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Comparison of Simulated and Statistical Model Prediction of Wheat at District Scale Yield under Sub-Temperate Climate of North Western Himalayas

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ABSTRACT

Crop growth models were successfully used for forecasting yields of various crops at district and state level. Multiple regression technique was employed to develop models to forecast wheat yield for district Kangra of Himachal Pradesh by using weather and yield data of 25 years (1985 to 2011). Data for two years (2011-12 and 2012-13) was used to calibrate and validate the model. The field experiment were conducted during rabi with three varieties viz., HPW-249, HPW-155 and HPW-42 and four sowing environments viz. 20th October, 10th November, 30th November and 20th December. The statistical model was validated for at mid-season (F2) and pre harvest stage (F3) corresponding to 15th March and 15th April respectively. The sensitive periods of statistical and phenological significance were selected for regression analysis. The GDD decreased with delay in sowing. The crop sown on 20th October accumulated 153-170 degree days to attain complete emergence, 508 to 591 degree days to vegetative, 781 to 853 degree days to heading stage and 1502 to 1688 degree days to physiological maturity. 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 in 2011-12 and 234 to 364 kg/ha 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 in 2011-12 and 302 kg/ha in 2012-13. The model performance was either underestimated or overestimated but found within acceptable limits. 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 found to be more reliable in pre-harvest (F3) stage for district Kangra. The simulated yield of 2012-13 showed 15.1 higher yield compared to actual yield of the year and more than 18.8 percent higher yield observed compared to statistical model. Hence, In order to augment the accuracy of simulated model yield more farmers' practices are to be surveyed to include in the model inputs.

Key words: Wheat, Simulation, Validation, Yield forecast, Statistical model prediction.

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INTRODUCTION

Wheat is the predominant *rabi* season crop of Himachal Pradesh and occupies 10% of country's acreage and produces nearly 9% of the total yield. The productivity of wheat in the state is around 2.8 tonnes/ha with an area and production of 0.36 million hectares and 1.02 million tonnes respectively[2]. Though, at present Himachal Pradesh is self-sufficient in wheat production but there is need to further increase its production and productivity to fulfill the requirement of growing population and to maintain the state's share to national production. It is also well known that crop productivity is highly dependent on climatic changes and variability. The state experiences inadequate and erratically distributed rainfall during critical stages of wheat growth resulting in poor germination and seedling growth of the crop. The low air and soil temperature conditions during initial phases of crop growth also results in lower crop productivity[11]. In order to sustain agricultural productivity under large range of climatic variations there is need to quantify the growth and yield of important crops and to identify suitable adaptation measures. Crop growth models have considerable potential in exploration of crop management and policy decisions for implementations and adapting to current and future climate change[4,13]. Crop growth models can be used effectively for evaluating crops/varieties and other management practices to optimize and stabilize production under various soil types and agro-climatic conditions. The models can be used for determining the production potential of a location, for matching agro-technology with the farmers' resources, analyzing yield gaps, forecasting yields, and assessing the impact of climatic variability and climate changes on agriculture[1]. Infocrop is a dynamic crop yield model and has capacity to evaluate the production of major annual crops and has an inbuilt database of Indian soils[1].

Advance estimates of production in major crops are required by the Government for taking various policy decisions relating to pricing, marketing, distribution, export/import etc[3]. The traditional approach of crop production estimation in India is based on crop cutting experiments (CCE) for forecasting crop yields. The crop acreage and corresponding yield estimate data is further used to obtain production estimates which are acquired after the crop season is over. These emphasis the need to develop the methodology for in-season estimation of crop production. Hence, an important project was launched by Ministry of Agriculture, Govt. of India in collaboration with Space Application Centre (SAC), Institute of Economic Growth (IEG) and India Meteorological Department (IMD) *viz.*, Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL). Under this FASAL project, IMD in collaboration with 46 Agromet Field Units (AMFU) located at different parts of the country develops intra-seasonal operational yield forecast at district and state level for 13 major crops of India during *kharif* and *rabi* seasons using statistical model[8]. The statistical models utilized crop growth parameters for yield predictions. This approach does not easily lead to an explanation of the cause and effect relationship but is a practical approach for assessment of yield. The coefficients in such 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. Dadhwal and Ray reported use of such regression models for district level yield forecasting in India. However, the regression-based models are highly variable and do not consistently provide adequate accuracy for larger areas since they are empirical in nature. The variables used in the regression models to increase the accuracy (or the R-square) cannot be of global application as such variables differ from region to region. In the present paper, in order to demonstrate the methodology for crop yield forecast through regression technique along with the interpretations, the relevant data of wheat, being the predominant crop in the State, have been used. Keeping these points in view, the present study was undertaken to develop multiple crop yield forecasts using simulations and land based observations for wheat crop in Kangra district of Himachal Pradesh.

MATERIALS AND METHODS

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, transpiration, 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_4-N and NO_3-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, specific 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* 2011-12 and 2012-13 at the research farm of the Department of Agronomy, Forage and Grassland Management, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (32 6’ N, 76 3’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 respectively. The experiment was laid out in randomized block design with three replications. The treatment combination comprised of four sowing dates 20 October (D1), 10 November (D2) and 30 November (D3) and 20 December (D4)) and three varieties (HPW-249 (V1), HPW-155 (V2) and HPW-42 (V3). The crop was grown with all recommended package and practice for the experimental stations. The crop experienced well distributed rainfall of 509.2mm and 475.5mm during the crop season in 2011-12 and 20012-13 respectively. 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 coefficients for mustard 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

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

$$RMSE = \frac{\sum_{i=1}^{n} (Si-Ob)^2}{n}$$

Where, n is the number of observations; Si and Ob are simulated and observed values, respectively, at the i^{th} observation.

Crop yield prediction through statistical modeling

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 (Tmax), minimum temperature (Tmin), 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[6] had been extended by including interaction terms as per the IASRI, New Delhi guidelines[7]. 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, riw = correlation coefficient of yield with ith weather variable in wth period rii´w = correlation coefficient of yield with product of ith and i´th weather variable in wth period m = number of meteorological weeks considered for forecast p = number of weather variables used c = random error distribution as N (0, σ2)

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):

$$RMSE = \left[\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{n}\right]^{1/2}$$

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^{th} March and 15^{th} April respectively. The wheat yield was predicted using the Info Crop growth simulation model for district of Kangra. For fertilizers' dose of NPK used by farmers, farmers from located in different blocks of district surveyed and ddat of ECF AICRIP cropping system was used . The previous year statistics of fertilizer use for the district were also considered[2]. The 50 kg NPK dose was used to simulate the yield productivity of the wheat crop for district Kangra and model was run for past five years 2010-2012. The seed rate of 120 kg was used and no irrigation was given to simulate the predicted yield simulation.

