varieties (2012 and 2013)

Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S ₁ (I FN of June)	108.5	90.9	557.2	490.2	178.1	166.7	179.8	178.2	180.3	163.1	212.4	212.0	99.0	112.6	1515.1	1439.6
S ₂ (II FN of June)	104.8	90.6	484.9	481.2	179.0	179.5	165.3	176.2	168.0	152.2	189.7	188.4	123.0	104.4	1414.6	1372.7
S ₃ (I FN of July)	97.4	85.0	463.2	455.9	170.7	191.5	161.8	201.5	176.1	183.1	173.9	170.1	110.9	90.8	1353.9	1377.7
S ₄ (II FN of July)	99.6	96.9	469.1	461.2	158.5	190.3	163.9	164.0	176.5	170.0	117.6	187.8	107.0	96.8	1292.0	1366.7
B) Varieties																
V ₁ (JS-335)	108.5	107.3	525.6	459.9	163.3	162.8	164.8	160.1	166.6	168.9	182.8	176.2	99.0	92.0	1410.4	1327.0
V ₂ (MACS-450)	108.5	107.3	542.0	486.7	178.1	151.0	164.8	160.3	180.3	181.1	198.2	194.9	99.0	112.6	1470.7	1393.8
V ₃ (DS-228)	108.5	107.3	557.2	473.9	178.1	178.1	179.8	177.4	180.3	194.7	212.4	227.0	99.0	112.6	1515.1	1470.7
GM	105.1	97.9	514.2	472.7	172.2	174.3	168.6	174.0	175.4	173.3	183.8	193.8	105.2	103.1	1424.5	1392.6

**EM-Emergence, VG- Vegetative phase, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M- Physiological maturity*



4.7.1 Heliothermal units

Heliothermal units (HTU) ($^{\circ}\text{C day hrs}$) required to attain different phenological stages and during the total growing period of the crop under different sowing times and genotypes are presented in Table 22 and depicted in Fig.37 (a and b) for the years 2012 and 2013.

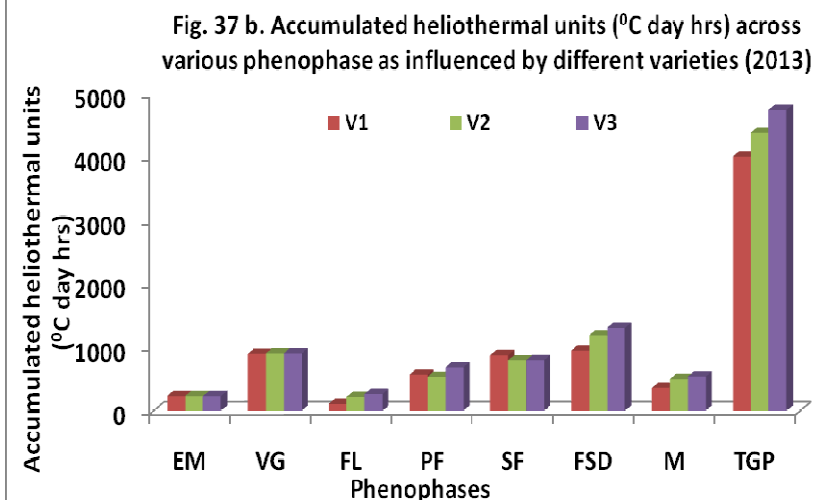
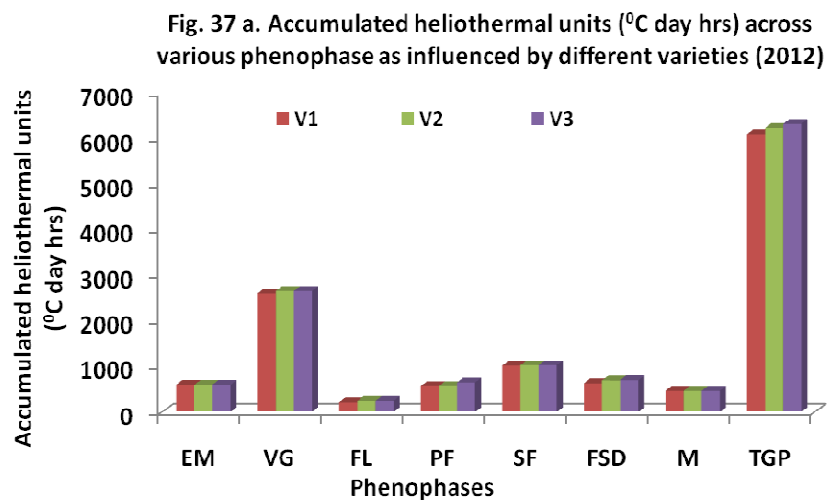
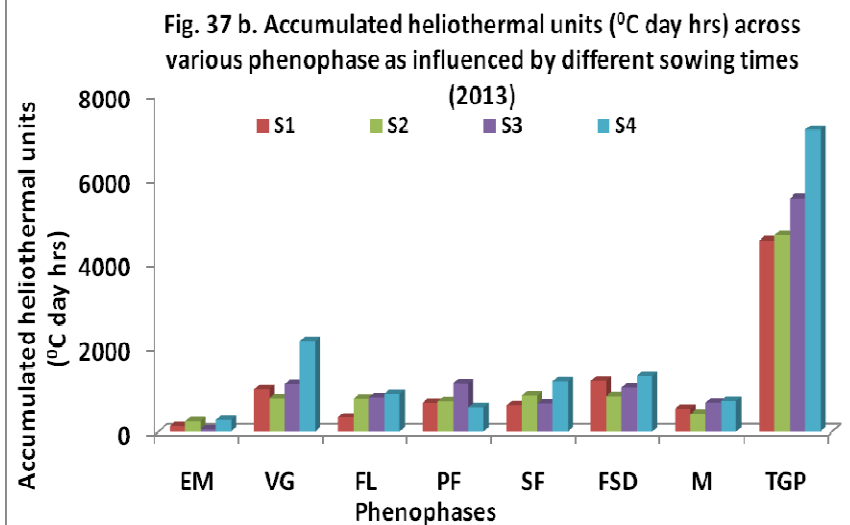
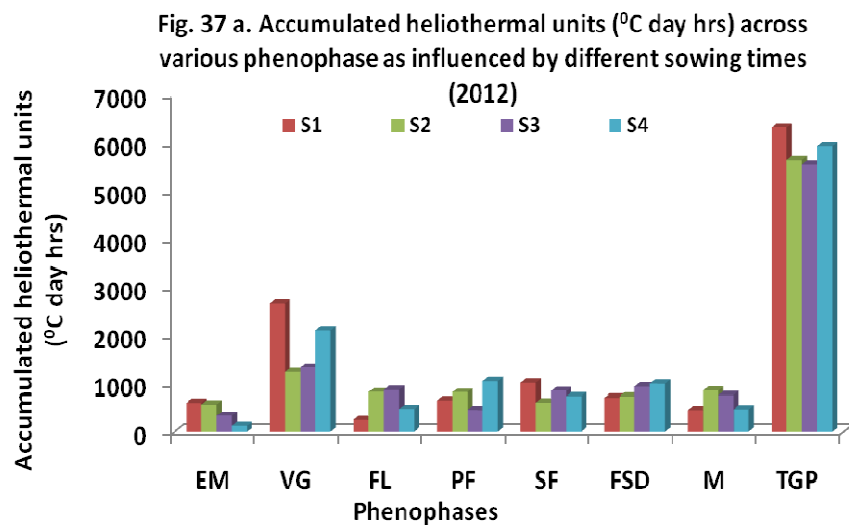
Sowing times

During the year 2012, the heliothermal units (HTU) availed to reach various growth stages noticeably differed sowing times. Among different crop phenophases, the accumulated HTUs were higher when cumulated across reproductive stage as compared to vegetative stage. Under all the sowings (I FN of June (S_1), II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4)), vegetative stage availed more number of HTU, which was followed by seed formation (SF) to seed development (FSD) as compared to the preceding phenophases. Overall, early sown crop I FN of June (S_1) availed higher HTU (6311.2 $^{\circ}\text{C day hour}$) followed by II FN of July (S_4) (5936.2 $^{\circ}\text{C day hour}$), II FN of June (S_2) (5632.9 $^{\circ}\text{C day hour}$) and I FN of July (S_3) (5542.7 $^{\circ}\text{C day hour}$). This was mainly due to more number of sunshine hours available across seed formation to seed development stage in middle sown crops (S_2 and S_3). During the year 2013, the heliothermal units (HTU) availed to reach various growth stages noticeably differed sowing times. Among different crop phenophases, the accumulated HTUs were higher when cumulated across reproductive stage as compared to vegetative stage. Under all the sowings (I FN of June (S_1), II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4)), seed formation (SF) to seed development (FSD) availed more number of HTU as compared to the preceding phenophases. Overall, late sown crop II FN of July (S_4) availed higher HTU (7165.0 $^{\circ}\text{C day hour}$), followed by I FN of July (S_3) (5554.3 $^{\circ}\text{C day hour}$), II FN of June (S_2) (4666.4 $^{\circ}\text{C day hour}$) and I FN of June (S_1) (4547.6 $^{\circ}\text{C day hour}$). This was mainly due to more number of sunshine hours available across seed formation to seed development stage in later sown crops (S_3 and S_4).

Table 37. Accumulated heliothermal units ($^{\circ}\text{C}$ days hrs) across various phenophases as influenced by sowing times and varieties (2012 and 2013)

Treatment	Phenophases *															
	EM		VG		FL		PF		SF		FSD		M		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S ₁ (I FN of June)	598.7	129.6	2652.5	1009.9	240.2	345.8	650.5	683.1	1016.4	627.8	701.6	1209.9	451.4	540.3	6311.2	4547.6
S ₂ (II FN of June)	563.9	248.3	1239.4	789.6	822.9	783.5	816.3	722.9	605.0	858.3	724.3	838.8	861.1	425.0	5632.9	4666.4
S ₃ (I FN of July)	332.2	53.6	1335.3	1132.8	875.4	814.7	453.9	1143.7	851.2	670.6	941.4	1051.6	753.3	687.4	5542.7	5554.3
S ₄ (II FN of July)	118.2	281.7	2099.6	2156.2	474.6	896.3	1047.8	576.3	730.8	1196.9	998.8	1326.7	466.4	730.7	5936.2	7165.0
B) Varieties																
V ₁ (JS-335)	598.7	232.6	2596.6	899.9	213.5	110.0	570.7	571.6	1006.8	878.6	633.1	949.8	451.4	364.6	6070.8	4007.2
V ₂ (MACS-450)	598.7	232.6	2652.5	906.9	240.2	220.5	570.7	535.0	1016.4	799.1	694.5	1188.6	451.4	500.6	6224.4	4383.4
V ₃ (DS-228)	598.7	232.6	2652.5	906.9	240.2	268.9	650.5	686.6	1016.4	800.4	701.6	1308.9	451.4	540.6	6311.2	4744.8
GM	487.0	201.6	2175.5	1114.6	443.8	491.4	680.1	702.7	891.9	833.1	770.8	1124.9	555.2	541.3	6004.2	5009.8

**EM-Emergence, VG- Vegetative phase, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M- Physiological maturity*



Varieties

During both the years i.e. 2012 and 2013, for the varieties, among different phenophase, similar trend prevailed as that observed under sowing times. Among different crop phenophases, the accumulated HTUs were higher when cumulated across reproductive stage as compared to vegetative stage. Amongst the varieties by and large, DS-228 (V_3) accrued more number of HTUs followed by MACS-450 (V_2), and JS-335 (V_1). Comparatively longer growth duration of crop coupled with greater sunshine hours in the respective sowing date and for the respective genotype caused higher accumulation of HTU.

4.7.2 Thermal use efficiency

Thermal use efficiency was computed with respect to seed yield and biomass production (biological yield) for the years 2012 and 2013. Relevant data are given in Table 38 and Fig. 38 (a and b).

Sowing times

Data presented in Table 38 revealed that different sowing times showing significant difference in thermal use efficiency over various yield parameters in soybean crop.

During the year 2012, initial sowing time I FN of June (S_1) upto II FN of July (S_4) decreasing trend of thermal use efficiency was found. The highest thermal use efficiency with more grain yield is observed in plant with sowing taken as I FN of June (S_1) (1.53 kg/ha/D°C), over the rest of sowing times which were followed by plant with sowing time of II FN of June (S_2) (1.48 kg/ha/D°C), I FN of July (S_3) (1.28 kg/ha/D°C) and II FN of July (S_4) (1.12 kg/ha/D°C) lowest thermal use efficiency in terms of grain yield observed in plant with sowing taken on II FN of July (S_4) (1.12 kg/ha/D°C). It is proved that there is decrease trend of thermal use efficiency with increase in sowing times. Same trends was observed in biological yield where plant with sowing as I FN of June (S_1) (3.99 kg/ha/D°C) shown highest thermal use efficiency followed by plant with sowing times of II FN of June (S_2) (3.89 kg/ha/D°C), I FN of July (S_3) (3.66 kg/ha/D°C) and II FN of July (S_4) (3.47 kg/ha/D°C).

Thermal use efficiency reduces with late sowing plant and lowest thermal use efficiency observed in plant with sowing done on II FN of July (S_4) (3.47 kg/ha/D°C) for biological yield.

Similar trend was observed during the year 2013, initial sowing times I FN of June (S_1) upto II FN of July (S_4) decreasing trend of thermal use efficiency was found. The highest thermal use efficiency with more grain yield is observed in plant with sowing taken as I FN of June (S_1) (2.12 kg/ha/D°C), over the rest of sowing dates which were followed by plant with sowing time II FN of June (S_2) (2.02 kg/ha/D°C), I FN of July (S_3) (1.83 kg/ha/D°C) and II FN of July (S_4) (1.70 kg/ha/D°C) lowest thermal use efficiency in terms of grain yield observed in plant with sowing taken on II FN of July (S_4) (1.70 kg/ha/D°C). Thermal use efficiency with respect to biological yield was more with II FN of June (S_2) (3.93 kg/ha/D°C), followed by plant with sowing times of I FN of June (S_1) (3.89 kg/ha/D°C), I FN of July (S_3) (3.67 kg/ha/D°C) and II FN of July (S_4) (3.48 kg/ha/D°C). Thermal use efficiency reduces with late sowing plant and lowest thermal use efficiency observed in plant with sowing done on II FN of July (S_4) (3.48 kg/ha/D°C) for biological yield.

Varieties

During the year 2012, in grain yield variety DS-228 (V_3) was observed highest thermal use efficiency i.e. (1.61 kg/ha/D°C) and lowest thermal use efficiency was observed by variety JS 335 (V_1) (1.09 kg/ha/D°C). Whereas, the highest thermal use efficiency was observed in variety DS-228 (V_3) with biological yield (4.07 kg/ha/D°C) while lowest thermal use efficiency has shown by the variety JS-335 (V_1) with biological yield (3.37 kg/ha/D°C). Overall, among the varieties, thermal use efficiency in terms of seed yield and biomass yield was higher with DS-228 (V_3) followed by MACS-450 (V_2) and JS-335 (V_1).

Similar trend was observed during the year 2013, in grain yield variety DS-228 (V_3) was observed highest thermal use efficiency i.e. (1.04 kg/ha/D°C)

Table 38. Thermal use efficiency in terms of seed yield and biological production ($\text{kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}$) as influenced by sowing times and varieties (2012 and 2013)

Varieties	Sowing date									
	S ₁ (I FN of June)		S ₂ (II FN of June)		S ₃ (I FN of July)		S ₄ (II FN of July)		Mean	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
V ₁ (JS-335)	1.24	2.03	1.11	1.91	1.06	1.68	0.97	1.56	1.09	1.79
	3.43	3.77	3.44	3.89	3.36	3.49	3.25	3.30	3.37	3.61
V ₂ (MACS-450)	1.58	2.12	1.64	2.01	1.22	1.84	0.98	1.70	1.35	1.92
	4.13	3.89	4.17	4.03	3.73	3.71	3.35	3.60	3.85	3.81
V ₃ (DS-228)	1.78	2.22	1.70	2.12	1.55	1.97	1.42	1.84	1.61	2.04
	4.40	4.01	4.07	3.86	3.87	3.80	3.80	3.55	4.03	3.81
Mean	1.53	2.12	1.48	2.02	1.28	1.83	1.12	1.70	1.35	1.92
	3.99	3.89	3.89	3.93	3.66	3.67	3.47	3.48	3.75	3.74
<i>Bold figures indicate heat use efficiency in terms of biomass</i>										

Fig. 38 a. Thermal use efficiency in terms of seed yield ($\text{kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}$) at different treatments (2012)

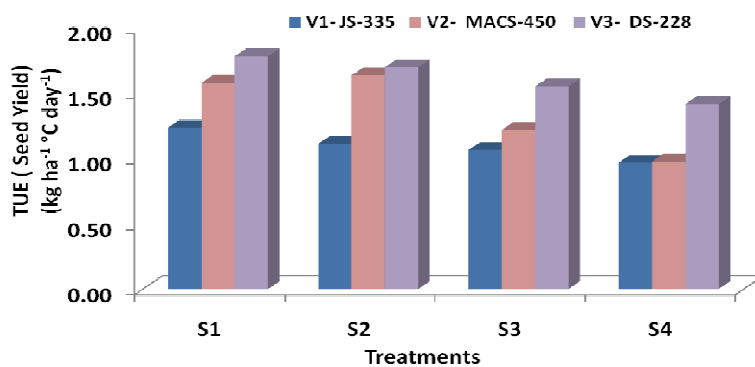


Fig. 38 b. Thermal use efficiency in terms of seed yield ($\text{kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}$) at different treatments (2013)

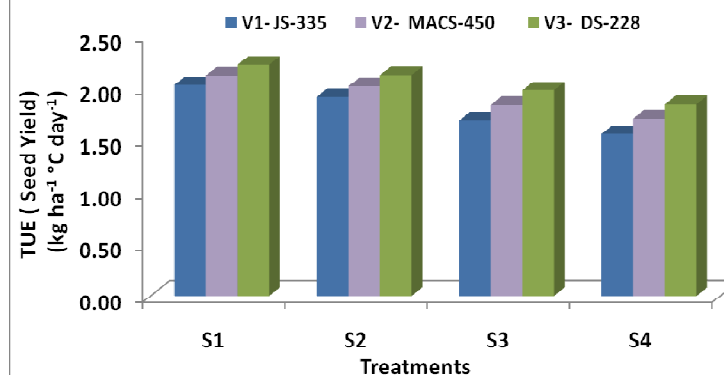


Fig. 38 a. Thermal use efficiency in terms of biological production ($\text{kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}$) at different treatments (2012)

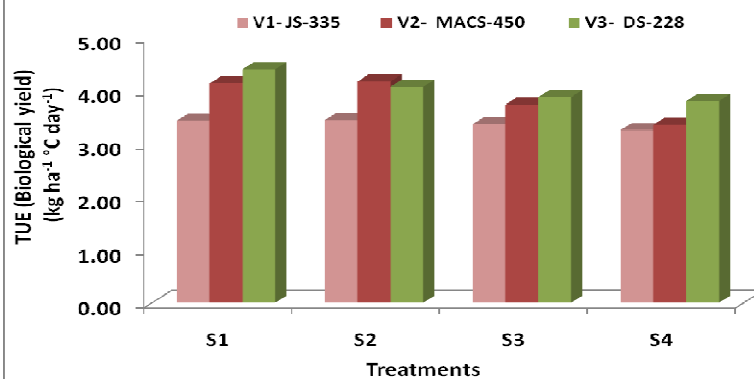
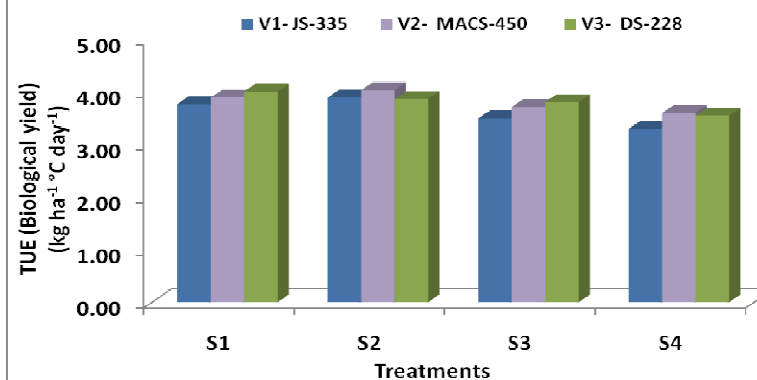


Fig. 38 b. Thermal use efficiency in terms of biological production ($\text{kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}$) at different treatments (2013)



and the lowest thermal use efficiency was observed by variety JS-335 (V_1) (1.79 kg/ha/D°C). Whereas, the highest thermal use efficiency was observed in both Varieties DS-228 (V_3) and MACS-450 (V_2) with biological yield (3.81 kg/ha/D°C) respectively, while lowest thermal use efficiency has shown by the variety JS-335 (V_1) with biological yield (3.61 kg/ha/D°C). Overall, among the varieties, thermal use efficiency in terms of seed yield and biomass yield was higher with DS-228 (V_3) followed by MACS-450 (V_2) and JS-335 (V_1). Similar results were recorded by Balkrishnan and Natrajaratnam (1986), Hundal *et al.* (2003), Jadhao (2009) and Mane (2011).

