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SIMULATING SOWING DATE EFFECT ON BARLEY VARIETIES USING CERES-BARLEY MODEL IN NORTH WESTERN HIMALAYAS

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SUMMARY

CERES-Barley model was calibrated and validated for three varieties (Dolma, Sonu and HBL-113) of barley sown on four dates between October and December under optimal agronomic management conditions in north western Himalayas. Cultivar specific genotypic coefficients were developed for these varieties during calibration. The model successfully predicted phenological stages, yield attributes and grain yield, but failed to simulate straw yield, biomass and harvest index of barley. Significant association between simulated and observed grain yield were supported by the test of significance for intercept and slope of regression line (R^2 =0.7204). The model was validated with fair degree of accuracy for grain yield (R^2 = 0.7545). Simulation guided management practices were worked out for these varieties under potential production and resource limiting situations.

***Key words*: CERES-Barley, Crop simulation, phenology, yield.**

INTRODUCTION

Many crop simulation models are now available to users; these range from multispecies models to types of models with shared characteristics (Jones *et al.* 1995). Decision support system (DSS) are interactive computer-based systems that help decision makers to effectively utilize the valuable data to solve unstructured problems (Sprague and Carlson 1982). One such system is Decision Support System for Agrotechnology Transfer (DSSAT) (Jones 1993, Uehara and Tsuji 1993). DSSAT is a software, which includes models of about two dozen crops. The models running under DSSAT include the CERES (Crop Environment Resource Synthesis) model for rice, wheat, maize, sorghum, pearl millet and barley (Ritchie 1985, Ritchie and Otter 1985 and Ritchie 1986). The barley model is specifically named as CERES-Barley. DSSAT has the capability to analyze multiple simulation treatments in simple economic terms (Godwin *et al.* 1990). The models can be used to address various management options like scheduling of irrigation (Boggess and Ritchie 1988, Bosch and Ross 1990), scheduling of N fertilization, time of sowing (Anapalli *et al.* 2005), development of agrotechniques (Kumar and Sharma 2005), risk analysis in rainfed cropping, selection of suitable varieties under varying agro-climatic situations, etc.

The crop models included in the DSSAT have very well been validated under agro-ecological situations of Europe and North America and have been reported to be highly versatile. However, there are only a few published reports on the performance of these models under Indian situation. Barley is the most important *Winter* cereal after wheat with respect to area and production in Himachal Pradesh. It is the crop of marginal lands and those areas where late maturity of wheat does not permit the feasibility of double cropping. That is why

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*Corresponding author's present address: Nature Plant Products Division, Institute of Himalayan Bioresource Technology (CSIR), Palampur-176 061, H.P., E-mail: rakeshkumar@ihbt.res.in it is a main crop in higher elevations under rainfed conditions and in high-hill dry temperate zone. Also, barley has several uses for the hill people, i.e. for food, feed, fodder and local beverages. CERES-Rice and CERES-Wheat models have been successfully used earlier for rice and wheat varieties in Himachal Pradesh by Kumar and Sharma (2004 & 2006), however, models capable of forecasting barley yields are yet to be tested under these conditions. Also, input data sets on ‘genotypic coefficients’ for the varieties cultivated in this region are lacking. The aim of this work was to calibrate CERES-Barley model for barley varieties (distinctly different in their genetic makeup, growth and development habits) sown on different dates and to validate model performance.

MATERIALS AND METHODS

Field experiments on barley crop were conducted at the experimental farm of Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur (32° 6' N latitude, 76° 3' E longitude, and 1290.8 m elevation above mean sea level) during *Winter* seasons of 2003-04 and 2004-05. Before conducting experiments, soil samples from 0-15, 15-30, 30-45 and 45-60 cm depth were collected. Results of various physico-chemical properties of soil have been summarized in Table 1.