RESULTS AND DISCUSSION

Validation of Info Crop model

Phenology

Days to vegetative stage

Simulated days to vegetative stage were compared with observed data for different treatments. The Info crop model simulated the days to vegetative stage between -4 to +4 days of the observed days (Fig 1). The root mean square error (RMSE) value for days taken vegetative stage was 6.3 days during 2011-12 and 8.6 days during 2012-13, this means good fit of model for this parameter.

Days to physiological maturity

The simulated days to physiological maturity were estimated between -6 to +5 days of the observed field data for different varieties (Fig. 2). The root mean square error (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 and observed RMSE of 1.73.

Growth and yield

Leaf area index (LAI)

Info Crop model was evaluated for leaf area index (LAI) of wheat measured at different crop growth stages (Fig. 3 to 6). The root mean square error (RMSE) values for leaf area index ranged from 0.10 to 0.17. The differences were higher in early and late sown crop. The results are in conformity with Singh *et al.,* 2013. The RMSE values from 0.08 to 0.11 for maximum LAI of wheat crop were obtained while validating WOFOST model by Mishra *et al*., 2013.

Dry matter production

The root mean square error (RMSE) values for dry matter accumulation ranged from 182.1 to 489.6 kg /ha in 2011-12 and 199.5 to 499.5 kg/ha in 2012-13 (Fig 7 to 10). The lower value of RMSE indicated good fit of model for this parameter. Similar results were reported by Sharma and Kumar (2005) under Palampur conditions.

Yield

Info crop model was validated for simulating wheat yield for Palampur location using wide range of yield data for dates of sowing and varieties. The economic yield simulated by model corresponded well with that actually observed in the field (Fig.11 & 12). The root mean square error (RMSE) value for yield was 258.3 kg/ha in 2011-12 and 302.4 kg/ha in 2012-13 which was 7-8 percent higher from the observed yields. Sharma and Kumar (2005) also observed less than 10 per cent variations in simulated and observed grain yields in wheat under similar environmental conditions while validating DSSAT crop model. Mishra *et al.,* 2013 reported RMSE values between 70 to 92 kg /ha for grain yield in wheat using WOFOST model.

Simulated Wheat yield prediction in district Kangra using Info Crop Model:

The wheat crop productivity was predicted using Info-Crop model. The Inputs used by farmers were surveyed and similar inputs values were used to predict the yield. The 16.5 % higher wheat yield was predicted in comparison to statistical model and more than 18.8 higher yield compared to actual productivity reported by Department of revenue GOHP. The simulated yield predicted in general was higher than both actual and statistical model.

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-1 and 1732.7 kg ha-1 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 R2 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. 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.*[5] 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. Neeraj et al. (2014) predicted the wheat yield using multiple regression model at district scale in Gujarat. The study revealed the wheat yield variation to the tune of -8.27 to 11.51% at Navsari and -12.07 to 6.86% at Bharuch district.

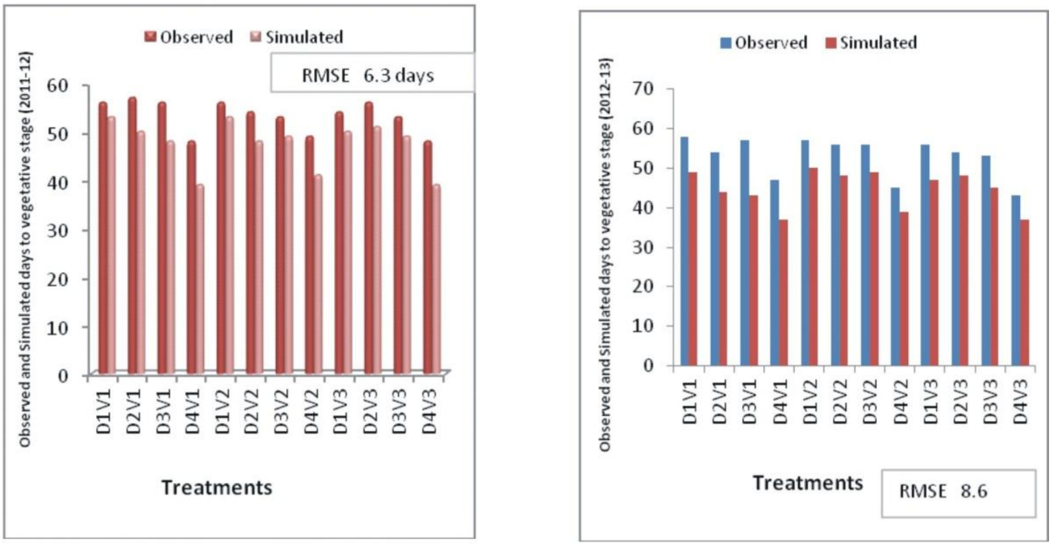

Fig. 1: Observed and Simulated days to vegetative stage during 2011-12 and 2012-13

