Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments

BY
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CERTIFICATE - I

This is to certify that this dissertation entitled **"Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments"** submitted for the degree of **Master of Science** in the subject of **Agril. Meteorology** of Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Sagar Kumar,** Admn. No. **2014A97M** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE–II

This is to certify that this dissertation entitled **“Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments”** submitted by **Sagar Kumar,** Admn. No. **2014A97M** to Chaudhary Charan Singh Haryana Agricultural University, Hisar in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Agril. Meteorology** has been approved by the Student’s Advisory Committee after an oral examination on the same.

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CHAPTER–I

INTRODUCTION

Cotton is a one of the most important fibre crop in the world. It is also called as white gold. The primary product of the cotton plant has been the lint that covers the seeds within the boll. Lint is the most important economical product of cotton plant, provides a source of high quality fibre for the textile industry. The cotton seeds, the primary by product of lint production, are an important source of oil for human consumption, and a high protein meal used as a livestock feed. The cotton waste after ginning is used for fertilizer and the cellulose from the stalk may be used for products such as paper and cardboard. In India, area under cotton crop was 11.8 million hectares with production of 26.8 m bales in 2015-2016. Average yield of the cotton was 0.494 ton/hectare (As per AICRP, 2015-16). Important cotton producing states are Gujarat, Maharashtra, Tamil Nadu, Punjab and Haryana. Average area under cotton during year 2015-2016 was 0.57 million hectares with an average production of 1.4 million bales and an average productivity of 0.503 t/ ha in Haryana.

Cotton, the ‘white gold’ enjoys a premier position amongst all commercial crops in India. Cotton is an important raw material supplying about 65% requirement of the Indian textile industry. In India, cotton productivity is very low as compared to other countries. Moreover, cultivation of hybrid cotton has become a costly affair because of severe pest attack, which led to indiscriminate use of pesticides and thus polluting the entire agro-ecosystem. With the launch of "Technology Mission on Cotton" by Government of India in February 2000 significant achievements have been made in increasing yield and productivity through development of high yielding varieties, better farm management practices, increased area under cultivation of *Bt* cotton hybrids. After introduction of transgenic *Bt* hybrid cotton in India, the productivity of cotton has increased substantially from 303 to 561 kg/ha within a span of seven years (Tayade *et al*., 2011).

The most important meteorological variables associated with agricultural production are air temperature (minimum and maximum), solar radiation and precipitation. In second order, variables are soil temperature, relative humidity and wind. Especially, solar radiation provides the energy for the process that drive photosynthesis, affecting carbohydrates partioning and biomass growth of the individual plant components. Biomass accumulation by a crop depends on its ability to intercept and utilize solar radiation. The amount of dry matter produced per unit area of intercepted radiation (g /MJ) is termed as the radiation use efficiency (RUE) of the crop. Average values of RUE range from 2.0 to 3.0 and 3.0 to 4.0 g /MJ absorbed photosynthetically active radiation for C_3 and C_4 plants, respectively.

Cotton requires a minimum daily air temperature of 15°C for germination, 21-27°C for vegetative growth, and above 15°C for crop growth (Waddle, 1984). All processes leading to square, blossom and boll initiation, and maturation are temperature-dependent. Cool nights are beneficial during the fruiting period, but extremes in temperature (low or high) can result in delayed growth and aborted fruiting sites. Sub-optimum temperature retarded growth and fibre development. Cotton development rates are related to air temperature during the growing season and can be expressed as accumulated heat units or growing degree days (Roussoppoulos et al., 1998). A heat unit is a measure of the amount of heat energy a plant accumulates each day during the growing season and has been used to describe the development of crops (Peng *et al*., 1989). A cotton plant can produce one open boll and four more bolls that are 85% mature with 1000 heat units, and crop termination through defoliation at this stage of plant development results in a loss of about 1% of total expected yield but does not reduce the fibre quality (Wrona *et al*.,1996). Cotton in its native state grows as a perennial shrub in a semi-desert habitat, and as such requires warm temperatures. Despite originating from hot climates, cotton does not necessarily yield best at excessive high temperatures, and a negative correlation has been reported between yield and high temperature during flowering and early boll development. When the temperature rises above 35°C, more of the anthers produced are sterile and therefore flower survival and fruit production is poor during that time. All stages of vegetative development from germination to initiation of floral structures are affected by high temperature (Paulsen, 1994). Cotton developmental events occur much more rapidly as maximum temperature increases (Reddy *et al*., 1996). Temperature plays a vital role in germination and emergence, and also in subsequent stand development, fruiting patterns and final yield. Roots generally have a lower optimum temperature range for growth than shoots, with optimum temperatures reported to be 30°C (Arndt, 1945; Pearson *et al*., 1970).

The numbers of vegetative and fruiting branches produced per plant were strongly influenced by temperature, with an increase in vegetative branches and a decrease in fruiting branches with high temperatures (Hodges *et al*., 1993). The number of fruiting sites increased by 50% as the temperature was raised from 30 to 40°C, however, the number of squares and bolls decreased dramatically above 40°C. Reddy *et al.* (1996) reported that young bolls shed when grown at average daily temperatures of 32°C or higher. High night temperature increases plant temperature because the cotton closes its stomata and ceases evaporative cooling when the sun sets. At night the only source of evaporative cooling is moist soil surface, or free water on the plant from a recent rain or sprinkle irrigation. When hot temperatures occur prior to bloom or after boll set, yield is often increased. Hot temperatures after boll set hasten the maturation and opening of the bolls. High night temperatures are detrimental to young boll set and boll size regardless of the moisture status, because the plant does not cool itself at night. Minimum night temperature reduces yield due to the high respiration and reduced supply of carbohydrates, resulting in the same "adjustment of boll load”.

Increase in the population demands increase in the agricultural production with available resources. Efficient management of available resources with variable weather conditions is essential to increase productivity of agriculture. In addition to this, the focus of agricultural production is changing from quantity towards quality and sustainability. Solution of these new challenges requires consideration of how numerous components interact to effect plant growth. Crop modelling can play a significant part in systems approaches by providing a powerful capability for scenario analyses.

The crop simulation model can be used as quantitative tools to evaluate effects of agronomic and genotypic factors on crop yield. The decision support system for agro-technology transfer (DSSAT) has been in use for the last 15 years by researchers worldwide (Hoogenboom *et al.*, 2012; Jones *et al.*, 2003). This package incorporates models of 28 different crops with software that facilitates the evaluation and application of the crop models for different purposes. DSSAT (Decision Support System for Agrotechnology Transfer) was developed to assess yield, resource use and risk associated with different crop production practices (Tsuji *et al.,* 1994). The system DSSAT (Tsuji *et al.,* 1994) is an example of a management tool that enables farmers to match the biological requirement of a crop to the physical characteristics of the land and ambient air to attain specified objectives. DSSAT software could help the decision makers to implement future agriculture strategies under different scenarios related to agriculture practices with the use of measured site - specific pedological, physiological, agronomical and meteorological data (Hoogenboom *el al.,* 1994).

Above approaches are well established and much effective for estimating cotton growth and yield in different growth environments from time to time. Present study has been designed to evaluate the performance of the above model in cotton crop under hisar conditions. Considering all the facts above, present study was proposed to ascertain following objectives:

i. To quantify the intercepted radiation by the cotton cultivars under different growing environments
ii. To develop the relationship of intercepted radiation with growth and yield of cotton cultivars
iii. To evaluate the genetic coefficients for validation of DSSAT model for cotton cultivars

CHAPTER–II

REVIEW OF LITERATURE

A brief resume of work done related to “Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments” is given below under the following heads:

2.1 Radiation interception and energy indices
    2.1.1 Sowing environments and cultivars
2.2 Relationship of IPAR with growth and yield
2.3 DSSAT validation

2.1 Radiation interception and energy indices

The proportion of solar radiation that was photosynthetically active radiation (PAR) was assumed to be 50% (Monteith, 1972).

Kiniry *et al.* (1989), summarized many RUE data for the maize (Zea mays L.) species, and reported a mean value of 3.5 g M J^{-1}, assuming that PAR is 45% of global solar radiation.

The effect of low temperatures on RUE would be expected to occur in cotton via their effect on photosynthesis (Peng and Krieg, 1991).

Savoy *et al.* (1992) found that narrower rows in soybean (0.36 m spaced rows) had higher light interception, greater biomass accumulation and higher radiation use-efficiency compared to wider rows (1.02 m spaced rows).

Mitchell *et al.* (1998) reported a maximum RUE value of 4.14 gMJ^{-1} for maize during vegetative growth.

The RUE values fall within the range of 1.0–2.5 g/MJ of PAR of cotton and are comparable with reported values for other C_3 crops (Kiniry *et al.*, 1989, Sinclair and Muchow, 1999).

Kiniry *et al.* (1999) reported a mean RUE of 4.4 gMJ^{-1} for switch grass in Texas, with a maximum value of 5.3 g MJ^{-1} for Alamo switch grass in the year 1997. Because these RUE values were calculated assuming that PAR is 45% of global solar radiation, instead of the 50% assumed in this study, these values can be translated for comparison into 3.96 and 4.77 g MJ^{-1} respectively.

Loomis and Amthor (1999) estimated theoretical maximum RUE values for a closed canopy of a maize crop, assuming PAR = 0.5 total solar radiation. They indicated maximum RUE values of 5.5 g MJ^{-1} intercepted PAR and 5.8 g MJ^{-1} absorbed PAR.

Sinclair and Muchow (1999) reported a maximum of 4.8 g MJ^{-1} absorbed PAR for faba bean (Viciafaba L.).

Kiniry *et al.* (2004) reported a maximum RUE of 3.98 g MJ^{-1} for maize growing in Texas under irrigated, non-limiting conditions.

Radiation energy was highest at 13.00 h, whereas latent heat was highest at 14.00 h. Both latent heat flux and net radiation energy were highest during the jointing stage (Das *et al.*, 2005).

Awal *et al.* (2006) studied that canopy light extinction coefficient (k) of peanut was decreased while intercropped with maize. The mean radiation use efficiency of intercropped peanut (2.13 g MJ^{-1}) was 79% higher than that of peanut stands alone. The RUE of combined intercropped stands (3.03 g MJ^{-1}) was more than two-fold that of sole peanut, but slightly lower than that of maize stands alone (3.27 g MJ^{-1}). The harvest index of intercropped peanut was about 13% lower than that of peanut grown alone.

Lunagaria and Shekh (2007) reported that the RUE at the booting stage of wheat showed the highest values (>3 g MJ^{-1}) with slight decline after that stage at Anand, India.

Singh (2007) computed heat units requirement for different cultivars of cotton at different phenophases. He found that photothermal unit requirement (PTU) was increased from germination till physiological maturity. PTU explained the variability in yield up to 56 per cent as a linear function and 43 per cent as a power function.

Bose (2008) reported that heliothermal units and photothermal units for different phenophases were highest in vegetative stage as compared to early reproductive stage and grain filling stage.

Singh *et al*. (2008) conducted the experiment to characterize energy use by cotton and revealed that latent heat flux component was major energy utilizing process which determine 58 percent of the yield variation in cotton during reproductive stage.

Sompal *et al.* (2008) found that heat unit requirements of different genotypes of cotton increased with advancement of crop growth *i.e.* from germination to maturity.

Wajid *et al*. (2010) studied response to different doses of nitrogen for radiation interception, canopy development, growth and seed yield under different climatic conditions in cotton and found strong relationship ($R^2 = 0.98$) with the accumulated intercepted radiation for the season and maximum mean value of fraction of incident PAR remained 0.9 % at 120 days after sowing due to maximum crop canopy development.

Yeates *et al.* (2010) reported that radiation use efficiency (RUE) changed significantly with ontogeny, peaking between squaring and early flowering. The range in RUE of 1.2 – 2.0 g/MJ throughout the crop life cycle for the upland cultivars was similar to temperate climates where biomass was corrected to a glucose equivalent.

Singer *et al*. (2011) conducted a field experiment at Ames and suggested that variability of light interception and its derivatives are poorly understood at the field-scale in maize (Zea mays L.) and soybean [Glycine max (L.) Merr.] and measured variability of cumulative intercepted photosynthetically active radiation(CI-PAR) and radiation use efficiency by deploying eight line quantum sensors in each field. Cumulative mean PAR interception for soybean was 575 MJ m^{-2} ending on day of the year (DOY) 249 compared with 687 MJ m^{-2} in maize ending on DOY 244. Soybean RUE using all sensors was 1.44 ± 0.06 g/ MJ PAR. The highest CI-PAR from a single sensor had RUE of 1.32 and the lowest was 1.55 g/ MJ PAR. Maize RUE using all sensors was 3.35 ± 0.09g/MJ. The highest CI-PAR from a single sensor had RUE of 2.87 and the lowest was 3.70 g /MJ PAR.

Kiniry *et al.* (2012) determined a RUE of 3.71 g MJ^{-1} for miscanthus and 4.30 g M J^{-1} for switch grass, which can be translated for comparison to 3.34 and 3.87 g M J^{-1}.

Pettigrew and Meredith (2012) observed that increased light interception by the high density treatment was offset by the ability of the leaves than low density canopy to more efficiently intercept and utilize sunlight.

Brodick *et al.* (2013) observed that increased plant density in UNR (Ultra-narrow row 36 plants m^{-2}) crop lead to differences in canopy development, radiation use efficiency (RUE) and light interception contributing to plant growth limitations. They also found that early canopy development (leaf area index LAI) and consequently early interception was higher in the UNR crops in two of the three experiments. This resulted in a 17% higher seasonal canopy extinction coefficient (k) in UNR crops over the season. However, seasonal RUE of the UNR crop was 19% lower as increase in light interception was not accompanied by increased total dry matter. Light distribution through the canopy was poorer (higher k) in the UNR crop and LAI continued to increase in the UNR crop after maximum light interception was reached, which combined with a lower leaf nitrogen concentration may have reduced the photosynthetic efficiency of the UNR crop.

Singh *et al.*(2014) conducted a field experiment at Kanpur(U P) and found that RH-8814, NRCDR-02 and BPR-549-9 recorded higher GDD (1703.0, 1662.9 and 1648.0 ^{o}C day), PTU (19129.8, 18694.2 and 18379.8 ^{o}C day hours), HTU (11397.7, 11072.2 and 10876.0 ^{o}C day hours), PTI (13.25, 13.14 and 13.08 ^{o}C day) and HUE (4.11, 3.84 and 3.71 kg/ha/^{o}C day) at physiological maturity, while higher HUE was recorded (9.62, 8.99 and 8.91 kg ha^{-1} degree-day) at sowing to 50 % flowering. On the basis of this study mustard genotypes RH-8814, NRCDR-02 and BPR-549-9 were identified as most heat-tolerant, as they maintained higher values for energy related parameters. Seed yield was highly and positively correlated with GDD (r = 0.61), PTU (r = 0.66), HTU(r = 0.79), while negatively correlated with PTI at maturity.

2.1.1 Sowing environments and cultivars

Rosenthal and Gerik (1991) studied radiation use efficiency among cotton cultivars and found that radiation use efficiency ranged from 1.5 g MJ^{-1} photosynthetically active radiation for Alca to 1.3 g MJ^{-1} for Tamcot.

The seasonal RUE was maximum (2.138 g MJ^{-1}) in 25 November sown crop and decreased with delay in sowing of wheat at Hisar, India. Dry matter production, LAI and yield were found maximum in 25 November sown crop and minimum in 25 December sown crop (Sharma *et al*., 2000).

Sridhara *et al.* (2001) conducted that the radiation use efficiency of sunflower increased from 15 to 75 DAS and then tended to decline. The decrease in RUE after anthesis is coupled with decrease in leaf nitrogen content. In general the RUE of sunflower ranged from 0.49 g MJ^{-1} to 1.84 g MJ^{-1} at different growth stages. The light transmission within the canopy increased exponentially with plant height and the canopy extension coefficient was 0.8.

Singh *et al.* (2003) reported that normal sown wheat crop (22 November) utilized radiation and thermal energy more efficiently and produced higher grain yield and yield attributes as compared to early (28 October) and late (17 December) sown wheat.

