

**MODELING AND FORECASTING YIELD OF  
WHEAT FOR KANGRA DISTRICT OF  
HIMACHAL PRADESH**

**THESIS**

*By*

**KARAN VERMA  
(A-2011-30-016)**

*Submitted to*



**CHAUDHARY SARWAN KUMAR  
HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA  
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*in*

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## **CERTIFICATE – I**

This is to certify that the thesis entitled “**Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Karan Verma** son of **Smt. Bimla Devi & Sh. Shri Chand Verma** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Palampur  
Dated: 24<sup>th</sup> December, 2013

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## CERTIFICATE- II

This is to certify that the thesis entitled “**Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh**” submitted by **Karan Verma (A-2011-30-016)** son of **Sh. Shri Chand Verma** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Agronomy** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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*Place: Palampur*

*(KARAN)*

*Dated: 24<sup>th</sup> December, 2013*

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## LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	₹	Rupees
2	%	Per cent
3	LAI	Leaf area index
4	/	Per
5	cm	Centimetre
6	DAS	Days after sowing
7	et al.	Et alii (and other)
8	Fig.	Figure
9	g	Gram
11	hr	Hour(s)
12	i.e.	Id est (that is)
13	kg	Kilo gram
14	kg ha <sup>-1</sup>	Kilogram per hectare
15	mm	Millimeter
16	°C	Degree Celsius
17	p.	Page
18	q ha <sup>-1</sup>	Quintal per hectare
19	viz.	Namely
20	RMSE	Root Mean Square Error

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**ABSTRACT**

The field experiment on Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh was conducted during *Rabi* 2011-12 and 2012-13. The experiment laid out in Randomized Block Design, comprising of four dates of sowing *viz.* October 20, November 10, November 30 and December 20, and three genotypes *viz.* HPW-249, HPW-155 and HPW-42 in silty clay loam, acidic soil, medium in available nitrogen, phosphorus, organic carbon and high in potassium. The growth and yield attributes *viz.* plant height, number of tiller m<sup>-2</sup>, number of grains tillers<sup>-1</sup> and 1000-grain weight were highest in variety HPW-249 during both the years. Amongst sowing environments, October 20 sown crop gave significantly highest values of growth and yield attributes during both the years. In the present investigation it was concluded that early sown crop averaged over two years took 35, 25 and 24 more days for maturity, heading and vegetative stages, respectively compared to with sowing delayed up to December 20. The decrease in grain yield averaged over two years was 3.4 percent in November 10, 7.9 percent in November 30 and 19.6 percent in December 20 sown crop compared to October 20 sown crop. The variety HPW-249 out yielded all other varieties whereas yields of HPW-155 and HPW-42 was at par with each other. The economic returns and benefit cost ratio were also significantly highest in HPW-249. Likewise, grain yield, net returns and B: C ratio was significantly highest in October 20 sown crop compared to subsequent dates of sowing. The agrometeorological indices indicated more values for October 20 to November 30 sown crops and lowest values in late sown crop. The simulated LAI, dry matter accumulation, grain yield, days to physiology maturity and vegetative stage matched closely with observed values for all sowing environments. The RMSE values for grain yield were 258 kg ha<sup>-1</sup> in 2011-12 and 302 kg ha<sup>-1</sup> in 2012-13. The model performance was somewhere under estimated or overestimated but found within acceptable limits. The predicted yields of wheat using validated statistical regression model indicated 1.5, 15.2 and 3.7 percent deviation at mid season (F2) stage during 2009-10, 2010-11 and 2011-12, respectively and 1.3, 10.9 and 2.0 percent errors during 2009-10, 2010-11 and 2011-12 at pre-harvest stage. The yield was more reliable in pre-harvest (F3) stage of district Kangra.

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# 1. INTRODUCTION

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Food Security has got the prime importance in our country. Advance information on agriculture production well before the actual harvesting can prove to be instrumental in saving foreign exchange. Reliable and timely forecast of crops yield provide important and useful input for proper, foresighted and informed planning. Crop acreage information and yield forecasting are two important components which are crucial for planning and policy making in agricultural sector of the country. Early prediction of crop yield is important for planning and taking various policy decisions. This enables planners and decision makers to predict how much to import in case of shortfall or optionally, to export in case of surplus. Regional level estimation of crop yield is the basis for planning crop production prospectus at national level. Crop simulation models are extensively used to establish the relationship between weather parameters and crop growth yield. They are used to predict crop yield in advance using the relationship. These approaches have been used in recent past for determining the production potential of a location knowing its resources, genotype and the level of available technology. It is helpful in matching agro-technology with the farmers resources, analysing the precise reasons for yield gap, estimating crop yield before the actual harvest, studying short- and long- term consequences of agricultural practices on agricultural environment and to study the consequences of climatic variability and climate change on agriculture.

The forecasting of crop yield at sowing stage would require use of weather data and information on economic factor controlling the farmer's response. Considering these facts Forecasting Agricultural output using Space, Agrometeorological and Land based observations (FASAL) concept was devised which aims at using econometric model to forecast the area and production. Matthews et al. (2002) reported that crop simulation models have been widely used to describe systems and processes at the level of genotypes, the crop, the farming system, the region, and the global environment.

Wheat (*Triticum aestivum* L.) is world's second important cereal crop after rice. India is second largest producer of wheat in the world after China with about 12 percent share in total world wheat production. Area under this crop in India is 28.04 million hectare with a production of 80.53 million tonnes (Anonymous 2009a). In Himachal Pradesh, this crop is presently being cultivated on 0.367 million hectare with a production of 562 thousand tones and productivity of 1531 kg ha<sup>-1</sup> (Anonymous, 2009b). Crop models can provide this information with savings in time and labour. Crop models running in real time can furnish data on irrigation and nitrogen stress studies and monitor the growth, development and yield potential of the crop. Therefore, results obtained from simulation models can provide the data essential for achieving greater accuracy in the field and increased efficiency in the inputs use (Boone et al. 1997).

The possibility of using the wheat InfoCrop simulation models has been explored to understand the cultivar diversity of wheat in the study areas. Reliable and timely forecasts of crop production are required for various policy decisions relating to storage, distribution, pricing, marketing and import- export etc.

Statistical models are playing successful role in producing the yield of crops at rate and natural levels in past one decade. These are statistical models which use crop growth parameter to predict the yield. This statistical approach does not easily lead to an explanation of the cause and effect relationship but it is a very practical approach for the assessment or prediction of yield. The coefficients in such empirical models and the validity of the estimates depend to a large extent on the design of the model, as well as on the representativeness of the input data.

Crop forecast are extremely useful in formulation of policies regarding stock, distribution and supply of agricultural produce to different areas in the country. Crop growth models were successfully used for forecasting yields of various crops at district, agro climatic zone and state level (Agrawal et al 2005).

In general, there is paucity of information on impact of weather parameters on growth and development of different varieties of wheat except a large number of modeling studies where in variable temperatures are used at different phenophases and yields are predicted. In general, the response of weather parameters to different varieties

at different growth stages is different. Keeping this in view, the present investigation entitled "Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh" was planned for execution during *Rabi* season of 2011-12 & 2012-13 at research farm of Department of Agronomy, Forages and Grassland Management, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur with the following objectives:

1. To calibrate and validate the wheat crop growth model for district Kangra of Himachal Pradesh.
2. To develop multiple crop yield forecasts for wheat using simulations and land based observations.

## 2. REVIEW OF LITERATURE

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An attempt has been made in this chapter to review the literature pertaining to growth and yield attributes agro meteorological indices and crop yield forecasting based on weather parameters of different genotypes of wheat under different sowing environments.

The available literature has been discussed under the following headings:

- 2.1 Effect of sowing windows on growth and yield attributes**
- 2.2 Effect of agrometeorological indices under varying sowing environment**
- 2.3 Crop yield forecasting**
  - i) Statistical regression model**
  - ii) Crop growth simulation model**

### **2.1 Effects of sowing windows on growth and yield attributes**

Padhi and Sahoo (1990) studied three wheat varieties *viz.* Sonalika, Sagarika and Utkalika on a series of five dates 1<sup>st</sup>, 15<sup>th</sup> and 30<sup>th</sup> November and 15<sup>th</sup>, 30<sup>th</sup> December and reported that highest grain yields was recorded from the first sowing in November under Madhya Pradesh conditions. Similarly, Singh and Verma (1990) reported that sowing dates significantly influenced the yield attributing characters, grain and straw yield. The crop sown on 4<sup>th</sup> November recorded significantly higher yield attributes and grain yield over crop sown on 4<sup>th</sup> December. Variety Raj 1555 recorded the highest yield than varieties WH 147 and HD 2236. The difference between latter two varieties was not significant.

Randhawa et al. (1992) reported that in Punjab under early sowing conditions, the rate of grain filling was lowest (0.62 mg/grain/day) which progressively increased in timely (16<sup>th</sup> November) and late sowings (12<sup>th</sup> December). The average duration of grain filling in early sowing was 65.3 days which progressively declined to 56 and 38.3 days in timely and late sowing, respectively, In another study by Jain et al. (1992) reported that late sowing of after 20<sup>th</sup> December significantly reduced the grain yield in all the varieties

by an average of 4.2 to 56.6 percent. Under rainfed conditions in Punjab, grain yield of cv. PBW-175 remained unaffected upto 25<sup>th</sup> October sowing of crop (Sandhu et al., 1993). Shiyani et al. (1994) conducted an experiment on two wheat varieties viz., Kalyansona and VW-120 and 3 sowing dates 15<sup>th</sup> or 30<sup>th</sup> October and 14<sup>th</sup> November. Grain yield was higher in VW-120 than Kalyansona sown on the 14<sup>th</sup> November.

In a comparison of 15 wheat cultivars in Nepal under five dates of sowing (20<sup>th</sup>, 30<sup>th</sup> November and 10<sup>th</sup>, 20<sup>th</sup> and 30<sup>th</sup> December), grain yield significantly decreased by delaying sowing after 30<sup>th</sup> November (Sharma and Chaudhary 1996). Whereas, Rajinder et al. (1996) reported that delaying sowing beyond mid November decreased grain yield of wheat under Haryana conditions. Singh and Uttam (1997) while studying the effect of sowing dates on yield attributes and yield of 8 wheat varieties under late sown conditions of central UP reported that grain yield was highest when sown on 5<sup>th</sup> December, although it was not significantly higher than that obtained from the 20<sup>th</sup> December sowing date. Sowing on 20<sup>th</sup> December and 6<sup>th</sup> January reduced grain yield by 13.7 and 34.2 percent, respectively, compared with sowing on 5<sup>th</sup> December cv. UP 115 had higher yield potential under all the sowing dates. However, cv. K 816 yielded higher when sown in December.

Gangwar and Sharma (1998) recorded maximum grain yield under 25<sup>th</sup> November planting which differed significantly from that of 10<sup>th</sup> and 25<sup>th</sup> December. The study conducted by Patel et al. (1999) at Raigarh (Chhattisgarh) revealed that the length of ear, grain/ear, test weight and yield were significantly influenced by sowing time and varieties. Sowing of wheat during the first week of December gave significantly higher yield compared to other sowing dates. (Patel et al. 1999) under Gujarat conditions where warmer climate is experienced reported that sowing of wheat in the first week of December was most suitable thereafter, yield decreased to 46.2-67.3 kg day<sup>-1</sup> with delay in sowing from 5<sup>th</sup> December to 5<sup>th</sup> January. The sowing in the last week of November (25<sup>th</sup> November) was also inferior to sowing in the first week of December. Nainwal and Singh (2000) from Pantnagar conditions reported that grain yield decreased significantly with delay in sowing after 27<sup>th</sup> November and the crop sown on 27<sup>th</sup> November gave 8.6 percent higher grain yield than sown on 27<sup>th</sup> December. Variety Raj 3077 recorded the highest grain yield and was at par with UP 2338 and PBW 226. Sardana and Sharma (2000) observed that in agro climatic conditions of Punjab the delayed sowing after 27<sup>th</sup>

November caused grain yield reduction. 25<sup>th</sup> December sowing took more number of days to heading and maturity, more number of spikes per metre row length and significantly higher grain yield. In another agro climatic conditions similar findings were reported by Verma et al. (2000), where wheat yield decreased linearly with delay in seeding as moderately late sown (1<sup>st</sup> December) wheat gave maximum grain yield (32.53 q ha<sup>-1</sup>) which reduced by 21.6, 42.4 and 66.2 percent when planted late (16<sup>th</sup> December), very late (1<sup>st</sup> January) and extremely late (16<sup>th</sup> January), respectively.

Khan and Haq (2002) reported that plant height wheat was significantly greater in the early planting than late planting. Spike numbers per unit area were greater in early planting than late planting of wheat. Tyagi et al. (2004) in a study conducted at Hisar reported that total dry-matter accumulation and its partitioning into different plant parts *viz.*, stems, leaves, roots, spikes and grain was reduced significantly at both anthesis and physiological maturity under late sowing (24<sup>th</sup> December to 3<sup>rd</sup> January) than normal sowing (20<sup>th</sup> to 25<sup>th</sup> November). However, spike weight at anthesis increased significantly because of faster phenological development. In another study from similar agroclimatic conditions conducted at Hisar by Khichar et al. (2005) revealed that 30 days delay in wheat sowing reduced the crop duration by 21 to 25 days during two crop seasons. Wheat sown on 20<sup>th</sup> November accumulated more growing degree-days than those sown on 20<sup>th</sup> December. Sharma and Kumar (2005) reported that wheat crop sown on 30 November accumulated significantly higher dry matter in different plant parts and yielded higher than late sown (30<sup>th</sup> December) but remained at par with 15<sup>th</sup> December sown crop. Root and leaf dry weight increased up to 135 days after sowing (DAS) and declined thereafter, whereas stem and total dry weight increased up to maturity. At maturity, the variety HPW-89 produced significantly higher total dry weight than HPW-155 but remained at par with HPW-42 and HPW-147. Crop sown on 30<sup>th</sup> November recorded the highest grains spike<sup>-1</sup>, 1000-grain weight, leaf area index (LAI) and produced more grain yield than sowing on other dates. There was no significant difference among the four varieties (HPW-89, HPW-42, HPW-147 and HPW-155) for grain yield during both the years but cultivar HPW-89 had higher grains /spike and 1000-grain weight.

Singh et al. (2013) conducted an experiment to screen out the most suitable variety of wheat under irrigated condition and its date of sowing requirement. The eight varieties of wheat *viz.*, K-9606, PBW-450, HP-1731, K-9107, NW-1012, HUW-468 and HP-17 were tested in two dates of sowing. Results indicated that the normal sowing at November 30 produced significantly higher number of shoots at all stages of wheat ears  $m^{-2}$  and plant height at 30, 60 and 90 (cm) DAS than late sowing on 25<sup>th</sup> December. The variety of PBW-443 was having significantly higher initial plant population and ears  $m^{-2}$  than rest of the wheat varieties. Kumar (2012) conducted field experiment at Palampur with five varieties (HS-490, VL-804, VL-829, VL-892 and VL-907) and four dates of sowing (5<sup>th</sup> November, 20<sup>th</sup> November, 5<sup>th</sup> December and 20<sup>th</sup> December) and revealed that early sown crop gave higher yield compared to subsequent dates of sowing.

## **2.2 Effect of agrometeorological indices under varying sowing environment**

The field experiment conducted under Palampur (Himachal Pradesh) conditions has revealed a gradual increase in the days taken for complete emergence and a reduction in the days taken for 50 percent heading and maturity with each week delay in sowing from 1<sup>st</sup> week of December to 3<sup>rd</sup> week of December Sharma (1993). It was also found that sowing of wheat resulted in significantly higher crop growth rate over December 3<sup>rd</sup> week sowing, whereas reverse trend was observed with respect to relative growth rate. Plants depend for growth and development on their genetic constituents and environmental conditions. Temperature may exhibit differential quantitative effect on growth and yield, over and above its influence on flowering and crop duration. Difference between the daily mean air temperature and a reference base temperature (heat unit) can be related to plant growth development and maturity. Temperature is considered to be one of the dominant factors (Yoshida, 1978). Heat summation indices like HTU, PTU and HUE can help to predict the phenology of crop (Hundal et al.1997).

Bazgeer (2005) worked out a significant relationship between wheat yield and minimum and maximum temperature, cumulative sunshine duration, temperature difference and pan evaporation for Hoshiarpur and Rupnagar districts of Punjab, India. Haiyan et al. (2007) reported that droughts caused by a lack of precipitation are one of the major factors limiting agricultural crop production.

Prabhakar et al. (2007) studied the effect of sowing dates from November to December end and four varieties (DWR-162, DWR-195, DWR-185 and DWR-1013) on phenological development, growth and productivity of wheat under Raichur (Karnataka, India) conditions. Maximum GDD (1989) and PTU (14760) were recorded in DWR-1013 followed by DWR-185, DWR-162 and DWR-195. It was concluded that GDD and PTU could also be used as tools for recommending the optimum sowing period for wheat genotypes. Kumari et al. (2009) reported that the maximum differences of 7.5 °C in temperature were observed at the milking stage between very late (19<sup>th</sup> December) and normal sown (19<sup>th</sup> November) conditions and exhibited maximum heat use efficiency of 2.23 kg grain ha<sup>-1</sup> degree day in timely sown wheat in agro climatic condition of Jharkhand. Solanki (2010) advocated that the normal sowing of wheat crop around 7<sup>th</sup> November to 20<sup>th</sup> November coincided with the mean temperature regimes of 16.8 to 20.0 °C, 14.5 to 18.9 °C and 18.4 to 21.7 °C at tillering to heading, heading to milking and milking to dough stages, respectively. The increase in 6.0 °C mean temperature during 90 to 105 days after sowing caused reduction in number of effective tillers m<sup>-1</sup> row at 105 days after sowing by 15 per cent. The highest grain yield was obtained under 20<sup>th</sup> November sown crop followed by 7<sup>th</sup> November sown crop under the agro-climatic conditions of Udaipur (Rajasthan). Similarly, Khan et al. (2010) revealed from their study that the highest thermal and radiation regimes of 2095° C day for GDD, 15515 °C day ha<sup>-1</sup> for HTU, 31880 °C day h for PTU and 2140 mmol m<sup>-2</sup> for PAR were associated with maximum yield from crop sown on 20<sup>th</sup> November. Grant et al. (2011) reported that climate warming may raise wheat (*Triticum aestivum L.*) yields in cooler climates and lower them in warmer climates.

Ram et al. (2012) revealed that grain yield recorded in October 25 sown crop was statistically at par with November 5 sowing date. The significant reduction in grain yield of timely sown varieties was recorded. However, in medium duration varieties the significant reduction was noticed when sowing was delayed beyond November 25 under Punjab conditions. Singh and Khushu (2012) conducted field experiments under irrigated as well as rainfed conditions and observed that the variety PBW 343 took higher thermal time (1602 degrees C days) as compared to Raj 3765 (1576 degrees C days) and RSP81 (1574 degrees C days) for attaining physiological maturity. Maximum heat use efficiency

(HUE) by variety PBW343 (5.87 kg ha<sup>-1</sup> degrees °C days) was found under irrigated situation as compared to other cultivars. GDD was found best indices for prediction of phenology followed by PTU, HTU.

## **2.3 Crop yield forecasting**

### **I) Statistical regression model**

Bannayan et al. (2003) observed that mechanistic crop growth models have many potential uses for crop management. These models can aid in pre-season and within-season management decisions for cultural practices such as fertilizer and irrigation applications and pest and disease management. Predicted grain yield had a root mean square difference (RMSD) only stochastically generated weather data to substitute measured data could provide a reliable forecast for wheat grain yield starting in June until the remainder of the season for conditions in the UK. Jong et al. (2009) conducted study to forecast regional spring wheat (*Triticum aestivum L.*) yields on the Canadian Prairies and revealed that based on simulated daily water use and soil water contents derived from the National Drought Model. Empirical linear regression models were calibrated from 1976 to 2006 spring wheat yield data for this purpose. Potential predictors assessed were mainly those indicators related to water stress conditions at different crop growth stages. Stepwise regression and cross-validation were employed for the selection of the predictors in multivariate linear regression models used for forecasting spring wheat yields from seeding to harvest. The cross-validated forecasts for 1976-2006, using data up to harvest, explained 7 percent, 64 percent, 63 percent and 70 percent of yield variances, respectively, for Alberta, Saskatchewan, Manitoba and the entire Prairie region. Root mean square error of the "forecasts" ranged from 8 percent to 11 per cent of the average yields. The prediction accuracy earlier in the season was often lower than later in the season. Usable prediction accuracy was found by the middle of the growing season (around heading or anthesis), but only marginally effective at seeding time, especially for Saskatchewan.