4.8 Crop model evaluation

The observed data was compared with the model simulation results. The model evaluation is a long term process in which the confidence in the model is enhanced or reduced through a succession of formal and informal tests.

4.8.1 Genetic coefficients

The genetic coefficients for the soybean varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) were determined with the embedded in the DSSAT v 4.5 model using data collected during the experiment. The goodness-of-fit between the predicted and measured variable was examined and the coefficient was decreased (increased), until the fit between the predicted and measured variable is good. To run the model, genetic coefficients are required Varieties wise to distinguish its phasic development uniquely. These genetic coefficients are related to the photothermal days required to attain phenological events and dry matter accumulation. Genetic coefficients are used to simulate the response of various cultivars to weather and management conditions. These coefficients allow the soybean crop growth model to predict differences in development, growth and yield among cultivars when sown in the same environment as well as the differences in the behavior of a single cultivar when sown in different environments. The estimated genetic coefficients of soybean cultivars used in the experimentation are presented in Table 39.

Table 39. Genetic coefficients development for soybean cultivars

Sr. No.	Growth and development aspects of the soybean crop	JS-335 (V₁)	MACS-450 (V₂)	DS-228 (V₃)
1	Critical Short Day Length below which reproductive development progresses with no day length effect (hour)	12.15	12.2	12.19
2	Slope of the relative response of development to photoperiod with time (photothermal days)	0.28	0.38	0.33
3	Time between plant emergence and flower appearance (Photothermal days)	25.3	26.5	26.8
4	Time between first flower and first pod (photothermal days)	8	8	8
5	Time between first flower and first seed (photothermal days)	18	19.3	20.1
6	Time between first seed (R5) and physiological maturity (photothermal days)	32.3	32.66	32.37
7	Time between first flower and end of leaf expansion (days)	20	20	20
8	Maximum leaf photosynthesis rate at 30°C, 350 ppm CO ₂ , and high light	1.03	1.03	1.03
9	Specific leaf area of cultivar under standard growth conditions	385	397	399
10	Maximum fraction of daily growth that is partitioned to seed + shell	1	1	1
11	Maximum weight per seed (g)	0.15	0.14	0.15
12	Seed filling duration for pod cohort at standard growth conditions (photothermal days)	22.8	23.1	24.2
13	Average seed per pod under standard growing conditions (#/pod)	2.2	2.09	2.21
14	Time required for cultivar to reach final pod load under optimal condition (photothermal days)	9	9	9
15	Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity	78	78	78

4.8.2 Phasic development

4.8.2.1 Anthesis day

Data pertaining to anthesis day and first pod day is given in Table 40 and graphically presented in fig. 39 a and b for the years 2012 and 2013. During the year 2012, the observed and predicted mean number of anthesis day was 38 and 37, 39 and 38, and 43 and 42 and the degree of agreement was 0.74, 0.67 and -1.78 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively (Table 40 and fig. 39 a). The percentage error (PE) was 5.65, 2.56 and 3.09, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013 the observed and predicted mean number of anthesis day was 40 and 38; 42 and 40; and 45 and 44 and the degree of agreement was -1.0, -0.45 and 0.79 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 5.00, 4.82 and 2.95, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Therefore, the days for anthesis predicted was well matched with observed days.

4.8.2.2 First pod day

During the year 2012, the observed and predicted mean number of first pod day was 48 and 47, 49 and 48, and 54 and 52 and the degree of agreement was 0.89, 0.88 and -0.56 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively (Table 40 and fig. 39 b). The percentage error (PE) was 2.76, 2.05 and 2.47, respectively, for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. However, for the year 2013-14, the observed and predicted mean number of first pod day was 50 and 48; 51 and 49; and 56 and 54 and the degree of agreement was 0.52, 0.41 and 0.83 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 3.98, 3.11 and 2.83, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. As the PE is less than ten per cent the prediction is acceptable.

Table 40. Error per cent by simulated and observed days to anthesis and first pod (2012 and 2013)												
Cultivar/Date of sowing	Anthesis day						First pod day					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error %	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	39.0	38.0	-2.56	41	39	-4.88	51	49	-3.92	52	50	-3.85
S ₂ (II FN of June)	38.0	37.0	-2.63	41	39	-4.88	48	47	-2.08	52	50	-3.85
S ₃ (I FN of July)	37.0	36.0	-2.70	40	38	-5.00	46	45	-2.17	50	48	-4.00
S ₄ (II FN of July)	37.0	36.0	-2.70	38	36	-5.26	46	45	-2.17	47	45	-4.26
Mean	37.8	36.8	-2.65	40	38	-5.00	48	47	-2.59	50	48	-3.99
SD			0.07			0.18			0.89			0.19
MAE			1.00			2.00			1.25			2.00
MBE			0.00			0.00			0.75			0.00
RMSE			1.00			2.00			1.32			2.00
PE			2.65			5.00			2.76			3.98
D			0.74			-1.00			0.89			0.52
MACS-450 (V₂)												
S ₁ (I FN of June)	40	39	-2.50	42	40	-4.76	50	49	-2.00	52	51	-1.92
S ₂ (II FN of June)	39	38	-2.56	43	41	-4.65	49	48	-2.04	52	50	-3.85
S ₃ (I FN of July)	38	37	-2.63	41	39	-4.88	48	47	-2.08	51	49	-3.92
S ₄ (II FN of July)	39	38	-2.56	40	38	-5.00	48	47	-2.08	48	47	-2.08
Mean	39	38	-2.56	42	40	-4.82	49	48	-2.05	51	49	-2.94
SD			0.05			0.15			0.04			1.09
MAE			1.00			2.00			1.00			1.50
MBE			0.00			0.00			0.00			0.50
RMSE			1.00			2.00			1.00			1.58
PE			2.56			4.82			2.05			3.11
D			0.67			-0.45			0.88			0.41
DS-228 (V₃)												
S ₁ (I FN of June)	44	43	-2.27	46	45	-2.17	56	55	-1.79	57	56	-1.75
S ₂ (II FN of June)	44	42	-4.55	46	45	-2.17	54	53	-1.85	57	56	-1.75
S ₃ (I FN of July)	42	41	-2.38	44	43	-2.27	52	51	-1.92	56	54	-3.57
S ₄ (II FN of July)	41	40	-2.44	43	41	-4.65	52	50	-3.85	53	51	-3.77
Mean	43	42	-2.91	45	44	-2.82	54	52	-2.35	56	54	-2.71
SD			1.09			1.22			1.00			1.11
MAE			1.25			1.25			1.25			1.50
MBE			0.75			0.75			0.75			0.50
RMSE			1.32			1.32			1.32			1.58
PE			3.09			2.95			2.47			2.83
D			-1.78			0.79			-0.56			0.83

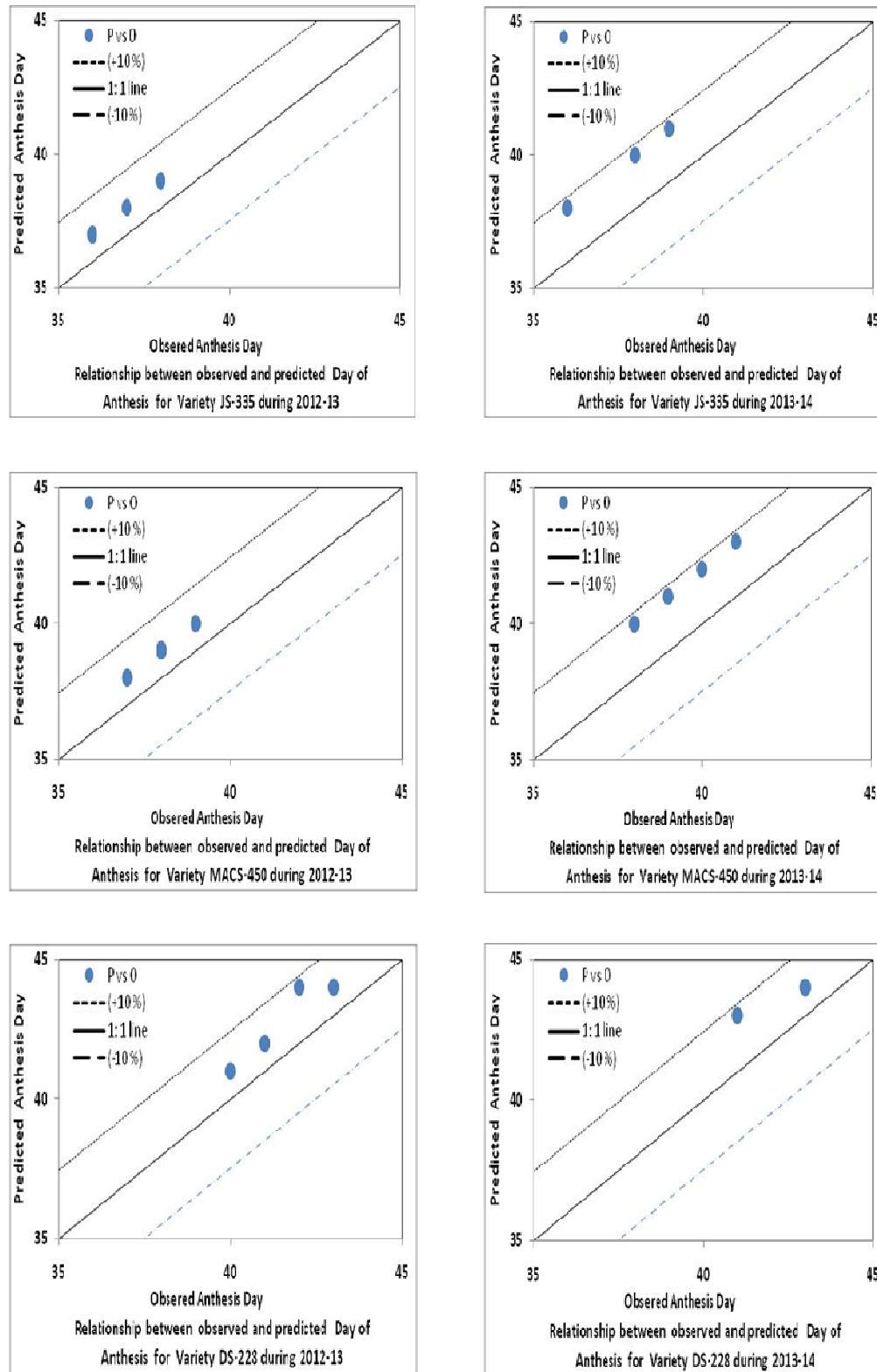


Fig. 39 a. Relationship between observed and predicted day of anthesis (2012 and 2013)

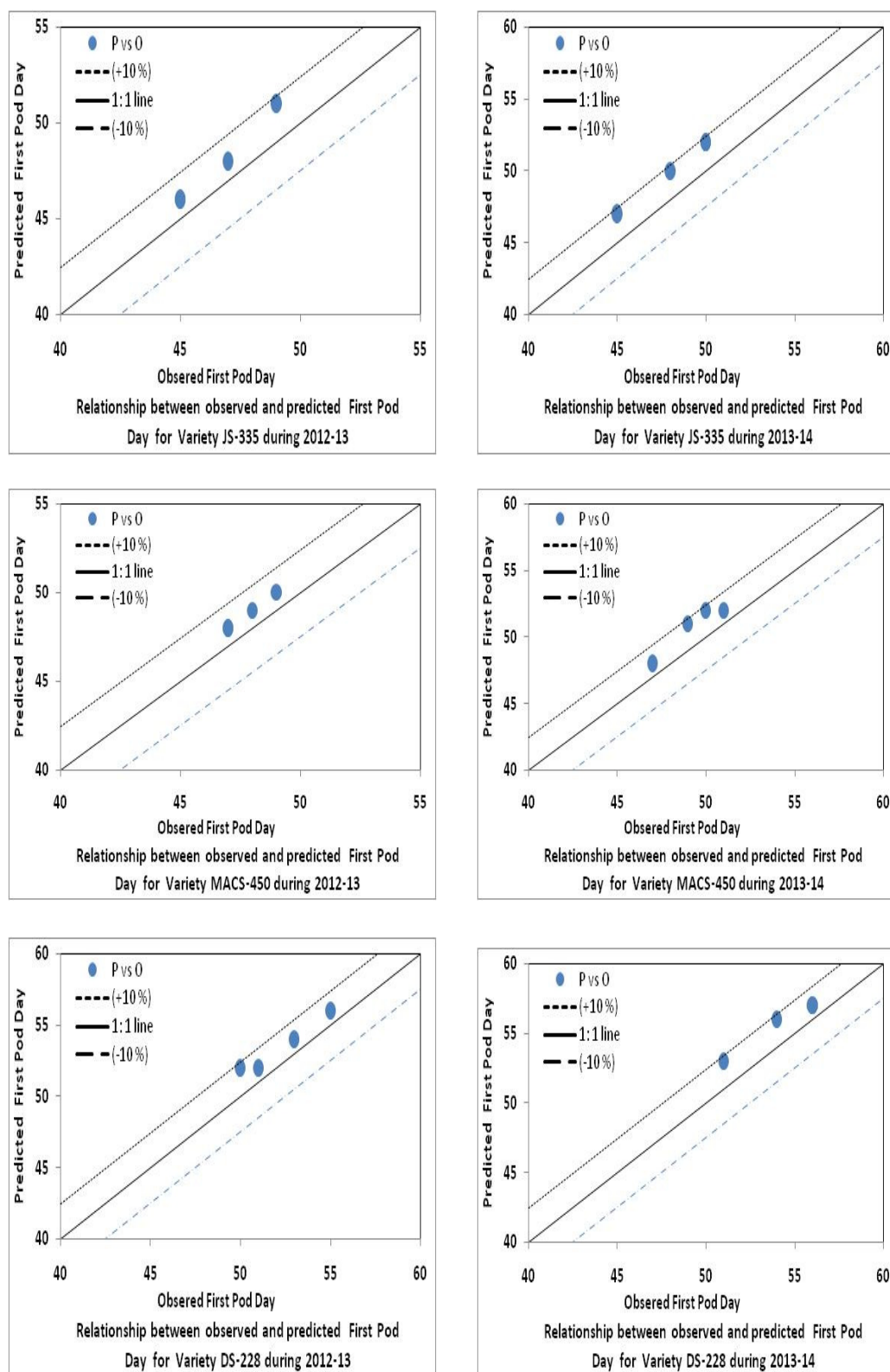


Fig. 39 b. Relationship between observed and predicted first pod day (2012 and 2013)

4.8.2.3 First seed day

Data pertaining to first seed day and physiological maturity is given in Table 41 and graphically presented in fig. 40 a and b for the years 2012 and 2013. During the year 2012, relevant data on first seed day is presented in Table 41 and fig. 40 a. The observed and predicted mean number of first seed day was 61 and 59, 62 and 61, and 70 and 68 and the degree of agreement was 0.72, 0.95 and -0.56 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 3.18, 3.43 and 2.16, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013, relevant data on first seed day, the observed and predicted mean number of first seed day was 63 and 61, 63 and 62, and 71 and 70 and the degree of agreement was 0.85, 0.48 and 1.00 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 2.53, 2.50 and 2.22, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Therefore, the prediction was well matched with observed values.