Kaur *et al.* (2004) reported that the accumulated growing degree days from sowing to physiological maturity ranged between 1476 and 1968°C day for different wheat cultivars with an average of 1762°C day. Mean heat use efficiency was 2.13 kg ha^{-1}°C day^{-1} for grain yield and 5.30 kg ha^{-1}°C day^{-1} for biomass yield. The highest heat use efficiency of 2.89 kg ha^{-1}°C day^{-1} for grain yield and 7.25 kg ha^{-1}°C day^{-1} for biomass yield was recorded in 2000-01.

Tripathi *et al*. (2004) revealed that highest HUE at anthesis (1.268 g m^{-2}°C day^{-1}) was obtained on 10 December sowing crop as compared to 25 December and 25 November sown wheat crop at Faizabad, India.

Mallick *et al*. (2006) also confirmed that for different sowing date (12 November, 27 November and 12 December) GDD from planting to maturity varied from 1499 to 1851°C day and recorded higher for 12 November sowing. Consequently, maximum PTU accumulated was in early sown crop and significantly different than other sowing dates. In another experiment, Prasad *et al.* (2005) also noted that AGDD, AHTU and APTU were higher in early sown crop (6 November) as compared to late sown crop (20 December) from emergence to physiological maturity of wheat. They also reported that GDD were the best Index to predict 50% grain filling and physiological maturity.

Patra and Sahu (2007) argued that the accumulated heat units decreased under late sowing during post-anthesis phase. PAR decreased as sowing time was delayed from 2nd week of November to 3rd week of December, but increased under very late sown condition (1st week of January). They also noted that under normal sowing condition the crop accumulated higher amount of heat units than that of late sown condition. The RUE and HUE were also higher for earlier sowings than late sowing of wheat.

Kumari *et al*. (2009) found that at flowering stage, the wheat crop under treatments, 20 November, 5 and 20 December and 5 January accumulated 983, 989, 1193 and 1214 °C day, respectively. Singh *et al*. (2008) revealed that wheat sown on 5 November and 20 November recorded higher accumulated GDD, heliothermal units, photothermal units and phenothermal index at all the phenophases over sowing done on 5 December. Khichar and Ram Niwas (2007) reported that the wheat crop sown on 20 November at Hisar, India consumed more photo-and helio-thermal units compared to crops sown on 20 December. They also observed that delay in sowing after 20 November resulted in decrease in biological and grain yields.

Monga *et al.* (2009) studied the effect of radiation on tomato cultivars. They found that reflection and absorption maximum during early sown conditions as compared to late sown conditions. Another yield parameters were also found significantly higher under early sown conditions.

Buttar *et al.* (2010) found no significant difference in seed cotton yield of all cotton genotype due to delay in sowing from April 30 to May 15 was observed during both the year (2006 & 2007), but significant reduction in seed cotton yield was observed when sowing was delayed to May 30 in all the genotypes as compared to April 30 and May 15 sowing at *Punjab Agricultural University, Regional station, Bathinda.*

Evangelos *et al*. (2012) studied the radiation use efficiency of cotton in two different environmental conditions and found that, higher productivity was observed due to larger amount of incident and intercepted radiation and decrease in radiation use efficiency with increasing vapour pressure deficit by a slope of 0.47g/MJ/k.Pa.

Kingra *et al*. (2012) conducted field experiments at Ludhiana and found the thermal units required to attain a particular phenological stage decreased as the sowing was delayed in both the cultivars during all the three crop seasons. The phenothermal index gradually decreased from emergence to maturity in all the three dates of sowing during all the years being the highest at emergence and lowest during maturity of the crop.

2.2 Relationship of IPAR with growth and yield

The low heat use efficiency (HUE) in case of late sown wheat was due to accumulation of higher GDD since both maximum and minimum temperatures shoot up rapidly in the region during late February and March. The higher temperature during reproductive phase caused enormous deleterious effect on dry matter accumulation, more so on seed yield of crop (Rao *et al*. 1999).

Mariscal *et al.* (2000) reported that RUE and biomass partitioning coefficients of young olive (*Oleaeuropaea* L.) trees for use in a general growth model. One year-old olive trees var. ‘Picual’ were planted at a density of either 0.5 or 2.0 trees m^{-2} near Córdoba, Spain, at a site providing favorable growth conditions. PAR interception by the canopy and plant area index (PAI) was measured with radiation sensors. Dry matter production was linearly related to cumulative intercepted PAR. Seasonal RUE, calculated as the slope of the regression of above ground biomass and cumulative intercepted PAR, was 1.35 g (MJ PAR)$^{-1}$. Radiation-use efficiency appeared to respond to environmental conditions, but was independent of planting density and LAI. The young olive trees allocated 0.26 of their total biomass to roots. Partitioning of above ground dry matter was 0.60 to wood and 0.37 to leaves. As competition increased, dry matter partitioning to wood increased to 0.70.

Kiran and Bains (2007) investigated the thermal requirement and heat use efficiency (HUE) in green gram and found 61-64% of variation in grain yield based on thermal index models and also found varied amount and distribution of rainfall affected grain –HUE considerably , but the effect was slight in biomass –HUE.

Yeates *et. al.*, (2010) studied that low temperature and radiation during flowering and boll growth combined to reduce crop growth rate but high yield were achieved when the crop boll filling phase was extended. Management must be tailored to ensure a high proportion of boll growth (60-80%) can occur after vegetative growth has terminated in Western Australia.

Saleem *et al.* (2011) determined significant effect of different irrigation schedules and integrated nutrition levels on fraction of intercepted radiation (Fi) in cotton and found positive and linear relationships between Fi and total dry matter; Fi and seed cotton yield.

Dehariya *et al.* (2012) examined the photosynthesis and yield of cotton and found that fluorescence measurements enhanced Fv/Fm (Fluorescence visible/ Fluorescence measured) ratio and reduction in capacity after exclusion of solar UV and also exclusion enhanced stomatal conductance and intercellular CO_2 concentration and reduced the stomatal resistance and concluded that exclusion of solar UV is beneficial for enhancing the yield of cotton plants.

Gudadhe *et al.* (2013) reported that HUE, HTUE and PTUE were 0.79 kg seed cotton yield/ha degree days^{-1}, 0.18 kg seed cotton yield/ha degree days $^{-1}$ and 0.06 kg seed cotton yield/ha degree days^{-1} with seed cotton yield 2012 kg/ha.

Milroy *et al.* (2013) conducted a field experiments at Narrabri in northern New South Wales, Australia (30^{o}S and 150^{o}E), on a gray-clay soil (vertosol) with a low drainage rate. Waterlogging reduced radiation use efficiency (RUE), but RUE calculated for short time periods during crop growth could not be related directly to soil O_2 status. The response of lamina net photosynthesis (Pn) to repeated water logging suggested some degree of acclimation. The long term suppression of RUE was in contrast to the relatively short duration for which Pn of the youngest fully expanded leaf was affected.

Supraptoa *et al.* (2013) found that dry matter production from high plant population density increased gradually to lower plant population density in all varieties. Interception efficiency (IE) increased in all varieties from early sowing. A plant population density of 25.0 and 44.4 plants m^{-2} intercepted more radiation over 11.1 and 16.0 plants m^{-2}. Conversion efficiency of radiation energy (CE) to total dry matter production on Kelinci variety (1.5%) indicated a slight higher percentage than on Kancil variety (1.4%).

Bangemann *et al.*(2014) reported that Late blight (*Phytophthorainfestans*(Mont.) de Bary) and nitrogen (N) significantly affect crop growth of potato (*Solanumtuberosum* L.), but little knowledge about their interactive effects on radiation interception(RI) and radiation use efficiency (RUE). N fertilization increased leaf area index (LAI), leaf area duration (LAD), and RI, and in consequence, tuber yield, but had no significant effect on RUE within a single cultivar. Late blight infection caused premature senescence and defoliation resulting in smaller LAI, shorter LAD, less RI and lower tuber yields. Late blight had no effect on RUE if leaf area was corrected for disease severity. This study shows that total DM accumulation of potatoes can be predicted by RI and RUE, even if N supply is limited and late blight control is incomplete as long as the late blight effect on RI can be properly estimated.

Brodrick *et al.* (2013) concluded that differences in canopy light interception and the efficiency of conversion of light to biomass were the primary factors responsible for differences in the pattern of biomass accumulation between UNR and conventionally spaced cotton.

2.3 DSSAT validation

Hundal and Kaur (1999) simulated wheat yield using CERES-Wheat model at research farm of Punjab Agricultural University, Ludhiana. The model predicted grain yields from 80 to 115% of the observed grain yields.

Crop growth simulation models are quantitative tool based on scientific knowledge that can evaluate the effect of climatic, edaphic, hydrological and agronomic factors on crop growth and yield. Nain *et al*. (2000) used CERES-Wheat (Ritchie and Otter, 1985) model for predicting wheat yield of Nanital. Published genetic coefficients, dominant soil properties and daily weather at Pantnagar were used as inputs for simulation. The study demonstrated that CERES-Wheat model could simulate the pattern of weather induced yield variability in district yield series over the long period of 19 years (1980-1998).

Guerra, (2007) use the Cropping System Model-CROPGRO-Cotton to simulate farmers' irrigation applications and compared the spatial and temporal distribution of irrigation amounts predicted by the Cropping System Model-CROPGRO-Cotton with the amount of water that the farmers actually applied. The Cropping System Model-CROPGRO-Cotton simulated the temporal pattern of irrigation applications very well during the 2002 and 2003 growing seasons from selected sites of the Agricultural Water Pumping Program and found a better agreement on the spatial distribution of monthly total irrigation for the observed and simulated obtained for 2003 than for 2002.

Kaur *et al*. (2007) found that mode of performance in CERES-Wheat (version 4) was satisfactory with regard to parameters, phenological events (days to anthesis and maturity) and seed yield. Predicted biomass yield was under estimated. They also observed that baring stem weight, total biomass and leaf and ear weight pattern provided good estimate of all tested varieties at different sowing dates.

Mani *et al. (*2007) found that prediction of phenological development was over estimated with in the acceptable limit (± 1). The prediction of peak leaf area index (LAI) was significantly on the higher side and deviated between -0.1 to 0.8 and also within the acceptable limits at CCS HAU, Hisar.

Aneja *et al.* (2008) found that yield of first picking after about five months of sowing along with number of unopened bolls was fairly adequate for use in building advance estimates of yield of cotton. The estimated yield of cotton (H-1098) in mid-October was 1124, 1245, 1409 and 1382 kg/ha for the years 2003-2004, 2004-2005, 2005-2006 and 2006-2007, respectively at CCSHAU, Hisar.

The error per cent of CERES-Wheat simulated value over observed was very low on 15 December sowing for 50% flowering (days) in wheat genotypes. Error % of simulated value over observed in respect of biomass (kg ha^{-1}) at harvest was found minimum for 4 January sowing genotypes. On the 15 December sowing, the error % of simulated value over observed LAI was found very close followed by 25 December and 4 January sowing, respectively i.e. accuracy decreases with delay in sowing (Pal *et al*., 2008).

The magnitudes of the genetic parameters of the local wheat cultivar Orestis were strongly influenced by seasonal weather fluctuations. For predicting yield and harvest biomass by CERES-Wheat model, the root mean square error was 2.2 t ha^{-1} and 3.2 t ha^{-1}, respectively (Langensiepen *et al*., 2008).

Zamora *et al.* (2009) used CROPGRO cotton, a process-based model, to simulate cotton (Gossypium hirsutum L.) production under different levels of light in a pecan (Carya illinoensis K. Koch) alley cropping system with four treatments (1) control (full amount of light transmittance), (2) Row 1 (50% light transmittance), (3) Row 4 (55% light transmittance), and (4) Row 8 (70% light transmittance). The CROPGRO-Cotton model was able to describe variations in growth among the shaded treatments well across both growing seasons 2001 and 2002. Parameters associated with photosynthesis and dry matter partitioning were reasonably stable across shading treatments and years.

Adhikari, (2016) evaluated the CROPGRO-Cotton module for the THP region over a period of four years (2010–2013). On an average, when compared to historic seed cotton yield, simulated future seed cotton yield across the THP decreased within a range of 4–17%

when carbon dioxide (CO_2) concentration was assumed to be constant at the current level (380 ppm) and when the CO_2 concentration was assumed to increase from 493 ppm (in year 2041) to 635 ppm (in year 2070), the simulated future average seed cotton yield increased within a range of 14–29%. And when the irrigation amount was reduced by 40%, the average (2041–2070) seed cotton yield decreased by 37% and 39% under the constant and increasing CO_2 concentration scenarios, respectively. These results imply that cotton is sensitive to atmospheric CO_2 concentrations, and cotton production in the THP region could potentially withstand the effects of future climate variability under moderate increases in CO_2 levels if irrigation water availability remains at current levels.

CHAPTER–III

MATERIALS AND METHODS

The Present investigation on "Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments" was carried out during the *kharif* season 2015. The details of materials used and techniques adopted during the course of investigations are described below:

3.1 Experimental site

The study was conducted at the Research Farm of the Department of Agricultural Meteorology Chaudhary Charan Singh Haryana Agricultural University, Hisar and situated in the semi-arid zone at an elevation of 215.2 m with a longitude of 75^0 $46^{/}$ E and latitude of $29^0 10^{/}$N.

3.2 Climatic conditions

The climate of Hisar region is continental and Hisar lies at the outer margins of the monsoon region *i.e.* 1600 km away from the ocean. It has semi-arid subtropical monsoonal climate. South westerly monsoon current in the summer brings rain generally from last week of June to middle of September. From October to the end of June next, the weather remains extremely dry, except for a few light showers received due to westerly disturbances. About 80 per cent of annual precipitation is received in the south-west monsoon season. Summers are very hot (maximum temperature touches 45^0C or sometimes more) and winters are fairly cool (minimum temperature around 1 to 2^0C or sometimes less). Some time temperature may fall below 0^0C in the month of December and January. The average annual rainfall is 450 mm.

3.3 Methods for raising crop

Delinted and certified seeds of recommended Pancham-541, SP-7121 and RCH-791 of cotton cultivars were sown in three growing environments by hand plough, keeping a distance of 67.5 cm from row to row. Thinning was done one month after sowing maintaining a plant to plant distance of 30 cm. All the agronomic practices were followed as per the recommended package of practices by the university for raising the crop under irrigated conditions

3.4 Study techniques

3.4.1 Experimental details

Treatments

Main plot : Growing environments: Three

G1 : 2nd week of May, 2015

G2 : 3rd week of May, 2015

G3 : 1nd week of June, 2015

Subplot : **Cultivars : Three**
C1 : *Bt* cotton (Pancham-541)
C2 : *Bt* cotton (SP-7121)
C3 : *Bt* cotton (RCH-791)
Replications : Three (3)
Plot size : 4.5 m x 4.05 m
Design : RBD (Random Block Design)

3.5 Observations recorded

3.5.1 Agrometeorological observations

Quantum sensor was used to measure PAR after 30 days of sowing and at 30 days interval during noon hours at top, middle and bottom of canopy. The reflected radiation was obtained by keeping the sensor inverted at 1m above the crop canopy and the sensor was also kept on ground across the rows diagonally at random sites to get transmitted radiation radiation at the ground. Daily radiation data was measured with Pyranometer installed at top of building situated north side of agrometeorological observatory.

Daily meteorological data recorded at Agrometeorological Observatory situated about 0.1 km away from the experimental plot, was used for computation of agrometerological indices.

3.5.2 Plant observations

3.5.2.1 Growth parameters (leaf area index, dry matter and plant height) were measured by taking plants samples at similar intervals of radiation observations.

Leaf area index (LAI): Three plants were uprooted from each plot and their leaves were used for measuring leaf area per plant (cm^2) with the help of leaf area meter (LI-3000 Leaf Area Meter, LICOR Ltd., Nebraska, USA) at the intervals mentioned above:

$$\text{LAI} = \frac{\text{Total green leaf area of plant (cm}^2\text{)}}{\text{Total ground area (cm}^2\text{)}}$$

Dry matter: Three plants per plot were harvested from the ground level. To know the change in dry matter accumulation at 30, 60, 90, 120 and 150 days after sowing and at harvest. The samples were first air dried and then oven dried at a temperature of 70°C till constant weight was obtained. Dry weight was recorded and was expressed on per plant basis.