Agroclimatically the experimental area falls in sub-temperate humid zone, characterised by high rainfall and

Table 1. Physico-chemical properties of experimental soil

Properties	**Soil layer (cm)**				**Method employed**
	0-15	**15-30**	**30-45**	**45-60**	
Physical properties					
Sand (%)	18.6	18.7	18.0	28.6	International Pipette method (Piper, 1966)
Silt (%)	43.6	37.9	34.2	23.2	
Clay (%)	37.8	43.4	47.8	48.2	
Bulk density(g cm^{-3})	1.33	1.44	1.33	1.33	Core sampler technique
Moisture content at 0.3 atm suction (cm^{3}cm^{-3})	0.265	0.268	0.270	0.250	Pressure plate apparatus (Richards, 1965)
Moisture content at 15 atm suction (cm^3 cm^{-3})	0.196	0.195	0.190	0.184	Pressure plate apparatus (Richards, 1965)
Chemical properties					
pH	5.6	5.5	5.5	5.5	1:2.5 soil water suspension glass electrode pH meter (Jackson, 1967)
Organic Carbon (%)	1.04	0.85	0.71	0.70	Walkley and Black’s Rapid titration method (Piper, 1966)
Total nitrogen (kg ha^{-1})	3368	3143	2470	449	Modified Kjeldahl’s method (Jackson, 1967)
NO^-_3N (kg ha^{-1})	12.35	11.23	6.74	2.25	Steam Distillation method (Jackson, 1967)
NH^+_4N (kg ha^{-1})	163.84	116.74	78.58	2.25	
Available phosphorous (kg P_2O_5 ha^{-1})	20.2	19.3	18.0	15.0	Olsen’s Method (Olsen *et al.*, 1954)
Available potassium (kg K_2O ha^{-1})	292	269	269	269	Neutral normal ammonium acetate method (Black, 1965)

mild temperatures. On an average, rainfall of the place is 2500 mm, of which about 80% is received during June to September. Weather data recorded at the Meteorological Observatory of Department of Agronomy. During winter season, (October-May), mean weekly temperatures ranged from a minimum of 3.3 °C in 4th standard week (22nd -28th January) to a maximum of 34.0 °C in 16th standard week (14th-20th May) during 2003-04, whereas, during 2004-05 it ranged from 3.0 °C in 4th standard week (22nd -28th January) to 29.5 °C in 20th standard week (14th-20th May). A total of 417 and 1023 mm rain was received during 2003-04 and 2004-05, respectively.

Field experiments on barley were conducted during Winter 2003-04 and 2004-05 in split plot design with a combination of four dates of sowing (October 10- D1; October 30- D2; November 20- D3; December 10- D4) and 3 varieties (Dolma - V1; Sonu - V2; HBL-113- V3). Each experiment was replicated four times. Farm yard manure (FYM) @ 10 t ha^{-1} on dry weight basis was incorporated uniformly in all the plots and mixed well at the time of field preparation. Only P was applied @ 20 kg ha^{-1} at the time of sowing through single super phosphate (16% P_2O_5). N was applied @ 40 kg ha^{-1} in 2 equal splits; half at sowing and half at tillering stage. All the test varieties were sown on respective dates as per treatment schedule. Barley was sown at seed rate of 100 kg ha^{-1}. A row spacing of 22.5 cm was used for line sowing resulting in 32 rows per gross plot. Two irrigations were given to the crop during both the years. Weeds were managed by spraying isoproturon 75WP herbicide @ 1.25 kg ha^{-1} sprayed after 30-35 days of sowing. Hand weeding was also done as per requirement to keep the crop weed free. Data used for model evaluation were the means of four replications.

Simulation Model

The crop growth model CERES-Barley (Otter-Nacke *et al.* 1991) was used in the present study. This model was run within the DSSAT v 3.5. (Decision Support System for Agrotechnology Transfer) environment (Hoogenboom *et al.* 1994). The accuracy of model prediction was evaluated by testing the significance of linear regression coefficients (‘a’ and ‘b’) and degree of goodness of fit (R^2) between simulated and observed values. The root mean squared error (RMSE) or standard error of mean (S.Em.) between simulated and observed data was also used. A smaller RMSE indicates less deviation of the simulated values from the observed values (McMaster *et al.* 1992). RMSE/S.Em. was further used to work out the coefficient of variation (CV) between the observed and simulated values. CV was worked out with the following formula:

$$\text{RMSE/ } S.Em. = \sqrt{\frac{\sum_{i=1}^{n}(Sim.Yi - Obs.Yi)^2}{n}}$$

CV(%)= S.Em *100/x

Where n is the number of observations and x is the mean observed value, *Sim Yi* and *Obs Yi* are the simulated and observed values of i^{th} observation.