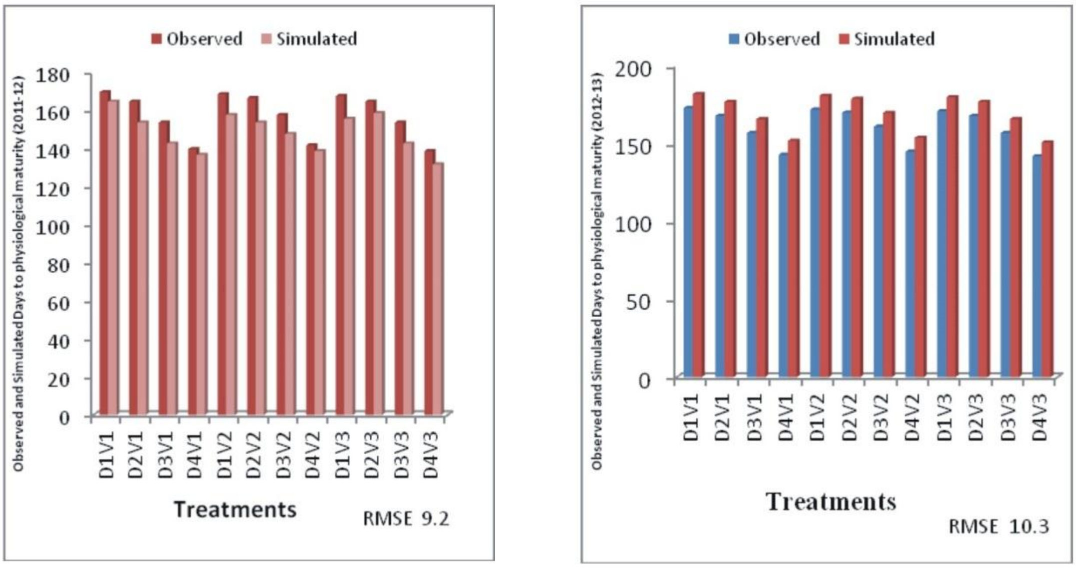

Fig. 2: Observed and Simulated days to physiological maturity during 2011-12 and 2012-13

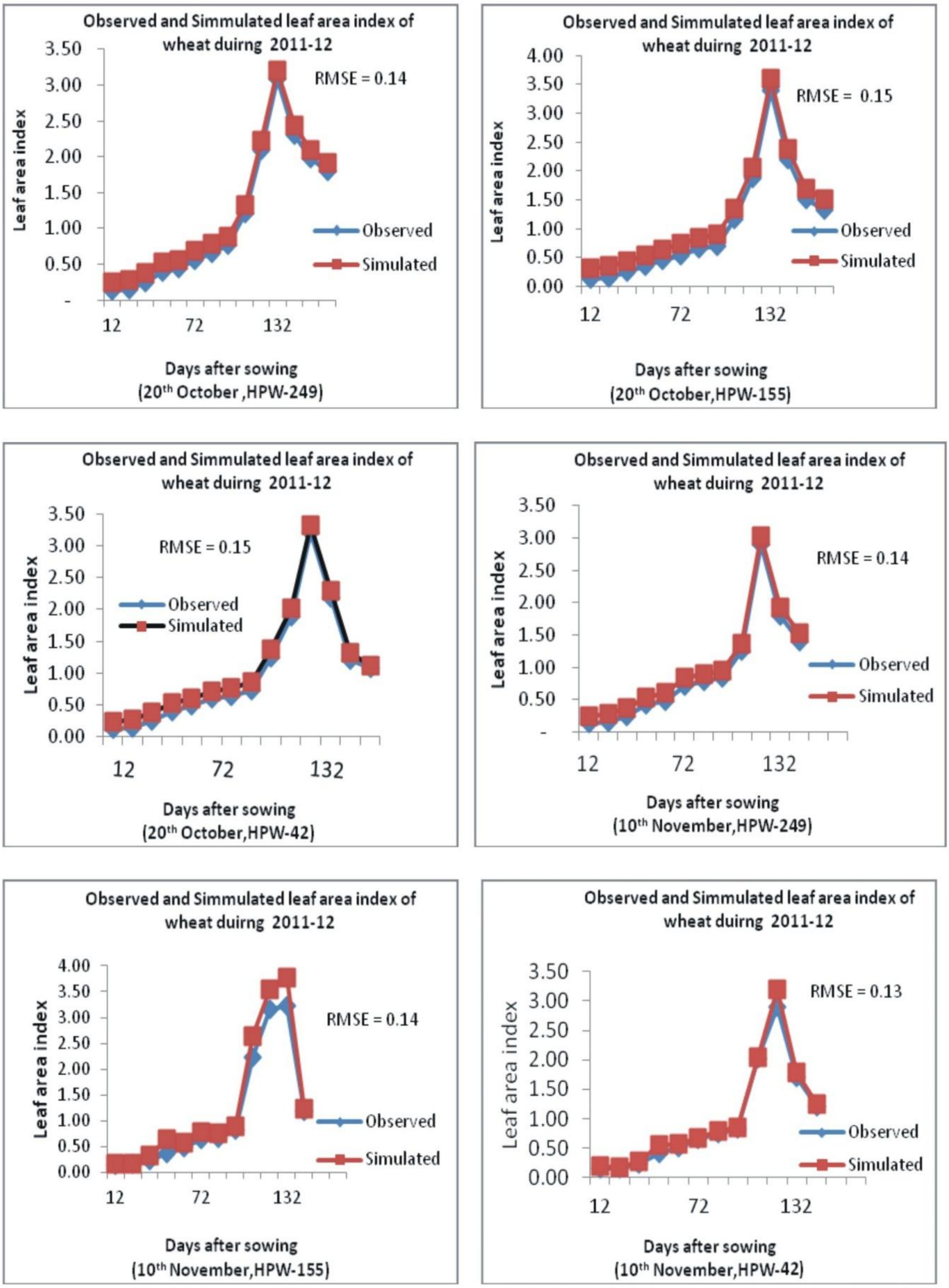

Fig. 3: Observed and simulated LAI of wheat varieties sown on 20th October to 10th November during 2011-12

