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Simulating the Interactive Impact of Nitrogen and Promising Cultivars on Yield of Lentil (*Lens culinaris*) Using CROPGRO-legume Model

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Abstract

Crop models are particularly valuable for understanding research across varying disciplines, crop system managements and policy analysis. The proposed study was carried out to evaluate the performance of CROPGRO-legume model under Chickpea in irrigated conditions of Faisalabad. The collected data against outstanding treatment in the field was used to calibrate the model and rest of data was used for model evaluation. Model simulated flowering and maturity dates well for all cultivars of chickpea. Comparison of simulated and observed data showed that model simulated TDM and grain yield with RMSE 248 and 34 kg ha^{-1}, respectively. Punjab Masoor-2009, NIAB Masoor-2002 and NIAB Masoor-2006 were simulated accurately by model with the values of R^2 96%, 95% and 94% for TDM, respectively. Agreement of statistics (d index) for TDM in all cultivars was 0.90. Generally model simulated well under non stressed condition. However error was higher in simulation at lesser level of nitrogen in all crop parameters. There is dire need to quantify growth and yield under varying climatic conditions to assess the accuracy of model simulations.

Keywords: Lentil; CROPGRO-legume Model; Simulation; Model calibration; RMSE

Introduction

Food legumes are an inexpensive source of protein, calories, minerals and some vitamins. Grain legumes being rich in protein provide balanced human diet especially when taken in combination with cereals. The per capita consumption of legume in Pakistan is 15.7 kg per annum. Lentil (*Lens culinaris*) is an important grain legume crop in Pakistan. Lentil (*L culinaris*) is an important winter crop in Pakistan and is usually grown on rainfed areas (Ahmad *et al*., 2008). Being a legume crop, lentil can fix atmospheric nitrogen via symbiotic rhizobia in root nodules and consequently has potential for maintaining soil fertility (Crook *et al*., 1999). The increasing importance of lentil is expected to continue due to increasing world demand and innovation in lentil research such as the development of improved varieties and better agronomic practices.

In Pakistan, total area under lentil crop is 22.5 thousand hectares with total production of 11.6 thousand tons, 12.8% less production as compared to 2010-11 (GOP, 2012). Area under lentil is limited; because of competition with the major crops, therefore the entire efforts are to be focused increasing the lentil production per unit area. The average lentil yield in Pakistan is low due to continuous cultivation of conventional low yield potential cultivars having excessive vegetative growth with poor response to inputs and improved agro-management practices (Hussain *et al.,* 2002). Variety plays an important role in producing high yield of lentil because different varieties responded differently for their genotypic characters.

Different lentil varieties showed some genetic variation for plant height, number of branch, number of pod per plant, number of seed per plant, harvest index and biological yield (Karadavut and Genc, 2010). Sadiq *et al.* (2001) reported that different cultivars of lentil have different potential and vary in response to different fertilizer levels. Although legumes can meet their nitrogen requirements by biological nitrogen fixation, but a starter dose of nitrogen is helpful in increasing the crop yield. Nitrogen is critical element for increasing the quality of food crops. Nitrogen is important macro element for growth of legumes. Despite having ability to fix atmosphere N application of suitable amount of nitrogen fertilizer in lentil increased pod number, seed number and seed weight. It was reported that the application of 40 kg N ha^{-1} was the suitable treatment in yield production.

Crop simulation models are important tools for agronomic management strategy evaluation (Sinclair and Seligman, 1996). Various research groups have conducted studies to estimate the possible effects of climate change on