Verma et al. (2012) observed that crop yield models are abstract presentation of the interaction of the crop with its environment and can range from simple correlation of yield with a finite number of variables to the complex statistical models with predictive

end. A perusal of the results indicated that the percent deviations of the predicted yields from the real time yields are very low (except oat and rapeseed crops where the residuals are comparatively higher) thus favoring the use of ARIMA models to get short-term crop yield forecast estimates. Ines et al. (2013) conducted a study on improving the prediction of crop yields at an aggregate scale and results suggested that assimilation of LAI independently might be preferable when conditions are extremely wet, while estimation of soil moisture + LAI might be more suitable when conditions are more normal. Devi et al. (2013) conducted study to forecast the yield of winter rice in seven districts of two agro-climatic zones of Assam. The daily weather data viz., maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity and rainfall used from sowing to flowering and the relation between weather parameters and yield was determined using statistical tools like correlation and regression. The results showed that climatic parameters and technological factors influenced the yield of winter rice differently in different districts. The yield fluctuation was due to variations of climatic parameters and adoption of new technologies.

## **II) Crop growth simulation model**

Crop growth models are useful tools to quantify the environmental limits to crop production. Their applications minimize the requirement for costly and lengthy experimentation (Loomis et al.1979).

An agrometeorological yield model for wheat production forecast by using IRS LISSIII data of 1993, historical wheat yields and meteorological parameters such as maximum and minimum temperatures, sunshine hours and rainfall was studied for Kangra district. The predicted yield for *Rabi* 1992-93 exhibited relative deviation of six per cent from department of agriculture (DOA) estimates (Datta et al. 1994). The updated spectral yield models for Punjab by incorporating the latest data set on district wise NDVI and historical yield trends for the past ten years and reported updated model performed better than simple linear model based on NDVI values (Medhavy et al. 1995). Debaeke et al. (1996) developed and tested a simulation model EPICPHASE-Wheat under various water and nitrogen regimes in France. The predictions of the model were satisfactory for water budget, biomass, and yield and nitrogen uptake, with mean relative errors of 8-18 percent.

Dadhwal et al. (2000) observed deviations of yearly-simulated wheat yield during 1980-1994 accounted for 33 percent variation in the observed yield, while segmented technology explained 58% variability in the yield. Forecasting using year wise deviations in simulated yield trends (YDSIM) and the relationship between YDSIM and yield deviations from the segmented linear technology (YDOBS) resulted in yield root mean square errors of 163.3 and 212.2 kg ha<sup>-1</sup>, respectively. Sehgal et al. (2001a) worked on development of a prototype Crop Growth Monitoring System (CGMS) for wheat using WTGROWS simulation model on a 5 $\times$ 5 $\phi$  grid in GIS environment. The model predicted yields were within  $\pm 10$  percent of reported yields in 12 districts. The Root Mean Square Errors (RMSE) of 335.4 kg ha<sup>-1</sup>, which is less than 10 per cent of the State mean yield, was obtained. Only in two districts, Mahendragarh and Bhiwani, the simulated district yields were lower than observed yields while for Kaithal, Karnal, Ambala and Yamunanagar, the simulated yields were higher than observed yields by more than 10 percent.

Further, Sehgal et al. (2001b) concluded the WTGROWS simulated grain yield for the combination of inputs showed yields variation between 1.1 and 4.9 t ha<sup>-1</sup>. Ziaei and Sepaskhah (2003) studied that accurately modeling crop water requirements can improve irrigation management. Forecasting of wheat yield at the time of planting under different irrigation management programmes is possible with a wheat growth simulation model calibrated for the study area. In this study, a model was developed for simulation of wheat growth and yield. The model can provide daily estimate of soil water content, potential and actual evapotranspiration, runoff, deep percolation, leaf area index (LAI), dry matter (DM) and finally grain yield. Soil properties and daily rainfall and pan evaporation are model inputs. The sowing date and soil water content at sowing date should be specified.

Kalubarme et al. (2003) developed wheat growth profile-based yield models for 12 districts of Punjab and 16 districts of Haryana, India, using the normalized difference vegetation index (NDVI) derived from NOAA-11 AVHRR data of the 1993/94 cropping season. The overall correlation of 0.82 for Punjab and Haryana was obtained between reported yield and growth profile derived parameters. Atmospheric normalization improved prediction model statistics (R increased from 0.42 to 0.86). Evaluation of the models indicated that 10 out of 16 districts of Haryana and 9 out of 12 districts of Punjab

showed relative deviations within 10 percent between the reported and model-predicted wheat yields. Sharma et al. (2004) conducted a study in six major districts of Himachal Pradesh (Kangra, Mandi, Bilaspur, Hamirpur, Solan and Una) during the *Rabi* season of 2002-03 to develop agro meteorological models for forecasting wheat yield. Results showed that in majority of the districts where wheat was mostly cultivated as a rainfed crop, rainfall significantly affected wheat yield. District level wheat yield was predicted using the models and the crop performance was evaluated. The models showed that wheat yield decreased by 6.8 to 32.3 percent compared to previous years, mainly due to moisture stress caused by delayed and insufficient rainfall. Temperature difference and growing degree days were negatively correlated with wheat yield. Baby and Shekh (2005a) studied the performance of the simulation model, InfoCrop, in estimating the yield of wheat cv. GW-496, sown on 1<sup>st</sup>, 15<sup>th</sup>, or 30<sup>th</sup> November and validate it using different statistical criteria in an experiment conducted in Anand, Gujarat, India during 2000-02. The model explained 92 percent of the variation in the pooled yield of the crop. In the Anand environment, the model was most applicable with sowing on 5<sup>th</sup> November and irrigation of not less than 5 or 6 times. Baby and Shekh (2005b) reported wheat growth simulator (WTGROWS) and InfoCrop models were calibrated and validated with the generic input data generated from field experiments conducted during the 2000 and 2001 *Rabi* seasons in Andhra Pradesh, India, to determine the sensitivity of the models to elevated CO<sub>2</sub> levels (5, 10 and 15 percent or 387, 406 and 442 ppm, respectively). Elevated levels of CO<sub>2</sub> by 5, 10 and 15 percent increased wheat yield as simulated by the WTGROWS model by 1.91, 3.83 and 5.73 percent, respectively, compared with the base (potential) yield. On the other hand, the corresponding yields under stressed conditions but at the same levels of CO<sub>2</sub> were 2.368 (2577 kg ha<sup>-1</sup>), 4.03 (2640 kg ha<sup>-1</sup>) and 4.83 (2698 kg ha<sup>-1</sup>), respectively. InfoCrop model also exhibited a positive linear trend to elevated CO<sub>2</sub>. The percentage changes from potential yield to 5, 10 and 15 percent of CO<sub>2</sub> increase were 1.24, 2.34 and 3.33, respectively. The corresponding yields under stressed conditions but at the same levels of CO<sub>2</sub> were 2.38, 4.03 and 4.83, respectively. Baby and Shekh (2005c) studied the sensitivity of InfoCrop simulated grain yield (e.g. wheat) under potential and stressed conditions to change in temperature and reported that with incremental unit increase in mean temperature, the simulated yields decreased and *vice versa*. But, the magnitude of change from the respective base yields was more to

temperature under stressed conditions. The InfoCrop model showed linear response to inputs of thermal time for vegetation, potential grain weight, grain number, initial nitrogen and water content at sowing.

Singh et al. (2007) predicted yield of wheat under variable growth conditions of temperate Kashmir using mechanistic crop growth models. Data from fields experiment was used to calibrate and validate CERES-wheat (ver. 4). Model performance was satisfactory with regard to parameters, phenological events (days to anthesis and maturity), grain yield and N-uptake (RMSE of 6.2 days, 6.9 days, 0.17 t fed<sup>-1</sup> and 6.8 kg fed<sup>-1</sup>, respectively). Predicted biomass yield was under estimated. Optimum period for higher wheat yield was predicted from 25<sup>th</sup> to 30<sup>th</sup> September. Shekhar et al. (2008) studied the predictive performance of WOFOST model for wheat was evaluated by comparing the model-generated values with the measured values recorded for 3 consecutive cropping seasons (2004-05, 2005-06 and 2006-07) in Hisar, Haryana, India. Wheat grain and straw yields simulated by the model showed deviations of around 11 and 33 percent, respectively. On average, the model over-estimated the grain yield by 57 kg ha<sup>-1</sup> and under-estimated straw yield by 771 kg ha<sup>-1</sup>. The predicted values of the maximum leaf area index attained by the crop were slightly similar to the measured value (deviation of 4.5 percent).

Chaudhary et al. (2010) conducted a study with a broad objective of developing and demonstrating a methodology for crop growth monitoring and yield forecasting which can provide periodical crop growth assessment with spatial information. The deviations between the estimated state yield and reported yield were more in case of the forcing (0.7-25.4%) as compared to regression approach (0.5-9.2%). Results indicated that regression approach is suitable for in season yield forecasting at state level and forcing approach is better for spatial crop condition assessment and crop growth monitoring. Tianjun and YuPing (2012) studied the SUCROS crop growth model with modification and concluded that the simulating results were reliable with an average relative error of 12.51 percent between measured and estimated yields. Pal et al. (2012) concluded that simulated days taken to 50 percent flowering and physiological maturity were over-predicted while, under-prediction were found in simulated LAI, biological and

grain yield over observed. Less percent deviations in simulated values were obtained with days achieved to 50 percent flowering and physiological maturity with 15<sup>th</sup> December (early) sowing while, in case of LAI, biological and grain yield error in simulated values over observed values were found to be less with 4<sup>th</sup> January (late) sowing. Singh et al. (2012) reported that increase of 1 °C and 2 °C temperature coupled with 50 and 100 per cent elevated level of CO<sub>2</sub> cause reduction in wheat yield under sub temperate condition of Himachal Pradesh. The results indicated that yield of crop was at par when sown in October and November months. Mishra et al. (2013) under middle Gujarat agroclimatic conditions validated WOFOST crop model and reported RMSE for maximum LAI and grain yield to the tune of 0.08 to 0.11 and 70 to 92 kg ha<sup>-1</sup> respectively showing best fit of model.

### 3. MATERIALS AND METHODS

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The field experiments on wheat crop entitled; 'Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh' was conducted during (*Rabi* season of 2011-12 and 2012-13) at research farm of Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur (Himachal Pradesh). The details of the materials used and methods employed in conducting the experiment are as follows:

#### 3.1. Experimental site

Geographically, the experimental site is situated at 32°6' N latitude and 76°3' E longitude at an elevation of about 1290.8 m above mean sea level in North-Western Himalaya.

#### 3.2 Weather conditions

Agro climatically the experimental area falls in sub-temperate and sub-humid zone, characterized by high rainfall with mild summers (19.0-31°C) and severe winters (3.5-13.4°C). The average rainfall of the place is 2500 mm, of which 78 percent is received during June to September. In general, the monsoon sets in during June. Winter rains usually occurs during December to February rendering October, November, April and May as dry months. Weather data recorded at the Meteorological Observatory of department of Agronomy Forages and Grassland Management during the crop season 2011-12 and 2012-13 has been presented in Appendix-I and II.

During crop growing season from October to May in 2011-12, the weekly maximum and minimum temperature ranged between 9.8 to 35.6 °C and 2.4 to 21.6 °C, respectively during the entire crop growing period. The crop experienced well distributed rainfall of 509.2 mm during the crop season. The highest weekly rainfall of 76.2 mm was received during Meteorological week 7. The sunshine duration ranged 6.8 hours day<sup>-1</sup> duration respectively during the season. Similarly during October to May 2012-13, the weekly maximum and minimum temperature ranged between 14.5 to 37.3 °C and 2.3 to 22.6 °C, respectively during ontogeny of crop. The crop experienced well distributed rainfall of 475.5 mm during the crop season. The highest weekly rainfall of 109.2 mm was received during Meteorological week 7. The sunshine duration ranged 6.2 hours day<sup>-1</sup>, respectively during the season.

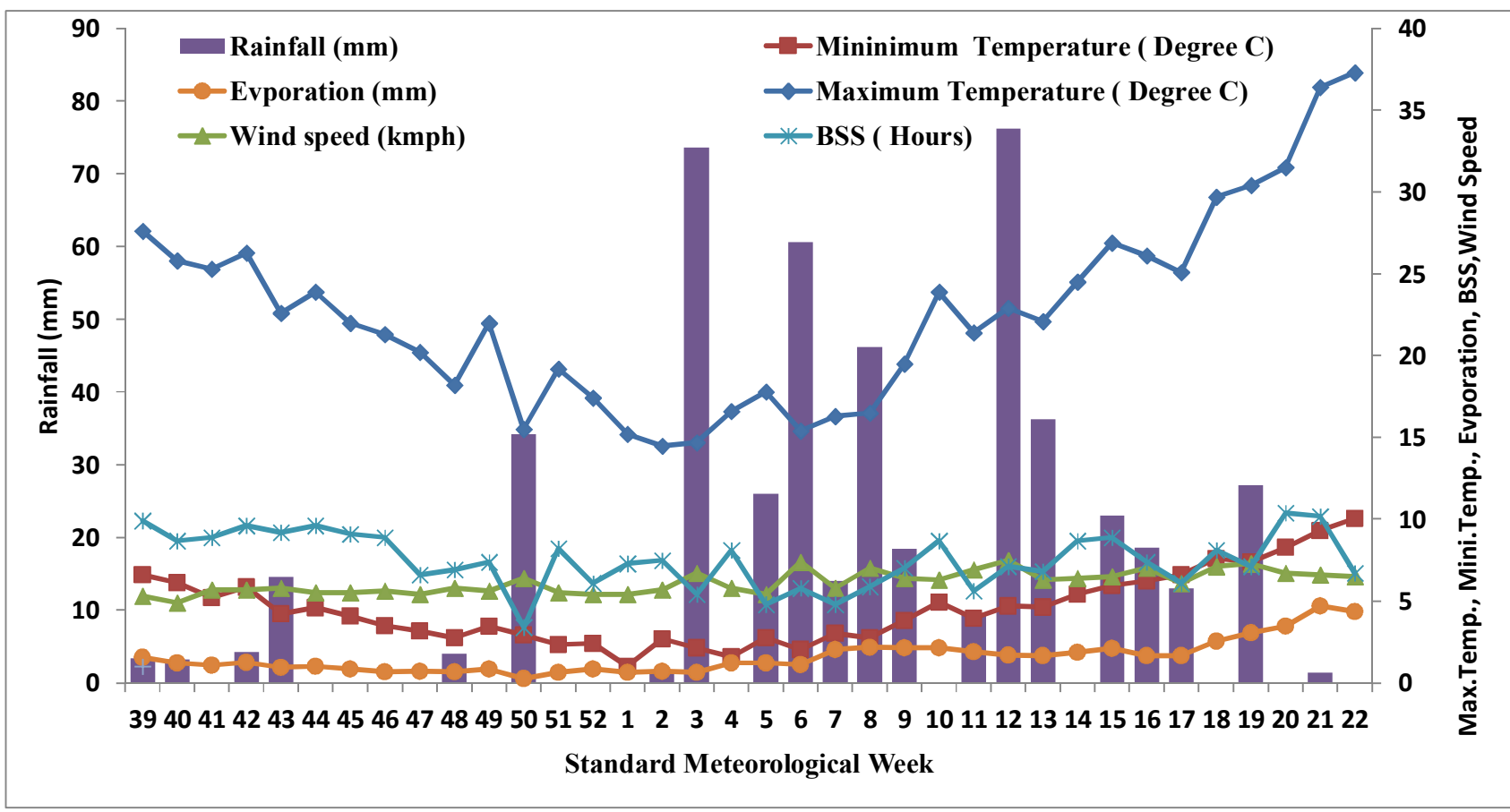


Fig. 3.1 Weather parameters during Rabi 2011-12 recorded at agrometeorological observatory, CSK HPKV, Palampur (Himachal Pradesh)

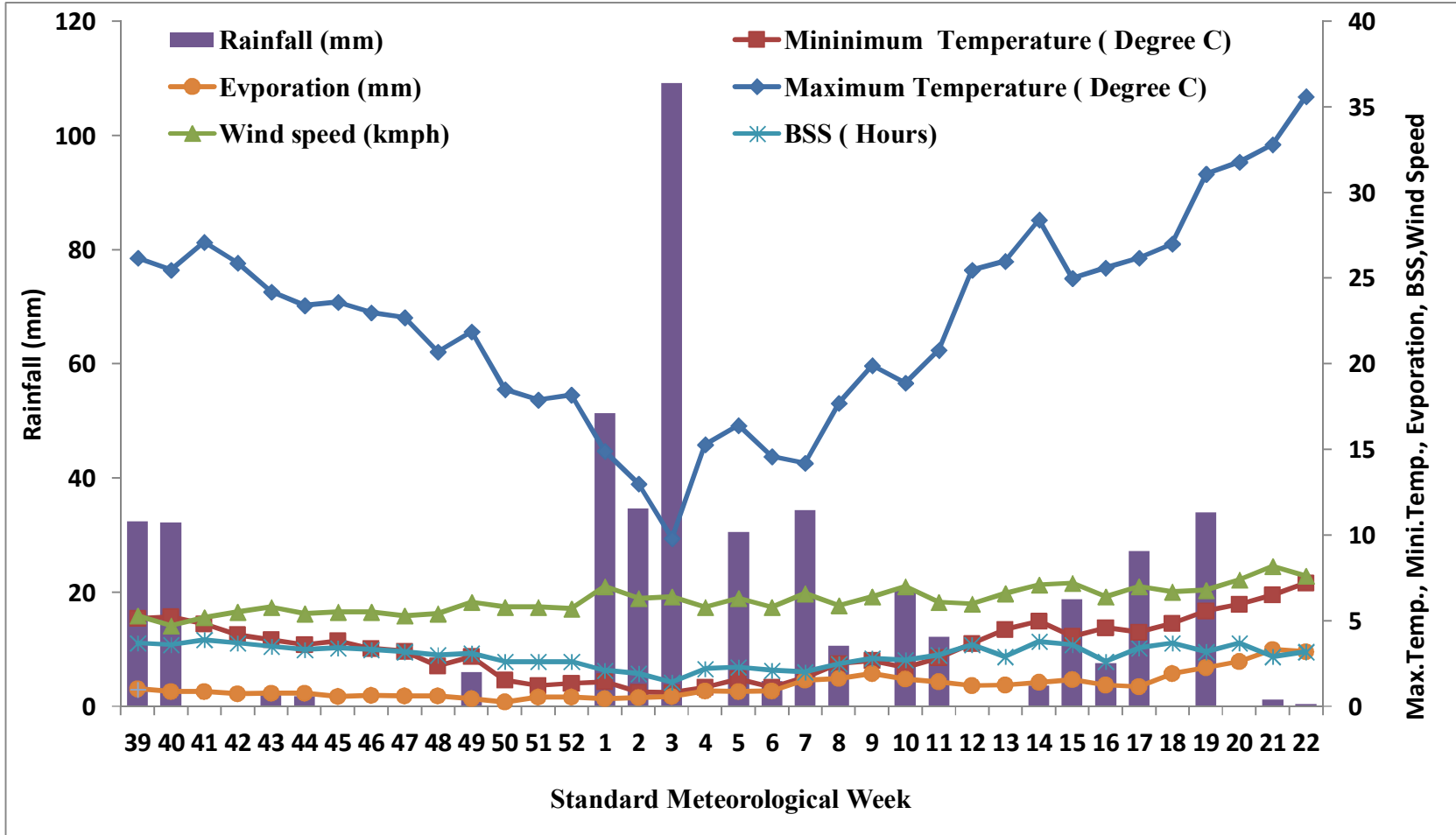


Fig. 3.2 Weather parameters during *Rabi* 2012 to 13 recorded agrometeorological observatory, CSK HPKV, Palampur (Himachal Pradesh)

### 3.3 Cropping history

The experimental site was under maize-wheat cropping system for a year before the sowing of wheat in first year (October 2011-12) and before the second year of field experiment (October 2012-13), the field was under maize crop.