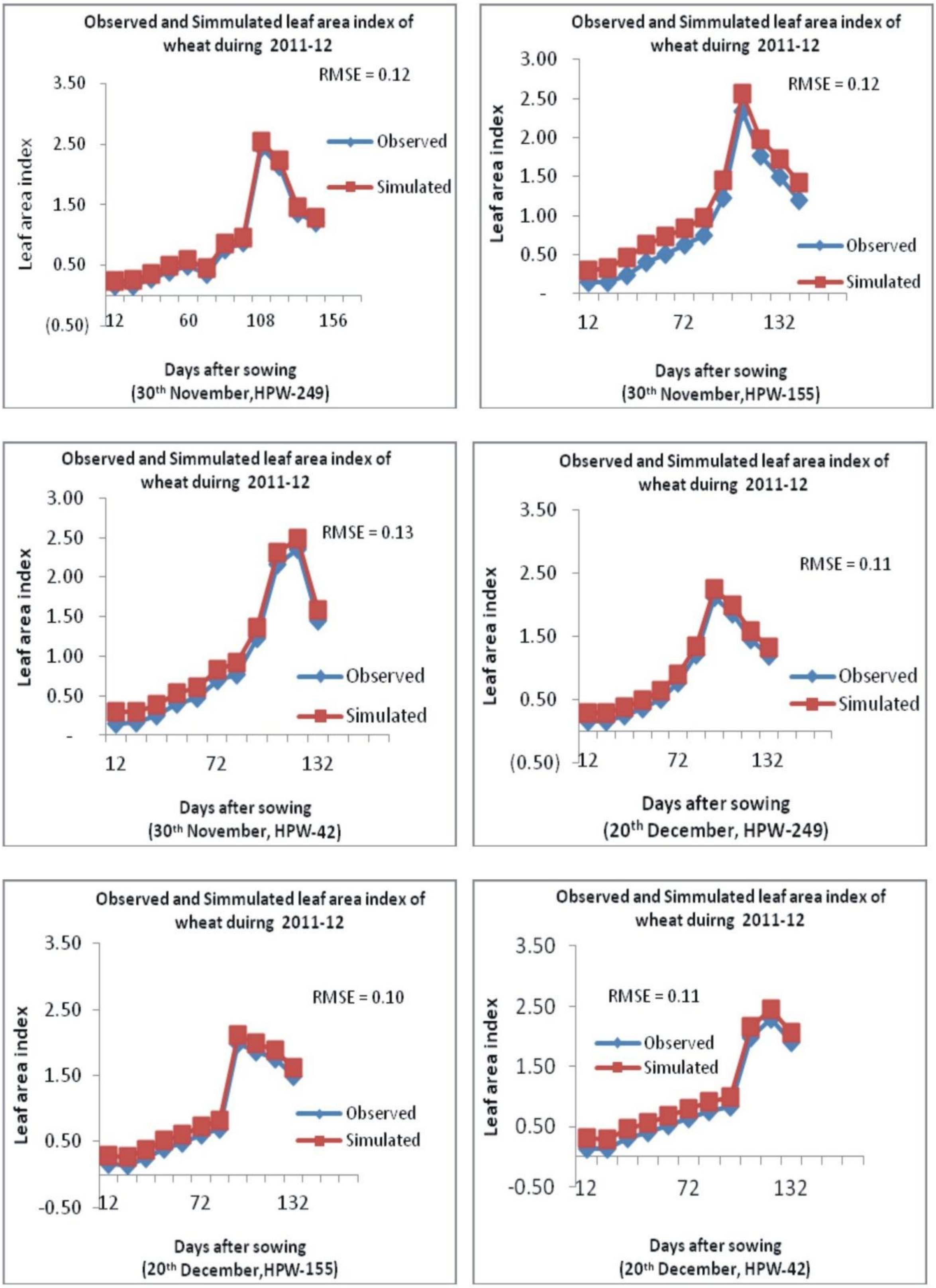

Fig. 4: Observed and simulated LAI of wheat varieties sown on 10th November to 20th December during 2011-12

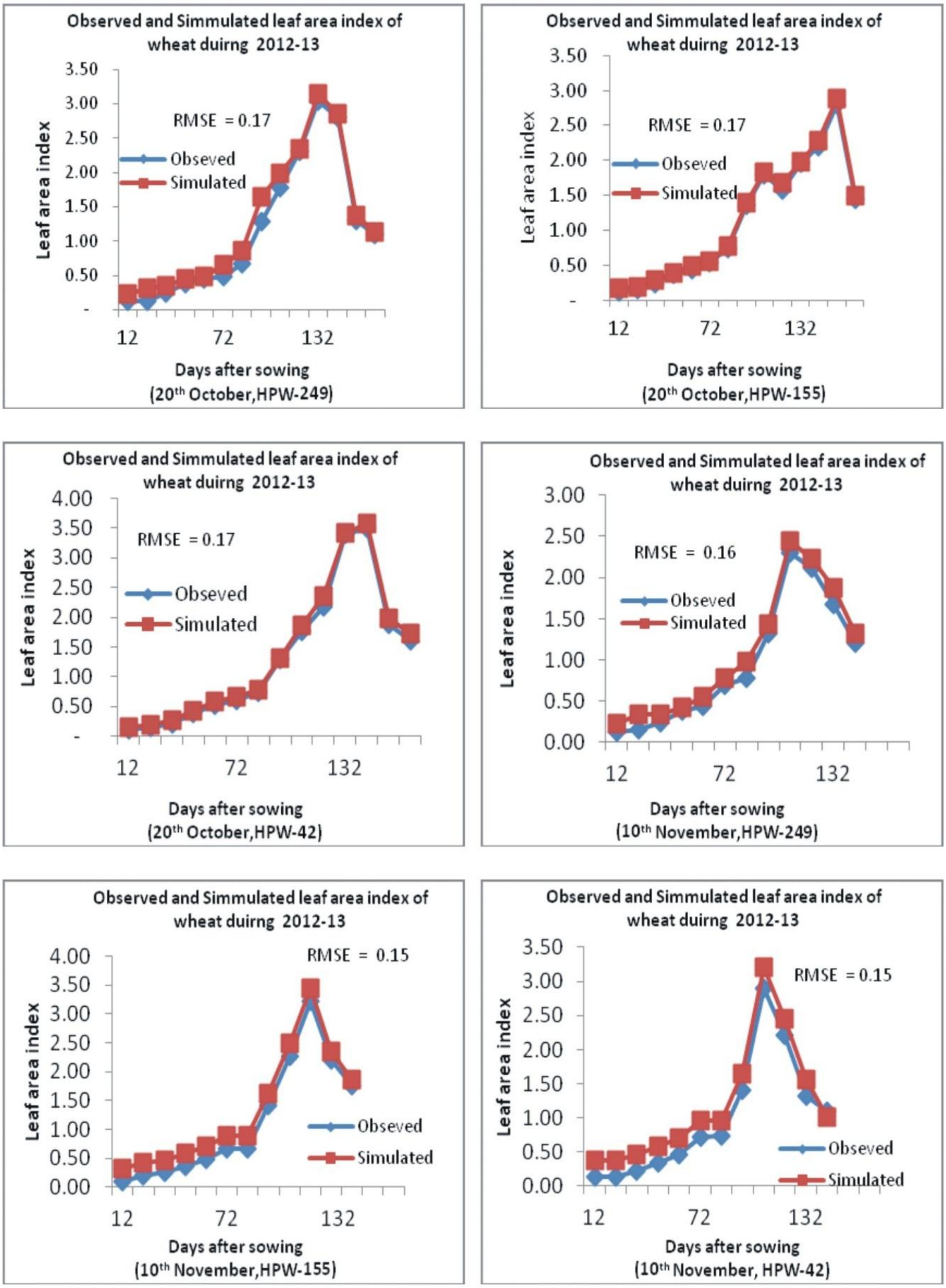

Fig. 5: Observed and simulated LAI of wheat varieties sown on 20th October to 10th November during 2012-13