4.8.2.4 Physiological maturity

The data on physiological maturity is presented in Table 41 and fig 40 b for the years 2012 and 2013. During the year 2012, the observed and predicted mean number of physiological maturity was 95 and 93, 96 and 95, and 105 and 104 and the degree of agreement was 0.36, 0.57 and 1.00 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 1.89, 1.27 and 0.95, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, during the year 2013, relevant data on physiological maturity, the observed and predicted mean number of physiological maturity was 97 and 95, 98 and 97, and 107 and 106 and the degree of agreement was 0.31, 0.77 and 1.00 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 1.94, 1.76 and 1.22, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Therefore, the prediction was well matched with observed values. Since all the growth stages were predicted by the model with percent

Table 41. Error per cent by simulated and observed days to first seed days and physiological maturity (2012 and 2013)

Cultivar/Date of sowing	First seed day						Physiological maturity					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error %	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	63	62	-1.59	65	64	-1.54	99	98	-1.01	99	99	0.00
S ₂ (II FN of June)	61	60	-1.64	64	63	-1.56	96	94	-2.08	98	97	-1.02
S ₃ (I FN of July)	61	58	-4.92	62	60	-3.23	93	91	-2.15	96	94	-2.08
S ₄ (II FN of July)	59	57	-3.39	59	57	-3.39	92	90	-2.17	93	90	-3.23
Mean	61	59	-2.88	63	61	-2.43	95	93	-1.85	97	95	-1.58
SD			1.59			1.02			0.56			1.39
MAE			1.75			1.50			1.75			1.50
MBE			0.25			0.50			0.25			0.50
RMSE			1.94			1.58			1.80			1.87
PE			3.18			2.53			1.89			1.94
D			0.72			0.85			0.36			0.31
MACS-450 (V₂)												
S ₁ (I FN of June)	63	66	4.76	65	64	-1.54	99	99	0.00	101	100	-0.99
S ₂ (II FN of June)	62	61	-1.61	64	63	-1.56	96	95	-1.04	99	98	-1.01
S ₃ (I FN of July)	61	59	-3.28	63	61	-3.17	94	93	-1.06	98	96	-2.04
S ₄ (II FN of July)	61	59	-3.28	61	59	-3.28	96	94	-2.08	95	93	-2.11
Mean	62	61	-0.85	63	62	-2.39	96	95	-1.05	98	97	-1.54
SD			3.82			0.97			0.85			0.62
MAE			0.50			1.50			1.00			1.50
MBE			0.50			0.50			0.00			0.50
RMSE			2.12			1.58			1.22			1.73
PE			3.43			2.50			1.27			1.76
D			0.95			0.48			0.57			0.77
DS-228 (V₃)												
S ₁ (I FN of June)	72	72	0.00	74	73	-1.35	110	110	0.00	112	111	-0.89
S ₂ (II FN of June)	70	69	-1.43	73	72	-1.37	106	105	-0.94	109	108	-0.92
S ₃ (I FN of July)	69	67	-2.90	71	69	-2.82	103	102	-0.97	105	104	-0.95
S ₄ (II FN of July)	67	65	-2.99	67	65	-2.99	101	100	-0.99	101	99	-1.98
Mean	70	68	-1.83	71	70	-2.13	105	104	-0.73	107	106	-1.19
SD			1.41			0.89			0.48			0.53
MAE			1.25			1.50			0.01			0.13
MBE			0.75			0.50			0.99			0.87
RMSE			1.50			1.58			0.01			0.13
PE			2.16			2.22			0.95			1.22
D			-0.56			0.48			1.00			1.00

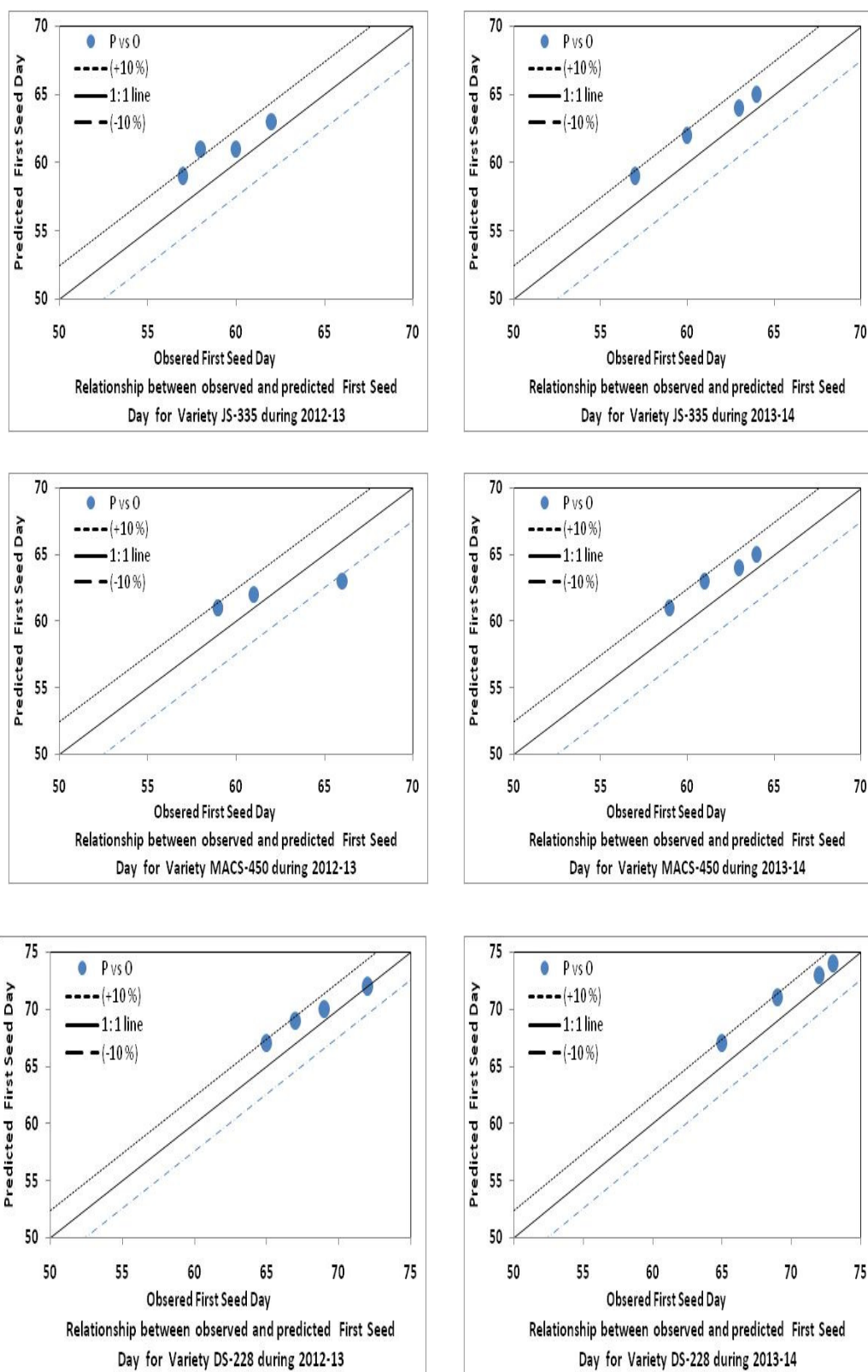


Fig. 40 a. Relationship between observed and predicted first seed day (2012 and 2013)

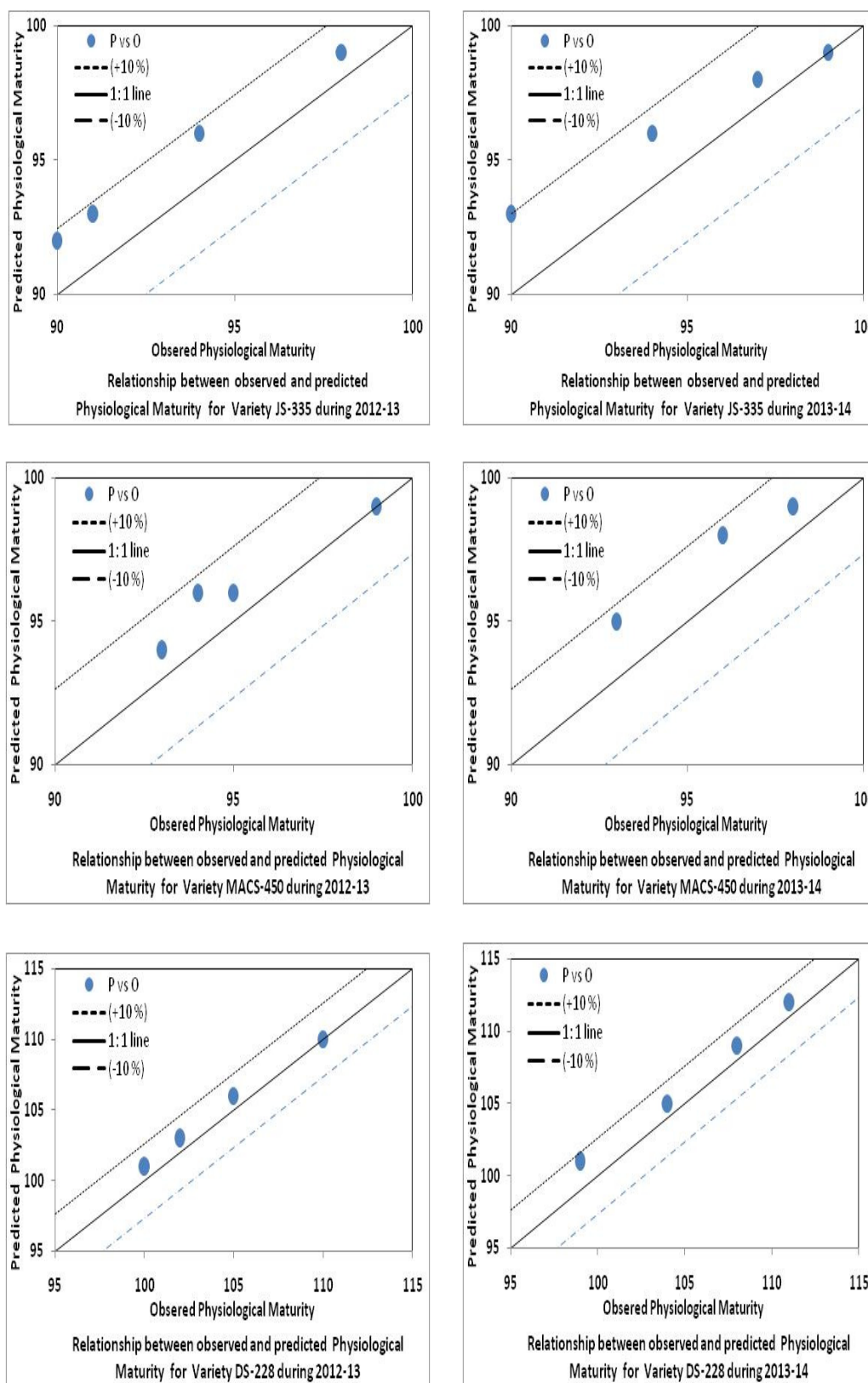


Fig. 40 b. Relationship between observed and predicted physiological maturity (2012 and 2013)

error less than 10%, it can be concluded that phenology was well predicted by the model.

4.8.2.5 Plant height

The data related to plant height expressed in metres (as expressed in the model) is given in Table 42 and graphically presented in fig. 41 a for the years 2012 and 2013. During the year 2012, the observed and predicted mean plant height was 0.54 and 0.64, 0.60 and 0.66, and 0.56 and 0.73 and the degree of agreement was 1.00, 1.00 and 0.99 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 18.39, 9.99 and 30.24, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013, the observed and predicted mean plant height was 0.56 and 0.64; 0.61 and 0.65; and 0.58 and 0.74 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The degree of agreement was 1.00. The percentage error (PE) was 14.99, 6.53 and 27.49, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. Therefore the prediction was slightly overestimated for the Varieties JS-335 (V_1) and DS-228 (V_3) but with less than 10% PE it was well matched with observed values in MACS-450 (V_2).

4.8.2.6 Leaf area index

The relevant data on leaf area index is shown in Table 42 and graphically presented in fig. 41 b for the years 2012 and 2013. During the year 2012, the observed and predicted mean leaf area index was 2.61 and 2.41, 2.97 and 2.36, 2.80 and 3.25 and the degree of agreement was between 1.00, 0.91 and 0.90 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 14.56, 21.19 and 21.41, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. However, for the year 2013, the observed and predicted mean leaf area index was 2.82 and 3.27, 3.15 and 3.55, 3.00 and 4.59 and the degree of agreement was between 0.90, 0.97 and 0.10 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error

Table 42. Error per cent by simulated and observed plant height and leaf area index (2012 and 2013)												
Cultivar/Date of sowing	Plant height (m)						Leaf area index					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error %	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	0.57	0.71	24.51	0.59	0.69	16.95	2.91	2.70	-7.30	3.09	3.90	26.33
S ₂ (II FN of June)	0.57	0.65	13.69	0.59	0.65	10.17	2.77	2.36	-14.72	2.94	3.47	18.20
S ₃ (I FN of July)	0.53	0.61	14.45	0.54	0.61	12.96	2.54	2.86	12.49	2.82	2.99	6.16
S ₄ (II FN of July)	0.50	0.58	16.06	0.52	0.60	15.38	2.22	1.70	-23.25	2.43	2.71	11.43
Mean	0.54	0.64	17.17	0.56	0.64	13.87	2.61	2.41	-8.20	2.82	3.27	15.53
SD			4.99			2.96			15.25			8.72
MAE			-0.09			-0.08			0.20			-0.45
MBE			0.09			0.08			0.80			0.45
RMSE			0.10			0.08			0.38			0.51
PE			18.39			14.29			14.56			18.10
D			1.00			1.00			1.00			0.90
MACS-450 (V₂)												
S ₁ (I FN of June)	0.63	0.72	13.65	0.65	0.69	6.15	3.40	2.87	-15.46	3.64	4.17	14.41
S ₂ (II FN of June)	0.62	0.66	6.97	0.63	0.67	6.35	3.02	2.53	-16.16	3.18	3.69	16.07
S ₃ (I FN of July)	0.60	0.64	7.38	0.59	0.62	5.08	2.95	2.06	-30.28	3.09	3.25	5.03
S ₄ (II FN of July)	0.56	0.61	9.52	0.58	0.61	5.17	2.53	1.99	-21.19	2.69	3.09	14.75
Mean	0.60	0.66	9.38	0.61	0.65	5.69	2.97	2.36	-20.77	3.15	3.55	12.56
SD			3.06			0.65			6.83			5.08
MAE			-0.06			-0.03			0.61			-0.40
MBE			0.06			0.03			0.39			0.40
RMSE			0.06			0.04			0.63			0.42
PE			9.99			6.53			21.19			13.32
D			1.00			1.00			0.91			0.97
DS-228 (V₃)												
S ₁ (I FN of June)	0.61	0.80	30.99	0.63	0.80	26.83	2.98	3.99	34.12	3.20	5.37	68.08
S ₂ (II FN of June)	0.60	0.76	27.09	0.62	0.76	22.98	2.96	3.55	19.83	3.12	4.86	55.78
S ₃ (I FN of July)	0.55	0.71	28.56	0.57	0.70	22.32	2.66	2.91	9.30	2.91	4.29	47.57
S ₄ (II FN of July)	0.49	0.65	33.33	0.51	0.69	35.96	2.61	2.55	-2.35	2.80	3.84	37.25
Mean	0.56	0.73	29.99	0.58	0.74	27.02	2.80	3.25	15.22	3.00	4.59	52.17
SD			2.75			6.28			15.52			13.04
MAE			-0.17			-0.16			-0.45			-1.59
MBE			0.17			0.16			0.45			0.59
RMSE			0.17			0.16			0.60			1.64
PE			30.24			27.49			21.41			54.58
D			0.99			1.00			0.90			0.10

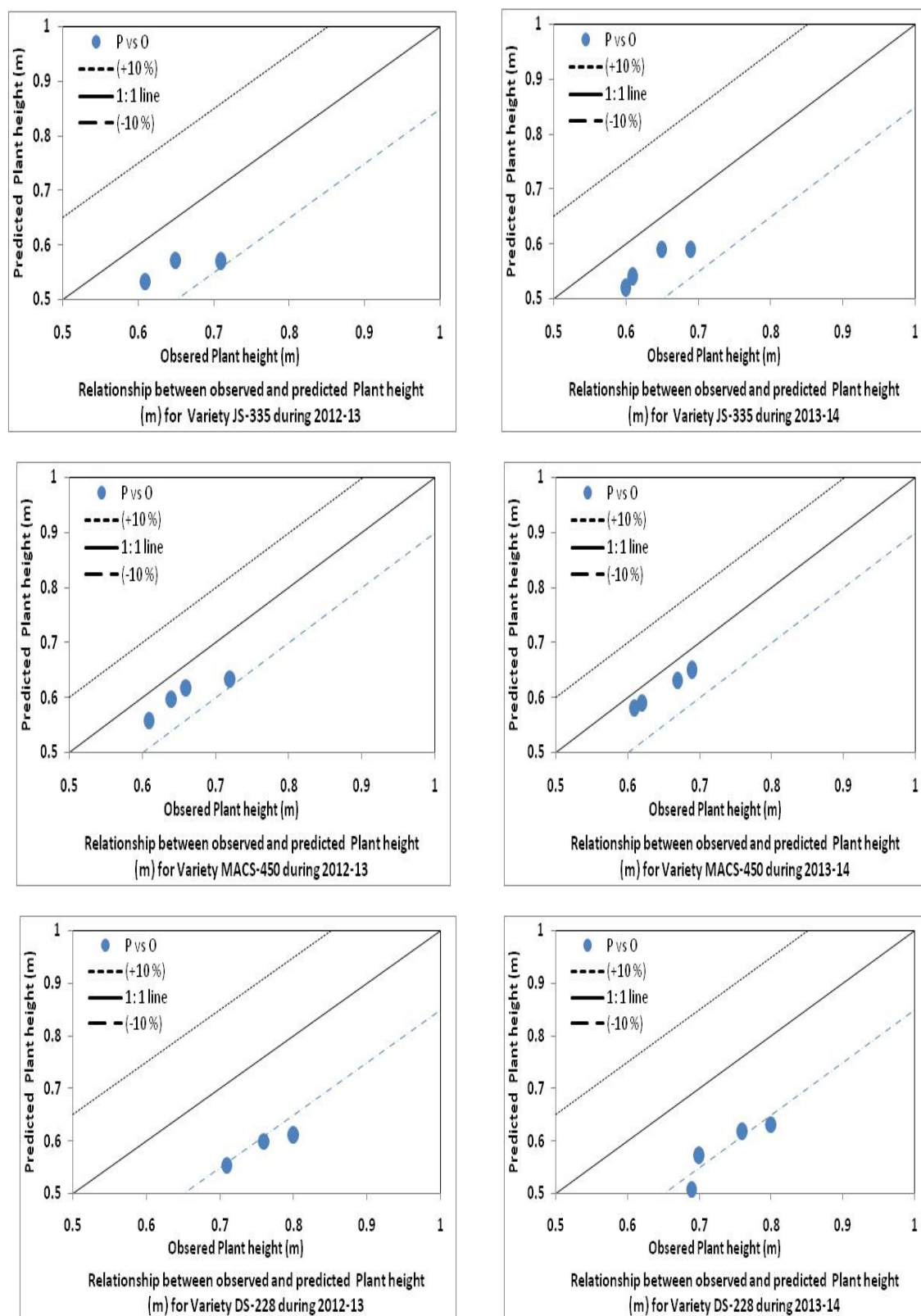


Fig. 41 a. Relationship between observed and predicted plant height (2012 and 2013)

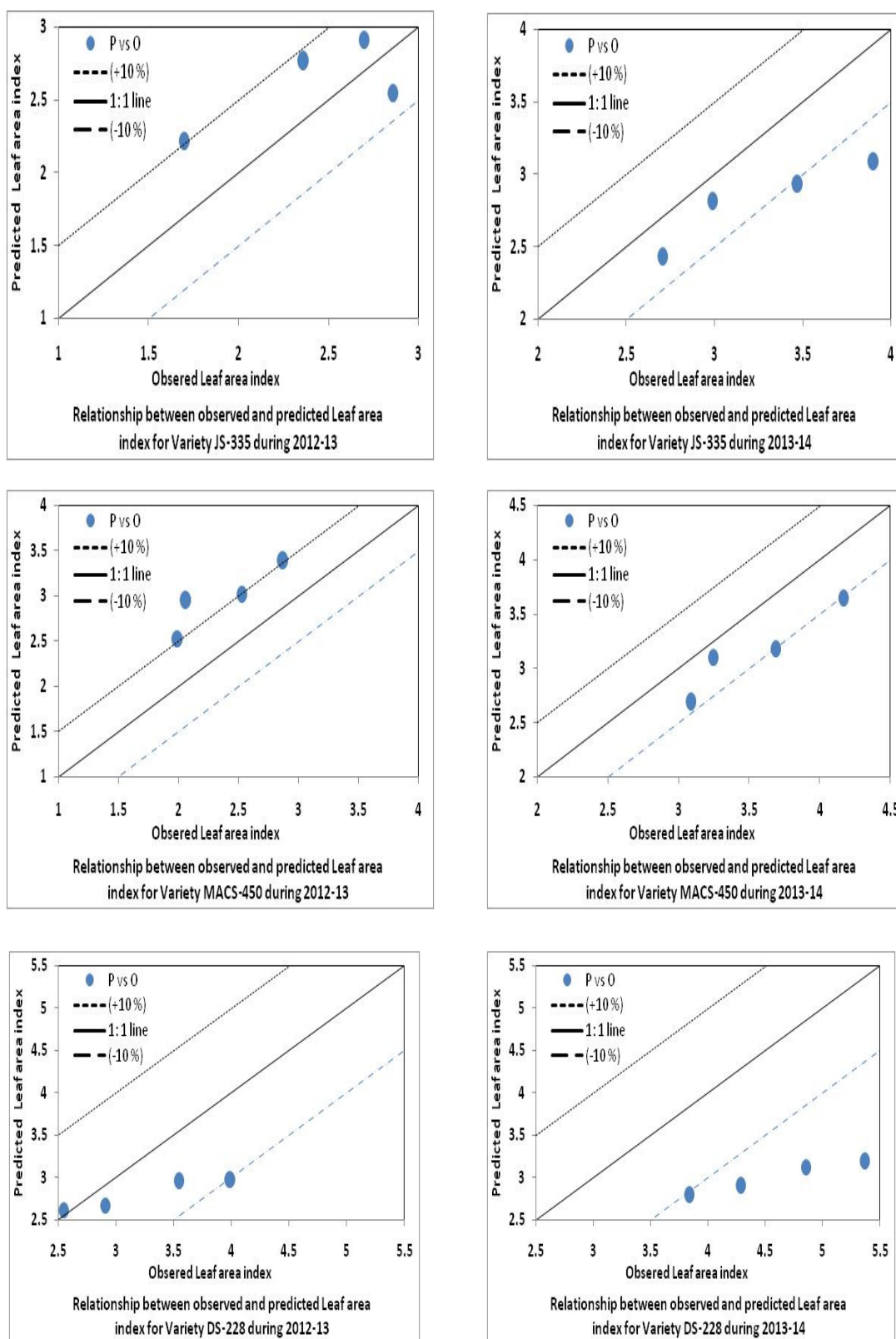


Fig. 41 b. Relationship between observed and predicted leaf area index (2012 and 2013)

(PE) was 18.10, 13.32 and 54.58, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore the prediction was overestimated by all the varieties.