Plant height: Plant height was measured at important phenophases on three tagged plants in each plot. The height was measured from the root-shoot junction to the apical point with a wooden meter scale and mean values were calculated.

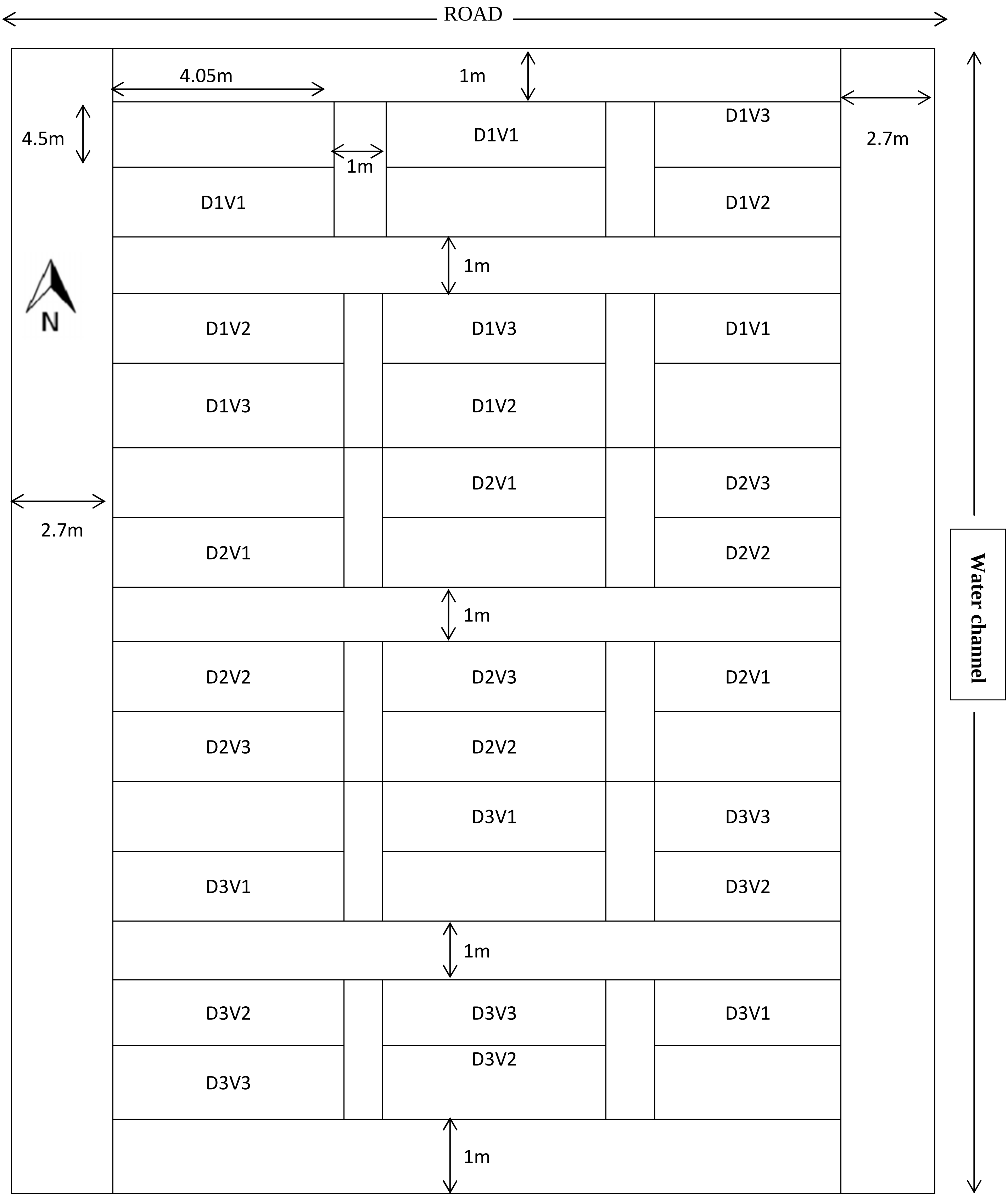


Figure 3.1: Layout of experimental field

3.5.2.2 The following phenological observation was observed on tagged plants by making frequent observations:

i) Emergence
ii) 50% square formation
iii) 50 percent flowering
iv) 50 percent boll formation
v) 50 percent boll opening

3.5.2.3 Number of sympodial per plant was recorded at 5 days interval.

3.5.2.4 Yield and yield attributes: Three plants were randomly taken from each plot for recording of biological parameters at crop maturity.

3.5.2.4.1 Number of bolls per plant: Number of detached bolls was counted and mean number of boll per plant was calculated.

3.5.2.4.2 Boll weight per plant: Weight of detached bolls was measured and mean weight of boll per plant was calculated.

3.5.2.4.3 Yield of seed cotton, cotton lint and cotton seed: The seed cotton was picked from three randomly selected plants from each plot. The seed cotton yield was calculated on net plot area basis. Cotton lint was removed from cotton seed by ginning and cotton lint weight was taken.

3.5.2.5 Protein content:

A. Digetion: Sample (0.2g) was taken in Kjedahl flask. Two gram digestion mixture and 10 ml conc. H_2SO_4 were added to it. The flask were placed on digestion bench and heated till the solution became clear. The flasks were removed, cooled and volume was made to 100 ml with distilled water.

B. Distillation: Aliquot (10 ml) was transferred to micro-Kjedahl assembly and 10 ml of 40% NaOH was added to it. 10 ml of N/100 H_2SO_4 was taken in conical flask and 2-3 drops of methyl red indicator were added to it. This conical flask was set under condenser. The distillation was carried for 10-15 minute till its volume become 50 ml. Blank was also run simultaneously.

C. Titration: The conical flask was removed after washing the tip of condenser with distilled water into the flask. The content of flask was titrated with N/100 NaOH till the end point (red to pink). The volume of alkali used for neutralization of H_2SO_4 was recorded. The amount of nitrogen and hence protein in the sample was calculated using following relationship.

$$1 \text{ ml N/100 } H_2SO_4 = 0.00014 \text{ g N}$$

$$\% \text{ Crude protein} = \frac{V \times 0.00014 \times D \times 100 \times 6.25}{W \times A}$$

Where, V = Volume of N/100 H_2SO_4 taken – volume of N/100 NaOH used for titration

D = Dilution factor (volume made in volumetric flask)

W = Weight (g) of sample

A = Aliquot taken for distillation

3.5.2.6 Oil content (%) - The oil content was determined by Soxhelt method.

For oil extraction, one gm each dried and grinded seed samples were treated with petroleum- ether for 1- 2 hours in Soxhlet apparatus. After oil extraction, the treated samples were dried and weighed. Percent reduction in oil content was calculated using simple formula given below:

$$\text{Oil content (\%)} = \frac{\text{(Weight of sample before extraction – Weight of sample after extraction)}}{\text{Weight of sample before extraction}} \times 100$$

3.6 Methodology

3.6.1. Thermal indices:

Energy indices like heat unit, heliothermal unit and photothermal unit were computed using daily weather data.

3.6.1.1 Heat unit: Cumulative heat units (HU) were determined by summing the daily mean temperature above base temperature and are expressed in ^{0}C day. This was calculated using the following formula:

$$HU = \Sigma(T_{max.} + T_{min.})/2 – T_b$$

Where,

$T_{max.}$ = Daily maximum temperature (^{0}C)

$T_{min.}$ = Daily minimum temperature (^{0}C)

T_b = Minimum threshold/base temperature (10^{o}C, WMO, 1996)

3.6.1.2 Heliothermal unit: Heliothermal unit (HTU) is the product of heat unit and bright sunshine hours for a day and is expressed in ^{o}C day hours. The sums of HTU for particular phenophases of interest were determined according to the equation:

$$HTU = \Sigma(HU \times n)$$

Where,

n = Actual sunshine hours

3.6.1.3 Photothermal unit: Day and night is one of the basic factors controlling the period of vegetative growth in a photosensitive crop. Photothermal unit (PTU) is product of heat unit and maximum possible sunshine hours and are expressed in ^{0}C day hours. PTU was calculated using the following formula:

$$PTU = \Sigma (HU \times N)$$

Where,

N = Maximum possible sunshine hours or day length

3.6.2 Photosynthetically Active Radiation (PAR): Daily solar radiation was computed by the expression

$$Rs = \sum_{i=0}^{n} Rsi$$

Where,

Rsi = Hourly radiation measured with Pyranometer.

n = Day hours.

Daily PAR was calculated by the formula:

PAR = Rs x 0.48 (Oleson et al., 2000)

The PAR values were converted into MJ/ m^2.

3.6.2.1 Intercepted PAR: The daily IPAR was calculated using the following expression:

IPAR= PAR ($1-e^{-kf}$) (Rosenthal and Gerik, 1991).

Where,

k (Extinction coefficient) = ln (I/Io)/f (Monsi and Saeki, 1953).

F = Cumulative leaf area index of foliage layer.

Io = Radiation energy at the top of the canopy,

I = Radiation energy at a level inside the crop canopy.

3.6.2.2 Transmitted PAR (%): It is the ratio of transmitted PAR to the total incidence on the crop surface and multiplied by 100.

3.6.2.3 Reflected PAR (%): It is the ratio of reflected radiation by crop with the total incidence PAR over crop surface and multiplied by 100.

3.6.2.4 Absorbed PAR (%): It is calculated by subtracting transmitted and reflected radiation from 100.

APAR = 100 - transmitted - reflected

3.6.2.5 Radiation use efficiency: The radiation use efficiency is a ratio of total dry biomass and the radiation intercepted. It can be expressed by the following formula:

Radiation use efficiency (g/MJ) = (Dry matter (g/m^2) / IPAR (MJm^{-2}))

3.6.2.6 Thermal use efficiency (TUE): Thermal use efficiency is a ratio of total dry matter and heat unit consumed by the crop. It can be represented by the following formula:

Thermal use efficiency (g/m^2/^{0}C day) = (Dry matter (g/m^2) / HU (^{0}Cday))

3.7 Statistical analysis

The data used in the study are the mean values of replicated observations. Correlation coefficients were computed between agrometeorological and crop parameters. Regression analysis was carried out to develop the relationship of crop parameters with significant weather parameters temperature, relative humidity, sunshine etc. and agrometeorological indices. Multiple regression equations were developed by taking two or more significant weather parameters together using stepwise regression technique. Analysis of variance (ANOVA) was computed using the replicated of all the treatments by OPSTAT software.

3.8 DSSAT model

3.8.1 Input data for CROPGRO-Cotton model

'CROPGRO-Cotton' is a physiological based dynamic crop growth simulation model which is responsive to daily weather inputs. The minimum data required for running CROPGRO-Cotton are given in Table 3.1.

Table 3.1: List of input required by CROPGRO-Cotton model

INPUT VARIABLES	**ACRONYM**	**UNITS**
Site data		
Latitude	LAT	Degree
Longitude	LONG	Degree
Elevation	ELEV	M
Average air temperature	TAV	°C
Height of temperature measurement	TMHT	M
Height of wind measurement	WMHT	M
CO_2 concentration		Ppm
Daily weather data		
Maximum temperature	TEMPMAX	°C
Minimum temperature	TEMPMIN	°C
Rainfall	RAIN	Mm
Sun Shine hours	SSH	hours
Soil characteristics		
Soil texture	SLTX	
Soil local classification	SLDESC	
Soil family SCS system	TACON	
Soil depth	SLDP	M
Colour, moist	SCOM	
Albedo (fraction)	SALB	Fraction
Evaporation limit	U	Cm
Drainage rate (fraction day^{-1})	SWCON	Fraction day^{-1}
Runoff curve number	CN2	
Mineralization (0 to 1 scale)	SLNF	
Photosynthesis factor (0 to 1 scale)	SLPE	
pH in buffer determination method	SMPX	
Potassium determination method	SMKE	
Horizon-wise		
Lower limit drained	LL(L)	cm^{3}cm^3
Upper limit drained	DUL(L)	cm^{3}cm^3

INPUT VARIABLES	**ACRONYM**	**UNITS**
Upper limit drained	SAT(L)	cm^{3}cm^3
Saturated hydraulic conductivity	SWCN(L)	cmhr^{-1}
Bulk density moist	BD(L)	gcm^{-3}
Organic carbon	OC(L)	%
Clay (<0.002 mm)`	CLAY(L)	%
Silt(0.05 to 0.002 mm)	SILT(L)	%
Coarse fraction (>2 mm)	STONES(L)	%
Total nitrogen	TOTN(L)	%
pH in buffer	PHKCL(L)	
Cation exchange capacity	CEC(L)	Cmolkg^{-1}
Root growth factor 0 to 1	SHF(L)	
Management data		
Sowing date	YRPLT	
Emergence date	IEMERG	
Plant population at seedling	PLNATS	Plantm^{-2}
Planting method (TP/direct seeded)	PLME	
Planting distribution (row/broadcast/hill)	PLDS	
Row spacing	ROWSPS	Cm
Row direction (degree from north)	AZIR	
Plants per hill	PLPH	
Seed rate	SDWTRL	kgha^{-1}
Sowing depth	SDEPTH	Cm
Irrigation dates	IDLAPL(J)	
Irrigation amount	AMT(J)	Mm
Method of irrigation	IRRCOD(J)	
Fertilizer application dates	FDAY(J)	
Fertilizer amount N	ANFER(J)	kgha^{-1}
Fertilizer type	IFTYPE(J)	
Fertilizer application method	FERCOD(J)	
Fertilizer incorporation depth	DFERT(J)	Cm
Tillage date	TDATE(J)	
Tillage implement	TIMPL(J)	
Tillage depth	TDEP(J)	Cm
Residue management	LNRES	
Chemical applications	LNCHE	
Environment modification	LNENV	
Harvest details		
Harvest	HDATE(J)	
Harvest stage	HSTG(J)	

INPUT VARIABLES	ACRONYM	UNITS
Harvest component	HCOM(J)	
Harvest percentage	kg ha^{-1}	%

3.8.2 Calibration of the model

Calibration of model involves computing and adjusting certain model parameters or relationships to make the model work for any desired location. When using a crop model, one has to estimate the cultivar characteristics if they have not been previously determined. The model requires twenty cultivar specific genetic coefficients. The details of these coefficients are given below:

Parameters	**Description of parameters**
EXPON	Number of experiment used to estimate cultivar parameters
ECO#	Code for the ecotype to which this cultivar belongs
CSDL	Critical Short Day Length below which reproductive development progresses with no day length effect (for short day plants) (hour)
PPSEN	Slope of the relative response of development to photoperiod with time (Positive for short day plants) (1/hour)
EM-FL	Time between plant emergence and flower appearance (R1) (photothrmal days)
FL-SH	Time between first flower and first pod (R3) (photothermal days)
FL-SD	Time between first flower and first seed (R5) (photothermal days)
SD-PM	Time between first seed (R5) and physiological maturity (R7) (photohermal days)
FL-LF	Time between first flower (R1) and end of leaf expansion (photothermal days)
LFMAX	Maximum leaf photosynthesis rate at 30^0 C, 350 vpm CO^2 and high light (mg CO^2/m^2-s) ---from Reddy Adv. Agron. 1997?
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZLE	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed+shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDPDV	Average seed per pod under standard growing conditions (#/pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)
THRSH	Threshing percentage. The maximum ratio of seed (seed/(seed+shell))
SDPRO	Fraction protein in seeds (g(protein)/g(seed))
SDLIP	Fraction oil in seed (g(oil)/g(seed))

3.8.3 Validation

The model was run and validated by comparing the predicted output with observed parameters. Deviation of predicted value from observed were calculated and accuracy of the model to predict different crop parameters was quantified.

CHAPTER–IV

EXPERIMENTAL RESULTS

The experimental results obtained from the present investigation entitled "Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments" are presented under the following heads.