The genotype file contains the genotypic coefficients, which describe the varietal characteristics, were worked out by using Gencalculator (GENCAL). Crop genotypic input data, which explains how the life cycle of a cultivar responds to its environment, are not usually available and therefore these are derived iteratively using Hunt’s method (Hunt *et al.* 1993). CERES-Barley model requires seven cultivar specific genotypic coefficients (Table 2).

CERES- Barley was validated for grain productivity (of different barley varieties of which the genotypic coefficients were worked out in this study) only for which reasonably good number of experimental data was available. Validation of the CERES- Barley for grain yield was attempted by using reported/published data of several field experiments on barley conducted during and preceding to the year of present investigation. Input data *viz.*, crop management practices, weather data and soil characteristics were computerized in accordance with the reported year and place of experimentation. Simulation runs were made and model predicted data was generated. Actually reported and simulated data were compared. CV and regression between observed and simulated data were worked out and tested for their statistical significance.

Table 2. Genotypic coefficients for barley varieties

Genotypic Coefficients	Dolma	Sonu	HBL-113
P1V–Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars	0.50	0.50	0.50
P1D–Relative amount that development is slowed when plants are grown in a photoperiod 1hour shorter that the optimum (which is considered to be 20 hours)	4.330	4.462	4.847
P5–Relative grain filling duration based on thermal time (degree days), where each unit increase above zero adds 40 degree days to an initial value of 300 degree days.	-2.0	-2.0	-2.0
G1–Kernel number per unit weight of stem (less leaf blades1 and sheaths) plus spike at anthesis (1 g^{-1})	4.223	4.425	2.251
G2–Kernel filling rate under optimum conditions (mg day^{-1})	3.223	4.523	4.100
G3–Non-stressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases (g)	3.245	3.289	3.141
PHINT–Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.	75	75	75

After the model was validated satisfactorily for prediction of grain yield, simulation guided management practices were worked out for yield maximization of different varieties of the crop. This was achieved by systematically altering the various management practices (time of sowing, time and methods of fertilizer N application) as input by using sensitivity analysis option in model and recording the output (grain yield) after each run. Following this procedure simulation guided management practices for yield maximization of barley under potential production and resource limiting (no N application) situations were worked out by running model over a period of 5 years.

RESULTS AND DISCUSSION

Calibration of CERES-Barley

The genotypic coefficients for three distinct varieties of barley *viz.*, Dolma (6 rowed hull less), Sonu and HBL-113 (2 rowed hulled) were calculated using GENCAL (Hunt *et al.*, 1993). The genotypic coefficients calculated and further used in CERES-Barley model validation are presented in Table 2. The genotypic coefficient P1D varied from 4.330 for Dolma to 4.847 in HBL-113. P1V, P5 and PHINT coefficient was constant for all the three varieties. Coefficients G1, G2 and G3 varied noticeably amongst varieties indicating their differences in sink capacity. The difference between simulated and observed days to flowering over the two years ranged from one to three days only. Therefore, Fig. 1 shows a close correspondence between observed and simulated number of days to flowering with low RMSE (2.76) and CV (2.07). Smaller value of RMSE indicates that the model's performance was satisfactory in this parameter. Similarly, goodness of fit ($R^2 = 0.9414$) between observed and simulated data was significant. Fig. 1 shows a close correspondence between observed and simulated number of days to physiological maturity with small value of CV (2.54) thus indicating that the model's performance was satisfactory in this parameter also. Similarly, goodness of fit ($R^2 = 0.928$) between observed and simulated data was significant. Hanchane *et al.* (1994) evaluated the CERES-Barley model in the semiarid condition of Morocco for phenology and yield under both drier and