4.8.2.7 Number of seeds pod⁻¹

The data related to number of seeds pod⁻¹ is given in Table 43 and graphically presented in fig. 42 a for the years 2012 and 2013. During the year 2012, the observed and predicted mean number of seeds pod⁻¹ was 2.31 and 2.11, 2.48 and 2.27, and 2.79 and 2.13 and the degree of agreement was 1.00, 1.00 and 0.83 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 15.17, 12.88 and 25.08, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013, the observed and predicted mean number of seeds pod⁻¹ was 2.55 and 2.10, 2.71 and 2.27, and 3.06 and 2.13 and the degree of agreement was 0.99, 0.93 and 0.77 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 20.01, 17.73 and 31.04 respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. Therefore, the prediction was slightly overestimated for the Varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Similar results matched with Anil kumar *et al.* (2008^b) and Singh *et al.* (2010).

4.8.2.8 Seeds per square meter

The relevant data on seeds per square meter is shown in Table 43 and graphically presented in fig. 42 b for the years 2012 and 2013. During the year 2012, the observed and predicted mean seeds per square meter were 2404 and 2443, 2010 and 2028, 2786 and 2824 and the degree of agreement was between 0.88, 0.97 and 0.99 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 2.12, 0.99 and 1.51, respectively, for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. However, for the year 2013, the observed and predicted mean seeds per square meter were 2957 and 3225, 2346 and 2379,

Table 43. Error per cent by simulated and observed seeds per pod and seeds per m² (2012 and 2013)												
Cultivar/Date of sowing	Seeds per pod						Seeds per m²					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error %	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	2.55	2.10	-17.65	2.95	2.10	-28.81	2713	2796	3.06	3215	3249	1.06
S ₂ (II FN of June)	2.60	2.10	-19.23	2.35	2.10	-10.64	2495	2509	0.56	3024	3088	2.12
S ₃ (I FN of July)	1.95	2.10	7.97	2.52	2.10	-16.58	2296	2301	0.22	2994	3047	1.77
S ₄ (II FN of July)	2.13	2.10	-1.52	2.38	2.10	-11.58	2110	2167	1.63	2595	2613	0.69
Mean	2.31	2.11	-7.61	2.55	2.10	-16.90	2403	2443	1.63	2957	2999	1.41
SD			13.11			8.36			1.45			0.65
MAE			0.21			0.45			-0.40			-0.42
MBE			0.79			0.55			0.40			0.42
RMSE			0.35			0.51			0.51			0.46
PE			15.17			20.01			2.12			1.56
D			1.00			0.99			0.88			0.93
MACS-450 (V₂)												
S ₁ (I FN of June)	2.58	2.27	-11.84	2.86	2.27	-20.56	2280	2308	1.23	2379	2402	0.97
S ₂ (II FN of June)	2.80	2.27	-18.93	2.90	2.27	-21.72	1999	2013	0.70	2433	2494	2.51
S ₃ (I FN of July)	2.43	2.27	-6.39	2.67	2.27	-14.98	1959	1961	0.10	2379	2409	1.26
S ₄ (II FN of July)	2.14	2.27	6.20	2.40	2.27	-5.42	1803	1828	1.39	2194	2205	0.50
Mean	2.48	2.27	-7.74	2.71	2.27	-15.67	2010	2028	0.85	2346	2379	1.31
SD			10.6			7.44			0.58			0.86
MAE			0.21			0.44			-17.2			-0.31
MBE			0.79			0.56			0.25			0.31
RMSE			0.32			0.48			0.20			0.36
PE			12.8			17.73			0.99			1.53
D			1.00			0.93			0.97			0.99
DS-228 (V₃)												
S ₁ (I FN of June)	3.10	2.13	-31.29	2.99	2.13	-28.80	2904	2940	1.24	3291	3313	0.67
S ₂ (II FN of June)	2.68	2.13	-20.37	3.38	2.13	-36.89	2805	2868	2.25	3217	3295	2.42
S ₃ (I FN of July)	2.87	2.13	-25.85	3.08	2.13	-30.73	2805	2817	0.43	2928	3056	4.37
S ₄ (II FN of July)	2.52	2.13	-15.39	2.80	2.13	-23.93	2629	2669	1.52	3035	3079	1.45
Mean	2.79	2.13	-23.23	3.06	2.13	-30.09	2786	2824	1.36	3118	3186	2.23
SD			6.87			5.36			0.75			1.60
MAE			0.66			0.93			-37.7			-68.0
MBE			0.34			0.07			0.75			0.00
RMSE			0.70			0.95			0.42			0.79
PE			25.0			31.0			1.51			2.53
D			0.83			0.77			0.99			0.92

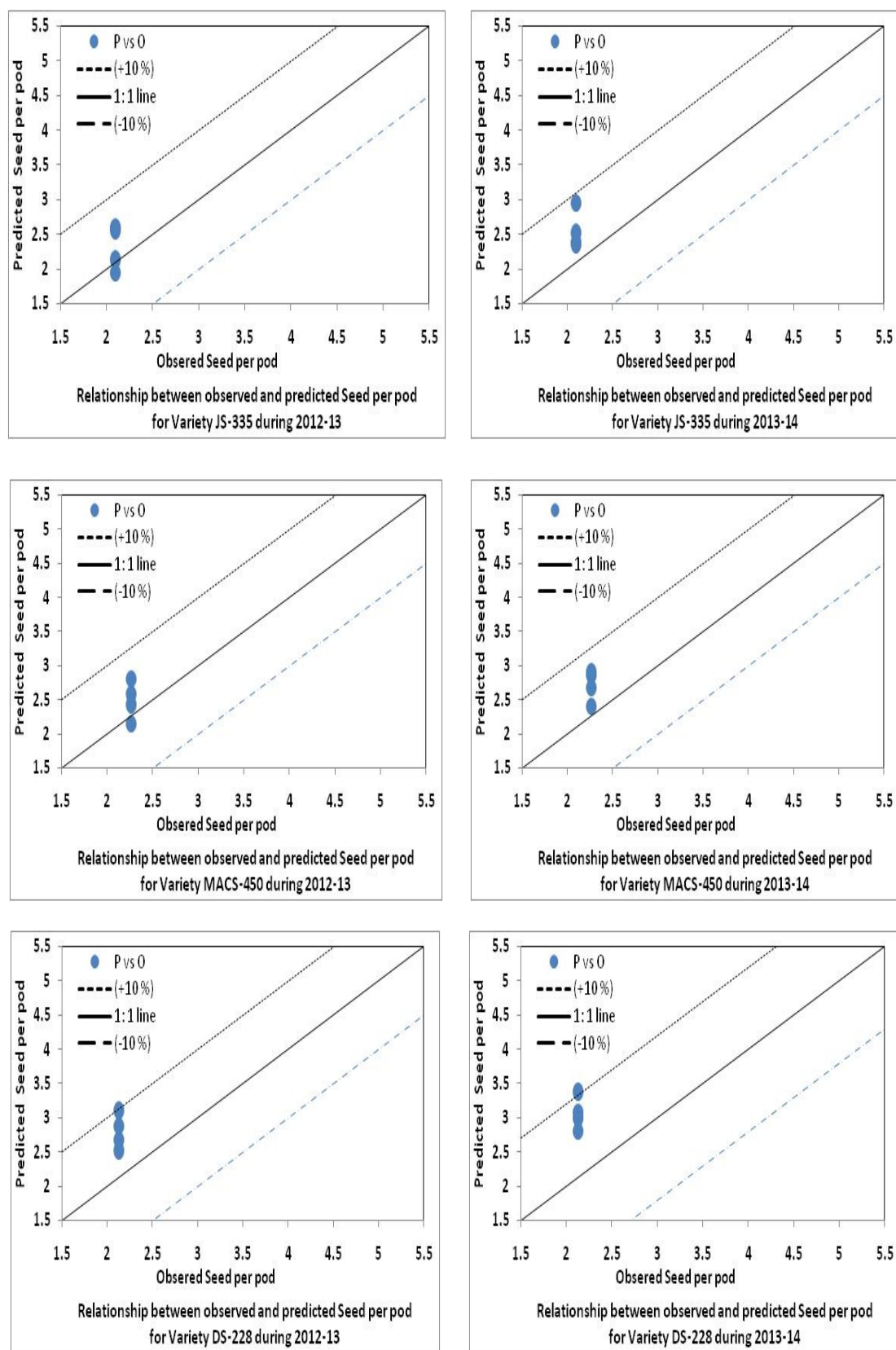


Fig. 42 a. Relationship between observed and predicted seed per pod (2012 and 2013)

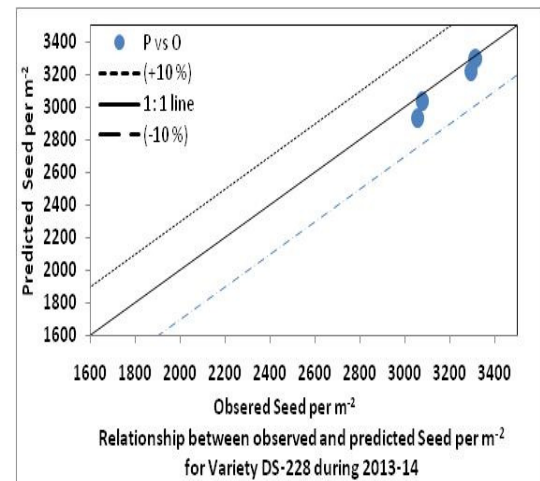
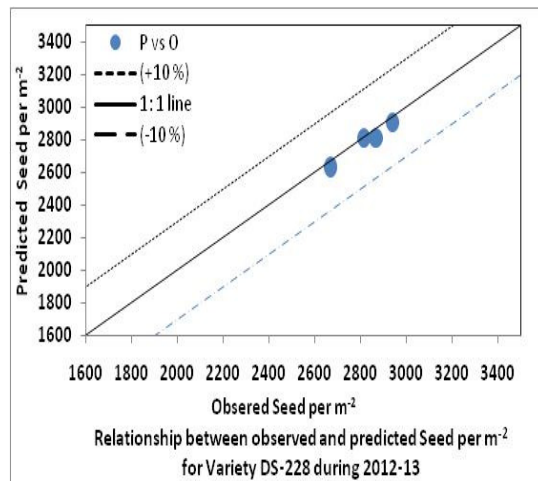
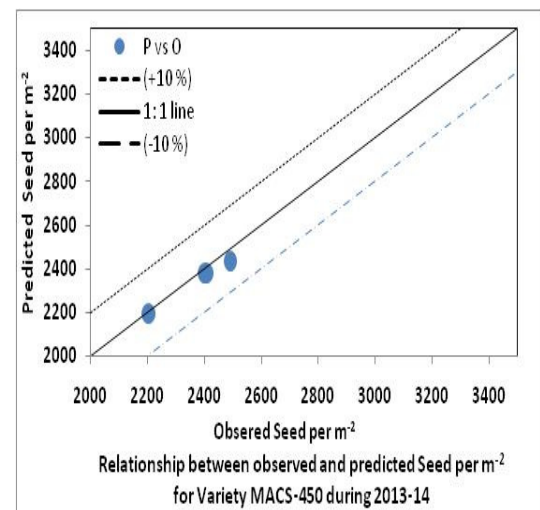
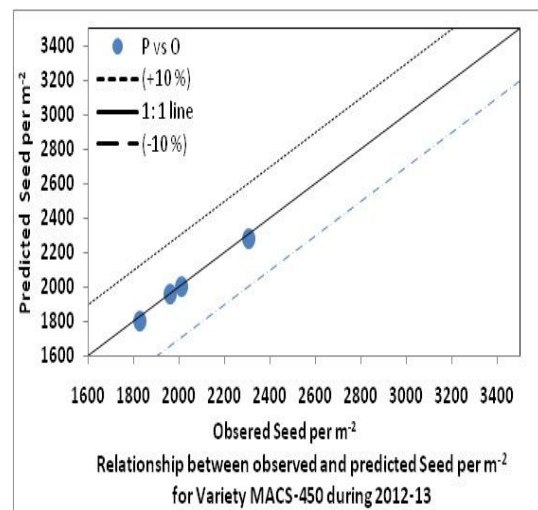
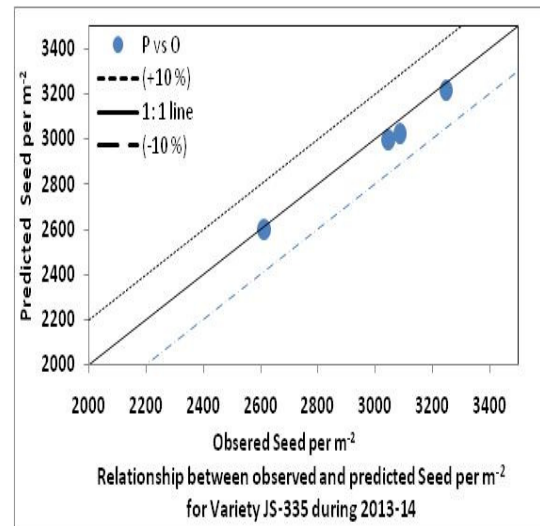
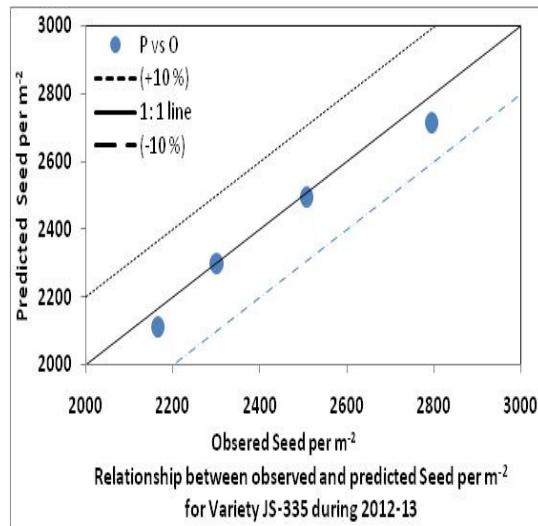


Fig. 42 b. Relationship between observed and predicted seed per square meter (2012 and 2013)

3118 and 3186 and the degree of agreement was between 0.93, 0.99 and 0.92 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 1.56, 1.53 and 2.53, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore the prediction by the model with percent error less than 10%, it can be concluded that seeds per square meter was well predicted by the model for all the varieties.

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

Relevant data on error percent by simulated seed yield from observed are presented in Table 44 and graphically presented in fig. 43 a for the years 2012 and 2013. During the year 2012, the observed and predicted mean seed yield (kg ha^{-1}) was 1538 and 2415 kg ha^{-1} ; 1946 and 2487 kg ha^{-1} ; and 2350 and 2850 kg ha^{-1} and the degree of agreement was -14.16, -2.54 and -2.25 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 57.40, 30.27 and 21.53, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. However, for the year 2013, the observed and predicted mean seed yield (kg ha^{-1}) was 2438 and 2876 kg ha^{-1} ; 2670 and 2991 kg ha^{-1} ; and 2904 and 3199 kg ha^{-1} and the degree of agreement was -4.35, -4.90 and 0.36 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 18.05, 12.28 and 10.23, respectively, for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore the prediction was slightly overestimated by for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Similar results matched with Singh *et al.* (2010).

4.8.2.10 Straw yield (kg ha^{-1})

Error percent by simulated straw yield (expressed as by product in the model) from observed are presented in Table 44 and graphically presented in fig. 43 b for the years 2012 and 2013. During the year 2012, the observed and predicted mean straw yield (kg ha^{-1}) was 3190 and 1952 kg ha^{-1} , 3575 and 2178 kg ha^{-1} , and 3526 and 2415 kg ha^{-1} and the degree of agreement was -8.42, -

26.26 and -33.35 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 40.81, 52.95 and 31.85, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. However, for the year 2013, the observed and predicted mean straw yield (kg ha^{-1}) was 2471 and 2065 kg ha^{-1} , 2631 and 2020 kg ha^{-1} , and 2514 and 2778 kg ha^{-1} and the degree of agreement was -1.53, -3.05 and 0.53 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 19.30, 25.01 and 15.32, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) across different sowing management. Therefore the prediction was slightly overestimated by for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3). Similar results match with Singh *et al.* (2010).