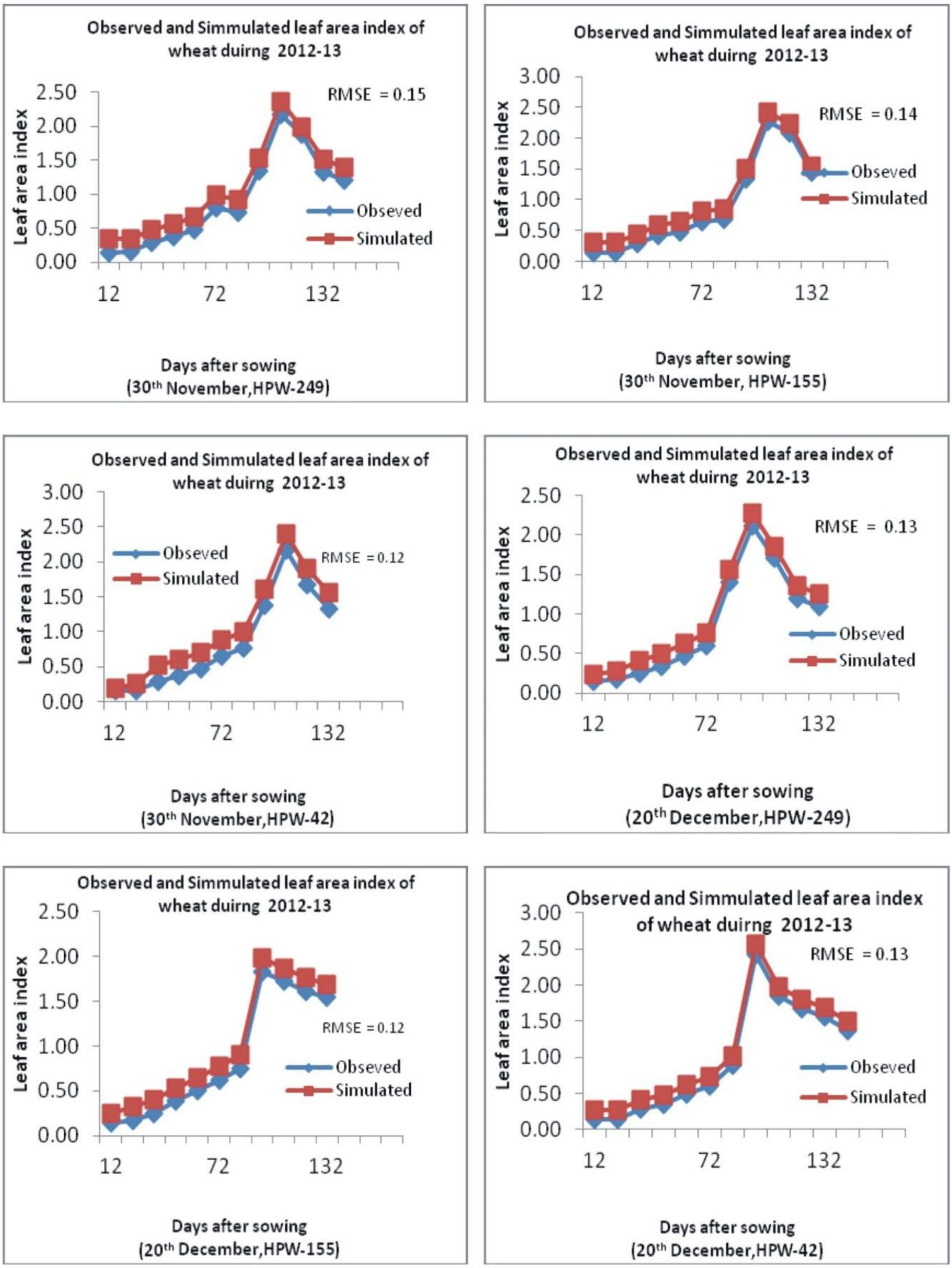

Fig. 6: Observed and simulated LAI of wheat varieties sown on 30th November to 20th December during 2011-12