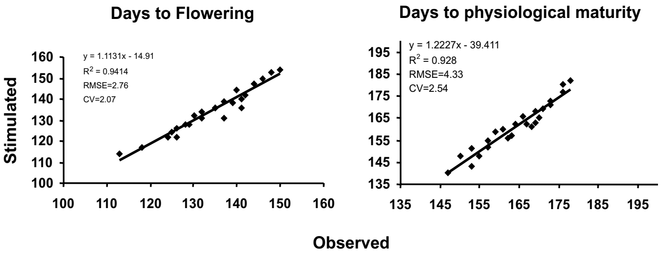

Fig. 1. Observed and simulated phenology of barley

irrigated conditions. The model predicted the days to flowering and maturity with reasonable accuracy in both conditions.

The observed and simulated values of all the three varieties at all the sowing dates matched closely all through the crop season except at 135 DAS (Figs. 2a & 2b). Model simulated a decrease in total dry matter accumulation over 120 DAS of all the three varieties when sown on D4. Similarly, model simulated a decrease in total dry matter accumulation at maturity of all the three varieties when sown on D3 (Fig. 2b) and V3 sown on D2 (Fig. 2a). The unusual deviations of simulated values from the observed data need to be probed.

The simulated number of grains spike^{-1} of both Sonu and Dolma were in general, underestimated by the model, however, in case of HBL-113, difference between observed and simulated values was smaller. Goodness of fit for number of grains spike^{-1} was found to be significant (R^2 = 0.5661) (Fig. 3). Also, the slope and intercept of regression line were significant as revealed

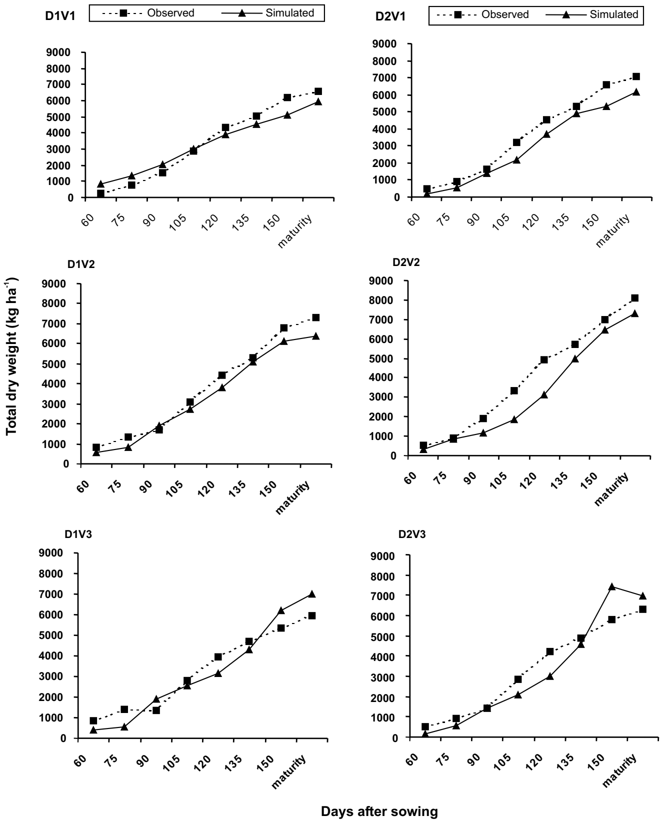

Fig. 2a. Simulated and observed total dry weight (kg ha^{-1}) of barley (D1V1= , D1V2= , D1V3= , D2V1= , D2V2= and D2V3=)

