

# **MICROMETEOROLOGICAL STUDIES IN SOYBEAN UNDER DIFFERENT ENVIRONMENTS AND EVALUATION OF 'SOYGRO' MODEL**

**By**

**AJIT SINGH  
2002A52D**

*Dissertation submitted to CCS Haryana Agricultural University in  
partial fulfilment of the requirements for the degree of :*

## **DOCTOR OF PHILOSOPHY IN AGRICULTURAL METEOROLOGY**



**DEPARTMENT OF AGRICULTURAL METEOROLOGY  
COLLEGE OF AGRICULTURE  
CCS HARYANA AGRICULTURAL UNIVERSITY  
HISAR - 125 004**

**2006**

*Dedicated*  
*To*  
*My Beloved Parents*

**Dr. V.U.M. Rao**  
Professor & Head  
Dept. of Agricultural Meteorology  
CCS Haryana Agricultural University  
Hisar-125 004, India

## **CERTIFICATE-I**

This is to certify that this thesis entitled, **“Micrometeorological studies in soybean under different environments and evaluation of ‘SOYGRO’ model”**, submitted for the degree of **Doctor of Philosophy**, in the subject of **Agricultural Meteorology** to the CCS Haryana Agricultural University, is a bonafide research work carried out by **Ajit Singh (2002A52D)** under my supervision and that no part of this thesis has been submitted for any other degree.

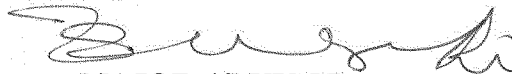
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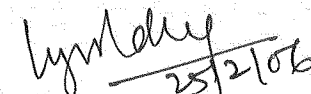
  
**[V.U.M. Rao]**  
Chairman  
Advisory Committee  
Professor & Head  
Dept. of Agricultural Meteorology  
CCS Haryana Agricultural University  
Hisar-125 004, India

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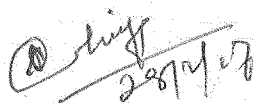
## CERTIFICATE-II

This is to certify that this thesis entitled, "**Micrometeorological studies in soybean under different environments and evaluation of 'SOYGRO' model**", submitted by **Ajit Singh (2002A52D)** to the CCS Haryana Agricultural University in partial fulfilment of the requirements for the degree of **Doctor of Philosophy**, in the subject of **Agricultural Meteorology** has been approved by the Student's Advisory committee after an oral examination on the same.

  
MAJOR ADVISOR 27/2/06

  
EXTERNAL EXAMINER 25/2/06

  
HEAD OF THE DEPARTMENT 27/2/06

  
28/2/06

DEAN, POST-GRADUATE STUDIES

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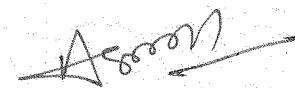
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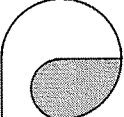
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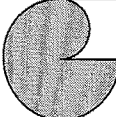
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## LIST OF ABBREVIATION

|                  |   |                                     |
|------------------|---|-------------------------------------|
| A                | : | Sensible heat flux                  |
| AGDD             | : | Accumulated growing degree days     |
| AHTU             | : | Accumulated helio-thermal units     |
| APTU             | : | Accumulated photo-thermal units     |
| D                | : | Deviation                           |
| DAS              | : | Days after sowing                   |
| DM               | : | Dry matter                          |
| EMF              | : | Emergence                           |
| G                | : | Soil heat flux                      |
| HUE              | : | Heat use efficiency                 |
| LAI              | : | Leaf area index                     |
| O                | : | Observed                            |
| PAR              | : | Photosynthetically active radiation |
| PM               | : | Physiological maturity              |
| P                | : | Predicted                           |
| R <sub>n</sub>   | : | Net radiation                       |
| R <sub>s</sub>   | : | Incoming solar radiation            |
| RUE              | : | Radiation use efficiency            |
| T <sub>b</sub>   | : | Base temperature                    |
| T <sub>c</sub>   | : | Canopy temperature                  |
| T <sub>max</sub> | : | Maximum temperature                 |
| T <sub>min</sub> | : | Minimum temperature                 |

## CHAPTER-I

### *Introduction*

---

The Eastern half of North China and Manchuria are believed to be the primary centre of origin of soybean [*Glycine max.* (L) Merr.]. Soybean tops in the world production of both among oilseeds and edible oils. The USA, Brazil, China, Argentina and India are the top five countries in area and production of soybean.

In India initially growing of soybean was limited to mid hills of Himalayas. But its nutritional make-up and industrial usage has promoted a shift in its cultivation to plain areas like M.P, U.P, Rajasthan, Maharashtra and Haryana after the introduction of the commercial cultivar Bragg from U.S.A in 1968. Soybean perhaps is the best crop to meet the dietary requirement of huge vegetarian population in the country. Soybean seeds contain as high as 40-42 per cent good quality protein and about 19-20 per cent oil content. The major fatty acids of soybean oil are linoleic acid (about 54%), linolenic acid (7%), stearic acid (5%), palmitic acid (10%) and oleic acid (24%).

Soybean has emerged as the third important oilseed crop next only to groundnut and rapeseed mustard in India. The present world soybean production is around 216.9 million metric tones (SOPA, 2004) and India rank 5<sup>th</sup> in the world in soybean cultivation grown over 7.28

million hectares with a production of 6.0 million metric tones (SOPA, 2004). However, the average productivity of soybean in our country is lowest i.e., 1244.2 kg/ha in comparison to world average of 2148 kg/ha (Hegde, 2004). The productivity is also lowest among the leading soybean producing countries for number of genetic, physiological and climatic factors.

Madhya Pradesh is called a 'soybean state', as it alone contributes around 76 per cent of the total area under soybean in the country. There are bright prospects for soybean cultivation in states like Rajasthan, Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh, Punjab, Haryana and Bihar etc. (Bhatnagar and Tiwari, 1997). It can be a good substitute for rice during *kharif* season which is intensively followed in the exhaustive rice-wheat cropping systems in the states like Punjab, Haryana and Andhra Pradesh to achieve the desired diversification. Being a legume crop, it is also a source for symbiotic nitrogen fixation in soil alongwith its high nutritional value and lower water requirement.

Soybean being a highly versatile crop, it can be grown over fairly wide range of climate and soil. However, soybean is highly sensitive to the latitudes rather than longitudes because of its photosensitivity and tolerance to a fair degree of biotic and abiotic stresses. The optimum temperature for rapid germination of soybean is approximately 30°C. According to the National Bureau of Soil Survey and Land Use Planing (NBSS & LUP) Nagpur (Sehgal *et al.* 1990) the predominant soybean growing agro-ecological regions are No. 5 consisting of central (Malwa) highlands with semiarid eco-region with medium to deep black soils

and No. 10 which spreads over central highlands Bundelkhand and Deccan plateau with hot sub humid eco-region.

Soybean is one of the classical short day plants (SDP), most of the genotypes respond as quantitative SDP. The variation of photoperiod sensitivity among soybean genotypes allows the crop to grow successfully across a wide range of latitudes. Photoperiod influence the rate of development in pre- and post-flowering stages. Changes in photoperiod are reported to alter the happening of growth stages, the growth and partitioning of dry matter of photo- and thermo-sensitive short day  $C_3$  plants (Lawn, 1989). This influences to a considerable extent the area of its adoption and time of maturity for different cultivars. Temperature alongwith photoperiod affect the flowering time, subsequently temperature along with humidity affects initiation and development of pods. Thus, soybean growth is influenced by several factors like the genetic make up of the cultivars, soil type, water regime, climatic parameters (temperature, humidity, rainfall, radiation etc.).

The environment, a crop is likely to encounter during its growth and development can be manipulated by various management practices such as time of sowing and selection of crop cultivars. A detailed micro-meteorological study in soybean under different crop growing environments constituted by varying sowing dates and selection of cultivar is therefore imperative to know the phenological behaviour, growth, development and yield variations occurring under different situations and the agrometeorological implications their of. Further, evaluation of widely adopted and used SOYGRO model, and seek the

possibility for its applications under Hisar conditions for its adoption. Such models if properly validated and evaluated can invariably prove an useful tool, not only to predict the yield potential and pricing of the crop, but also aid farmers in determining the environmental factors that limit crop yield under local conditions. SOYGRO is a generic photosynthesis process oriented legume crop model. The major components of the SOYGRO- soybean model are the vegetative and reproductive development; CROPGRO- soybean model was empirical function to modify daily crop canopy photosynthesis relative to CO<sub>2</sub> and air temperature, daily evapotranspiration. The input data required to run the SOYGRO model includes daily weather data such as maximum and minimum temperature, daily solar radiation(derived from sunshine hours data using Angstrom standard formula) and rainfall, soil albedo, soil water drainage soil moisture at different layers , maximum root depth, crop genetic coefficient and management practices( date of sowing, plant population, spacing etc.).

While scanning the literature one fails to find much useful and relevant information on the aspects listed above for soybean crop in the country in general, and Haryana in particular. It was therefore, felt necessary to undertake a study to work out the micrometeorology of soybean under different environments and evaluate the SOYGRO'. The use of a crop simulation model provides a suitable tool to evaluate the crop potential under different management and environment factors and their interactions.

Keeping in view the problems outlined and possible solution in sight discussed above, the present investigations entitled

**Micrometeorological studies in soybean under different environments and evaluation of “SOYGRO” model’** were therefore conducted to achieve the following objectives:

**OBJECTIVES**

- 1) To study the effect of sowing time and crop variety on phenology, growth and yield of soybean
- 2) To quantify the micrometeorological variations in different soybean varieties grown on different dates
- 3) To validate the ‘SOYGRO’ model and conduct sensitivity analysis using the field experiment data

## **CHAPTER-II**

### *Review of Literature*

---

Review of literature presented here, covers only those aspects, which are pertinent to the present study and reviewed under the following heads:

2.1 Soybean response to date of sowing and cultivars

2.2 Soybean response to soil moisture status

2.3 Soybean response to micro environmental factors

2.3.1 Micro-meteorological studies

2.3.2 Temperature and vapor pressure profiles

2.4 Phenological response in soybean

2.5 Soybean growth and yield simulation models

#### **2.1 SOYBEAN RESPONSE TO DATE OF SOWING AND CULTIVAR**

Date of sowing is an important factor influencing phenology, yield potential and water use efficiency of field crops. Optimum date of sowing provides proper environmental conditions for optimum germination, vegetative and reproductive growth, yield and optimum utilization of available soil moisture and nutrients by roots.

Boerma and Ashley (1982) found that the optimum planting time for soybean in the south-eastern USA is early May to mid-June. They

also reported that the premature flowering induced by short days was the major seed yield reduction factor in early planting dates.

Anderson and Vasilas (1985) found that the delayed planting after mid-May decreased grain yield by decreasing number of seeds, dry matter and poor mobilization of assimilates to the developing seeds.

Bravesman (1986) reported that the delay in planting delayed the maturity but the number of days to maturity was still reduced.

Park *et al.* (1987) recorded decreased LAI and total plant dry weight under late sowings. They also concluded that the higher seed yield in early sowing was attributed to more number of pods per plant, more number of seeds per pod and higher 100 seed weight.

Singh *et al.* (1987) stated that the early sown crop (15 June) had longer duration of vegetative and reproductive phases and exerted favorable effect on LAI, RGR, PAR, interception, pods per plant, grain weight and higher yield of soybean as compared to the late sown crop (30 June and 15 July).

<sup>et al.</sup>  
Lee<sup>1</sup> (1988) reported that the seed weight was reduced under delayed sowing which was positively correlated with days to flowering, leaf number at flowering, stem length, number of nodes on main stem and maturity duration.

Hatam and Khalif (1989) reported that the number of days to flower initiation, 50% flowering, pod formation, pod filling and maturity were reduced under late (15 May) as compared to early (8 April) sown crop.

Shah and Hatam (1990) reported decreased seed yield under delayed sowing when three soybean cultivars were sown on different sowing dates commencing in early May at 15 day interval.

Potdar and Asmatoddin (1991) found that the soybean cultivars sown on 9 June, 17 June (at the onset of monsoon) or 5 July produced seed yields of 0.65, 0.64 and 0.48 t/ha respectively. However, seed yield did not differ significantly between cultivars.

Sahoo *et al.* (1991) reported that the June month sown crop produced higher seed yield (1.20 to 1.27 t/ha) as compared to July month sown crop. They also reported that seed yield was positively correlated with cumulated mean daily temperature and mean photo-period, and negatively correlated with sun shine hours.

Sharma *et al.* (1991) reported decrease in seed yield with delay in sowing at Jabalpur (MP).

Shimada *et al.* (1991) found that the early sowing resulted into increased vegetative growth and seed filling period, which was contributed to increased seed yield in soybean.

Singh and Singh (1991) reported seed yield of 3.52, 2.99, 2.61 and 2.08 t/ha when sown on 31 May, 15 June, 30 June and 15 July, respectively. They also reported decreased 100-grain weight from 15.4 to 11.4 g with successive delay in sowing from 31 May to 15 July.

Ramesh and Gopalasamy (1992) recorded that the planting of soybean on 16 June resulted into higher leaf area, shoot dry matter, number of pods/plant and seed yield than mid May sowing. Sharma (1994) found that the average number of days to maturity deceased

from 153 to 83 days when sowing was delayed from 10 May to 10 August.

Jasani *et al.* (1994) found that the number of pods/plant and test weight decreased with delay in sowing and hence seed yields were lower under delayed sowing dates.

Karmakar and Bhatnagar (1995) observed that under normal sowing (up to 30 June) soybean cultivar PK-472 was the most suitable cultivar for higher seed yield.

Shishodia and Singh (1995) revealed that the average seed yield decreased with delay in sowing and was the highest in cultivar PS-564.

Mayers *et al.* (1996) observed that the dry matter accumulation during the vegetative phase was limited primarily by cumulative PAR interception by the crop canopy rather than the efficiency of conversion of intercepted PAR.

Yang and Fan (1996) reported a significant correlation between sowing dates and seed yield. Rani (1997) revealed that yield decreased markedly with delay in sowing (1.28 t/ha decreasing to 0.68 t/ha). However, the seed yield did not differ significantly among cultivars.

Egli (1998) reported the soybean yield changed with environmental changes whether induced by cultural practices or abiotic stresses mainly through effects on number of seeds/unit area.

Batwal *et al.* (2004) in a study conducted in Maharashtra concluded that the plant height, dry matter, number of pods, test weight and seed yield was higher in S<sub>1</sub> (25 SMW sowing) as compared to S<sub>2</sub> (26 SMW), S<sub>3</sub> (27 SMW), S<sub>4</sub> (28 SMW) and S<sub>5</sub> (SMW) sowing.

Pedersen and Josph (2004) reported that the early planted soybean had more total dry matter than the late planted.

## **2.2 SOYBEAN RESPONSE TO SOIL MOISTURE STATUS**

Soil moisture is an utmost important factor influencing the crop production and the performance of crop greatly depends upon its optimum availability particularly under limited water status.

Shivakumar and Shaw (1978) reported that the plant growth is directly affected by deficit of water in plant and indirectly by soil water deficit and atmospheric stress. They also observed that the stomatal conductance and leaf water potential in soybean were closely related to changes in soil water potential. The relative growth rate of soybean showed a negative correlation with stomatal conductance, leaf water potential and rate of leaf area expansion.

Al-ithawi *et al.* (1980) concluded the consumptive water use, total dry matter, seed yield of soybean and uptake of all nutrients increased under high soil moisture levels.

Meckel *et al.* (1984) observed reduced soybean yield under moisture stress. However, seed growth rate (mg/seed/day) was not affected indicating that seed filling period was shortened and being more sensitive to moisture stress than seed growth rate.

Smiciklas *et al.* (1992) examined the soybean seed quality response to drought stress and concluded that variable seed quality resulting from drought stress can be attributed to the timing of stress and pod position on the plant.

Sridhara and Thimmegowda (1994) reported that the reduction in seed and biomass yield were higher when moisture stress conditions occurred during both flowering and pod filling as compared to moisture stress during pod filling stage.

## **2.3 SOYBEAN RESPONSES TO MICROENVIRONMENTAL FACTORS**

### **2.3.1 Micro-Meteorological studies**

The greatest annual input to solar radiation occurs in sub-tropical regions in latitudes between 20° to 30° and corresponding low rainfall (Cooper, 1970).

Andre and Viswanathan (1983) recorded the albedo value in order of 0.12 to 0.26 over soybean and they indicted that it was inversely related to height.

Johnson (1987) studied the leaf reflection and transmittance in soybean. Near normal incidence, directional hemispherical reflection and transmittance of *in-situ* individual leaves of soybean were characterized as a function of wave-lengths and growth. He reported that the visible reflection and transmittance decreased as leaves expanded, but increased after full leaf expansion. An opposite pattern was observed near infrared radiation reflection. Reflection and transmittance properties of adaxial and abaxial surfaces differed by as much as an absolute 5% which were attributed to the dorsi-ventral morphology of soybean leaves. The positive effects of narrow vs. wide-row culture might be due to increased LI during the vegetative (E to R1) or reproductive stages (R1-R7).

Rochette *et al.* (1995) reported that RUE of soybean was low in the early season and then remain fairly stable after that. Sinclair and Muchow (1999) reported that the radiation use efficiency (RUE) for soybean tends to be lower than that reported for other species. The mean maximum RUE value in six studies was  $1.02 \text{ g MJ}^{-1}$ . Curiously enough, the two highest RUE values ( $1.26$  and  $1.15 \text{ g MJ}^{-1}$ ) were both reported from Japan.

Samui, *et al.* (2002) conducted a comparative study of radiation balance components at different growth stages on soybean crop and bare soil at Central Agrometeorological Observatory, Pune, during the *kharif* season 1995 and found that the net and reflected radiation and albedo over crop canopy were higher by 7, 26 and 25 per cent, respectively than bare soil. The net short wave (absorbed) radiation and net long wave (outgoing) radiation evaluated over the crop canopy were less than those over bare soil *i.e.* 5 and 20 per cent, respectively. The mean daily global solar radiation during the crop growing season was  $19.2 \text{ MJm}^{-2}$ . The highest albedo (26 per cent) of the crop recorded in the 10<sup>th</sup> week after the sowing (WAS) was in correspondence to maximum LAI (5.9) observed at pod formation stage.

Sunil (2005) at CCS HAU, Hisar reported that the AGDD, AHTU, APTU, RUE and HUE were more in early sown crop as compared to delayed sown crop. He also found that soybean cultivar PK 416 followed by DS 9814 accumulated higher AGDD, AHTU and APTU and also recorded higher RUE and HUE as compared to other two cultivars namely, PS 1042 and SH 40.

### 2.3.2 Temperature and Vapor pressure profiles

Rosenberg (1974) reported that the profiles of vapour pressure in soybean crop above the ground surface were almost always lapse except when condensation was occurring. The shape of the vapour pressure profiles varied throughout the day. At dawn it may be nearly isolines. As the day progress with increasing evaporation or transpiration, the vapour concentration near the surface increases with increasing windiness and turbulence, so that by mid-day profiles showing a steep lapse in vapour pressure. Profiles were nearly isolines at 0900 hrs and 1700 hours in all treatments and the profile again become moderate. He also depicted the temperature profile in soybean and reported that the temperature profile showed sharp lapse during mid-day to inversion condition early in the evening.

Baldocchi *et al.* (1983) studies the microclimate in soybean and found that vapor pressure profiles was generally lapse through out the day with a strong gradient in the upper canopy and a weak gradient in the lower canopy. The influence of leaf orientation, pubescence and water-stress on vapor pressure profiles was not discernable.

Ghadekar (2001) reported that the germination is most critical stage to temperature and requires 8 to 10°C for germination in soybean. Excessive cold, moisture or prolonged drought caused injury to soybean crop. The most optimum temperature for its growth was 24 to 30°C. The minimum temperature for most growth process is 10°C. This temperature can be taken as a lower threshold (base) temperature. Total heat units requirement was about 2400 day °C.

Shamim (2003) at CCS HAU, Hisar reported that the relative humidity profiles showed reverse trend with temperature profiles throughout the crop duration in soybean.

Sundari, (2003) from Tamil Nadu observed that the highest grain yield of soybean was obtained from 15 June sowing during *kharif*-2002. Maximum temperature showed a positive effect on number of pods per plant, 100 grain weight and grain yield during the vegetative and ripening stages. Minimum temperature showed a positive effect on different yield components during the vegetative stage, but a negative effect during the other stages.

Sunil (2005) at CCS HAU, Hisar found that the temperature profile and relative humidity profile were reversed but the inclination of the temperature profiles was greater at vegetative stage in soybean.

## **2.4 PHENOLOGICAL RESPONSE OF SOYBEAN**

Lee *et al.* (1993) observed that the seed weight was reduced due to delay in sowing which was positively correlated with days to flowering. Shah and Hatam (1990) reported reduced number of days to flower initiation, 50% flowering, pod formation, pod filling and maturity when sowing delayed from 8 April to 15 May.

Kolak (1990) found that the flowering stage, reproductive period and crop duration were significantly affected by sowing date and best yields were obtained when sowing of soybean was done between 10 and 20 April.

Lal *et al.* (1993) Jabalpur (MP) calibrated the SOYGRO model with concentration of CO<sub>2</sub>, maximum, minimum temperature and

rainfall and found that the soybean to be more sensitive to higher heat units than normal and also observed the swings in the continuity of monsoon during the cropping season had adversely affect the crop development and yields. Dhingra *et al.* (1995) reported that 45 days delay in sowing (5 June to 20 July) curtailed the vegetative period by 26 days and reproductive phase by 14 days. Total maturity period of the crop was cut down from 145 days in 5 June sown crop to 131, 117 and 105 days in 20 June, 5 July and 20 July sown crops, respectively. There were large fluctuations in accumulated heat units and helio-thermal units at various phenophases under different dates of sowing.

Bhatia *et al.* (1997) reported that the initiation of flowering and the start of the pod development stages were the most susceptible to variation in photo period. Early maturing genotypes appeared to be less sensitive to photoperiod as compared to late maturing genotypes.

Sales *et al.* (1999) reported that the number of days to flowering, ripening and harvesting and crop yield was positively correlated with sowing time.

Veni and Murthy (2003) Hyderabad (AP) showed that the increase in soybean yield with appropriate sowing time and they also observed the magnitude of mean yield loss 22.8 per cent by the late sown crop

## **2.5 SOYBEAN GROWTH AND YIELD SIMULATION MODELS**

Not much work has been done on soybean crop on dynamic growth and yield simulation modeling in India. Recently the dynamic growth and yield simulation model 'SOYGRO' US 42 has been developed at University of Florida by making numerous changes to the

earlier version of SOYGRO. Some other models have also been reported from USA to simulate the growth and yield of soybean.

Henderson and Badhwar (1984) proposed a model for soybean development stages but on direct relationship between remotely sensed spectral data on landsat bands. No difference in model performance was detected between early and late sowing fields, small or large field or high or low yielding fields.

Hood *et al.* (1987) performed computer analysis of soybean irrigation management strategies using the modified crop growth simulation model (SOYGRO) for the centre pivot irrigation system in south-east costal plain region of USA. The irrigation strategies included threshold and refill levels, which were percentages of non-available of soil water and based on crop phenology. A growth phase development (GDP) strategy gave higher average stimulated economic return than the constant refill level.

Camargo *et al.* (1988) estimated potential yield of seven soybean cultivars as a function of sowing date with the help of modified model incorporating productivity coefficient and reported the variations within the cultivars at different sowing dates. Egli *et al.* (1988) attributed the reduction in seed yield to reduction in number of seeds/m<sup>2</sup> and weight per seed under delayed sowing.

Sarti and Jones (1989) described a simulation model of soybean production for tropical Mexico. The model calculated soybean production levels in two situations, one at optimal conditions for growth and the other when water is a limiting factor. Model results showed satisfactory agreement with values obtained by field

experimentation and may, therefore, be used with reasonable limit as an auxiliary research tool.

Board *et al.* (1990) used soybean seed yield components since the seed yield criteria was not promising because of their high variation and the difficulty for assessing them in production environments.

Yazer (1991) compared the simulated and measured soybean plant and soil data favourable until 1 August in all plots but at later dates dry weight, LAI and SMC (soil moisture content) were underestimated by the model except in the non-irrigated treatment. The model predicted slower development during the first two reproductive stages but compared well with field observations during later stages. Further, the model over-estimated the seed yield in irrigated treatments but under-estimated yield from limited or no irrigation plots.

Egli and Bruening (1992) reported decreased simulated soybean yield in cv. Willium under June sowing, when there was no water stress. Increased maximum and minimum temperature by 20 per cent during the reproductive growth, decreased the simulated yield of cv. Willium sown in June but increased the yield of cv. Essan. Increased insolation by 20 per cent increased the simulated yield of both cultivars. The result indicated that lower insolation during reproductive growth was primary cause of reduced yield from delayed sowing and low temperature contributed to lower yield only for the late maturity cultivars.

Peterson *et al.* (1992) showed the potential soybean seed number per area is determined about 10-12 days after the start of seed filling.

Allison *et al.* (1995) calibrated 'SOYGRO' model (version 4.2) under irrigated condition in central Portugal. The calibrated model satisfactorily predicted soybean phenology, leaf area index, dry matter accumulation, pods and seed dry weight.

Board and Tan (1995) observed that the soybean yield potential can be affected by a number of plant components *viz.*, number of seeds per pod, pod number per unit area, pods per reproductive node, reproductive node per unit area, number of node per unit area, and fraction of nodes becoming reproductive (%). Here, a reproductive node is a node having at least one developed seed. They also reported that the node number per area is determined between emergence and the start of seed filling.

Coloson (1995) adopted a model (SOYGRO) to European crop condition with respect to genetic parameters for pod set, pod growth, seed set and seed enlargement. The structure of reproductive development in the model, takes into account the hierarchy in assimilate partitioning for pod addition, and seed initiation, the validation of pod production and yield and provided good agreement with field data collected over several locations in Europe. Maize, SOYGRO and PNUTGRO compared the potential (no water stress) and the lowest (no irrigation) yield for maize, soybean and groundnut. Fifteen most severe drought years out of the 53 years period were selected in Georgia, USA. The simulated yield losses averaged 75 per cent for maize, 73 per cent for soybean and 64 per cent for groundnut.

Gerdes *et al.* (1995) reported that the calibrated model satisfactorily predicted soybean phenology, leaf area index, dry matter

accumulation and seed dry weight. The best simulated irrigation plan was the weekly water supply of 30 mm in first four week after sowing followed by the amount of 30 mm at an interval of 4 days.

Piper *et al.* (1996) compared the phenology model in SOYGRO V 5.42 with the phenology model in CROPGRO V 3.0 for prediction of flowering and maturity date. Based on the root mean square error (RMSE) criterion between predicated and observed dates, SOYGRO and CROPGRO predicted flowering equally well. Development rate after flowering was under-predicted by SOYGRO in cool environments so that in some years maturity was predicted very late. CROPGRO decreased the RMSE for prediction of maturiy date compared with SOYGRO model especially for early maturing cultivars.

Wang *et al.* (1997) concluded that the accurately prediction of days to flower in soybean is important because the time between emergence to flowering determines the plant size and thus affects dry matter production and final crop yield. A cold temperature affects the flowering, dry matter production and yield.

Egli (1998) showed that the soybean yield components *viz.* seed number per area, number of grains per pod and yield per area affect on low environmental changes

Bhatia, *et al.* (2000) in a field study conducted in 1992-93 at Indore, Madhya Pradesh, India, where 12 soybean cultivars were sown on 5 dates between 20 June and 30 July reported that there were significant difference for yield and most of the yield components among sowing dates and cultivars. Yields decreased with delay in sowing.

Sundari (2003) conducted an experiment during the *kharif* season of June-July 2000 in Tamil Nadu, India to investigate the effects of weather parameters (maximum/minimum temperature, mean relative humidity, mean sunshine and total rainfall) of the optimum sowing time of soybean and the sowing date were 1 June, 15 June, 1 July and 15 July and observed that the highest grain yield was obtained from the 15 June sowing. Maximum temperature showed a positive effect on pods per plant, 100-grain weight and grain yield during the vegetative and ripening stages. Minimum temperature showed a positive effect on the different yield components during the vegetative stage, but a negative effect during the other stages. Crops sown on 15 June of showed the maximum yield and also indicate that high relative humidity delayed maturity, while high sunshine hours increased the maturity of the crop.

Batwal *et al.* (2004) undertook studies in Maharashtra, India, to determine the appropriate meteorological week for sowing soybean cv. MACS-124 in *kharif* 2000 and the sowing was done over five standard meteorological weeks [25 SMW (S<sub>1</sub>), 26 SMW (S<sub>2</sub>), 27 SMW (S<sub>3</sub>) 28 SMW (S<sub>4</sub>) and 29 SMW (S<sub>5</sub>)]. The growth characters, except leaf area per plant, were all influenced by the sowing date and observed that plant height was higher in S<sub>1</sub> than the remaining sowing date except S<sub>2</sub>. Among the treatments, the mean dry matter was highest in S<sub>1</sub> but was at par with S<sub>2</sub>. The number of pods, test weight and seed yield were highest in S<sub>1</sub> among all treatments.

Kaur *et al.* (2004) used the dynamic simulation model 'SOYGRO' to predict soybean growth and yield from 1997 to 1999 at Ludhiana for

the commonly grown cultivars, PK 416 and SL 295. The simulated phenological 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. The model predicated the seed yield to be within 98-124% and pod yield to be within 75-111% of the observed values. The results obtained with the model for the three consecutive crop seasons revealed satisfactory prediction (except for 1999 season) of phenology, growth and yield of soybean.

## CHAPTER-III

### *Materials and Methods*

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The present investigations on “**Micrometeorological studies in soybean under different environments and evaluation of ‘SOYGRO’ model**” were conducted during two consecutive *kharif* (summer) seasons of 2004 and 2005. The details of materials used and techniques adopted during the course of investigation are described in this chapter.

#### **3.1 EXPERIMENTAL SITE AND LOCATION**

The field experiments were conducted at the Research Area of Department of Agricultural Meteorology, Chaudary Charan Singh Haryana Agricultural University, Hisar (29°10'N latitude 75°46'E longitude and altitude of 215.2 m above mean sea level).

#### **3.2 WEATHER AND CLIMATIC CONDITIONS OF THE REGION**

Hisar is situated in semi-arid sub-tropics and owing to its continental location on the outer margins of monsoon region *i.e.* 1600 km away from ocean it has typical dry climate. The maximum temperature of around 45°C during summer months of May and June is common for the place. On the other hand, the minimum temperature can touch very low and even fall below the freezing point accompanied by frost on occasion in winter months of December and January. The

main rainy season in the region is during the summer season which extends over July to September months and almost 80% of annual rainfall occurs during this period due to south western monsoon. A few showers also occur during the months from December to February from the western disturbances. The annual rainfall variation ranges between 45 to 50 per cent. The average annual rainfall in the tract is 450 mm. The weekly weather data recorded at agromet observatory close to the field site during soybean growing season 2004 and 2005 are depicted in Fig. 2 in next chapter (Appendix-I & II).

### 3.3 SOIL CHARACTERISTICS OF THE EXPERIMENTAL FIELD

The soils of this area are derived from Indo-Gangetic alluvium deposits and are sandy loam in texture.