### 3.4 Experimental details

The field experiments were conducted during the *Rabi* season of 2011-12 and 2012-13 in randomized block design (RBD) with the combination of four dates of sowing and three varieties, replicated three times. The details of treatments are as below:

Date of sowing	Varieties	Treatment combinations - 12
D <sub>1</sub> - 20 <sup>th</sup> October	V <sub>1</sub> -HPW- 249	Design - RBD
D <sub>2</sub> - 10 <sup>th</sup> November	V <sub>2</sub> -HPW- 155	Replications - Three
D <sub>3</sub> - 30 <sup>th</sup> November	V <sub>3</sub> -HPW- 42	Total no. of plots - 36
D <sub>4</sub> - 20 <sup>th</sup> December		Gross plot size - 17.71 m <sup>2</sup> Net plot size- 4.68 X 3.0 m <sup>2</sup>

#### Details of varieties-

- *HPW-249*: This variety is recommended for mid hills areas for timely sowing in irrigated and un-irrigated areas. It has shown resistance to yellow rust, brown rust and loose smut and also resistance to powdery mildew disease. It gives an average yield of 48-49 q ha<sup>-1</sup>.
- *HPW-155*: This variety is recommended for timely sowing in rainfed conditions and high hill. It has also shown resistance to yellow and brown rust. Plants are dark green in color. It gives an average yield of 35-37 q ha<sup>-1</sup>.
- *HPW-42*: This variety is recommended for timely sown rainfed conditions. Produce higher yield. It is semi-dwarf variety with fully-bearded, dense spikes, white glumes and good tillering ability. It has also shown resistance to flag smut, hill bunt and powdery mildew diseases and early maturing. It has semi-hard, shining amber grains with good chapati making qualities. It is resistant to yellow and brown rusts. It gives an average yield of 30 q ha<sup>-1</sup>.

**Chadhlar road (R3)**

36	35	34	33	32	31	30	29	28	27	26	25
D3V1	D2V2	D1V1	D2V3	D1V2	D3V2	D4V1	D4V3	D3V3	D4V2	D2V1	D1V3

**Irrigation channel (R2)**

13	14	15	16	17	18	19	20	21	22	23	24
D2V3	D1V3	D3V1	D2V1	D4V2	D1V1	D4V3	D3V3	D4V1	D2V2	D1V2	D3V2

**Irrigation channel (R1)**

12	11	10	9	8	7	6	5	4	3	2	1
D3V3	D4V2	D2V1	D1V3	D3V2	D1V2	D2V3	D3V1	D4V3	D2V2	D1V1	D4V1

**Fig. 3.3** Layout plan of the field experiment for *Rabi* during 2011-12 and 2012-13

**Table 3.1 Details of field operation 2011-12 and 2012-13 crop seasons**

Sr. No.	Operation	Date of sowing							
		2011-12				2012-13			
		20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
1.	Irrigation before ploughing	12/10/2011	03-11-2011	23-11-2011	13-12-2011	11/10/2012	05-11-2012	21-11-2013	14-12-2012
2.	Land preparation	18-10-2011	08-11-2011	27-11-2011	18-12-2011	16-10-2012	07-11-2012	24-11-2012	16-12-2012
3.	Layout	18-10-2011	08-11-2011	28-11-2011	18-12-2011	18-10-2012	08-11-2012	27-11-2012	18-12-2012
4.	Sowing and basal fertilizer application	20-10-2011	10-11-2011	30-11-2011	20-12-2011	20-10-2012	10/11/2012	30-11-2012	20-12-2012
5.	Irrigation	19-11-2011	09-12-2011	-	-	20-11-2012	10-12-2012	-	-
		-	-	31-12-2011	16-01-2012	-	-	28-12-2012	17-01-2013
		12-03-2012	15-03-2012	17-03-2012	30-03-2012	13-03-2013	16-03-2013	18-03-2013	29-03-2013
6.	Top dressing (N fertilizer)	06-12-2011	26-12-2011	16-01-2012	19-01-2012	08-12-2013	28-12-2013	17-01-2013	20-01-2013
		06-01-2012	25-01-2012	17-02-2012	16-02-2012	06-01-2013	25-01-2013	19-02-2013	17-02-2013
7.	Herbicide application	22-11-2011	12/12/2011	03-01-2012	24-01-2012	24-11-2013	13/12/2012	05-01-2013	23-01-2013
8.	Weeding and hoeing	04-01-2012	25-01-2012	14-02-2012	06-03-2012	04-01-2013	26-01-2013	15-02-2013	07-03-2013
9.	Harvesting	13-05-2012	13-05-2012	19-05-2012	19-05-2012	15-05-2013	15-05-2013	20-05-2013	20-05-2013
10.	Threshing	17-05-2012	17-05-2012	23-05-2012	23-05-2012	19-05-2013	19-05-2013	25-05-2013	25-05-2013

### 3.6 Soil analysis

Prior to planning, composite soil samples from 0-15 cm depth were collected from the experimental field before the sowing of the crop. The soil samples were then air dried, ground, passed through 2 mm sieve and analyzed for various physico-chemical properties as per standard methods. The results of the analysis have been presented in table 3.6.

The soil of experimental area was silty clay loam in texture, acidic in reaction, medium in available nitrogen, medium in available phosphorus, medium in organic carbon and high in available potassium.

**Table: 3.2 Initial physico-chemical properties of experimental soil (0-15 cm) experimental site**

Soil Characteristics	Content	Methods used for analysis
<b>Mechanical analysis</b>		
Sand (%)	19.5	
Silt (%)	45.1	International pipette method (Piper 1966)
Clay (%)	35.2	
Texture	Silty clay loam	
<b>B. Chemical analysis</b>		
pH (1:2.5 soil water suspension)	5.7	Glass electrode pH meter method (Jackson 1967)
Organic carbon (%)	0.8	Rapid titration method (Walkley and Black 1934)
Available Nitrogen (kg ha <sup>-1</sup> )	316	Alkaline permanganate method (Subbiah and Asija 1956)
Available Phosphorus (kg ha <sup>-1</sup> )	16.7	NaHCO <sub>3</sub> , pH=8.5 (Olsen 1954)
Available Potassium (kg ha <sup>-1</sup> )	298	1 N Neutral ammonium acetate (Black 1965)

### **3.7 Details of observations recorded**

#### **3.7.1 Phenological studies**

##### **3.7.1.1 Days to complete emergence**

The emergence count was recorded from the sampling area daily from the date of first emergence of seeding till it was constant. The number of days taken to emergence was worked out from the date of sowing.

##### **3.7.1.2 Days to vegetative stage**

The vegetative stage is considered from days after complete emergence to till the heading stage begins. When the tip of the spike (head) can be seen emerging from the flag leaf sheath and emergence continues until the head is completely emerged. The heading date in most wheat varieties is determined by temperature (accumulation of heat units). In some varieties, a combination of heat accumulation and day length determines heading date.

##### **3.7.1.3 Days to heading stage**

Complete emergence of spike out of the top leaf sheath was considered to be the heading stage. When 75 per cent of the shoots in the observational hills/area borne the spike, the stage was considered to have reached and data was reported as days after sowing

##### **3.7.1.4 Days to physiological maturity**

The stage on which plants in each plot turned golden yellow and the grains did not crush with nails was carefully judged. The date on which grains attained sufficient hard stage was recorded and days taken for physiological maturity were counted from the sowing date.

### **3.8 Biomass studies**

#### **3.8.1 Dry matter**

Periodic dry matter accumulation at 10 to 12 days interval after emergence till maturity was recorded by drawing a random sample of plants. At each observation, fresh plant samples (from 1/2 m row length) cut from the ground level were kept in the paper bags and dried at 70 °C in oven till constant weight. The weight of dried samples was recorded in gram and reported as kg ha<sup>-1</sup>.

### **3.9 Growth and yield attributes**

#### **3.9.1 Plant height**

Five plants were selected randomly from the net plot area. The height of these plants was measured in centimeters from the ground level to the top of the upper most leaf before heading and up to the tip of the ear-head in the harvesting time. The mean height was worked out.

#### **3.9.2 Leaf area index**

The leaf area was measured at 10 to 12 days interval on the basis of a sample of five plants at each stage. The leaf area was measured with leaf area metre and then leaf area index was worked out.

$$\text{Leaf area index} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

#### **3.9.3 Number of tillers**

Five tillers were selected randomly in each treatment and the numbers of tillers were counted and the number of tillers per tiller was computed.

#### **3.9.4 Number of grains spike<sup>-1</sup>**

Five spikes were selected randomly from net plot area at maturity. These spikes were then threshed and the grains counted. The mean number of grains of these five spikes was expressed as number of grains per spike.

#### **3.9.5 1000-grain weight**

Composite random samples from the produce of net plots were drawn and 1000-grains were counted by seed counter, and recorded as 1000-grain weight.

#### **3.9.6 Grain yield**

The produce from each net plot was harvested and threshed after sun drying. The grains were cleaned and weighed after threshing. The weight of grains recorded on each plot was converted into (q ha<sup>-1</sup>).

### 3.9.7 Straw yield

Total biological yield (grain + straw) from each net plot was recorded by weighing the sun dried harvested crop. The straw yield was worked out by subtracting the grain yield from biological yield ( $q \text{ ha}^{-1}$ )

### 3.10 Agro meteorological indices

#### 3.10.1 Growing degree days (GDD)

The GDD were computed using Nuttonson (1955) method given as under:

$$\text{GDD} = \frac{(T_{\max} + T_{\min})}{2} - T_t$$

Where,

$T_{\max}$  = Maximum temperature ( $^{\circ}\text{C}$ ) of the day

$T_{\min}$  = Minimum temperature ( $^{\circ}\text{C}$ ) of the day

$T_t$  = Threshold temperature ( $4.5^{\circ}\text{C}$ , Hundal et al. 1997)

GDD is expressed as degree C day, day degrees or heat units.

#### 3.10.2 Photo thermal units

The product of the growing degree days and the length of the day in hours over a given period were expressed as photo thermal units (Dhaliwal et al. 2007).

$$\text{PTU} = \text{GDD} \times \text{day length}$$

#### 3.10.3 Helio thermal units

Helio thermal units (HTU) were computed following methods given by Chakarvarty and Sastry (1985). In this method, the actual bright sunshine hours were used in place of total day length in PTU to arrive at heat summations. Thus the product of day degrees and corresponding actual bright sunshine hours has been termed as helio thermal units and accumulated for the period of crop growth.

$$\text{HTU} = \text{GDD} \times \text{actual sunshine hours}$$

### 3.10.4 Pheno thermal index

The heat units accumulated per day between two phenological stages were computed to obtain pheno-thermal index (PTI), which is expressed as degree-days per growth day; following Nuttonson (1948) Chakravarty and sastry (1983).

$$\text{PTI} = \frac{\text{Degree days consumed between two phenological stages}}{\text{Number of days between two phenological stages}}$$

### 3.10.5 Heat use efficiency

With the view to compare the relative performance of two different genotype and treatments with respect to utilization of heat in term growing degree days during the crop growth period, heat use efficiency HUE was computed by the methods suggested by Sastry et al. 1985. It is given by the expression.

$$\text{HUE (kg ha}^{-1}\text{day}^{-1}\text{)} = \frac{\text{Accumulated dry matter (kg ha}^{-1}\text{)}}{\text{Accumulated heat units (degree day }^{\circ}\text{C)}}$$

## 3.11 Economic studies

In order to work out the most profitable treatment, the economics of each treatment was worked out on the basis of prevalent market prices of the inputs and output.

### 3.11.1 Cost of cultivation

Cost of cultivation was calculated by adding all the costs involved in each operation or input. The computed cost of cultivation has been appended in Appendix-VIII and IX.

### 3.11.2 Gross returns

The yield of the crop was converted into gross returns in rupees based on the prevailing market prices of seed to obtain treatment-wise gross returns.

### 3.11.3 Net returns

The treatment-wise net returns were obtained by subtracting the cost of cultivation from gross returns.

### 3.11.4 Benefit cost ratio

The returns per rupee invested were calculated as follow:

$$\text{Benefit cost ratio (B: C)} = \frac{\text{Net return (₹)}}{\text{Cost of cultivation (₹)}}$$

## 3.12 Crop growth simulation model description

### 3.12.1 InfoCrop

#### Model Description

Info Crop, a process based model considers the processes such as crop growth and development (phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, tran spiration, uptake, allocation and redistribution of nitrogen), effects of water, nitrogen, temperature, flooding and frost stresses on crop growth and development, crop-pest interactions (damage mechanisms of insects and diseases), soil water balance, soil nitrogen balance, soil organic carbon dynamics, emissions of green house gases and climate change module.

#### Model input requirements

The input data files required for running the INFOCROP growth model are crop/variety master, soil texture master and weather data files.

**Crop/variety file:** is used to enter the crop variety details and its parameters. The attributes of three varieties of mustard recommended for region recorded from field experiments were added in the file.

**Weather file:** Daily bright sunshine hours, daily maximum and minimum temperature, wind speed, rainfall and physiographic attributes of the meteorological stations were entered to prepare the weather file for Palampur region. The model calculates itself vapour pressure to run the model. For calibration and validation of the model weather data of recorded from Agro meteorological observatory, situated in CSKHPKV, Palampur was used.

**Soil texture file:** For three soil layers depth (mm) the parameters like organic carbon (%), soil texture (sand, silt, clay %), bulk density, hydraulic saturated conductivity and NH<sub>4</sub>-N and NO<sub>3</sub>-N content were input in the soil files representing the soils of Palampur conditions.

**Crop management:** Agronomic attributes required in the model were recorded and updated in the model e.g. Seed rate, leaf area of variety, grain weight, date of sowing, dates of irrigation and fertilizer application etc.

### **Calibration and validation of model**

The two field experiments comprising three varieties and four dates of sowing were conducted to generate data for calibration and validation of the model. The field experiments were conducted during *Rabi* 2011-2012 and 2012-2013 at the research farm of the Department of Agronomy, Forage and Grassland Management, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (32°06'N, 76°03'E and 1290.8 m amsl). The soil was silty clay loam in texture with pH 5.7 and available N, P and K were 316, 16.7 and 298 kg ha<sup>-1</sup> respectively. The crop was grown with all recommended package and practices for the experimental station. The crop was inspected at frequent intervals to monitor the phenological events closely. Data on phenology, leaf area, dry matter accumulation, and yield were recorded for calibration of the model. Crop input parameters for wheat were calculated by using information from field experiments and a wide literature survey. Further calibration of these coefficients was done by the observations recorded from the field experiment conducted. These coefficients were used in the subsequent validation and application.

### **Statistical analysis of the model product**

Model performance using the coefficients developed was evaluated by calculating root mean square error (RMSE). The RMSE describes mean absolute deviation between simulated and observed and accuracy of simulation is characterized by lower RMSE.

### 3.12.9 Statistical analysis

The statistical analysis for Randomized Block Design (RBD) was carried out by using the methods suggested by Cochran and Cox (1963). Whenever the effects exhibited significance at five per cent level of probability, the critical difference was calculated.

The growth and yield attributes data was subjected to statistical analysis and RBD design. The root mean squared error (RMSE) between simulated and observed was also used to work out the accuracy of the model.

RMSE indicates less deviation of the simulated from the observed values

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n \hat{U} (S_i - O_i)^2}{n}}$$

Where, n is the number of observations;  $S_i$  and  $O_i$  are simulated and observed values, respectively, at the  $i^{\text{th}}$  observation.

### 3.12.10 Crop yield prediction through statistical modeling

The most commonly used models in crop forecasting are empirical statistical models. In this approach, one or several variables (representing weather or climate, soil characteristics or a time trend) are related to crop responses such as yield.

The wheat crop yield data for the district Kangra was collected from the Department of Agriculture, Himachal Pradesh for the past 25 years since 1985-2011 was utilized in the present analysis for the preparation of forecast using statistical technique. The daily weather data *viz.* maximum temperature ( $T_{\text{max}}$ ), minimum temperature ( $T_{\text{min}}$ ), morning relative humidity (RHI), evening relative humidity (RHII) and rainfall (RF) were arranged week-wise from the date of sowing to flowering stage of wheat and the relation between weather parameters and yield was determined using statistical correlation and regression analysis. To study the joint effects of weather variables on wheat yield, the model used for studying effect of individual weather variables (Jain et al. 1980) had been extended by including interaction terms as per the IASRI, New Delhi guidelines (Jain et al. 1985). The modified model used is:

$$Y = A_0 + \sum_{i=1}^p \sum_{j=0}^2 a_{ij} Z_{ij} + \sum_{i \neq i'=1}^p \sum_{j=0}^2 a_{ii'j} Z_{ii'j} + bT + e$$

$$Z_{ij} = \sum_{w=1}^m r_{iw}^j X_{iw}$$

$$Z_{ii'j} = \sum_{w=1}^m r_{ii'w}^j X_{iw} X_{i'w}$$

where,

$r_{iw}$  = correlation coefficient of yield with  $i^{\text{th}}$  weather variable in  $w^{\text{th}}$  period

$r_{ii'w}$  = correlation coefficient of yield with product of  $i^{\text{th}}$  and  $i'^{\text{th}}$  weather variable in  $w^{\text{th}}$  period

$m$  = number of meteorological weeks considered for forecast

$p$  = number of weather variables used

$e$  = random error distribution as  $N(0, \sigma^2)$

In this model, for each weather variable, two types of indices were developed, one as simple total values of weather variable in different periods (un-weighted index-Zi0) and the other one as weighted total (weighted index-Zi1) weights being correlation coefficients between yield de-trended yield (if trend is present) and weather variable in respective periods. On similar lines, for studying joint effects, un-weighted and weighted indices for interactions were computed with products of weather variables (taken two at a time).

Regression analysis was used for fitting equation taking yield as dependent variable and considering year and weather as independent variable using the SPSS software. Test criteria have been separated into two groups, called summary measures and difference measures. The summary measures describe the quality of simulation while, the difference measures try to locate and quantify the errors such as Root Mean Square error (RMSE). These were calculated according to Willmott (1982) as follows and were based on terms (Pi-Oi):

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}}$$

The various notations of various indices are given as:

<b>Indices</b>	<b>Notation for un-weighted index (<math>Z_{ij}</math>)</b>	<b>Notation for weighted index (<math>Z_{ii'j}</math>)</b>
Tmax	Z10	Z11
Tmin	Z20	Z21
Rain	Z30	Z31
RHI	Z40	Z41
RHII	Z50	Z51
Tmax-Tmin	Z120	Z121
Tmax-RF	Z130	Z131
Tmax-RHI	Z140	Z141
Tmax-RHII	Z150	Z151
Tmin-RF	Z230	Z231
Tmin-RHI	Z240	Z241
Tmin-RHII	Z250	Z251
Rain-RHI	Z340	Z341
Rain-RHII	Z350	Z351
RHI-RHII	Z450	Z451
Year number		T

RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between forecasted/predicted yield (P) and observed yield (O).

The statistical model was validated for wheat crop at the mid season (F2) and pre-harvest stage (F3) corresponding to 15<sup>th</sup> March and 15<sup>th</sup> April respectively.

## 4. RESULTS AND DISCUSSION

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The results of the present investigation entitled "Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh" have been described in this chapter and supported with relevant cause and effect relationships.

### 4.1 Development studies

#### 4.1.1 Days to complete emergence

From the data presented in table 4.1 it is revealed that variety did not significantly influence the days to complete emergence during both the years. However, HPW-42 took significantly more number of days (13 days in 2011-12 and 13 days in 2012-13 to complete emergence followed by HPW-155 (11.9) and HPW-249 (11.8). Amongst dates of sowing, 20<sup>th</sup> December sown crop took more number of days to complete emergence followed by 30<sup>th</sup> November, 10<sup>th</sup> November and 20<sup>th</sup> October which were at par with each other during both years. The interaction effects of sowing dates and varieties were not significant during both the years.

#### 4.1.2 Days to vegetative stage

The data presented in table 4.1 revealed that variety HPW-249 took more number of days (57 in 2011-12 and 54 in 2012-13) to complete vegetative stage followed by HPW-155 and HPW-42 during both years. Amongst dates of sowing, 20<sup>th</sup> October sown crop took significantly more number of days to complete vegetative stage (66 days in 2011-12 and 62 days in 2012-13) followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December during both the years. The interaction effects of sowing dates and varieties were not significant during both years.

#### 4.1.3 Days to heading stage

A perusal of data during *Rabi* season 2011-12 and 2012-13 revealed that variety HPW-249 took more number of days to complete heading stage (143 days in 2011-12 and

139 days in 2012-13) followed by HPW-42 and HPW-155. Amongst dates of sowing, 20<sup>th</sup> October took significantly more number of days to the tune of 153 during 2011-12 and 151 during 2012-13 to heading stage followed by subsequent dates of sowing. The interaction effects of sowing dates and varieties were not significant (Table 4.1).