4.8.2.11 Threshing percentage

Data as regards the error percent by simulated threshing percentage from observed are presented in Table 45 and graphically presented in fig. 44 a for the years 2012 and 2013. During the year 2012, the observed and predicted mean threshing percentage was 68.32 and 68.49, 70.96 and 71.91 and 65.65 and 66.05 and the degree of agreement was 0.99, 0.80 and 0.95 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 1.58, 1.58 and 3.15, respectively, for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013, the observed and predicted mean threshing percentage was 72.82 and 69.45, 71.99 and 72.87, and 68.26 and 66.99 and the degree of agreement was -0.75, 0.96 and 0.05 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 5.00, 2.08 and 1.93, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. Therefore the prediction was well matched with observed values for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) of both the years.

Table 44. Error per cent by simulated and observed seed yield and straw yield (2012 and 2013)

Cultivar/Date of sowing	Seed Yield						Straw Yield					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error%	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	1807	2759	52.73	2776	3167	14.07	3210	2157	-32.81	2387	2400	0.57
S ₂ (II FN of June)	1570	2547	62.28	2567	2966	15.56	3287	1780	-45.84	2660	2200	-17.30
S ₃ (I FN of July)	1470	2349	59.77	2303	2770	20.26	3177	2500	-21.30	2477	1920	-22.48
S ₄ (II FN of July)	1307	2005	53.40	2106	2600	23.46	3087	1370	-55.62	2362	1740	-26.34
Mean	1538	2415	57.05	2438	2876	18.34	3190	1952	-38.89	2471	2065	-16.39
SD			4.72			4.31			14.99			11.89
MAE			-8.77			-4.38			12.38			4.06
MBE			0.77			0.38			0.62			0.94
RMSE			8.83			4.40			13.02			4.77
PE			57.4			18.0			40.81			19.30
D			-14.1			-4.35			-8.42			-1.53
MACS-450 (V₂)												
S ₁ (I FN of June)	2355	2824	19.94	2973	3241	9.02	3814	2070	-45.72	2489	2270	-8.78
S ₂ (II FN of June)	2359	2619	11.02	2771	3036	9.56	3652	1730	-52.63	2777	2180	-21.49
S ₃ (I FN of July)	1722	2250	30.66	2575	2891	12.28	3552	1520	-57.21	2627	1850	-29.58
S ₄ (II FN of July)	1348	2253	67.11	2363	2796	18.34	3283	1420	-56.74	2633	1780	-32.39
Mean	1946	2487	32.18	2670	2991	12.30	3575	2178	-53.07	2631	2020	-23.06
SD			24.63			4.27			5.32			10.58
MAE			-5.41			-3.21			18.90			6.11
MBE			0.41			0.21			0.10			0.89
RMSE			5.89			3.28			18.93			6.58
PE			30.2			12.2			52.95			25.01
D			-2.54			-4.90			-26.26			-3.05
DS-228 (V₃)												
S ₁ (I FN of June)	2700	3307	22.50	3188	3426	7.47	3961	2830	-28.55	2561	3140	22.60
S ₂ (II FN of June)	2487	3014	21.19	2984	3293	10.35	3470	2560	-26.20	2453	2960	20.67
S ₃ (I FN of July)	2225	2633	18.32	2828	3170	12.07	3328	2290	-31.19	2620	2590	-1.13
S ₄ (II FN of July)	1987	2446	23.10	2615	2907	11.16	3346	1980	-40.81	2421	2420	-0.02
Mean	2350	2850	21.28	2904	3199	10.26	3526	2415	-31.69	2514	2778	10.53
SD			2.13			1.99			6.41			12.85
MAE			-5.00			-2.95			11.11			-2.64
MBE			0.00			0.95			0.89			0.64
RMSE			5.06			2.97			11.23			3.85
PE			21.5			10.2			31.85			15.32
D			-2.25			0.36			-33.35			0.53

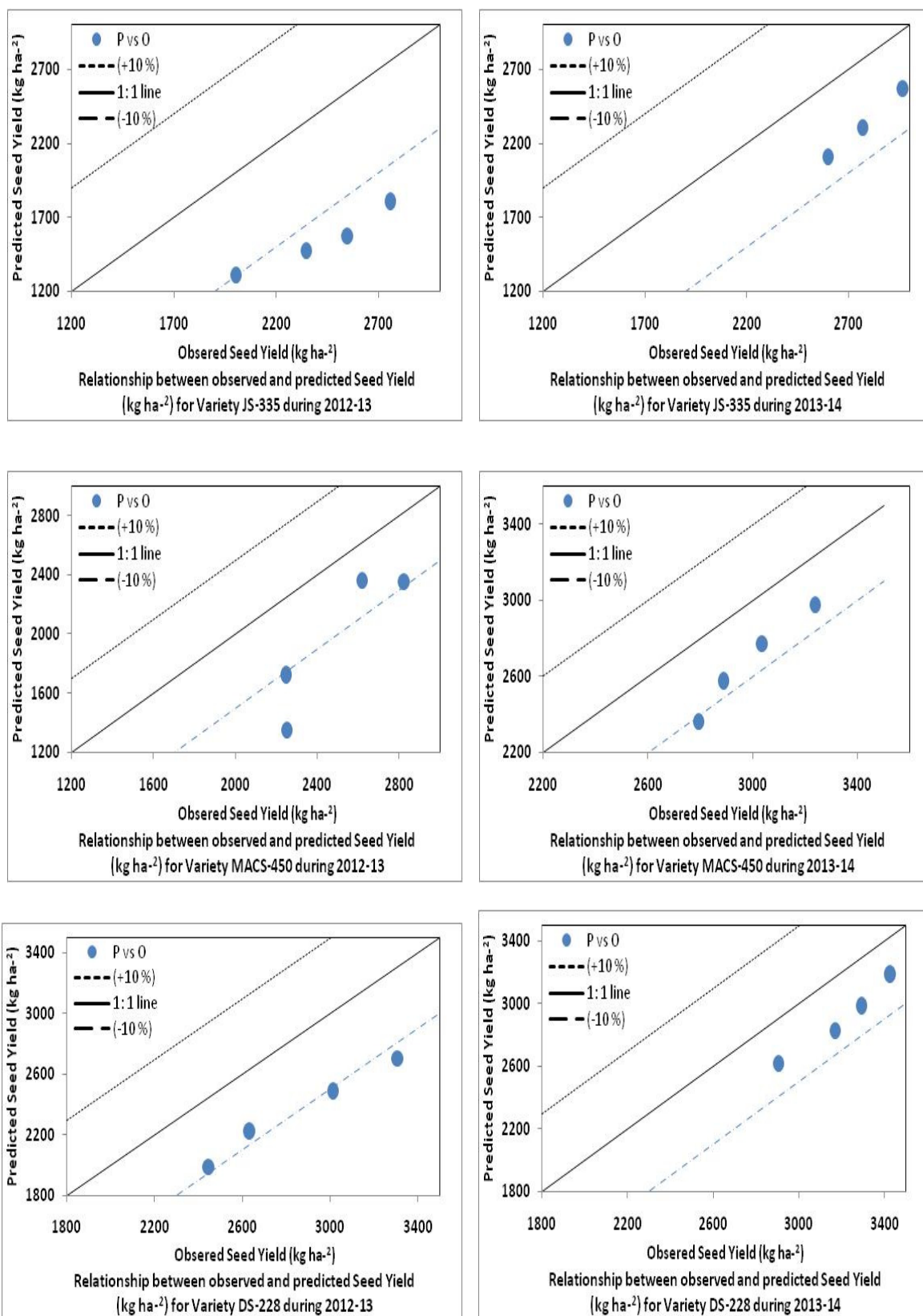


Fig. 43 a. Relationship between observed and predicted seed yield (2012 and 2013)

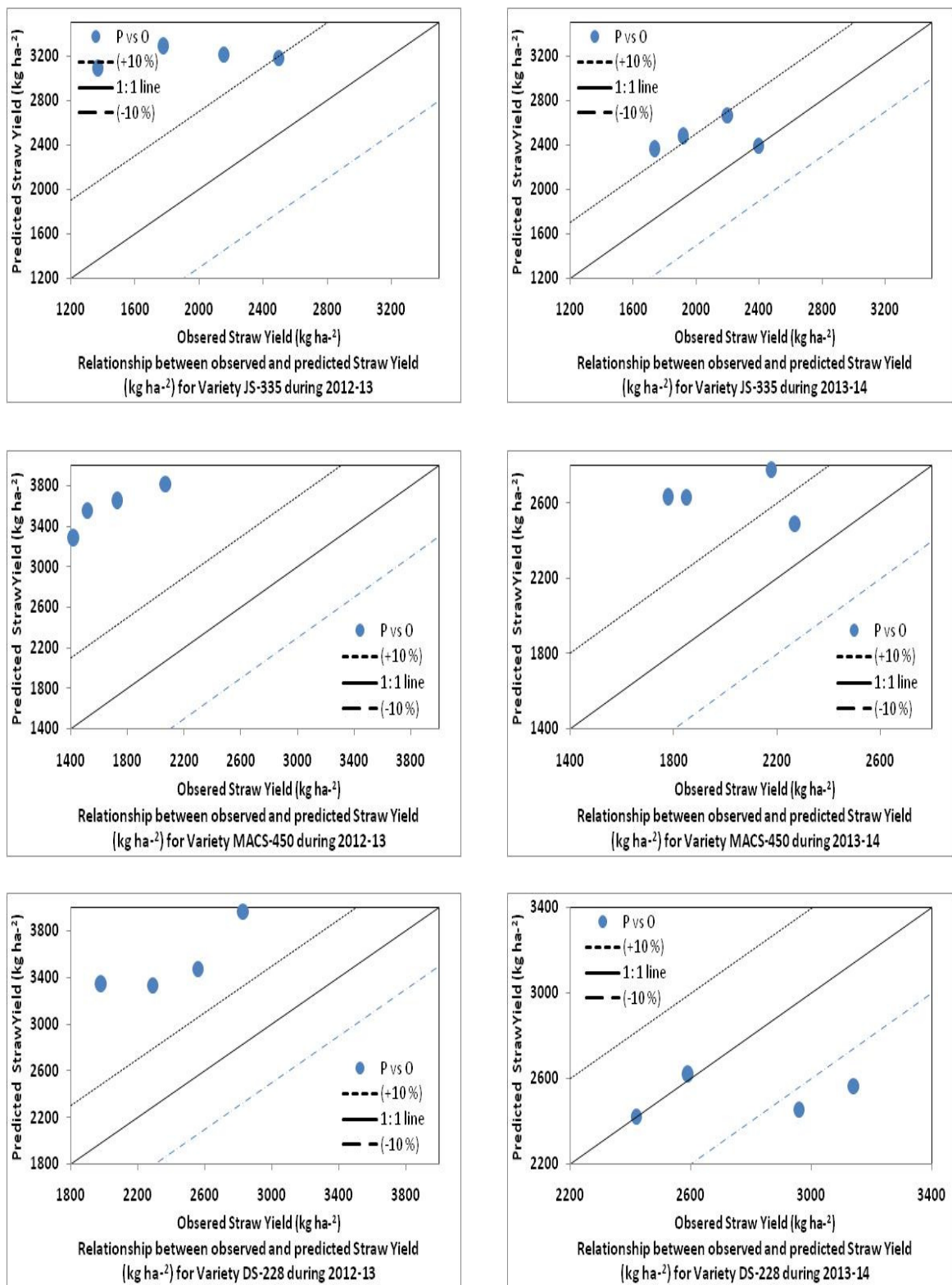


Fig. 43 b. Relationship between observed and predicted straw yield (2012 and 2013)

4.8.2.12 Harvest index

Data as regards the error percent by simulated harvest index yield from observed are presented in Table 45 and graphically presented in fig. 44 b for the years 2012 and 2013. During the year 2012, the observed and predicted mean harvest index was 0.32 and 0.57, 0.35 and 0.59, and 0.40 and 0.53 and the degree of agreement was 0.98, 0.98 and 0.99 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 80.16, 71.86 and 35.10, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. However, for the year 2013, the observed and predicted mean harvest index was 0.50 and 0.57, 0.50 and 0.59, and 0.54 and 0.53 and the degree of agreement was 1.00 for the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), respectively. The percentage error (PE) was 18.11, 19.81 and 5.59, respectively for JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3), across different sowing management. Therefore the prediction was slightly overestimated for the varieties JS-335 (V_1) and MACS-450 (V_2) but with less than 10% PE it was well matched with observed values in DS-228 (V_3).

Therefore the prediction with less than 10% PE was well matched with observed values in all the varieties across different sowing management. The model is capable of predicting the seed yield and harvest index reliably in the cultivars DS-228 (V_3) and MACS-450 (V_2). Seed yield was slightly overestimated in JS-335 (V_1) and MACS-450 (V_2).

The evaluation of the model on an overall basis revealed that the model simulation performance in respect of phenological phases was found to be highly reliable. Plant height and LAI was found to be slightly overestimated except that plant height prediction was well matched for MACS-450 (V_2). By and large the model performance for the years 2012 and 2013 was found good during *kharif* season for soybean crop under Pune location.

Table 45. Error per cent by simulated and observed threshing per cent and harvest index (2012 and 2013)

Cultivar/Date of sowing	Threshing (%)						Harvest index (%)					
	2012			2013			2012			2013		
	O	P	Error %	O	P	Error %	O	P	Error %	O	P	Error %
JS-335 (V₁)												
S ₁ (I FN of June)	66.87	68.13	1.88	71.33	69.00	-3.27	0.36	0.56	55.22	0.54	0.56	3.96
S ₂ (II FN of June)	71.91	70.31	-2.23	74.68	69.00	-7.61	0.32	0.58	78.88	0.49	0.57	15.88
S ₃ (I FN of July)	66.07	66.68	0.92	72.43	70.12	-3.19	0.32	0.58	83.35	0.48	0.59	22.05
S ₄ (II FN of July)	68.41	68.82	0.60	72.86	69.69	-4.35	0.30	0.59	99.34	0.47	0.59	24.64
Mean	68.32	68.49	0.30	72.83	69.45	-4.60	0.32	0.58	79.20	0.50	0.58	16.63
SD			1.77			2.07			18.24			9.21
MAE			-0.17			3.37			-0.25			-0.08
MBE			0.17			0.63			0.25			0.08
RMSE			1.08			3.64			0.26			0.09
PE			1.58			5.00			80.16			18.11
D			0.99			-0.75			0.98			1.00
MACS-450 (V₂)												
S ₁ (I FN of June)	70.84	71.19	0.49	73.81	72.67	-1.54	0.38	0.57	49.25	0.55	0.58	6.04
S ₂ (II FN of June)	72.78	73.24	0.63	69.83	71.98	3.08	0.39	0.60	52.83	0.50	0.58	15.71
S ₃ (I FN of July)	68.62	70.44	2.65	72.43	73.60	1.62	0.33	0.59	80.43	0.50	0.60	20.79
S ₄ (II FN of July)	71.58	72.76	1.65	71.89	73.21	1.84	0.29	0.61	110.3	0.47	0.61	28.58
Mean	70.96	71.91	1.36	71.99	72.87	1.25	0.35	0.59	73.21	0.50	0.59	17.78
SD			1.01			1.97			28.41			9.45
MAE			-0.95			-0.88			-0.24			-0.09
MBE			0.95			0.88			0.24			0.09
RMSE			1.12			1.50			0.25			0.10
PE			1.58			2.08			71.86			19.81
D			0.80			0.96			0.98			1.00
DS-228 (V₃)												
S ₁ (I FN of June)	69.07	67.74	-1.93	67.74	66.24	-2.21	0.41	0.53	30.80	0.55	0.52	-6.24
S ₂ (II FN of June)	63.51	66.43	4.60	67.71	66.94	-1.14	0.42	0.54	29.39	0.55	0.52	-5.43
S ₃ (I FN of July)	62.45	64.29	2.95	69.78	68.18	-2.29	0.40	0.53	32.48	0.52	0.55	5.59
S ₄ (II FN of July)	67.57	65.72	-2.74	67.98	66.62	-2.00	0.37	0.55	47.53	0.52	0.54	3.73
Mean	65.65	66.05	0.72	68.30	67.00	-1.91	0.40	0.54	35.05	0.54	0.53	-0.59
SD			3.60			0.53			8.41			6.12
MAE			-0.40			1.31			-0.14			0.00
MBE			0.40			0.69			0.14			1.00
RMSE			2.07			1.35			0.14			0.03
PE			3.15			1.98			35.10			5.59
D			0.95			0.05			0.99			1.00

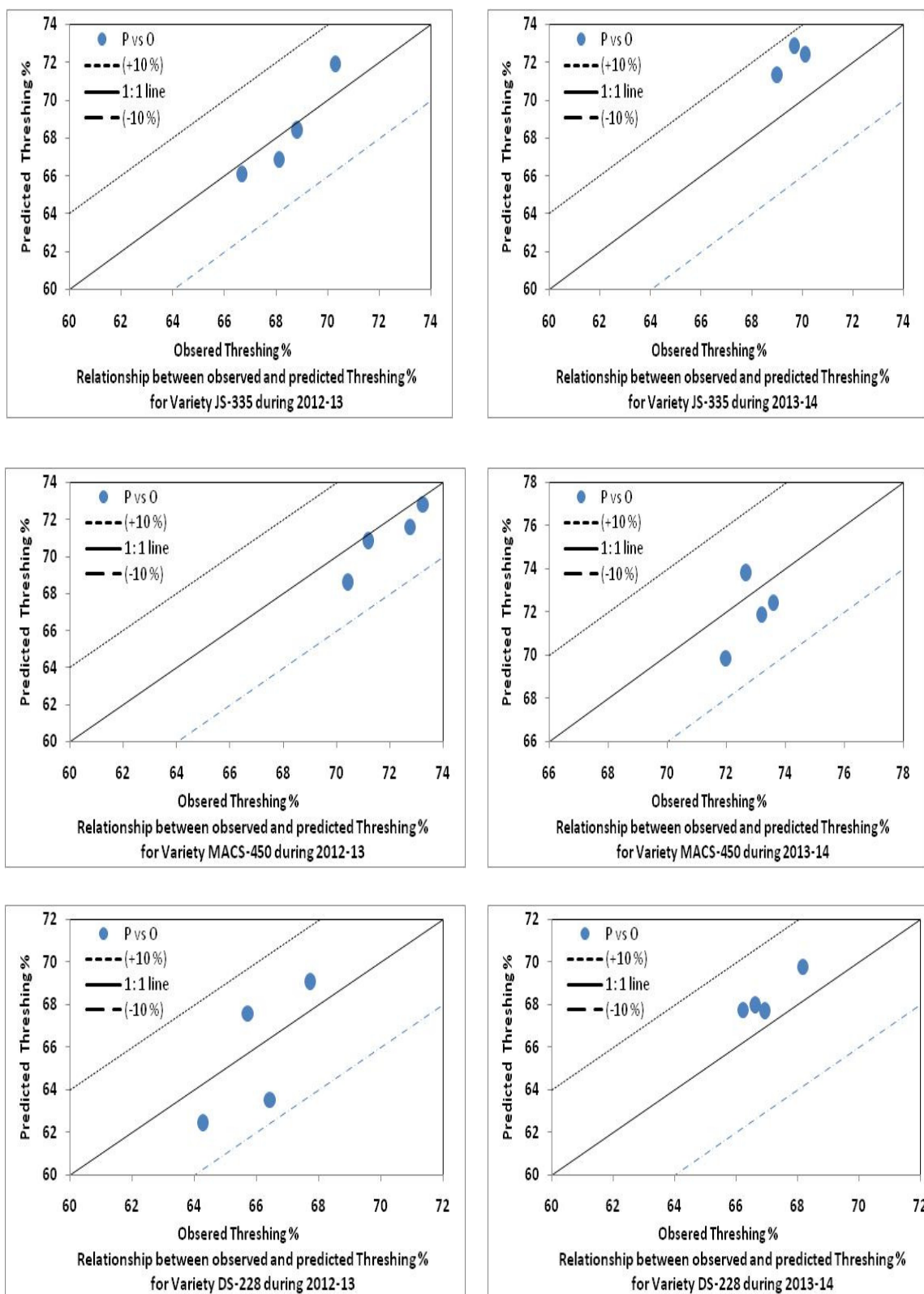


Fig. 44 a. Relationship between observed and predicted threshing % (2012 and 2013)