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agriculture production using different crop growth models (Zalud and Dubrovsky, 2002; Bannayan *et al.*, 2003). Crop simulation models represent an attempt to reproduce development and yield of crops in comeback to weather, soil and managing scenario. The Decision Support System for Agro-technology Transfer (DSSAT V4.0.2) has been found to be one of the most efficient decision support system (Hoogenboom *et al.*, 2004) that also includes CROPGRO-legume model. It is a dynamic simulation model that simulates the growth and yield of wide range of leguminous crops, such as soybean, peanut and chickpea. CROPGRO-legume has been tested for a wide range of applications in many countries of the world **(**Boote *et al.*, 2004). The CROPGRO-Legume model, a part of the DSSAT system and of the IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) is composed of a deterministic and mechanistic model that simulates the duration of vegetative and reproductive stages, accumulation of biomass and grain yield for a specific cultivar associated to management practices, soil and climatic conditions (Hoogenboom *et al*., 1994). Boote *et al*. (2002) tested CROPGRO-legume model for chickpea to simulate phenology, growth and yield. The dates of physiological maturity, total dry matter (TDM) and final grain yield were predicted well using the model.

The present study was conducted with the objective to evaluate the performance of CROPGRO model to simulate growth, development and seed yield for promising lentil hybrids in semi-arid conditions of Punjab, Pakistan.

Materials and Methods

An experiment was conducted at Agronomic Research Area, University of Agriculture Faisalabad (Latitude 31° 26´ N, longitude 73° 60´ E) during winter season of 2009-2010. The experiment was laid out in Split Plot Design having three replications. The crop was sown in 30 cm apart rows with a net plot size of 1.2 m × 6 m having 4 rows plot^{-1}. Lentil cultivars were kept in main plots and nitrogen rates in sub plots. The varieties used were Punjab Masoor-2009, NIAB Masoor-2006 and NIAB Masoor-2002 (in the main plots) and nitrogen levels applied were 13, 19 and 25 kg ha^{-1} in sub plots.

The crop was sown in the last week of October with the help of single row hand drill. The field was irrigated 15 days before planting lentil and plowed at a time when the field was in proper moisture condition. Two plowing per cultivations followed by planking were undertaken to make a desirable seedbed for seed germination. Crop was sown on 30 cm spaced rows at a seed rate of 30 kg ha^{-1}. Nitrogen and phosphorus was applied in the form of urea and DAP. Doses of Nitrogen N_1 = 13 kg ha^{-1}, N_2 = 19 kg ha^{-1} and N_3 = 25 kg ha^{-1} were applied at sowing. All other cultural practices such as hoeing, irrigation and plant protection measures were kept normal for all the treatments.

Data collected during 2009-2010 was used as input data for calibration and evaluation of the crop-model. The model simulation was performed under optimum growth conditions. The comparison of model simulations with the observed data assessed accuracy of the model (Hoogenboom *et al*., 2004). Crop data on growth was recorded fortnightly from an area of one square foot and then dry matter on gram per square meter was calculated. Half of the plot area was used for growth and developmental studies and the other half for the final harvest data. After completion of germination five plants were tagged at random in each plot for studying (phenology), the days to 50% flowering and physiological maturity. Thermal time was calculated according to Gallagher *et al.* (1978). It calculates thermal time (Tt) as a function of mean temperature above a base temperature (T_b) $Tt = \sum (T_{max} + T_{min}) - T_b$ Where, T_b was base temperature taken as 4°C for lentil. An area of 0.9 m^2 from each plot was harvested at ground level fortnightly leaving appropriate borders. Fresh and dry weight of component fractions of plant (leaf, stem and pods) was determined. A sub-sample in each fraction was taken to dry in an oven to a constant weight. Also, an appropriate sub-sample of Greenleaf lamina was used to record leaf area on leaf area meter (Model LASER CI 203). From the measurement of leaf area leaf area index (LAI) was then calculated as the ratio of leaf area to land area (Watson, 1947) as ratio of leaf area/land area.

Standard weather data were obtained for each site using nearest weather station. Each station provided daily maximum and minimum air temperature (ºC), rainfall (mm), and daily sunshine hours (h). Decision support system for agro-technology transfer (DSSAT) system's component Weatherman used these sun shine hours for calculation of daily solar radiation (MJ m^{-2} day^{-1}).