#### **4.1.4 Days to physiological maturity**

A perusal of data (Table 4.1) during first year revealed that variety HPW-249 took more number of days (162) to physiological maturity followed by a HPW-155 and HPW-42. Amongst dates of sowing, 20<sup>th</sup> October sown crop took significantly more number of days (176) to physiological maturity followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crop. Similarly, during second year the variety HPW-249 took more number of days (159) to physiological maturity followed by HPW-42 and HPW-155. Amongst dates of sowing, 20<sup>th</sup> October sown crop (173) took significantly more number of days for physiological maturity followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crop. The interaction effects of sowing dates and varieties were not significant.

During both the years, the data on number of days taken to different phenological stages *viz.* complete emergence, vegetative, heading and physiological maturity indicated non-significant differences amongst varieties. The different sowing environments had profound effect on number of days taken to attain different phenological stages. The possible reason being lesser availability of thermal energy in late sown crop due to low temperature. Similar findings were also reported by Sehgal (2010) and Jhanji and Gill (2011). Late sown crop took less number of days to complete vegetative stage, heading stage and physiological maturity as compared to 20<sup>th</sup> October, 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crop. This might be due to prevailing higher day temperature during reproductive phase in late sown crop which led to reduction in time taken to maturity. Similar results were also concluded by Sharma and Kumar et al (2005) under similar environmental conditions.

**Table 4.1** Effect of varieties and dates of sowing on number of days taken to different phenological stage during 2011-12 and 2012-13

Variety	Days to complete emergence		Days to vegetative stage		Days to heading stage		Days to physiological maturity	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
HPW-155	11.9	12.0	55.5	51.8	137.2	133.8	159.9	156.8
HPW-249	11.8	11.8	56.8	53.7	143.2	139.8	162.3	158.8
HPW-42	13.2	12.8	54.8	52.3	137.8	138.4	159.3	157.2
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Dates of sowing								
20-Oct	12.2	12.1	65.7	62.1	153.2	151.1	176.3	172.6
10-Nov	12.2	12.4	59.5	55.2	143.7	140.1	169.6	165.4
30-Nov	12.7	11.6	52.3	49.2	136.4	132.3	156.3	153.6
20-Dec	13.3	12.8	45.4	44.3	124.5	125.8	139.4	138.2
CD (5%)	NS	NS	4.2	3.9	8.3	7.1	13.1	14.1

## 4.2 Growth and yield attributes

The data on plant height, tiller count, number of grain per tiller, 1000 grain weight, grain yield and straw yield of wheat recorded during course of study have been presented in the table 4.2 and the relevant analyses have been given in Appendix-III, IV and VI.

### 4.2.1 Plant height (cm)

During *Rabi* seasons of 2011-12 and 2012-13, the data revealed that variety HPW-249 attained longer plant height 105.7 and 103.1 cm respectively, followed by HPW-42 and HPW-249. Amongst dates of sowing, 20<sup>th</sup> October sown crop recorded significantly taller plant height 107 and 105 cm respectively, followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December. The interaction effects of sowing dates and varieties were not significant.

#### 4.2.2 Tiller count

The data on tiller count of wheat recorded at the time of harvesting of crop are presented in the table 4.2.

During both the years, results showed that variety HPW-249 produced significantly higher number of tillers (297 during 2011-12 and 302 during 2012-13) followed by HPW-155 and HPW-42. Amongst dates of sowing, 20<sup>th</sup> October produced significantly higher number of tillers (301 during 2011-12 and 312 during 2012-13) followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December. This might be due to the early sowing and early emergence of crop and also because of optimum temperature during the different pheno-phases. Decline in number of tillers meter<sup>-2</sup> with successive delay in sowing was also reported by Prabhakar et al. (2007) and Kumar (2011) under similar agro climatic conditions. The interaction effects of sowing dates and varieties were not significant for both years.

#### 4.2.3 Number of grains tiller<sup>-1</sup>

The data revealed that variety HPW-249 produced more number of grains tiller<sup>-1</sup> to the tune of 48.5 and 49.1 during crop seasons of 2011-12 and 2012-13, respectively as compared to varieties HPW-155 and HPW 42 (Table 4.2). Amongst dates of sowing, 20<sup>th</sup> October sown crop produced significantly more number of grains tiller<sup>-1</sup> to the tune of 48.2 during 2011-12 and 49.2 during second year followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crop during both the years. The interaction effects of sowing dates and variety were not significant during both the years.

#### 4.2.4 1000-grain weight (g)

A perusal of the data revealed that varieties did not differ statistically with each other in respect of 1000-grain weight during both the years. However, HPW-249 produced higher grain weight (46.3 g during 2011-12 and 47.3 g during 2012-13) followed by HPW-155 and HPW-42 during both the years (Table 4.2). The 1000-grain weight varied significantly in sowing environments. The crop sown on 20<sup>th</sup> October produced significantly highest grain weight to the tune of 47.1 g during 2011-12 and 48.4 g during 2012-13 followed by 10<sup>th</sup> November 30<sup>th</sup> November and 20<sup>th</sup> December sown

crop during both the years. This might be due to the early sowing and early vegetative growth and heading of crop and also because of optimum temperature during the different phases. Decline in number of grains spike<sup>-1</sup> with successive delay in sowing was also reported by Singh and Kumar (2005). Similar findings were also reported by Singh et al. (2013). The interaction effects of sowing dates and varieties were not significant for both the years.

#### **4.2.5 Grain yield (q ha<sup>-1</sup>)**

The data presented in table 4.2 revealed that variety HPW-249 gave significantly highest grain yield (41.3 q ha<sup>-1</sup> during 2011-12 and 44.2 q ha<sup>-1</sup> during 2012-13) as compared to HPW-155 and HPW-42 during both the years. Amongst dates of sowing, 20<sup>th</sup> October sown crop significantly out yielded the subsequent dates of sowing (43.0 q ha<sup>-1</sup> during 2011-12 and 45.6 q ha<sup>-1</sup> during 2012-13) during both the years. The interaction effects of sowing dates and varieties were not significant during both the years. The highest grain yield on 20<sup>th</sup> October sown crop is due to higher 1000-grain weight, number grains per tiller and LAI which reflected in higher grain yield.

#### **4.2.6 Straw yield (q ha<sup>-1</sup>)**

A perusal of data in table 4.2 indicated significantly highest straw yield in variety HPW-249 to the tune of (59.1 q ha<sup>-1</sup> during 2011-12 and 65.8 q ha<sup>-1</sup> during 2012-13) followed by HPW-155 and HPW-42 during both the years. The sowing environments significantly influenced the straw yields during both the years. The early sown crop on 20<sup>th</sup> October gave significantly highest straw yield of 61.5 q ha<sup>-1</sup> during 2011-12 and 68.4 q ha<sup>-1</sup> during 2012-13 followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crops. The interaction effects of sowing dates and varieties were not significant during both the years. The higher yields in early sown crop on October might be due to the reason that October 20 sown crop received optimum environmental conditions for crop growth and get more time for attaining different pheno-phases. Similar findings were also reported by Sharma and Kumar (2005) under similar agro climatic conditions of Palampur.

**Table 4.2 Effect of sowing dates and varieties on growth yield attributes and yield of wheat during 2011-12 and 2012-13.**

	Plant height (cm)		Number of tillers m <sup>-2</sup>		Number of grains tiller <sup>-1</sup>		1000 grain weight (g)		Grain yield (q ha <sup>-1</sup> )		Straw yield (q ha <sup>-1</sup> )	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Variety												
HPW-155	97.1	98.2	280.3	283.3	47.1	47.2	44.2	45.4	38.7	41.3	55.4	61.9
HPW-249	105.7	103.1	296.8	302.2	48.5	49.1	46.3	47.3	41.3	44.2	59.1	65.8
HPW-42	99.4	100.1	263.2	268.2	45.1	45.1	43.1	43.4	37.6	39.8	52.2	59.1
CD (5%)	NS	NS	12.8	16.2	NS	NS	NS	NS	2.2	1.8	2.9	3.1
Dates of sowing												
20 Oct	107.5	105.2	301.2	311.9	48.2	49.4	47.1	48.4	43.0	45.6	61.5	68.4
10 Nov	102.9	103.8	296.1	298.1	47.3	47.5	46.1	47.3	41.5	44.4	59.3	66.0
30 Nov	99.9	98.6	276.2	281.3	45.2	46.1	43.3	43.1	37.8	40.4	54.1	60.6
20 Dec	96.5	94.2	247.1	251.3	43.3	45.3	41.9	42.6	34.5	36.6	47.9	54.1
CD (5%)	5.2	6.3	13.4	17.2	2.1	3.2	2.7	2.9	2.5	2.1	3.4	3.6

#### 4.2.7 Leaf Area Index

The data on leaf area index (LAI) for wheat was recorded at 12 days interval after sowing crop and have been presented in table 4.3 and analyses have been given in Appendix-V.

A perusal of data for *Rabi* 2011-12 and 2012-13 indicated that leaf area index (LAI) did not vary significantly within varieties *viz.* HPW-249, HPW-42 and HPW-155 from 12 DAS to 60 DAS except during second year at 60 DAS. However, the highest LAI values were recorded in HPW-249 followed by HPW-155 and HPW-42 during both the years. The LAI values at 12 DAS varied between 0.141 and 0.144 and progressively increased slowly *i.e.* 0.605 to 0.642 up to 72 DAS, thereafter fast growths in leaves were observed which reflected in increased LAI after 84 DAS. The maximum LAI was observed at 120 to 132 DAS in all the varieties. The LAI started decreasing after 132 DAS in all the varieties. The maximum value of LAI was observed to the tune of 3.11 and 2.90 at 120 and 132 DAS respectively, in variety HPW-249 followed by HPW-155 and HPW-42. Similar trends were observed from 12 DAS to 132 DAS. On 144 DAS, the significantly highest LAI was observed in HPW-249 in both the years of field experimentation which was followed by HPW-155 and HPW-42.

Amongst the sowing windows from 20<sup>th</sup> October to 20<sup>th</sup> December, LAI values showed significant differences from 12 DAS to 144 DAS. The significantly lowest LAI was observed in 20<sup>th</sup> December sown crop and highest values was observed when sown on 20<sup>th</sup> October in all the periodic observations of LAI from 12 DAS to 144 DAS except 96 DAS. The maximum LAI was observed during 120 to 132 DAS and there after it decreased progressively up to 72 DAS. The LAI observed increasing with higher rate after 72 DAS. The significantly highest LAI values were observed to the tune of 3.21 and 3.30 during 2011-12 at 120 and 132 DAS during 2012-13 in 20<sup>th</sup> October sown crops. The LAI was not significantly varied between 20<sup>th</sup> October to 10<sup>th</sup> November, 10<sup>th</sup> November to 30<sup>th</sup> November sown crops but significantly lowest values were recorded in 20<sup>th</sup> December sown crop. At 156 DAS revealed that variety HPW-249 produced higher leaf area index both the years 1.27 in 2011-12 and 1.24 in 2012-13 followed by a HPW-155 and HPW-42. Amongst dates of sowing, 20<sup>th</sup> October sown crop produced LAI to the tune of 1.31 during 2011-12 and 1.37 in 2012-13 followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December in both the years. The interaction effects of sowing dates and varieties were not significant.

**Table 4.3 Effect of sowing dates and varieties on leaf area index during 2011-12 and 2012-13**

	12 DAS		24 DAS		36 DAS		48 DAS		60 DAS		72 DAS		84 DAS	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
<b>Variety</b>														
HPW-155	0.144	0.136	0.152	0.253	0.253	0.283	0.460	0.369	0.488	0.485	0.642	0.662	0.949	1.080
HPW-249	0.144	0.136	0.156	0.256	0.299	0.283	0.474	0.383	0.496	0.508	0.677	0.687	1.160	1.210
HPW-42	0.141	0.130	0.150	0.253	0.247	0.276	0.431	0.364	0.481	0.468	0.605	0.623	0.893	0.943
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.028	0.031	0.036	0.038	0.051
<b>Dates of sowing</b>														
20 Oct	0.155	0.148	0.158	0.284	0.268	0.294	0.531	0.390	0.506	0.514	0.674	0.672	1.180	1.310
10 Nov	0.152	0.144	0.156	0.260	0.253	0.280	0.467	0.380	0.494	0.489	0.693	0.696	1.035	1.100
30 Nov	0.142	0.125	0.152	0.240	0.252	0.260	0.416	0.359	0.492	0.479	0.632	0.654	0.934	0.977
20 Dec	0.123	0.119	0.144	0.231	0.294	0.241	0.406	0.359	0.463	0.466	0.567	0.608	0.852	0
CD (5%)	0.013	0.015	0.012	0.021	0.024	0.033	0.026	0.023	0.032	0.036	0.039	0.044	0.049	0.064

Continued

	96 DAS		108 DAS		120 DAS		132 DAS		144 DAS		156 DAS	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Variety												
HPW-155	1.80	1.84	2.24	2.39	3.05	2.81	2.84	2.88	1.71	1.76	1.27	1.24
HPW-249	1.81	1.84	2.34	2.44	3.11	2.89	2.90	2.96	1.80	1.90	1.27	1.24
HPW-42	1.76	1.82	2.24	2.31	3.03	2.79	2.81	2.83	1.66	1.57	1.25	1.22
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	0.11	0.13		
Dates of sowing												
20-Oct	1.84	1.87	2.46	2.51	3.21	3.00	3.30	3.35	2.28	2.17	1.31	1.37
10-Nov	1.82	1.85	2.26	2.12	3.10	2.91	3.14	3.25	2.10	2.22	1.30	1.28
30-Nov	1.78	1.84	2.23	2.34	3.02	2.81	2.84	2.98	1.99	1.87	1.23	1.25
20-Dec	1.70	1.78	2.01	2.22	2.93	2.60	2.01	1.98	1.06	1.12		
										(Before harvest)		
CD (5%)	NS	NS	0.13	0.14	0.16	0.12	0.18	0.23	0.21	0.26		

The maximum leaf area index was observed in variety HPW-249 in both the years. Amongst dates of sowings, 20<sup>th</sup> October sown crop recorded significantly higher leaf area index. By virtue of optimum climatic conditions, October 20 sown crop plants attained more plant height and dry matter accumulation in wheat during both the years. These results are in conformity with the results reported by Sharma and Kumar (2005) under similar agro-climatic conditions. Leaf area index at harvest decreased due to increased leaf aging and senescence, shading and competition between plants for light and other resources, especially, when wheat encounters high temperatures. Dalirie et al. (2010) and Khan et al. (2005) corroborated similar findings.

#### **4.2.8 Dry matter accumulation (kg ha<sup>-1</sup>)**

The data on periodic dry matter accumulation for wheat was recorded at 12 days interval after sowing of crop and have been presented in the table 4.4. The analyses of variance have been given in Appendix-V.

##### **4.2.8.1 Effect of Varieties**

During *Rabi* seasons of 2011-12 and 2012-13, data revealed that dry matter accumulation did not significantly differ in all varieties at 12 DAS. However, the dry matter significantly differed in all periodic observations of the crop from 12 DAS on ward till physiological maturity. At 24 days after sowing to till physiological maturity HPW-249 produced significantly highest dry matter which ranged from 69.2 kg ha<sup>-1</sup> at 24 DAS to 10240 kg ha<sup>-1</sup> at physiological maturity followed by HPW-155 and HPW-42. The dry matter accumulation upto 84 DAS was slow and thereafter it increased with faster rate up to 132 DAS. At 36 DAS, variety HPW-249 recorded significantly highest dry matter accumulation (381 kg ha<sup>-1</sup> during 2011-12 and 400 kg ha<sup>-1</sup> during 2012-13) compared to HPW-155 and HPW-42. The similar trends of dry matter accumulation were followed up to physiological maturity for all the varieties. At 48 days after sowing, variety HPW-249 recorded significantly highest dry matter to the tune of 651 kg ha<sup>-1</sup> during 2011-12 and 655 during 2012-13 followed by HPW-155 and HPW-42. Similarly, at 60 DAS to Physiological maturity, variety HPW-249 recorded significantly highest dry

**Table 4.4 Effect of varieties sowing dates and on dry matter accumulation (kg ha<sup>-1</sup>) of wheat during 2011-12 and 2012-13**

	12 DAS		24 DAS		36 DAS		48 DAS		60 DAS		72 DAS		84 DAS	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Variety														
HPW-155	6.5	8.5	62.1	67.2	263.3	266.2	451.7	455.3	996.7	1000.9	1624.5	1648.1	2031.1	2120.2
HPW-249	7.1	9.1	69.2	72.6	380.7	400.1	651.4	655.0	1229.8	1234.0	1769.2	1792.9	2448.5	2550.5
HPW-42	5.4	7.4	57.8	61.8	222.7	220.6	431.1	434.7	966.4	970.6	1540.5	1564.1	1711.8	1877.3
CD (5%)	NS	NS	3.2	4.7	24.2	31.2	41.2	44.6	57.3	62.1	102.3	108.2	156.2	136.2
Dates of sowing														
20 Oct	6.9	8.9	75.1	78.5	335.7	338.6	584.8	588.4	1133.8	1138.0	1793.5	1817.1	2563.8	2725.2
10 Nov	6.7	8.7	66.5	69.4	330.6	333.5	551.1	554.7	1130.2	1134.4	1692.4	1716.0	2251.9	2413.6
30 Nov	6.3	8.3	58.8	62.7	248.8	258.7	467.3	470.9	1012.8	1016.9	1564.3	1588.0	1938.8	1898.9
20 Dec	5.4	7.4	51.7	58.2	240.4	251.7	442.4	446.0	980.4	984.6	1528.7	1552.3	1500.6	1693.1
CD (5%)	NS	NS	4.3	5.5	28.2	34.5	52.1	54.9	68.6	74.3	128.5	121.4	178.9	151.5

Continued

	96 DAS		108 DAS		120 DAS		132 DAS		144 DAS		156 DAS		At Maturity	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
<b>Variety</b>														
HPW-155	3274.0	3340	4750	4990	6660.5	6982	7925	8110	8337	9243	9710.2	9910	9819	9819
HPW-249	3496.1	3615	5090	5210	6990.3	7311	8111	8420	8647	9609	10010	10240	10205	10405
HPW-42	3195.9	3320	4490	4680	6510.3	6831	7794	7830	8057	8805	9228	9652	9484	9484
CD (5%)	182.1	201.5	313.2	316.2	401.3	380.2	427	434.5	604.3	469.5	716.6	548		
<b>Dates of sowing</b>														
20 Oct	3534.7	3740	5220	5420	7110.6	7432	8210	8750	8977	9558	9817	10143.9	10743.9	10743
10 Nov	3383.1	3410	4850	5010	6860.7	7182	8073	8330	8557	9107	9540	9990.3	10190.3	10190
30 Nov	3220	3320	4620	4820	6560.0	6881	7804	7820	8047	8993	9290	9670		
20 Dec	3150	3230	4415	4590	6350.0	6671	7690	7580	7807					
									(Before harvest )					
CD (5%)	215.3	249.9	362.2	365.2	493.4	476.8	493.4	501.7	427.3	542.3	506.7	632.8		

matter accumulation than HPW-249 and HPW-155. At physiological maturity HPW-249 recorded significantly higher dry matter accumulation (10010 kg ha<sup>-1</sup> in 2011-12 and 10240 in 2012-13 kg ha<sup>-1</sup>) than HPW-155 and HPW-42.

#### **4.2.8.2 Effect of sowing environments**

The data presented in table 4.4 revealed that 20<sup>th</sup> October sown crop during 2011-12 recorded significantly highest dry matter accumulation compared to subsequent dates of sowing *viz.* November 10, November 30 and December 20 sown crop **except in 12 DAS**. In the second year (2012-13) analogous trends were observed in dry matter accumulation from 24 days after sowing to physiological maturity. At physiological maturity October 20 sown crop recorded significantly highest dry matter accumulation to the tune of 9817 kg ha<sup>-1</sup> during 2011-12 and 10144 kg ha<sup>-1</sup> during 2012-13 in comparison to November 10 (9540 kg ha<sup>-1</sup> during 2011-12 and 9990 kg ha<sup>-1</sup> during 2012-13), November 30 (9290 kg ha<sup>-1</sup> during 2011-12 and 9670 kg ha<sup>-1</sup> during 2012-13) and 20 December (8047 kg ha<sup>-1</sup> during 2011-12 and 8993 kg ha<sup>-1</sup> during 2012-13) sown crops. The interaction effects were not significant during both the years of experimentation.