Mechanical and chemical analysis was done to know the important characteristics of the soil. The soil samples from different depths were drawn from four locations in the experimental field. Composite samples were prepared for different depths by through mixing. The samples were then analysed adopting the standard methods to know the mechanical composition and the important chemical characteristics. The results obtained are shown in Table 1 and 2.

**Table 1: Mechanical Analysis of soil**

| <b>Soil depth<br/>(cm)</b> | <b>Sand<br/>(%)</b> | <b>Silt<br/>(%)</b> | <b>Clay<br/>(%)</b> | <b>Textural Class</b> |
|----------------------------|---------------------|---------------------|---------------------|-----------------------|
| 0-15                       | 57.0                | 25.3                | 17.7                | Sandy loam            |
| 15-30                      | 55.0                | 26.8                | 18.0                | Sandy loam            |
| 30-60                      | 54.0                | 22.1                | 23.0                | Sandy clay            |
| 60-90                      | 52.0                | 25.2                | 22.8                | Loam                  |

**Table 2 : Chemical composition of soil**

| Particulars                   |      | Methods used                                              |
|-------------------------------|------|-----------------------------------------------------------|
| PH (1:2)                      | 8.2  | Glass electrode pH meter (Jackson, 1973)                  |
| EC (dsm <sup>-1</sup> )       | 0.40 | Conductivity bridge method (Richards, 1954)               |
| Organic carbon (%)            | 0.39 | Walkeley and Black rapid titration method (Jackson, 1973) |
| Available nitrogen (kg/ha)    | 90   | Alkaline permanganate method (Subbhiah and Asija, 1956)   |
| Available phosphorous (kg/ha) | 20   | Olsen's method (Olsen <i>et al.</i> , 1954)               |
| Available potassium (kg/ha)   | 291  | Flame photometer method (USDA) Handbook (Richards, 1954)  |

The chemical analysis of soil showed that the soil of experimental field was slightly alkaline in reaction, low in organic carbon, low in available nitrogen, medium in available phosphorous and high in available potassium.

### 3.3.1 Crop history

The crop of the experimental field for the previous season is presented below the Table 3 :

**Table 3 : Crop history of experimental field**

| Year | Kharif   | Rabi    |
|------|----------|---------|
| 2002 | Dhaincha | Mustard |
| 2003 | Fallow   | Mustard |
| 2004 | Soybean  | Barley  |
| 2005 | Soybean  | Barley  |

### 3.4 EXPERIMENTAL DETAILS

The experiment was laid out in split plot design with soybean cultivars. The details of which are being given below:

**Site:** Research Farm, Agricultural Meteorology, CCS HAU, Hisar

**Crop season:** *Kharif*-2004 and 2005

**Crop:** Soybean (*Glycine max* L.)

**Experimental design:** Split plot design

**Replications:** Four

**Main plot treatments:** Three dates of sowing

**D<sub>1</sub>:** 1<sup>st</sup> week of June      **D<sub>2</sub>:** 3<sup>rd</sup> week of June      **D<sub>3</sub>:** 1<sup>st</sup> week of July

**Sub plot treatments:** - Four cultivars

**V<sub>1</sub>:** SH-40      **V<sub>2</sub>:** DS-9814      **V<sub>3</sub>:** PK-416      **V<sub>4</sub>:** PS-1042

**Plot size**

Gross: 6.0 m X 4.5 m

Net: 4.0 m X 2.7 m

**Spacing**

Row to row: 45 cm

Plant to plant: 10 cm

### 3.5 CULTURAL OPERATION

#### 3.5.1 Land preparation

Ploughing was done pre-sowing irrigation. Two harrowing each followed by planking was done. When the field comes in vatter

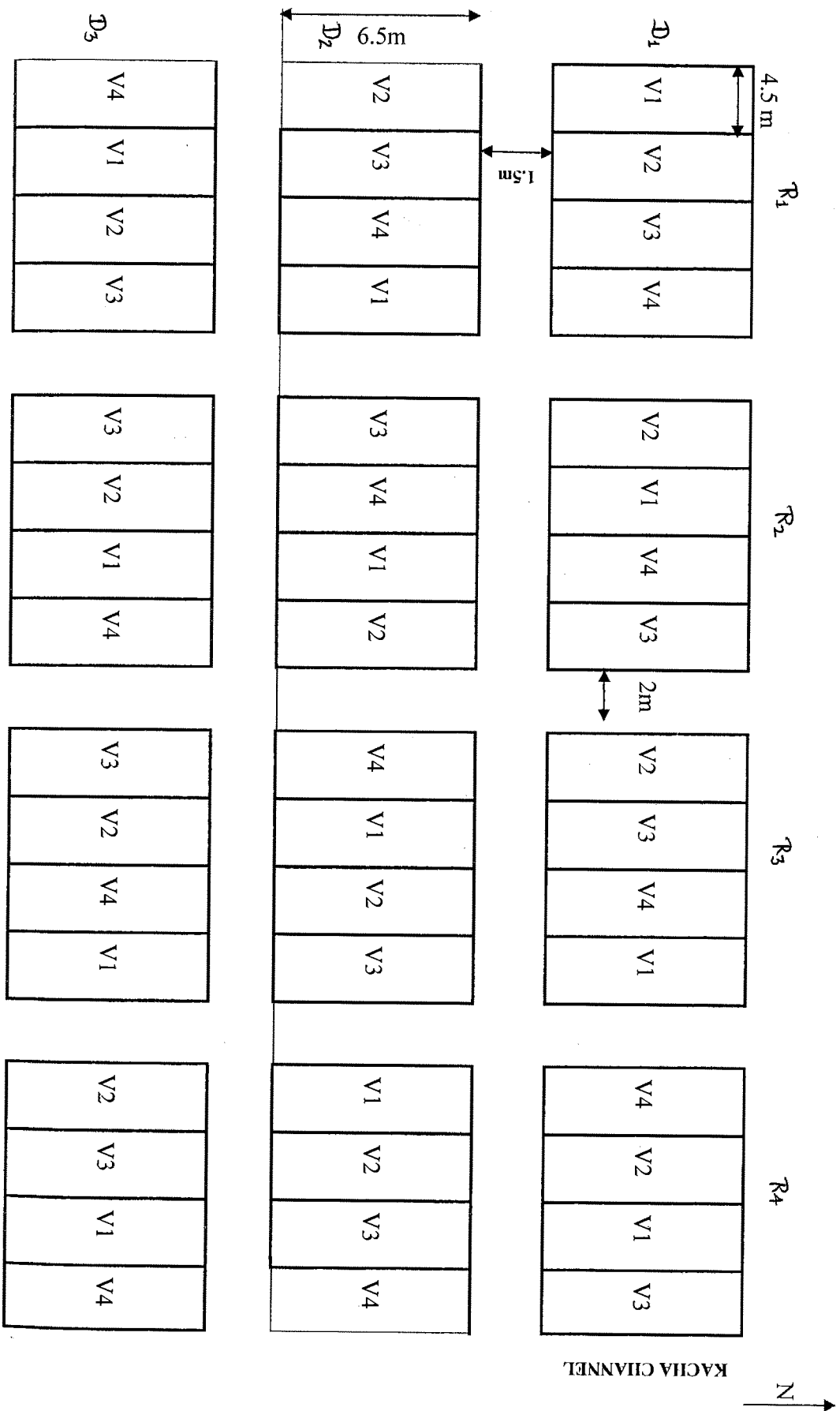


**Fig. 1 : Layout of experimental field**

condition after pre sowing irrigation to prepare fine compact seed bed with sufficient moisture at seeding depth.

### **3.5.2 Seed and Sowing methods**

The crop was sown by hand drawn plough by *pura* method as per experimental layout. The soybean was sown on three date of sowing *viz*, 1st week of June, 2nd was 3<sup>rd</sup> week of June and third was 1st week of July during 2004 and 2005. Sowing was done at 45 cm row spacing, at 4 cm depth using 75 seed kg/ha.

### **3.5.2 Fertilizer application**

The fertilizer was applied as per the recommendation contained in Package of Practices for soybean crop prescribed by CCS HAU, Hisar. The basal application of Nitrogen at 25 kg/ha and 80 kg P<sub>2</sub>O<sub>5</sub> /ha through Urea (46-0-0) and DAP (18-46-0), respectively was done to meet the initial requirement of the crop.

### **3.5.3 Thinning, gap filling and weeding**

The first hoeing was done after 15 days after sowing to control weeds and provides aeration to plant roots. Second hoeing was done at 30 days after sowing. Thinning was done manually after three weeks of sowing for each treatment to maintain the plant-to-plant distance 5 cm.

### **3.5.4 Harvesting and threshing**

Rows from 2 meters on either side of net plot and 1.8 meter on either side were harvested as borders for minimizing the experimental error. Harvesting was done after 145 days after sowing for first treatment, 130 days after sowing for second treatment and 115 days after sowing for third treatment. Harvested plants were spreaded on the

field itself for sun drying to reduce the moisture content in seed. Threshing was done by using power drawn thresher.

### **3.6 OBSERVATIONS RECORDED**

Daily meteorological data were taken from Agro meteorological observatory situated just 10 meter away from the experimental field and presented in appendix 1

#### **3.6.1 Soil moisture content**

Soil moisture content was determined from 0-15, 15-30, 30-60 and 60-90 cm soil depth profiles by the gravimetric method. The gravimetric water values were converted to volumetric per cent for respective layers with bulk density values of 1.40, 1.42, 1.44 and 1.46 for respective soil layers. The observations were recorded at phenophases starting from sowing till to physiological maturity.

#### **3.6.2 Micro-meteorological observations**

The following micro-meteorological observations were recorded in the experimental field on days with mainly clear sky at hourly interval trend 0800 to 1700 hours at initiation of flowering (50% of plant population with open flower), end of flowering ( major flushes of flowering ceased with only sporadic flower) pod development and physiological maturity( 95% of all pods lost chlorophyll) stages. The following observations were recorded.

- i) Diurnal PAR observation
- ii) Temperature and Vapor pressure profile
- iii) Canopy temperature ( $T_c$ )
- iv) Energy balance components

### 3.6.2.1 Photosynthetically active radiation (PAR)

Quantum sensor (LICOR, Q-735) was used to measure the amount of intercepted radiant energy (Photosynthetically active radiation in the range of 380-700 nm) above the crop surface and ground surface keeping the sensor 5 cm above the surface. The reflection was recorded by keeping the quantum sensor inverted 5 cm above the surface. The radiation observations were recorded at different growth stages. The reflection, transmission and absorption coefficient were calculated using following formula:

$$\text{A) Reflection coefficient (R)} = R_r/R_o$$

Where,

R- is the reflection coefficient from plant canopy and soil

R<sub>r</sub>- is the reflected radiation from plant canopy and soil surface

$$\text{B) Transmission coefficient (T)} = R_t/R_o$$

Where,

R<sub>t</sub>- transmitted radiation at the soil surface

R<sub>o</sub>- incoming radiation above the crop canopy

$$\text{C) Absorption coefficient (A)} = 1 - (R) - (T)$$

### 3.6.2.2 Air temperature and vapor pressure profiles

Air temperature was measured with the help of Assman psychrometer at ground level, 50 cm, 100 cm and 200 cm heights at early vegetation, 50% flowering, pod development stage and physiological maturity stages. Vapor pressure was compiled by using the psychometric tables. Wherein, the corresponding values were found

for the dry and wet bulb temperatures were worked out at different heights. The values were represented in the form of figures with values of temperature and vapour pressure recorded at different heights in and above the canopy.

### **3.6.2.3 Canopy temperature (Tc)**

Canopy temperature was recorded with the help of infrared thermometer. The canopy temperature was measured at 1430 hours important growth stages *viz.*, at initiation of flowering (50% of plant population with open flower), completion of flowering (major flushes of flowering ceased with only sporadic flower), pod development and physiological maturity (95% of all pods lost chlorophyll). While recording the canopy temperature observations the infra red thermometer was hand held at 45° to the horizontal plane at 1 m height above the canopy.

### **3.6.2.4 Energy balance components**

The energy balance of the cropped field can be represented as per the following equation:

$$R_n = G + A + LE + M_i$$

Where,

$R_n$  = net radiation,  $mW\ cm^{-2}$

$G$  = ground heat flux  $mW\ cm^{-2}$

$A$  = sensible heat flux  $mW\ cm^{-2}$

$M_i$  = Miscellaneous, used in the physiological process by crop plants,  $mW\ cm^{-2}$ . This parameter is generally neglected since the energy utilized in  $M_i$  is less than 1 per cent.

#### **3.6.2.4.1 Net radiation (R<sub>n</sub>)**

Diurnal cycle for the net radiation (difference between the incoming and outgoing radiation) was measured by Net Radiometer at initiation of flowering (50% of plant population with open flower), end of flowering (major flushes of flowering ceased with only sporadic flower) pod development and physiological maturity (95% of all pods lost chlorophyll) at 1 m above the crop canopy.

#### **3.6.2.4.2 Latent heat flux (LE)**

The latent heat flux was calculated using the following formula:

$$LE = (R_n - G) / (1 + \beta)$$

Where,

$\beta$  = is Bowen ratio ( $0.66 \times dt/de$ )

dt= temperature gradient between two height

de= vapour pressure gradient between two height

#### **3.6.2.4.3 Sensible heat flux (A)**

Sensible heat flux was calculated by the formula:

$$A = R_n - G - LE$$

#### **3.6.2.4.4 Soil heat flux (G)**

Soil heat flux was measured with the help of soil heat flux plates, which were embedded in the soil at 5 cm depth in cropped and bare field. The output was recorded with the help of digital multi-voltmeter.

### **3.7 CROP GROWTH OBSERVATIONS**

#### **3.7.1 Plant height**

Plant height was measured at 15 days interval from 30 days onward for five tagged plants/plot selected randomly. The height was measured from the root-shoot junction to the base of apical shoot with a wooden meter scale.

#### **3.7.2 Dry matter accumulation (DM)**

Dry weight consists of everything in the plant except water, including carbohydrates, proteins, oils, and mineral nutrients. These were oven dried at 65°C for 48 hours. The dry samples were weighed for dry matter accumulation.

#### **3.7.3 Leaf area index (LAI)**

Leaf area index is the leaf area per unit area of the ground. This form of growth analysis was formulated by Watson (1958), Green leaf area (cm<sup>2</sup>) was measured from randomly selected three plants with the help of leaf area meter (LI-COR model 3050A) for computation of LAI from five tagged plants all the treatments at different phenological stages starting from 30 days after sowing. Leaf area was measured by using the following formula:

$$\text{Leaf area index} = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Area occupied by plant (cm}^2\text{)}}$$

### **3.8 PHENOLOGICAL OBSERVATIONS**

The crop was inspected at frequent intervals (2 or 3 days) observe the phenological events closely. The following phenological events were recorded emergence date, first true leaf, end of juvenile, flower

initiation, 50 per cent of plant with flower, any where on plant, 50 per cent of plant with least leaf extended , full pod development and 50 per cent of plant at physiological maturity.

### **3.9 AGRO-METEOROLOGICAL INDICES**

#### **3.9.1 Growing Degree Days (GDD)**

The cumulative growing degree-days were determined by summing the daily mean temperature above the base temperature. It states with the assumption that the growth of plants is dependent on the total amount of heat to which it is subjected during its lifetime. This can be worked out by using the following formula:

$$\text{Growing degree days} = \sum \frac{(T \text{ max} + T \text{ min})}{2} - T_b$$

Where,

T max=Daily maximum temperature (°C)

T min=Daily minimum temperature (°C)

T<sub>b</sub> = Minimum threshold/Base temperature (10°C Ghadekar, 2001).

#### **3.9.2 Helio-thermal units (HTU)**

The helio-thermal units for a day represent the product of GDD and the hours of bright sunshine for that day. The sum of HTU for particular phenophases of interest was determined according to the equation:

$$\text{Helio-thermal units} = \sum (\text{GDD} \times \text{BSS} (n))$$

Where,

GDD = growing degree days (°C days hr)

BSS (n) = bright sun shine hours

### 3.9.3 Photo-thermal units (PTU)

The day and night period is one of the basic factors controlling the period of vegetative growth for photosensitive varieties. In case of long day plants the length of night is critical for determining, whether plant will enter into reproductive phase or not. Photo-thermal units are the cumulative value of growing degree days, multiplied by bright sunshine hours. This can be mathematically represented using the following formula:

$$\text{Photo-thermal units} = \sum (\text{GDD} \times \text{N})$$

Where,

GDD=Growing degree days ( $^{\circ}\text{C days hr}$ )

N = Maximum possible sunshine hours

### 3.9.4 Radiation use efficiency (RUE g /MJ)

The radiation use efficiency is a ratio of biological yield and the radiation intercepted. It can be represented by using the following formula:

$$\text{Radiation use efficiency} = \frac{\text{Biomass yield}}{\text{Radiation intercepted}}$$

### 3.9.5 Heat use efficiency (HUE kg/ha/ $^{\circ}\text{C day}$ )

Heat use efficiency is also represented by Thermal Time Use Efficiency (TTUE), which indicates the amount of dry matter produced per unit of growing degree days or thermal time. This was computed by using the following formula :

$$\text{Heat use efficiency} = \frac{\text{Biomass yield}}{\text{Heat units required}}$$

### **3.10. YIELD AND YIELD ATTRIBUTES**

#### **3.10.1 Number of plant/m<sup>2</sup>**

The number of plants was calculated manually over an area of one square metre to represent plant population per m<sup>2</sup>.

##### **3.10.1. Number of branches per plant**

The numbers of primary branches were counted from the three plants, which were randomly selected in each plot at the time of harvesting.

##### **3.10.2. Number of pods per plant**

The numbers of pods from three plants selected randomly from each plot at harvest were counted and mean number of pods per plant was worked out.

##### **3.10.3 Number of grain per pod**

The total number of grains from three plants was counted for each plot and their mean values were worked out.

##### **3.10.4 100-Grain weight (Grain Index)**

One hundred seeds were counted from bulk produce of the net plot for each treatment and the weight was taken in gm per 100 grain using the electronic balance.

### **3.10.5 Grain yield (kg/ha)**

After sun drying of the harvested produce for a few days in plots, threshing was done manually and the produce was weighed to record the yield per net plot. The grain yield was then expressed in kg/ha.

### **3.10.6 Straw yield (kg/ha)**

Straw yield was obtained by subtracting the dry weight of seed from biological yield harvested from the net plot and then converted to (kg/ha).

### **3.10.7 Biomass yield (kg/ha)**

Straw collected from threshed plant of net plots was weighed separately for each plot. The values obtained so were added to grain yield of that plot to give biological yield per plot. It was then converted to biological yield kg per hectare

### **3.10.8 Harvest index (HI)**

The harvest index refers to the partitioning ability of the plant and is its efficiency of grain production as an index, and it was named by Donald (1962) as harvest index. It is calculated by using the following formula:

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Biomass yield}} \times 100$$

## **3.11 STATISTICAL ANALYSIS**

The data on yield and yield parameters in respect of three dates of sowing were analyzed by using split block design as described by Panse and Sukhatme (1961) were followed to analysis the data. The

differences for significance were tested at 5 per cent level of significance. Simple quadratic regression analysis was performed between Crop growth indices and Agro-meteorological indices *vs.* yield and yield attributes.

### **3. 12 SOYGRO MODEL DESCRIPTIONS**

Baier (1979) proposed a classification of model based on time scale, data source approach, purpose and application of selected crop weather model;

- i) Crop weather simulation model that consider the impact of meteorological variables on specific plant processes, which can be adequately simulated variables knowledge.
- ii) Crop weather analysis model producing a running account of the accumulated daily crop response to selected agro-meteorological variables as a function of time (crop developed).
- iii) Empirical statistical model in which one or several variables representing weather/climate, soil characteristic/time trend are statistically related to mostly to seasonal yield/ crop production.

Whistler *et al.* (1986) the crop growth models are classified in various groups as follows:

- a) Empirical/correlative model that describe the relationship between variables without referring to any underlying biological/physiological structure that may exist between variables.
- b) Mechanistic/explanatory models explicating represents the known/ hypothesis mechanism that relates variable and their

observed behaviour. These models represent causality between variable.

- c) Stostics models are based upon the probability of occurrence of some events/ or exogenous variables.
- d) Deterministic (Physiologically, physically based simulation) model are those model whose plant/soil process can be physically or chemically.
- e) Static model (Phenological model) is a broad class of models that predict crop development from one growth status.
- f) Dynamic simulation crop models predict changes in crop status with time as a function of exogenous parameters.

‘SOYGRO’ is a physiologically based dynamic crop growth simulation model that is responsive to daily weather inputs. The SOYGRO (DSSAT) V 3.5 model can predict the following growth and development parameters:-

- i) Dry matter
- ii) LAI
- iii) Crop development
- iv) Final yield

The minimum data required for running ‘SOYGRO’ is given below:-

#### **A) Weather data**

- i) Daily air temperature (Maximum and minimum °C)
- ii) Daily rainfall mm/day
- iii) Daily solar radiation MJ/m<sup>2</sup>/day

**B) Management data**

- i) Planting date
- ii) Row spacing
- iii) Plant population, No. of plants/m<sup>2</sup>
- iv) Cultivar name and maturity group, if known

**C) Crop data****1) Date of phenological events**

- a) First true leaf V-1
- b) 50 per cent of plant with flower, any where on plant
- c) 50 per cent of plant with pod
- d) 50 per cent of plant with last leaf extended
- e) 50 per cent of plant at physiological maturity (R-7)

**2 Growth analysis Data (at four or more dates of season)**

- a) Total dry weight gm<sup>-2</sup>
- b) Total biomass gm<sup>-2</sup>
- c) Seed biomass gm<sup>-2</sup>
- d) Number of pods gm<sup>-2</sup>
- e) Leaf area index

**3. Final Harvest Data**

- a) Number of pods/m<sup>2</sup>
- b) Number of seeds/m<sup>2</sup>
- c) Above ground dry weight g/m<sup>2</sup>
- d) Pod weight g/m<sup>2</sup> (Seed weight)

The 'SOYGRO' model runs in the sequence given below:-

**(A) Input File:**

File 1 : daily weather data file

File 2 ; Soil profile properties

File 5 : Soil profile initiation conditions

File 6 : Treatment management data

File 7 : Genetic coefficient data

File 8 : Crop coefficient

**(B) Model directory Files**

i) Experimental directory file

ii) Weather directory file

**(C) Model validation files**

File A: Measured crop summary data

File: Observed data for graphics

**D) Output files**

Out 1 : Summary output

Out 2 : Simulated crop variables vs. time

Out 3 : Simulated weather and soil variable vs. time

**3.13 Sensitivity analysis**

Sensitivity analysis of SOYGRO model was conducted by changing following parameters:

- 1.) Phenological constants
- 2.) Growth coefficients
- 3.) Soil physical coefficients

The sensitivity analysis for particular constant was done by keeping all other factors constant, only one parameter was varied at a time to determine the effect of variation of coefficients for estimated seed and straw yields.

The following option can be changed in the management of sensitivity analysis section of the model.

A. Cultivar

B. Simulation date

a) Planting date

b) Start of soil water balance

C. Soil series or type of soil

D. Weather data

a) Year and location

b) Site of the experiment conducted

### **3.16 VALIDATION**

After sensitivity analysis of first year crop season the different coefficients were finalized. The model run second season crop field and validated the predicted output by comparing with observed parameters. Deviation of predicted from observed were calculated and accuracy of the model to predict different crop parameters were quantified.

## **CHAPTER-IV**

# *Results and Discussion*

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Field experiments were conducted on soybean crop (*Glycine max* (L) Merr.) during the *kharif* seasons of 2004 and 2005. In the present chapter, an attempt has been made to describe and discuss the salient findings of the research problem entitled “Micrometeorological studies in soybean under different environments and evaluation of SOYGRO model” to achieve the objectives put forth for the study with the help of appropriate tables and figures. The results obtained from the experimental field and SOYGRO model (DSSAT 3.5) have been presented and discussed under the following heads:

### **4.1 Weather conditions prevailed during the crop seasons**

- 4.1.1 Maximum temperature
- 4.1.2 Minimum temperature
- 4.1.3 Relative humidity
- 4.1.4 Bright sunshine hours
- 4.1.5 Rainfall
- 4.1.6 Evaporation

### **4.2 Soil moisture status at different crop growth stages**

### **4.3 Crop growth and development**

- 4.3.1 Crop phenology
- 4.3.2 Plant height
- 4.3.3 Dry matter accumulation
- 4.3.4 Leaf area index

### **4.4 Agrometeorological observations**

- 4.4.1 Growing degree days (GDD)
- 4.4.2 Helio-thermal units (HTU)
- 4.4.3 Photo-thermal units (PTU)
- 4.4.4 Radiation Use Efficiency (RUE)
- 4.4.5 Heat Use Efficiency (HUE)

### **4.5 Micrometeorological observations**

- 4.5.1 Temperature profile
- 4.5.2 Vapor pressure profile
- 4.5.3 Canopy temperature
- 4.5.4 Photosynthetically active Radiation (PAR)
- 4.5.5 Energy balance components

### **4.6 Yield and its attributes**

### **4.7 SOYGRO model**

## **4.1 WEATHER CONDITIONS PREVAILED DURING THE CROP SEASONS**

The daily weather parameters were recorded at Agrimet Observatory CCS HAU, Hisar situated at a distance of 10 m away from the experimental site during *kharif* seasons of 2004 and 2005. The weekly values of weather parameters were worked out and the same have been shown in Fig. 2 and Appendix-I & II.

#### **4.1.1 Maximum temperature**

The mean weekly maximum temperature values during the initial crop establishment phase (22<sup>nd</sup> to 26<sup>th</sup> week during 2004 and 2005) were slightly below normal. Thereafter, it exceeded the normal for about four week period because of break in the monsoon. Subsequently with occurrence of rainfall the day temperature values dipped below normal with few exceptions when the temperature was above normal.

The break in monsoon during vegetative phase led to stress conditions and crop suffered temporarily due to moisture stress owing to high evaporative demand of atmosphere during (2004) crop season. The mean maximum temperature was highest at 40.2 °C in 27<sup>th</sup> week and at 44.1°C in 25<sup>th</sup> week, whereas it was lowest at 28.3°C (44<sup>th</sup> week) and 31°C (37<sup>th</sup> week) during 2004 and 2005 crop seasons, respectively. On an average maximum temperature during two respective growing seasons was 33.7 and 35.4°C and it was higher than the normal.

#### **4.1.2 Minimum temperature**

The mean weekly minimum temperature during the two crop seasons have been depicted in Fig. 2. The mean weekly minimum temperature was above normal for most part of both the crop season (2004 and 2005) except for the month of July (26<sup>th</sup> to 28<sup>th</sup> week) when it exceeded the normal in absence of rainfall activity. The above than normal day and night temperatures in July had a deleterious effect on crop growth and led to higher evapo-transpiration losses. During reproductive phase the minimum temperature was higher than the normal in both crop seasons (2004 and 2005).

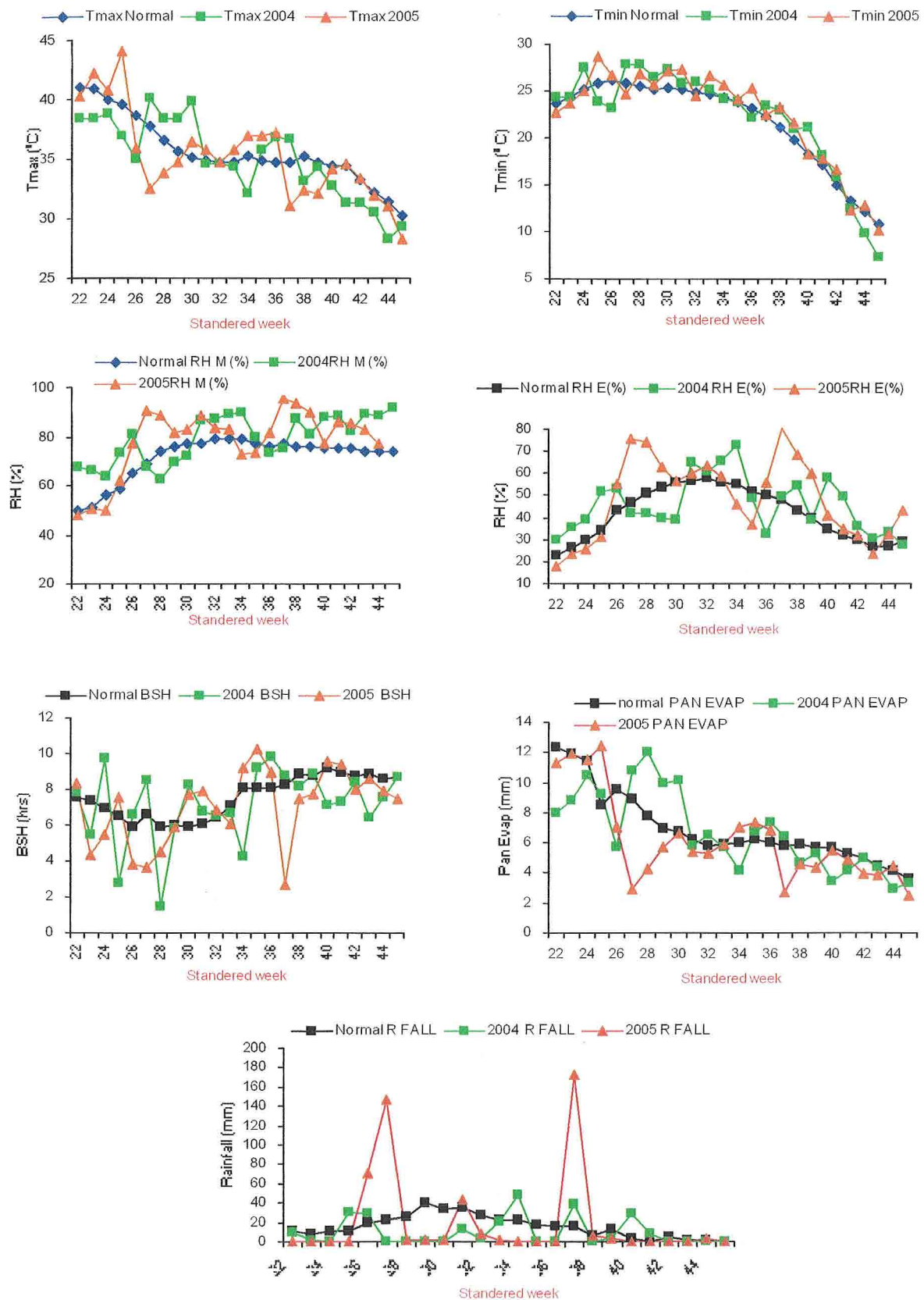


**Fig. 2 :** Mean weekly weather during *kharif* seasons of 2004 and 2005 alongwith their normal values

#### **4.1.3 Relative humidity**

The mean weekly relative humidity values have been shown in Fig. 2. The mean weekly morning relative humidity values were higher than the normal for major part of crop growing season (in both the years with few exceptions occurring from 27<sup>th</sup> to 30<sup>th</sup> week and then from 36<sup>th</sup> to 37<sup>th</sup> week during 2004 and 34<sup>th</sup> to 35<sup>th</sup> week during 2005, where, the morning relative humidity values were lower than normal values due to the higher temperature prevailed, which led to higher evapo-transpiration losses. The mean maximum relative humidity values during two crop seasons was to the tune of 90% (34<sup>th</sup> week) and 95.9% (37<sup>th</sup> week) in 2004 and 2005, respectively.