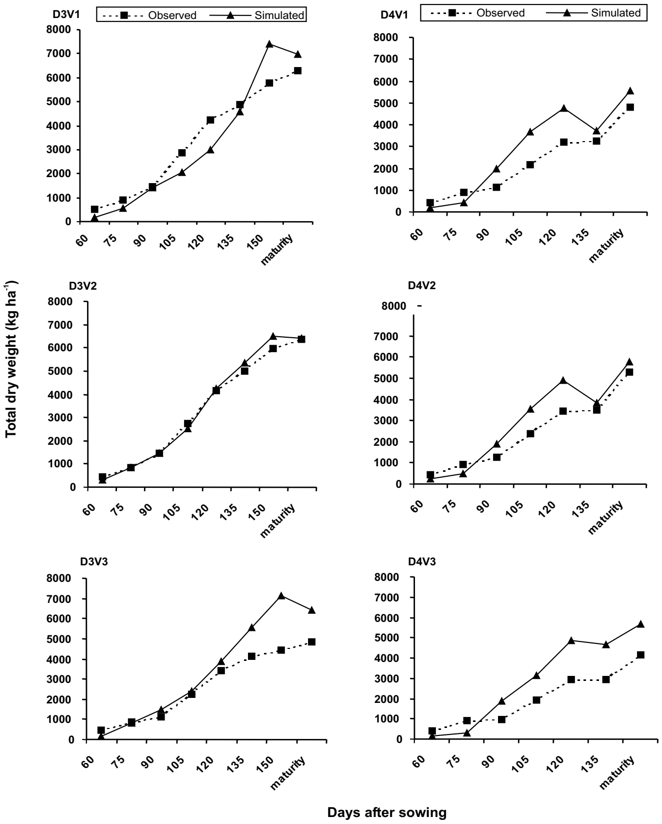

Fig. 2b. Simulated and observed total dry weight (kg ha^{-1}) of barley (D3V1= , D3V2= , D3V3= , D4V1= , D4V2= and D4V3=)

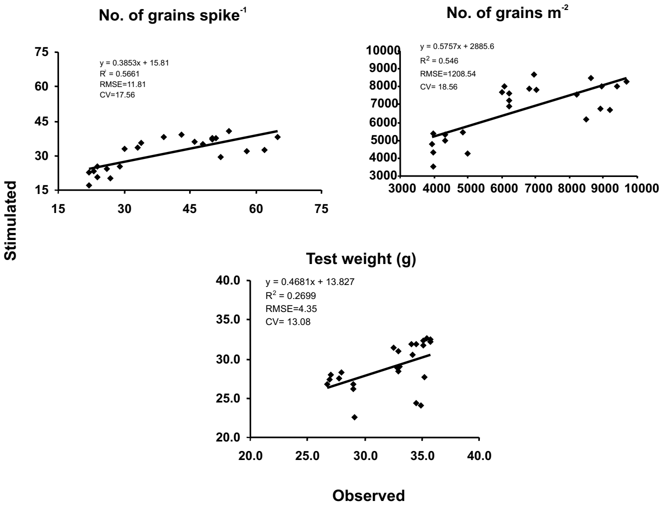

Fig. 3. Observed and simulated yield attributes of barley crop

by the tests of significance. In spite of inconsistency in prediction of number of grains m^{-2}, the statistical parameters such as R^2 and regression coefficient (Fig. 3) were found to be significant suggesting the model to be reliable. Similar results were noticed in number of grains m^{-2} also. Ritchie *et al.* (1998) also reported that model underestimates grain number and further stressed that since the model predictions for biomass were reasonable, it is necessary to evaluate the model further for relationships used to partition biomass into stems and ears, especially during ear development. This will perhaps help to improve the prediction of grain number.

Unlike number of grains m^{-2}, test weight of the grains simulated by the model was consistently lower than the observed values in all the treatment. The association between observed and simulated values was found to be significant as evident from small RMSE value of 4.35 (Fig. 3) and also by test of goodness of fit (R^2= 0.2699). Value of CV was also within the acceptable level (13.15%). This further supported the accuracy of model in predicting test weight of barley. Travasso and Magrin (1998) also reported that the model is able to simulate grain weight with a 13% of variation.

Observed and simulated grain yield of barley pooled over the two years has been reported in Table 3. The model performed well in predicting the grain yield of all the three varieties sown on four different dates and the association between observed and simulated data was found to be significant (Fig. 4). Likewise the goodness of fit was also significant (R^2= 0.7204). This was also well supported by small value of CV (10.18%). Further the precision of model in predicting grain yield was evident from small value of RMSE (212 kg ha^{-1}). Wahbi and Sinclair (2005) undertook a study to compare the two crops (barley and wheat) using same model structure under normal sowing dates CERES-Barley was able to simulate grain yield reliably for Argentine conditions.