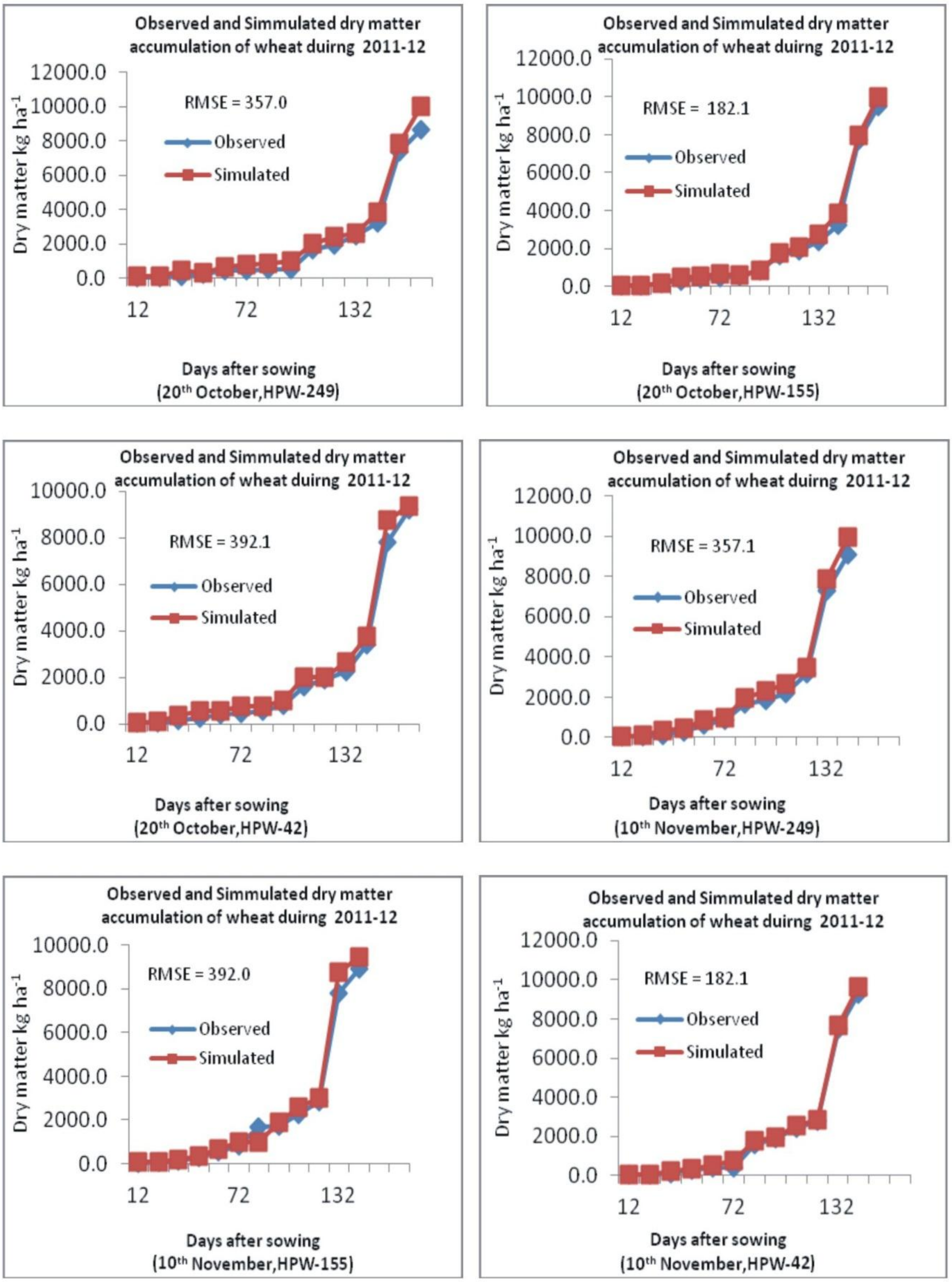

Fig. 7: Observed and simulated dry matter kg ha^{-1}of wheat varieties sown on 20th October to 10th November during 2011-12

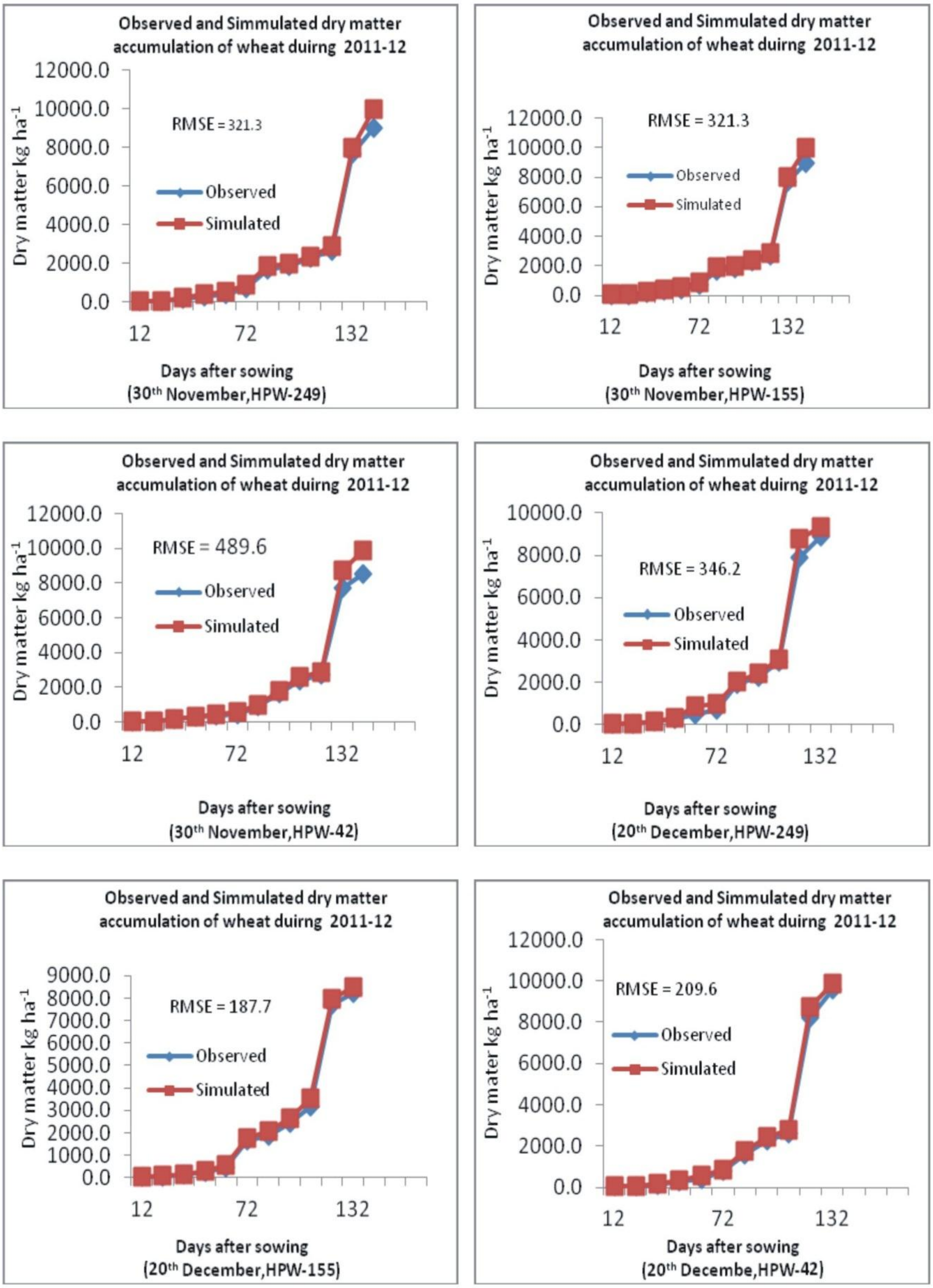

Fig. 8: Observed and simulated dry matter kg ha^{-1} of wheat varieties sown on 30th November to 20th December during 2011-12