The delay in sowing adversely affected the dry matter accumulation which might be due to the less plant height and number of tillers plant<sup>-1</sup> which consequently reflected in low dry matter accumulation. These findings were in conformity with Sharma and Kumar (2005) and Kumar (2011) under similar environmental conditions.

### **4.3 Agrometeorological Indices**

#### **4.3.1 Growing degree days (GDD)**

The data on GDD revealed that to attain complete emergence 153-170 degree days averaged over two years were accumulated in all the varieties when crop sown on 20<sup>th</sup> October. The GDD decreased with delay in sowing during both the years. However, GDD varied between 123 to 158 degree days in sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December. The lowest GDD values were observed on 20<sup>th</sup> December sown crop during both the years. Similar trends of GDD were observed in vegetative, heading and physiological maturity stages of the crop during both the years. The magnitudes of the values were highest in early sown crop of 20<sup>th</sup> October during both the years. Pooled date

of two years revealed that varieties HPW-249, HPW-155 and HPW-42 accumulated 1661, 1641 and 1586 degree days in October sown crop and GDD decreased with delay in sowing windows. The GDD values varied between 1428 to 1547 degree days in all varieties in sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December. Similarly, GDD values varied between 376 to 591 degree days to attain vegetative and 851 to 853 degree days to heading stage of the crop (Table 4.5a and 4.6b). The possible reasons for decrease in thermal requirements with delay in sowing may be due to low temperature in late sown crop. These findings are in conformity with Ram et al. (2012).

#### **4.3.2 Helio thermal unit (HTU)**

The data on helio thermal unit (HTU) revealed that to attain complete emergence HTU accumulated in all the varieties ranged from 1657-1850 and highest values were observed in all varieties when sown on 20<sup>th</sup> October during both the years. The HTU decreased with delayed in sowing. However, HTU varied from 1409 to 1780 in sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December during both years. The lowest HTU values were observed in 20<sup>th</sup> December sown crop. Similar trends of HTU were followed in vegetative, heading stage and physiological maturity stages of the crop. The magnitudes of the values were highest in early sown crop 20<sup>th</sup> October. Data revealed that varieties HPW-249, HPW-155 and HPW-42 accumulated HTUs to the tune of 11310, 11786 and 10169 respectively average over two years in October sown crop. The HTU value varied between 8894 to 10695 HTU for all varieties in sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December. Similarly, HTU values varied between 4652 to 5649 HTU to attain vegetative and 4685 to 9538 HTU for heading stage of the crop (Table 4.7a and 4.8b). Hundal et al. (1997) also observed that cumulative helio thermal units (HTU) were reduced with delay in sowing after October and this is might be due to reduction in actual sunshine hours also.

#### **4.3.3 Photo thermal unit (PTU)**

The data on photo thermal unit (PTU) presented in table 4.9a and 4.10b revealed similar results and trends as observed in HTUs and GDD for all varieties and sowing environments. The studies conducted by Sharma (1993) and Ram (2012) also observed that accumulated photo thermal units (PTU) were reduced with delayed in sowing after October and this might be due to reduction in day length for late sown crop.

#### 4.3.4 Pheno thermal index (PTI)

The data averaged over two years on pheno thermal index (PTI) revealed that PTI values were 11.0-13.8 in all the varieties to attain complete emergence. The highest PTI values were observed in crop sown on 20<sup>th</sup> October for all varieties. Like GDD the PTI values decreased when sowing was delayed. However, PTI varied from 6.9 to 12.8 in sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December. The lowest PTI values were observed in 20<sup>th</sup> December sown crop. Amongst dates and different stages of crop, the lowest values were obtained during vegetative stages of crop. The values were highest in early sown crop on 20<sup>th</sup> October. The varieties *viz.* HPW-249, HPW-155 and HPW-42 observed 10.4, 17.7 and 17.2 PTI values averaged over two years, respectively in October sown crop. Similarly, PTI values varied between 6.7 to 9.8 to attain vegetative and 13.9 to 15.4 for heading stage of the crop (Table 4.11a and 4.12b). Similar results were reported by Kumari et al. (2009) under Jharkhand conditions.

#### 4.3.5 Heat use efficiency (HUE)

The data presented in table 4.13a and 4.14b revealed that heat use efficiency (HUE) values averaged over two years to attain complete emergence were 0.07-0.09 in sowing windows from 20 October to 20<sup>th</sup> December irrespective of all varieties. The HUE decreased with delayed in sowing. However, HUE values varied from 0.04 to 0.09 during sowing windows from 10<sup>th</sup> November to 20<sup>th</sup> December. The lowest HUE values were observed in 20<sup>th</sup> December sown crop. Similar trends of HUE were observed in vegetative, heading stage and physiological maturity stages of the crop. However, the HUE values varied between 0.3 to 1.4 during heading and 3.4 to 8.5 in physiological maturity stages of the crop. The magnitudes of the values were highest in early sown crop 20<sup>th</sup> October. The results indicated that varieties *viz.* HPW-249, HPW-155 and HPW-42 showed 4.6, 5.3 and 4.2 HUEs values, respectively in October sown crop and it decreased with delay in sowing windows. Amongst dates of sowing, the values of HUE were different for the different dates of sowing and did not follow decreasing trend with delay in sowing. The results reported by Solanki (2010) under Udaipur, Rajasthan conditions revealed inconsistent trends within different genotypes and sowing environments of wheat crop. Bhosale (2009) also reported similar findings in mustard crop grown during *Rabi* season under similar agro-climatic conditions.

**Table: 4.5 (a) Effect of sowing dates and varieties on growing degree days (GDD) at different growth stages of wheat during 2011-12**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	170	158	153	148	168	155	152	146	168	155	163	156
Days to vegetative stage	591	498	480	468	545	490	485	472	550	495	482	376
Days to heading	800	798	782	685	781	695	672	651	806	775	755	748
Days to physiological maturity	1688	1523	1506	1465	1658	1571	1503	1442	1565	1502	1456	1428

**Table 4.6 (b) Effect of sowing dates and varieties on growing degree days (GDD) at different growth stages of wheat during 2012-13**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	158	155	147	133	156	153	147	138	153	145	139	123
Days to vegetative stage	514	513	458	435	512	508	485	548	508	455	442	425
Days to heading	853	843	833	785	885	848	835	795	835	823	815	785
Days to physiological maturity	1635	1580	1555	1495	1625	1570	1538	1460	1608	1565	1505	1476

**Table 4. 7 (a) Effect of sowing dates and varieties on Helio Thermal Unit (HTU) at different growth stages of wheat during 2011-12**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	1730	1630	1540	1450	1850	1780	1685	1550	1685	1532	1458	1409
Days to vegetative stage	5547	4865	4755	4652	5649	5553	5435	4935	5558	4958	4848	4785
Days to heading	9530	8753	7754	7635	9855	9538	9453	9449	8595	8485	8355	8342
Days to physiological maturity	11952	11231	10252	9882	11586	11043	10550	10449	11081	10891	10851	9585

**Table 4.8 (b) Effect of sowing dates and varieties on Helio Thermal Unit (HTU) at different growth stages of wheat during 2012-13**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	1657	1627	1567	1436	1687	1595	1485	1427	1752	1635	1532	1507
Days to vegetative stage	5321	5258	5153	5050	5435	5330	5227	5058	5325	5220	5110	5021
Days to heading	6738	6635	6358	6258	6385	6286	6209	5851	5758	4846	4787	4685
Days to physiological maturity	10668	9320	8320	8235	11987	10485	9325	8895	9258	9256	8285	7894

**Table 4.9 (a) Effect of sowing dates and varieties on Photo Thermal Unit (PTU) at different growth stages of wheat during 2011-12**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	1952	1855	1803	1785	1885	1789	1685	1595	1793	1633	1555	1458
Days to vegetative stage	6925	6744	6568	6335	5859	5853	5765	5585	5885	5652	5459	5348
Days to heading	9530	8750	8552	8400	9253	9058	8553	8168	8386	8355	7852	7552
Days to physiological maturity	15583	15089	11500	10800	14853	14805	13355	13098	15895	15861	14856	14651

**Table 4 10 (b) Effect of sowing dates and varieties on Photo Thermal Unit (PTU) at different growth stages of wheat during 2012-13**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	1595	1395	1218	1105	1581	1519	1453	1395	1699	1558	1503	1481
Days to vegetative stage	6154	5825	5758	4758	5358	5347	5258	5185	4858	4758	4536	4358
Days to heading	9225	8588	8487	8395	9389	9155	8595	8493	9585	8485	8395	8137
Days to physiological maturity	16576	15976	14934	11569	16976	15858	15355	14853	16851	14281	12865	11940

**Table 4.11 (a) Effect of sowing dates and varieties on Pheno Thermal Index (PTI) at different growth stages of wheat during 2011-12**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	13.8	12.3	11.6	12.8	11.8	10.3	10.7	9.5	11.0	11.2	10.9	12.5
Days to vegetative stage	9.5	8.6	8.6	9.8	8.9	9.7	7.9	9.5	6.7	8.0	9.0	7.0
Days to heading	15.3	14.6	15.4	14.4	14.3	13.9	15.2	13.9	14.8	14.7	15.3	14.8
Days to physiological maturity	16.6	17.9	16.5	17.7	17.5	18.8	18.2	17.5	17.4	17.5	16.9	16.7

**Table 4.12 (b) Effect of sowing dates and varieties on Pheno Thermal Index (PTI) at different growth stages of wheat during 2012-13**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	12.3	11.5	10.2	7.8	11.6	10.9	10.5	6.9	12.0	10.2	9.9	7.5
Days to vegetative stage	9.0	8.0	8.0	9.2	8.0	9.0	7.9	8.5	7.7	9.0	8.0	8.0
Days to heading	15.3	14.6	15.4	14.4	14.3	13.9	15.2	13.9	14.8	14.7	15.3	14.8
Days to physiological maturity	17.8	17.9	18.5	16.7	17.5	17.8	16.8	17.5	17.4	17.5	16.9	17.9

**Table 4.13 (a) Effect of sowing dates and varieties on Heat Use Efficiency (HUE) at different growth stages of wheat during 2011-12**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	0.08	0.08	0.06	0.048	0.07	0.08	0.06	0.04	0.09	0.08	0.07	0.08
Days to vegetative stage	0.6	0.7	0.8	1.4	0.6	0.7	0.8	1.4	0.6	0.7	0.8	1.1
Days to heading	7.9	8.2	7.3	8.5	4.8	3.4	3.5	6.2	6.1	3.6	5.8	7.2
Days to physiological maturity	5.8	4.7	4.1	5.5	5.2	4.5	4.4	3.8	2.9	4.5	5.2	3.6

**Table 4.14 (b) Effect of sowing dates and varieties on Heat Use Efficiency (HUE) at different growth stages of wheat during 2012-13**

Growth Stages	HPW-249				HPW-155				HPW-42			
	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec	20 Oct	10 Nov	30 Nov	20 Dec
Days to complete emergence	0.09	0.05	0.07	0.04	0.08	0.08	0.07	0.09	0.06	0.08	0.09	0.08
Days to vegetative stage	0.6	0.6	0.3	1.5	0.8	0.8	0.4	1.5	0.8	0.6	0.7	1.1
Days to heading	7.9	8.1	7.5	7.2	4.8	3.4	3.5	6.2	6.1	3.6	5.8	4.2
Days to physiological maturity	4.8	6.7	5.7	4.6	4.8	4.3	4.8	7.5	4.9	5.5	5.2	6.9

#### **4.4 Crop growth simulation Modeling**

##### **4.4.1 Simulated versus observed days to vegetative stage**

Observed and simulated days taken to vegetative stage have been given in the Fig. 4.4.1. The field observed and model simulated days to vegetative stage were in agreement and the differences were within the range of variations encountered in field observations for these parameters. The crop model simulated days to vegetative stage varied between -4 to +4 days of the observed dates. The RMSE values for days taken to vegetative stage was 6.0 days during 2011-12 and 8.6 during 2012-13 which means good fit of model for this parameter.

##### **4.4.2 Simulated versus observed days to physiological maturity**

The physiological maturity days simulated by model corresponded well with that actually observed in the field (Fig 4.4.2). The simulated days to physiological maturity were estimated between -6 to +5 days of the field observed days. The RMSE values for days taken to maturity were 9.2 days during 2011-12 and 10.3 during 2012-13. Sharma and Kumar (2005) validated DSSAT model under similar agro climatic conditions and reported RMSE of 1.73 for days to physiological maturity.

##### **4.4.3 Simulated versus observed LAI**

A comparison between observed and simulated values for leaf area index is presented graphically in Fig. 4.4.3a, 4.4.3b, 4.4.4a and 4.4.4.b. The results revealed that simulated leaf area index matched closely with observed LAI for all the treatments. The RMSE values for leaf area index ranged from 0.2 to 0.5. The differences were higher in early and late sown crop. These results are in conformity with the results obtained by Singh et al. (2013). Mishra et al. (2013) validated WOFOST model under middle Gujarat conditions and reported RMSE values from 0.08 to 0.11 for maximum LAI of wheat crop.

#### 4.4.4 Simulated versus observed dry matter accumulation

The observed and simulated values for dry matter accumulation were presented graphically in Fig. 4.4.5a, 4.4.5b, 4.4.6a and 4.4.6b. A close look on these figures revealed that simulated dry matter accumulation matched closely with observed dry matter accumulation for all treatments. The RMSE values for dry matter accumulation ranged from 147 to 348 kg ha<sup>-1</sup> in 2011-12 and 234 to 365 kg ha<sup>-1</sup> in 2012-13. The lower value of RMSE indicates good fit of model for this parameter. Similar results were also concluded by Sharma and Kumar (2005) under Palampur conditions when DSSAT crop model was validated for the region. Bhosale (2009) also validated Infocrop crop growth model under similar environmental conditions for *Rabi* crop (Mustard) and indicated RMSE values between 53 to 142 kg ha<sup>-1</sup> between simulated and observed dry matter recorded different stages of crop

#### 4.4.5 Simulated versus observed yields

The observed and simulated grain yield of wheat was presented in Fig. 4.4.7 and 4.4.8. The economic yield simulated by model corresponded well with that of actually observed in the field. The RMSE values for yield were 258 kg ha<sup>-1</sup> in 2011-12 and 302 kg ha<sup>-1</sup> in 2012-13 which was 7-8 percent higher from the observed yields. Sharma and Kumar (2005) validated DSSAT crop model under similar environmental conditions for wheat crop and reported less than 10 percent variations in simulated and observed grain yields. Mishra et al. (2013) also reported RMSE values between 70 to 92 kg ha<sup>-1</sup> for grain yield of wheat between simulated and observed using WOFOST model over three years of study in middle Gujarat.

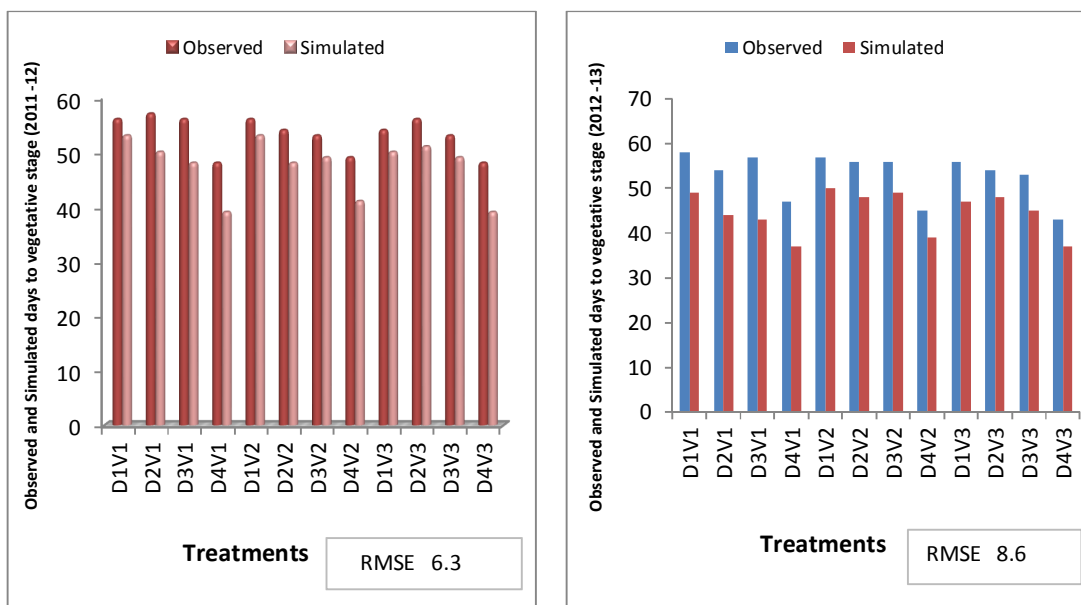


Fig. 4.4.1 Observed and Simulated days to vegetative stage during 2011-12 and 2012-13

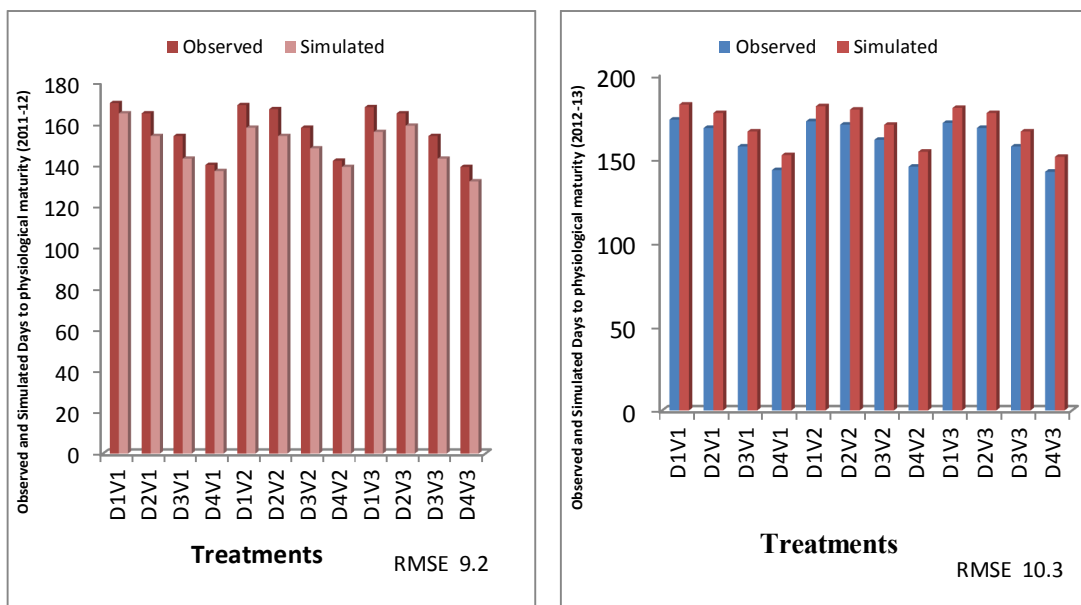


Fig. 4.4.2 Observed and Simulated days to physiological maturity during 2011-12 and 2012-13