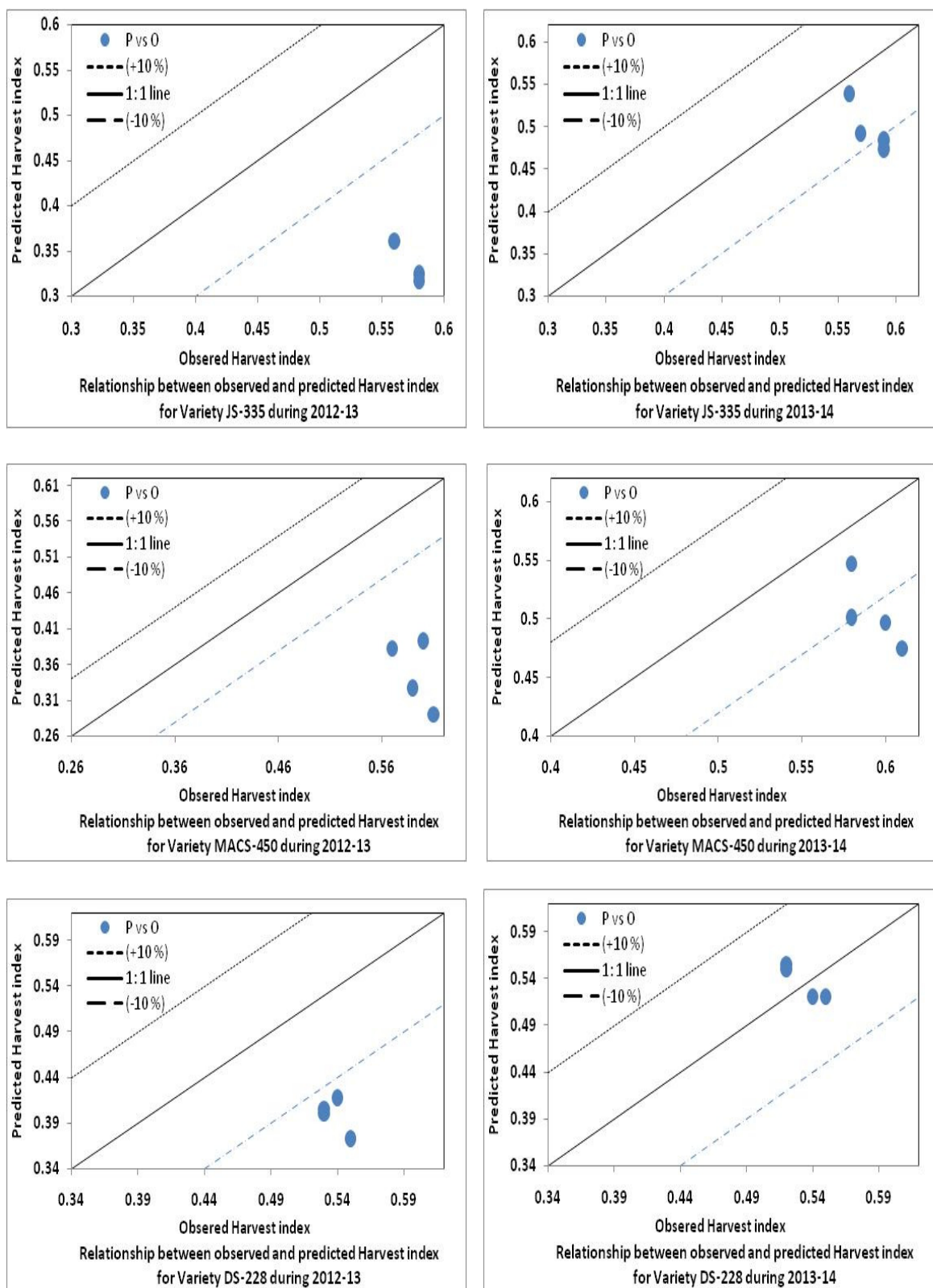


Fig. 44 b. Relationship between observed and predicted harvest index (2012 and 2013)

4.9. Pest population dynamics

The data on seasonal incidence of leaf defoliators of soybean on three varieties sown during different dates was recorded. The influence of defoliator abundance on the activity of natural enemies in soybean ecosystem is elucidated.

4.9.1 Seasonal incidence of major pests on soybean

The study was conducted during both the years of *kharif* season (2012 and 2013). During the course of study the incidence of three major pests were recorded on soybean crop were sown at different dates with three varieties as per the procedure mentioned in “Material and Methods”.

4.9.1.1 Defoliators

During the course of study, two insect *viz.* Semilooper and Girdle beetle were recorded as major pests associated with soybean crop.

Semilooper larvae

During the year 2012 (Table 46), the early instar larvae of semilooper, feed on leaves by scratching the green matter and grown up larvae consume entire leaves leaving behind only the midribs and veins. This pest was noticed defoliating from vegetative stage of the crop.

The incidence of semilooper was recorded all varieties during the year 2012 (Table 46), across all the dates of sowing. During the sowing I FN of June (S_1) with the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) the incidence of semilooper was in the ranged of 0.13-1.38, 0.12-1.02 and 0.02-0.98 larvae/mrl with a peak in 37 SMW with 1.38, 1.02 and 0.98 larvae/mrl, respectively, which was less than late sowings similar results reported by Meena and Sharma (2006).

Similarly it is evident from the data that there was clear cut difference in population of girdle beetle infested plants in soybean crop in different dates of sowing. The infestation activity of girdle beetle increased during the I FN of June

(S₁) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) abundance ranged between 0.05-0.94, 0.02-0.39 and 0.02-0.24 grubs/mrl and it attained its peak in 37 SMW with 0.94, 0.39 and 0.24 grubs/mrl, respectively.

Sowing II FN of June (S₂) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) the incidence of semilooper was in the ranged of 0.31-2.82, 0.11-1.85 and 0.22-1.97 larvae/mrl, and it recorded peak in 37, 39 and 35 SMW with 2.82, 1.85 and 1.97 larvae/mrl, respectively. Similarly, the activity of girdle beetle increased with peak density of the crop during the II FN of June (S₂) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) ranged between 0.11-0.61, 0.12-0.72 and 0.10-0.65 grubs/mrl and it attained its peak in 37, 35 and 35 SMW with 0.61, 1.85 and 0.65 grubs/mrl, respectively. Similar result reported by Negoyen Phi-Dieu Hoyen (2001)

Sowing I FN of July (S₃) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) the incidence of semilooper was ranged between 0.09-1.01, 0.12-2.01 and 0.12-2.91 larvae/mrl and it attained its peak in 39, 36 and 38 SMW with 1.01, 2.01 and 2.91 larvae/mrl, respectively. Similarly, the activity of girdle beetle during the I FN of July (S₃) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) was ranged between 0.07-0.86, 0.14-0.71 and 0.12-1.69 grubs/mrl and it attained its peak in 37, 38 and 39 SMW with 0.86, 0.71 and 1.69 grubs/mrl, respectively.

Sowing II FN of July (S₄) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) the incidence of semilooper was ranged between 0.22-1.98, 0.11-1.17 and 0.18-1.91 larvae/mrl and it attained its peak in 39, 41 and 40 SMW with 1.98, 1.17 and 1.91 larvae/mrl, respectively. Similar result reported by Didonet *et al.* (1998). Similarly the activity of girdle beetle increased during II FN of July (S₄) and was in the ranged of 0.12-0.57, 0.01-0.87 and 0.08-0.55 grubs/mrl. Peak, girdle beetle abundance was recorded in 41, 42 and 40 SMW with 0.57, 0.87 and 0.55 grubs/mrl, respectively.

Early sowing on I FN of June (S_1) recorded lower incidence of semilooper (0.26 to 0.51 larvae/mrl) whereas, crop sown on II FN of June (S_2) recorded the maximum incidence (1.12 to 1.95 larvae/mrl). Similar result were reported by Kamala (2000) and Sastawa (2004)

Present findings are in agreement with that of Harish (2008) who reported higher incidence of *T. orichalcea* on crop sown during I FN of June (S_1) (3.27 larvae/mrl) and late sown crop I FN July (S_3) recorded the maximum incidence of 4.80 larvae/mrl at Dharwad .

During the year 2013 two major pests were observed viz. semilooper and *S. litura* (Table 47). This pest was noticed defoliating at vegetative stage of the crop.

The incidence of semilooper was recorded in crop sown during all the dates of sowing and varieties. Sowing I FN of June (S_1) with the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) the incidence of semilooper was ranged between 0.18-1.80, 0.22-1.30 and 0.23-1.32 larvae/mrl with a peak in 37 SMW with 1.80, 1.30 and 1.32 larvae/mrl, respectively. Similar result reported by Madrap *et al* (2007). Similarly, the activity of the population of *S. litura* increased with peak density of the crop during the I FN of June (S_1) with the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) ranged between 0.11-1.40, 0.09-1.42 and 0.10-1.40 larvae per meter row length (larvae/mrl) and it attained its peak also in 35 SMW with 1.40, 1.42 and 1.40 larvae/mrl, respectively.

Sowing II FN of June (S_2) with the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) the incidence of semilooper and *S. litura* was recorded in crop sown during all the dates of sowing and varieties. During the sowing II FN of June (S_2) with the varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) the incidence of semilooper was in the ranged of 0.71-2.92, 0.81-2.72 and 0.92-2.97 larvae/mrl with its peak in 37 SMW with 2.92, 2.72 and 2.97 larvae/mrl, respectively. Similarly the activity of the population of *S. litura* increased with peak density of the crop during the I FN of June (S_1) with the varieties JS-335

(V₁), MACS-450 (V₂) and DS-228 (V₃) with its ranged of 0.20-1.22, 0.12-1.42 and 0.19-1.52 (larvae/mrl) and it attained its peak also in 37 and 39 SMW with 1.22, 1.42 and 1.52 larvae/mrl, respectively.

Sowing I FN of July (S₃) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) the incidence of semilooper was in the ranged of 0.80-1.32, 0.72-1.42 and 0.65-1.48 larvae/mrl and it attained its peak in 37 SMW with 1.32, 1.42 and 1.48 larvae/mrl, respectively. Similarly the activity of the population of *S. litura* increased with peak density of the crop during the I FN of July (S₃) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) ranged between 0.65-1.20, 0.61-1.32 and 0.55-1.35 (larvae/mrl) and it attained its peak also in 38, 38 and 36 SMW with 1.20, 1.32 and 1.35 larvae/mrl, respectively.

Sowing II FN of July (S₄) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) the incidence of semilooper with its ranged of 0.60-1.82, 0.55-1.81 and 0.61-1.87 larvae/mrl and it attained its peak in 39 SMW with 1.82, 1.81 and 1.87 larvae/mrl, respectively. Similarly the activity of the population of *S. litura* increased with peak density of the crop during the II FN of July (S₄) with the varieties JS-335 (V₁), MACS-450 (V₂) and DS-228 (V₃) ranged between 1.02-1.45, 1.12-1.48 and 1.09-1.40 (larvae/mrl) and it attained its peak also in 36 SMW with 1.45, 1.48 and 1.40 larvae/mrl, respectively. Similar result reported by Negoyen Phi-Dieu Hoyen (2001).

Present findings are in agreement with that of Harish (2008) who reported higher incidence of *T. orichalcea* on crop sown during I FN of June (S₁) (3.27 larvae/mrl) and late sown crop II FN of July (S₄) recorded the maximum incidence of 4.80 larvae/mrl.

Sontakke and Mishra (1994), who reported that lowest pest incidence and greatest yield were recorded with early sowing (20 June, 5 July and 1-15 November). Semilooper, *T. orichalcea*, neonate larvae were found feeding on

leaves by scratching the green matter, grown up larvae consumed entire leaves. This pest was noticed defoliating at vegetative stage of the crop.

4.9.2 Influence if weather parameters on major pests of soybean

The influence of different weather parameters *viz.*, maximum and minimum temperature, morning and evening relative humidity, wind speed evaporation and rainfall on the seasonal incidence of semilooper, caterpillar pests and girdle beetle based on the number of larvae and girdle beetles infested plants was observed by working out correlation coefficient (r) (Table 48 and 49)

During the year 2012, Semilooper and girdle beetle observed as a major pests. The multiple correlation of semilooper with weather parameters are given in Table 48 and 49 during the experimental period, temperature and relative humidity played a major role in the population fluctuations. Results of the cumulative data correlation showed that the population of semilooper and girdle beetle was found to have significant and positive correlation with maximum temperature, morning relative humidity and sunshine hours whereas minimum temperature, evening relative humidity, wind speed, evaporation and rainfall showed negative correlation. These findings were in concurrence with the reports of Malik and Parihar (1996) and Dhawan and Simwat (1996).

On the basis of different sowing dates and varieties, the incidence of semilooper and girdle beetle with weather factors was studies. The correlation matrix between the weather factors and semilooper revealed that a significant positive correlation existed with maximum temperature with varieties JS-335 (V_1) ($r=0.838$), MACS-450 (V_2) ($r=0.689$) and DS-228 (V_3) ($r=0.581$) during I FN of July (S_3) and II FN of July (S_4) sowing times, morning relative humidity with JS-335 (V_1) ($r=0.631$), MACS-450 (V_2) ($r=0.665$) and DS-228 (V_3) ($r=0.600$) during I FN of June (S_1) sowing time, sunshine hours with JS-335 (V_1) ($r=0.597$), MACS-450 (V_2) ($r=0.523$) and DS-228 (V_3) ($r=0.594$) during I FN of July (S_3) sowing time, whereas a significantly negative correlation was recorded with minimum

temperature during all sowing times and varieties, evening relative humidity with JS-335 (V_1) ($r=-0.810$), MACS-450 (V_2) ($r=-0.641$) and DS-228 (V_3) ($r=-0.543$) during I FN of July (S_3) and II FN of July (S_4) sowing times, wind speed was highly significantly negative correlation with all the sowing times and varieties at 1% level. While non significant and negative correlation was recorded with evaporation and rainfall with JS-335 (V_1) ($r=-0.269$), MACS-450 (V_2) ($r=-0.271$) and DS-228 (V_3) ($r=-0.314$) during II FN of June (S_2) sowing times. Joshi and Patel (2010) also observed non-significant relationship between the insect pest population and the ambient weather.

The correlation matrix between the weather factors and girdle beetle revealed that temperature and relative humidity played a major role in the population fluctuations. Results of the cumulative data correlation showed that the population of girdle beetle was found to have significant and positive correlation with maximum temperature, morning relative humidity and sunshine hours whereas minimum temperature, evening relative humidity, wind speed, evaporation and rainfall showed negative correlation. These findings were in concurrence with the reports of Malik and Parihar (1996) and Dhawan and Simwat (1996).

On the basis of different sowing dates and varieties, the incidence of girdle beetle with weather factors was studied. The correlation matrix between the weather factors and girdle beetle revealed that a significant positive correlation existed with maximum temperature with varieties JS-335 (V_1) ($r=0.802$), MACS-450 (V_2) ($r=0.874$) and DS-228 (V_3) ($r=0.641$) during I FN of July (S_3) and II FN of July (S_4) sowing times, morning relative humidity with JS-335 (V_1) ($r=0.751$), MACS-450 (V_2) ($r=0.703$) during I FN of June (S_1) sowing times and DS-228 (V_3) ($r=0.622$) at I FN of July (S_3) sowing times, sunshine hours with JS-335 (V_1) ($r=0.418$), MACS-450 (V_2) ($r=0.509$) and DS-228 (V_3) ($r=0.390$) during I FN of July (S_3) and II FN of July (S_4) sowing times, whereas a significantly negative

correlation was recorded with minimum temperature during all sowing times and varieties, evening relative humidity with JS-335 (V_1) ($r=-0.720$), MACS-450 (V_2) ($r=-0.782$) and DS-228 (V_3) ($r=-0.537$) during II FN of July (S_4) sowing times, wind speed was highly significantly negative correlation with all the sowing times and varieties at 1% level. While non significant and negative correlation was recorded with evaporation and rainfall with JS-335 (V_1) ($r=-0.264$), MACS-450 (V_2) ($r=-0.237$) and DS-228 (V_3) ($r=-0.241$) during II FN of June (S_2) and I FN of July (S_3) sowing times. Similar results were recorded by Netam *et al.* (2013), and Sinha *et al.* (2013). Joshi and Patel (2010) also observed non-significant relationship between the insect pest population and the ambient weather. During the year 2013, Semilooper and *spodoptera* were recorded as a major pests. The multiple correlation of semilooper with weather parameters are given in Table 50 and 51. During the experimental period, temperature and relative humidity played a major role in the population fluctuations. Results of the cumulative data correlation showed that the population of semilooper was found to have significant and positive correlation with maximum temperature, morning relative humidity, evaporation, sunshine hours and rainfall and whereas minimum temperature, evening relative humidity, wind speed, showed negative correlation. Similarly, the population of *spodoptera* was found significant and positive correlation showed that with maximum temperature, evaporation and sunshine hours whereas, minimum temperature, evening and morning relative humidity, wind speed and rainfall showed negative correlation. These findings were in concurrence with the reports of Malik and Parihar (1996) and Dhawan and Simwat (1996).