Crop Growth Modeling

Data collected on crop development, growth (LAI), biomass and grain yield of the lentil genotypes was used as input data for calibration and evaluation of the crop model. The weather data (solar radiation, rainfall, mean temperature) were collected from the meteorological observatory of the University of Agriculture, Faisalabad, Pakistan. The model simulation was performed under optimum growth conditions. CROPGRO-legume model was calibrated using the experimental data. An online version of simulation for crop growth and yield of Decision Support System for Agro-technology Transfer (DSSAT) (Hoogenboom *et al*., 2004) was used. DSSAT incorporates many models related to different field crops including CROPGRO-Legume.

Model Calibration and Genotype Coefficient

Calibration is a process of adjusting some model parameters to the local experimental field conditions. It is also necessary for getting genetic coefficients for new cultivars used in modeling study. The model was calibrated with data collected against the treatment that showed best performance in the field trials. Cultivars coefficients were determined using sensitivity analysis. The ‘P’ coefficients (P_1, P_2 and P_3) predict flowering and maturity, while the ‘G’ coefficients (G_2 and G_3) LAI, grain yield and TDM.

Model Evaluation

To check the accuracy of the model simulations, it was run with data, recorded for all locations during the year 2009, while year 2010 was used for further validation. During all this process available data on growth and yield was compared with simulated values. Simulation performance will be evaluated by calculating different statistic indexes.

The root mean square error (RMSE) of mean weighed difference between observed and simulated values was also used. A smaller value of RMSE indicated less deviation of the simulated from the observed values.

$$RMSE = \left[\sum_{i=1}^{n} (p_i - o_i)^2 / n \right]^{0.5} \quad (1)$$

$$MPD = \left[\sum_{i=1}^{n} \left(\frac{|o_i - p_i|}{o_i} \right) 100 \right] / n \quad (2)$$

$$\text{Error (\%)} = \left(\frac{(p - o)}{o} \right) 100 \quad (3)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (p_i - o_i)^2}{\sum_{i=1}^{n} \left(|p_i'| + |o_i'| \right)^2} \right] \quad (4)$$

Where, P_i and O_i are the predicted and observed values for studied variables, respectively and n is the number of observation.

Statistical Analysis

Data collected on growth, biomass, radiation use efficiency and yield was analyzed statistically by employing the Fisher’s analysis of variance technique and significance of treatment means was tested using least significance difference (LSD) test at 5% probability level (Steel *et al*., 1996). Root mean square error (RMSE) i.e. residual variation among observed and stimulated data tests the accuracy of model.

Results

Genetic Coefficient for CROPGRO Model

Calibration of the CROPGRO model included 15 cultivars coefficients that defined phenology and growth include in (Table 1). Scope of the response of development to photoperiod was negative and ranged between -0.170 to -0.190 (negative for long day plants). Photo-thermal days (time between plant emergence and flower appearance i.e., EM-FL) remained between 30 and 32^0C days for three cultivars. Time between first and physiological maturity (SD-PM) was same for cv. NIAB-2002 and NIAB-2006 (33^oC days) but 31^oC were taken for cv. PM-2009. Photo-thermal time (time between first flower and termination of leaf expansion) ranged from 24-26^oC days specific leaf area for cv. NIAB-2002 and Punjab Masoor-2009 differed from cv. Punjab Masoor -2009 (149 VS 152 cm^{-2} g^{-1}). cv. NIAB took less time in days (26^oC days) in filling grain than cv. Punjab Masoor-2009 (29^oC days). Almost similar trend was observed in NIAB-cultivars for bearing maximum pod (PODUR) than first cultivar.

Calibration of Model

Model calibration is the adjustment of the parameters so that the simulated values compare well with observed ones. The genetic coefficients used in CROPGRO-legume model represent the growth, development and yield of crop cultivars having different maturity days. In model calibration (Table 2), crop phenology days to flowering and maturity were excellent with percent error of 0 between observed and maturity days. Model underestimated canopy development 3 vs 2 for observed and simulated values with 20% error showing inadequacy of the model for canopy development under our climatic conditions. The agreement of d-statistics between simulated and observed data was high 0.95 for phenology, growth and development excepting LAI and TDM in which it remained 0.48 and 0.88. Performance of the model was judged on the basis of individual percent difference and RMSE. There was only low RMSE of 30 kg ha^{-1} for grain yield and 189 kg ha^{-1} for TDM with coefficient of determination 99 and 97% (Fig. 1).