4.1 Agrometeorological indices

4.2 Biological parameters

4.3 DSSAT model

4.1 Agrometeorological indices

4.1.1 Optical characteristics (Indices)

The optical characteristics (Transmitted, Reflected and Absorbed PAR) of cotton cultivars in three growing environments are presented in table 4.1. The maximum reflection (14.8%) was observed in 1st week of June, followed by 3rd week of May (9.5%) and 2nd week of May (9.4%). Pancham 541 showed maximum transmission (8.5%), followed by SP 7121 (8%) and RCH 791 (6.5%). Higher absorption (88.4%) was found in RCH 791 as compared to SP 7121 (81.7%) and Pancham 541 (71.9%). The minimum transmission and maximum absorption of PAR were in RCH 791 and first sowing environment.

Table 4.1: Optical characteristics (Indices) of cotton cultivars under different growing environments

Growing environments	Reflection (%)	Transmission (%)	Absorption (%)
2nd week of May	9.4	7.5	83.1
3rd week of May	9.5	7.9	82.6
1st week of June	14.8	8.9	76.3
Varieties			
Pancham 541	19.6	8.5	71.9
SP 7121	10.3	8.0	81.7
RCH 791	3.8	7.8	88.4

4.1.2 ENERGY INDICES

The various agrometeorological energy based indices (HU, HTU, PTU and IPAR) were computed for different phenophases of cotton crop and thermal indices are depicted in figure 4.1, 4.2.4.3 and 4.4.

4.1.2.1 Heat units: The thermal time or heat units (HU) consumed/accumulated for completion of different phenological stages of cotton cultivars under different growing environments were worked out and are presented in figure 4.1. The cumulated thermal time was maximum in the 2nd week of May (D1) sown crop followed by 3rd week of May (D2) and 1st week of June (D3) sown crop at all phenological stages. These values at physiological maturity were 3372.4, 3186.9 and 2938.0 °C days for D_1, D_2 and $D_{3,}$ respectively. Among the cotton varieties, the highest number of heat units were accumulated 3198.8 °C day by RCH 791; the next higher were 3161.4 °C days by SP 7121 and 3137.2 °C days by Pancham 541. Among varieties, RCH 791 accumulated higher thermal time as compared to other varieties. The cotton crop sown on 2nd week of May accumulated higher thermal units as compared to 3rd week of May and 1st week of June sown crops.

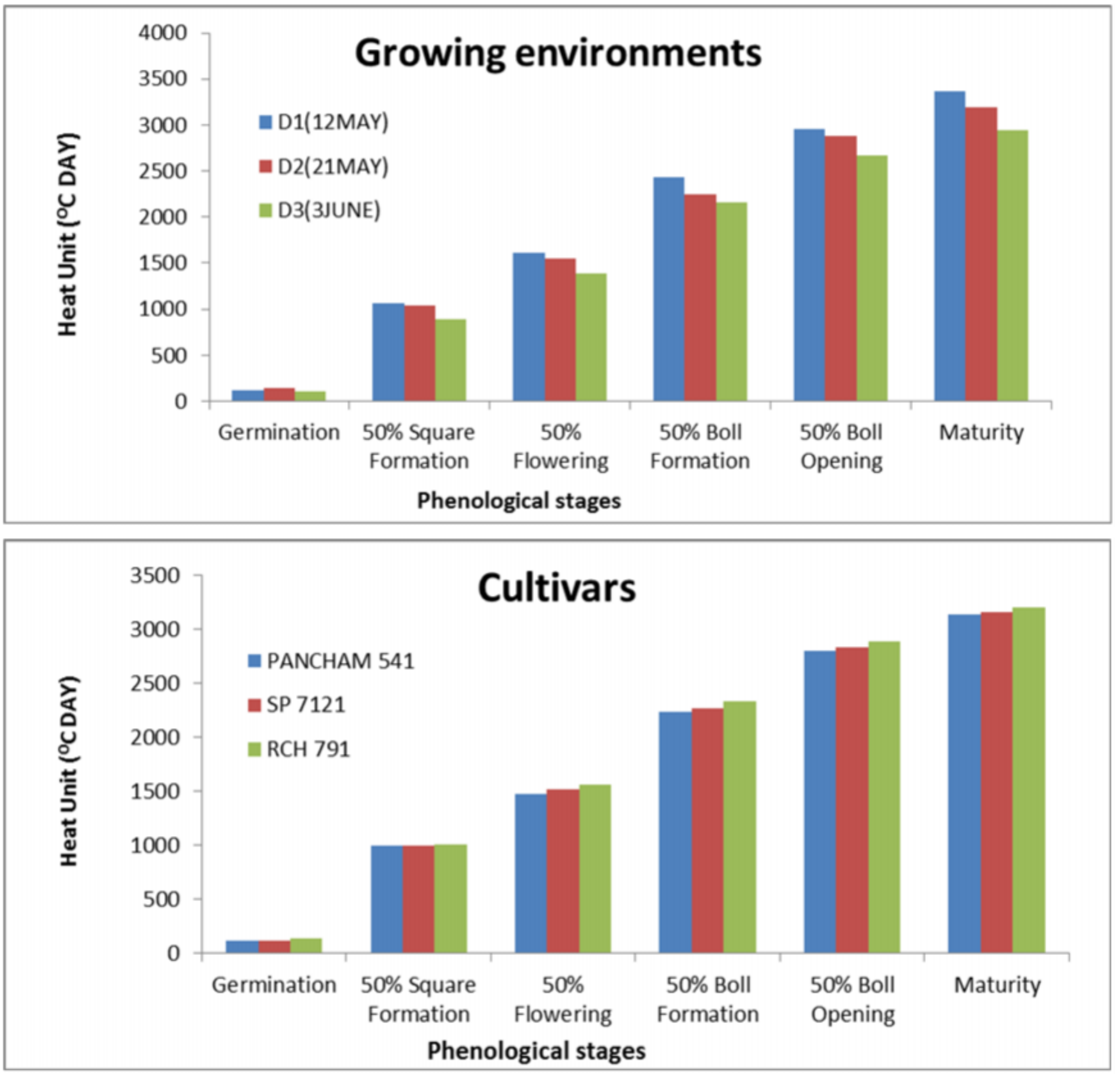


Figure 4.1: Heat units (^{0}C days) consumed by cotton cultivars at various phenophases under different growing environments

4.1.2.2 Heliothermal units

The heliothermal units (HTU) accumulation at different phenophases of cotton cultivars under different growing environments were worked out and are presented in figure 4.2.

The cumulative value of HTU at physiological maturity was higher in the first sown crop as compared to late sown cotton crop. The HTU values were higher in the 2nd week of May (D1) sown crop followed by 3rd week of May (D2) and 1st week of June (D3) sown crop at all phenological stages. These values at physiological maturity were 25781.5, 24181.5 and 21734.4 °C day hours for D1, D2 and D3 respectively. Among cotton varieties, RCH 791 accumulated higher amount of HTU with the value of 24129.3 °C day hours as compared to SP 7121 and Pancham 541.The cotton crop sown on 2nd week of May accumulated higher thermal units as compared to 3rd week of May and 1st week of June sown crops.

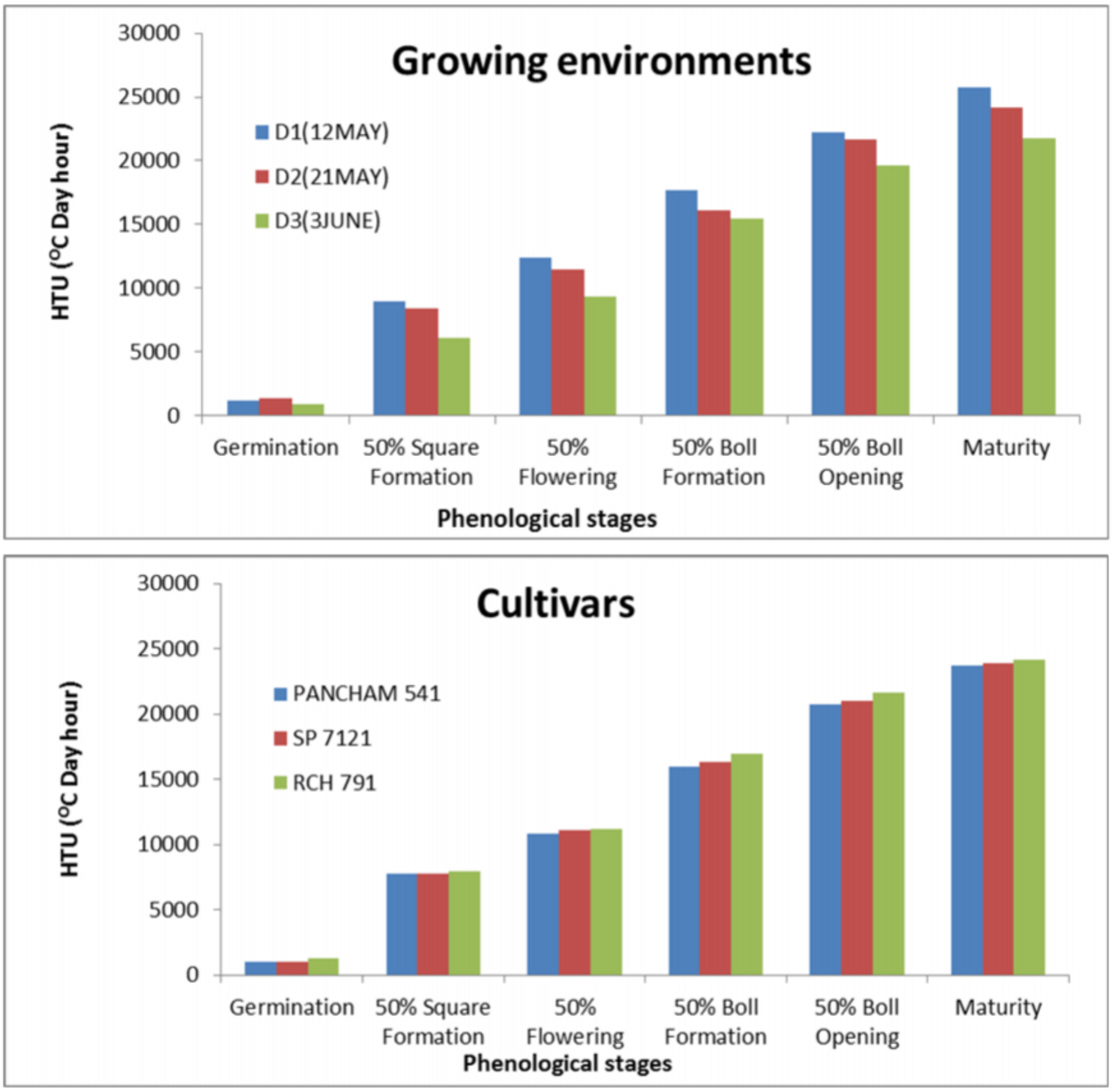


Figure 4.2: Heliothermal units (^{0}C day hours) requirement of cotton cultivars at various phenophases under different growing environments

4.1.2.3 Photothermal units:

The photothermal units (PTU) were accumulated at different phenophases of cotton cultivars under different growing environments and are presented in figure 4.3.

Photothermal units were significantly higher in the 2nd week of May (D1) sown crop followed by 3rd week of May (D3) and 1st week of June (D3) sown crop at all phenological stages. These values at physiological maturity were 43408.9, 40865.5 and 37290.9 ^{0}C day hours for D1, D2 and D3, respectively. RCH 791 accumulated higher PTU, 40879.8 ^{0}C day hour as compared to SP 7121 and Pancham 541.

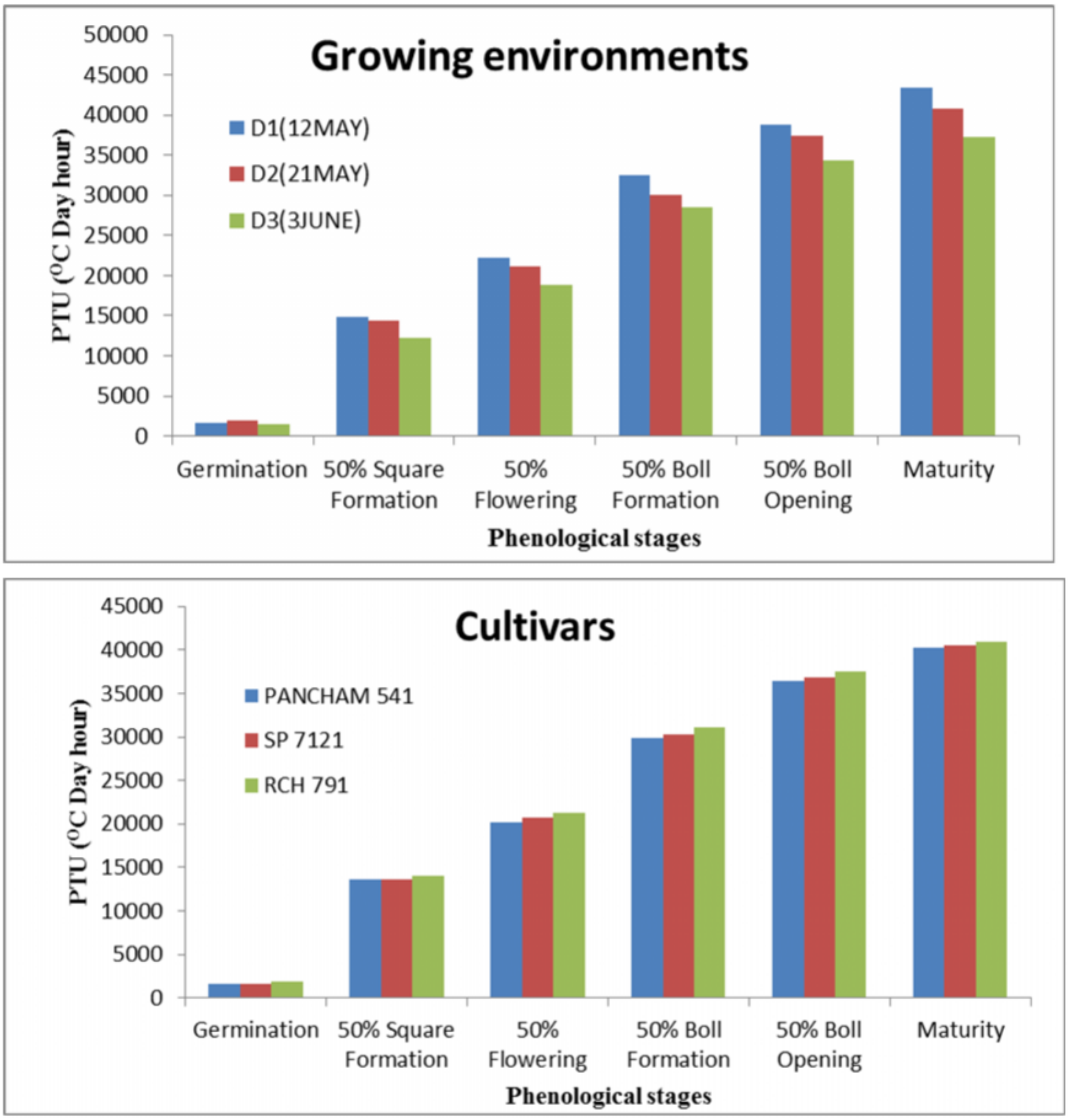
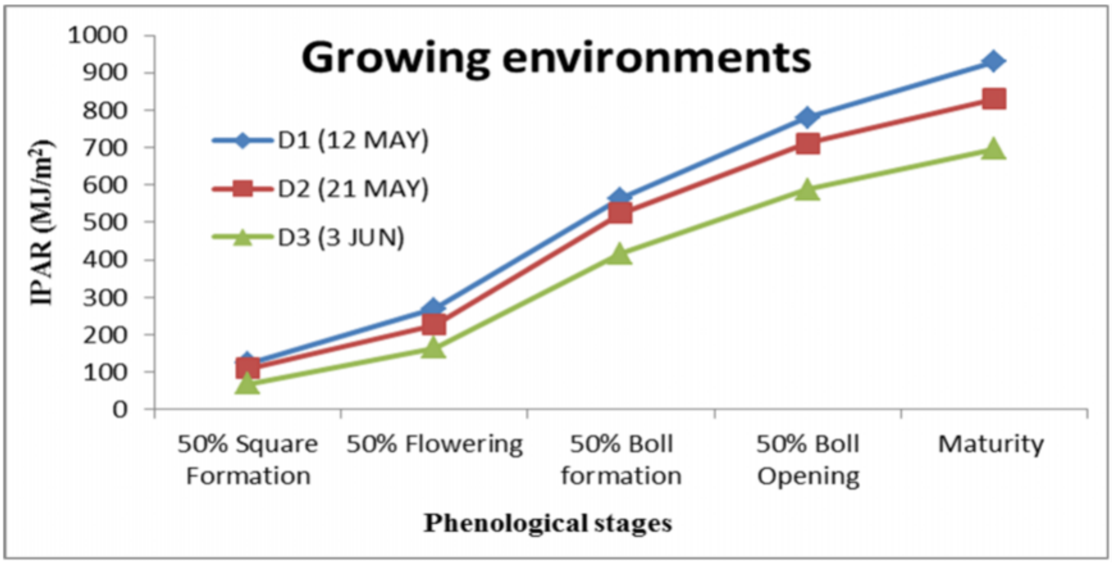


Figure 4.3: Photothermal units requirement of cotton cultivars at various phenophases under different growing environments

4.1.2.4 Intercepted photosynthetically active radiation:

The intercepted photosynthetically active radiation (IPAR) at various phenophases was computed under different growing environments and is depicted in figure 4.4.