Table. 46. Seasonal incidence of insect -pests association with soybean (2012)																
S ₁ (I FN of June)	Sr. No	Name of the Insect Pest	Mean of observations taken on SMW											Range	Mean	
			27	28	29	30	31	32	33	34	35	36	37			
			JS-335													
	1	Semilooper (larvae/mrl*)	0.00	0.13	0.15	0.17	0.20	0.27	0.38	0.78	1.15	1.02	1.38	0.00	1.38	0.51
	2	Girdle beetle (grubs/mrl*)	0.05	0.09	0.13	0.17	0.23	0.28	0.28	0.34	0.54	0.63	0.94	0.05	0.94	0.33
	MACS-450															
	1	Semilooper (larvae/mrl*)	0.00	0.00	0.12	0.15	0.17	0.19	0.23	0.25	0.38	0.59	1.02	0.00	1.02	0.28
	2	Girdle beetle (grubs/mrl*)	0.00	0.00	0.02	0.05	0.08	0.13	0.18	0.21	0.23	0.27	0.39	0.00	0.39	0.14
	DS-228															
	1	Semilooper (larvae/mrl*)	0.02	0.03	0.07	0.10	0.15	0.18	0.21	0.24	0.27	0.60	0.98	0.02	0.98	0.26
2	Girdle beetle (grubs/mrl*)	0.00	0.02	0.05	0.08	0.12	0.13	0.15	0.17	0.20	0.22	0.24	0.00	0.24	0.13	
S ₂ (II FN of June)	Sr. No	Name of the Insect Pest	Mean of observations taken on SMW											Range	Mean	
			29	30	31	32	33	34	35	36	37	38	39			
			JS-335													
	1	Semilooper (larvae/mrl*)	0.31	0.57	0.58	1.52	2.31	2.35	2.67	2.71	2.82	2.82	2.82	0.31	2.82	1.95
	2	Girdle beetle (grubs/mrl*)	0.11	0.11	0.11	0.15	0.25	0.30	0.51	0.55	0.61	0.61	0.61	0.11	0.61	0.36
	MACS-450															
	1	Semilooper (larvae/mrl*)	0.11	0.34	0.37	0.75	0.90	1.25	1.62	1.65	1.72	1.81	1.85	0.11	1.85	1.12
	2	Girdle beetle (grubs/mrl*)	0.12	0.13	0.20	0.24	0.41	0.43	0.72	0.72	0.72	0.72	0.72	0.12	0.72	0.47
	DS-228															
	1	Semilooper (larvae/mrl*)	0.22	0.45	0.58	0.92	1.32	1.81	1.97	1.97	1.97	1.97	1.97	0.22	1.97	1.38
2	Girdle beetle (grubs/mrl*)	0.10	0.12	0.17	0.21	0.37	0.41	0.65	0.65	0.65	0.65	0.65	0.10	0.65	0.42	
*mrl-meter row length, SMW=Standard Meteorological Week																

S ₃ (I FN of July)	Sr. No	Name of the Insect Pest	Mean of observations taken on SMW												Range	Mean	
			30	31	32	33	34	35	36	37	38	39	40				
			JS-335														
			1	Semilooper (larvae/mrl*)	0.00	0.09	0.11	0.12	0.70	0.21	0.19	0.40	1.00	1.01			1.01
2	Girdle beetle (grubs/mrl*)	0.00	0.07	0.11	0.22	0.34	0.61	0.76	0.86	0.86	0.86	0.86	0.00	0.86	0.50		
MACS-450																	
1	Semilooper (larvae/mrl*)	0.12	0.31	0.34	1.02	1.92	1.97	2.01	2.01	2.01	2.01	2.01	0.12	2.01	1.43		
2	Girdle beetle (grubs/mrl*)	0.14	0.15	0.16	0.30	0.41	0.53	0.60	0.67	0.71	0.71	0.71	0.14	0.71	0.46		
DS-228																	
1	Semilooper (larvae/mrl*)	0.12	0.32	0.47	1.87	2.35	2.51	2.66	2.85	2.91	2.91	2.91	0.12	2.91	1.99		
2	Girdle beetle (grubs/mrl*)	0.12	0.14	0.21	0.27	0.69	1.02	1.17	1.41	1.43	1.69	1.69	0.12	1.69	0.89		
S ₄ (II FN of July)	Sr. No	Name of the Insect Pest	Mean of observations taken on SMW											Range	Mean		
			33	34	35	36	37	38	39	40	41	42	43				
			JS-335														
	1	Semilooper (larvae/mrl*)	0.22	0.47	0.49	1.15	1.45	1.91	1.98	1.11	1.11	1.11	1.11	0.22	1.98	1.10	
	2	Girdle beetle (grubs/mrl*)	0.12	0.14	0.19	0.24	0.32	0.44	0.48	0.49	0.57	0.57	0.57	0.12	0.57	0.38	
	MACS-450																
	1	Semilooper (larvae/mrl*)	0.00	0.11	0.19	0.21	0.92	0.94	0.99	1.12	1.17	1.17	1.17	0.00	1.17	0.73	
	2	Girdle beetle (grubs/mrl*)	0.00	0.01	0.12	0.17	0.18	0.41	0.52	0.63	0.79	0.87	0.87	0.00	0.87	0.42	
	DS-228																
	1	Semilooper (larvae/mrl*)	0.18	0.22	0.38	1.32	1.78	1.87	1.89	1.91	1.91	1.91	1.91	0.18	1.91	1.39	
	2	Girdle beetle (grubs/mrl*)	0.08	0.09	0.19	0.31	0.42	0.44	0.48	0.55	0.55	0.55	0.55	0.08	0.55	0.38	
*mrl-meter row length, SMW=Standard Meteorological Week																	

Table. 47. Seasonal incidence of insect -pests association with soybean (2013)

S ₁ (I FN of June)	Sr. No.	Name of the Insect Pest	Mean of observations taken on SMW											Range		Mean
			27	28	29	30	31	32	33	34	35	36	37			
			JS-335													
	1	Semilooper (larvae/mrl*)	0.18	1.20	1.40	1.48	1.55	1.22	0.93	1.12	1.27	1.80	1.38	0.18	1.80	1.23
	2	<i>Spodoptera</i> (larvae/mrl*)	0.11	0.12	0.18	0.32	0.61	1.12	1.18	1.27	1.40	1.15	0.75	0.11	1.40	0.75
	MACS-450															
	1	Semilooper (larvae/mrl*)	0.22	1.15	1.37	1.52	1.62	1.35	0.92	0.98	1.22	1.30	1.15	0.22	1.62	1.16
	2	<i>Spodoptera</i> (larvae/mrl*)	0.09	0.11	0.22	0.34	0.55	1.17	1.27	1.30	1.42	1.10	0.85	0.09	1.42	0.77
	DS-228															
	1	Semilooper (larvae/mrl*)	0.23	1.12	1.22	1.55	1.68	1.18	1.11	1.01	1.30	1.32	1.11	0.23	1.68	1.17
2	<i>Spodoptera</i> (larvae/mrl*)	0.10	0.13	0.27	0.40	0.55	1.22	0.13	1.31	1.40	0.19	0.89	0.10	1.40	0.60	

S ₂ (II FN of June)	Sr. No.	Name of the Insect Pest	Mean of observations taken on SMW											Range		Mean
			29	30	31	32	33	34	35	36	37	38	39			
			JS-335													
	1	Semilooper (larvae/mrl*)	0.71	0.87	0.58	0.52	0.31	0.35	2.67	2.71	2.92	0.82	0.82	0.31	2.92	1.21
	2	<i>Spodoptera</i> (larvae/mrl*)	0.20	0.20	1.30	1.40	1.75	1.00	1.02	1.18	1.22	1.00	1.35	0.20	1.75	1.06
	MACS-450															
	1	Semilooper (larvae/mrl)*	0.81	1.34	1.37	0.75	0.90	1.25	2.62	2.65	2.72	1.81	1.75	0.75	2.72	1.63
	2	<i>Spodoptera</i> (larvae/mrl*)	0.12	0.12	1.15	1.18	1.85	1.87	0.94	1.12	1.22	1.24	1.42	0.12	1.87	1.11
	DS-228															
	1	Semilooper (larvae/mrl*)	0.92	1.45	1.58	0.92	1.32	1.81	2.97	2.97	2.97	0.97	1.97	0.92	2.97	1.80
2	<i>Spodoptera</i> (larvae/mrl*)	0.15	0.17	1.22	1.34	1.65	1.52	1.52	1.52	1.52	0.52	1.52	0.15	1.65	1.15	

*mrl-meter row length, SMW=Standard Meteorological Week

	Sr. No.	Name of the Insect Pest	Mean of observations taken on SMW												Range	Mean
			30	31	32	33	34	35	36	37	38	39	40			
			JS-335													
S ₃ (I FN of July)	1	Semilooper (larvae/mrl*)	0.80	0.92	0.92	1.01	0.93	0.99	0.99	1.32	1.12	0.75	0.80	0.75	1.32	0.96
	2	<i>Spodoptera</i> (larvae/mrl*)	0.65	0.70	1.18	1.22	1.27	1.22	1.32	1.15	1.20	1.20	1.20	0.65	1.32	1.12
	MACS-450															
	1	Semilooper (larvae/mrl*)	0.72	0.82	0.97	0.99	0.98	1.01	1.02	1.42	1.22	0.85	0.85	0.72	1.42	0.99
	2	<i>Spodoptera</i> (larvae/mrl*)	0.61	0.77	1.01	1.16	1.32	1.21	1.36	1.29	1.32	1.28	1.28	0.61	1.36	1.15
	DS-228															
	1	Semilooper (larvae/mrl*)	0.65	0.81	0.92	1.05	1.06	1.06	1.07	1.48	1.21	0.89	0.89	0.65	1.48	1.01
	2	<i>Spodoptera</i> (larvae/mrl*)	0.55	0.65	0.98	1.19	1.30	1.18	1.35	1.28	1.20	1.30	1.32	0.55	1.35	1.12
S ₄ (II FN of July)	Sr. No.	Name of the Insect Pest	Mean of observations taken on SMW												Range	Mean
			33	34	35	36	37	38	39	40	41	42	43			
			JS-335													
	1	Semilooper (larvae/mrl*)	0.60	0.82	1.01	1.65	1.82	1.90	1.82	1.35	1.22	1.25	1.25	0.60	1.90	1.34
	2	<i>Spodoptera</i> (larvae/mrl*)	1.02	1.22	1.35	1.45	1.40	1.52	1.32	1.30	1.21	1.15	1.15	1.02	1.52	1.28
	MACS-450															
	1	Semilooper (larvae/mrl*)	0.55	0.72	1.09	1.55	1.67	1.82	1.81	1.32	1.18	1.19	1.19	0.55	1.82	1.28
	2	<i>Spodoptera</i> (larvae/mrl*)	1.12	1.21	1.37	1.48	1.35	1.31	1.37	1.39	1.35	1.22	1.22	1.12	1.48	1.31
	DS-228															
	1	Semilooper (larvae/mrl*)	0.61	0.82	1.01	1.67	1.69	1.91	1.87	1.15	1.21	1.18	1.18	0.61	1.91	1.30
	2	<i>Spodoptera</i> (larvae/mrl*)	1.09	1.18	1.31	1.40	1.37	1.22	1.18	1.11	1.22	1.19	1.19	1.09	1.40	1.22
*mrl-meter row length, SMW=Standard Meteorological Week																

On the basis of different sowing dates and varieties, the incidence of semilooper and *spodoptera* with weather factors was studied. The correlation matrix between the weather factors and semilooper revealed that a significant positive correlation existed with maximum temperature with varieties JS-335 (V_1) ($r=0.868$), MACS-450 (V_2) ($r=0.841$) and DS-228 (V_3) ($r=0.852$) at 1% level during sowing times I FN of July (S_3), morning relative humidity with JS-335 (V_1) ($r=0.661$), MACS-450 (V_2) ($r=0.420$) and DS-228 (V_3) ($r=0.321$) during I FN of July (S_3) sowing times, evaporation with JS-335 (V_1) ($r=0.333$), MACS-450 (V_2) ($r=0.235$) and DS-228 (V_3) ($r=0.364$) during I FN of July (S_3) sowing times, sunshine hours with JS-335 (V_1) ($r=0.499$), MACS-450 (V_2) ($r=0.376$) and DS-228 (V_3) ($r=0.551$) during I FN of June (S_1) and II FN of June (S_2) sowing times and rainfall with JS-335 (V_1) ($r=0.629$), MACS-450 (V_2) ($r=0.568$) and DS-228 (V_3) ($r=0.577$) during II FN of July (S_4) sowing times, whereas a significantly negative correlation was recorded with evening relative humidity with JS-335 (V_1) ($r=-0.642$) during I FN of June (S_1) sowing times, wind speed was significantly negative correlation with all the sowing times and varieties MACS-450 (V_2) at 1% level in II FN of June (S_2) sowing times. While non significant and negative correlation was recorded with minimum temperature, evaporation and sunshine hours during all sowing times and varieties.

Joshi and Patel (2010) also observed non-significant relationship between the insect pest population and the ambient weather.

The correlation matrix between the weather factors and *spodoptera* revealed that temperature and relative humidity played a major role in the population fluctuations. Results of the cumulative data correlation showed that the population of *spodoptera* was found to have significant and positive correlation with maximum temperature, evaporation and sunshine hours whereas minimum temperature, morning and evening relative humidity, wind speed and rainfall showed negative correlation. These findings were in concurrence with the reports of Malik and Parihar (1996) and Dhawan and Simwat (1996).

Table 48. Correlation coefficient between meteorological factors and pest incidence in soybean under different sowing times (2012)

‘r’ values for soybean pest semilooper (larvae/mrl*)									
Sowing times	Varieties	Weather elements							
		Tmax	Tmin	R H I	R H II	W S	Epan	B S S	RAIN
S ₁ (I FN of June)	JS-335 (V ₁)	0.261	-0.835**	0.631*	-0.336	-0.902**	-0.299	0.416	0.059
	MACS-450 (V ₂)	0.250	-0.839**	0.664*	-0.306	-0.842**	-0.365	0.348	0.099
	DS-228 (V ₃)	0.176	-0.849**	0.599	-0.301	-0.813**	-0.361	0.310	0.008
S ₂ (II FN of June)	JS-335 (V ₁)	0.571	-0.675*	0.483	-0.517	-0.942**	0.073	0.536	-0.269
	MACS-450 (V ₂)	0.569	-0.714*	0.608*	-0.454	-0.961**	-0.074	0.434	-0.271
	DS-228 (V ₃)	0.515	-0.641*	0.569	-0.411	-0.954**	0.006	0.426	-0.314
S ₃ (I FN of July)	JS-335 (V ₁)	0.838**	-0.800**	0.328	-0.809*	-0.770**	0.159	0.597	0.048
	MACS-450 (V ₂)	0.537	-0.605*	0.454	-0.483	-0.920**	0.134	0.523	-0.268
	DS-228 (V ₃)	0.581	-0.671*	0.453	-0.543	-0.928**	0.123	0.594	-0.298
S ₄ (II FN of July)	JS-335 (V ₁)	0.228	-0.350	0.180	-0.196	-0.458	-0.190	-0.013	0.243
	MACS-450 (V ₂)	0.688*	-0.680*	0.226	-0.640*	-0.844**	0.119	0.299	-0.068
	DS-228 (V ₃)	0.482	-0.573	0.337	-0.436	-0.789**	-0.181	0.093	-0.079
* Significant at 0.05 level. ** Significant at 0.01 level, Multiple r value for 5 % level =0.602 and 1 % level=0.735									
*mrl-meter row length, Tmax= Maximum temperature, Tmin= Minimum temperature, RH-I= Relative humidity (morning),									
RH-II= Relative humidity (evening), WS= Wind Speed, Epan= Pan evaporation, BSS= Bright Sunshine hours, RAIN= Rainfall									

Table 49. Correlation coefficient between meteorological factors and pest incidence in soybean under different sowing times (2012)

‘r’ values for soybean pest Girdle Beetle (grubs/mrl*)									
Sowing times	Varieties	Weather elements							
		Tmax	Tmin	R H I	R H II	W S	Epan	B S S	RAIN
S ₁ (I FN of June)	JS-335 (V ₁)	0.142	-0.805**	0.751**	-0.184	-0.883**	-0.418	0.289	0.025
	MACS-450 (V ₂)	0.240	-0.860**	0.703**	-0.301	-0.876**	-0.375	0.433	0.090
	DS-228 (V ₃)	0.120	-0.428	-0.102	-0.364	-0.242	-0.086	0.164	-0.214
S ₂ (II FN of June)	JS-335 (V ₁)	0.564	-0.729*	0.570	-0.475	-0.903**	-0.122	0.338	-0.161
	MACS-450 (V ₂)	0.503	-0.691*	0.574	-0.429	-0.919**	-0.114	0.354	-0.237
	DS-228 (V ₃)	0.502	-0.686*	0.578	-0.422	-0.925**	-0.106	0.352	-0.241
S ₃ (I FN of July)	JS-335 (V ₁)	0.529	-0.692*	0.594	-0.426	-0.943**	-0.057	0.362	-0.264
	MACS-450 (V ₂)	0.599	-0.709*	0.547	-0.511	-0.952**	0.017	0.442	-0.219
	DS-228 (V ₃)	0.641*	-0.710*	0.622*	-0.498	-0.955**	-0.005	0.390	-0.130
S ₄ (II FN of July)	JS-335 (V ₁)	0.802**	-0.744*	0.198	-0.720**	-0.908**	0.130	0.418	-0.045
	MACS-450 (V ₂)	0.874**	-0.791*	0.172	-0.782**	-0.931**	0.195	0.509	-0.093
	DS-228 (V ₃)	0.633*	-0.631*	0.374	-0.537	-0.902**	-0.064	0.187	-0.101
* Significant at 0.05 level. ** Significant at 0.01 level, Multiple r value for 5 % level =0.602 and 1 % level=0.735									
*mrl-meter row length, Tmax= Maximum temperature, Tmin= Minimum temperature, RH-I= Relative humidity (morning),									
RH-II= Relative humidity (evening), WS= Wind Speed, Epan= Pan evaporation, BSS= Bright Sunshine hours, RAIN= Rainfall									

Table 50. Correlation coefficient between meteorological factors and pest incidence in soybean under different sowing times (2013)

'r' values for soybean pest semilooper (larvae/mrl*)									
Sowing times	Varieties	Weather elements							
		Tmax	Tmin	R H I	R H II	W S	Epan	B S S	RAIN
S ₁ (I FN of June)	JS-335 (V ₁)	0.009	-0.580	-0.530	-0.642*	-0.513	0.333	0.499	0.021
	MACS-450 (V ₂)	-0.329	-0.303	0.187	0.303	-0.073	-0.318	-0.214	0.322
	DS-228 (V ₃)	-0.288	-0.329	0.146	0.200	-0.058	-0.223	-0.105	0.272
S ₂ (II FN of June)	JS-335 (V ₁)	0.566	-0.200	0.340	-0.095	-0.522	0.090	0.219	0.629*
	MACS-450 (V ₂)	0.467	-0.439	0.037	-0.308	-0.698*	0.175	0.376	0.449
	DS-228 (V ₃)	0.790**	-0.222	0.321	-0.319	-0.540	0.352	0.551	0.427
S ₃ (I FN of July)	JS-335 (V ₁)	0.868**	0.342	0.661*	-0.126	-0.301	0.108	0.254	0.569
	MACS-450 (V ₂)	0.841**	0.180	0.420	-0.347	-0.427	0.235	0.369	0.476
	DS-228 (V ₃)	0.852**	0.095	0.311	-0.479	-0.429	0.364	0.490	0.357
S ₄ (II FN of July)	JS-335 (V ₁)	0.034	-0.223	0.031	0.173	-0.463	-0.333	-0.250	0.629*
	MACS-450 (V ₂)	-0.028	-0.259	-0.026	0.150	-0.471	-0.325	-0.249	0.568
	DS-228 (V ₃)	0.014	-0.203	0.023	0.239	-0.361	-0.295	-0.325	0.577
* Significant at 0.05 level. ** Significant at 0.01 level, Multiple r value for 5 % level =0.602 and 1 % level=0.735									
*mrl-meter row length, Tmax= Maximum temperature, Tmin= Minimum temperature, RH-I= Relative humidity (morning),									
RH-II= Relative humidity (evening), WS= Wind Speed, Epan= Pan evaporation, BSS= Bright Sunshine hours, RAIN= Rainfall									