In the absence of rainfall during July, the mean weekly evening relative humidity values were lower than the normal in 2004 and this was because of the higher daytime temperature and low moisture load in the air. The high temperature coupled with low relative humidity led to elevated evapo-transpiration losses due to increase in atmospheric demand. The 2005 crop season had higher relative humidity throughout the crop growing season than during 2004.

#### **4.1.4 Bright sunshine hours**

The mean weekly bright sunshine hours are shown in Fig. 2. The mean weekly bright sunshine hour values in early crop season were mostly higher than normal. However, during reproductive phase the bright sunshine hours were below normal. The lower bright sunshine hours were due to the cloud cover during the rainy weeks. During 2005 the mean weekly bright sunshine hours followed almost similar trend to that in 2004 crop growing season.

#### **4.1.5 Rainfall**

Heavy rains in the 2<sup>nd</sup> fortnight of June were followed by a long break in rainfall and it extended over the entire month of July (Fig. 2). The rainfall was deficient throughout the crop season except 25, 26, 34 and 41 standard week. A total rainfall of 235.5 mm was recorded in 22<sup>nd</sup>, 23<sup>rd</sup>, 25<sup>th</sup>, 26<sup>th</sup>, 31<sup>st</sup>, 32<sup>nd</sup>, 33<sup>rd</sup>, 34<sup>th</sup>, 37<sup>th</sup>, 39<sup>th</sup>, 40<sup>th</sup> and 41<sup>st</sup> standard weeks during 2004 against the normal of 370 mm. During the 2005 total rainfall of 622.8 mm was recorded. Highest (49 mm, 2004) rainfall was observed during the 34<sup>th</sup> week and 37<sup>th</sup> (172 mm, 2005).

#### **4.1.6 Pan evaporation**

The mean weekly pan evaporation values are shown in Fig.2. The mean weekly pan evaporation values during the crop season followed a trend of rise and fall similar to the one observed in case of maximum temperature. The cumulative pan evaporation amounted to more than 251.6 mm as against the normal of 244 mm during 2005 and thus leading to stress conditions for most part of the growing season, more so during the month of July, when there was a long break in rainfall extending over entire month was quite damaging for the crop during the vegetative phase. However it was less than the cumulative evaporation of September 2005 due to higher rainfall.

#### **4.2 Soil moisture status at different growth stages**

The soil moisture content at different depths recorded under various treatments over growth stages of soybean have been presented in Fig 3. The profile moisture content behaved in a *zig-zag* way during both the crop season (2004 and 2005) because of the consistent and regular occurrence of rains at short intervals during most part of the

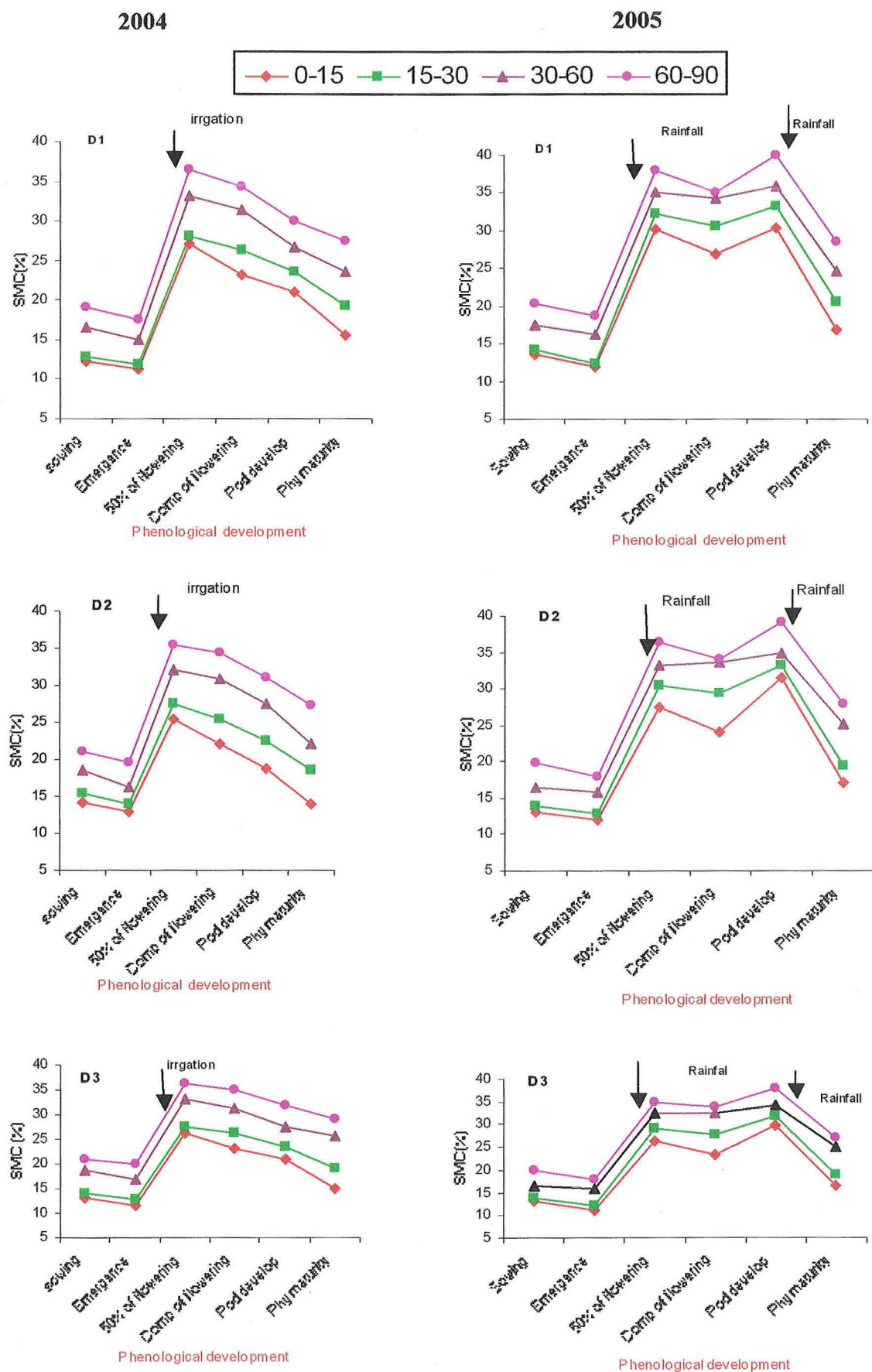


**Fig. 3. : Profile soil moisture content (v/v %) in soybean crop under different growing environments at different phenological development during 2004 and 2005**

crop season. The maximum soil moisture content in the uppermost layer (0-15cm) at flowering stage in all the treatments during two crop seasons (27.0, 25.4 and 26.2% in 2004) and (30.1, 27.5 and 26.3% in 2005). However soil moisture content was higher in 2005 crop growing season as compared to 2004 due to consistent rainfall.

Among the sowing dates the maximum soil moisture content in 1<sup>st</sup> week of June and lowest was in 1<sup>st</sup> week of July sown crop during both the years of study. It might be due to consumptive water use, seed yield, total dry matter and uptake of all nutrients increased under high soil moisture levels. Similar results were obtained by Alithawi *et al.* (1980) studied the moisture level effect on yield, depth of root activity and nutrient uptake by soybean.

### **4.3 CROP GROWTH AND DEVELOPMENT**

#### **4.3.1 Crop Phenology**

The observations on important phenological events were recorded by monitoring the crop at regular interval of 2 to 3 days in different treatments and the results are shown in Table 4a and 4b. Among the sowing dates, the delayed sowing during 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July resulted in reduced crop duration by 4 and 13 days, respectively over early sown crop of 1<sup>st</sup> week of June. During vegetative crop growth phase, the days taken to reach different sub-phase were less distinguished as compared to the reproductive phase in both the crop seasons (2004 and 2005). In phenophase flower initiation the treatments were shown recognizable variation among which third date of sowing(1<sup>st</sup> week of July) had consumed less number of days to reach.

**Table 4a : Phenological development (days) in soybean cultivars under different growing environments during (2004)**

| Treatments                | 1 <sup>st</sup> week of June |      |     |      |  | 3 <sup>rd</sup> week of June |      |     |      |  | 1 <sup>st</sup> week of July |      |     |      |  |
|---------------------------|------------------------------|------|-----|------|--|------------------------------|------|-----|------|--|------------------------------|------|-----|------|--|
|                           | SH 40                        | DS   | PK  | PS   |  | SH 40                        | DS   | PK  | PS   |  | SH 40                        | DS   | PK  | PS   |  |
|                           |                              | 9814 | 416 | 1042 |  |                              | 9814 | 416 | 1042 |  |                              | 9814 | 416 | 1042 |  |
| <b>Vegetative phase</b>   |                              |      |     |      |  |                              |      |     |      |  |                              |      |     |      |  |
| EME                       | 7                            | 8    | 7   | 6    |  | 6                            | 8    | 7   | 6    |  | 5                            | 6    | 6   | 5    |  |
| Unifolial                 | 13                           | 15   | 13  | 12   |  | 12                           | 14   | 13  | 12   |  | 10                           | 11   | 11  | 10   |  |
| End of Juvenile           | 19                           | 19   | 19  | 16   |  | 16                           | 18   | 18  | 17   |  | 14                           | 15   | 16  | 15   |  |
| <b>Reproductive phase</b> |                              |      |     |      |  |                              |      |     |      |  |                              |      |     |      |  |
| Initiation of Flowering   | 63                           | 65   | 63  | 62   |  | 56                           | 56   | 55  | 54   |  | 41                           | 44   | 43  | 41   |  |
| First pod                 | 78                           | 82   | 80  | 77   |  | 77                           | 75   | 75  | 74   |  | 71                           | 71   | 71  | 70   |  |
| Full pod                  | 108                          | 110  | 110 | 108  |  | 94                           | 96   | 96  | 94   |  | 81                           | 84   | 84  | 81   |  |
| End pod                   | 120                          | 122  | 123 | 120  |  | 99                           | 102  | 102 | 99   |  | 88                           | 93   | 93  | 87   |  |
| PM                        | 132                          | 135  | 135 | 132  |  | 110                          | 113  | 113 | 106  |  | 106                          | 108  | 108 | 108  |  |

**Table 4b : Phenological development (days) in soybean cultivars under different growing environments during (2005)**

| Treatments                 | 1 <sup>st</sup> week of June |         |        |         | 3 <sup>rd</sup> week of June |         |        |         | 1 <sup>st</sup> week of July |         |        |         |
|----------------------------|------------------------------|---------|--------|---------|------------------------------|---------|--------|---------|------------------------------|---------|--------|---------|
|                            | SH 40                        | DS 9814 | PK 416 | PS 1042 | SH 40                        | DS 9814 | PK 416 | PS 1042 | SH 40                        | DS 9814 | PK 416 | PS 1042 |
| <b>Vegetative phase</b>    |                              |         |        |         |                              |         |        |         |                              |         |        |         |
| EME                        | 6                            | 8       | 8      | 6       | 6                            | 7       | 7      | 5       | 4                            | 6       | 6      | 5       |
| Unifolial                  | 12                           | 14      | 14     | 14      | 12                           | 14      | 13     | 12      | 9                            | 10      | 10     | 9       |
| End of Juvenile            | 18                           | 19      | 19     | 18      | 16                           | 18      | 19     | 16      | 13                           | 16      | 16     | 14      |
| <b>Reproductive growth</b> |                              |         |        |         |                              |         |        |         |                              |         |        |         |
| Initiation of flowering    | 62                           | 67      | 64     | 63      | 55                           | 57      | 56     | 55      | 50                           | 53      | 52     | 53      |
| First pod                  | 75                           | 76      | 80     | 80      | 82                           | 85      | 87     | 84      | 70                           | 77      | 76     | 76      |
| Full pod                   | 110                          | 113     | 112    | 110     | 104                          | 106     | 106    | 104     | 98                           | 100     | 99     | 97      |
| End pod                    | 125                          | 127     | 127    | 124     | 119                          | 123     | 123    | 120     | 109                          | 112     | 112    | 110     |
| PM                         | 136                          | 136     | 137    | 135     | 131                          | 133     | 134    | 132     | 119                          | 121     | 120    | 119     |

This might be due to large fluctuation in accumulated heat units and heliothermal units at a particular phenophases and different dates of sowing. Similar results obtained by Dhingra *et al.* (1995) at Ludhiana in soybean cultivars.

Among the cultivars PK 416 and DS 9814 has consumed more number of days to complete vegetative growth as well as reproductive growth in both the crop seasons. This might be due to its indeterminate growth habit and growing degree days. Similar results were obtained by Dhingra *et al.* (1995) at Ludhiana.

#### **4.3.2 Plant height**

The data on Plant height under various treatments in both the crop season (2004 and 2005) are presented in Table 5. Among the dates of sowing the maximum plant height was recorded in 1<sup>st</sup> week of June (62.8, 64.2 cm) and delay in sowing resulted in decrease of plant height i.e. 3<sup>rd</sup> week of June (60.9, 61.2 cm) and 1<sup>st</sup> week of July (60.2, 57.0 cm) in *kharif* 2004 and 2005 respectively. In 30, 60 DAS and Physiological maturity the plant height differ significantly during 2004. This plant height differ under different planting dates may be due to growing degree days, radiation use efficiency and heliothermal requirements is more in early sowing plants then delayed sowing.

Similar results were obtained by Batwal *et al.* (2004) in Maharashtra wherein they have concluded that the plant height and dry matter were higher in S<sub>1</sub> (25 SMW sown) as compared to S<sub>2</sub> (27 SMW sown) and S<sub>3</sub> (28 SMW sown) crop.

**Table 5 : Plant height (cm) at different growth intervals (DAS) in soybean cultivars under different growing environments**

| Treatments                   | 2004                   |      |      |      |      |      |      |      | 2005                   |      |      |      |      |      |  |  |
|------------------------------|------------------------|------|------|------|------|------|------|------|------------------------|------|------|------|------|------|--|--|
|                              | Growth intervals (DAS) |      |      |      |      |      |      |      | Growth intervals( DAS) |      |      |      |      |      |  |  |
|                              | 30                     | 45   | 60   | 75   | 90   | 105  | PM   | 30   | 45                     | 60   | 75   | 90   | 105  | PM   |  |  |
| Date of Sowing               |                        |      |      |      |      |      |      |      |                        |      |      |      |      |      |  |  |
| 1 <sup>st</sup> week of June | 10.5                   | 17.4 | 25.3 | 35.7 | 43.4 | 50.4 | 62.9 | 11.2 | 21.3                   | 26.9 | 37.3 | 45.2 | 52.8 | 64.2 |  |  |
| 3 <sup>rd</sup> week of June | 10.4                   | 17.0 | 25.0 | 34.7 | 42.7 | 49.5 | 60.1 | 10.7 | 19.2                   | 24.0 | 35.6 | 43.0 | 50.0 | 61.0 |  |  |
| 1 <sup>st</sup> week of July | 10.4                   | 16.5 | 24.6 | 34.0 | 42.3 | 48.2 | 59.0 | 10.0 | 16.7                   | 23.0 | 34.2 | 41.2 | 48.6 | 57.0 |  |  |
| CD at 5%                     | NS                     | 0.3  | NS   | 0.4  | 0.7  | 0.8  | 0.5  | 0.3  | 1.4                    | 0.4  | 0.7  | 1.1  | 1.0  | 1.5  |  |  |
| Cultivars                    |                        |      |      |      |      |      |      |      |                        |      |      |      |      |      |  |  |
| SH 40                        | 9.3                    | 14.5 | 21.3 | 33.5 | 39.6 | 42.6 | 58.7 | 9.8  | 17.9                   | 22.3 | 34.5 | 41.6 | 49.4 | 57.6 |  |  |
| DS 9814                      | 10.4                   | 15.4 | 22.2 | 34.6 | 44.2 | 49.9 | 62.9 | 10.6 | 20.3                   | 23.5 | 36.0 | 44.8 | 50.0 | 63.0 |  |  |
| PK 416                       | 12.6                   | 19.0 | 33.3 | 39.9 | 46.1 | 52.3 | 65.3 | 12.7 | 21.0                   | 33.0 | 40.1 | 46.8 | 53.7 | 67.0 |  |  |
| PS 1042                      | 9.1                    | 18.5 | 20.3 | 32.8 | 38.5 | 41.3 | 56.0 | 9.6  | 17.2                   | 21.4 | 33.2 | 40.0 | 48.8 | 55.4 |  |  |
| CD at 5%                     | NS                     | 0.3  | 0.4  | 0.5  | 0.7  | 0.7  | 1.0  | 0.3  | 1.1                    | 0.3  | 0.8  | 0.9  | 1.0  | 1.5  |  |  |

Among the cultivars the plant height was significantly higher in PK 416 which was tallest followed by DS 9814. The shortest plant height was recorded in cultivar PS 1042 during both growing seasons. The variation in plant height was because of the differential genetic make up of these cultivars.

#### **4.3.3 Dry matter accumulation**

The dry matter production of soybean differed significantly among the date of sowing and cultivars in both crop seasons (Table 6).

Initially, the rate of increase in dry matter was slow, but from 45 DAS onwards the increase was rapid till 90 DAS irrespective of sowing date. The differences in dry matter accumulations among sowing dates became wider with the advancement of crop age. The crop sown on 1<sup>st</sup> week of June accumulated significantly higher dry matter at physiological maturity followed by 3<sup>rd</sup> week of June and it was lowest in 1<sup>st</sup> week of July at all the stage. Pedersen *et al.* (2004), Ramesh and Gopalaswamy (1992) have earlier observed that the dry matter accumulation decreased with delay in sowing of soybean.

The dry matter accumulation was highest in PK 416 followed by DS 9814 and it was lowest in PS 1042. The cultivar SH 40 and DS 9814 accumulated significantly higher biomass over other two cultivars from 45 to 105 DAS, however these two cultivars were statistically at par. The gain in total dry matter accumulation declined during the terminal growth stage, which was due to leaf senescence and consequent reduction in net photosynthesis. The highest dry matter accumulation was observed in 1<sup>st</sup> week of June sown crop followed by

**Table 6 : Dry matter accumulation (g m<sup>-2</sup>) in soybean cultivars under different growing environments**

| Treatments                   | 2004 |      |       |       |       |       |       | 2005 |      |       |       |       |       |       |
|------------------------------|------|------|-------|-------|-------|-------|-------|------|------|-------|-------|-------|-------|-------|
|                              | DAS  |      |       |       |       |       |       | DAS  |      |       |       |       |       |       |
|                              | 30   | 45   | 60    | 75    | 90    | 105   | PM    | 30   | 45   | 60    | 75    | 90    | 105   | PM    |
| Date of Sowing               |      |      |       |       |       |       |       |      |      |       |       |       |       |       |
| 1 <sup>st</sup> week of June | 11.6 | 20.6 | 196.6 | 309.7 | 681.8 | 736.3 | 694.0 | 13.9 | 21.1 | 198.6 | 311.5 | 994.1 | 732.5 | 696.2 |
| 3 <sup>rd</sup> week of June | 11.0 | 28.7 | 201.4 | 360.0 | 628.9 | 694.5 | 653.0 | 11.2 | 29.4 | 203.4 | 317.3 | 860.1 | 694.5 | 661.6 |
| 1 <sup>st</sup> week of July | 10.7 | 34.9 | 201.9 | 385.0 | 625.5 | 636.0 | 685.2 | 10.4 | 35.3 | 203.1 | 386.8 | 626.2 | 636.2 | 586.7 |
| CD at 5%                     | NS   | 0.4  | 0.6   | 2.6   | 2.5   | 3.4   | 10.2  | 1.   | 1.5  | 0.8   | 1.0   | 1.3   | 7.0   | 10.0  |
| Cultivars                    |      |      |       |       |       |       |       |      |      |       |       |       |       |       |
| SH 40                        | 11.2 | 27.2 | 199.2 | 324.0 | 541.0 | 690.2 | 662.8 | 11.7 | 27.8 | 200.0 | 335.9 | 543.2 | 635.2 | 663.2 |
| DS 9814                      | 11.2 | 27.3 | 201.6 | 336.3 | 638.1 | 693.7 | 679.3 | 11.5 | 28.8 | 202.8 | 339.2 | 641.2 | 693.4 | 686.0 |
| PK 416                       | 11.8 | 30.6 | 201.3 | 351.3 | 645.4 | 705.8 | 698.3 | 12.3 | 31.1 | 205.0 | 353.0 | 646.5 | 705.0 | 705.2 |
| PS 1042                      | 10.5 | 27.3 | 197.0 | 315.2 | 503.0 | 666.0 | 655.4 | 10.8 | 26.7 | 199.6 | 326.1 | 505.3 | 667.0 | 660.0 |
| CD at 5%                     | NS   | 0.2  | 1.0   | 2.4   | 2.4   | 3.0   | 8.2   | 0.6  | 1.0  | 1.1   | 1.3   | 2.3   | 6.5   | 9.7   |

3<sup>rd</sup> week of June and it was lowest in 1<sup>st</sup> week of July. This might be due to healthy plant, vegetative growth performance and more canopies as compared to delayed sowing crop. Similar results have been earlier obtained by Pederson and Joseph (2004).

Among the cultivars, PK 416 recorded significantly higher dry matter accumulation than other cultivars due to better adaptability and suitability of this cultivar to Hisar weather conditions. Similar results have earlier been reported by Sunil (2005).

#### **4.3.4 Leaf Area index (LAI)**

The LAI of soybean showed wide variation among the four cultivars and three dates of sowing both the crop seasons. The LAI increased gradually from 30 DAS onwards till it reached the maxima at 90, 75 and 75 DAS in 1<sup>st</sup> week of June, 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sown crops, respectively during both crop season and then it declined gradually till the physiological maturity of crop.

Among the dates of sowing, maximum LAI was attained in 1<sup>st</sup> week of June sown crop. The highest peak value of LAI (3.8 and 4.0) were observed in cultivar PK 416 in 1<sup>st</sup> week of June sown crop, whereas the lowest peak values (3.1 and 3.4) were observed in PS 1042 in 1<sup>st</sup> week of July sown crop during 2004 and 2005, respectively. The maximum LAI was observed in PK 416 and DS 9814 was possibly because of broader leaf and tall plant characteristic of these cultivars as compared to the other two cultivars, where the leaves were comparatively smaller in size. Senescence was slow and continued till physiological maturity. According to Singh (1987) the leaf senescence is probably promoted due to the imbalance in auxins *vs* cytokynins ratio

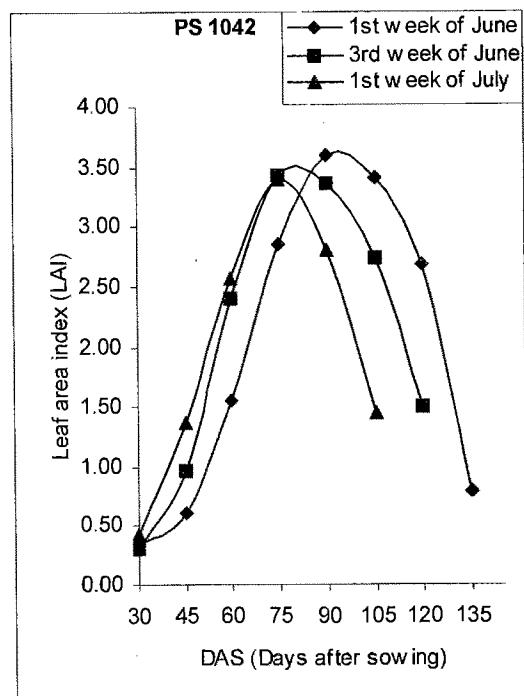
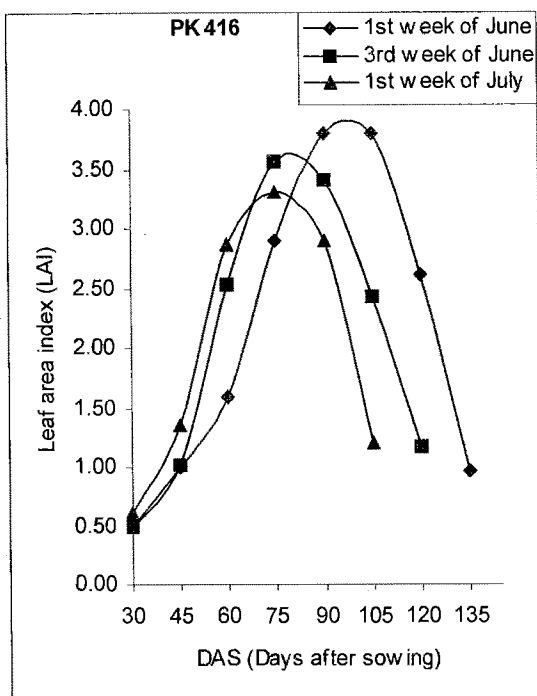
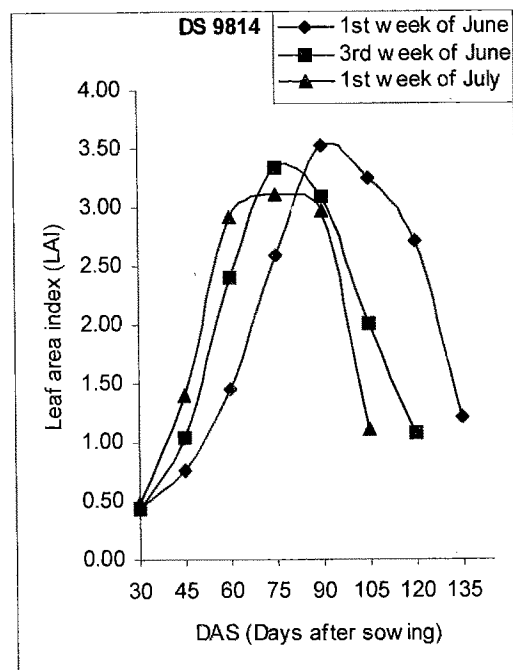
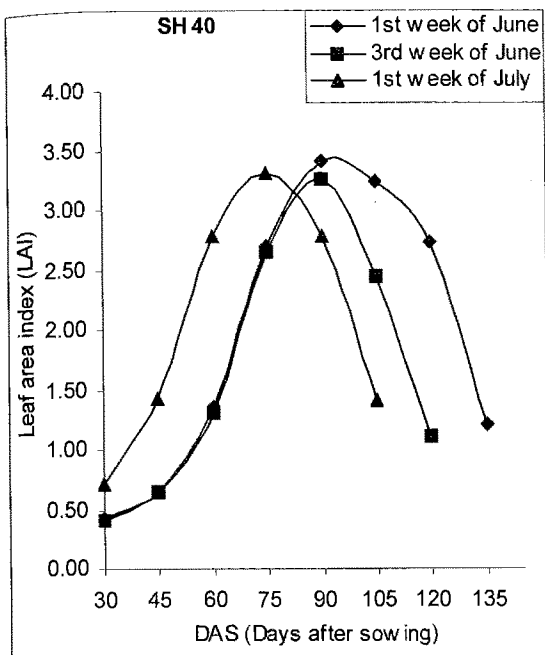


**Fig 4 : Leaf area index (LAI) in soybean cultivars under different growing environments during *kharif*- 2004**

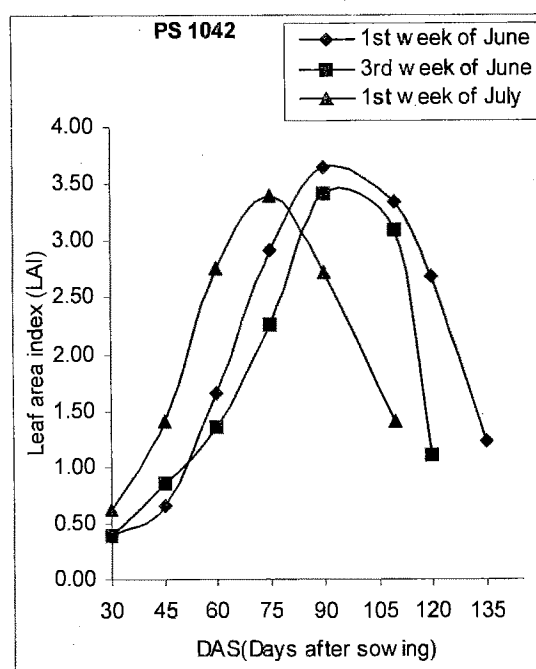
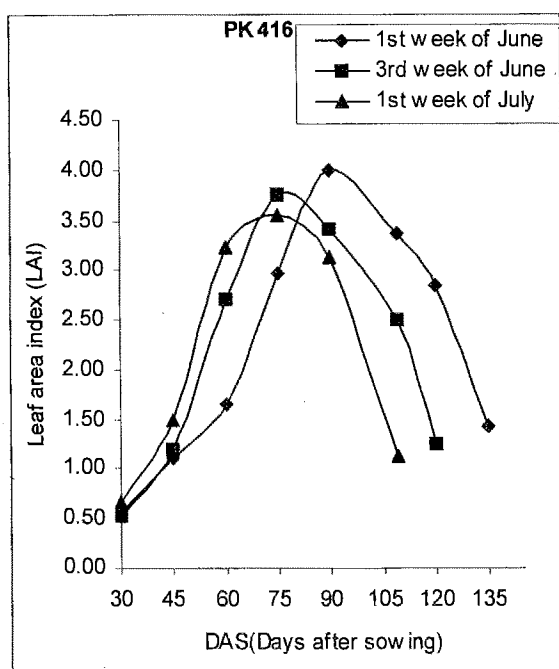
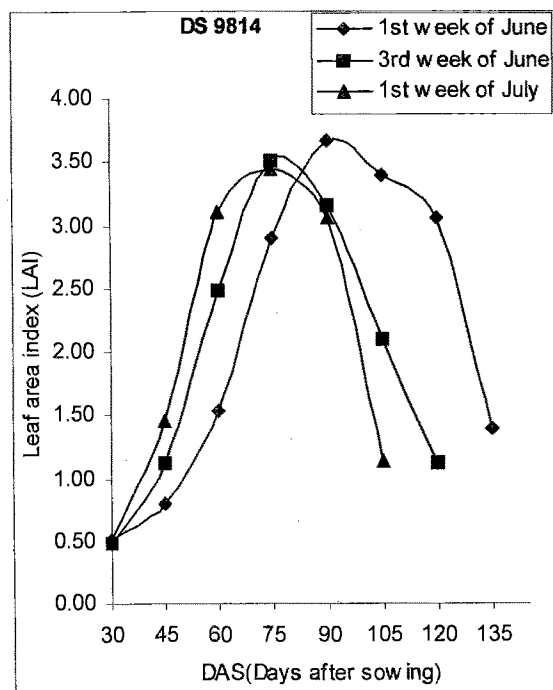
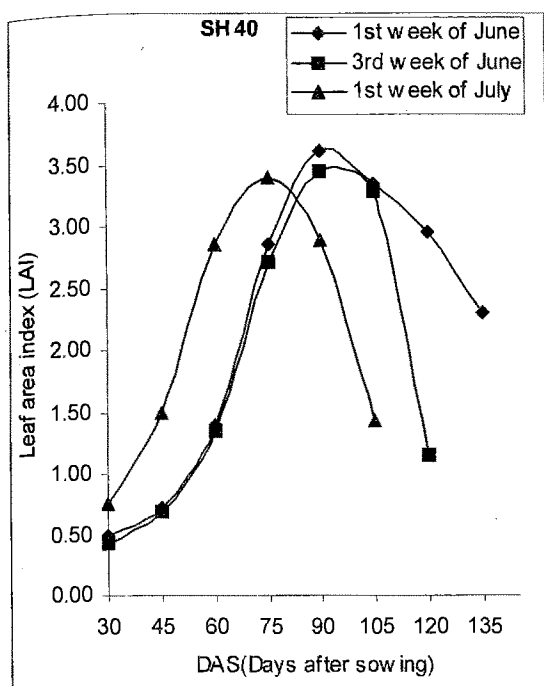


**Fig 5 : Leaf area index (LAI) in soybean cultivars under different growing environments during *kharif*- 2005**

in leaf petiole during later reproductive growth stages. Among the cultivars the LAI was higher in PK 416 followed by DS 9814, whereas, leaves remained greener for longer time in SH 40 and PS 1042. Similar results were observed by Sunil (2005) (Fig 4 and 5).