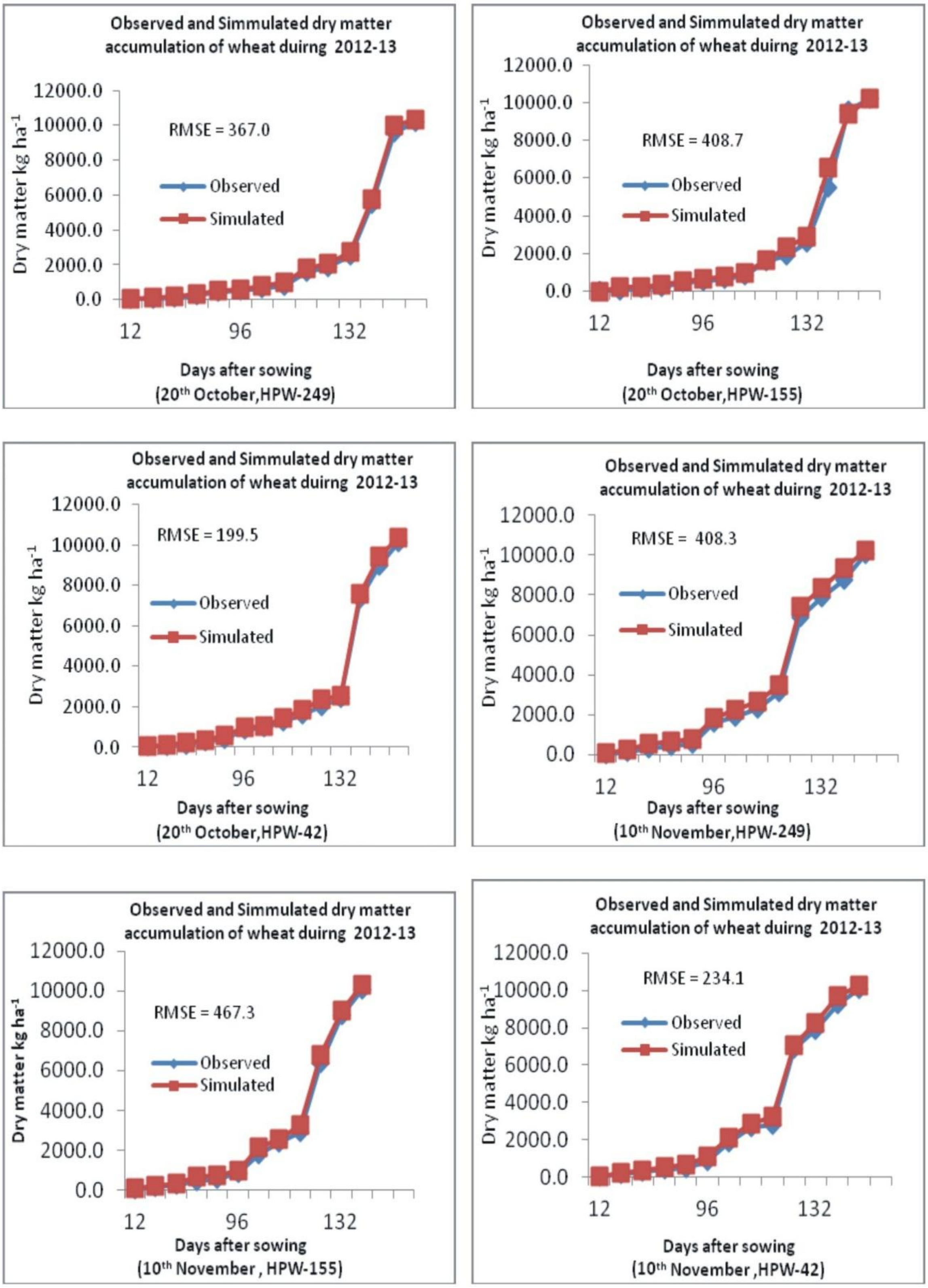

Fig. 9: Observed and simulated dry matter kg ha^{-1} of wheat varieties sown on 20th October to 10th November during 2012-13