The accumulated photosynthetically active radiation was higher in the 2nd week of May sown crop followed by 3rd week of May and 1st week of June sown crop at all phenological stages. These values at physiological maturity were 929.4, 829.2 and 695.9 MJ m^{-2} for D1, D2 and D3 respectively. Cultivar RCH 791 intercepted higher PAR with value of 880.6 MJ m^{-2} as compared to SP 7121 and Pancham 541.The decrease in IPAR values with delay in sowing was due to reduction in leaf area index with delay in sowing.



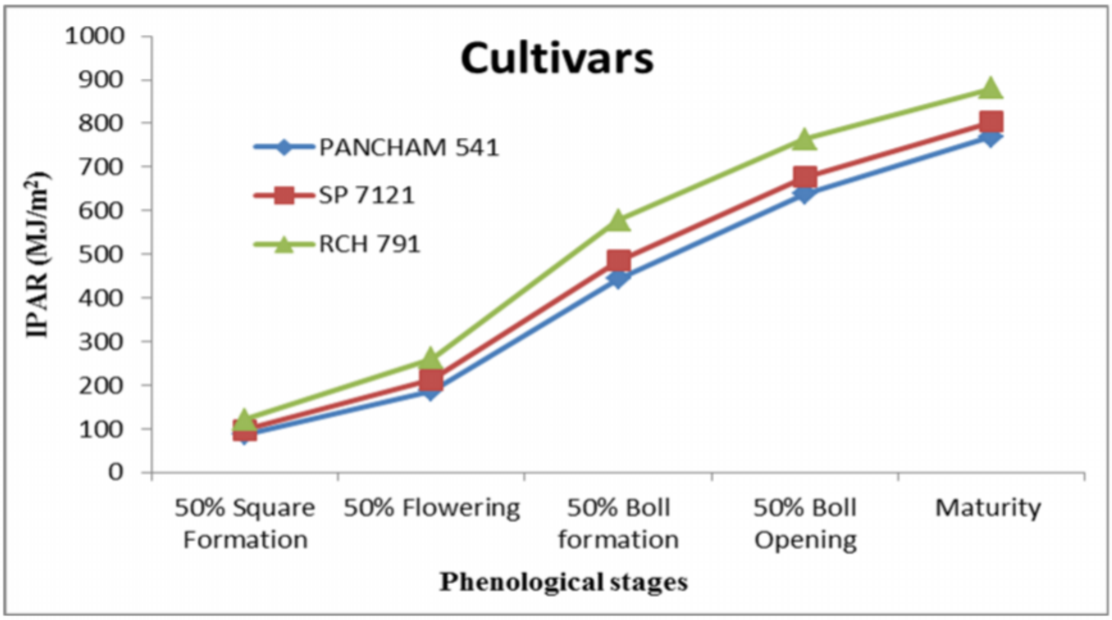


Figure 4.4: Photosynthetically active radiation intercepted by cotton cultivars at various phenophases under different growing environments

4.1.2.5 Thermal use efficiency:

The thermal use efficiency (TUE) for dry matter production at various phenophases under different growing environments was computed and is presented in the table 4.2. Significantly highest TUE was found in the 2nd week of May sown crop followed by 3rd week of May and 1st week of June, at all phenophases. Among varieties, RCH 791 had significantly higher TUE at 50% flowering, completion of flowering and physiological maturity followed by SP 7121 and Pancham 541. The TUE value was maximum at maturity stage in all the treatments .The decrease in TUE with delay in sowing was due to the fact that delayed sowing of cotton crop led to early reproductive phase due to low temperature and shorter days prevailed in the late sown crop.

Table 4.2: Thermal use efficiency of cotton cultivars at various phenophases under different growing environments

	Thermal use efficiency (g/m^2/^{0}C day)					
Growing environments	**Germination**	**50% Square Formation**	**50% Flowering**	**50% Boll formation**	**50% Boll Opening**	**Maturity**
2nd week of May	0.06	0.09	0.19	0.36	0.38	0.39
3rd week of May	0.05	0.08	0.16	0.34	0.36	0.37
1st week of June	0.04	0.07	0.11	0.27	0.33	0.35
CD at 5%	0.01	0.01	0.01	0.02	0.02	0.02
Varieties						
Pancham 541	0.04	0.06	0.12	0.29	0.33	0.35
SP 7121	0.05	0.07	0.14	0.31	0.35	0.36
RCH 791	0.06	0.11	0.20	0.37	0.39	0.40
CD at 5%	0.01	0.01	0.01	0.02	0.02	0.02

4.1.2.6 Radiation use efficiency:

The phenophases wise variations in radiation use efficiency (RUE) for biomass production of cotton cultivars under three growing environments are presented in table 4.3

The cotton crop sown on 2nd week of May was most efficient in PAR utilization in comparison with crop sown on 3rd week of May and 1st week of June. Though the amount of PAR received above the canopy was almost same in all treatments, the proportion of intercepted PAR differed because of differential crop cover owing to variation in LAI and varying levels of biomass production in different treatments, implying that RUE also differed RCH 791 showed maximum RUE followed by SP 7121 and Pancham 541 at all stages. The maximum value of RUE for dry matter production was observed at 50% boll formation stage in all treatments because of maximum LAI recorded at this phenophase. The highest RUE in the earlier sown crop was due to the maximum PAR absorption and dry matter production, both of which decreased subsequently due to reduction in LAI with the delayed sowing.

Table 4.3: Radiation use efficiency of cotton cultivars at various phenophases under different growing environments

	Radiation use efficiency (g/MJ)				
Growing environments	**50% Square Formation**	**50% Flowering**	**50% Boll Formation**	**50% Boll Opening**	**Maturity**
2nd week of May	0.78	1.16	1.55	1.43	1.39
3rd week of May	0.72	1.07	1.44	1.33	1.30
1st week of June	0.84	0.95	1.40	1.31	1.27
CD at 5%	0.05	0.08	0.16	0.14	NS
Varieties					
Pancham 541	0.72	0.97	1.44	1.33	1.30
SP 7121	0.71	1.00	1.45	1.34	1.31
RCH 791	0.92	1.21	1.51	1.40	1.35
CD at 5%	0.05	0.08	0.16	0.14	0.17

4.2 Biological parameters

4.2.1 Leaf Area Index:

Leaf area index (LAI) of cotton crop was computed at various growth intervals under different growing environments and is presented in Table 4.4.

Table 4.4: Leaf area index of cotton cultivars at various growth intervals/phenophases under different growing environments

	DAS (Days After Sowing)				
Growing environments	**30**	**60**	**90**	**120**	**150**
2nd week of May	0.11	0.97	1.81	3.46	1.47
3rd week of May	0.10	0.94	1.69	3.33	1.31
1st week of June	0.12	0.84	1.62	2.75	1.27
CD at 5%	N/A	N/A	N/A	0.29	N/A
Varieties					
Pancham 541	0.10	0.75	1.55	2.92	1.16
SP 7121	0.10	0.87	1.61	3.11	1.29
RCH 791	0.14	1.13	1.95	3.50	1.60
CD at 5%	N/A	0.15	0.29	0.29	0.20

Maximum leaf area index was observed at 120 DAS in three cotton cultivars under different growing environments. Cotton crop sown on 2nd week of May (D1) produced maximum leaf area index followed by 3rd week of May (D2) and 1st week of June (D3) with values 3.46, 3.33 and 2.75, respectively. Leaf area index was 2.9, 3.1 and 3.5 for the cultivars

RCH 791, SP 7121 and Pancham 541, respectively. The first sown cotton crop and cultivar RCH 791 produced maximum LAI because of highest PAR intercepted by them.

4.2.2 Plant height

Plant height of cotton crop was computed at various growth intervals under different growing environments and is presented in Table 4.5.

Table 4.5: Plant height of cotton cultivars at various growth intervals under different growing environments

	DAS (Days After Sowing)				
Growing environments	**30**	**60**	**90**	**120**	**150**
2nd week of May	35.1	88.2	116.8	122.3	127.5
3rd week of May	22.7	82.0	114.1	120.3	124.1
1st week of June	20.9	77.2	88.4	91.9	95.1
CD at 5%	**2.8**	**6.9**	**9.6**	**6.3**	**5.1**
Varieties					
Pancham 541	24.2	69.9	91.8	97.9	102.7
SP 7121	29.5	94.6	120.0	125.5	128.8
RCH 791	24.9	82.9	107.4	111.0	115.3
CD at 5%	**2.8**	**6.9**	**9.6**	**6.3**	**5.1**

Maximum plant height was observed at 150 DAS in three cotton cultivars under different growing environments. Cotton crop sown on 2nd week of May (D1) attained maximum plant height followed by 3rd week of May (D2) and 1st week of June (D3) with values 127.5, 124.1 and 95.1cm respectively. Plant height was 115.3cm, 128.8cm and 102.7cm for the cultivars RCH 791, SP 7121 and Pancham 541, respectively. The first sown cotton crop and cultivar SP 7121 attained maximum plant height.

4.2.3 Dry matter

Dry matter accumulation is a good index to express the photosynthetic efficiency of plants. The dry matter production by three cotton cultivars under various growing environments is given in table 4.6.

Dry matter increased with advancement of crop stage and maxima was observed at physiological maturity in all the cultivars and growing environments. Dry matter production was maximum 326.1 g/plant in cotton crop sown on 2nd week of May followed by 3rd week of May and 1st week of June. The cultivar RCH 791 yielded maximum 314.3 g and Pancham 541 yielded minimum 277.1 g dry matter per plant.

The dry matter accumulation was highest in first date of sowing as compared to late sown crop due to more LAI and PAR absorption observed in the first growing environment.

RCH 791 produced maximum dry matter, because of highest LAI and PAR interception by this cultivar.

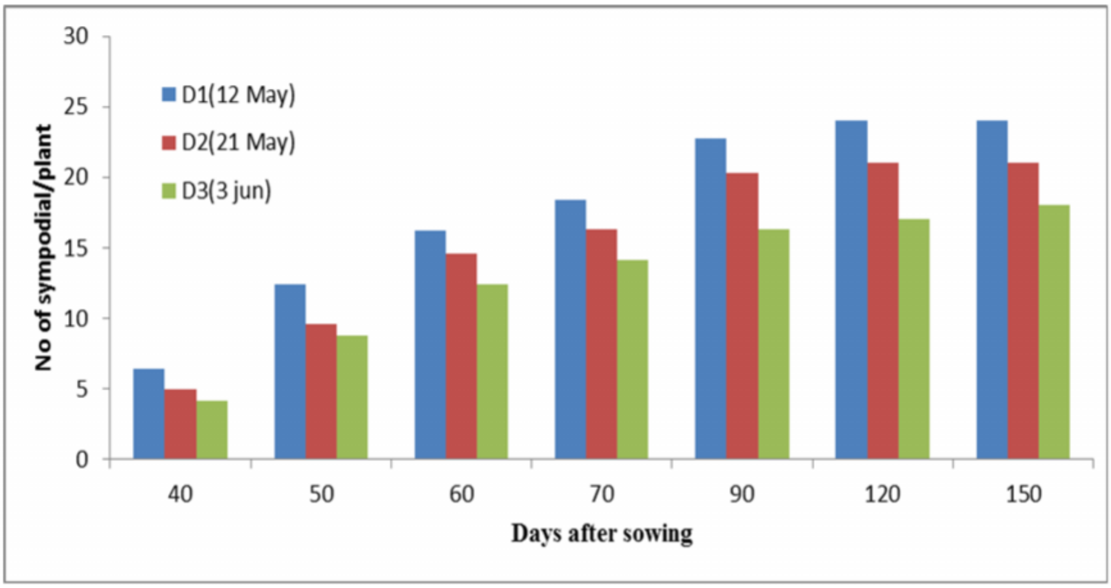
Table 4.6: Dry matter (g/plant) of cotton cultivars at various growth intervals under different growing environments

	DAS (Days After Sowing)					
Growing environments	**30**	**60**	**90**	**120**	**150**	**Maturity**
2nd week of May	9.8	35.1	128.0	247.1	297.6	326.1
3rd week of May	9.1	30.7	117.4	227.2	279.4	293.4
1st week of June	7.5	27.1	105.7	208.2	257.1	257.1
CD at 5%	1.2	2.2	4.1	12.5	16.1	9.8
Varieties						
Pancham 541	7.7	23.0	107.7	210.9	262.6	277.1
SP 7121	8.5	25.8	110.3	221.0	270.9	285.1
RCH 791	10.2	44.1	133.1	250.5	300.6	314.3
CD at 5%	1.2	2.2	4.1	12.5	16.1	9.8

4.2.4 Number of sympodial/plant

The number of sympodial branches per plant production by all the three cotton cultivars under various growing environments is given in figure 4.5.

Number of sympodial/plant increased from 40 to 90 DAS and there after no more production of sympodial branches per plant in all the cultivars and growing environments. Number of sympodial/plant was recoded maximum in cotton crop sown on 2nd week of May (24) followed by 3rd week of May (21) and 1st week of June (18). The cultivar RCH 791 produced maximum (23) and Pancham 541 produced minimum (19) number of sympodial /plant.



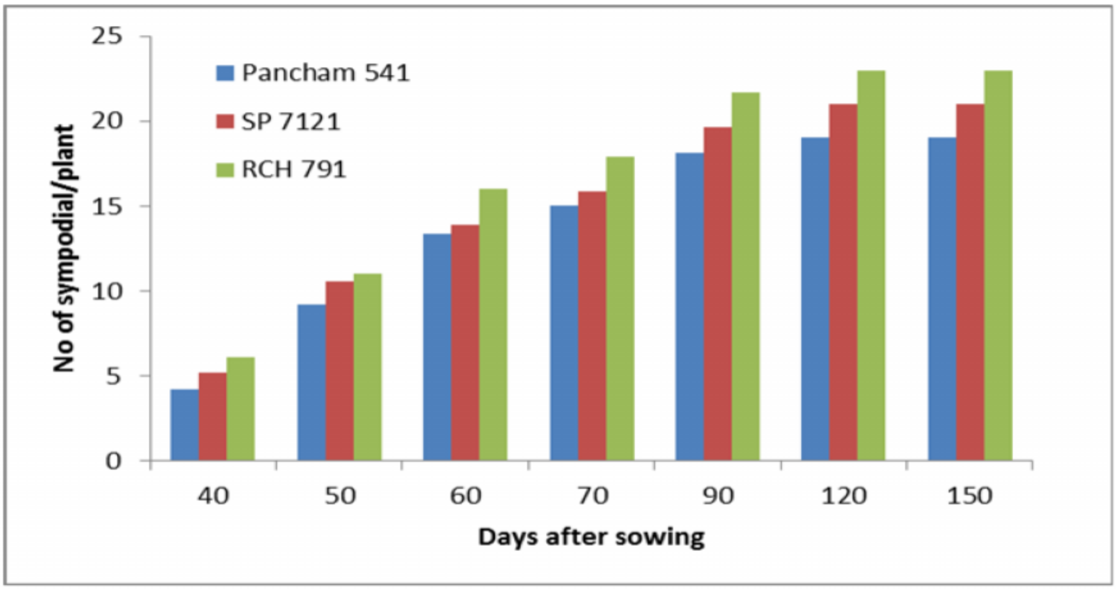


Figure 4.5: Number of sympodial/plant of cotton cultivars at various growth intervals under different growing environments

4.2.5 Yield and its attributes

Yield and yield attributes of cotton cultivars under different growing environments were recorded in terms of number of bolls per plant, bolls weight per plant, seed cotton yield per plant, cotton lint yield per plant and cotton seed per plant which are presented in following subheads:

4.2.5.1 Bolls weight per plant

Data pertaining to boll weight per plant (Table 4.7) indicates that the maximum bolls weight per plant (64.6g) were recorded in crop sown on 2nd week of May and the minimum bolls weight per plant was observed in crop sown on 1st week of June. In case of cotton cultivars the maximum bolls weight per plant (66.3g) was found in RCH 791 followed by SP 7121 and Pancham 541 (48.1 and 41.1g), respectively.