#### **4.4 AGROMETEOROLOGICAL INDICES**

##### **4.4.1 Accumulated growing day degrees (AGDD)**

The accumulated growing day degrees (AGDD) to reach various growth stages showed appreciable variation among the dates of sowing and cultivars in both crop seasons which are presented in Table 7.

The early sown crop accumulated higher growing degree days to reach various phenophases (2733 and 2655°C day) followed by 3<sup>rd</sup> week of June and it was lowest in 1<sup>st</sup> week of July sown crop (2174 and 2265°C day in 2004 and 2005, respectively). This was due to the availability of longer growth period for early sown crop.

Among the cultivars the highest growing degree days were accumulated by cultivars PK 416 (2759, and 2668 in 2004 and 2005 crop seasons, respectively) as compared to other two dates of sowing. The favorable photoperiodic conditions in 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sown crops induced the crop to enter reproductive phase early and thus short duration of vegetative phase and maturity duration. Similar results were earlier reported by Dhingra *et al.* (1995) and Sunil (2005).

**Table 7 : Accumulated growing degree day (AGDD °C day) to attain various phenophases in soybean cultivars under different growing environments**

| Phenophase                   | 2004  |         |        |         |      | 2005  |         |        |         |      |
|------------------------------|-------|---------|--------|---------|------|-------|---------|--------|---------|------|
|                              | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean |
| 1 <sup>st</sup> week of June |       |         |        |         |      |       |         |        |         |      |
| EME                          | 162   | 186     | 162    | 186     | 174  | 137   | 162     | 162    | 137     | 149  |
| 50 F                         | 1738  | 1777    | 1778   | 1733    | 1758 | 1706  | 1760    | 1746   | 1706    | 1729 |
| POD                          | 2283  | 2321    | 2321   | 2283    | 2302 | 2258  | 2308    | 2292   | 2258    | 2279 |
| PM                           | 2707  | 2759    | 2759   | 2707    | 2733 | 2655  | 2655    | 2668   | 2645    | 2655 |
| 3 <sup>rd</sup> week of June |       |         |        |         |      |       |         |        |         |      |
| EME                          | 117   | 141     | 141    | 117     | 129  | 159   | 152     | 165    | 134     | 145  |
| 50 F                         | 1630  | 1651    | 1651   | 1603    | 1635 | 1604  | 1646    | 1646   | 1625    | 1630 |
| POD                          | 1949  | 1949    | 1986   | 1986    | 1967 | 2114  | 2146    | 2142   | 2114    | 2130 |
| PM                           | 2221  | 2254    | 2254   | 2221    | 2237 | 2312  | 2342    | 2552   | 2431    | 2404 |
| 1 <sup>st</sup> week of July |       |         |        |         |      |       |         |        |         |      |
| EME                          | 106   | 132     | 127    | 106     | 123  | 75    | 117     | 117    | 96      | 101  |
| 50 F                         | 1287  | 1347    | 1347   | 1667    | 1413 | 1479  | 1522    | 1522   | 1501    | 1506 |
| POD                          | 1718  | 1774    | 1774   | 1713    | 1746 | 1849  | 1884    | 1885   | 1867    | 1871 |
| PM                           | 2170  | 2184    | 2184   | 2157    | 2174 | 2256  | 2281    | 2268   | 2256    | 2265 |

#### **4.4.2 Accumulated helio-thermal units (AHTU)**

The accumulated helio-thermal units (AHTU) accumulated by the crop to attain under different growing stages in four cultivars and three dates of sowing in both crop seasons are shown in Table 8.

The 1<sup>st</sup> week of June sown crop accumulated highest AHTU (36476 and 35447°C day hr in 2004 and 2005, respectively) followed by 3<sup>rd</sup> week of June and minimum were accumulated in July sown crop (1<sup>st</sup> week of July).

Among the cultivars the highest helio-thermal units required to reach physiological maturity was observed in PK 416 (36776 and 35596°C day hr) followed by DS 9814 and lowest in Ps 1042 (28081 and 33487°C day hr) during two crop seasons, respectively.

#### **4.4.3 Accumulated photo-thermal units (APTU)**

The accumulated photo-thermal units (APTU) showed considerable variation under different growing environments in soybean cultivars and the results obtained are presented in Table 9.

Early (1<sup>st</sup> week of June) sown crop accumulated highest number of APTU (19467 and 18948°C day hr) followed by 3<sup>rd</sup> week of June and lowest APTU were consumed (15705 and 16242°C day hr) in 1<sup>st</sup> week of July sown crop during two crop seasons, respectively, since the delayed sowing resulted in shortening of over all crop duration.

Among the cultivars PK 416 accumulated maximum APTU (19657, 16009, 15783, 2004 and 19070, 18495, and 16264°C day hr) during two crop seasons, respectively in 1<sup>st</sup> week of June, 3<sup>rd</sup> week of

**Table 8 : Accumulated helio- thermal units (AHTU °C day hrs) to attain various phenophases in soybean cultivars under different growing environments**

| Phenophase                   | 2004  |         |        |         |       | 2005  |         |        |         |       |
|------------------------------|-------|---------|--------|---------|-------|-------|---------|--------|---------|-------|
|                              | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean  | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean  |
| 1 <sup>st</sup> week of June |       |         |        |         |       |       |         |        |         |       |
| EME                          | 2266  | 2598    | 2266   | 2598    | 2432  | 2233  | 2971    | 2971   | 1876    | 2512  |
| 50 F                         | 24078 | 24595   | 24545  | 24078   | 24324 | 23625 | 24413   | 24413  | 24152   | 24150 |
| POD                          | 31053 | 31528   | 31528  | 31053   | 31291 | 30693 | 31311   | 31112  | 30696   | 30952 |
| PM                           | 36176 | 36776   | 36776  | 36176   | 36476 | 35449 | 35449   | 35596  | 32294   | 35447 |
| 3 <sup>rd</sup> week of June |       |         |        |         |       |       |         |        |         |       |
| EME                          | 1652  | 1987    | 1987   | 1652    | 1820  | 1910  | 2257    | 2257   | 1910    | 2083  |
| 50 F                         | 17543 | 18319   | 18319  | 17545   | 17932 | 22155 | 22708   | 22708  | 22424   | 22498 |
| POD                          | 22734 | 22734   | 23445  | 23445   | 23090 | 28648 | 29053   | 29053  | 28648   | 28851 |
| PM                           | 28201 | 28349   | 28349  | 28081   | 28245 | 33487 | 33749   | 33867  | 33628   | 33683 |
| 1 <sup>st</sup> week of July |       |         |        |         |       |       |         |        |         |       |
| EME                          | 1652  | 1987    | 1987   | 1652    | 1819  | 1064  | 1645    | 1645   | 1357    | 1428  |
| 50 F                         | 17345 | 13319   | 13319  | 17545   | 15432 | 20312 | 20871   | 20871  | 20595   | 20662 |
| POD                          | 22734 | 23445   | 23445  | 22735   | 23090 | 25027 | 25463   | 25463  | 25251   | 23301 |
| PM                           | 28201 | 28349   | 28349  | 28081   | 28245 | 29928 | 30219   | 30064  | 29228   | 29866 |

**Table 9 : Accumulated photo- thermal units (APTU °C day hrs) to attain various phenophases in soybean cultivars under different growing environments**

| Phenophase                   | 2004  |         |        |         |       | 2005  |         |        |         |       |
|------------------------------|-------|---------|--------|---------|-------|-------|---------|--------|---------|-------|
|                              | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean  | SH 40 | DS 9814 | PK 416 | PS 1042 | Mean  |
| 1 <sup>st</sup> week of June |       |         |        |         |       |       |         |        |         |       |
| EME                          | 1310  | 1529    | 1310   | 1529    | 1419  | 1286  | 1606    | 1606   | 1171    | 1417  |
| 50 F                         | 11334 | 11642   | 11642  | 11334   | 11488 | 11366 | 11993   | 11779  | 11366   | 11625 |
| POD                          | 15798 | 16098   | 16098  | 15798   | 15948 | 15375 | 15874   | 15707  | 15375   | 15582 |
| PM                           | 19277 | 19657   | 19657  | 19270   | 19467 | 18947 | 18947   | 19070  | 18831   | 18948 |
| 3 <sup>rd</sup> week of June |       |         |        |         |       |       |         |        |         |       |
| EME                          | 509   | 935     | 735    | 509     | 675   | 851   | 960     | 960    | 851     | 905   |
| 50 F                         | 10795 | 10988   | 10988  | 10588   | 10890 | 11033 | 11475   | 11475  | 11247   | 11307 |
| POD                          | 13627 | 13951   | 13951  | 13627   | 13789 | 14583 | 14914   | 14914  | 14583   | 14748 |
| PM                           | 15792 | 16009   | 16098  | 15792   | 15900 | 18224 | 18404   | 18495  | 18315   | 18359 |
| 1 <sup>st</sup> week of July |       |         |        |         |       |       |         |        |         |       |
| EME                          | 1142  | 1335    | 1335   | 1142    | 1238  | 1162  | 1420    | 1420   | 1293    | 1324  |
| 50 F                         | 4245  | 8783    | 8783   | 4245    | 6514  | 13305 | 10682   | 10682  | 10520   | 10547 |
| POD                          | 11906 | 12434   | 12434  | 11906   | 12170 | 12480 | 12809   | 12809  | 12643   | 12685 |
| PM                           | 15672 | 15783   | 15782  | 15583   | 15705 | 16159 | 16381   | 16264  | 16159   | 16242 |

June and 1<sup>st</sup> week of July sown crop, and was followed by DS 9814 with lowest in PS 1042.

In early sown crop, higher values of agrometeorological indices (GDD, HTU and PTU) were accumulated to attain physiological maturity as compared to later sown dates. All the cultivars have shown variation in three dates of sowing due to variation in their maturity duration. Similar results were obtained by Sunil (2005) under different dates of sowing in soybean cultivars.

#### **4.4.4 Radiation use efficiency (RUE)**

The most important aspect of crop development affecting the dry matter production and economic yield is concerned with the development of leaf canopy and its effect on the efficiency of radiation interception. Radiation use efficiency (RUE) values of soybean cultivars showed appreciable variations and are presented in Table 10.

RUE based on biological yield was highest (2.38 and 2.54 g/MJ) in 1<sup>st</sup> week of June followed by 3<sup>rd</sup> week of June sown in it was lowest in crop 1<sup>st</sup> week of July sown crop (2.32 and 2.26 g/MJ) during 2004 and 2005, respectively.

In cultivars highest RUE were recorded in PK 416 followed by DS 9814 and were lowest RUE in PS 1042 during both years. The variation in RUE arose because of the differential dry matter production in four cultivars while intercepting different amount of radiation because of variation in canopy structure and the LAI. RUE depends mainly on three factors, *viz.*, architecture of the canopy intercepting the radiation, photosynthetic efficiency of the leaves in utilizing the intercepted

**Table 10 : Radiation use efficiency (RUE g/MJ) of soybean cultivars under different growing environments**

| Treatments        | 2004                         |                              |                              |      | 2005                         |                              |                              |      |
|-------------------|------------------------------|------------------------------|------------------------------|------|------------------------------|------------------------------|------------------------------|------|
|                   | 1 <sup>st</sup> week of June | 3 <sup>rd</sup> week of June | 1 <sup>st</sup> week of July | Mean | 1 <sup>st</sup> week of June | 3 <sup>rd</sup> week of June | 1 <sup>st</sup> week of July | Mean |
| <b>Biological</b> |                              |                              |                              |      |                              |                              |                              |      |
| SH 40             | 2.17                         | 2.00                         | 1.92                         | 2.03 | 2.15                         | 2.09                         | 1.98                         | 2.07 |
| DS 9814           | 2.53                         | 2.25                         | 2.15                         | 2.31 | 2.63                         | 2.38                         | 2.15                         | 2.38 |
| PK 416            | 2.63                         | 2.30                         | 2.26                         | 2.40 | 2.69                         | 2.45                         | 2.24                         | 2.46 |
| PS 1042           | 2.10                         | 1.95                         | 1.87                         | 1.97 | 2.05                         | 2.00                         | 1.90                         | 1.98 |
| Mean              | 2.35                         | 2.12                         | 2.05                         |      | 2.38                         | 2.23                         | 2.06                         |      |
| <b>Grain</b>      |                              |                              |                              |      |                              |                              |                              |      |
| SH 40             | 0.92                         | 0.87                         | 0.82                         | 0.87 | 0.91                         | 0.88                         | 0.84                         | 0.87 |
| DS 9814           | 1.04                         | 0.95                         | 0.90                         | 0.96 | 1.12                         | 1.05                         | 0.97                         | 1.04 |
| PK 416            | 1.13                         | 1.04                         | 0.98                         | 1.05 | 1.15                         | 1.08                         | 1.00                         | 1.07 |
| PS 1042           | 0.91                         | 0.85                         | 0.80                         | 0.85 | 0.92                         | 0.90                         | 0.86                         | 0.89 |
| Mean              | 1.00                         | 0.91                         | 0.87                         |      | 1.04                         | 0.97                         | 0.92                         |      |

radiation used in production of dry matter and loss of dry matter due to physiological processes like respiration. Similar results were observed by Sunil (2005).

#### **4.4.5 Heat use efficiency (HUE)**

Heat use efficiency (HUE) of soybean cultivars for biomass production and seed yield under three dates of sowing based on two year study are given in Table 11.

The highest HUE for dry matter production and seed yield were highest for 1<sup>st</sup> week of June followed by 3<sup>rd</sup> week of June sown crop during both years of study. Among the cultivars highest RUE were recorded in PK 416 followed by DS 9814 and lowest RUE in PS 1042 during both crop growing season.

### **4.5 MICROMETEOROLOGICAL OBSERVATIONS**

#### **4.5.1 Temperature profile**

The microclimate of a crop is largely influenced by temperature within and above the canopy. Temperature within canopy has direct effect on physiological process like transpiration, photosynthesis and respiration. It is also responsible for thermal environment within the crop.

The temperature profiles during two crop growing seasons (2004 and 2005) are shown in Fig 6a, 6b, 6c, 6d and Fig 7a, 7b, 7c and 7d. The results indicated that the temperature inside the canopy was lower than that recorded at top of the canopy under different growing environments *i.e* 1<sup>st</sup> week of June, 3<sup>rd</sup> week of June and 1<sup>st</sup> week of

**Table 11: Heat use efficiency (HUE Kg/ha/°C day) of soybean cultivars under different growing environments**

| Treatments        | 2004                         |                              |                              |       | 2005                         |                              |                              |       |
|-------------------|------------------------------|------------------------------|------------------------------|-------|------------------------------|------------------------------|------------------------------|-------|
|                   | 1 <sup>st</sup> week of June | 3 <sup>rd</sup> week of June | 1 <sup>st</sup> week of July | Mean  | 1 <sup>st</sup> week of June | 3 <sup>rd</sup> week of June | 1 <sup>st</sup> week of July | Mean  |
| <b>Biological</b> |                              |                              |                              |       |                              |                              |                              |       |
| SH 40             | 0.862                        | 0.901                        | 0.900                        | 0.882 | 0.940                        | 0.953                        | 0.974                        | 0.955 |
| DS 9814           | 0.940                        | 0.970                        | 0.942                        | 0.950 | 1.016                        | 1.057                        | 1.040                        | 1.037 |
| PK 416            | 1.021                        | 0.991                        | 0.970                        | 0.994 | 1.128                        | 1.129                        | 1.061                        | 1.106 |
| PS 1042           | 0.856                        | 0.821                        | 0.821                        | 0.832 | 0.916                        | 0.84                         | 0.916                        | 0.895 |
| Mean              | 0.920                        | 0.918                        | 0.908                        |       | 1.013                        | 0.984                        | 0.997                        |       |
| <b>Grain</b>      |                              |                              |                              |       |                              |                              |                              |       |
| SH 40             | 0.351                        | 0.370                        | 0.360                        | 0.360 | 0.397                        | 0.401                        | 0.407                        | 0.401 |
| DS 9814           | 0.394                        | 0.405                        | 0.381                        | 0.393 | 0.433                        | 0.450                        | 0.438                        | 0.440 |
| PK 416            | 0.452                        | 0.430                        | 0.410                        | 0.430 | 0.476                        | 0.488                        | 0.454                        | 0.472 |
| PS 1042           | 0.380                        | 0.370                        | 0.360                        | 0.370 | 0.402                        | 0.383                        | 0.405                        | 0.396 |
| Mean              | 0.397                        | 0.391                        | 0.377                        |       | 0.427                        | 0.430                        | 0.426                        |       |

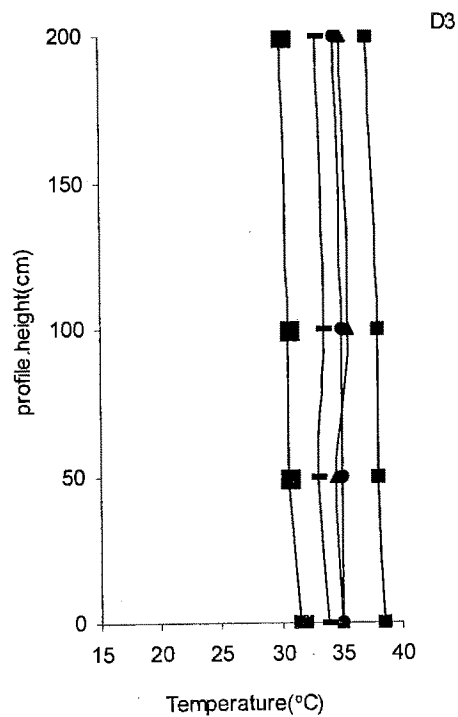
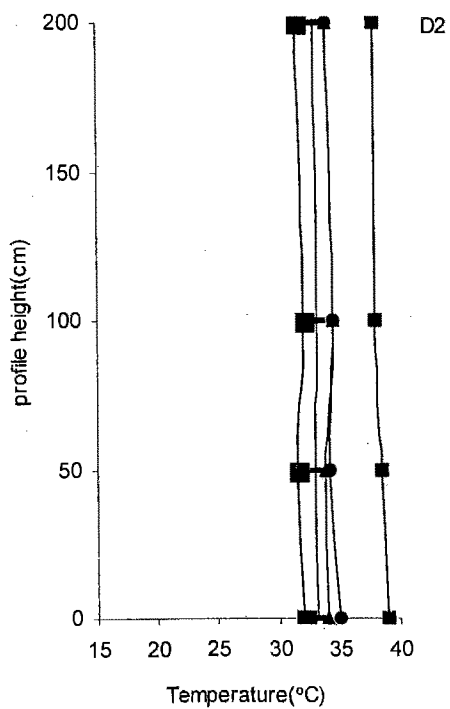
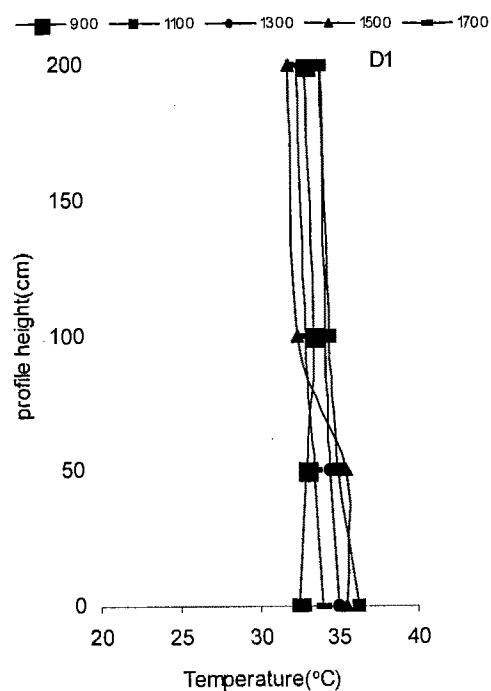
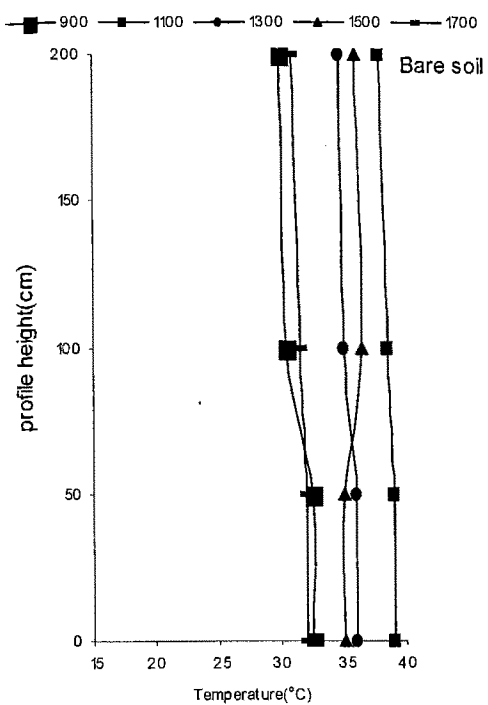


**Fig 6a :** Diurnal variation of temperature profile under different environmental conditions in soybean (Glycine max.) and over bare soil: 20 Aug 2004

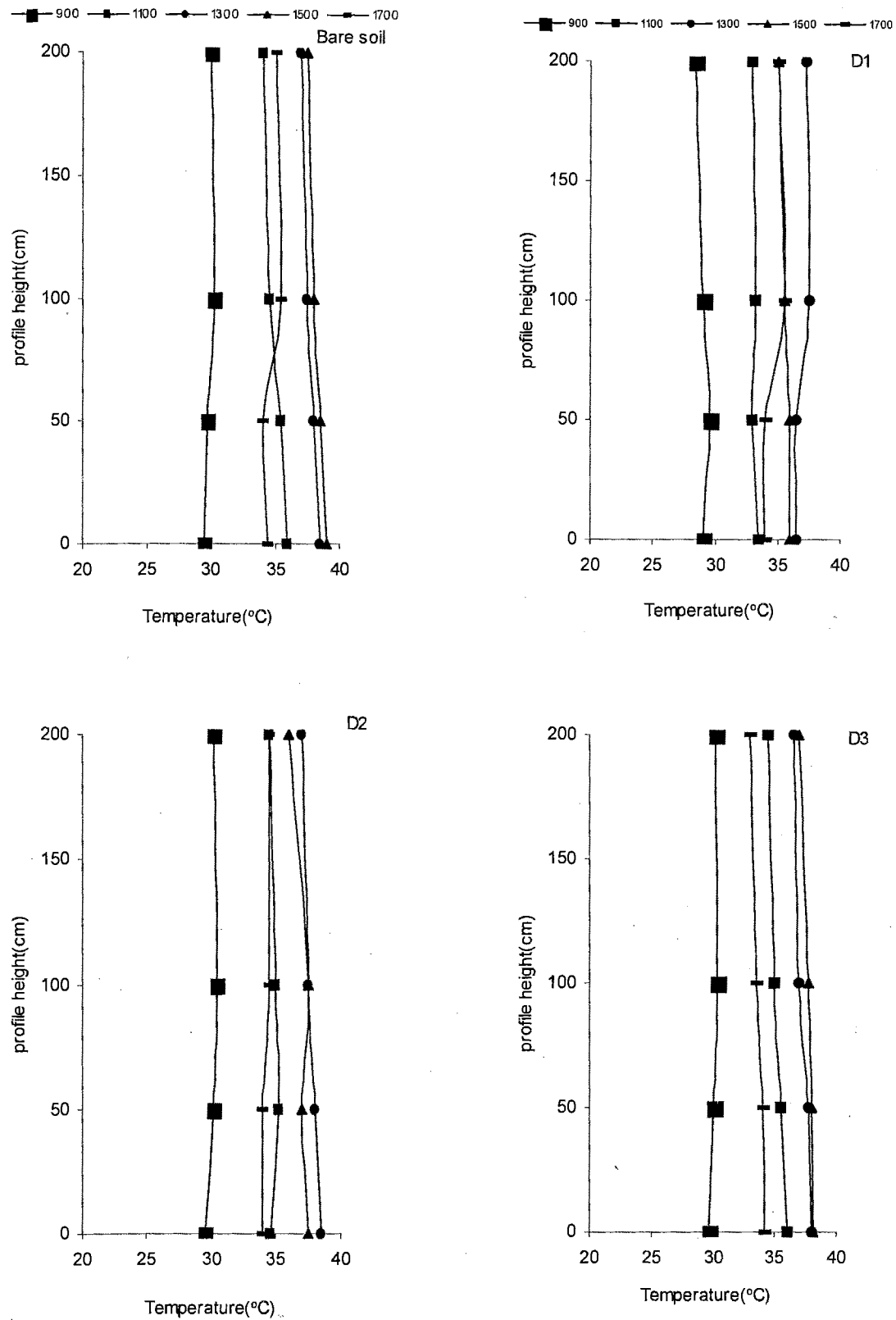


**Fig 6b : Diurnal variation of temperature profile under different environmental conditions in soybean and over bare soil: 7 Sep 2004**

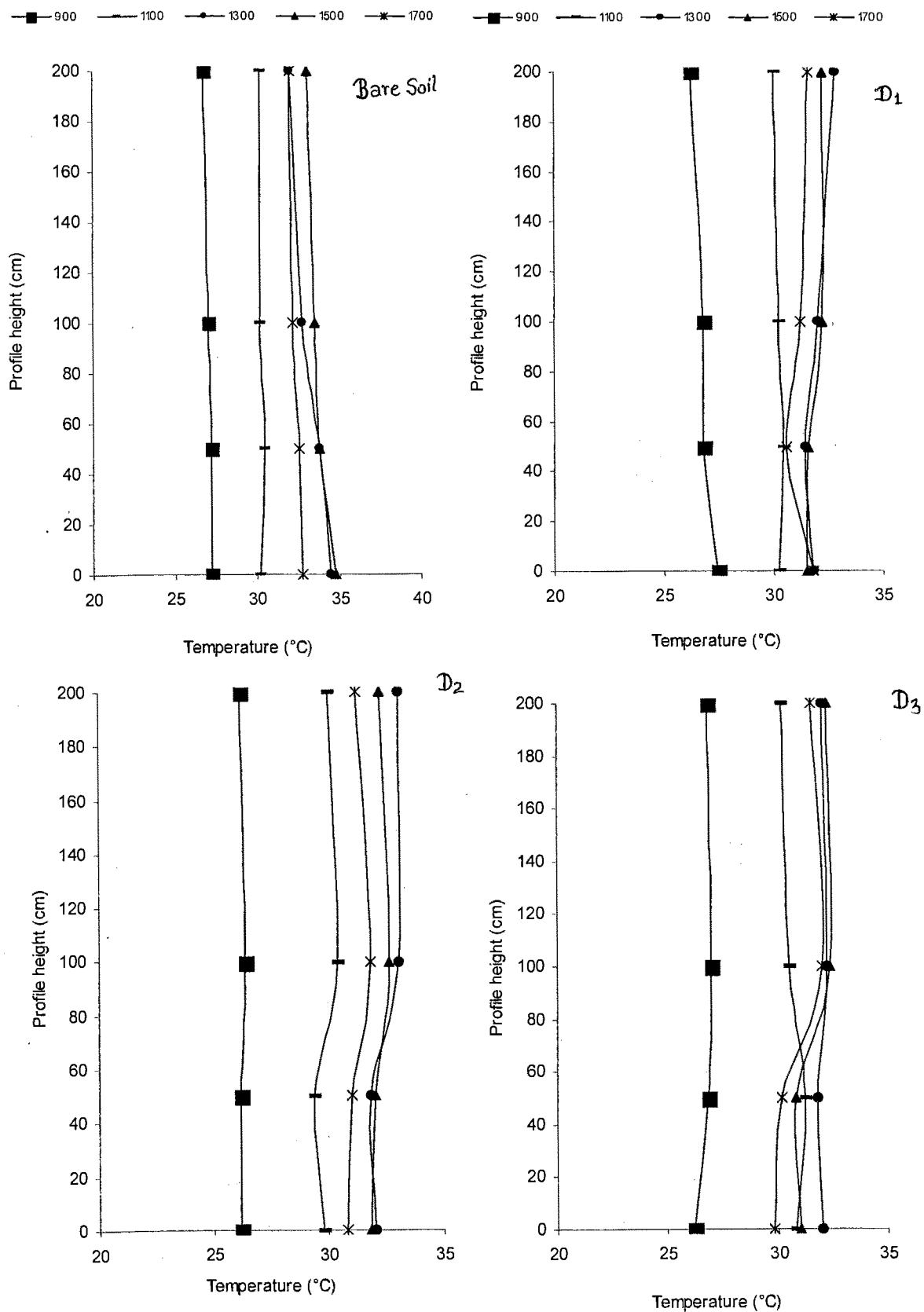


**Fig 6c : Diurnal variation of temperature profile under different environmental conditions in soybean (23 Sep 2004) and over bare soil: 23 Sep 2004**