Model Evaluation

It involves comparison of the output of a calibrated model to the real data and a determination of maturity for grain. The precision and accuracy of the treatments are checked within the model. Thus, if it is devised to predict grain yield, evaluation should cover information on the relationship between predicted and actual grain yield, TDM, max LAI, days to flowering and maturity. CROPGRO-legume model was evaluated for three cultivars at different N rates (13, 19 and 25 kg ha^{-1}) for the following parameters.

Phenology

The evaluation of the CROPGRO model for simulating the days taking to flowering showed similar values for three cultivars between simulated and observed values; 81 VS. 82 days (C_1), 77 VS 76 days (C_2) and 77 VS 76 days (C_3). Common regression (R^2) accounted for days to flowering (0.99) with the slope of the regression equation not statistically different from one and the intercept was not different from zero (P = 0.05) with RMSE of zero.

Grain Yield and TDM

CROPGRO model (Ver. 4.02) under DSSAT slightly under predicted grain yield for three cultivars. Model evaluation was well with RMSE of 34 kg ha^{-1} for cv. PM-2009.

Table 1: Genetic coefficients of different Lentil cultivars grown at Faisalabad during November 2009 To April 2010

Genotypes	EM-FL	FL-SH	SD-PM	FL-LF	SLAVR	WTPSD	SFDUR	PODUR
Punjab Masoor 2009	30.0	8.0	31.0	26.0	152.0	0.160	29.0	20.0
NIAB Masoor-2002	32.0	8.0	33.0	24.0	149.0	0.160	26.0	23.0
NIAB Masoor-2006	32.0	8.0	33.0	25.0	149.0	0.160	26.0	23.0

Table 2: Simulated and observed values of Masoor cultivars at different nitrogen rates under ecological condition of Faisalabad using CROPGRO-chickpea model calibration

Treatment	Calibration (2009-2010)					
	Obs.	Sim	RMSE	R^2	d-Stat	Difference (%)
Anthesis	79	79	0.82	0.99	0.96	0.00
Maturity	131	131	0.82	1.00	0.96	0.00
LAI	3	2	0.48	0.36	0.48	-20.57
TDM	4429	4643	188.68	0.99	0.86	4.61
GY	877	860	30.31	0.97	0.98	-1.98
MPD (%)	5.43					

Table 3: Simulated and observed values of Masoor cultivars at different nitrogen rates under ecological condition of Faisalabad using CROPGRO-chickpea model evaluation

Treatment	Evaluation (2009-2010)					
	Obs.	Sim	RMSE	R^2	d-Stat	Difference (%)
Flowering	79	79	0.82	0.99	0.96	0.00
Maturity	131	131	1.29	0.99	0.92	0.00
LAI	2.37	2.11	0.33	0.99	0.63	-12.32
TDM	4138	4277	248.10	0.80	0.79	3.25
GY	810	803	34.00	0.94	0.98	-0.87
MPD (%)	3.29					

Coefficient of determination (R^2) between simulated and observed grain yield was 99% and d-index = 0.94 with mean percent difference (MPD) of 5.06%. Model evaluation was quite high for all cultivars with good RMSE, low mean difference, higher R^2 value and good agreement of index. There was only one day difference between observed and simulated to flowering (78 VS 77) and two days (127 VS 129) for maturity. Model did not predict TDM fairly and difference between observed and simulated TDM was 849 kg ha^{-1} with RMSE of 851.33 kg ha^{-1} for cv. Punjab Masoor-2009, 921 kg ha^{-1} with RMSE 928.47 kg ha^{-1} for cv. NIAB-2002 786.29 kg ha^{-1} having RMSE 673.25 kg ha^{-1} for cv. NIAB-2006. Agreement of statistics (d-index) and coefficient of determination (R^2) remained was very high in evaluating the CROPGRO model. Cv. Punjab Masoor-2009 produced TDM with R^2 of 0.92 and d-index 0.94. Coefficient of determination was equal to 1 in model evaluation by cv. NIAB-2002 and good agreement of index (0.94). Likewise, CROPGRO model evaluated well for cv. NIAB-2006 with higher statistics parameters (R^2 = 0.97 and d-index 0.95).