4.2.5.2 Number of bolls per plant

The highest number of bolls per plant (18) were observed in 2nd week of May sown crop and the lowest (11) were recorded in 1st week of June sown crop. In case of cultivars the number of bolls per plant was higher in RCH 791 (19) as compared to SP 7121 (14) and Pancham 541 (12).

4.2.5.3 Seed cotton yield

From the results (Table 4.7) it is revealed that the highest seed cotton yield was obtained in 2nd week of May sown crop. Seed cotton yield was obtained maximum (35.9 g/plant) in 2nd week of May sown crop and minimum (20.5 g/plant) in 1st week of June sown crop. Among the various cultivars, RCH 791 produced maximum seed cotton yield (36.8 /plant) and minimum seed cotton yield (22.8 g/plant) was found in cultivar Pancham 541.

4.2.5.4 Cotton lint

Highest cotton lint was obtained (11.6 g/plant) in 2nd week of May sown crop and lowest (7.1 g/plant) in 1st week of June sown crop. Among the various cultivars, RCH 791 recorded maximum cotton lint (12.3 g/plant) and minimum cotton lint (7.6 g/plant) was observed in cultivar Pancham 541.

4.2.5.5 Cotton seed

Data pertaining (Table 4.7) to cotton seed (g/plant) indicates that maximum cotton seed (24.3 g/plant) was recorded in crop was sown on 2nd week of May and minimum cotton seed (13.4 g/plant) was observed in crop was sown on 1st week of June . In case of cotton cultivars the maximum cotton seed (24.6 g/plant) was found in RCH 791 followed by SP 7121 (17.8 g/plant) and Pancham 541 (15.2 g/plant).

4.2.5.6 Protein content

Maximum protein was observed (18.8%) in 3rd week of May sown crop and lowest (16.5%) in 1st week of June sown crop. Among the various cultivars, Pancham 541 recorded maximum protein content (18%) and minimum protein content (17.2%) was observed in cultivar SP 7121.

4.2.5.7 Oil content

Maximum oil content was observed (19.8%) in 2nd week of May sown crop and lowest (15.9%) in 1st week of June sown crop. Among the various cultivars, RCH 791 recorded maximum oil content (19.7%) and minimum oil content (16.1%) was observed in cultivar Pancham 541.

Table 4.7: Effect of growing environments on bolls/plant, bolls weight/plant, seed cotton, cotton lint, cotton seed, oil and protein content of cotton cultivars

Growing environments	Seed cotton (g)	Lint (g)	Cotton seed (g)	Oil (%)	Protein (%)	Bolls/ plant	Bolls weight /plant
2nd week of May	35.9	11.6	24.3	19.8	17.7	18.0	64.6
3rd week of May	30.0	10.2	19.8	17.9	18.8	16.0	54.0
1st week of June	20.5	7.1	13.4	15.9	16.5	11.0	36.8
CD at 5%	2.6	0.9	1.7	1.0	1.0	1.4	3.1
Varieties							
Pancham 541	22.8	7.6	15.2	16.1	18.0	12.0	41.1
SP 7121	26.7	8.9	17.8	17.9	17.2	14.0	48.1
RCH 791	36.8	12.3	24.6	19.7	17.8	19.0	66.3
CD at 5%	2.6	0.9	1.7	1.0	NA	1.4	3.1

4.3 Crop weather relationships

The correlation and regression analysis were carried out to quantify the relationship of crop parameters with weather parameters: maximum temperature (T_{max}), minimum temperature (T_{min}), morning relative humidity (RH_m), evening relative humidity (RH_e), sunshine hour (SSH), wind speed (WS) and rainfall.

4.3.1 Dry matter and energy indices:

Relationship of energy indices with dry matter production was quantified and depicted in figures 4.6 and 4.7 by pooling the data for growing environments and cultivars.

Dry matter production was directly and linearly related with intercepted photosynthetically radiation by the crop (figure 4.6).The slope value of the regression line shows that growing environment of cotton sown on 2nd week of May was highly efficient in utilizing PAR for dry matter production. Around 99 percent variability in dry matter was explained by intercepted PAR in all growing environments. RCH 791 was more efficient in PAR utilization as compared to other two cultivars as reflected by slope value of linear relationships.

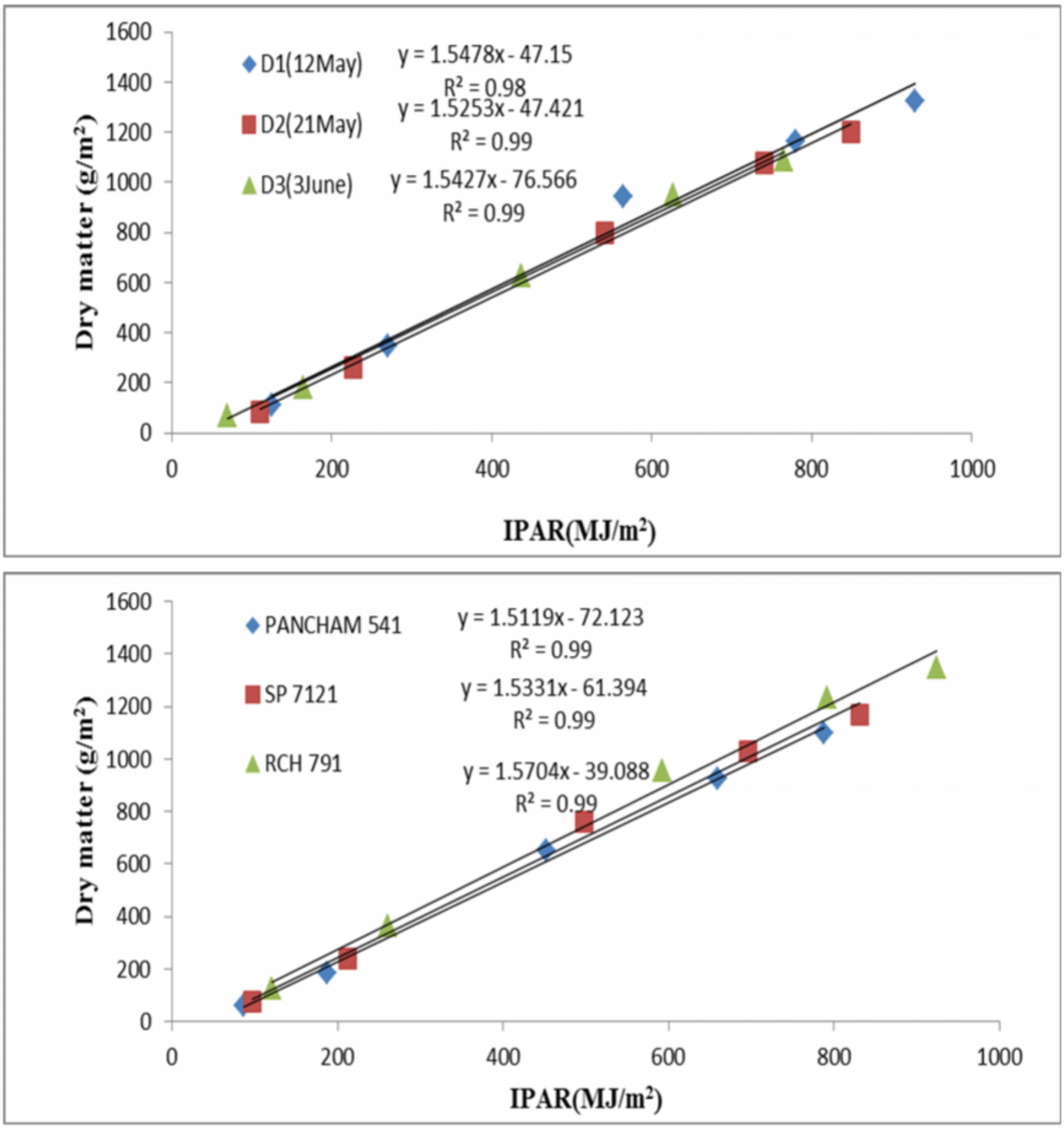


Figure 4.6: Relationship of dry matter production with intercepted photosynthetically active radiation under different growing environments

The accumulated heat units showed direct linear relationship with dry matter production in all the cultivars and growing environments. Thermal efficiency of cotton crop sown on 2nd week of May for dry matter production was maximum, followed by 3rd week of May and 1st week of June (figure 4.7). The thermal use efficiency of RCH 791 was maximum and was minimum of Pancham 541 as indicated by slope values of linear relationships. Nearly 93 percent variability in dry matter production was explained by heat units, irrespective of cultivars and growing environments.

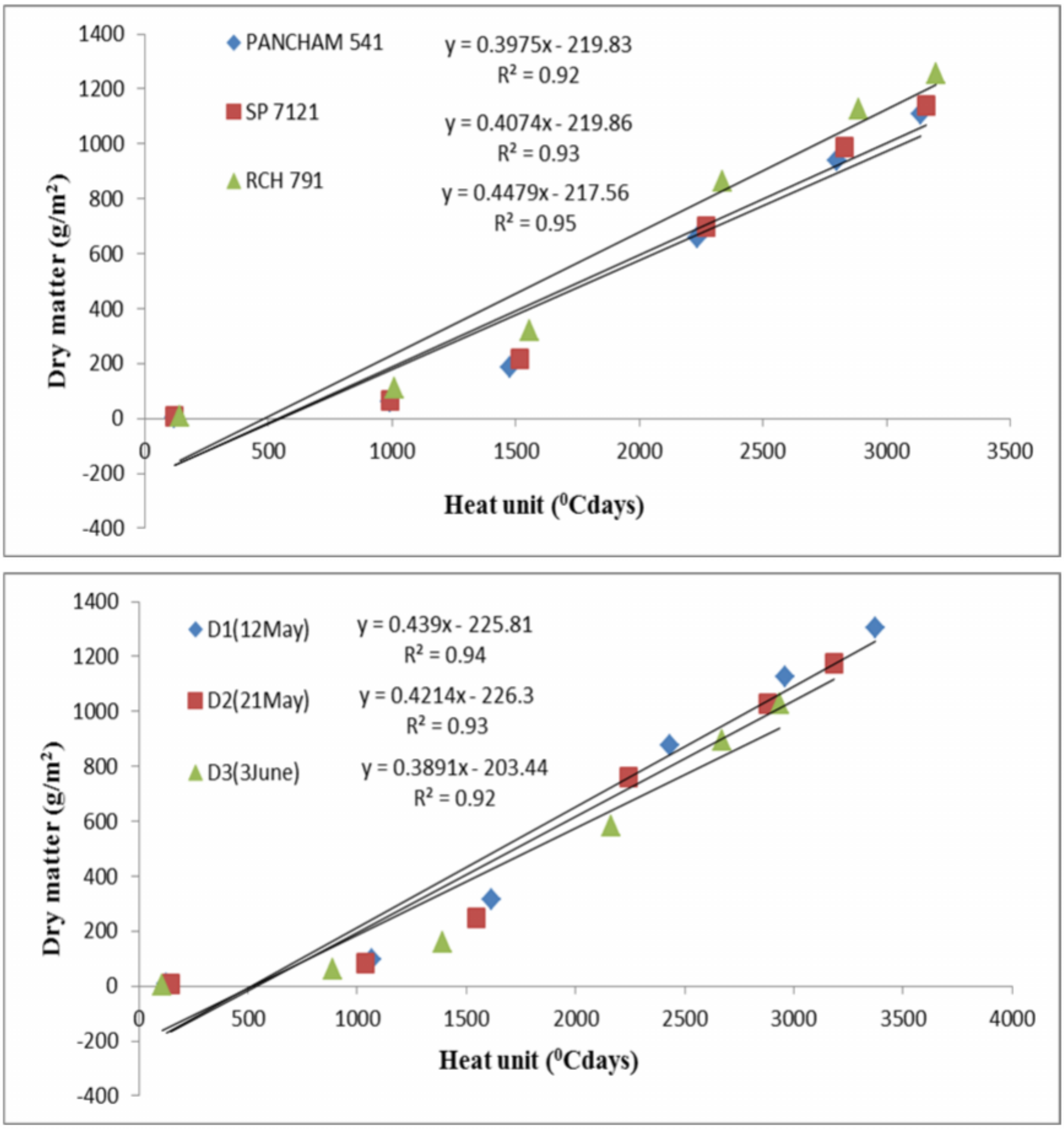


Figure 4.7: Relationship of dry matter production with heat units under different growing environments

4.3.2 Cotton yield and energy indices:

Relationship of energy indices with Seed cotton, lint and cotton seed was quantified and depicted in figures 4.8 by pooling the data for growing environments and cultivars.

A linear direct relationship was found between IPAR and seed cotton explaining the variability up to 84 percent . A similar relationship was found between IPAR and lint yield explaining the variability up to 79 per cent as depicted in Figure (4.8). Also cotton seed yield showed linear and direct relationship with IPAR which explained the variability up to 85 per cent.

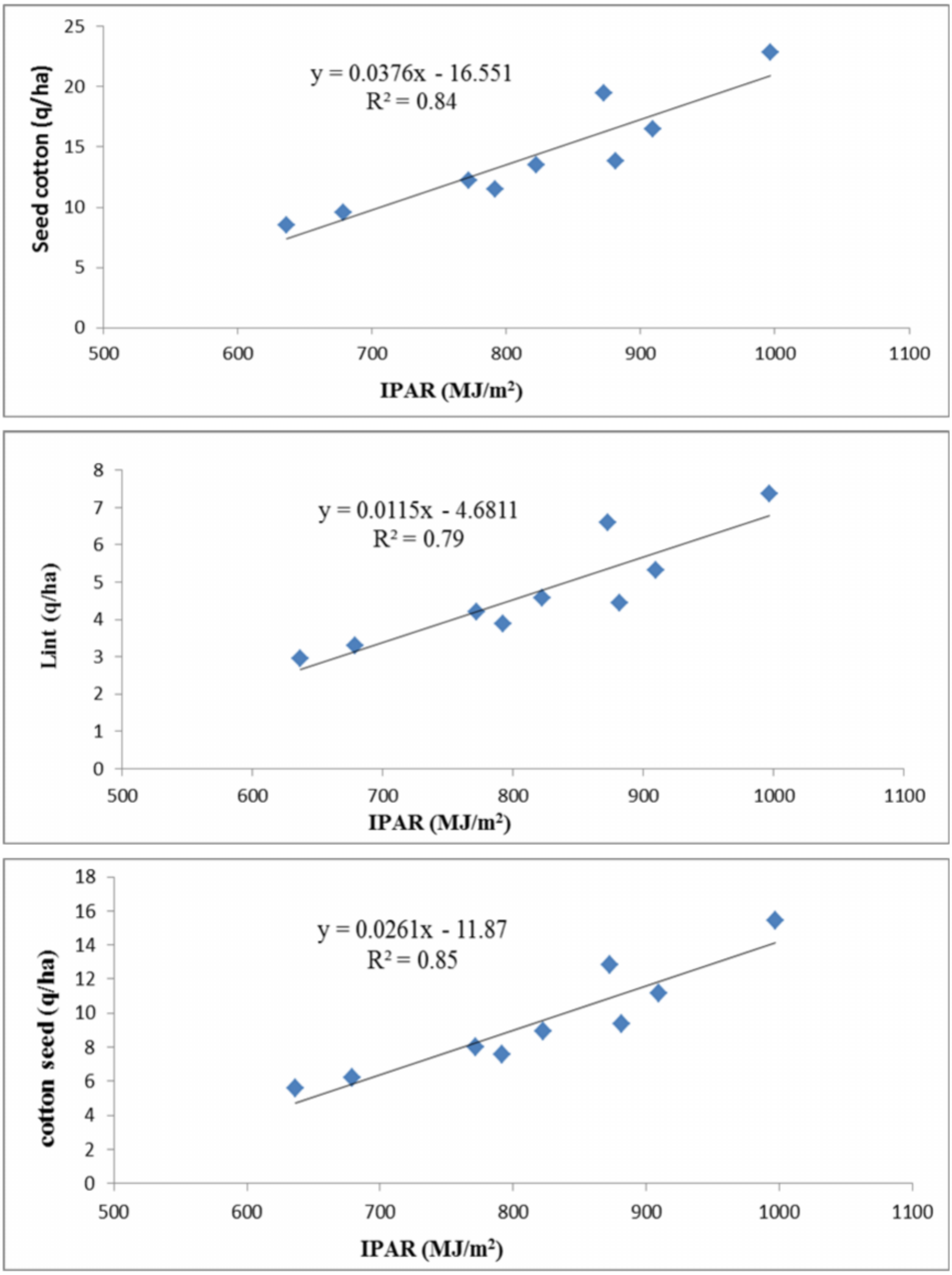


Figure 4.8: Relationship of Seed cotton, lint, cotton seed with energy indices under different growing environments

4.3.3 Correlation

The correlation coefficients of weather parameters with pooled crop parameters during various phenophases for different cultivars and growing environments and are presented in table 4.8.