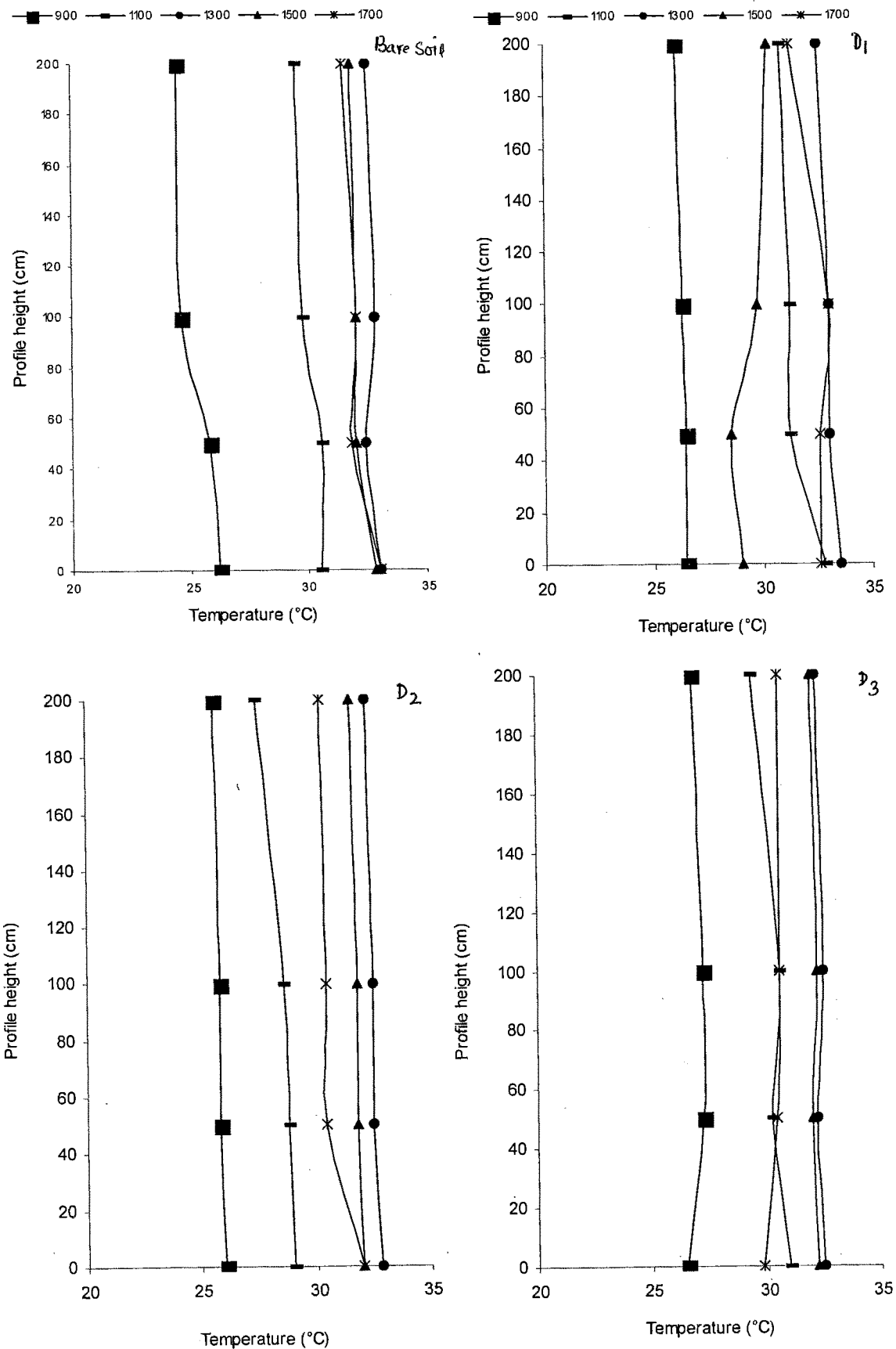


**Fig 6d : Diurnal variation of temperature profile under different environmental conditions in soybean and over bare soil: 19 Oct 2004**

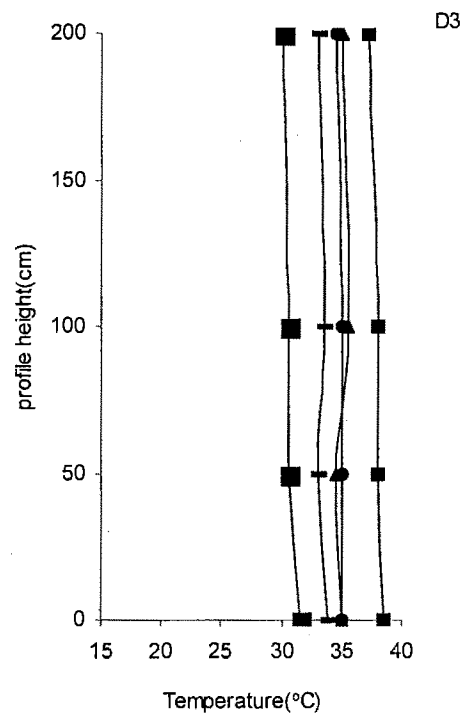
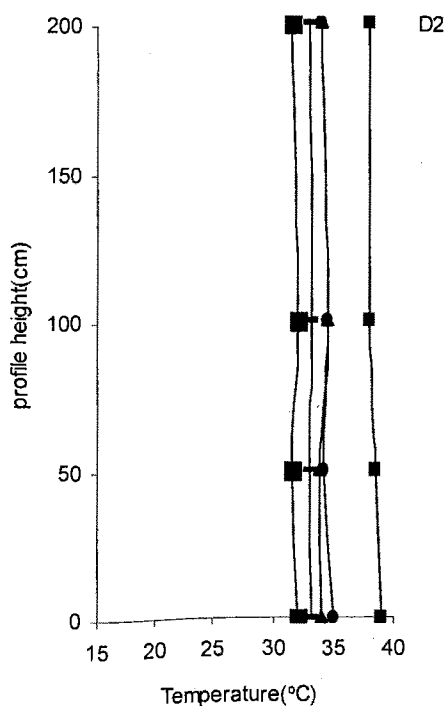
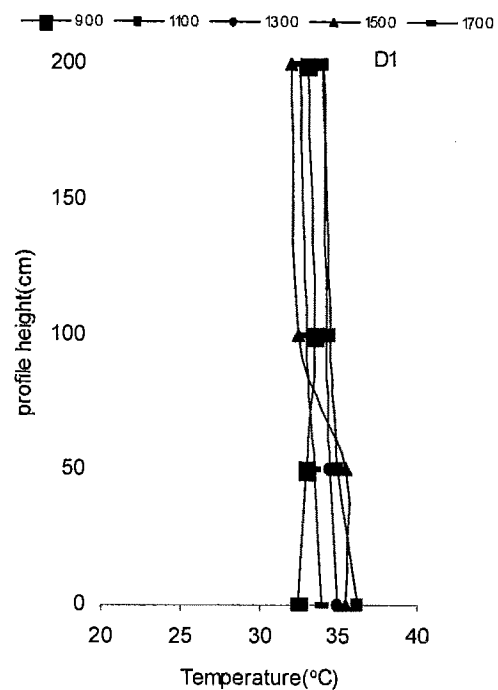
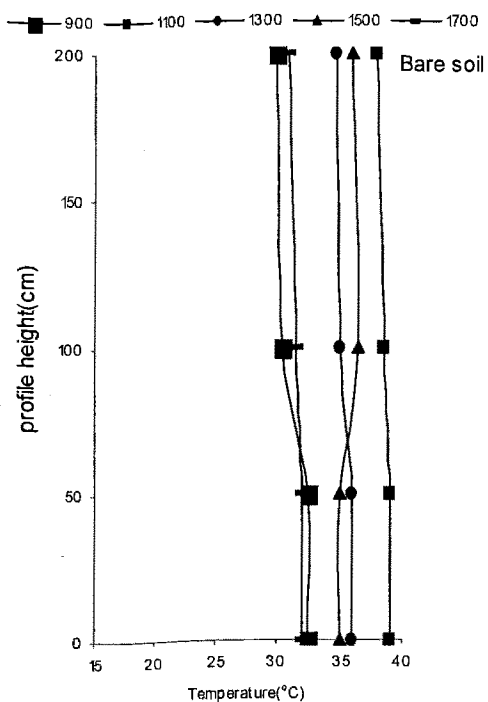


**Fig 7a : Diurnal variation of temperature profile under different environmental conditions in soybean and over bare soil : 30 Aug. 2005**

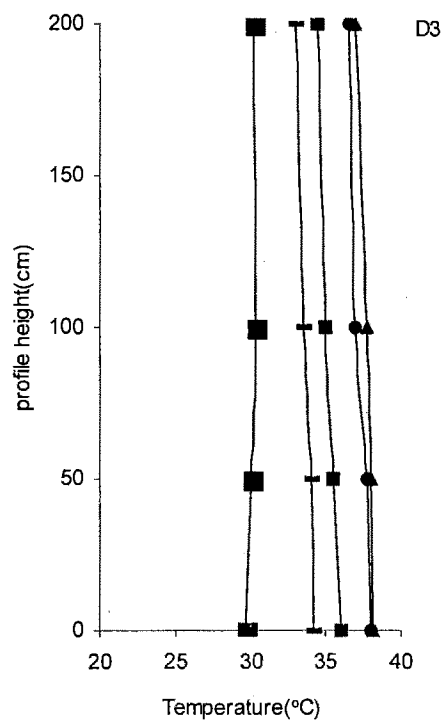
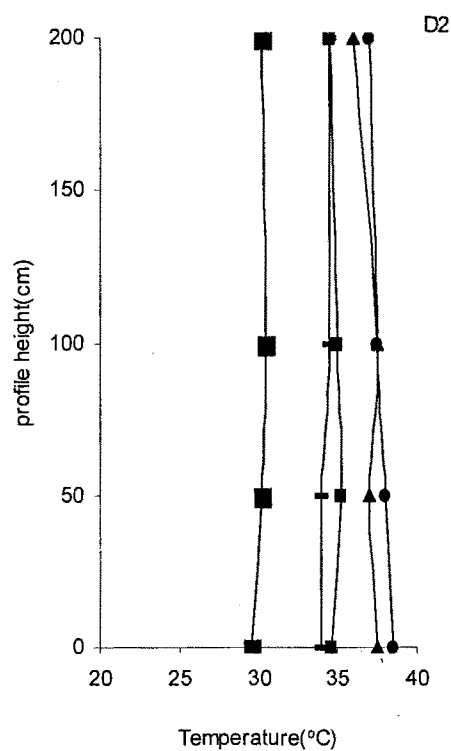
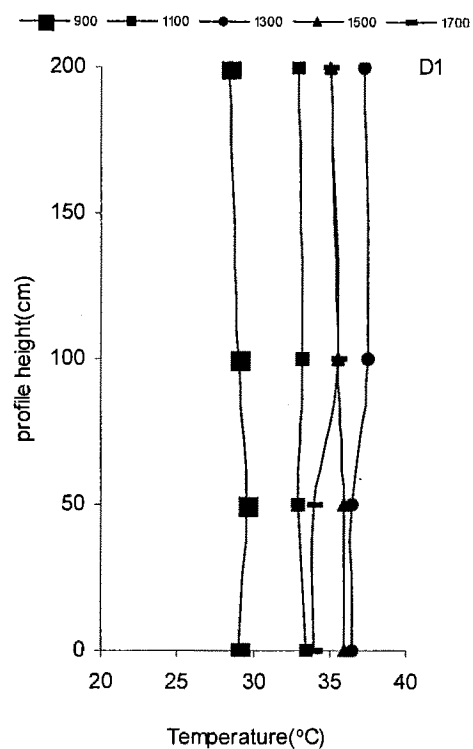
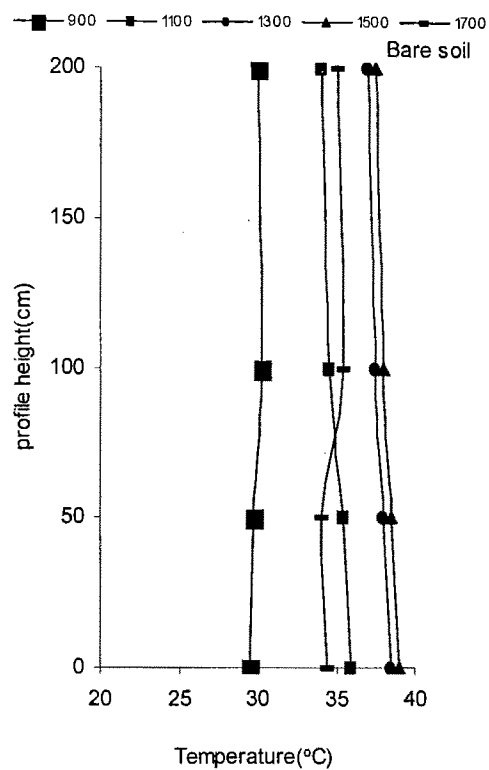


**Fig 7b : Diurnal variation of temperature profile under different environmental conditions in soybean *CONSTRUCOES AGRARIAS* and over bare soil : 9 Sep 2005**

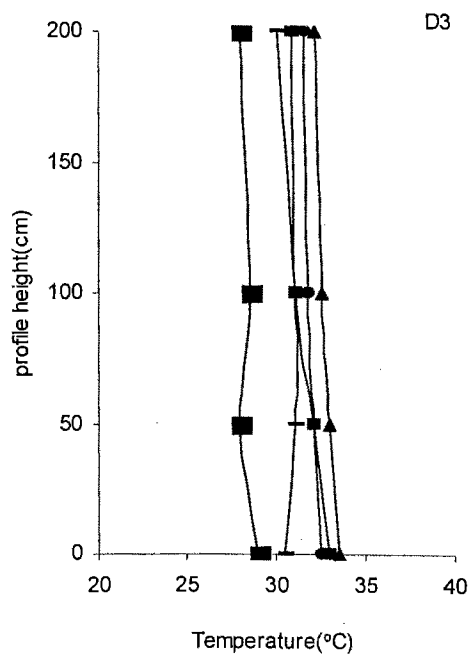
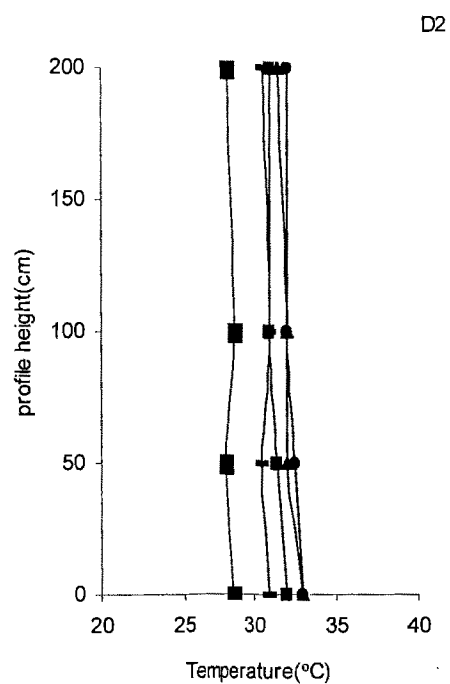
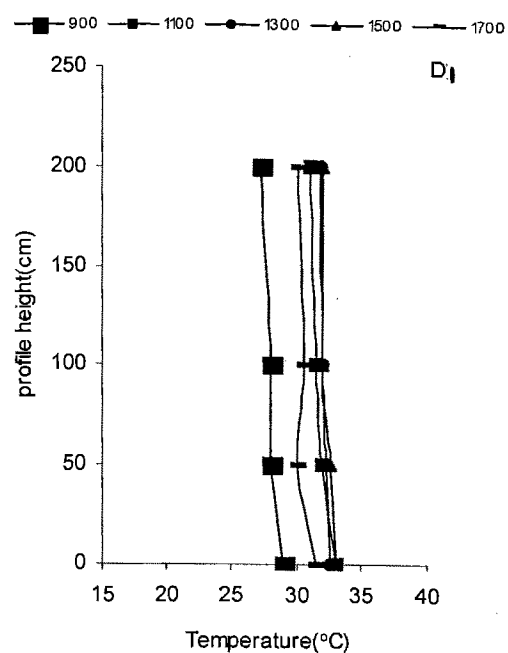
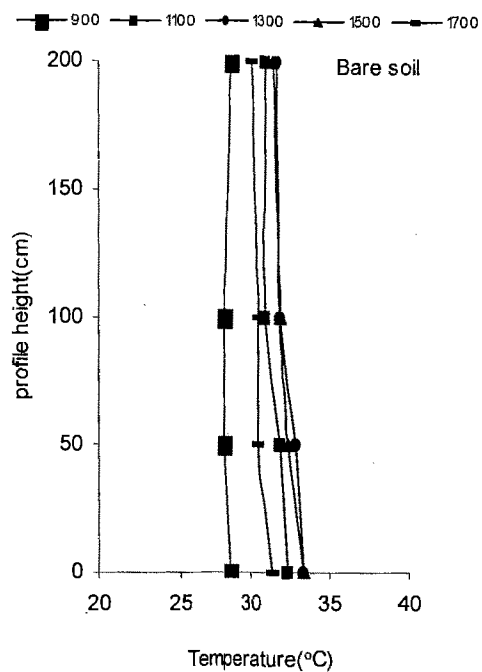


**Fig 7c : Diurnal variation of temperature profile in bare soil and soybean canopy under different growing environments** *Journal of Agricultural Science* 2005

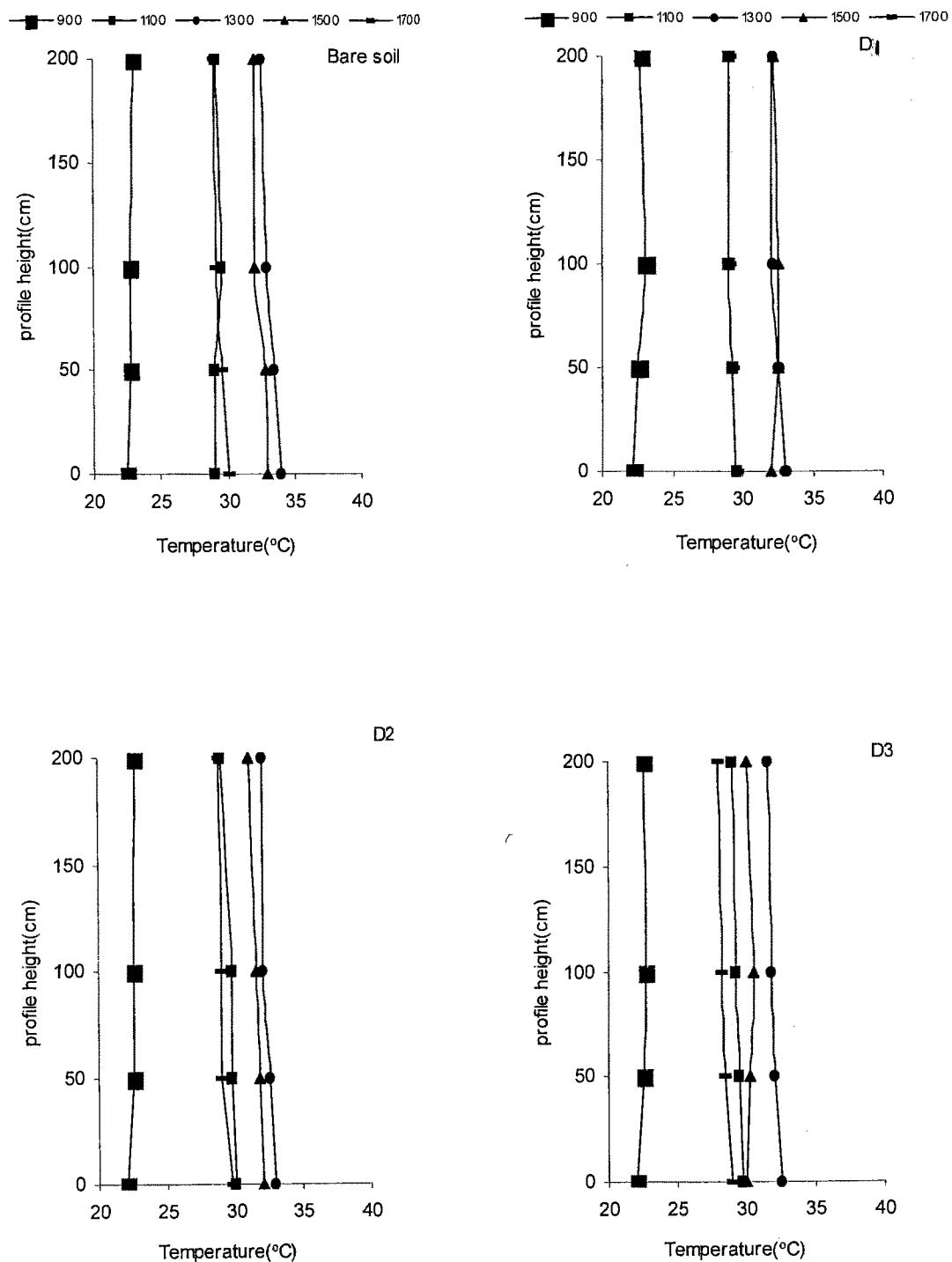


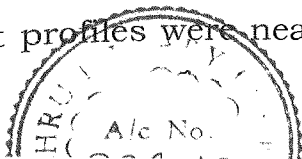
**Fig.7d : Diurnal variation of temperature profile in bare soil and soybean canopy under different growing environments 2005**

July sown crop. The temperature profiles were inverse throughout the day. The inclination of temperature profile during the noon was greater at 50% flowering because of the presence of higher leaf area than at physiological maturity where it was largely absent due to the senescence. The maximum temperature recorded was recorded in the canopy where more number of green leaves existed. Such changes can be expected since most of the incoming solar radiation is either absorbed by the leaf or the surrounding atmospheric moisture thus raising the temperature in its vicinity rather than a decrease. Top of the canopy profile were lapse in both the crop growing seasons. Similar results have been earlier reported by Rosenberg (1974) and Sunil (2005).

Beneath the maximum leaf area layer the temperature inversion occurred because of the warmness of the canopy resulting due to the presence of warmer soil surface underneath. The temperature variations from bottom to top of canopy could have resulted partly because of the transpiration cooling occurred inside the crop canopy and partly because of the poor transmission of solar radiations to the bottom layers inside the canopy since most of it was being replaced by the crop as LE component.

#### **4.5.2 Vapour pressure profile**

Vapour pressure profiles were higher inside the crop canopy than above the canopy in three dates of sowing viz., 1<sup>st</sup> week of June, 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July and are shown in Fig 8a, 8b, 8c and 8d. The vapour pressure profiles were lapse inside the crop canopy throughout the day but profiles were nearly isolinic at 9:00 hours and



2004

2005

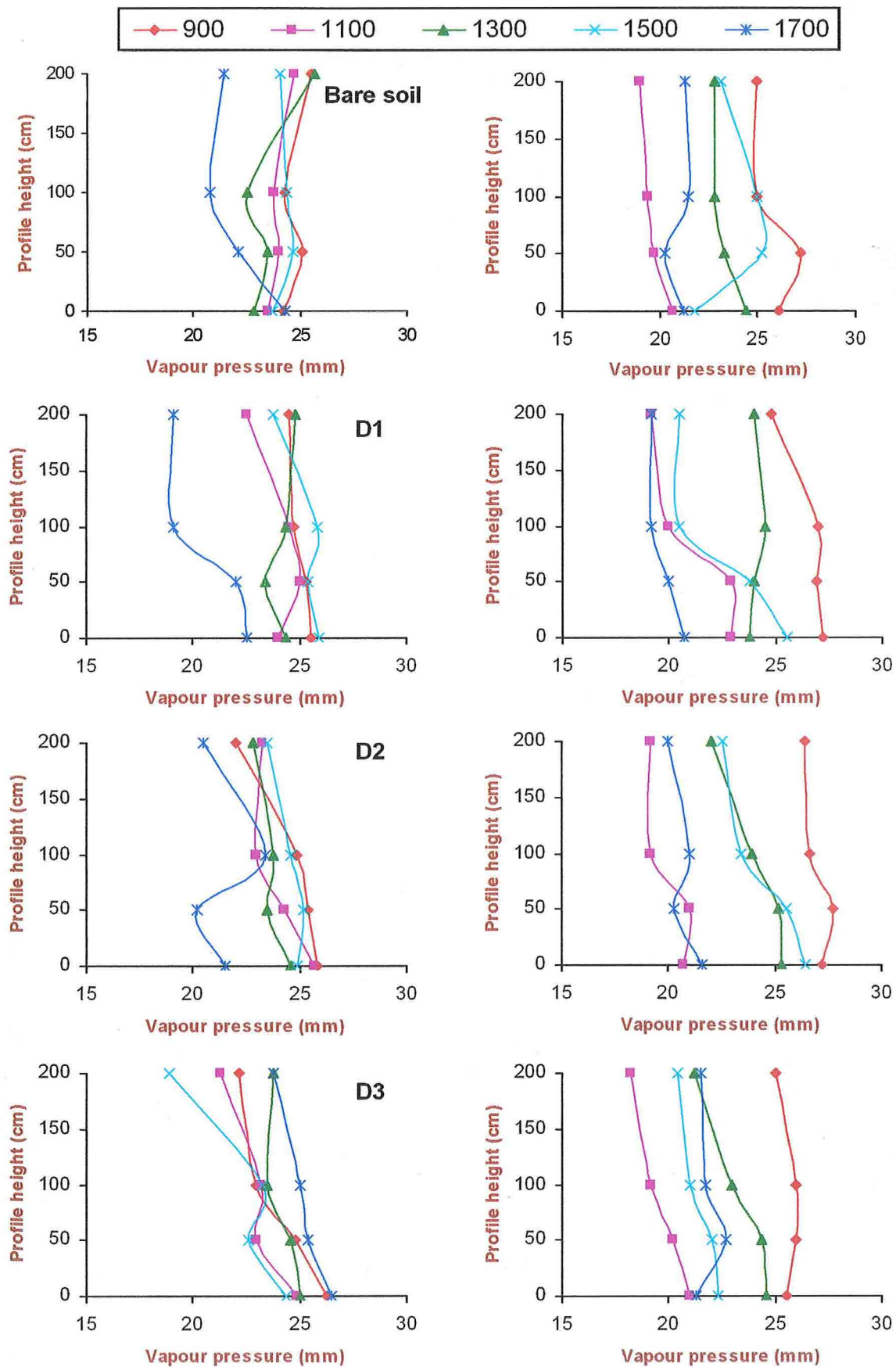


**Fig. 8a :** Diurnal variation of vapour pressure profile in soybean cultivars under different growing environments On (20.08.2004) and (30.08.2005)

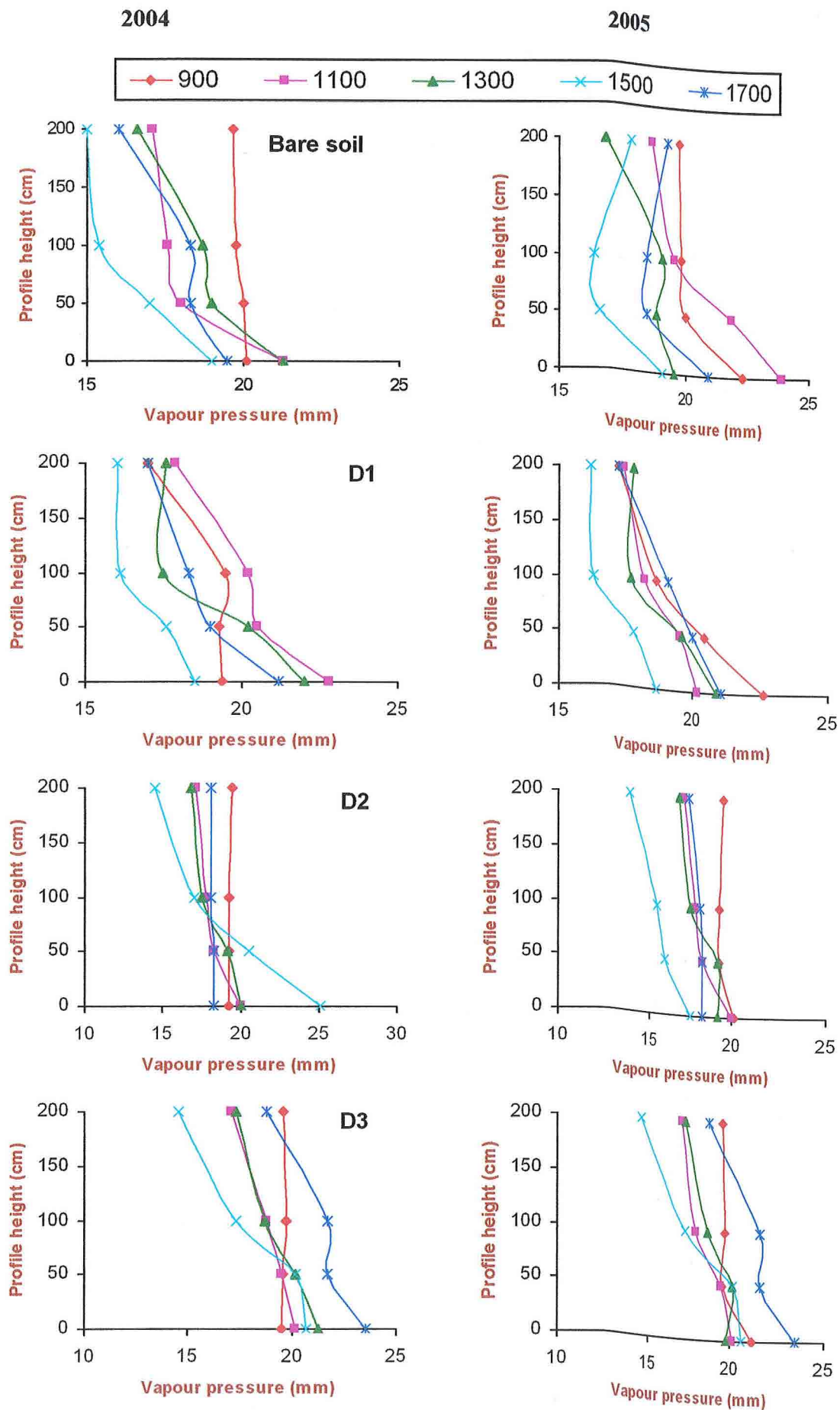


**Fig. 8b : Diurnal variation of vapor pressure profile in soybean cultivars under different growing environments on 07.09.2004 and 09.09.2005)**

2004

2005

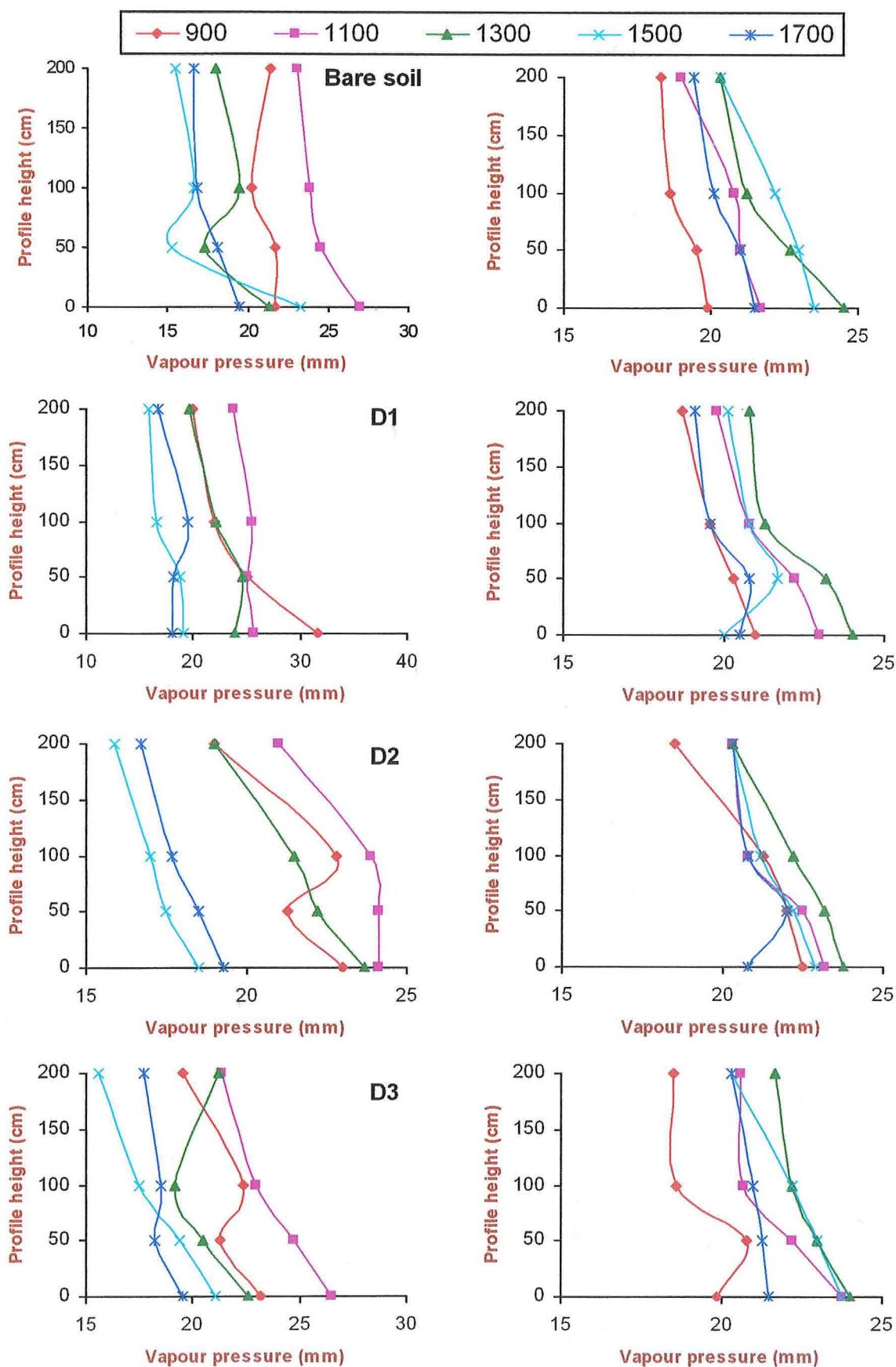


Fig. 8c : Diurnal variation of vapor pressure profile in soybean cultivars under different growing environments on (23.09.2004) and (30.09.2005)