Leaf Area Index

CROPGRO model underestimated LAI in C_1 and C_2 cultivar. In cv. Punjab Masoor-2009 RMSE between simulated and observed LAI was 2.48 with error of 2.2% and 7.3%, for N_1 (13 kg N ha^{-1}) and N_2 (19 kg ha^{-1}) application of nitrogen respectively. RMSE in C_2 (NIAB-2006) and C_3 cultivar remained 0.15 and 0.46, which were not quite satisfactory in C_3 cultivar.

Model Validation

Validation is determining whether the model works with independent set of data to predict growth, yield and development. CROPGRO model was validated with independent data set for year 2008-2009. Model validation for crop phenology was good with low RMSE of 1.15 (days to flowering) and 2.51 (days to maturity). Coefficient of determination was higher (0.98) for days to flowering and satisfactory (0.83) in days taken to maturity. RMSE for TDM between simulated and observed values was quite satisfactory (131.95 kg ha^{-1}) in all the treatments. Time course increase in TDM ranged between 0.85-0.91 and 0.71-0.87 for all LAI values. Index of agreement (d-index) for TDM and LAI remained between 0.85-0.91 and 0.87-0.95.

Discussion

Crop models are available for most economically important crops, and on many occasions they have been successfully used in research and farmer fields. Many researchers calibrated and parameterized CROPGRO model for chickpea peanut and soybean to evaluate different management strategies and selection criteria for promising cultivars for future use in different parts of the world. There was a dire need to evaluate this model for quantification of management options considering seasonal variability of nutrient status in the soil under semi-arid conditions of Faisalabad, Pakistan. The selection of two years (one year for calibration and the second for validation) proved quite helpful in monitoring the model performance under diversified weather conditions. CROPGRO model can be estimated with collected data (2009-10) from field trials with the help of sensitivity analysis for the treatment performed best in the field for cv. Punjab Masoor-2009, NIAB-Masoor-2002 and NIAB-Masoor-2006 at application of recommended rate. Model cultivars calibration approach offers the opportunity to derive the cultivar coefficients of crop cultivars when their data are readily available from multi-environment trials, but prior to cultivar release to producers as reported by Anothai *et al.* (2008).

Table 4: Simulated and observed values of different Masoor Cultivars at different nitrogen rates under ecological condition of Faisalabad using CROPGRO legume model evaluation

Treatment	Anthesis		Maturity		LAI			TDM (kg ha^{-1})			Grain yield (kg ha^{-1})	
	Obs	Sim	Obs	Sim	Obs	Sim	R^2	Obs	Sim	R^2	Obs	Sim
N 13 kg ha^{-1}	78	78	127	129	2.25	2.2	0.90	4000	4100	0.989	897	943
N 19 kg ha^{-1}	78	78	127	129	2.35	2.19	0.93	4290	4400	0.986	989	983
N 25 kg ha^{-1}	82	81	134	133	2.29	2.27	0.79	4270	4380	0.995	725	751
Punjab Masoor-2009	82	81	134	133	2.48	2.26	0.76	4395	4525	0.997	799	779
NIAB Masoor-2006	76	77	131	131	2.33	1.86	0.85	3860	4080	0.993	709	668
NIAB Masoor-2002	76	77	131	131	2.5	1.88	0.81	4010	4195	0.994	741	696