Maximum and minimum temperatures during vegetative phase had positive correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant, whereas minimum temperature during reproductive phase showed negative correlation with the above said crop parameters (Table 4.8). This reflects to differential crop response to minimum temperature at different growth stages.

Sunshine hours during reproductive phase had positive correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant with correlation coefficient values of 0.62, 0.71, 0.62, 0.63, 0.58, 0.47, 0.27, 0.62 and 0.62, respectively, whereas sunshine hours during vegetative phase showed negative correlation with the above said crop parameters. Sunshine hours was significant with max. LAI during reproductive phase as compared to other crop parameters.

Relative humidity at morning and evening hours had negative correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during reproductive phase but positively correlation during vegetative phase (table 4.8). Relative humidity significantly correlated with max. LAI and cotton seed during reproductive phase.

Wind speed and rainfall had positive correlation with all crop parameters during vegetative phase but negative correlation with all crop parameters. While wind speed had positive correlation with protein during reproductive phase.

4.4: DSSAT model

Validation of model was performed by different data sets on seed cotton yield, leaf area index, biomass, bolls weight per plant and phenological dates.

4.4.1 Genetic coefficients

Genetic coefficients were evaluated and presented in table 4.9. The core coefficients such as maximum threshing percentage was calculated and observed in RCH 791(91%) followed by SP 7121(79%) and Pancham 541(74%).

The value of CSDL, PP-SEN, LFMAX and WTPSD used as default. The value of EM-FL, FL-SH, SD-PM, FL-LF, SLAVR, SIZLF, XFRT, SDPRO and SDLIP was computed and they are maximum in cotton cultivar RCH 791 followed by SP 7121 and Pancham 541. SFDUR, SDPDV and PO-DUR were computed and found equal in SP 7121 and Pancham 541 and maximum in RCH 791.

Table 4.8: Correlation of weather with crop parameters at different phenophases

Vegetative phase									
Weather parameters	**Dry Matter**	**Max. LAI**	**Seed Cotton**	**Lint**	**Cotton Seed**	**Oil**	**Protein**	**Boll**	**Boll Wt./Plant**
Tmax.	0.48	0.56	0.48	0.53	0.46	0.31	0.59	0.48	0.48
Tmin.	0.57	0.64	0.57	0.53	0.59	0.46	0.37	0.57	0.57
RHm	0.35	0.38	0.35	0.28	0.38	0.29	0.04	0.35	0.35
RHe	0.50	0.55	0.50	0.45	0.53	0.42	0.25	0.50	0.50
Sunshine hours	-0.41	-0.50	-0.41	-0.36	-0.43	-0.22	-0.17	-0.41	-0.41
Wind speed	0.52	0.53	0.52	0.46	0.54	0.49	0.19	0.52	0.52
Rainfall	0.50	0.61	0.50	0.45	0.52	0.46	0.10	0.50	0.50

Reproductive phase									
Weather parameters	**Dry Matter**	**Max. LAI**	**Seed Cotton**	**Lint**	**Cotton Seed**	**Oil**	**Protein**	**Boll**	**Boll Wt./Plant**
T max.	0.63	0.71	0.63	0.59	0.65	0.56	0.28	0.63	0.63
T min.	-0.67	-0.70	-0.67	-0.62	-0.69	-0.58	-0.31	-0.67	-0.67
RHm	-0.65	-0.73	-0.65	-0.62	-0.67	-0.56	-0.32	-0.65	-0.65
Rhe	-0.65	-0.71	-0.65	-0.61	-0.67	-0.57	-0.29	-0.65	-0.65
Sunshine hours	0.62	0.71	0.62	0.58	0.63	0.47	0.27	0.62	0.62
Wind speed	-0.35	-0.27	-0.35	-0.28	-0.38	-0.41	0.04	-0.35	-0.35
Rainfall	-0.50	-0.61	-0.50	-0.45	-0.52	-0.46	-0.10	-0.50	-0.50

“r” value at 5% level of significance = 0.67

Table 4.9: Genetic coefficient of cotton cultivar evaluated under different growing environments

VARITIES	CSDL	PP-SEN	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LF MAX	SLAVR	SIZLF
SP 7121	23	0.01	42	13	18	55	70	1.3	390	390
PANCHAM 541	23	0.01	40	11	16	54	68	1.3	380	380
RCH 791	23	0.01	46	14	19	56	75	1.3	420	410

VARITIES	XFRT	WTPSD	SFDUR	SDPDV	PO- DUR	THRSH	SD PRO	SDLIP
SP 7121	0.75	0.18	35	27	10	79	0.141	0.12
PANCHAM 541	0.65	0.18	35	27	10	74	0.153	0.10
RCH 791	0.91	0.18	40	30	12	91	0.145	0.13

4.6.2 Validation

4.6.2.1 Phenology

Test criteria of cotton phenology simulated by DSSAT model during 2015-16 are presented in Table 4.10

4.6.2.1.1 Days to flowering

The observed mean values of days to flowering for three cotton cv. Pancham 541, SP 7121 and RCH 791 were 70, 72 and 74, whereas the model simulated 70, 72 and 72 days, respectively (table 4.10). The percent error was observed lower for cv. SP 7121 (0.0) followed by Pancham 541 (0.0) and RCH 791 (-3.3). Similarly, the percent error was observed lower for 3rd week of May (D2) followed by 1st week of June (D3) and 2nd week of May (D1). This clearly showed that model performance was found good for all the three cotton cultivars and for all the growing environments for simulation of days to flowering as percent error was < ± 5.

Table.4.10: Test criteria of cotton phenology using DSSAT model during 2015-16

Days to Flowering			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	73	72	-1.4
D2(21MAY)	73	72	-0.9
D3(3JUNE)	70	69	-1.0
Pancham 541	70	70	0.0
SP 7121	72	72	0.0
RCH 791	74	72	-3.3
Days to physiological maturity			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	139	139	0.0
D2(21MAY)	139	140	0.2
D3(3JUNE)	137	138	0.7
Pancham 541	136	137	0.2
SP 7121	138	139	0.2
RCH 791	141	142	0.5

4.6.2.1.2 Days to maturity

Pancham 541, SP 7121 and RCH 791 matured in 136, 138 and 141 days, while model simulated 137, 139 and 142 days, respectively as sown in table 4.10. SP 7121 performed better and the model overestimated the days to maturity. The percent error was over estimated by the model or error was negligible. The simulation performance of the model in respect of days taken to maturity was found best as error was < 1.0%.

4.6.2.2 Growth and yield parameters

Test criteria of growth and yield of cotton varieties using DSSAT model during 2015-16 are presented in table 4.11.

4.6.2.2.1 Maximum LAI

LAI of Pancham 541, SP 7121 and RCH 791 was 2.9, 3.1 and 3.5, while model simulated LAI was 3.1, 3.4 and 3.6, respectively. The percent error was ranged between -9.6 and 19.4%.The performance of model was not in acceptable range in 3rd date of sowing (D3). The evaluation of the model on an overall basis revealed that the simulation performance of the model in respect of LAI was found good with an accepted level (±10.0%) for 1st and 2nd date of sowing and all the three cultivars.

Table.4.11: Test criteria of maximum LAI and bolls wt./plant using DSSAT model during 2015-16

Maximum LAI			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	3.5	3.6	4.5
D2(21MAY)	2.7	2.5	-9.6
D3(3JUNE)	3.3	4.0	19.4
Pancham 541	2.9	3.1	6.8
SP 7121	3.1	3.4	7.7
RCH 791	3.5	3.6	2.7
Bolls Weight / Plant			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	27.7	25.9	-6.7
D2(21MAY)	19.7	18.1	-7.7
D3(3JUNE)	10.8	9.6	-11.8
Pancham 541	17.7	16.2	-8.3
SP 7121	19.3	18.0	-7.0
RCH 791	21.2	19.4	-8.7

4.6.2.2.2 Bolls weight/plant

Bolls weight/plant obtained for cv Pancham 541, SP 7121 and RCH 791 were 17.7, 19.3 and 21.2 g, while model simulated 16.2, 18.0 and 19.4 g, respectively as shown in table 4.11. The average percent error was found 8.3(Pancham 541), 7.0 (SP 7121) and 8.7 (RCH 791). The model underestimated bolls weight/plant in all the three growing environments and in all the three cotton cultivars. The overall performance of simulation was found good within accepted level (±10%) for cotton.

4.6.2.2.3 Biomass

DSSAT model was evaluated for biomass (q/ha) and seed cotton yield (q/ha) of cotton under different growing environments and presented in table 4.12.

The biomass yield of RCH 791and SP 7121 was underestimated and of Pancham 541 overestimated by the model. The average percent error for biomass yield was found 8.5(RCH 791), 0.5 (SP 7121) and 7.4 % (Pancham 541). The average percent error was 4.1(D1), 4.0(D2) and 17.4(D3). The biomass yield simulation was found good (±10.0%) for cotton for all varities and 1st and 2nd date of sowing, except 3rd date of sowing.

Table 4.12: Test criteria of Biomass and Seed cotton yield using DSSAT model during 2015-16

Biomass (q/ha)			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	36.3	37.8	4.1
D2(21MAY)	28.1	29.2	4.0
D3(3JUNE)	20.9	17.3	-17.4
Pancham 541	24.9	26.8	7.4
SP 7121	28.6	28.4	-0.5
RCH 791	31.8	29.1	-8.5
Seed cotton yield (q/ha)			
	Observed	**Simulated**	**Error(%)**
D1(12MAY)	17.7	19.3	9.0
D2(21MAY)	14.8	14.2	-4.0
D3(3JUNE)	10.1	8.3	-17.6
Pancham 541	11.3	11.5	2.5
SP 7121	13.2	13.6	3.2
RCH 791	18.2	16.7	-8.2

4.6.2.2.4 Seed cotton yield

The seed cotton yield observed in field experiment for cv. Pancham 541, SP 7121 and RCH 791 were 18.2, 13.2 and 11.3 q/ha while model simulated yield was 16.7, 13.6 and 11.5 q/ha, respectively. The average percent error was within acceptable error limit in all the treatment except 1st week of June (D3) which was not within acceptable limit of the model. This shows that the evaluation of the model on an overall basis revealed that the simulated yield was good with an accepted level of percent error for cotton except 1st week of June (D3) sown crop.

CHAPTER–V

DISCUSSION

The results of study conducted on "Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments" presented in previous chapter are discussed with available suitable literature.

5.1 Agrometeorological indices

5.1.1 Optical characteristics (Indices)

More absorption (%) and less transmission (%) were recorded in 2nd week of May (D1) sown crop as compared to 3rd week of May (D2) and 1st week of June (D3) crop which might be due to maximum leaf area index was produced by 2nd week of May sown crop. Cultivar RCH 791 absorbed maximum PAR followed by SP 7121 and Pancham 541. This might be also due to maximum value of leaf area index was observed in RCH 791.

On the contrary, transmission (%) was found to be higher in 1st week of June (D3) sown crop as compared to 3rd week of May and 2nd week of May. This was due to lower leaf area index was recorded in late sown crop in comparison with early sown crop. Monga *et al.* (2009) also reported the same radiation pattern in tomato crop under different sowing environments.

5.1.2 Energy indices

Thermal indices accumulated (HU, HTU, PTU) at different phenophases were higher in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June sown crops. This might be due to more days taken by 2nd week of May sown crop to attain the different developmental phenophases as compared to other growing environments. Singh *et al.* (2007) found that heat unit requirements of different genotypes of cotton increased with advancement of crop growth *i.e.* from germination to maturity. Kaur and Hundal (2006) also reported that the heat units accumulated were higher in early sown *Brassica sp.* as compared to middle and late sown crop.

In case of cultivars, RCH 791 consumed maximum heat unit as compared to SP 7121 and Pancham 541. This might be due the fact that it matured in more days as compared to other cultivars. Dhaliwal *et al.* (2005) observed that accumulated degree days during crop season of mustard were 287, 329 and 839 ºC day for first aphid population, maximum aphid population and the last aphid population, respectively. Sompal *et al.* (2008) found that heat unit requirements of different genotypes of cotton increased with advancement of crop growth *i.e.* from germination to maturity.

Intercepted photosynthetically radiation (IPAR) was higher in first growing environment as compared to other growing environments. This might be due to higher leaf area index recorded in first growing environment than that of others. IPAR was highest in RCH 791 because of maximum LAI produced by this cultivar. Brodick *et al.* (2013) reported increase in light interception with increase in leaf area index and both were higher in ultra-narrow row crops.

5.2 Energy efficiency

5.2.1 Radiation use efficiency

Cotton crop sown on 2nd week of May was most efficient in PAR utilization in comparison with crop sown on 3rd week of May and 1st week of June. RCH 791 showed higher RUE followed by SP 7121 and Pancham 541 at all stages. The highest RUE in the earlier sown crop and cultivar RCH 791 was due to maximum dry matter production, both of which decreased subsequently due to reduction in LAI with delayed sowing. Similarly highest RUE in the earlier sown crop was due to the maximum PAR absorption and dry matter production but these subsequently decreased with the delayed sowing. Squire *et al*. (1984) and Kinery *et al*. (1989) also reported that RUE varied significantly among dates of sowing. Singh (1999) also obtained similar results. Tripathi (2005) also observed that RUE was highest in early sown crop.

5.2.2 Thermal use efficiency

Highest value TUE was found in first sown crop followed by second and latter sown crop at all phenophases. Among varieties, RCH 791 had highest TUE followed by SP 7121 and Pancham 541.The decrease in TUE with delay in sowing was due to the fact that delayed sowing of cotton crop led to early reproductive phase due to low temperature and shorter days experienced by late sown crop thereby less dry matter was accumulated. Singh (1999) observed similar decline in TUE with delayed sowing and explained that it was due to less biomass production and less number of heat units accumulation in delayed sown crops.

5.3 Crop parameters

5.3.1 Leaf area index

Leaf area index (LAI) observed was maximum in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June sown crop. This might be due to maximum PAR intercepted by 2nd week of May sown crop .Among cultivars RCH 791 produced more leaf area index as compared to SP 7121 and Pancham 541. This was due to more PAR absorption in RCH 791 as compared to other cultivars. Tyagi (1994) found that RH 30 exhibited higher LAI followed by Varuna and Laxmi .The reduction in LAI with delay in sowing was because of less PAR absorption by late sown crop due to reduced vegetative phase as compared to earlier sown crop and also shorter days led to the initiation of reproductive stage quickly and life cycle of the crop became shorter. These findings are in tune with findings of Mendham *et al*.(1981), Nanda *et al*.(1995), Rameshwar *et al.(*2000), Kumari and Rao (2005), Triphati (2005) and Pouresia and Nabipour (2007).