Table 51. Correlation coefficient between meteorological factors and pest incidence in soybean under different sowing times (2013)

'r' values for soybean pest <i>Spodoptera</i> (larvae/mrl*)									
Sowing times	Varieties	Weather elements							
		Tmax	Tmin	R H I	R H II	W S	Epan	B S S	RAIN
S ₁ - (I FN of June)	JS-335 (V ₁)	-0.061	-0.588	-0.733*	-0.720*	-0.496	0.419	0.572	-0.196
	MACS-450 (V ₂)	0.580	-0.410	-0.431	-0.807**	-0.141	0.759*	0.800**	-0.433
	DS-228 (V ₃)	0.274	-0.045	-0.236	-0.364	-0.078	0.302	0.327	-0.134
S ₂ - (II FN of June)	JS-335 (V ₁)	0.444	-0.021	-0.321	-0.728**	-0.019	0.656*	0.638*	-0.379
	MACS-450 (V ₂)	0.384	-0.159	-0.407	-0.782**	-0.091	0.723**	0.647*	-0.472
	DS-228 (V ₃)	0.770**	-0.113	-0.030	-0.713**	-0.201	0.777**	0.811**	-0.183
S ₃ - (I FN of July)	JS-335 (V ₁)	0.527	-0.382	-0.397	-0.866**	-0.231	0.845**	0.800**	-0.452
	MACS-450 (V ₂)	0.529	-0.439	-0.397	-0.866**	-0.391	0.759**	0.795**	-0.236
	DS-228 (V ₃)	0.481	-0.477	-0.452	-0.924**	-0.415	0.785**	0.818**	-0.304
S ₄ - (II FN of July)	JS-335 (V ₁)	0.307	0.062	0.251	0.559	-0.037	0.081	-0.310	0.598
	MACS-450 (V ₂)	0.016	-0.399	-0.132	0.196	-0.212	0.229	0.108	0.191
	DS-228 (V ₃)	0.644*	-0.101	0.482	0.276	-0.159	0.315	0.044	0.440
* Significant at 0.05 level, ** Significant at 0.01 level, Multiple r value for 5 % level =0.602 and 1 % level=0.735									
*mrl-meter row length, Tmax= Maximum temperature, Tmin= Minimum temperature, RH-I= Relative humidity (morning),									
RH-II= Relative humidity (evening), WS= Wind Speed, Epan= Pan evaporation, BSS= Bright Sunshine hours, RAIN= Rainfall									

On the basis of different sowing times and varieties, the incidence of *spodoptera* with weather factors was studied. The correlation matrix between the weather factors and *spodoptera* revealed that a significant positive correlation existed with maximum temperature with varieties DS-228 (V_3) ($r=0.770$) during II FN of June (S_2) sowing times, evaporation and sunshine hours were positively high significant during II FN of June (S_2) and I FN of July (S_3) sowing times at 1% level throughout the sowings, whereas a significantly negative correlation was recorded with minimum temperature during all sowing times and varieties, morning and evening relative humidity at all the sowing times. Wind speed was significantly negative correlation with all the sowing times and varieties at 1% level. While non significant and negative correlation was recorded with wind speed and rainfall during II FN of June (S_2) and I FN of July (S_3) sowing times. Similar results were recorded by Netam *et al.* (2013), and Sinha and Netam (2013) and (Anonymous, 1992). Zag and Kushwaha (1983) reported the population of *S. litura* in cabbage crop to be negatively correlated with average and maximum temperature. Sojitra (1990) reported the infestation of *S. litura* during July to September in Soybean cultivated at Junagadh. The minimum temperature, evening relative humidity, morning and evening vapour pressure showed negative effect on oviposition behaviour and larval development of *S. litura*, whereas, correlation analysis showed non significant difference between various abiotic factors and leaf damage caused by *S. litura* infesting castor crop in middle Gujarat (Thanki *et al.* 2003). Minimum temperature, morning and evening relative humidity and rainfall exhibited non significant and negative relationship with population of *S. litura* infesting onion crop in Guntur area (Sailaja Rani, 2006). Selvaraj *et al.* (2010) reported that infestation of bollworms in bhendi crop to be positively correlated with maximum temperature and dewfall.

CHAPTER- V

SUMMARY AND CONCLUSIONS

The investigation in this treatise entitled “Simulation of soybean growth and yield by using DSSAT model under varied environmental conditions at Pune location” was conducted at ‘D’ division of Agronomy Farm, at the experimental field of Department of Agricultural Meteorology, College of Agriculture, Pune-5 during *kharif* seasons of 2012 and 2013.

In the present investigation four sowing times (I FN of June (S_1), II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4)) were undertaken to create a different set of environmental conditions and three varieties JS-335 (V_1), MACS-450 (V_2), and DS-228 (V_3), were tested. The experiment was laid out in split plot design with four replications consisting of twelve treatment combinations in each. The objective was to study the crop weather relationship of soybean and to calibrate and validate CROPGRO-Soybean model (DSSAT v 4.5) under Pune condition.

Sowing times

Phenophases results

- 1) Initial and final plant population, plant height, number of branches, number of leaves, leaf area plant⁻¹, leaf area index, dry matter accumulation plant⁻¹ and dry matter accumulation in stem, grain and stover were significantly superior with early sown crop I FN of June (S_1) and decreased with delay in sowing II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) during both the years.
- 2) Significantly higher values for number of pods plant⁻¹, seed weight plant⁻¹, seeds pod⁻¹ and hundred seed weight were obtained due to early sowing I FN of June (S_1) which was found to be at par with II FN of June (S_2) sowing. Later sowings I FN of July (S_3) and II FN of July (S_4) was found to decrease the yield components during 2012 and 2013.

- 3) Significantly higher seed yield (22.87 q ha^{-1}) was obtained when soybean crop was sown on I FN of June (S_1) but the lowest yield (15.47 q ha^{-1}) was obtained with sown on II FN of July (S_4) during 2012. Similarly significantly the highest seed yield (29.78 q ha^{-1}) was obtained when soybean crop was sown on I FN of June (S_1) followed by II FN of June (S_2) i.e. 27.74 q ha^{-1} however, the lowest yield (23.61 q ha^{-1}) was obtained in the crop sown on II FN of July (S_4) during 2013. Similar trend was observed in terms of straw, biological yield and harvest index.
- 4) Early sown crop I FN of June (S_1) taken more number of days for attaining each of the phenophase. Duration taken from emergence to physiological maturity was of 95, 91, 89 and 88 days in 2012 and 96, 92, 91 and 90 under the four sowing times 2013, respectively.

Meteorological results

- 5) Late sowing time I FN of July (S_3) received higher amount of rainfall (433.6 mm) during the total growing period of 2012 and the amount of rainfall distribution across the crop growth duration decreased (353.8 , 333.0 and 422.9 mm) with each sowing time. However, during 2013 crop sown on I FN of June (S_1) received higher amount of rainfall (636.8 mm) during the total growing period. Amount of rainfall distribution across the crop growth duration decreased (459.9 , 455.1 and 312.6 mm) with each delay sowing time. The distribution of rainfall at each phenophase is not same but highly varied in both the years.
- 6) Across seed formation and seed development stage maximum temperature increased to some extent from I FN of June (S_1) to II FN of July (S_4) sowings; however the minimum temperature regime reduced during the same sowings times for the years 2012 and 2013. Maximum evening relative humidity (93%) was recorded under II FN of July (S_4) followed by II FN of June (S_2) (90%), I FN of July (S_3) and II FN of July (S_4) (86%) during 2012, at seed formation stage (SF). However, it was 92% under II FN of June (S_2) followed by I FN of June (S_1) (89%), I FN of

July (S_3) and II FN of July (S_4) (88%) during 2013. Mean morning relative humidity remained between 81 % to 89 % and 86 % to 90 % and mean evening relative humidity remained between 62% to 79% and 60 % to 79% respectively during all phenophase of crop in 2012 and 2013.

- 7) Early sowing I FN of June (S_1) crop recorded significantly higher mean values of PARo, RPAR, TPAR, and RPARs ($\mu \text{ mol m}^{-2}\text{s}^{-1}$) during phenological phases of vegetative to physiological maturity during the years 2012 and 2013.
- 8) Early sowing I FN of June (S_1) crop recorded significantly higher percentage of radiation interception during phenological phases of vegetative to physiological maturity stage during the years 2012 and 2013.
- 9) Growing degree days (GDD) to reach various phenological stages decreased with each delay in sowing. Overall, early sown crop I FN of June (S_1) availed the highest GDD from emergence to maturity 1515.1 $^{\circ}\text{C}$ days and 1439.6 $^{\circ}\text{C}$ days, and the lowest being under II FN of July (S_4) sowing 1292.0 $^{\circ}\text{C}$ days and 1366.7 $^{\circ}\text{C}$ days during 2012 and 2013, respectively.
- 10) During 2012, all the sowing times, availed more number of HTU at vegetative stage, which was followed by seed formation (SF) to seed development (FSD) as compared to the preceding phenophases and during 2013 under all the sowing times, seed formation (SF) to seed development (FSD) availed more number of HTU as compared to the preceding phenophases. Overall, late sown crop II FN of July (S_4) availed higher HTU (7165.0 $^{\circ}\text{C}$ day hour), followed by I FN of July (S_3) (5554.3 $^{\circ}\text{C}$ day hour), II FN of June (S_2) (4666.4 $^{\circ}\text{C}$ day hour) and I FN of June (S_1) (4547.6 $^{\circ}\text{C}$ day hour).
- 11) During the year 2012, decreasing trend of thermal use efficiency were found during early sowing times I FN of June (S_1) upto II FN of July (S_4). The highest thermal use efficiency with more grain yield was observed in sowing time I FN of June (S_1) (1.53 kg/ha/ $^{\circ}\text{C}$), over the rest of sowing

times. It proved that there was decrease trend of thermal use efficiency with increase in sowing times. Similar trend was observed during the year 2013. The highest thermal use efficiency with more grain yield was observed in sowing times I FN of June (S_1) (2.12 kg/ha/D°C), over the rest of sowing times.

Crop simulation modeling

- 1) The genetic coefficients for the soybean varieties JS-335 (V_1), MACS-450 (V_2) and DS-228 (V_3) were determined with estimator embedded in the DSSAT v 4.5 model using data collected during the experiment 2012 and 2013.
- 2) Initial testing of the model during 2012 and 2013 showed that the model predicted dates of anthesis, first pod day, first seed day and physiological maturity is correct and within limit of plus minus 10 per cent deviation from 1:1 line.
- 3) Plant height and LAI was found to be slightly overestimated except that plant height prediction was well matched for MACS-450 (V_2) during the year 2013.
- 4) The model predicted the seed yield reliable in DS-228 (V_3) and MACS-450 (V_2) during 2013 and seed yield was slightly overestimated in JS-335 (V_1) and MACS-450 (V_2) during both the years. Straw yield was slightly overestimated in all the cultivars during 2012 and 2013 except cultivars DS-228 (V_3).
- 5) Threshing percentage was completely matched with the predicted values in all the varieties during 2012 and 2013. The harvest index was reliable in DS-228 (V_3) during 2013 but slightly over estimated in all the cultivars during both the years.
- 6) Overall, The MBE (mean bias error) values in most of the cases were negative, which indicates that results were slightly under predicted and Crop simulation model (CROPGRO-soybean, DSSAT v 4.5) performance in respect of phenological phases was found to be highly reliable.

Therefore, by and large the model performance during both the year 2012 and 2013 was found good during *kharif* season for soybean crop under Pune condition.

Pest incidence

- 1) Results on the cumulative data for the years 2012 and 2013, correlation showed that the population of *semilooper* and girdle beetle was found to be significant and positively correlated with maximum temperature, morning relative humidity and sunshine hours whereas minimum temperature, evening relative humidity, wind speed, evaporation and rainfall showed negatively correlation.

Varieties

- 1) Soybean variety MACS-450 (V_2) recorded higher plant height as compared to DS-228 (V_3) and JS-335 (V_1). In respect of the number of branches plant⁻¹ varietal differences were non- significant but interaction effect was significant at 40 DAS during 2012 and at 40, 60 and 80 DAS during 2013.
- 2) Number of leaves plant⁻¹ in different treatments were significant at 40, 60 and 80 DAS during both the year.
- 3) Variety MACS-450 (V_2) recorded significantly higher leaf area and leaf area index followed by DS-228 (V_3) and JS-335 (V_1) during 2012 and 2013.
- 4) Variety MACS-450 (V_2) produced significantly higher dry matter weight plant⁻¹ followed by DS-228 (V_3) and JS-335 (V_1). Variety DS-228 (V_3) recorded significantly higher dry matter weight plant⁻¹ than JS-335 (V_1) during 2012 and 2013.
- 5) Variety DS-228 (V_3) recorded the maximum number of pods plant⁻¹, seed weight plant⁻¹, number of seeds pod⁻¹ and hundred seed weight during 2012 and 2013.

- 6) Soybean variety DS-228 (V_3) was recorded significantly higher seed yield (23.50 q ha^{-1}) over MACS-450 (V_2) (19.46 q ha^{-1}) and JS-335 (V_1) (15.38 q ha^{-1}) during the year 2012 and variety DS-228 (V_3) (29.04 q ha^{-1}) over MACS-450 (V_2) (26.70 q ha^{-1}) and JS-335 (V_1) (24.38 q ha^{-1}) in the year 2013.
- 7) Soybean variety DS-228 (V_3) recorded significantly higher biological yield (58.76 q ha^{-1}) over MACS-450 (V_2) (55.21 q ha^{-1}) and JS-335 (V_1) (47.21 q ha^{-1}) but MACS-450 (V_2) was at par over variety JS-335 (V_1) during 2012. However, during the year 2013, DS-228 (V_3) recorded significantly higher biological yield (54.02 q ha^{-1}) over MACS-450 (V_2) (53.02 q ha^{-1}) and JS-335 (V_1) (49.09 q ha^{-1}).
- 8) The maturity period averaged was more in variety DS-228 (V_3) (95 and 96 days) followed by MACS-450 (V_2) (93 and 93 days) and JS-335 (V_1) (88 and 89 days) during the year 2012 and 2013, respectively.
- 9) Total rainfall received during the crop growing period varied slightly during the total growth duration of varieties JS-335 (V_1) (339.7 and 454.0 mm), MACS-450 (V_2) (351.2 and 481.5 mm) and DS-228 (V_3) (353.8 and 544.7 mm) during 2012 and 2013, respectively.
- 10) Among the varieties, the maximum and minimum temperature regime; and relative humidity regime did not vary much and remained more or less similar at most of the phenophases during 2012 and 2013.
- 11) During the years 2012 and 2013, among all the varieties, MACS-450 (V_2) ($1388 \mu \text{ mol m}^{-2}\text{s}^{-1}$) availed maximum PAR values at flowering stage followed by variety JS-335 (V_1) ($1385 \mu \text{ mol m}^{-2}\text{s}^{-1}$). However, varieties, DS-228 (V_3) ($456 \mu \text{ mol m}^{-2}\text{s}^{-1}$) availed maximum RPAR values at all the stages followed by variety MACS-450 (V_2) ($453 \mu \text{ mol m}^{-2}\text{s}^{-1}$) during 2012 and variety, MACS-450 (V_2) ($455 \mu \text{ mol m}^{-2}\text{s}^{-1}$) availed maximum RPAR values at vegetative and flowering during year 2013.
- 12) Varieties, MACS-450 (V_2) ($1026 \mu \text{ mol m}^{-2}\text{s}^{-1}$) recorded maximum TPAR values at maturity followed by variety DS-228 (V_3) ($993 \mu \text{ mol m}^{-2}\text{s}^{-1}$)

during both the year. However, maximum RPARs values availed in variety MACS-450 (V_2) ($371 \mu \text{ mol m}^{-2}\text{s}^{-1}$) during the year 2012 and variety JS-335 (V_1) ($393 \mu \text{ mol m}^{-2}\text{s}^{-1}$) during 2013.

- 13) Similar trend was observed for the varieties which was found to be non significant with respect to radiation interception during all the physiological stages during both the years of 2012 and 2013.
- 14) Variety DS-228 (V_3) availed more number of GDD (1515 and 1470 $^{\circ}\text{C}$ day) followed by MACS-450 (V_2) (1370 and 1393 $^{\circ}\text{C}$ day), JS-335 (V_1) (1310 and 1327 $^{\circ}\text{C}$ day) during 2012 and 2013, respectively. Similarly, DS-228 (V_3) accrued more number of HTUs (6311 and MACS-450 (V_2) (6224 and 4383 $^{\circ}\text{C}$ day hour) and JS-335 (V_1) (6070 and 4007 $^{\circ}\text{C}$ day hour) during year 2012 and 2013, respectively.
- 15) Thermal use efficiency in terms of seed yield and biomass yield was higher with DS-228 (V_3) followed by MACS-450 (V_2) and JS-335 (V_1) during both the years 2012 and 2013.
- 16) During the year 2012, the correlation matrix between the weather factors with Semilooper and girdle beetle revealed that a significant positive correlation existed with maximum temperature and morning relative humidity and negatively correlated with minimum temperature and wind speed. However, during 2013, sowing during I FN of July (S_3) found to be positively correlated with maximum temperature and the incidence of *spodoptera* found to be negative significance with afternoon relative humidity.

Conclusions

1. All the biometric observations recorded were significantly the highest in early sowing during I FN of June (S_1) followed by II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4). When soybean was sown during II FN of June (S_2) and I FN of July (S_3) recorded significantly higher and favourable growth characters.

2. Sowing of soybean during I FN of June (S_1) was found to be significantly superior over rest of the sowing times with the highest grain yield, therefore, it can be considered as optimum sowing time.
3. The model predicted the seed yield reliable in varieties DS-228 (V_3) and MACS-450 (V_2) during the year 2013 and seed yield was slightly overestimated in varieties JS-335 (V_1) and MACS-450 (V_2) during both the years. Overall, The MBE (mean bias error) values in most of the cases were negative, which indicated that results was slightly under predicted.
4. The model calibration and validation results from two year field study revealed that 'SOYGRO model' can be used to predict soybean phenology, growth and yield parameters under different environment with reasonably satisfactory predictions.
5. Significant positive correlation existed between maximum temperature and girdle beetle pest with all the varieties when soybean sown during I FN of July (S_3) and II FN of July (S_4), however, morning relative humidity with varieties JS-335 (V_1), MACS-450 (V_2) sown during I FN of June (S_1) and variety DS-228 (V_3) when sown during I FN of July (S_3) showed similar results.
6. The correlation matrix between the weather elements and Semilooper revealed that a significant positive correlation existed with maximum temperature with varieties JS-335 (V_1) followed by MACS-450 (V_2) during I FN of July (S_3) and II FN of July (S_4) sowing times. While, similar results were recorded for the pest girdle beetle during both the year.
7. The correlation matrix between the weather elements and *spodoptera* revealed that a significant positive correlation existed with maximum temperature with varieties DS-228 (V_3) ($r=0.770$) during S_2 -II FN of June sowing times,

CHAPTER- VI

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