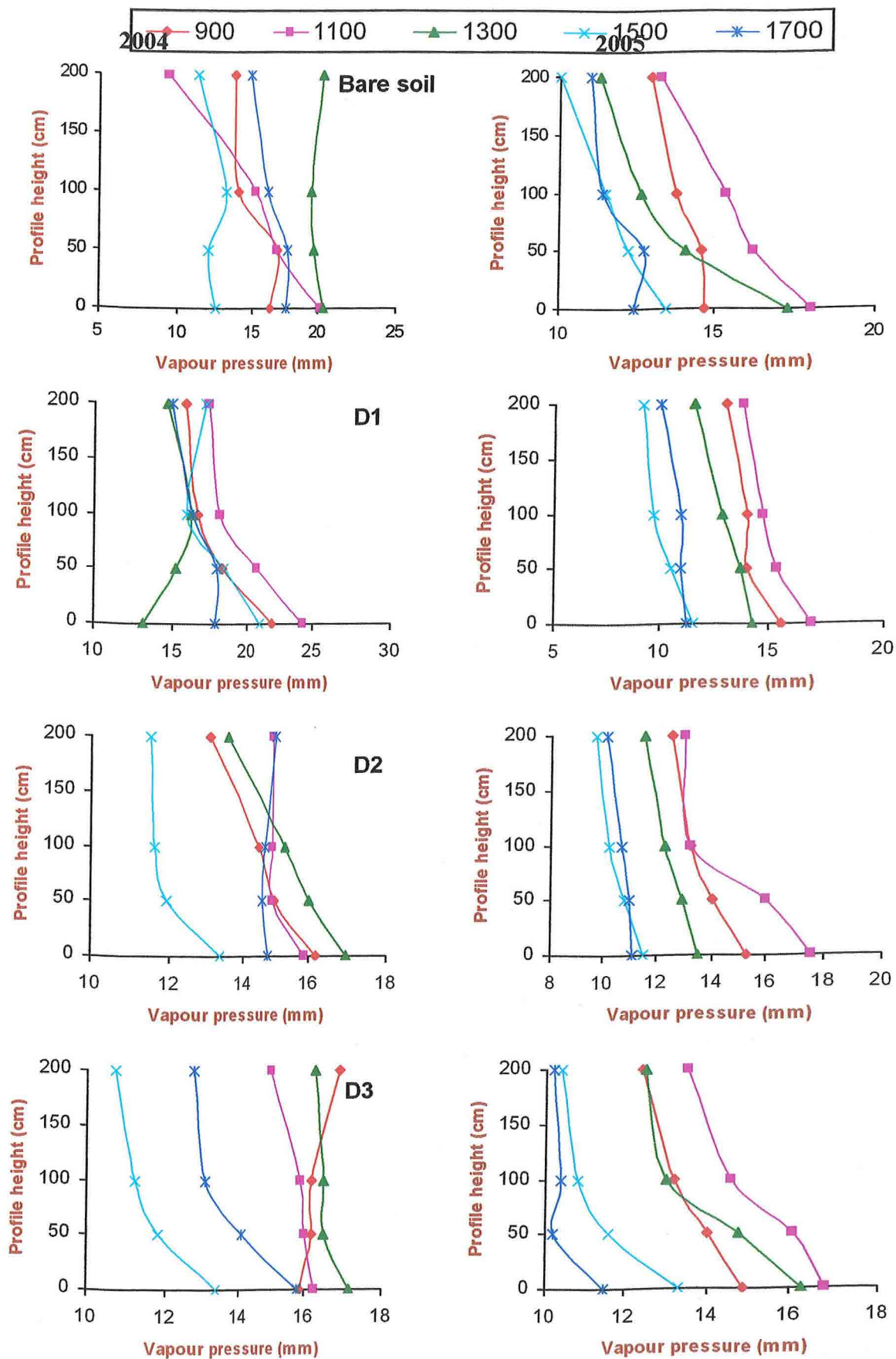


**Fig. 8d : Diurnal variation of vapor pressure profile in soybean cultivars under different growing environments on (19.10.2004) and (27.10.2005)**

17:00 hours in all treatments. The peak vapour pressure profiles were recorded at 9:00 hrs at 50% flowering stage. The vapour pressure profiles at noon time appeared on extreme left because of low moisture inside the crop canopy due to stomatal closure at noon whereas in bare soil the profiles had lowest values as compared crop canopy. Similar results were observed by Shamim (2003) and Baldocchi *et al.* (1983). They studies the microclimate in soybean and found that vapor pressure profiles were generally lapse throughout the day with a strong gradient in the upper canopy and a weak gradient in the lower canopy.

#### **4.5.3 Canopy temperature ( $T_c$ )**

The canopy temperature were recorded under different growing environments in soybean cultivars during both crop seasons (2004 and 2005) and the results are presented in Fig 9.

Data recorded at different phenological stages *i.e.*, early vegetative stage, 50 per cent flowering, pod development and physiological maturity. The soil surface temperature was always higher than the ambient temperature ( $T_a$ ) throughout the day. In early sown crop (1<sup>st</sup> week of June) highest canopy temperature was recorded followed by 3<sup>rd</sup> week of June and lowest in delayed sown crop (1<sup>st</sup> week of July). This might be due to the more vegetative growth in early sown crop and its reflection in incoming radiation.

Among cultivars PS 1042 recorded highest canopy temperature followed by DS 9814 except 50 per cent flowering in 3<sup>rd</sup> week of June sown crop and it was lowest in PK 416 during both crop growing seasons (2004 and 2005). Similar result was obtained by Singh (1998) under different sowing dates and soybean cultivars.

2004

2005

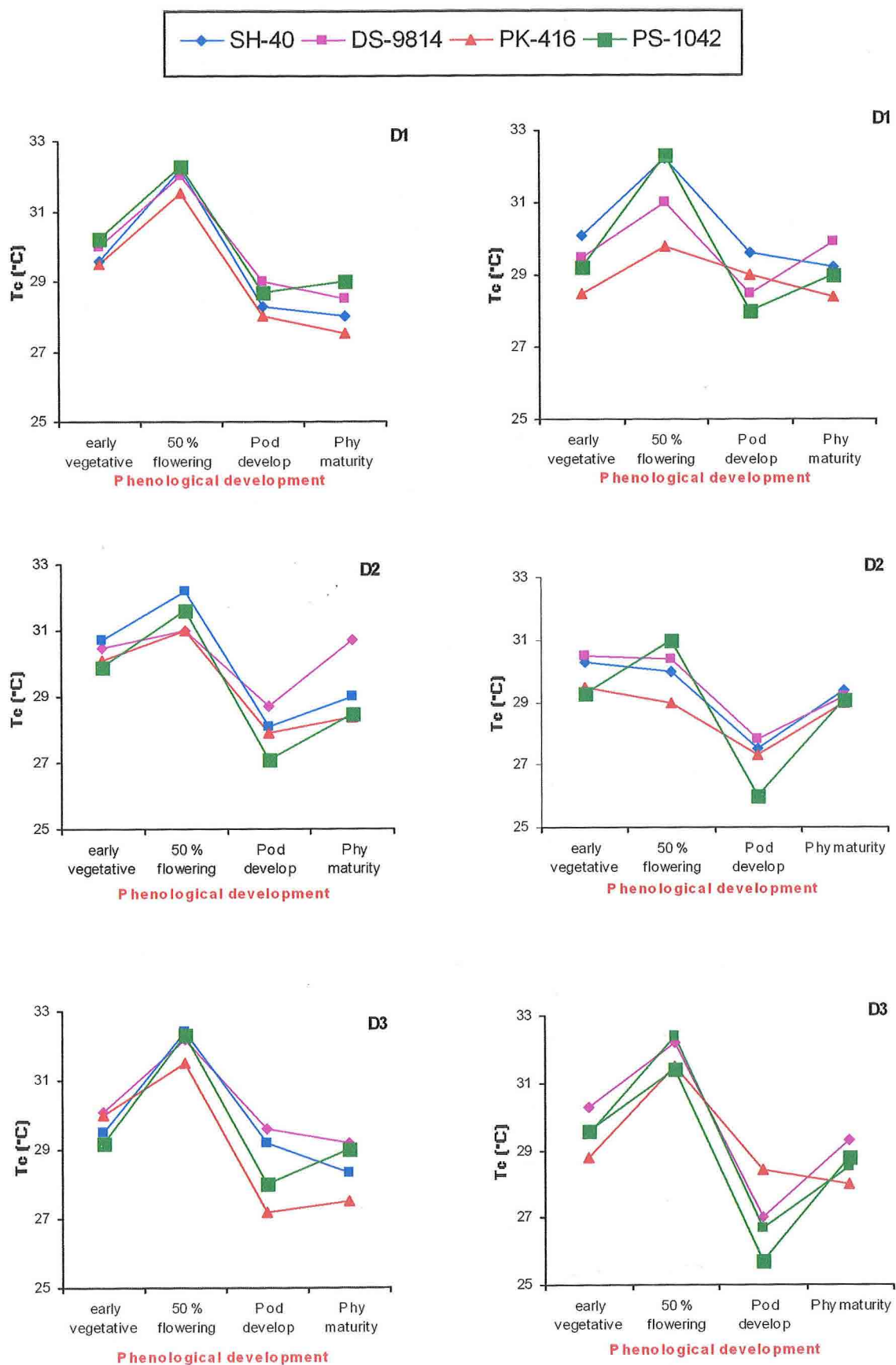


**Fig. 9 : Canopy temperature ( $T_c$ °C) in soybean cultivars under different growing environments at different phenological development during kharif 2004 and 2005**

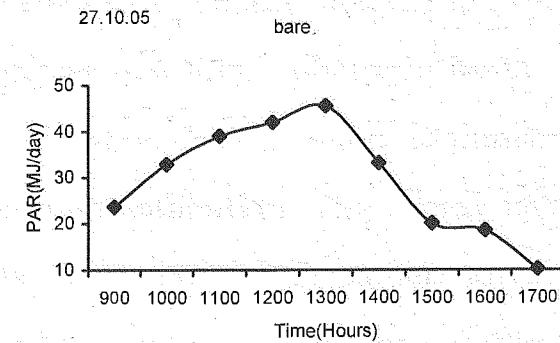
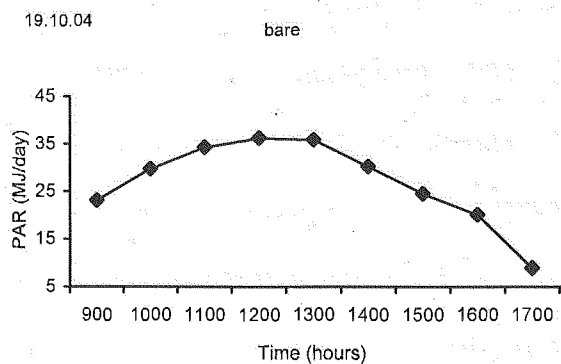
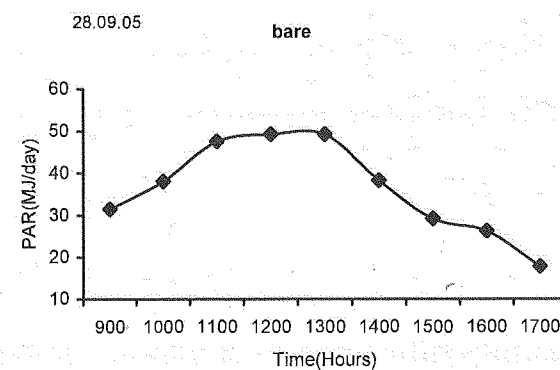
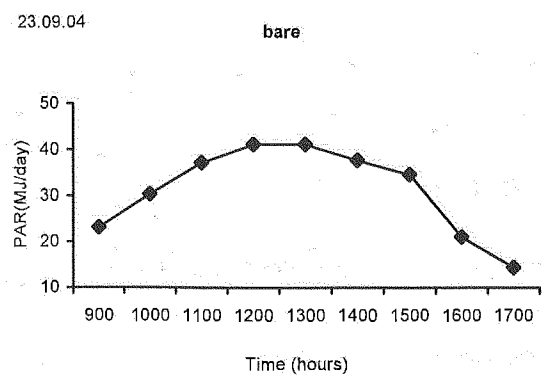
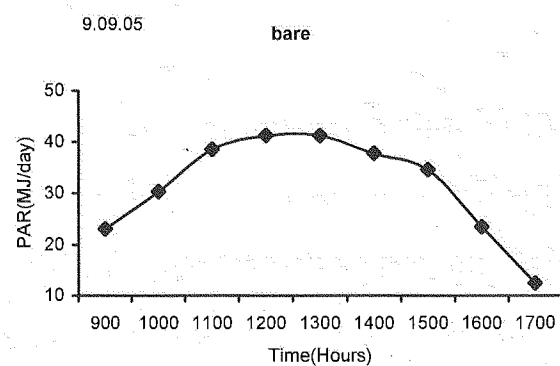
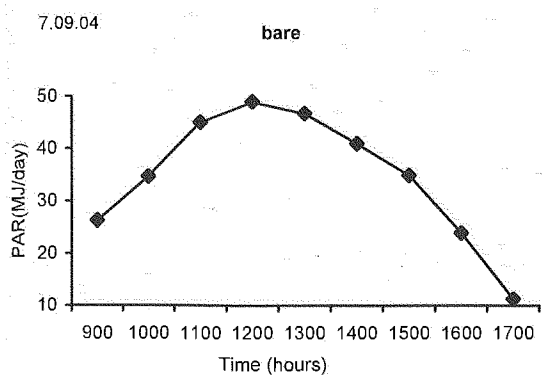
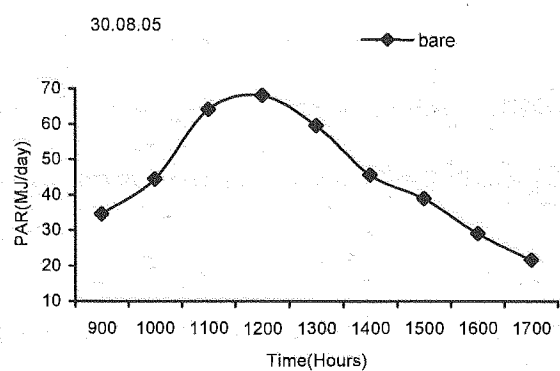
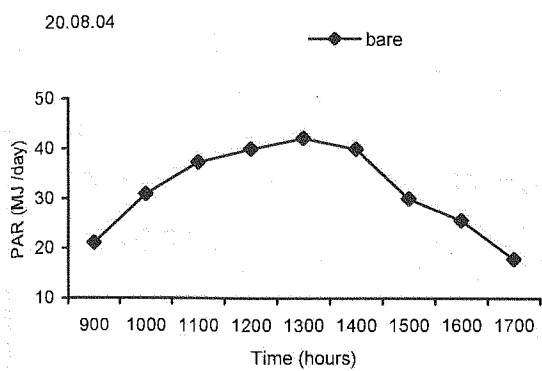


**Fig. Diurnal variation of PAR in bare soil different phenological development in soybean during kharif - 2004 and 2005**

#### **4.5.4 Photosynthetically Active Radiation (PAR)**

Diurnal photosynthetically active radiation under different growing environments in soybean observed in two *Kharif* seasons (2004 and 2005) is presented in Fig. 10.

There were no clear cut differences among the different phonological stages over bare soil during both the year (2004 and 2005).

In general PAR increased from morning till noon time (1200 to 1300 hrs) in all the treatments and then declined consistently till evening among all the dates of sowing. Similar results were obtained by Padmavathi *et al.* (2003). They reported that intercepted PAR was highest in the intercropping system, followed by sole pigeon pea and sole soybean. Extinction coefficient an indicator of PAR distribution within the canopy was higher in sorghum+pigeon pea and sole as compared to other systems.

#### **4.5.5 Energy balance components**

The energy balance over a crop canopy is of great importance, as it shows the amount or proportion of the energy utilized for various processes including the evapotranspiration, photosynthesis and convective heat exchange. Net radiation is the main parameter in several methods of evapotranspiration estimation. The energy balance study over crop surface can be more helpful in understanding of various physical and physiological processes taking place in the crop environment. The incident radiation is dependent on several factors like height and arrangement of plants, plant structure, leaf angle and

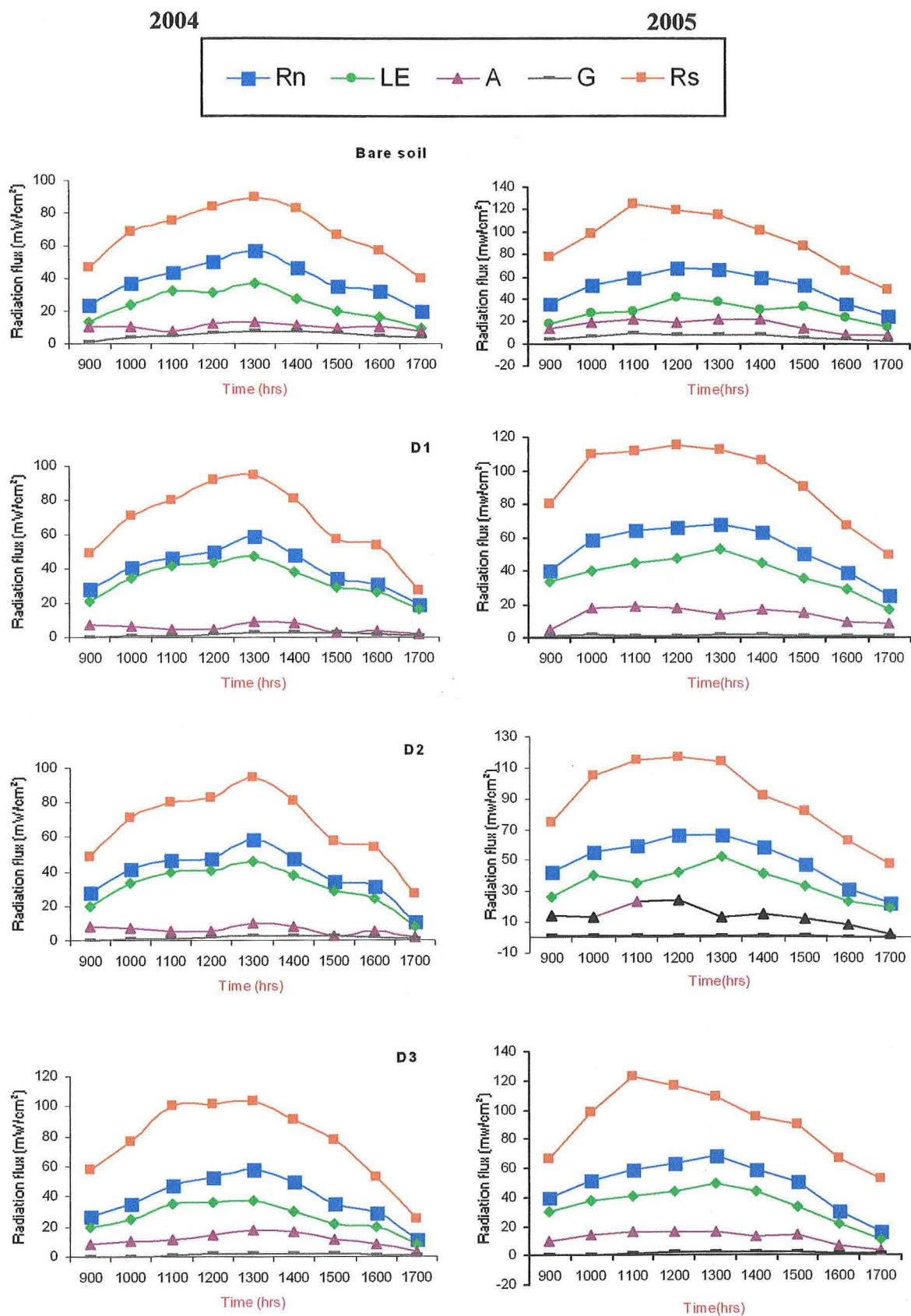


**Fig. 11a : Diurnal variation in energy balance components in soybean and bare soil under different growing environments on (20.08.2004) and (30.08.2005)**

2004

2005

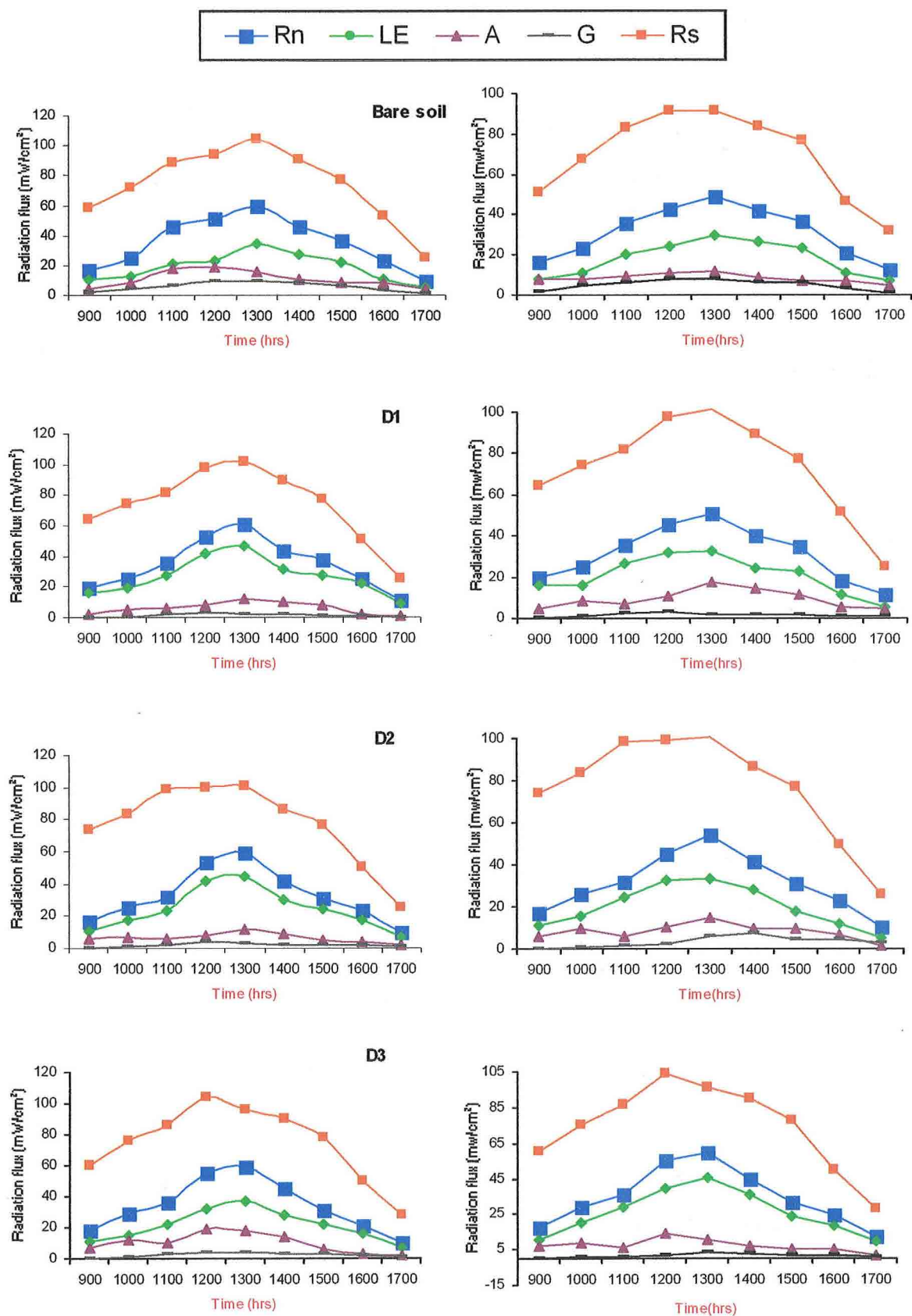


**Fig. 11b : Diurnal variation in energy balance components in soybean and bare soil under different growing environments on (7.09.2004) and (09.09.2005)**

2004

2005

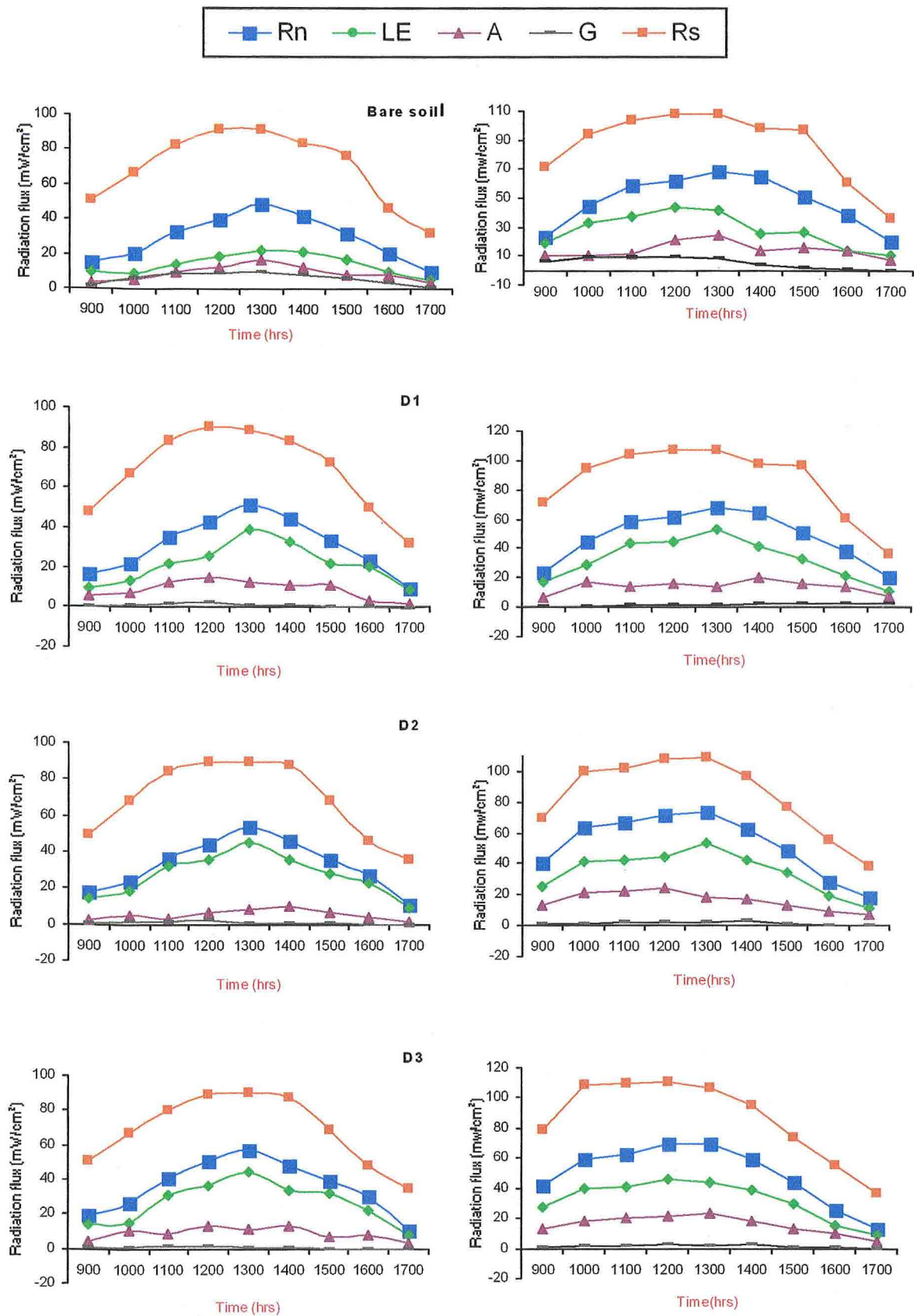


**Fig. 11c : Diurnal variation in energy balance components in soybean and bare soil under different growing environments on (23.09.2004) and (30.09.2005)**

2004

2005

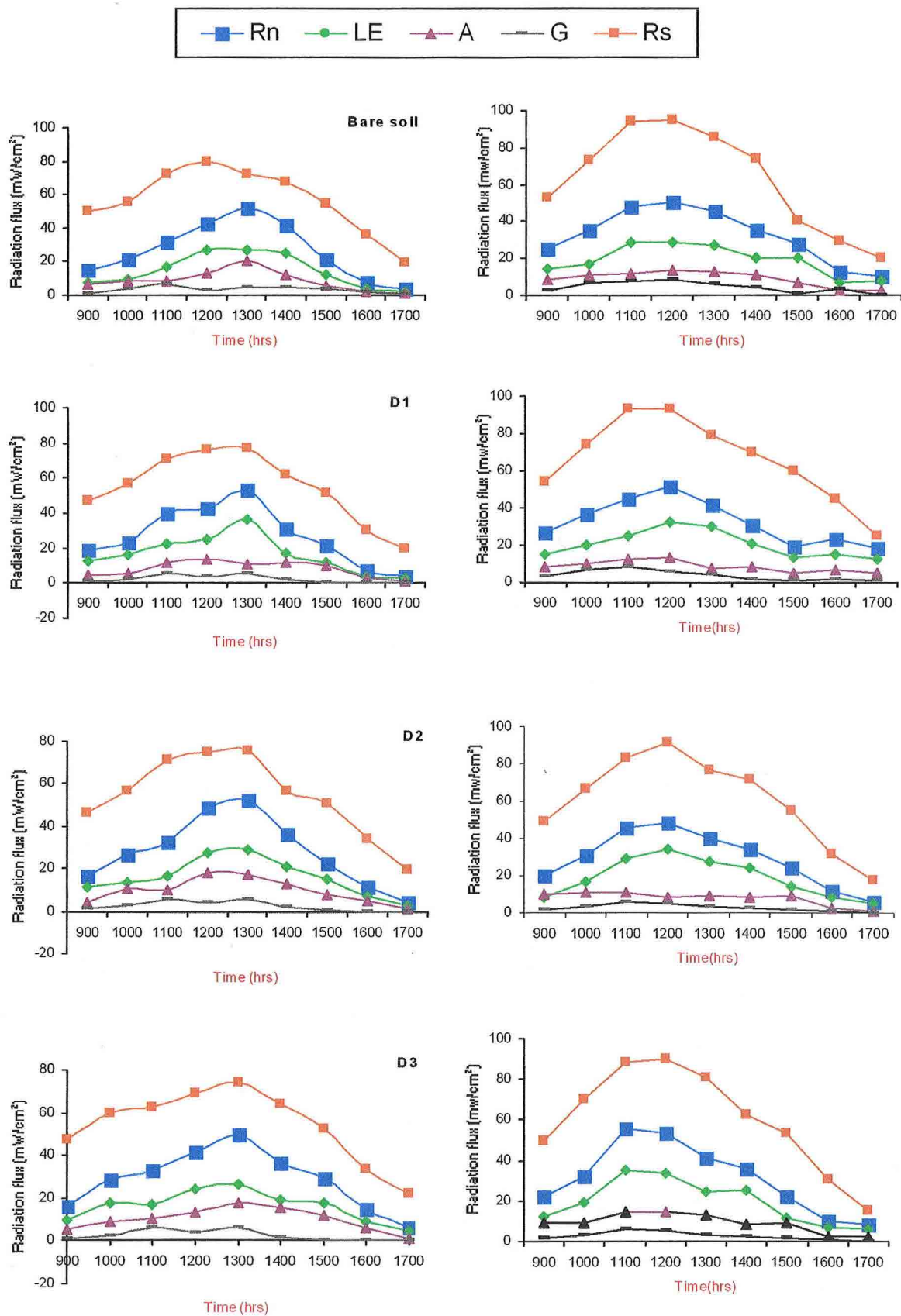


**Fig. 11d : Diurnal variation in energy balance components in soybean and bare soil under different growing environments on 19.10.2004 and 27.10.2005**

geometry, leaf size and age. The diurnal pattern of energy components namely, net radiation ( $R_n$ ), short wave radiation ( $R_s$ ), latent heat of vaporization (LE) sensible heat flux (A) and soil heat flux (G) in different treatments and over the bare soil were recorded or calculated at different growing stages viz., early vegetative stage, 50% flowering, 50% pod filling and physiological maturity and the results are presented in Fig. 11a, 11b, 11c and Fig. 11d for two crop seasons (2004 and 2005).