Table 3. Observed and simulated grain yield (kg ha^{-1}) of barley as influenced by dates of sowing and varieties (Pooled data)

Dates of sowing	Varieties							
	Dolma		Sonu		HBL-113		Mean	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
			Pooled data					
D1	2031	1859	2353	2256	1609	1500	1998	1872
D2	2143	2024	2547	2504	1650	1665	2113	2064
D3	1803	2116	2042	2154	1443	1556	1763	1942
D4	1549	1864	1816	1968	1209	1313	1525	1715
Mean	1882	1966	2190	2221	1478	1509		
RMSE								164.19
CV								8.88

Comparison of observed and simulated straw and biological yield due to different treatments revealed an extreme inconsistency (Fig. 4). Consequently, the association between observed and simulated values were not significant as the goodness of fit was very-very low (R^2= 0.0002). This may be attributed to inability of model to accurately simulate leaf and stem dry weight. Likewise, harvest index was also not accurately simulated by the model and hence the association between observed and simulated value was not significant (Fig. 4) as variation between the corresponding values was high. Likewise the goodness of fit was also not significant.

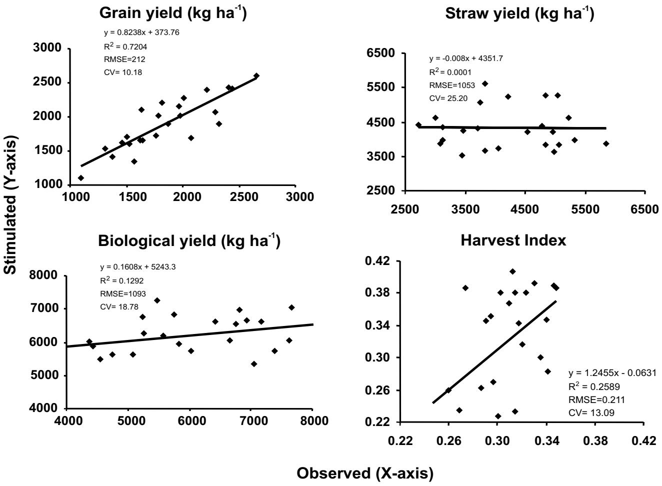

Fig. 4. Observed and simulated yield and harvest index of barley crop

Validation of CERES-Barley

CERES-Barley crop model was validated for grain productivity (of different barley varieties of which the genotypic coefficients were worked out in this study) only for which reasonably good number of experimental data was available. A perusal of Fig. 5 indicates that the simulated and observed values of grain yield of different varieties were close in all the experiments which is supported by high value of goodness of fit (R^2=0.7545). This was further supported by tests of significance of intercept and slope of regression line. The RMSE value was 301 kg ha^{-1} which further reveals the level of precision of model in yield prediction. CV was also within an acceptable limit of 12%. All these statistical tools indicate that the CERES-Barley model was validated with a fair degree of accuracy and hence can be used as a decision support system and work out simulation guided management practices for yield maximization of barley under different resource base situations.

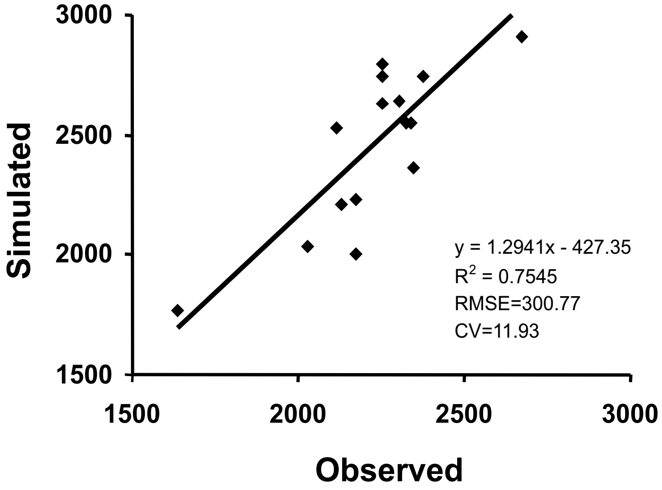

Fig. 5. Validation of CERES-Barley model for barley yield (kg ha^{-1})