5.3.2 Plant height

2nd week of May sown crop produced taller plants as compared to 3rd week of May and 1st week of June sown crop. This might be due to more PAR interception by 2nd week of May sown crop. Among cultivars SP 7121 attained maximum plant height compared to RCH 791 and Pancham 541. This might be a genetical character of this cultivar. Mehram *et.al*. (2014) also reported that plant heights at Lubbock were significantly different for all N treatments at 66 and 79 DAP only. Plant height at Halfway showed significant N effects only after 66 DAP.

5.3.3 Dry matter

Dry matter accumulation was higher in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June sown crop. This might be because of more LAI and PAR absorption by 2nd week of May sown crop which resulted in higher dry matter. Among cultivars RCH 791 produced higher dry matter as compared to SP 7121 and Pancham 541. The highest biomass in earlier sown crop and cultivar RCH 791 might be also due to maximum LAI and PAR absorption by this cultivar. These results are in unison with those obtained by Tyagi (1994), Tripathi (2005) and Chakravarty *et al*. (2006) in *B. juncea*; Rajput *et al*. (1991), Rameshwar *et al*. (2000) and Robertson *et al*. (2004) in *B. napus.*

5.3.4 Number of sympodial/plant

Number of sympodial/plant was higher in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June sown crop. This might be due to more LAI and PAR interception by 2nd week of May sown crop which resulted in more sympodial branches. Among cultivars, RCH 791 produced higher number of sympodial/plant as compared to SP 7121 and Pancham 541. The highest number of sympodial/plant in earlier sown crop and cultivar RCH 791 might be due to highest PAR absorption by first sown crop and RCH 791. Deho (2014) also reported maximum sympodial branches plant^{-1} (14.2) was in variety Sadori followed by Chandi-95 (14.2) and maximum sympodial branches plant^{-1} (21.3) was in sowing dates 1st June as comparison with other dates. Also in cotton, the maximum (15.1) sympodial branches was observed at 90% boll opening.

5.3.3 Yield and its attributes

The maximum value of yield attributes (number of bolls plant^{-1}, bolls weight /plant, seed cotton, cotton lint and cotton seed) was observed in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June sown crop. Among the cultivars, yield and its attributes were more in RCH 791 as compared to SP 7121 and Pancham 541. It might be due to more LAI, PAR absorption and dry matter in RCH 791. The yield of seed cotton and its attributes were higher in crop sown on 2nd week of May as compared to crop sown on 3rd week of May and 1st week of June in all the treatment combinations which might be because of the better energy conservation efficiency of cotton cultivars in first growing environment and resulted in better crop growth in this environment. Maximum oil content was observed in 2nd week of May sown crop and lowest in 1st week of June sown crop. Among the cultivars, RCH 791 yielded maximum oil followed by SP 7121and Pancham 541. This was a genetic characters or all the growth factors are higher is RCH 791 and 2nd week of May sown crop. Maximum protein was observed in 3rd week of May sown crop and lowest in 1st week of June sown crop. This might be due to 3rd week of May sowing is more favorable for protein accumulation, because of moderate temperature provided by this growing environment. Among the cultivars, Pancham 541 yielded maximum protein content followed by RCH 791 and SP 7121.

Saroya *et al.* (1984) while determining the optimum sowing period of cotton under Sahiwal conditions concluded that sowing done during the month of May produced better yield than the plantings done in the month of June. Qayyum *et al.* (1990), Rajput *et al.* (1993) and Qayyum *et al.* (1996) expressed their views that medium and early sown cotton produced significantly higher seed cotton yield than late sowing under Tandojam climatic conditions.

Kaushik and Kapoor (2007) observed that significant differences with environment were observed for days taken to 50 percent flowering, number of bolls/ plant, seed cotton yield. Patil *et al.* (2009) reported that seed cotton yield was significantly more in early sown crop. Similarly Farooq *et al.* (2011) found that yield and yield attributes were significantly higher in early sown crop as compared to late sown conditions.

Deho *et.al.*(2014) also reported that 1st May sowing produced maximum seed oil content (20.58%) followed by 15th May sown crop (20.25%).

5.4 Crop weather relationship:

5.4.1 Dry matter and energy indices:

Dry matter production was directly and linearly related with intercepted photosynthetically radiation by the crop. The slope value of the regression line shows that growing environment of cotton sown on 2nd week of May was highly efficient in utilizing PAR for dry matter production. RCH 791 was more efficient in PAR utilization. Evangelos *et al.* (2012) studied the radiation use efficiency of cotton in two different environmental conditions and found that, higher productivity was observed due to larger amount of incident and intercepted radiation and decrease in radiation use efficiency with increasing vapour pressure deficit by a slope of -0.47g/MJ/k Pa.

Accumulated heat units showed direct linear relationship with dry matter production in all the cultivars and growing environments. Thermal efficiency of cotton crop sown on 2nd week of May for dry matter production was maximum followed by 3rd week of May and 1st week of June. The maximum thermal use efficiency was found in RCH 791 and minimum was of Pancham 541 as indicated by slope values of linear relationships. Singh (2007) computed heat units requirement for different cultivars of cotton at different phenophases. He found that photothermal unit requirement (PTU) was increased from germination till physiological maturity. Kiran and Bains (2007) investigated the thermal requirement and heat use efficiency in green gram and found 61-64% of variation in grain yield was due to thermal indices based models and also found varied amount and distribution of rainfall affected grain – HUE considerably, but the effect was slight in biomass –HUE.

5.4.2 Seed cotton, lint, cotton seed and energy indices:

Seed cotton, lint and cotton seed were directly and linearly related with intercepted photosynthetically radiation by the crop. The slope value of the regression line shows seed cotton, lint and cotton seed were highly efficient in utilizing PAR for dry matter production and 84%, 79% and 85% variability in Seed cotton, lint and cotton seed production was explained by IPAR.

5.4.3 Correlation

Weather parameters were better associated with the crop parameters during vegetative phase. Maximum temperature, minimum temperature, relative humidity morning and evening, wind speed and rainfall showed a positive correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during vegetative phase, whereas morning and evening relative humidity showed negative correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during reproductive phase. This might be due to negative effect of higher relative humidity on reproductive traits and caused shedding of reproductive organs. Tripathi (2005) and Pouresia and Nabipour (2007) also observed a negative correlation between air temperature and sunshine hours during seed development phase with leaf area index. Negative correlations between minimum temperatures during reproductive phase and seed yield were due to higher temperatures during reproductive phase. Similar results were also obtained by Sahoo *et al*. (2000), Singh (2005), Pouresia and Nabipour (2007) and Liyong *et al*. (2007). Relative humidity at morning and evening hours at reproductive phase had significantly negative correlations with seed and biological yields, whereas during vegetative phase, it had significantly positive correlation. Similar results were reported by Singh (1999). The negative correlations of temperature and sunshine hours during reproductive phase with oil content were also reported by Sang and Hillard (1985), Walton (1998), Hocking and Stapper (2001), Robertson *et al*. (2002), Omidi *et al*. (2007) and Liyong *et al*. (2007).

5.5 DSSAT model

The genetic coefficients were evaluated and the model was validated in different sowing environment with different cultivars: Pancham 541, SP 7121 and RCH 791. DSSAT model was calibrated by different data sets on phenology, leaf area index, bolls weight/plant, biomass and seed cotton yield for the evaluation of genetic coefficients.

5.5.1 Genetic coefficients

Genetic coefficients were evaluated for DSSAT model. The value of CSDL, PP-SEN, LFMAX and WTPSD used as default. The value of EM-FL, FL-SH, SD-PM, FL-LF, SLAVR, SIZLF, XFRT, SDPRO, SDLIP, SFDUR, SDPDV and PO-DUR was evaluated. Ortiz *et.al,* (2009) reported the values for most of the vegetative and reproductive cultivar coefficients were higher than those from the other commercial cotton cultivars that are part of the DSSAT data- base, suggesting that the cultivar that was grown in this experiment required more days to the beginning of the reproductive phase.

5.5.2 Validation

5.5.2.1 Phenology

These results showed that model performance was found good for all the three cotton cultivars and for all the growing environments for simulation of days to flowering. The simulation performance of the model in respect of days taken to maturity was found within an accepted level of error percent. Ortiz *et.al,* (2009) also showed the difference between observed and simulated values for the flowering and physiological maturity dates over the control treatment was two days. Also, the results of phenological stages of maize simulated by InfoCrop model are supported by Singh *et.al*., (1994), Akula (2003), Soler *et.al*., (2007).

5.4.2.2 Growth and yield parameter

DSSAT model was validated for leaf area index (LAI), bolls weight/plant, biomass and seed cotton yield of cotton measured at different crop growth stages. The simulation performance of the model in respect of LAI was good within an accepted level of error percent. Ortiz *et.al,* (2009) reported that model under predicted maximum LAI for all fumigated treatments. The evaluation of the model on an overall performance of simulation was good. Ortiz *et.al,* (2009) also reported the changes in boll weight accumulation throughout the season and the final boll weight at harvest were fairly well predicted by the CSM-CROPGRO-Cotton model. The biomass and seed cotton yield simulation was found good for all cultivars and 2nd and 3rd week of May sown crop. Ortiz *et.al,* (2009) also reported that calibrated coefficients improved the total biomass and boll weight predictions by 14.3% and 6.1%, respectively, when compared to the original default values. Also, this results are supported by finding of Soler *et al.* (2007) for maize and Singh *et al*. (1994) for groundnut yield and yield attributes simulated by PNUTGROW model.

CHAPTER–VI

SUMMARY AND CONCLUSION

The field experiment on “Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments” was carried out at the Research area of the Department of Agricultural Meteorology, CCS Haryana Agricultural University, Hisar during *the Kharif season* of 2015-16.The main plot treatments consisted of three date of sowing (2nd week of May, 3rd week of May and 1st week of June) and sub plot treatments consisted of three genotypes. The twenty seven combinations were evaluated in random block design with three replications. The findings of the present investigation are summarized as below:

Heat unit, heliothermal and photothermal units were higher in 2nd week of May sown crop as compared to 3rd week of May and 1st week of June at all phenological stages. The PAR interception was highest in 2nd week of May followed by 3rd week of May and 1st week of June. The transmitted PAR was lowest in early sown crops as compared to late sown crops. Transmitted PAR values were highest in Pancham 541, whereas absorbed PAR values were highest in RCH 791.

Among cotton varieties, RCH 791 consumed highest heat units, heliothermal units and photothermal units as compared to SP 7121 and Pancham 541 under different growing environments. The efficiency of PAR utilization for dry matter production was highest in RCH 791 at all phenophases. The efficiency of heat utilization was also more in RCH 791 as compared to SP 7121 and Pancham 541 at all phenophases.

The crop sown on 2nd week of May produced significantly highest leaf area index, plant height and dry matter as compared to 3rd week of May and 1st week of June sown crops at all phenophases. The delay in sowing significantly reduced the number of sympodial branches as compared to early sown crop. RCH 791 variety produced maximum LAI and dry matter. RCH 791 had maximum sympodial branches and bolls weight per plant followed by SP 7121 and Pancham 541. The final dry matter, seed cotton, cotton seed, cotton lint and oil percentage values were found highest in RCH 791. The delay in sowing of cotton crop also reduced the seed cotton yield, cotton seed yield, cotton lint, oil percentage and bolls per plant as compared to early sowing of crop. The seed cotton, cotton seed , cotton lint, oil percentage, bolls weight per plant and bolls per plant were significantly higher in 2nd week of May over 3rd week of May and 1st week of June sown crop.

Correlation analysis was carried out to study the relationships between weather and crop parameters. Among the phenophases, Weather parameters were better associated with the crop parameters during reproductive phase. Maximum temperature, minimum temperature, relative humidity morning and evening, wind speed and rainfall showed a strong positive correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during vegetative phase, whereas morning and evening relative humidity showed negative correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during reproductive phase. Relative humidity at morning and evening hours at reproductive phase had significantly negative correlations with seed and biological yields, whereas during vegetative phase, it had positive correlations.

The slope value of the regression line shows that growing environment of cotton sown on 2nd week of May was highly efficient in utilizing PAR and heat unit for dry matter production and also 99% variability in dry matter production was explained by IPAR and 93% variability was explained by heat unit.

Among yield attributes, Seed cotton, lint and cotton seed were directly and linearly related with IPAR and it explained 84, 79 and 85% variability in seed cotton, lint and cotton seed production, respectively.

The model performance in respect of phenology was found good for all the three cotton cultivars and for all the growing environments. Also the model performance was good for all the cultivars and 2nd and 3rd week of May sown crop for seed cotton yield, biomass and maximum LAI. But the model performance was not good for the crop sown in 1st week of June.

CONCLUSION:

Based on the above result it is concluded that

1. *Bt.* Cotton hybrid RCH 791 intercepted maximum radiation followed by SP 7121 and Pancham 791. Also, 2nd week of May sown crop intercepted maximum radiation and 1st week of June sown crop intercepted minimum radiation.
2. IPAR was linear related with growth and yield of cotton cultivars and RCH 791 was most efficient in radiation utilization for dry biomass production followed by SP 7121 and Pancham 541 at 50% boll formation.
3. Genetic coefficients were evaluated and DSSAT Model was validated for cotton cultivars: Pancham 541, SP 7121 and RCH 791.

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ABSTRACT

Title of thesis	:	**Radiation interception and DSSAT validation in Cotton (*Gossypium hirsutum* L.) under different growing environments**
Name of degree holder	:	**Sagar Kumar**
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Major subject	:	Agricultural Meteorology
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Key words: Yield attributes agrometeorological indices, radiation interception, correlation, DSSAT Model

The study entitled 'Radiation interception and DSSAT validation in cotton (*Gossypium hirsutum* L.) under different growing environments' was conducted at the research area of the Department of Agricultural meteorology, CCS Haryana Agricultural University, Hisar, during the *kharif* season of 2015-16. The main plots treatments consisted of three date of sowing (2nd week of May (D1), 3rd week of May (D2) and 1st week of June (D3) and the sub-plots consisted of three varieties (Pancham 541, SP 7121 and RCH 791). The twenty seven treatment combinations were tested in random block design with three replications.

The 2nd week of May sown crop consumed highest thermal and radiation indices. Radiation and heat use efficiency were also highest in this growing environment as compared to 3rd week of May and 1st week of June sown crops. Among cotton varieties, RCH 791 consumed highest heat units, heliothermal units and photothermal units as compared to SP 7121 and Pancham 541 under different growing environments. All growth parameters, yield and yield attributes were found highest in 2nd week of May sown crop. The efficiency of PAR utilization for dry matter production was highest in RCH 791 at all phenophases. The efficiency of heat utilization was also more in RCH 791 as compared to SP 7121 and Pancham 541 at all phenophases.

Maximum temperature, minimum temperature, relative humidity morning and evening, wind speed and rainfall showed a positive correlation with dry matter, max. LAI, seed cotton, cotton seed, lint, oil, protein, boll/plant and bolls wt. per plant during vegetative phase, whereas morning and evening relative humidity showed negative correlation during reproductive phase. Relative humidity at morning and evening hours at reproductive phase had significantly negative correlations with seed and biological yields, whereas during vegetative phase, it had positive correlation.

The slope value of the regression line shows that growing environment of cotton sown on 2nd week of May was highly efficient in utilizing PAR and accumulation heat units for dry matter production. 99 and 93% variability in dry matter production was explained by IPAR and heat unit, respectively. Among yield parameters, Seed cotton, lint and cotton seed were directly and linearly related with IPAR and IPAR explained 84%, 79% and 85% variability in seed cotton, lint and cotton seed production respectively.

The model performance was good for all the three cotton cultivars and for all the growing environments for simulation of days to flowering and physiological maturity. Also the model performance was good for all the cultivars and 2nd and 3rd week of May sown crops for seed cotton yield, biomass and max. LAI but simulation was not satisfactory in case of cotton sown on 1st week of June.

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