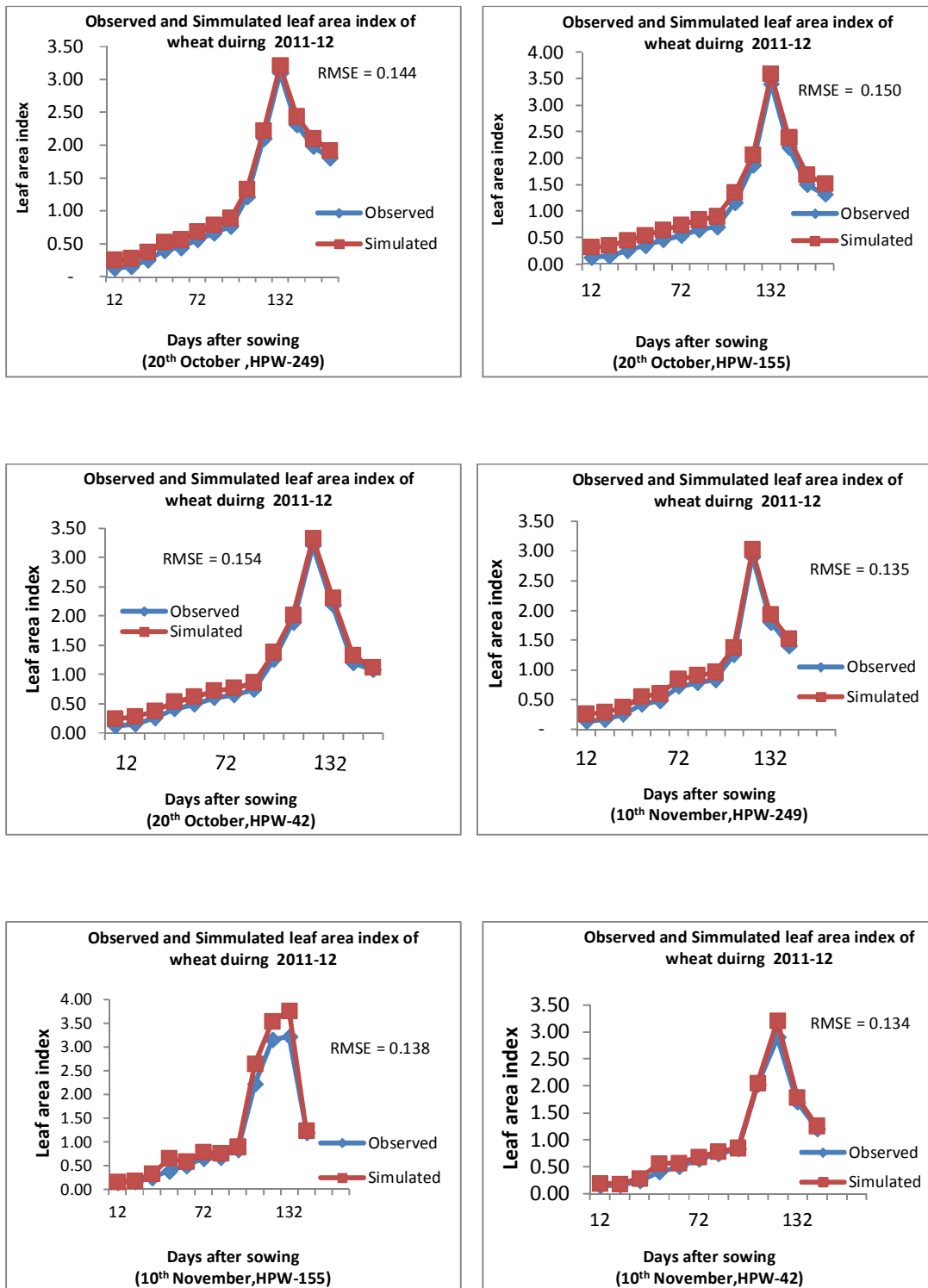


Fig. 4.4.3(a) Observed and simulated LAI of wheat varieties sown on 20<sup>th</sup> October to 10<sup>th</sup> November during 2011-12

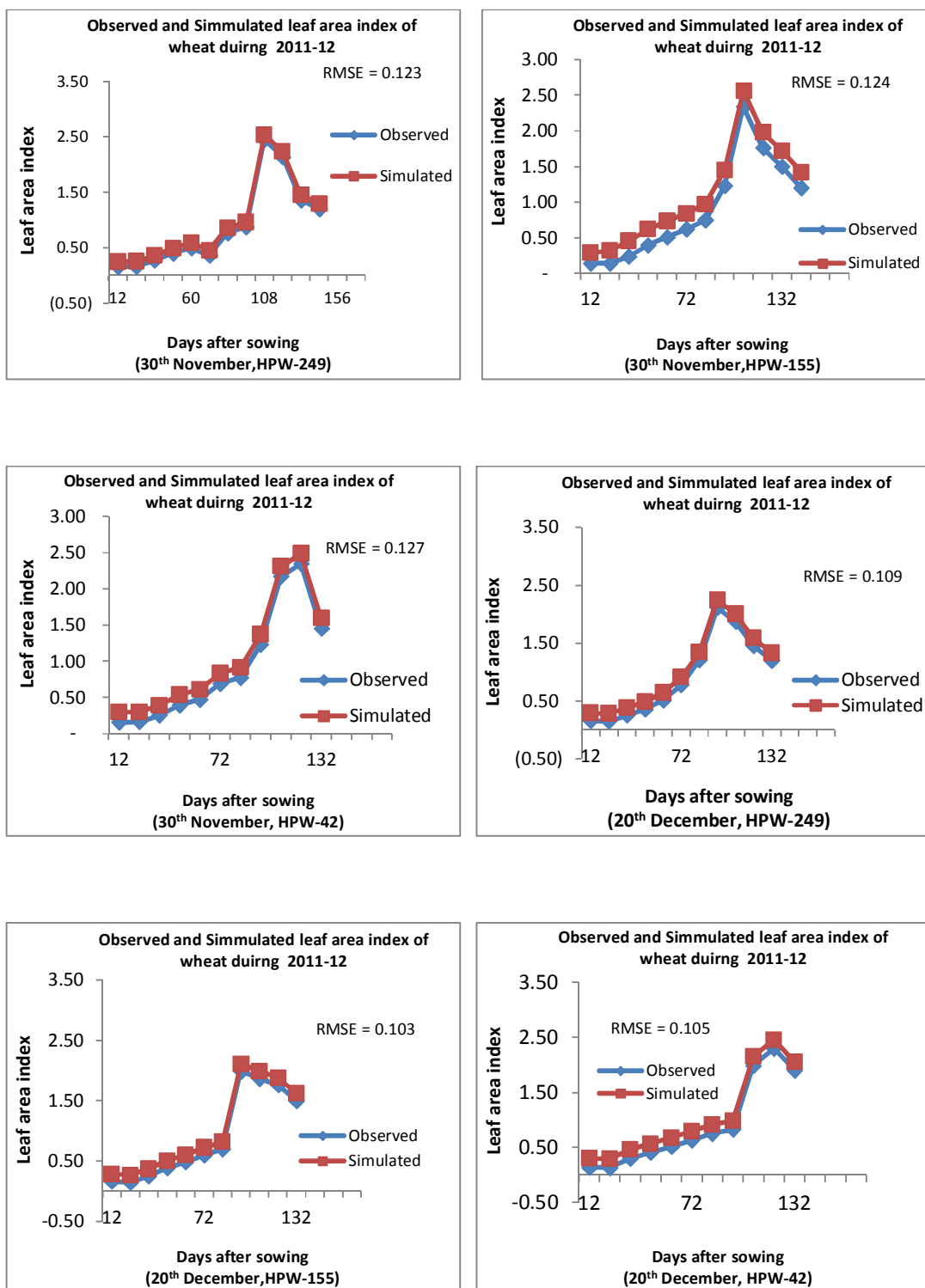


Fig. 4.4.3(b) Observed and simulated LAI of wheat varieties sown on 10<sup>th</sup> November to 20<sup>th</sup> December during 2011-12

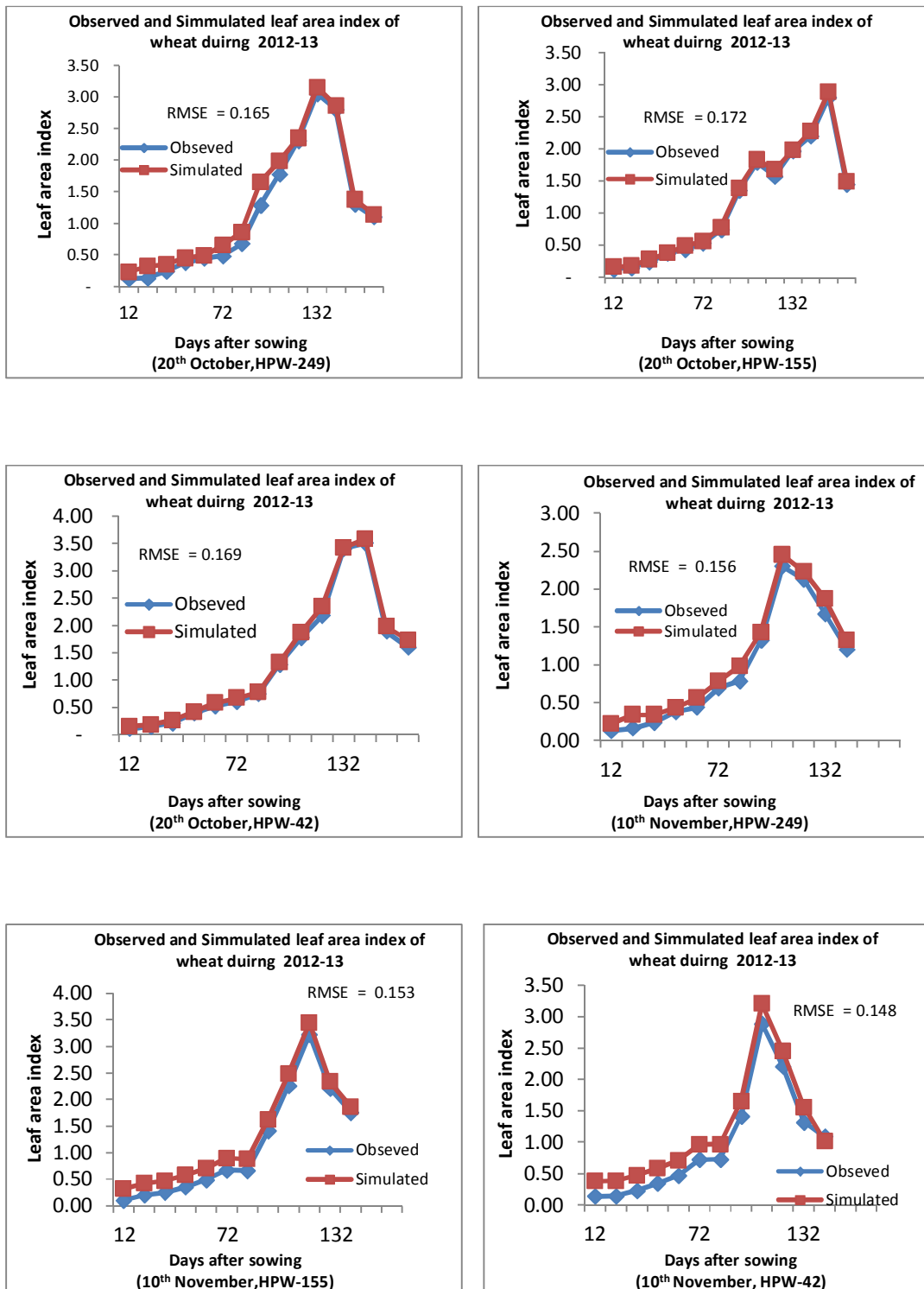


Fig. 4.4.4(a) Observed and simulated LAI of wheat varieties sown on 20<sup>th</sup> October to 10<sup>th</sup> November during 2012-13

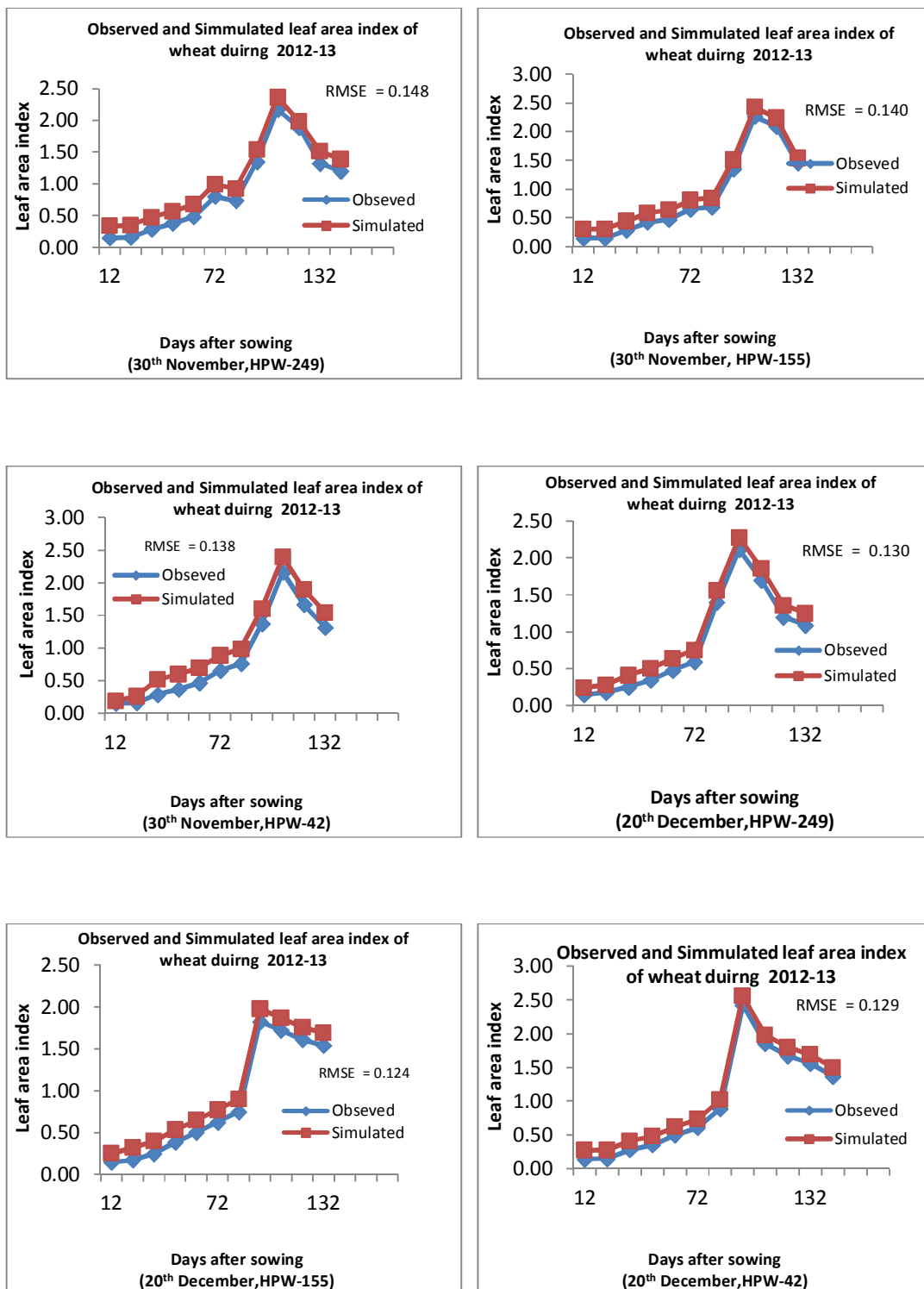


Fig. 4.4.4(b) Observed and simulated LAI of wheat varieties sown on 30<sup>th</sup> November to 20<sup>th</sup> December during 2011-12

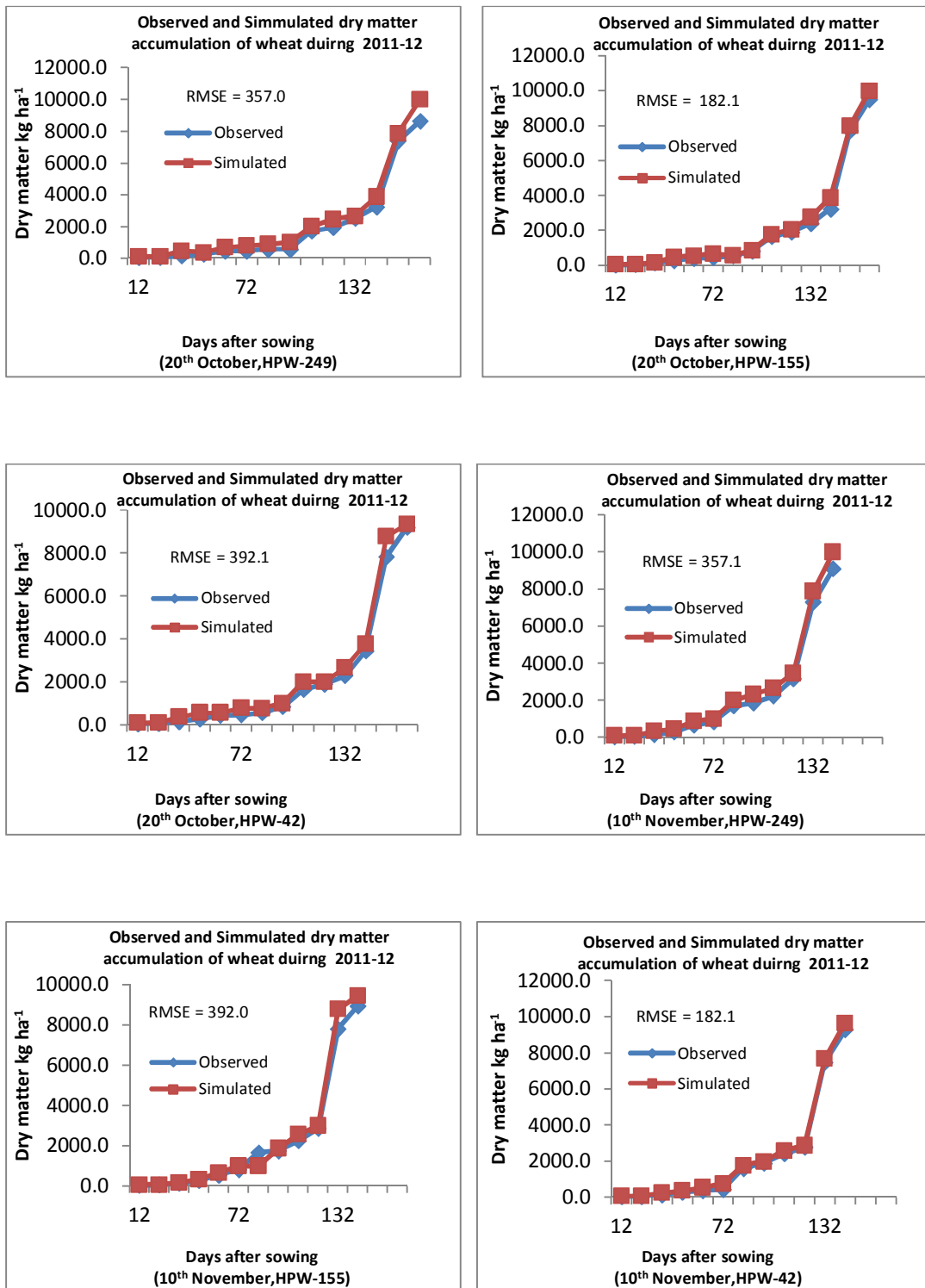


Fig. 4.4.5(a) Observed and simulated dry matter kg ha<sup>-1</sup> of wheat varieties sown on 20<sup>th</sup> October to 10<sup>th</sup> November during 2011-12