Simulation guided management practices

After validation of CERES-Barley model, simulation guided management practices for yield maximization of barley under potential production and resource limiting situations were worked out by using sensitivity analysis option in the model and concluding the decisions by running model over a period of five years. The management practices that the model simulate, included time of sowing, nitrogen fertilizer scheduling (levels and time of application). The model did not respond to various irrigation levels under weather conditions of Palampur, where rainfall was good enough to meet the water requirement of crop.

From simulation guided management, it was concluded that best time for sowing of Dolma variety was last week of October to first week of November (Table 4). When the variety was sown in first week of September, the grain yield was reduced to half. This variety responded N application upto 80 kg ha^{-1}. The best schedule for application of N was 60:20 kg ha^{-1} i.e. 60 kg N at the time of sowing and 20 kg N as top dressing after 30 days of sowing. This variety has yield potential of 18-22 q ha^{-1} under potential production situation, whereas, under resource constraints situation i.e. under no nitrogen and rainfed conditions the yield declined to 6-15 q ha^{-1}.

Table 4. Simulation guided management practices for yield maximization in Barley

Variety	**Optimum Time of Sowing**	**Grain Yield (q ha^{-1})**		
		Without N application	**Optimum N application**	**Potential yield**
Dolma	27th October- 3rd November	6-15	18-20 (60+20 kg N ha^{-1})*	18-22
Sonu	27th October- 3rd November	7-12	22-25 (60+20 kg N ha^{-1})*	22-26
HBL-113	20th October- 27th October	6-10	16-18 (50+50 kg N ha^{-1})#	17-18

* 60 kg N ha^{-1}at the time of sowing and 20 kg N ha^{-1} after 30 days of sowing

50 kg N ha^{-1}at the time of sowing and 50 kg N ha^{-1} 30 after days of sowing

When Sonu variety was sown in last week of October to first week of November, its yield ranged between 22-26 q ha^{-1} during different years. When the variety was sown in first week of September, the grain yield was reduced by more than 50 per cent. This variety also responded to increased level of N and leveled off at 80 kg N ha^{-1}. The best schedule for application of N was same as for Dolma. Under potential production situation this variety has a yield potential of 22-26 q ha^{-1}. However, under resource constraints situation i.e.

under no nitrogen and rainfed conditions the yield declined to 7-12 q ha^{-1}.

HBL-113 being a late maturing variety, the appropriate time of sowing for this variety as worked out by sensitivity analysis was from 20th October to 27th October. Later sowings resulted in yield reductions. Also too early sowing as in September 1st week resulted in drastic yield reduction. This variety was, however, more fertilizer responsive and yield increased with increase in N levels upto 100 kg N ha^{-1}and thereafter grain yield leveled off. The best schedule for application of N was 50:50 kg ha^{-1} i.e. 50 kg N at the time of sowing and 50 kg N as top dressing at 30 days after sowing. With these management practices this variety registered 16-18 q ha^{-1} yield over the years. Under potential production situation this variety has a yield potential of 17-18 q ha^{-1}. However under resource constraints situation i.e. under no nitrogen and rainfed conditions the yield declined to 6-10 q ha^{-1}.

CERES-Barley model simulated phenological stages (days taken to flowering and physiological maturity), number of grains spike^{-2} as well as m^{-2} and test weight very well. The model also performed well in predicting the grain yield of all the three varieties sown on four different dates and the association between observed and simulated data of two years was found to be significant. The goodness of fit was also significant (R^2= 0.7204). However, comparison of observed and simulated straw, biological yield and consequently harvest index due to different treatments revealed an extreme inconsistency. CERES-Barley crop model was validated for grain productivity with fair degree of accuracy and can be used for forecasting barley productivity.

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