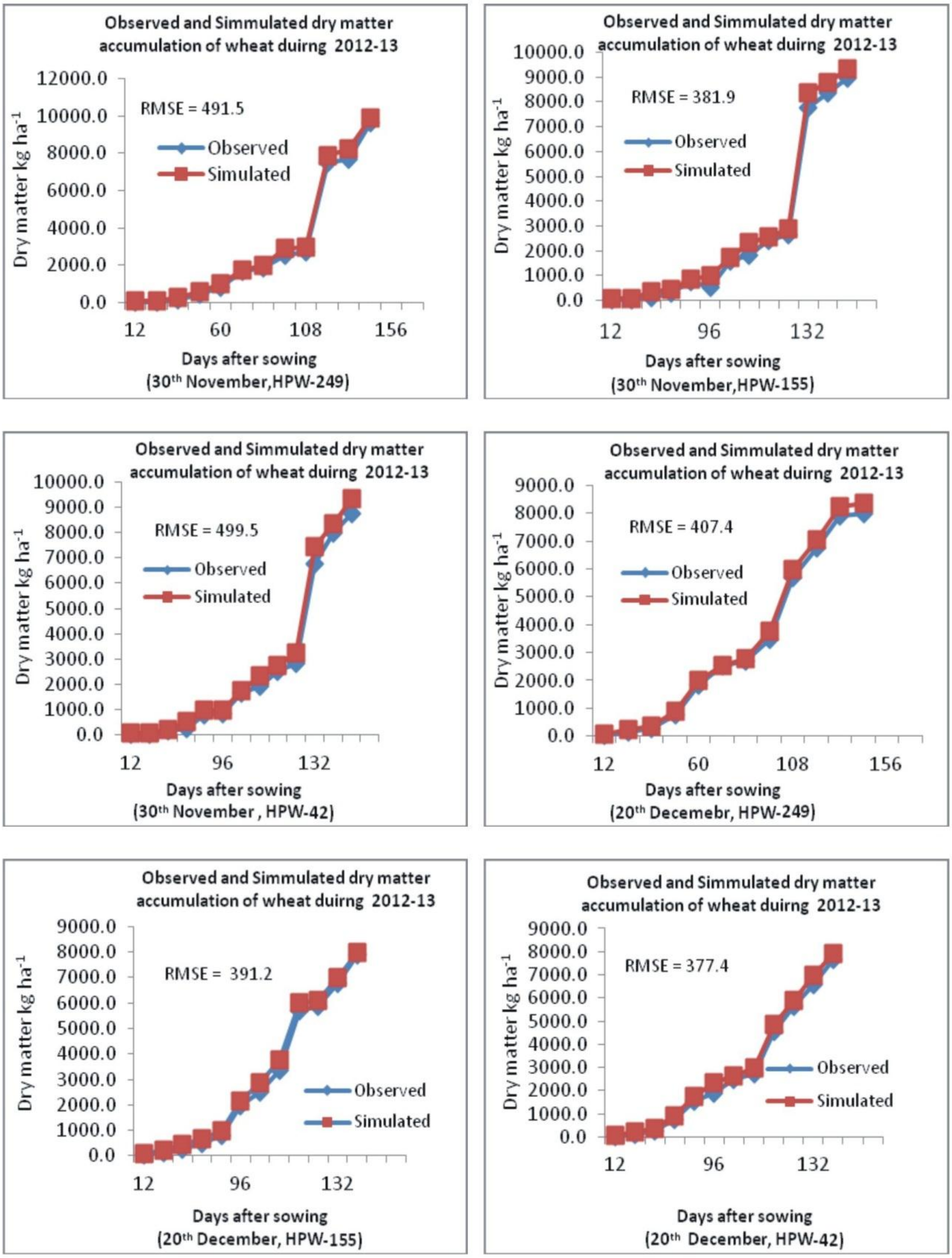

Fig. 10: Observed and simulated dry matter kg ha^{-1} of wheat varieties sown on 10th November to 20th December during 2012-13

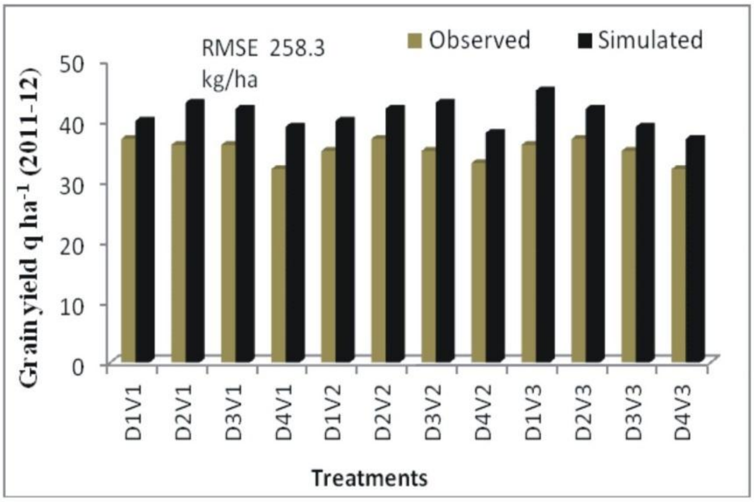

Fig. 11: Observed and simulated grain yield q ha^{-1} during 2011-12

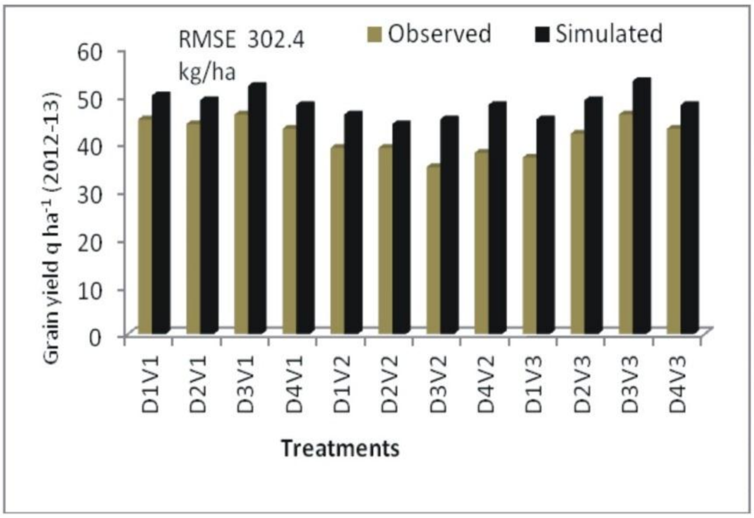

Fig. 12: Observed and simulated grain yield q ha^{-1} during 2012-13

Table 1: Regression models and prediction of *Rabi* wheat yield at mid-season (F2) and pre-harvest (F3) stage

Equation	Statistical model Predicted yield (kg ha^{-1}) 2012-13	Average yield (Last 10 yrs) (kg ha^{-1})	Error (%) from statistical model		
			2010-11	2011-12	2012-13
F2 equation Y = 1160.634742+1.895728* Z241 + 0.079382*Z341	1702.6	1395.1	1740 **2.23**	1774 **4.19**	1790 **5.13**
F3 equation Y=1823.924389+1.832711*Z1211+4 .896764*Z31+ 6.173853*Z51	1732.7	1395.1	1740 **0.5**	1774 **2.38**	1790 **3.30**

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)

Table 2: Comparison of district productivity of wheat in district Kangra using Info crop Model

Equation	Statistical model Predicted yield (kg ha^{-1}) 2012-13	Simulated Predicted yield 2012-13	Percent change in productivity from statistical model to simulated yield	Average yield (last 3 yrs, 2010 to 2013) (kg ha^{-1})	Percent change in productivity from three years average to simulated yield	Actual yield (2012-2013) (kg ha^{-1})	Error (%) from Simulated yield to 2012-13
F2 equation	1702.6	2060	+20.9	1768	+16.5	1790	+15.1
F3 equation	1732.7	2060	+18.9	1768	+16.5	1790	+15.1

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