A close perusal of the results indicated that the value for different components of energy balance ( $R_n$ ,  $R_s$ , LE, A and G) was higher during noon hours than that observed during morning and evening hours for all treatments alongwith bare field. The per cent of net energy diverted to the component varied with crop growth stage. In general, a major portion of  $R_n$  was utilized in LE followed by A and G. The variation was due to change in the sun angle, similar results were earlier reported by Shamim (2003) and Samui *et al.*, (2002) for soybean.

The value of latent heat flux in soybean was recorded highest at 50% of flowering, when the crop has developed maximum LAI. Maximum  $R_n$  value was recorded at early vegetative stage might be due to nearer to summer solstice, similar results were observed by Rosenberg (1974). The  $R_s$  values have shown maximum at 50% of flowering over the crop canopy. The sensible heat flux (A) was highest during noon time throughout the crop season and soil heat flux was higher during the early vegetative stage followed by physiological maturity and lower during the 50 % flowering and 50 % pod filling stage.

Net radiation partitioning (LE, A and G), at four growth stages (early vegetative stage, 50 per cent flowering, pod development and physiological maturity) under different growing environments during two crop seasons (2004 and 2005) have been presented in Table 12. In general a major portion of the net radiation was utilized as LE irrespective of growth stage of the crop. However, the values of various components varied in magnitude over crop growth stages and seasons. LE values were higher at early vegetative stage in both the cropping seasons and lowest were recorded at physiological maturity stage. The LE values were higher during 2004 crop growth season as compared to 2005. The most probable reason for which might be the higher LAI values resulting in higher evapotranspirational losses. In 1<sup>st</sup> week of June sown crop the LE was highest (83.37%) and it was lowest (67.06) in 1<sup>st</sup> week of July sown crop.

The sensible heat (A) was recorded highest in 1<sup>st</sup> week of July sown crop at all growth stages in both seasons except at 50% flowering during 2005 sown crop. It must be because of the poor leaf area development. The A values were recorded highest at physiological maturity which can be expected since most of the leaves were senesced at physiological maturity. Soil heat flux (G) values increased with advancement of crop age and the highest values were recorded at physiological maturity stage in both the crop seasons.

The higher values of LE in the cropped field can be attributed due to higher values of ET losses, on the other hand, the higher values of sensible and soil heat flux in the bare field were because of the more

**Table 12 : Energy balance components (at different phenophases) in soybean grown under different environments and over bare soil during 2004 and 2005 crop seasons**

| Treatments                         | 2004 |                   |                   |                   |                  | 2005 |                   |                      |                   |                  |
|------------------------------------|------|-------------------|-------------------|-------------------|------------------|------|-------------------|----------------------|-------------------|------------------|
|                                    | Rs   | Rn                | LE                | A                 | G                | Rs   | Rn                | LE                   | A                 | G                |
| <b>Initiation of flowering</b>     |      |                   |                   |                   |                  |      |                   |                      |                   |                  |
| <b>1<sup>st</sup> week of June</b> | 604  | 357.32<br>(59.07) | 297.90<br>(83.37) | 46.45<br>(13.00)  | 12.98<br>(3.63)  | 842  | 475.20<br>(56.38) | 244.10<br>(72.41)    | 121.40<br>(25.50) | 9.70<br>(2.04)   |
| <b>3<sup>rd</sup> week of June</b> | 596  | 346.74<br>(58.18) | 278.40<br>(82.35) | 54.30<br>(15.67)  | 14.03<br>(3.71)  | 808  | 453.49<br>(55.64) | 314.20<br>(70.12.87) | 126.60<br>(28.15) | 8.90<br>(2.10)   |
| <b>1<sup>st</sup> week of July</b> | 687  | 347.04<br>(50.48) | 232.27<br>(67.06) | 101.30<br>(29.20) | 12.98<br>(3.74)  | 816  | 437.10<br>(53.52) | 313.00<br>(71.61)    | 111.10<br>(25.42) | 13.00<br>(2.97)  |
| <b>Bare soil</b>                   | 610  | 348.03<br>(57.02) | 211.20<br>(60.63) | 92.90<br>(26.67)  | 44.20<br>(12.70) | 834  | 452.90<br>(54.27) | 252.50<br>(55.75)    | 147.10<br>(32.48) | 53.40<br>(11.79) |
| <b>End of Flowering</b>            |      |                   |                   |                   |                  |      |                   |                      |                   |                  |
| <b>1<sup>st</sup> week of June</b> | 662  | 311.35<br>(47.05) | 244.00<br>(78.35) | 56.00<br>(17.99)  | 11.39<br>(3.66)  | 662  | 281.55<br>(42.51) | 168.97<br>(60.01)    | 83.52<br>(29.66)  | 11.05<br>(3.92)  |
| <b>3<sup>rd</sup> week of June</b> | 695  | 291.25<br>(41.90) | 316.60<br>(74.38) | 57.60<br>(19.77)  | 17.04<br>(5.85)  | 695  | 287.98<br>(43.14) | 180.20<br>(64.54)    | 82.25<br>(29.61)  | 29.33<br>(4.10)  |
| <b>1<sup>st</sup> week of July</b> | 669  | 302.84<br>(45.23) | 189.80<br>(62.67) | 91.70<br>(30.29)  | 21.34<br>(7.05)  | 669  | 307.92<br>(45.99) | 230.36<br>(74.84)    | 64.38<br>(20.91)  | 13.18<br>(4.28)  |
| <b>Bare soil</b>                   | 663  | 312.47<br>(47.12) | 165.50<br>(52.97) | 96.50<br>(30.88)  | 50.48<br>(16.16) | 624  | 279.00<br>(44.68) | 159.30<br>(57.10)    | 74.50<br>(26.70)  | 45.30<br>(16.24) |

| Treatments                   | 2004 |                   |                   |                  |                  | 2005 |                   |                   |                   |                  |
|------------------------------|------|-------------------|-------------------|------------------|------------------|------|-------------------|-------------------|-------------------|------------------|
|                              | Rs   | Rn                | LE                | A                | G                | Rs   | Rn                | LE                | A                 | G                |
| Pod Development              |      |                   |                   |                  |                  |      |                   |                   |                   |                  |
| 1 <sup>st</sup> week of June | 616  | 279.80<br>(45.37) | 194.50<br>(69.51) | 80.01<br>(28.60) | 7.75<br>(2.77)   | 776  | 431.10<br>(55.53) | 295.90<br>(68.64) | 125.30<br>(29.07) | 11.90<br>(2.72)  |
| 3 <sup>rd</sup> week of June | 619  | 295.33<br>(47.69) | 241.70<br>(67.84) | 47.54<br>(29.10) | 6.10<br>(2.07)   | 754  | 474.70<br>(62.92) | 316.00<br>(66.57) | 145.80<br>(30.71) | 12.80<br>(2.70)  |
| 1 <sup>st</sup> week of July | 616  | 323.17<br>(52.46) | 237.31<br>(73.43) | 78.11<br>(24.17) | 5.29<br>(1.64)   | 775  | 444.30<br>(57.33) | 293.50<br>(66.38) | 149.90<br>(33.74) | 11.90<br>(1.90)  |
| Bare soil                    | 624  | 236.40<br>(46.62) | 130.12<br>(55.04) | 76.95<br>(32.55) | 29.33<br>(12.41) | 742  | 425.20<br>(57.29) | 249.80<br>(58.75) | 126.80<br>(29.82) | 48.60<br>(11.43) |
| Physiological maturity       |      |                   |                   |                  |                  |      |                   |                   |                   |                  |
| 1 <sup>st</sup> week of June | 490  | 241.55<br>(49.25) | 184.33<br>(76.31) | 72.07<br>(29.84) | 21.15<br>(8.76)  | 593  | 293.20<br>(49.40) | 184.60<br>(62.96) | 76.40<br>(26.06)  | 32.20<br>(10.98) |
| 3 <sup>rd</sup> week of June | 485  | 250.91<br>(51.68) | 143.03<br>(57.00) | 86.72<br>(34.56) | 21.15<br>(8.43)  | 544  | 261.90<br>(48.13) | 167.90<br>(64.11) | 70.40<br>(26.88)  | 23.60<br>(9.01)  |
| 1 <sup>st</sup> week of July | 485  | 256.28<br>(52.75) | 145.16<br>(56.64) | 89.97<br>(35.11) | 21.15<br>(8.25)  | 541  | 281.16<br>(51.90) | 174.06<br>(61.91) | 83.55<br>(29.72)  | 23.56<br>(8.38)  |
| Bare soil                    | 507  | 262.50<br>(42.04) | 128.04<br>(48.78) | 79.79<br>(30.40) | 54.61<br>(20.83) | 563  | 289.20<br>(51.33) | 170.00<br>(58.78) | 79.40<br>(27.46)  | 39.80<br>(13.76) |

exposed soil surface to the sun. Net radiation partitioned towards heating of soil was lower than LE and A in cropped field.

In general, the per cent values of net radiation utilized towards G were less than 10% in cropped field, whereas in bare files these values exceeded 10%. Similar results were reported by Shamin (2003) at Hisar and Samui, *et al.* (2002) in comparative studies of radiation balance components at different growth stages of soybean crop and bare soil made at Central Agrometeorological Observatory, Pune.

#### **4.6 YIELD AND ITS ATTRIBUTES**

The seed yield and its attributes in four soybean cultivars, which were grown under different environments *i.e.* date of sowing in *kharif* season 2004 and 2005 are presented in Table 13 and 14.

The number of plants/m<sup>2</sup> was shown statistically non-significant in both the crop season (2004 and 2005). The highest plant population/m<sup>2</sup> was recorded in 1<sup>st</sup> week of June sown crop in both the crop seasons. Among the cultivars did not statistically significantly but, PK 416 was recorded more number of plant/m<sup>2</sup> in *kharif* 2004 and 2005 season respectively and less number of plant /m<sup>2</sup> recorded in PS 1042 during both *kharif* growing seasons.

Pods per unit decreased with subsequent delay in sowing from 1<sup>st</sup> week of June onward in both crop growing season. Among the cultivars in *kharif* 2004, PK 416 recorded highest pods per plant and it was lowest in SH 40. This might be due to higher number of branches/plant in PK 416 compared to other cultivars and its adaptability to the existing climatic conditions for better growth and development. Similar results were recorded in 2005 season.

**Table 13: Yield attributes of soybean cultivars under different growing environments**

| Treatments                      | 2004                      |                             |                          |                          |                         | 2005                      |                             |                          |                          |                         |
|---------------------------------|---------------------------|-----------------------------|--------------------------|--------------------------|-------------------------|---------------------------|-----------------------------|--------------------------|--------------------------|-------------------------|
|                                 | Plants<br>m <sup>-2</sup> | Primary<br>branch/<br>Plant | No. of<br>pods/<br>Plant | No. of<br>grains/<br>pod | 100-<br>grain<br>weight | Plants<br>m <sup>-2</sup> | Primary<br>branch/<br>Plant | No. of<br>pods/<br>Plant | No. of<br>grains/<br>pod | 100-<br>grain<br>weight |
| <b>Sowing Time</b>              |                           |                             |                          |                          |                         |                           |                             |                          |                          |                         |
| 1 <sup>st</sup> week of<br>June | 15.5                      | 3.6                         | 62.0                     | 2.4                      | 1.9                     | 15.9                      | 3.7                         | 64.0                     | 2.7                      | 11.0                    |
| 3 <sup>rd</sup> week of<br>June | 14.9                      | 3.2                         | 59.0                     | 2.3                      | 10.6                    | 15.2                      | 3.3                         | 62.0                     | 2.5                      | 10.6                    |
| 1 <sup>st</sup> week of<br>July | 14.8                      | 2.8                         | 57.6                     | 2.2                      | 10.0                    | 15.0                      | 2.8                         | 28.6                     | 2.4                      | 10.0                    |
| CD at 5%                        | NS                        | 0.4                         | 2.0                      | NS                       | 0.3                     | NS                        | 0.3                         | 2.0                      | 0.3                      | 0.3                     |
| <b>Cultivars</b>                |                           |                             |                          |                          |                         |                           |                             |                          |                          |                         |
| SH 40                           | 14.5                      | 2.8                         | 54.4                     | 2.2                      | 10.4                    | 14.7                      | 2.9                         | 58.0                     | 2.4                      | 10.4                    |
| DS 9814                         | 15.5                      | 3.2                         | 61.4                     | 2.3                      | 11.3                    | 15.8                      | 3.4                         | 63.9                     | 2.7                      | 11.4                    |
| PK 416                          | 16.3                      | 4.0                         | 65.5                     | 2.4                      | 10.3                    | 16.8                      | 4.0                         | 67.5                     | 2.8                      | 10.3                    |
| PS 1042                         | 14.0                      | 2.7                         | 55.0                     | 2.2                      | 10.1                    | 14.3                      | 2.8                         | 56.2                     | 2.3                      | 10.1                    |
| CD at 5%                        | NS                        | 0.3                         | 1.7                      | NS                       | 0.2                     | NS                        | 0.2                         | 2.1                      | 0.2                      | 0.2                     |

**Table 14 : Grain, straw and biological yield and harvest index of soybean cultivars under different<sup>t</sup> growing environments**

| Treatments                   | 2004                   |                           |                                |                      | 2005                      |                           |                                |                      |
|------------------------------|------------------------|---------------------------|--------------------------------|----------------------|---------------------------|---------------------------|--------------------------------|----------------------|
|                              | Grain yield<br>(kg/ha) | Straw<br>yield<br>(kg/ha) | Biological<br>yield<br>(kg/ha) | Harvest<br>index (%) | Grain<br>yield<br>(kg/ha) | Straw<br>yield<br>(kg/ha) | Biological<br>yield<br>(kg/ha) | Harvest<br>index (%) |
| Sowing Time                  |                        |                           |                                |                      |                           |                           |                                |                      |
| 1 <sup>st</sup> week of June | 1032                   | 1370                      | 2402                           | 43.1                 | 1102                      | 1465                      | 2567                           | 42.9                 |
| 3 <sup>rd</sup> week of June | 961                    | 1309                      | 2270                           | 42.0                 | 1044                      | 1374                      | 2418                           | 43.1                 |
| 1 <sup>st</sup> week of July | 872                    | 1210                      | 2083                           | 42.0                 | 975                       | 1308                      | 2284                           | 42.7                 |
| CD at 5%                     | 32                     | 26                        | 56                             | 0.8                  | 39                        | 20                        | 33                             | 0.7                  |
| Cultivars                    |                        |                           |                                |                      |                           |                           |                                |                      |
| SH 40                        | 916                    | 1288                      | 2176                           | 41.2                 | 976                       | 1347                      | 2323                           | 42.0                 |
| DS 9814                      | 961                    | 1373                      | 2334                           | 41.5                 | 1071                      | 1451                      | 2522                           | 42.4                 |
| PK 416                       | 1057                   | 1397                      | 2453                           | 43.0                 | 1151                      | 1542                      | 2693                           | 42.7                 |
| PS 1042                      | 887                    | 1128                      | 2045                           | 45.0                 | 964                       | 1190                      | 2154                           | 44.7                 |
| CD at 5%                     | 24                     | 23                        | 36                             | 0.6                  | 26                        | 21                        | 27                             | 0.3                  |

The number of grains per pod were highest in 1<sup>st</sup> week of June sown crop followed by 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July. In *kharif* 2005 number of grains per pod were differ significantly but followed similar trend. Among the cultivars highest grains per pod was recorded in PK 416 and lowest in PS 1042.

The 100-grain weight was highest in 1<sup>st</sup> week of June sown crop followed by 3<sup>rd</sup> week of June and it was lowest in 1<sup>st</sup> week of July sown crop. Among the cultivars highest 100-grain weight was recorded in DS 9814 followed by SH 40, PK 416 and PS 1042 during both the years of study. Highest 100-grain weight in DS 9814 was due to its bold seed size than other cultivars.

The number of primary branches decreased significantly with delay in sowing beyond 1<sup>st</sup> week of June in both experimental crop seasons. Among the cultivar PK 416 had more number of primary branches followed by DS 9814 and lowest branches in PW-1042 and SH 40 cultivars. This might be due to the adaptability of growth factors and this was due to the genetic makeup of the cultivar.

Grain yield, straw yield and biological yield reduced significantly with delay in sowing from 1<sup>st</sup> week of June, where these were highest in both the crop seasons. This might be due to soybean was influenced by environmental changes, whether induced by cultural practices / abiotic stresses. Similar result recorded by Egli (1998) and Batwal *et al.* (2004). Among the cultivars highest grain yield was recorded in PK 416 followed by DS 9814, PS 1042 and SH 40, which are presented in Table 13 & 14. This could probably be due to the better adaptability of cultivar PK 416 to prevailing weather condition of Hisar.

Among dates of sowing the highest (43.0 and 45.0%) harvest index were recorded in 1<sup>st</sup> week of June sown crop followed by 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July in both the crop seasons. The cultivar PS 1042 recorded highest (45.0 and 44.7) harvest index followed by PK 416 (43.0), DS 9814 (41.2) and SH 40 (40.8).

## **4.7 SOYGRO MODEL**

### **4.7.1 Sensitivity analysis**

Sensitivity analysis of the model was conducted by changing the value of different coefficients which may probably influence the model output specifically for the seed yield and straw yield and the magnitude of the variation of model output with change of different coefficient were calculated.

The sensitivity analysis was conducted separately for cultivars PK 416, DS 9814, SH 40 and PS 1042 because the magnitude of variation of yield and other growth parameters with different coefficient are different among the cultivars. The sensitivity analysis for the genetic coefficient for soybean cultivar PK 416 is presented in Table 15 to 18.

The model showed sensitivity to all genetic coefficients and seed yield of PK 416 cultivar showed an increasing trend with an increase in the value of coefficient, a reverse trend was noted with decrease in the values of these coefficients. The seed yield was found more sensitive to FSD-PHM and PODDUR as they induced higher magnitude of variation as compared to the others. In case of straw yield the model was found non-sensitive to WTPSD and SDPDVR since the change in these coefficients failed to influence the straw yield whereas the other

**Table 15 : Sensitivity test results for genetic coefficients and growth coefficients PK 416 (preferred values of parameter are indicated in bold letters)**

| Genetic / growth coefficients | Range        | Estimated Seed yield (kg/ha) | Estimated Straw yield (kg/ha) |
|-------------------------------|--------------|------------------------------|-------------------------------|
| CSDVAR                        | 12.1         | 1396                         | 1650                          |
|                               | <b>12.25</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 12.35        | 998                          | 1425                          |
| EMG- FLW                      | 20.40        | 1386                         | 1681                          |
|                               | <b>20.50</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 20.60        | 955                          | 1438                          |
| FLW- FDS                      | 16.90        | 1379                         | 1696                          |
|                               | <b>17.00</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 17.10        | 921                          | 1383                          |
| FSD- PHM                      | 36.40        | 1400                         | 1708                          |
|                               | <b>36.50</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 36.60        | 901                          | 1377                          |
| SDFDUR                        | 20.90        | 1385                         | 1692                          |
|                               | <b>21.00</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 21.10        | 921                          | 1382                          |
| PODDUR                        | 9.90         | 1409                         | 1633                          |
|                               | <b>10.00</b> | <b>1356</b>                  | <b>1440</b>                   |
|                               | 10.10        | 915                          | 1364                          |
| WTPSD                         | 0.11         | 1360                         | 1440                          |
|                               | <b>0.12</b>  | <b>1356</b>                  | <b>1440</b>                   |
|                               | 0.13         | 998                          | 1440                          |
| SDPDVR                        | 1.95         | 1362                         | 1440                          |
|                               | <b>2.05</b>  | <b>1356</b>                  | <b>1440</b>                   |
|                               | 2.15         | 916                          | 1420                          |
| PPSEN                         | 0.20         | 1359                         | 1440                          |
|                               | <b>0.30</b>  | <b>1356</b>                  | <b>1440</b>                   |
|                               | 0.40         | 921                          | 1420                          |
| XFRUIT                        | 0.90         | 1364                         | 1684                          |
|                               | <b>1.00</b>  | <b>1356</b>                  | <b>1440</b>                   |
|                               | 1.10         | 938                          | 1435                          |

**Table 16 : Sensitivity test results for genetic coefficients and growth coefficients PS 1042 (preferred values of parameter are indicated in bold letters)**

| <b>Genetic / growth coefficients</b> | <b>Range</b> | <b>Estimated Seed yield (kg/ha)</b> | <b>Estimated Straw yield (kg/ha)</b> |
|--------------------------------------|--------------|-------------------------------------|--------------------------------------|
| CSDVAR                               | 12.52        | 1396                                | 1650                                 |
|                                      | <b>12.62</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 12.72        | 988                                 | 1250                                 |
| EMG- FLW                             | 22.40        | 1386                                | 1681                                 |
|                                      | <b>22.50</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 22.60        | 955                                 | 1205                                 |
| FLW- FDS                             | 16.90        | 1379                                | 1696                                 |
|                                      | <b>17.00</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 17.10        | 921                                 | 1200                                 |
| FSD-PHM                              | 34.40        | 1400                                | 1708                                 |
|                                      | <b>34.50</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 34.60        | 901                                 | 1223                                 |
| SDFDUR                               | 21.40        | 1385                                | 1692                                 |
|                                      | <b>21.50</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 21.60        | 921                                 | 1210                                 |
| PODDUR                               | 9.90         | 1409                                | 1633                                 |
|                                      | <b>10.00</b> | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 10.10        | 915                                 | 1198                                 |
| WTPSD                                | 0.07         | 1360                                | 1390                                 |
|                                      | <b>0.17</b>  | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 0.27         | 998                                 | 1390                                 |
| SDPDVR                               | 1.95         | 1362                                | 1440                                 |
|                                      | <b>2.05</b>  | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 2.15         | 916                                 | 1340                                 |
| PPSEN                                | 0.23         | 1359                                | 1626                                 |
|                                      | <b>0.33</b>  | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 0.43         | 921                                 | 1208                                 |
| XFRUIT                               | 0.90         | 1364                                | 1684                                 |
|                                      | <b>1.00</b>  | <b>1086</b>                         | <b>1390</b>                          |
|                                      | 1.10         | 938                                 | 1204                                 |

**Table 17 : Sensitivity test results for genetic coefficients and growth coefficients SH 40 (preferred values of parameter are indicated in bold letters)**

| <b>Genetic / growth coefficients</b> | <b>Range</b> | <b>Estimated Seed yield (kg/ha)</b> | <b>Estimated Straw yield (kg/ha)</b> |
|--------------------------------------|--------------|-------------------------------------|--------------------------------------|
| CSDVAR                               | 12.52        | 1396                                | 1650                                 |
|                                      | <b>12.62</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 12.72        | 988                                 | 1280                                 |
| EMG- FLW                             | 21.40        | 1386                                | 1681                                 |
|                                      | <b>21.50</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 21.60        | 955                                 | 1240                                 |
| FLW- FDS                             | 15.90        | 1428                                | 1696                                 |
|                                      | <b>16.00</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 16.10        | 921                                 | 1205                                 |
| FSD-PHM                              | 35.40        | 1470                                | 1708                                 |
|                                      | <b>35.50</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 35.60        | 901                                 | 1220                                 |
| SDFDUR                               | 21.40        | 1385                                | 1692                                 |
|                                      | <b>21.50</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 21.60        | 921                                 | 1214                                 |
| PODDUR                               | 9.90         | 1409                                | 1633                                 |
|                                      | <b>10.00</b> | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 10.10        | 915                                 | 1364                                 |
| WTPSD                                | 0.07         | 1360                                | 1440                                 |
|                                      | <b>0.17</b>  | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 0.27         | 998                                 | 1302                                 |
| SDPDVR                               | 1.95         | 1362                                | 1440                                 |
|                                      | <b>2.05</b>  | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 2.15         | 916                                 | 1280                                 |
| PPSEN                                | 0.21         | 1359                                | 1626                                 |
|                                      | <b>0.31</b>  | <b>1198</b>                         | <b>1409</b>                          |
|                                      | 0.41         | 921                                 | 1356                                 |
| XFRUIT                               | 0.90         | 1364                                | 1684                                 |
|                                      | <b>1.00</b>  | <b>1198</b>                         | <b>1387</b>                          |
|                                      | 1.10         | 938                                 | 1250                                 |

**Table 18 : Sensitivity test results for genetic coefficients and growth coefficients DS 9814 (preferred values of parameter are indicated in bold letters)**

| Genetic / growth coefficients | Range        | Estimated Seed yield (kg/ha) | Estimated Straw yield (kg/ha) |
|-------------------------------|--------------|------------------------------|-------------------------------|
| CSDVAR                        | 12.48        | 1396                         | 1650                          |
|                               | <b>12.58</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 12.68        | 988                          | 1425                          |
| EMG- FLW                      | 21.40        | 1386                         | 1681                          |
|                               | <b>21.50</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 21.60        | 955                          | 1438                          |
| FLW- FDS                      | 16.40        | 1379                         | 1696                          |
|                               | <b>16.50</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 16.60        | 921                          | 1383                          |
| FSD-PHM                       | 34.80        | 1400                         | 1708                          |
|                               | <b>36.90</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 35.00        | 901                          | 1377                          |
| SDFDUR                        | 21.90        | 1385                         | 1692                          |
|                               | <b>22.00</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 22.10        | 921                          | 1382                          |
| PODDUR                        | 9.90         | 1409                         | 1633                          |
|                               | <b>10.00</b> | <b>1111</b>                  | <b>1471</b>                   |
|                               | 10.10        | 915                          | 1364                          |
| WTPSD                         | 0.08         | 1360                         | 1471                          |
|                               | <b>0.18</b>  | <b>1111</b>                  | <b>1471</b>                   |
|                               | 0.28         | 998                          | 1471                          |
| SDPDVR                        | 1.95         | 1362                         | 1471                          |
|                               | <b>2.05</b>  | <b>1111</b>                  | <b>1471</b>                   |
|                               | 2.15         | 916                          | 1471                          |
| PPSEN                         | 0.21         | 1359                         | 1626                          |
|                               | <b>0.31</b>  | <b>1111</b>                  | <b>1471</b>                   |
|                               | 0.41         | 921                          | 1420                          |
| XFRUIT                        | 0.90         | 1364                         | 1684                          |
|                               | <b>1.00</b>  | <b>1111</b>                  | <b>1471</b>                   |
|                               | 1.10         | 938                          | 1435                          |

coefficients were found sensitive to straw yield. The model predicted higher straw yield when the values of the coefficients (other than WTPSD and SDPDVR) were increased and *vice-versa*. An interesting observation was that the magnitude of variation was more when the value of coefficient was decreased as compared to increase in value of coefficient and this trend was followed for both *i.e.*, seed yield and straw yield estimation.

The sensitivity analysis for soybean cultivars *viz.*, DS 9814 and SH 40 and PS 1042 are presented in Table 15 to 18. The similar trend was observed in the sensitivity to coefficients as that observed under PK 416 cultivar. A noticeable difference was found in case of SH 40 and PS 1042 as these two cultivars were found more sensitive to the coefficients namely, FLW-FSD and FSD-PHM. An increase or decrease in the value of these coefficients showed a greater corresponding magnitude of variation in seed and straw yield estimation as compared to PK 416 and DS 9814 and this may possibly be because of the reason that the cultivars SH 40 and PS 1042 are short duration.

The genetic coefficients finally selected for four cultivars are given as under:

**PK 416:** CSDVAR= 12.25, PPSEN= 0.30, EMG-FLW= 20.50, FLW-FSD= 17.00, FSD-PHM= 36.50, WTPSD= 0.120, SDPDVR= 2.05, SDFDUR= 21.00, PODDUR= 10.00 and XFRUIT= 1.00

**DS 9814:** CSDVAR= 12.58, PPSEN= 0.31, EMG-FLW= 21.50, FLW-FSD= 16.50, FSD-PHM= 34.90, WTPSD= 0.180, SDPDVR= 2.05, SDFDUR= 22.00, PODDUR= 10.00 and XFRUIT= 1.00

**SH 40:** CSDVAR= 12.62, PPSEN= 0.31, EMG-FLW= 21.50, FLW-FSD= 16.00, FSD-PHM= 35.50, WTPSD= 0.170, SDPDVR= 2.05, SDFDUR= 21.50, PODDUR= 10.00 and XFRUIT= 1.00

**PS 1042:** CSDVAR= 12.62, PPSEN= 0.33, EMG-FLW= 22.50, FLW-FSD= 17.00, FSD-PHM= 34.50, WTPSD= 0.170, SDPDVR= 2.05, SDFDUR= 21.50, PODDUR= 10.00 and XFRUIT= 1.00

#### **4.7.2 Soil physical constants**

The data in Table 19 represents the sensitivity of the model to different soil physical constant *viz.*, soil albedo, the upper limit of stage I soil evaporation (mm), soil water drainage constant and run off curve number used. The model is not much sensitive to any of these constants.