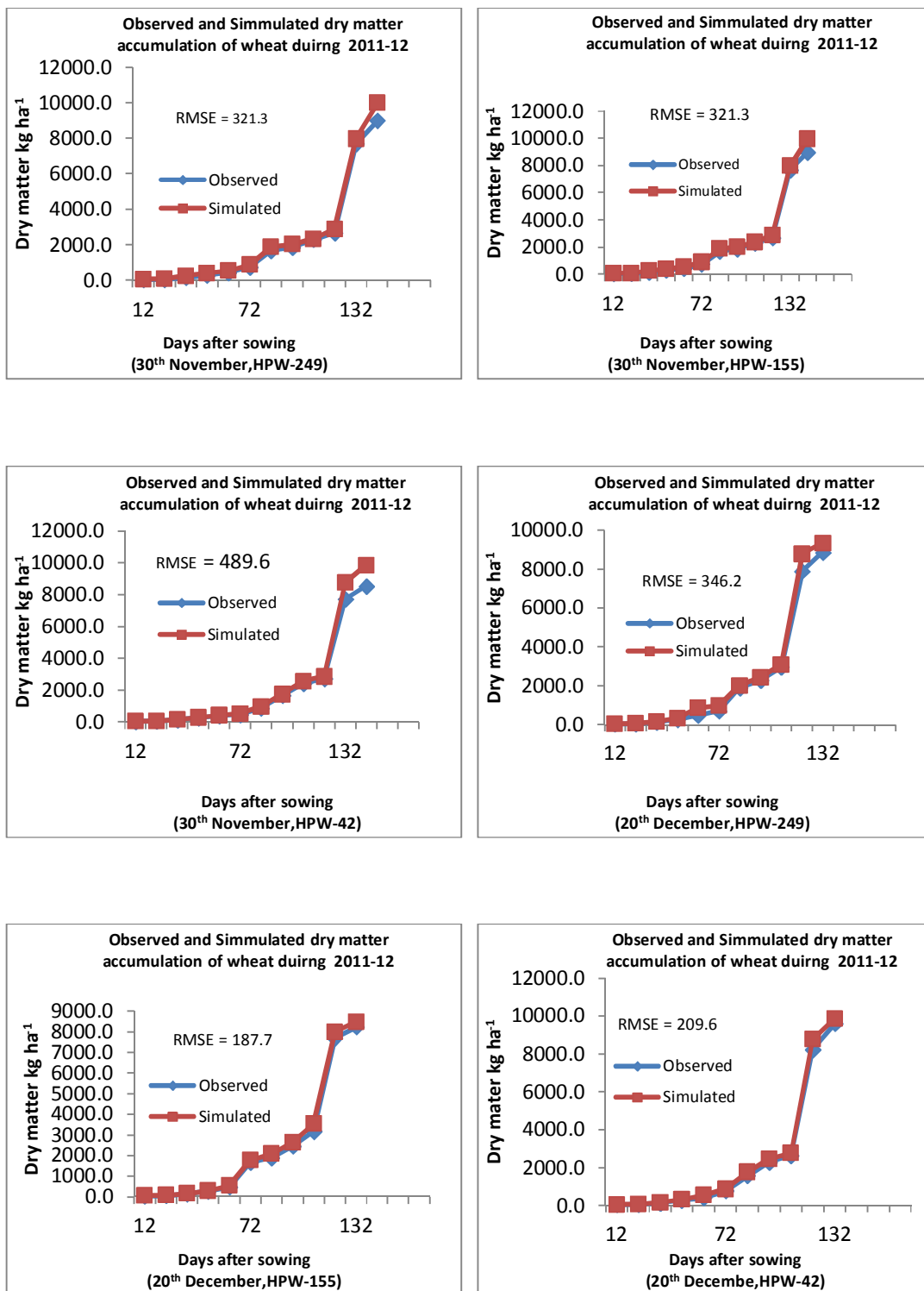


Fig. 4.4.5(b) Observed and simulated dry matter kg ha<sup>-1</sup> of wheat varieties sown on 30<sup>th</sup> November to 20<sup>th</sup> December during 2011-12

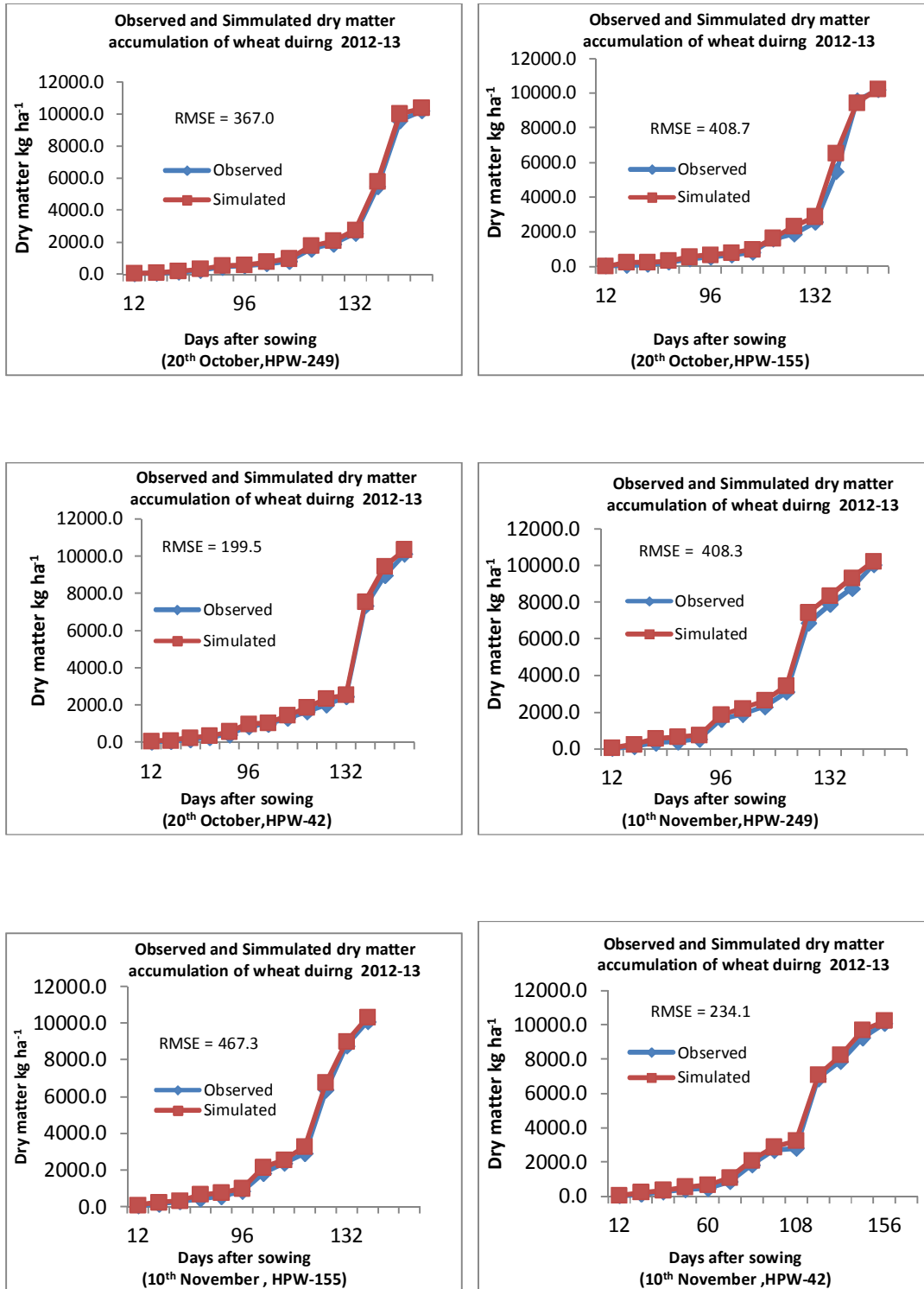


Fig. 4.4.6(a) Observed and simulated dry matter  $\text{kg ha}^{-1}$  of wheat varieties sown on 20<sup>th</sup> October to 10<sup>th</sup> November during 2012-13

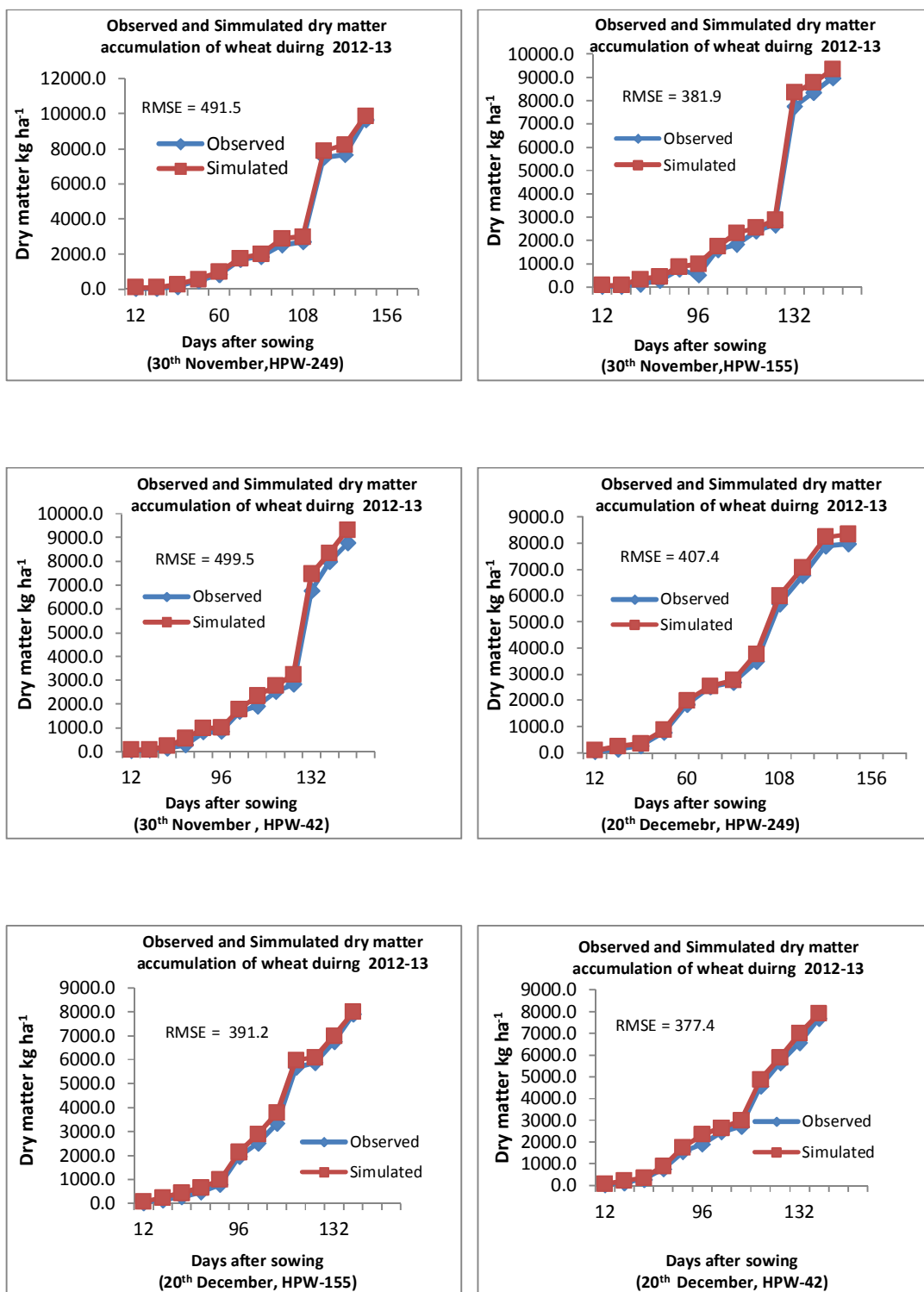


Fig. 4.4.6(b) Observed and simulated dry matter kg ha<sup>-1</sup> of wheat varieties sown on 10<sup>th</sup> November to 20<sup>th</sup> December during 2012-13

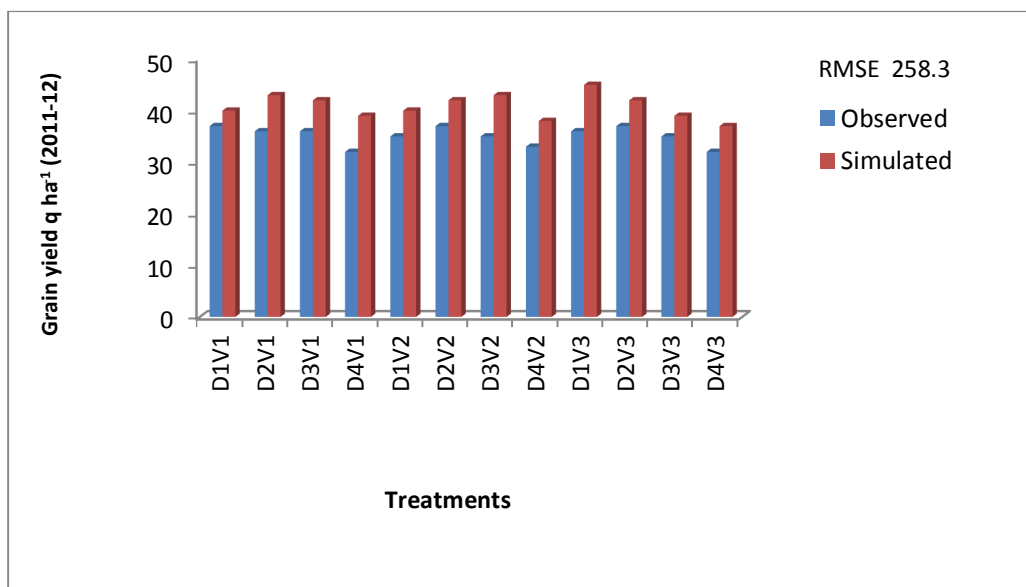


Fig. 4.4.7 Observed and simulated grain yield  $q \text{ ha}^{-1}$  during 2011-12

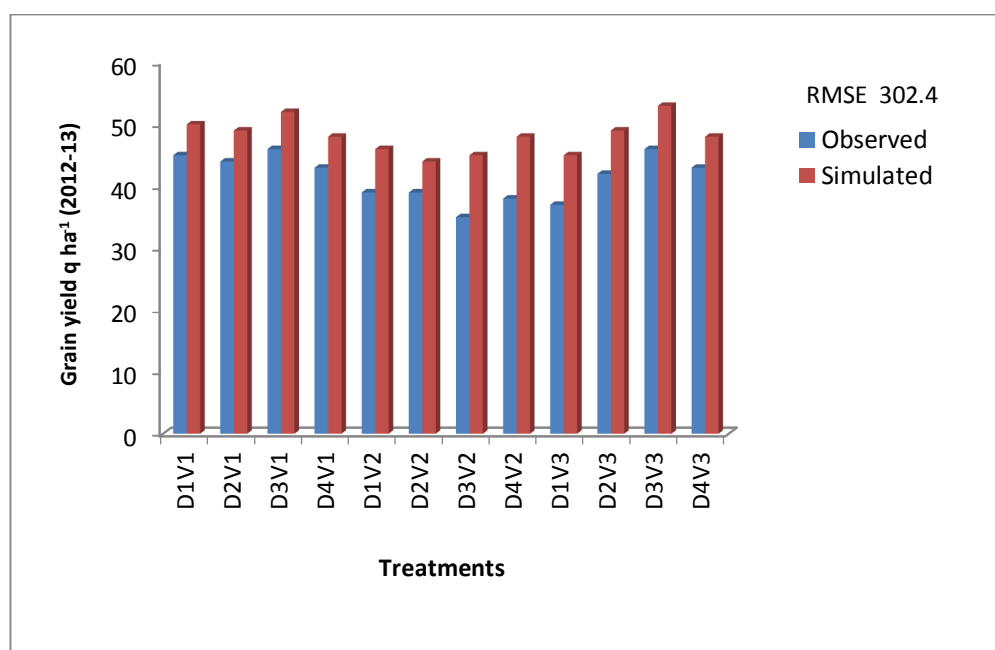


Fig. 4.4.8 Observed and simulated grain yield  $q \text{ ha}^{-1}$  during 2012-13

## **4.5 Economic studies**

The data pertaining to gross returns, net returns and benefit cost ratio have been presented in table 4.15 and analyses of variance have been given in appendix-VIII

### **4.5.1 Cost of cultivation**

The cost of inputs used, cost of intercultural practices etc. have been given in appendix-VI.

### **4.5.2 Gross Returns**

The data revealed that significantly highest gross returns were obtained in variety HPW-249 to the tune of ₹75568 during 2011-12 and ₹81219 during 2012-13 as compared to HPW-155 (₹70828 in 2011-12 and ₹76426 during 2012-13) and HPW-42 (₹ 67383 during 2011-12 and ₹72943 in 2012-13). Amongst sowing dates, 20<sup>th</sup> October sown crop gave significantly highest gross returns of ₹78708 during 2011-12 and ₹84394 during 2012-13 followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December during both the years.

### **4.5.3 Net returns**

Likewise, for gross returns the data revealed that significantly highest net returns were accrued in variety HPW-249 as compared to HPW-155 and HPW-42 during both the years. Amongst sowing dates, October 20 sown crop gave significantly highest net returns to the tune of ₹50210 during 2011-12 and ₹54855 during 2012-13 followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December. The interaction effects were not significant in both the years.

### **4.5.4 Benefit cost ratio**

The data revealed significantly highest benefit cost ratio in variety HPW-249 (₹1.6 during 2011-12) and (₹1.7 during 2012-13) as compared to HPW-155 and HPW-42. Amongst sowing dates, October 20 sown crop showed significantly highest benefit

cost ratio of ₹1.7 in 2011-12 and ₹1.8 in 2012-13 followed by 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December. The interaction effects were not significant in both the years.

The data on gross returns, net returns and B: C ratio revealed gradual reduction due to the delayed planting of crop from October 20 in both years. The highest gross returns, net returns and benefit cost ratio of ₹ 75568, 47070 and 1.6, respectively in the first year and ₹ 81219, 51681 and 1.7, respectively during second year were obtained from 20<sup>th</sup> October sown crop. Kumar (2011) also worked out the economics of the wheat crop under varying sowing environments and concluded higher net returns in early sown crop during October compared to December sown crop.

**Table 4.15** Effect of sowing dates and varieties on gross returns, (₹ ha<sup>-1</sup>), net returns (₹ ha<sup>-1</sup>) and B: C ratio of wheat during 2011-12 and 2012-13.

	Gross returns (₹ ha <sup>-1</sup> )		Net returns (₹ ha <sup>-1</sup> )		B:C ratio	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Variety						
HPW-155	70828	76426	42330	46888	1.4	1.5
HPW-249	75568	81219	47070	51681	1.6	1.7
HPW-42	67383	72943	38885	43405	1.3	1.4
CD (5%)	3807	3849	3807	3849	0.133	0.130
Dates of sowing						
20 Oct	78708	84394	50210	54855	1.7	1.8
10 Nov	75842	81496	47344	51958	1.6	1.7
30 Nov	69197	74777	40699	45239	1.4	1.5
20 Dec	61291	66783	32793	37245	1.1	1.2
CD (5%)	4396	4445	4396	4445	0.154	0.150

#### 4.5.5 Wheat yield prediction in district Kangra using statistical regression models

Multiple regression technique with the yield data for the period of 1985-2009 was used in developing model for wheat crop yield forecasting for the year 2011-12 and 2012-13. The yield predicted for the year 2012-13 was 1702.6 kg ha<sup>-1</sup> and 1732.7 kg ha<sup>-1</sup> at F2 and F3 stage, respectively. The forecast obtained from the regression equation revealed the deviation in yield prediction as low as 1.2 percent at F3 stage in the validation year 2009-10. During the yield simulation for the validation of the year 2011-12, the deviation percentage in the yield was 3.7 and 2.0 percent for F2 and F3 stage, respectively (Table 4.16).

The amount of variation in the deviation error percentage as explained by the fitted regression equations in terms of R<sup>2</sup> values which differed from mid season F2 stage to pre harvest F3 stage indicated improvement in the forecast model. The results revealed that more reliable forecasts can be obtained when the crops are at the pre harvest stage of the crop.

**Table 4.16 Regression models and prediction of *Rabi* wheat yield at mid-season (F2) and pre-harvest (F3) stage**

Equation	Predicted yield (kg ha <sup>-1</sup> ) 2012-13	Average yield (last 10 yrs) (kg ha <sup>-1</sup> )	Error (%)		
			2009-10	2010-11	2011-12
F2 equation Y = 1160.634742 + 1.895728 * Z241 + 0.079382 * Z341	1702.6	1395.1	1.5	15.2	3.7
F3 equation Y = 1823.924389 + 1.832711 * Z1211 + 4.896764 * Z31 + 6.173853 * Z51	1732.7	1395.1	1.2	10.9	2.0

Z241 - weighted weather index of Minimum Temperature and Relative humidity (morning)  
Z341 - weighted weather index of Rainfall and Relative humidity (morning)  
Z121 - weighted weather index of Maximum temperature and Minimum temperature  
Z31 - weighted weather index of Rainfall  
Z51 - weighted weather index Relative humidity (evening)

The yield of wheat was predicted using statistical regression model and validated with observed data. The predicted yields indicated 1.5, 15.2 and 3.7 percent at F2 stage during 2009-10, 2010-11 and 2011-12, respectively and 1.3, 10.9 and 2.0 percent errors

during 2009-10, 2010-11 and 2011-12, respectively at pre-harvest stage. The yield was more reliable in F3 stage for district Kangra. Similar results were also reported by Devi et al. (2013) under Assam conditions for rice crop. The model predicted 10 to 14.5 percent deviation in rice yield compared to actual productivity and yield variation was 10 to 18.1 per cent in different districts under study.

## 5. SUMMARY AND CONCLUSIONS

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The field experiment on wheat crop entitled, "Modeling and forecasting yield of wheat for Kangra district of Himachal Pradesh" was conducted during *Rabi* season of 2011-12 and 2012-13 at research farm of Department of Agronomy, Forages and Grassland Management, CSK HPKV, Palampur (Himachal Pradesh) with following objectives.

1. To calibrate and validate the wheat crop growth model for district Kangra of Himachal Pradesh.
2. To develop multiple crop yield forecasts for wheat using simulations and land based observations.

### 5.1 Growth characters

The emergence count was significantly highest in 20<sup>th</sup> October sown crop as compared to subsequent dates of sowing. Amongst varieties, HPW-249 showed significantly highest emergence count as compared to other varieties during both the years. The crop sown on 20<sup>th</sup> October produced significantly tallest plants whereas, 20<sup>th</sup> December sown crop resulted in significantly lowest plant height. Variety HPW-249 produced significantly taller plants as compared to other varieties during both the years.

Tiller count was significantly highest in 20<sup>th</sup> October sown crop as compared to other dates of sowing. The variety HPW-249 produced significantly highest number of tillers throughout the crop cycle. The crop sown on 20<sup>th</sup> October resulted in significantly higher dry matter production at all stages except at earing stage where 10<sup>th</sup> November sown crop produced significantly higher dry matter accumulation. The dry matter accumulation at harvest was significantly highest in HPW-249 compared to other two varieties in both the years. The crop sown on 20<sup>th</sup> October resulted in significantly highest leaf area index at all stages except at earing stage where 10<sup>th</sup> November sown crop produced significantly highest leaf area index. The leaf area index was significantly higher in HPW-249 over other varieties in both the years.

The highest emergence of seedling was recorded under 20<sup>th</sup> October sowing followed by 10<sup>th</sup> November. However, tillering was highest in 20<sup>th</sup> October sown crop. The number of days for attainment of physiological maturity was highest under 20<sup>th</sup> October sown crop followed by subsequent dates of sowing. Among different varieties, HPW-42 took more number of days for emergence. For attaining physiological maturity HPW-249 took significantly more number of days.

## 5.2 Yield attributes and yield

The tillers, grains per spike and 1000-grain weight were significantly highest in 20<sup>th</sup> October sown crop resulting in significantly highest grain and straw yields over subsequent dates of sowing during both the years. Amongst varieties, HPW-249 recorded significantly highest tillers<sup>-2</sup>, highest number of grains spike<sup>-1</sup> and 1000-grain weight resulted in highest grain and straw yields. The grain and straw yields were significantly were significantly highest in HPW-249.

## 5.3 Agro meteorological indices

Five different accumulated heat units indices *viz.* growing degree days (GDD), helio thermal unit (HTU), photo thermal unit (PTU), phenol thermal index (PTI) and heat use efficiency (HUE) were calculated.

The variety HPW-249, HPW-155 and HPW-42 accumulated 1661, 1641 and 1586 growing degree averaged over two years days under mid hill sub-humid region of Himachal Pradesh. Amongst sowing dates, *viz.* 20<sup>th</sup> October, 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crops, accumulated 1629, 1551, 1503 and 1461 growing degree days, respectively averaged over two years. The growing degree days decreased when sowing was delayed up to December 20.

Likewise, with respect to thermal time, the variety *viz.*, HPW-249, HPW-155 and HPW-42 accumulated 11310, 11786 and 10169 helio thermal unit (HTU) respectively pooled over two years. Amongst sowing dates, 20<sup>th</sup> October, 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December sown crops, accumulated 11952, 10983, 10430 and 9156 helio thermal unit (HTU) based on mean values of two years. The accumulated helio thermal units (HTU) reduced with delayed sowing and this was due to reduction in actual sunshine hours. Similar trends in photo thermal unit (PTU) were observed and values

averaged over two years were 16079, 15331 and 16373 for variety *viz.* HPW-249, HPW-155 and HPW-42, respectively during both years. The crop sown on 20<sup>th</sup> October, 10<sup>th</sup> November, 30<sup>th</sup> November and 20<sup>th</sup> December accumulated 16075, 15311, 13807 and 12818 average photo thermal units (PTU) during both years. The PTI values for attaining maturity in varieties HPW-155, HPW-42 and HPW-249 were 18.8, 17.5 and 16.5, respectively during the first year and 18.5, 17.9 and 17.8, respectively during second year of experimentation. The lowest pheno thermal index (PTI) was observed in HPW-42 to the tune of 16.7 when sown on 20<sup>th</sup> December during both the years. The lowest pheno thermal index (PTI) was observed when crop sown on December 20 during 2012-13. The HUEs values at maturity, for varieties *viz.* HPW-249 and HPW-155 and HPW-42 were 5.8, 5.2 and 5.2, respectively during the first year and 7.5, 6.9 and 6.7 respectively, during second year. The lowest HUE was observed in HPW-42 (2.9) when sown in October 20 in first year. The lowest HUE was obtained in HPW-249 (4.6) when sown in 20<sup>th</sup> December in second year.

#### **5.4 Crop modeling studies**

The crop model simulated days to vegetative stage varied between -4 to +4 days compared to the observed days. The RMSE values for days taken to vegetative stage were 6.3 and 8.6, means good fit of model for this parameter in both the years. The simulated days to physiological maturity were estimated and the RMSE values for days to maturity were 9.2 and 10.3 during 2011-12 and 2012-13, respectively. The crop model simulated days to physiological maturity varied between -6 to +5 days compared to the observed days. The simulated dry matter accumulation matched closely with observed dry matter accumulation for all sowing environments. The RMSE values for dry matter accumulation ranged from 147 to 348 kg ha<sup>-1</sup> in 2011-12 and 234 to 364 kg ha<sup>-1</sup> in 2012-13. It was observed that the differences between simulated and observed biomass were marginal in early and late sown crops in three cultivars.

The simulated leaf area index matched closely with observed for all treatments. The RMSE values for leaf area index ranged from 0.2 to 0.5. The differences were higher in early and late sown crop.

The simulated grain yield by the model corresponded well with that of observed grain yield. The RMSE values for grain yield were 258 kg ha<sup>-1</sup> in 2011-12 and 302 kg ha<sup>-1</sup> in 2012-13 with 7-8 per cent variation from the observed.

### **5.5 Wheat yield prediction in district Kangra using statistical regression models**

Multiple regression technique with the yield data for the period of 1985-2009 of district Kangra was used in developing statistical model for wheat crop yield forecasting for the year 2011-12 and 2012-13. The yield predicted for the year 2012-13 was 1702.6 kg ha<sup>-1</sup> and 1732.7 kg ha<sup>-1</sup> at F2 (Mid season) and F3 (Preóharvest) stage, respectively. The forecast obtained from the regression equation revealed the deviation as low as 1.2 percent at F3 stage in the validation year 2009-10 in yield prediction. During the yield simulation for the validation of the year 2011-12 the deviation percentage in the yield was 3.7 and 2.0 percent for F2 and F3 stage, respectively.

## CONCLUSIONS

- The results indicated that the variety HPW-249 out yielded all other varieties whereas yields of HPW-155 and HPW-42 was at par with each other. The sowing windows influenced the growth and yield attributes, grain and straw yields significantly.
- The growth and yield attributes *viz.* plant height, number of tiller metre<sup>-2</sup>, number of grains tillers<sup>-1</sup> and 1000-grain weight was higher in variety HPW-249 during both the years. Amongst sowing environments, 20<sup>th</sup> October sown crop gave significantly highest values of growth and yield attributes during both the years.
- The days taken to complete vegetative, heading and physiological stage were significantly highest in crop sown on 20<sup>th</sup> October during both years. In the present investigation it was concluded that early sown crop averaged over two years took 35,25 and 24 more days for maturity, heading and vegetative stages, respectively compared to with sowing delayed up to 20<sup>th</sup> December.
- The sowing beyond 30<sup>th</sup> November up to 20<sup>th</sup> December resulted in significant reduction in yield. The decrease in grain yield averaged over two years was 3.4 per cent in 10<sup>th</sup> November, 7.9 percent in 30<sup>th</sup> November and 19.6 percent in 20<sup>th</sup> December sown crop compared to 20<sup>th</sup> October sown crop under mid hill conditions of Himachal Pradesh. The HPW-249 gave 9.4 and 6.9 percent higher grain yield averaged over two years in comparison to HPW-155 and HPW-42. The economic returns and benefit cost ratio were also significantly highest in HPW-249. Likewise, grain yield, net returns and B: C ratio was significantly highest in 20<sup>th</sup> October sown crop compared to subsequent dates of sowing.
- The agro meteorological indices indicated more values for 20<sup>th</sup> October to 30<sup>th</sup> November sown crop and lowest values in late sown crop. GDD, HTU and PTU were higher in early sown crop. Amongst varieties, HPW-249 showed higher values compared to other varieties. Amongst dates of sowing, similar patterns were followed for HTU and PTU at different growth stages and also indicated that emergence to heading registered lower growth rate compared to other growth stages.

- The simulated LAI, dry matter accumulation, grain yield, days to physiology maturity and vegetative stage matched closely with observed values for all sowing environments. The RMSE values for dry matter accumulation varied from 147 to 348 kg ha<sup>-1</sup> in 2011-12 and 234 to 364 kg ha<sup>-1</sup> in 2012-13. It was observed that the differences between simulated and observed biomass were marginal in early and late sown crops in three cultivars. The RMSE values for leaf area index ranged from 0.5 to 0.2. The differences were higher in early and late sown crop. The RMSE values for yield were 258 kg ha<sup>-1</sup> in 2011-12 and 302 kg ha<sup>-1</sup> in 2012-13. The model performance was somewhere under estimated or overestimated but found within acceptable limits.
- The yield of wheat was predicted using statistical regression model and validated with observed data. The predicted yields indicated 1.5, 15.2 and 3.7 percent deviation at mid season (F2) stage during 2009-10, 2010-11 and 2011-12, respectively and 1.3, 10.9 and 2.0 percent errors during 2009-10, 2010-11 and 2011-12, respectively at pre-harvest stage. The yield was more reliable in preó harvest (F3) stage for district Kangra.

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**APPENDICES****Appendix I. Week wise meteorological observations from October, 2011 to May, 2012 of Palampur (H.P)**

Met. Weeks	Max Temp ( <sup>o</sup> C)	Min Temp ( <sup>o</sup> C)	Wind speed (kmph)	Rainfall (mm)	BSS	Evp (mm)
39	27.6	14.9	5.3	3.4	9.9	3.5
40	25.8	13.8	4.9	3.2	8.7	2.7
41	25.3	11.7	5.7	0.0	8.9	2.4
42	26.3	13.2	5.7	4.2	9.6	2.8
43	22.6	9.5	5.8	14.6	9.2	2.1
44	23.9	10.3	5.5	0.0	9.6	2.3
45	22.0	9.2	5.5	0.0	9.1	1.9
46	21.3	7.9	5.6	0.0	8.9	1.5
47	20.2	7.1	5.4	0.0	6.6	1.6
48	18.2	6.2	5.8	4.0	6.9	1.5
49	22.0	7.8	5.6	0.0	7.4	1.9
50	15.5	6.6	6.4	34.2	3.4	0.6
51	19.2	5.3	5.5	0.0	8.2	1.4
52	17.4	5.4	5.4	0.0	6.1	1.9
1	15.2	2.3	5.4	0.0	7.3	1.4
2	14.5	6.0	5.7	1.8	7.5	1.6
3	14.7	4.8	6.7	73.6	5.4	1.4
4	16.6	3.6	5.8	0.0	8.1	2.7
5	17.8	6.2	5.4	26.0	4.8	2.7
6	15.4	4.6	7.4	60.6	5.8	2.5
7	16.3	6.8	5.8	14.0	4.8	4.6
8	16.5	6.2	7.0	46.2	5.9	4.9
9	19.5	8.6	6.4	18.4	7.0	4.8
10	23.9	11.1	6.3	0.0	8.7	4.8
11	21.4	8.9	6.9	9.4	5.6	4.3
12	22.9	10.6	7.5	76.2	7.1	3.8
13	22.1	10.4	6.3	36.2	6.8	3.7
14	24.5	12.2	6.4	0.0	8.7	4.2
15	26.9	13.4	6.5	23.0	8.9	4.7
16	26.1	14.0	7.0	18.6	7.4	3.7
17	25.1	14.9	6.1	13.0	6.1	3.7
18	29.7	17.1	7.1	0.0	8.1	5.7
19	30.4	16.6	7.3	27.2	7.1	6.9
20	31.5	18.6	6.7	0.0	10.4	7.8
21	36.4	20.9	6.6	1.4	10.2	10.6
22	37.3	22.6	6.5	0.0	6.7	9.8

**Appendix II. Week wise meteorological observations from October, 2012 to May, 2013 of Palampur (H.P)**

Met. Weeks	Max Temp ( <sup>0</sup> C)	Min Temp ( <sup>0</sup> C)	Wind speed (kmph)	Rainfall (mm)	BSS	Evp (mm)
39	26.2	15.4	5.3	32.4	3.7	3.1
40	25.5	15.7	4.7	32.2	3.6	2.6
41	27.1	14.4	5.2	0.0	3.9	2.6
42	25.9	12.5	5.5	0.0	3.7	2.2
43	24.2	11.7	5.8	2.6	3.5	2.3
44	23.4	10.8	5.4	1.8	3.3	2.3
45	23.6	11.5	5.5	0.0	3.4	1.7
46	23.0	10.1	5.5	0.0	3.3	1.9
47	22.7	9.7	5.3	0.0	3.2	1.8
48	20.7	7.1	5.4	0.0	3.0	1.8
49	21.9	8.7	6.1	6.0	3.1	1.3
50	18.5	4.6	5.8	0.0	2.6	0.8
51	17.9	3.6	5.8	0.0	2.6	1.6
52	18.2	4.0	5.7	0.0	2.6	1.6
1	14.9	4.3	7.0	51.4	2.1	1.3
2	13.0	2.5	6.3	34.6	1.9	1.5
3	9.8	2.4	6.4	109.2	1.4	1.7
4	15.3	3.3	5.8	0.0	2.2	2.7
5	16.4	4.8	6.3	30.5	2.3	2.6
6	14.6	3.3	5.8	4.4	2.1	2.7
7	14.2	5.1	6.6	34.4	2.0	4.6
8	17.7	7.5	5.9	10.6	2.5	4.9
9	19.9	8.0	6.4	0.0	2.8	5.7
10	18.9	6.8	7.0	20.4	2.7	4.8
11	20.8	8.5	6.1	12.2	3.0	4.3
12	25.5	11.0	6.0	0.0	3.6	3.6
13	26.0	13.5	6.6	0.0	2.9	3.7
14	28.4	14.9	7.1	3.6	3.8	4.2
15	25.0	12.2	7.2	18.8	3.6	4.7
16	25.6	13.8	6.4	7.6	2.6	3.7
17	26.2	13.0	7.0	27.2	3.4	3.4
18	27.0	14.5	6.7	0.0	3.7	5.7
19	31.1	16.7	6.8	34.0	3.2	6.8
20	31.8	17.9	7.4	0.0	3.7	7.8
21	32.8	19.5	8.2	1.2	2.9	9.9
22	35.6	21.6	7.6	0.4	3.2	9.6

**Appendix III. Analyses of variance for plant height (cm) and tiller m<sup>-2</sup> growth and yield attributes during 2011-12 and 2012-13**

Source of variation	d.f.	Mean sum of square	
		Plant height (cm)	Tiller m <sup>-2</sup>
<b><u>2011-12</u></b>			
Replication	2	204.6	469.1
Varieties(V)	2	447.8	804.4
Dates of sowing(D)	3	178.6	201.4
Interaction (V X D)	6	95.6	505.6
Error	22	92.2	352.2
<b><u>2012-13</u></b>			
Replication	2	328.4	469.1
Varieties(V)	2	546.3	804.1
Dates of sowing(D)	3	376.6	201.4
Interaction (V X D)	6	98.2	505.6
Error	22	93.6	352.2

**Appendix IV. Analyses of variance for grains spike<sup>-1</sup> and 1000-grain weight, growth and yield attributes during 2011-12 and 2012-13**

Source of variation	d.f.	Mean sum of square	
		Grains spike <sup>-1</sup>	1000-grain weight
<b><u>2011-12</u></b>			
Replication	2	1.8	4.0
Varieties(V)	2	5.6	20.0
Dates of sowing(D)	3	3.7	41.0
Interaction (V X D)	6	2.3	11.3
Error	22	4.8	7.5
<b><u>2012-13</u></b>			
Replication	2	6.1	7.7
Varieties(V)	2	1.0	60.5
Dates of sowing(D)	3	2.2	161.5
Interaction (V X D)	6	2.6	1.7
Error	22	2.7	6.0

**Appendix V. Analyses of variance for dry matter kg ha<sup>-1</sup> and leaf area index during 2011-12 and 2012-13**

Source of variation	d.f.	Mean sum of square	
		Dry matter kg ha <sup>-1</sup>	Leaf area index
<b><u>2011-12</u></b>			
Replication	2	459614.5	0.001
Varieties(V)	2	3577106	0.041
Dates of sowing(D)	3	9536742	0.061
Interaction (V X D)	6	100826.2	0.022
Error	22	356922.9	0.008
<b><u>2012-13</u></b>			
Replication	2	565705.4	0.002
Varieties(V)	2	3826977	0.006
Dates of sowing(D)	3	9784958	0.022
Interaction (V X D)	6	113480.7	0.005
Error	22	294932.4	0.009

**Appendix VI. Analyses of variance for grain yield (q ha<sup>-1</sup>), straw yield (q ha<sup>-1</sup>), gross returns (₹ ha<sup>-1</sup>), net returns (₹ ha<sup>-1</sup>) and B: C ratio during 2011-12 and 2012-13**

Source of variation	d.f.	Mean sum of square				
		Grain yield (q ha <sup>-1</sup> )	Straw yield (q ha <sup>-1</sup> )	Gross returns (₹ ha <sup>-1</sup> )	Net returns (₹ ha <sup>-1</sup> )	B:C ratio
<b><u>2011-12</u></b>						
Replication	2	7.7	15.9	26038055	26038055	0.032
Varieties(V)	2	60.5	123.8	2.03E+08	2.03E+08	0.249
Dates of sowing(D)	3	161.5	330.2	5.4E+08	5.4E+08	0.66
Interaction (V X D)	6	1.7	3.4	5711999	5711999	0.007
Error	22	6.0	12.8	20220377	20220377	0.024
<b><u>2012-13</u></b>						
Replication	2	7.8	17.4	26622132	26622132	0.030
Varieties(V)	2	68.2	135.9	2.07E+08	2.07E+08	0.23
Dates of sowing(D)	3	171.5	362.4	5.52E+08	5.52E+08	0.63
Interaction (V X D)	6	1.8	3.8	5840129	5840129	0.006
Error	22	7.0	13.5	20673954	20673954	0.023

Appendix VII. Cost of cultivation ₹ ha<sup>-1</sup> calculated *Rabi* during 2011-12 and 2012-13

Sr. No	Particular	2011-12			2012-13		
		Quantity Unit	Rate (₹ Unit <sup>-1</sup> )	Amount (₹ ha <sup>-1</sup> )	Quantity Unit	Rate (₹ Unit <sup>-1</sup> )	Amount (₹ ha <sup>-1</sup> )
1.	Land preparation						
	Ploughing (Tractor hrs)	20	300	6000	22	300	6600
2.	Sowing	3	120	360	4	120	480
	Plot preparation	6	120	720	6	120	720
	Irrigation	4	120	480	4	120	480
	Hand weeding	2	120	240	2	120	240
	Herbicide + fungicide spray	4	120	480	5	120	600
	Harvesting	4	120	480	4	120	480
	Threshing	4	120	480	4	120	480
	Watch and ward	2	120	240	2	120	240
3.	Cost of input						
	Seed (kg ha <sup>-1</sup> )	100	10	1000	100	11	1100
	Isoproturon	1.67	400	668	1.67	400	668
	N (Urea 120 kg ha <sup>-1</sup> )	260.9	11	2869.9	260.9	11	2869.9
	P <sub>2</sub> O <sub>5</sub> (SSP 60 kg ha <sup>-1</sup> )	375	27	10125	375	27	10125
	K <sub>2</sub> O (MOP 30 kg ha <sup>-1</sup> )	50	8.2	410	50	8.3	415
	Miscellaneous	100	32.2	3220	100	33.2	3320
				695.1			720.4
	<b>Total</b>			<b>28498</b>			<b>29538</b>

### Brief Biodata of student

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Total-13

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Scientific Popular Articles-12

Others- Book chapter-1

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