#### **4.7.3 Crop phenology**

##### **4.7.3.1 Comparison of observed and simulated crop phenology**

Phenological parameters predicted by 'SOYGRO' model those actually recorded in the field are shown in Table 20 & 21. The model predicted the anthesis date between -8 to +4 days of the observed. However, it overestimated the phenology for 1<sup>st</sup> week of July sown crop during both the seasons (2004 and 2005). The most probable reason for this variation was the variation in the weather conditions prevailed during the two the years (2004 and 2005). Among different cultivars, the anthesis date in PK 416 was predicted more accurately in all the sowing dates during both the seasons with an exception for 1<sup>st</sup> week of July sown crop in *kharif* 2004.

Table 19 : Sensitivity test results for the soil parameters (preferred values of parameter are indicated in bold letters)

| Soil parameters                                           | Range        | Estimated Seed yield<br>(kg/ha) | Estimated Straw yield<br>(kg/ha) |
|-----------------------------------------------------------|--------------|---------------------------------|----------------------------------|
| Bare soil <i>albedo</i>                                   | 0.30         | 1990                            | 1469                             |
|                                                           | <b>0.25</b>  | <b>1365</b>                     | <b>1440</b>                      |
|                                                           | 0.20         | 1350                            | 1435                             |
| Upper limit of stage I soil evaporation<br>(mm)           | 5.90         | 1370                            | 1472                             |
|                                                           | <b>6.00</b>  | <b>1365</b>                     | <b>1440</b>                      |
|                                                           | 6.10         | 1350                            | 1435                             |
| Soil water drainage constant fraction<br>drainage per day | 0.40         | 1370                            | 1485                             |
|                                                           | <b>0.50</b>  | <b>1365</b>                     | <b>1440</b>                      |
|                                                           | 0.60         | 1350                            | 1429                             |
| SCS curve number used to calculate daily<br>runoff        | 65.00        | 1380                            | 1485                             |
|                                                           | <b>70.00</b> | <b>1365</b>                     | <b>1440</b>                      |
|                                                           | 75.00        | 1360                            | 1435                             |

**Table 20: Comparison of observed (O) and predicted (P) phenology of soybean cultivars under different growing environments during *kharif* 2004**

| Treatments                   | Sowing date<br>(Julian days) | Days to anthesis |    |    | Days to 1 <sup>st</sup> pod |    |     | Days to 1 <sup>st</sup> seed |     |     | Days to phy. maturity |     |    |
|------------------------------|------------------------------|------------------|----|----|-----------------------------|----|-----|------------------------------|-----|-----|-----------------------|-----|----|
|                              |                              | O                | P  | D  | O                           | P  | D   | O                            | P   | D   | O                     | P   | D  |
| 1 <sup>st</sup> week of June |                              |                  |    |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 151                          | 63               | 57 | -6 | 78                          | 78 | 0   | 104                          | 124 | +20 | 141                   | 143 | +2 |
| DS 9814                      | 151                          | 65               | 60 | -5 | 80                          | 79 | -1  | 106                          | 130 | +24 | 140                   | 137 | -3 |
| PK 416                       | 151                          | 63               | 63 | 0  | 77                          | 80 | +3  | 108                          | 129 | +21 | 139                   | 140 | +1 |
| PS 1042                      | 151                          | 62               | 57 | -5 | 78                          | 79 | 1   | 108                          | 120 | +12 | 139                   | 133 | -6 |
| 3 <sup>rd</sup> week of June |                              |                  |    |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 176                          | 56               | 51 | -5 | 75                          | 86 | +9  | 90                           | 98  | +2  | 116                   | 115 | -1 |
| DS 9814                      | 176                          | 56               | 52 | -4 | 75                          | 82 | +7  | 90                           | 89  | +1  | 116                   | 112 | -4 |
| PK 416                       | 176                          | 55               | 53 | -2 | 74                          | 90 | +8  | 98                           | 98  | 0   | 114                   | 113 | -1 |
| PS 1042                      | 176                          | 54               | 49 | -5 | 74                          | 84 | +10 | 90                           | 88  | -2  | 114                   | 110 | -4 |
| 1 <sup>st</sup> week of July |                              |                  |    |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 180                          | 41               | 45 | +4 | 70                          | 73 | +3  | 81                           | 83  | +2  | 105                   | 108 | +3 |
| DS 9814                      | 180                          | 44               | 45 | +1 | 71                          | 74 | +3  | 87                           | 89  | +2  | 108                   | 104 | +1 |
| PK 416                       | 180                          | 43               | 46 | +3 | 71                          | 73 | +2  | 87                           | 84  | -3  | 108                   | 105 | +2 |
| PS 1042                      | 180                          | 41               | 45 | +4 | 70                          | 60 | -10 | 81                           | 83  | +2  | 102                   | 105 | +3 |

\* O means Observed, P means Predicted, D mean deviation (Days)

Table 21: Comparison of observed (O) and predicted (P) phenology of soybean cultivars under different growing environments during *kharif* 2005

| Treatments                   | Sowing date<br>(Julian days) | Days to anthesis |     |    | Days to 1 <sup>st</sup> pod |    |     | Days to 1 <sup>st</sup> seed |     |     | Days to phy. maturity |     |    |
|------------------------------|------------------------------|------------------|-----|----|-----------------------------|----|-----|------------------------------|-----|-----|-----------------------|-----|----|
|                              |                              | O                | P   | D  | O                           | P  | D   | O                            | P   | D   | O                     | P   | D  |
| 1 <sup>st</sup> week of June |                              |                  |     |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 163                          | 62               | 55  | -7 | 75                          | 79 | +4  | 102                          | 102 | 0   | 132                   | 125 | -7 |
| DS 9814                      | 163                          | 67               | 64  | -3 | 76                          | 72 | -4  | 103                          | 103 | 0   | 134                   | 129 | -5 |
| PK 416                       | 163                          | 64               | 64  | 0  | 80                          | 81 | +1  | 104                          | 112 | +8  | 134                   | 132 | -2 |
| PS 1042                      | 163                          | 63               | 58  | -5 | 80                          | 69 | -11 | 102                          | 103 | +1  | 132                   | 128 | -6 |
| 3 <sup>rd</sup> week of June |                              |                  |     |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 170                          | 55               | 48  | -7 | 82                          | 81 | -1  | 105                          | 101 | -4  | 129                   | 127 | -1 |
| DS 9814                      | 170                          | 57               | 51  | -6 | 85                          | 85 | 0   | 107                          | 108 | +1  | 129                   | 123 | -6 |
| PK 416                       | 170                          | 56               | 54  | -2 | 87                          | 91 | +4  | 107                          | 107 | 0   | 130                   | 123 | -7 |
| PS 1042                      | 170                          | 55               | 49  | -6 | 84                          | 86 | +2  | 105                          | 101 | -4  | 129                   | 120 | -9 |
| 1 <sup>st</sup> week of July |                              |                  |     |    |                             |    |     |                              |     |     |                       |     |    |
| SH 40                        | 178                          | 50               | 54  | +4 | 70                          | 76 | -6  | 98                           | 98  | 0   | 119                   | 118 | -1 |
| DS 9814                      | 178                          | 53               | 45  | -8 | 79                          | 79 | -2  | 100                          | 101 | +11 | 121                   | 120 | -2 |
| PK 416                       | 178                          | 52               | 52  | -4 | 76                          | 85 | -6  | 101                          | 101 | +13 | 120                   | 114 | -7 |
| PS 1042                      | 178                          | 53               | -49 | -4 | 84                          | 78 | -6  | 97                           | 91  | +11 | 121                   | 119 | -2 |

\* O means Observed, P means Predicted, D mean deviation (Days)

The first pod dates predicted by the model showed underestimation from that observed. The first pod dates were estimated between -17 to +3 days of the observed during the two crop seasons. But during 2004, the first pod date was underestimated in all treatments except PK 416 in 1<sup>st</sup> week of June and 1<sup>st</sup> week of July sown crops which showed a little bit overestimation. Among the cultivars, PK 416 was close in agreement between observed and predicted values during both the seasons. PS 1042 and SH 40 cultivars were underestimated.

First seed dates were estimated between -10 to +2 days of the observed dates during two seasons (*kharif* 2004 and 2005). Among the dates of sowing, the first seed was overestimated in delayed sown crop (1<sup>st</sup> week of July), whereas, 1<sup>st</sup> week of June sown crop showed underestimation of high magnitude during both the years of study.

Among the cultivars the modeled results gave both overestimation and underestimation for first seed dates. PK 416 was best estimated during both seasons under all dates of sowing.

The physiological maturity dates were estimated between -9 to +3 days of the field observed dates. During *kharif* 2004, the model overestimated the physiological maturity in July sown crop, whereas, underestimated the 3<sup>rd</sup> week of June sown crop. However, the 1<sup>st</sup> week of June sown crop showed both overestimation and underestimation for all cultivars. During *kharif* 2005, the model underestimated for all the cultivars and dates of sowing. It was possibly because of the variable weather conditions *viz.*, the rainfall and solar radiation. Almost similar

results were obtained by Kaur *et al.* (2004) to predict the soybean yield by SOYGRO model.

#### **4.7.3.2 Comparison of observed and simulated crop growth and yield of soybean**

Observed leaf area index (LAI) *vs* predicted LAI under different growing environments of soybean cultivars are presented in Table 22 and 23. In general, the model underestimated the LAI in all the treatments during both the seasons (2004 and 2005). During 2004 crop season the percentage LAI deviation was less and however deviation was towards underestimation in all treatments as compared to 2005 crop season. The values deviated between 0 to -11.8 per cent for different cultivars during 2004, however during 2005 these deviated between -42.9 to -21.9 since the weather was highly variable during this season.

Among the cultivars, PK 416 showed a better agreement between the predicted and observed values during both the seasons as compared the other three cultivars.

The model underestimated the seeds per pod under all sowing dates and among all the cultivars during both the crop seasons. The per cent deviation varied between 0 to -13 during 2004, whereas, during 2005 it varied between 0 to -10.7 per cent. Among cultivars, PS 1042 was predicted most accurately over all sowing dates over both crop seasons.

The results presented in Table 24 and 25 shows the comparison of observed and simulated yield parameters *viz.*, pod yield, seed yield

**Table 22 : Comparison of observed (O) and predicted (P) yield parameters in soybean cultivars under different growing environments during *kharif* 2004**

| Treatments                   | Sowing date<br>(Julian days) | Leaf area index |     |       | Seeds /pod |     |       |
|------------------------------|------------------------------|-----------------|-----|-------|------------|-----|-------|
|                              |                              | O               | P   | D (%) | O          | P   | D (%) |
| 1 <sup>st</sup> week of June |                              |                 |     |       |            |     |       |
| SH 40                        | 151                          | 3.4             | 3.0 | -11.8 | 2.1        | 2.0 | -5    |
| DS 9814                      | 151                          | 3.6             | 3.2 | -11.1 | 2.1        | 2.0 | -5    |
| PK 416                       | 151                          | 3.8             | 3.7 | -2.6  | 2.3        | 2.1 | -13   |
| PS 1042                      | 151                          | 2.5             | 2.5 | 0     | 2.0        | 2.0 | 0     |
| 3rd week of June             |                              |                 |     |       |            |     |       |
| SH 40                        | 176                          | 3.5             | 3.2 | -8.6  | 2.1        | 2.0 | -7    |
| DS 9814                      | 176                          | 3.4             | 3.2 | -5.9  | 2.1        | 2.0 | -2    |
| PK 416                       | 176                          | 3.5             | 3.4 | -2.9  | 2.2        | 2.0 | -9    |
| PS 1042                      | 176                          | 3.2             | 3.0 | -6.3  | 2.0        | 2.0 | 0     |
| 1 <sup>st</sup> week of July |                              |                 |     |       |            |     |       |
| SH 40                        | 182                          | 3.2             | 3.0 | -6.3  | 2.1        | 2.0 | -5    |
| DS 9814                      | 182                          | 3.4             | 3.1 | -8.8  | 2.1        | 2.0 | -4    |
| PK 416                       | 182                          | 3.4             | 3.3 | -2.9  | 2.1        | 2.0 | -5    |
| PS 1042                      | 182                          | 3.0             | 2.8 | -6.7  | 2.0        | 2.0 | 0     |

**Table 23 : Comparison of observed (O) and predicted (P) yield parameters in soybean cultivars under different growing environments during *kharif* 2005**

| Treatments                   | Sowing date<br>(Julian days) | Leaf area index |     |       | Seeds /pod |     |       |
|------------------------------|------------------------------|-----------------|-----|-------|------------|-----|-------|
|                              |                              | O               | P   | D (%) | O          | P   | D (%) |
| 1 <sup>st</sup> week of June |                              |                 |     |       |            |     |       |
| SH 40                        | 163                          | 3.5             | 2.6 | -25.7 | 2.1        | 2.0 | -2.4  |
| DS 9814                      | 163                          | 3.6             | 2.1 | -41.7 | 2.8        | 2.5 | -10.7 |
| PK 416                       | 163                          | 3.7             | 2.8 | -24.3 | 2.8        | 2.5 | -10.7 |
| PS 1042                      | 163                          | 3.5             | 2.0 | -42.9 | 2.1        | 2.0 | -2.4  |
| 3rd week of June             |                              |                 |     |       |            |     |       |
| SH 40                        | 170                          | 3.2             | 2.2 | -31.3 | 2.2        | 2.1 | -4.5  |
| DS 9814                      | 170                          | 3.5             | 2.0 | -42.9 | 2.1        | 2.0 | -2.4  |
| PK 416                       | 170                          | 3.7             | 2.8 | -30.9 | 2.1        | 2.0 | -2.4  |
| PS 1042                      | 170                          | 3.1             | 2.3 | -25.8 | 2.2        | 2.2 | 0     |
| 1 <sup>st</sup> week of July |                              |                 |     |       |            |     |       |
| SH 40                        | 178                          | 3.0             | 2.2 | -26.7 | 2.3        | 2.1 | -8.7  |
| DS 9814                      | 178                          | 3.2             | 2.5 | -21.9 | 2.2        | 2.0 | -9.1  |
| PK 416                       | 178                          | 3.4             | 2.4 | -29.4 | 2.1        | 2.0 | -4.8  |
| PS 1042                      | 178                          | 3.2             | 2.3 | -21.9 | 2.0        | 2.0 | 0     |

**Table 24: Comparison of observed (O) and predicted (P) yield in soybean cultivars under different growing environments during *kharif* 2004**

| Treatments                   | Sowing date<br>(Julian days) | Pod yield (kg/ha) |      |       | Seed yield (kg/ha) |      |       | Straw yield (kg/ha) |      |       |
|------------------------------|------------------------------|-------------------|------|-------|--------------------|------|-------|---------------------|------|-------|
|                              |                              | O                 | P    | D (%) | O                  | P    | D (%) | O                   | P    | D (%) |
| 1 <sup>st</sup> week of June |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 151                          | 1450              | 1673 | +13.3 | 933                | 1198 | +22   | 1333                | 1409 | +5    |
| DS 9814                      | 151                          | 1420              | 1500 | +5.3  | 1024               | 1111 | +7    | 1459                | 1416 | -3    |
| PK 416                       | 151                          | 1820              | 1933 | +5.8  | 1184               | 1356 | +12   | 1519                | 1440 | -5    |
| PS 1042                      | 151                          | 1390              | 1557 | +10.7 | 986                | 1086 | +9.2  | 1168                | 1390 | +16   |
| 3 <sup>rd</sup> week of June |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 176                          | 1320              | 1418 | +6.9  | 900                | 1106 | +18   | 1298                | 1140 | -14   |
| DS 9814                      | 176                          | 1296              | 1384 | +6.9  | 983                | 1084 | +9    | 1380                | 1139 | -21   |
| PK 416                       | 176                          | 1426              | 1502 | +6.4  | 1041               | 1145 | +9    | 1380                | 1121 | -21   |
| PS 1042                      | 176                          | 1240              | 1887 | +5.1  | 921                | 1086 | +15   | 1168                | 1425 | +4    |
| 1 <sup>st</sup> week of July |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 182                          | 1108              | 1309 | +18.1 | 916                | 1050 | +14.6 | 1288                | 1425 | +10.6 |
| DS 9814                      | 182                          | 1180              | 1291 | +9.4  | 961                | 1082 | +12.5 | 1378                | 1447 | +5.3  |
| PK 416                       | 182                          | 1498              | 1523 | +1.6  | 1057               | 1174 | +11.0 | 1397                | 1398 | +0.1  |
| PS 1042                      | 182                          | 1200              | 1360 | +13.0 | 887                | 1073 | +14.2 | 1228                | 1339 | +9.1  |

\* O means Observed, P means Predicted, D mean deviation (%)

**Table 25: Comparison of observed (O) and predicted (P) yield in soybean cultivars under different growing environments during kharif 2005**

| Treatments                   | Sowing date<br>(Julian days) | Pod yield (kg/ha) |      |       | Seed yield (kg/ha) |      |       | Straw yield (kg/ha) |      |       |
|------------------------------|------------------------------|-------------------|------|-------|--------------------|------|-------|---------------------|------|-------|
|                              |                              | O                 | P    | D (%) | O                  | P    | D (%) | O                   | P    | D (%) |
| 1 <sup>st</sup> week of June |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 163                          | 1301              | 1471 | +11.1 | 1036.4             | 1136 | +9.6  | 1416.4              | 1379 | -2.6  |
| DS 9814                      | 163                          | 1420              | 1547 | +8.2  | 1130.1             | 1200 | +6.2  | 1518.9              | 1471 | -3.2  |
| PK 416                       | 163                          | 1820              | 1982 | +8.2  | 1243.6             | 1511 | +5.8  | 1698.8              | 1848 | +8.8  |
| PS 1042                      | 163                          | 1320              | 1543 | +14.5 | 999.0              | 1205 | +17.1 | 1228.0              | 1320 | +7.0  |
| 3 <sup>rd</sup> week of June |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 170                          | 1401              | 1575 | +11.0 | 961.3              | 961  | 0     | 1325.1              | 1810 | +12.6 |
| DS 9814                      | 170                          | 1450              | 1660 | +12.7 | 1080.0             | 1170 | +7.7  | 1456.3              | 1700 | +14.3 |
| PK 416                       | 170                          | 1720              | 1936 | +11.2 | 1170.1             | 1240 | +5.6  | 1540.4              | 1420 | +8.5  |
| PS 1042                      | 170                          | 1442              | 1659 | +13.0 | 964.2              | 1123 | +14.1 | 1173.9              | 1245 | +5.7  |
| 1 <sup>st</sup> week of July |                              |                   |      |       |                    |      |       |                     |      |       |
| SH 40                        | 178                          | 1108              | 1375 | +14.2 | 931.5              | 1078 | +13.5 | 1299.2              | 1420 | +8.5  |
| DS 9814                      | 178                          | 1180              | 1279 | +10.6 | 1002.0             | 1085 | +8.5  | 1378.0              | 1390 | +0.9  |
| PK 416                       | 178                          | 1498              | 1348 | +11.0 | 1040.3             | 1151 | +9.5  | 1387.7              | 1480 | +6.2  |
| PS 1042                      | 178                          | 1122              | 1348 | +16.8 | 928.0              | 1061 | +12.5 | 1169.2              | 1121 | -4.1  |

\* O means Observed, P means Predicted, D mean deviation (Days)

and straw yield during 2004 and 2005, respectively. The model overestimated the pod yield in all the cultivars among the three sowing dates during both crop seasons. The magnitude of model overestimation varied between 1.6 to 17.3 per cent. The pod yield predicted in PK 416 cultivar showed least deviation and PS 1042 showed the highest deviation during 2005 but the trend was not similar to the one observed during the previous season of 2004. The best prediction of pod yield by the model was for cultivar PK 416 under late sown crop during 2004 with 1.6 per cent deviation only.

The model overestimated the seed yield for all four cultivars in three dates of sowing during both crop seasons. The predictions deviated from 0 to 22 per cent. However, the predicted seed yields were closer to the observed during 2005 as compared to 2004. The per cent deviations during 2004 were in the range of 6 to 22 per cent, whereas, during 2005 they ranged between 0 to 17.1 per cent. The model predicted highest seed yield for PK 416 in all the sowing dates during both the crop seasons and the present finding are in close agreement with those reported earlier by Kaur *et al.* (2004).

The straw yield were underestimated during 2004 and overestimated during year 2005 and the overestimation was possibly because of higher soil moisture content during 2005. The deviations in straw yield prediction from the observed values ranged between 16 to -21 per cent. The model predicted the straw yield for DS 9814 more accurately in 1<sup>st</sup> week of June and 1<sup>st</sup> week of July sown crops as compared to the other cultivars in both the seasons.

The prediction for seeds per pod, ranged from 2.0 to 2.8 for different treatments during two seasons (2004 and 2005) and the results are presented in Table 25. The seeds per pod were observed maximum in 1<sup>st</sup> week of June sown crop in 2004 and 2005 and were lowest in 1<sup>st</sup> week of July sown crop. The model predicted values for seeds per pod deviated from observed in the range of -2 to -13 per cent during the two crop growing seasons. The predicted numbers of seeds per pod were almost similar for all the treatments except 1<sup>st</sup> week of June sown crop (2005).

## CHAPTER-V

### *Summary and Conclusions*

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The filed experiments on “Micrometeorological studies in soybean under different environments and evaluation of ‘SOYGRO’ model” were carried out at the Research Farm, Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar during *kharif* seasons of 2004 and 2005. The experiment was laid out in split plot design with four replications. The main plot treatments comprised of different growing environments *viz.*, 1<sup>st</sup> week of June, 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sowing dates. Sub plot treatments consisted of four cultivars *viz.*, SH 40 (V1), DS 9814 (V2), PK 416 (V3) and PS 1042 (V4).

The soil of the experimental field was sandy loam, slightly alkaline in reaction and poor in available N, medium in available P and high in available K content. The summary of findings based on experimental result is summarized here:

#### **5.1 SOYBEAN RESPONSE TO DATE OF SOWING AND CULTIVARS**

##### **5.1.1 Crop phenology**

The observations on phenological events revealed that the weather elements influenced the crop phenology and duration in

soybean. The delayed sowing reduced the total crop and pod filling duration, which ultimately squeezed the sink development phase during both the seasons (2004 and 2005). Among the cultivars, PK 416 took maximum number of days to physiological maturity.

#### **5.1.2 Plant height**

Plant height was significantly higher in 1<sup>st</sup> week of June as compared to delayed sowing during both the seasons. Among the cultivars, it was higher in PK 416 and lowest in PS 1042 during both the seasons, respectively.

#### **5.1.3 Dry matter accumulation**

Dry matter accumulation was higher in early sown crop i.e. 1<sup>st</sup> week of June and delay sowing resulted in lower dry matter accumulation in both the seasons. Among the cultivars, PK 416 had significantly higher dry matter accumulation followed by DS 9814, SH 40 and PS 1042.

#### **5.1.4 Leaf area index**

Irrespective of sowing dates, the LAI increased with advancement of crop age till it reached flowering stage and decreased thereafter during pod development phase. However, early sown crop (1<sup>st</sup> week of June) had significantly higher LAI than third sowing dates (1<sup>st</sup> week of July) but at par with 3<sup>rd</sup> week of June sown crop during both the seasons. Among the cultivars, PK 416 was significantly higher LAI as compared to other cultivars.

## **5.2 SOIL MOISTURE STATUS**

The soil profile moisture content (0–90cm) fluctuated throughout the crop season (2004 and 2005), owing to irrigation applications and rainfall occurred during crop growing period. The soil profile moisture content did not differ among the sowing dates but, it differed over soil profile i.e., in 0-15 cm depth soil moisture content was lower than 15-30, 30-60 and 60-90 depths during both the seasons. Soil profile moisture content was higher during 2005 on compared to 2004.

## **5.3 AGROMETEOROLOGICAL INDICES**

The agrometeorological indices viz., accumulated growing degree days, accumulated helio-thermal units, accumulated photothermal units had almost similar trend for three sowing dates during both years of study. The values of these indices attained at various growth stages were higher in 1<sup>st</sup> week of June sown crops followed by 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sown crop during both the seasons. The highest radiation use efficiency and heat use efficiency were recorded in PK 416 followed by DS 9814 and it was lowest in SH 40 and PS 1042 during both years of the study.

## **5.4 MICROMETEOROLOGICAL INDICES**

In general, a major portion of net radiation ( $R_n$ ) was utilized in latent heat flux ( $LE$ ) followed by sensible heat flux ( $A$ ) and soil heat flux ( $G$ ). Whereas, in bare field, the soil heat flux values were higher than those observed over the crop canopy. Sensible heat flux remained positive throughout the day. Sometimes, the soil heat flux had negative values at 1700 hours (evening).

Air temperature profiles were nearly isothermal during 0900 hrs and 1700 hours. The air temperature profiles were found inverse throughout the day in all treatments, but inclinations of temperature profiles were greater at initial flowering stage than other growth stages.

In early morning, the vapour pressure profiles were isolines, however with advancement of time the shape of vapour pressure profile was lapse from after noon hours till 1700 hours during 2004 and 2005 crop seasons, respectively. In early sown crop (1<sup>st</sup> week of July) the canopy temperature was recorded followed by 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sown crop. In general, PAR increased from morning till noon time (1200 to 1300 hour) in all the treatment and thereafter it declined consistently till evening among all the sowing date over bare soil.

## **5.5 YIELD AND YIELD ATTRIBUTES**

Yield attributes viz., number of grains/pods, number of pods/plant, number of branches/plant, number of plant/m<sup>2</sup>, 1000-grain weight were significantly higher in early sown crop (1<sup>st</sup> week of June) Similarly the seed and biological yield were also significantly higher in 1<sup>st</sup> week of June followed by 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July sown crop during both years of the study.

Among cultivars, yield attributes, the seed and biological yield were significantly higher in PK 416 cultivar followed by DS 9814, SH 40 and PS 1042 during both years of study.

## **5.6 SOYBEAN GROWTH AND YIELD SIMULATION MODELS USING SOYGRO MODEL**

The phenological stages simulated by the model revealed overestimation as well as underestimation of flowering date during both the years. The number of days to flowering were underestimated under late sown condition (1<sup>st</sup> week of July sown crop). Days to first pod, days to first seed and days to physiological maturity were either overestimated or underestimated in different sowing dates in the two year study by the model (DSSAT 3.5). Among cultivars PK 416 has the best estimation of phenolgy followed by DS 9814 under Hisar conditions.

The comparison of observed and simulated yield parameters viz., pod yield, seed yield and straw yield, showed that the model gave overestimation for pod yield in all cultivars under all the sowing dates during both seasons (2004 and 2005).

The seed yield predicted deviation varied from 0 to 22 per cent during 2004, whereas during 2005 deviation percentage range was 0 to 17.6 per cent.

Among the cultivars the model predicted highest seed yield for PK 416 in all sowing dates during both the crop seasons. Straw yield was underestimated during 2004 and overestimated during 2005. Model predicted straw yield of DS 9814 most accurately in 1<sup>st</sup> week of June and 1<sup>st</sup> week of July sown crop.

## CONCLUSION

On the basis of results obtained from two years field study on soybean cultivars *viz.*, SH 40, DS 9814, PK 416 and PS 1042 under different environment i.e. sowing dates, it can be concluded that the crop sown on 1<sup>st</sup> week of June was found best in terms of plant growth (dry matter accumulation, LAI and plant height) and crop yields due to favorable weather parameters prevailed during the crop growth and development and as such had an extended crop duration. The same is reflected in overall higher values for different agrometeorological parameters namely AGDD, AHTU, APTU, RUE and HUE. The delayed sowings resulted in shorter grain filling duration and lower thermal and radiation use efficiency. Among the cultivars, PK 416 performed best followed by DS 9814 and the PS 1042 was the poorest under all three sowing dates, because of their differential growth habit, crop duration, yield potential owing to the differential genetic constitution. The cultivar PK 416 had higher growth parameter values and as such accumulated higher biomass and utilized the weather resources most efficiently (*viz.*, higher radiation and heat use efficiency). 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 parameter under different environment with reasonable satisfactory predictions. However, the model parameters need further refinement and validation with data from several field multi-location experiments conducted under varied environments.

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## ABSTRACT

|                                             |                                                                                                                                                         |
|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Title of Thesis</b>                      | <b>: Micrometeorological studies in soybean under different environments and evaluation of 'SOYGRO' model</b>                                           |
| <b>Full Name of Degree Holder</b>           | <b>: AJIT SINGH</b>                                                                                                                                     |
| <b>Admission No.</b>                        | <b>: 2002A52D</b>                                                                                                                                       |
| <b>Title of Degree</b>                      | <b>: DOCTOR OF PHILOSOPHY</b>                                                                                                                           |
| <b>Name and Address of Major Advisor</b>    | <b>: Dr. V.U.M. Rao<br/>Professor &amp; Head<br/>Dept. of Agricultural Meteorology<br/>CCS Haryana Agricultural University<br/>Hisar-125 004, India</b> |
| <b>Degree awarding University/Institute</b> | <b>: CCS Haryana Agricultural University, Hisar</b>                                                                                                     |
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Field experiments entitled, "Micrometeorological studies in soybean under different environments and evaluation of 'SOYGRO' model" were conducted at Research Farm, Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar during *kharif* seasons of 2004 and 2005. The experiment was laid out in split-plot design with four replications. The main plot treatments comprised of three sowing dates viz., 1<sup>st</sup> week of June, 3<sup>rd</sup> week of June and 1<sup>st</sup> week of July. The sub-plot treatments comprised of four cultivars viz., SH-40, DS-9814, PK-416 and PS-1042.

Subsequent delay in sowing from 1<sup>st</sup> week of June resulted in shortening of the crop growth period and decrease of plant height, dry matter accumulation, leaf area index, yield and its attributes, harvest index. The growth and yield parameters were highest in early sown crop, followed by 3<sup>rd</sup> week of June and least recorded in 1<sup>st</sup> week of July sowing during both years of study.

Among the cultivars, yield and its attributes were highest in PK-416 and lowest in SH-40. A differential decrease in LAI was noted in four cultivars in later reproductive stages due to leaf senescence.

The crop sown on 1<sup>st</sup> week of June accumulated maximum AGDD, AHTU and APTU. Among the cultivars RUE and HUE were highest in PK-416 followed by DS 9814 and lowest in SH-40 and PS-1042.

A large consumption of net radiation in the form of latent heat block followed by sensible heat flux and soil heat flux were observed in cropped field whereas, soil heat flux values were higher in bare field. Inclination of temperature profiles was higher at initiation of flowering then latter growth stages. The vapour pressure profiles were lapse inside the crop canopy throughout daytime and it was isolinic at 900 and 1700 hrs. In early sown crop (1<sup>st</sup> week of June) canopy temperature values were highest followed by 3<sup>rd</sup> week sown crop during both years of study. PAR increased from morning till noon time (12:00 to 13:00 h) in all treatments.

The model calibration and validation results from field study revealed that 'SOYGRO model' can be used to predict soybean phenology, growth and yield parameter under different environment reasonably satisfactory predictions. However, the model parameters need further refinement and validation with data of several field experiments conducted under varied environments.

  
**MAJOR ADVISOR**

  
**SIGNATURE OF STUDENT**

  
**HEAD OF THE DEPARTMENT**