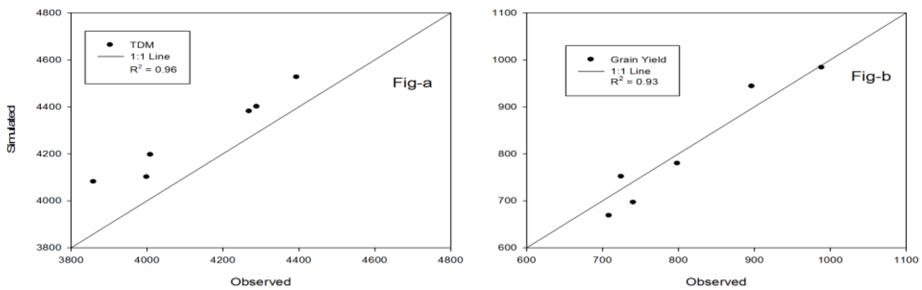

Fig. : Relaionship between Simulated and observed values of (a) TDM and (b) Grain Yield for different Nitrogen levels (13, 19 and 25 kg ha^{-1}))and Lentil Cultivars (Punjab Masoor-2009, NIAB Masoor-2006 and NIAB Masoor-2002).

Fig. 1: Relationship between Simulated and observed values of (a) TDM and (b) Grain Yield for different Nitrogen levels (13, 19 and 25 kg ha^{-1}) and Lentil Cultivars (Punjab Masoor-2009 and NIAB-200)

In the current study genetic coefficients derived from the yield trial experiments for calibration (2009-2010) predicted flowering and maturity dates very well with percent difference of zero while d-stat were 0.96 and 0.92 and R^2 was 0.99, respectively as compared to validation (2008-2009), model slightly under simulated phenology with percent difference of -1.41 and -0.79 and higher R^2 (0.98 and 0.83) for flowering and maturity respectively during 2008-2009. Flowering and maturity of lentil cultivars was 7 and 4 days earlier during validated year as compared to evaluation, phenological date's difference was due to weather phenomenon of the location. CROPGRO Model has some error also regarding phonological events just like as reported by Ben Nouna *et al.* (2000) that phenological module in CERES-Maize under the shell of DSSAT has some error for phenology, it was also reported for the same model by Mubeen *et al.* (2013). Fair to excellent results were found in this study because the simulation is considered excellent when error is less than 10%, good if it is 10 to 20%, fair if 20 to 30%, and poor if the error exceeds 30% (Soler *et al.*, 2007).

There was excellent agreement for calibration of lentil cultivars between observed and simulated maturity yield with percent difference of -1.98 and TDM coefficient of determination (R^2) and index of agreement (d-stat) were 0.99 and 0.86. Evaluation results for CROPGRO model were good with over all mean percent difference of 3.29% only while during validation 4.09% was observed because model over simulated grain yield and TDM 2.59 and 2.65%,

Table 5: Simulated and observed values of Masoor cultivars at different nitrogen rates under ecological condition of Faisalabad using CROPGRO legume model validation

Treatment	Validation (2008-2009)					
	Obs.	Sim	R^2	RMSE	d-Stat	% Difference
Anthesis	72	71	0.98	1.16	0.89	-1.41
Maturity	127	126	0.83	2.52	0.78	-0.79
LAI	2.78	2.46	0.18	0.79	0.52	-13.01
TDM	4633	4759	0.97	131.96	0.89	-2.65
GY	865	888	0.96	27.35	0.97	-2.59
MPD (%)	4.09					

respectively and observed grain yield and TDM were 6.35and 10.68% was higher during validation as compared to evaluation (2009-2010). Temperature functions affecting the rate of vegetative node expression and leaf area expansion and phenology and ultimately affected the yield and TDM of CROPGRO model as reported by Pedersen and Lauer (2003) for soybean using CROPGRO that by increasing temperature decreased biomass and grain yield by 273 and 134 kg ha^{-1} respectively and RMSE increased for biomass from 734 to 739 kg ha^{-1} and decreased for grain yield from 410 to 408 kg ha^{-1}. Andales *et al.* (2000) found that the CROPGRO-Soybean model over-predicted accumulation of biomass and translate error due to soil initial temperature and cool wet conditions. Temperature changes and more wet conditions, over and/or under estimate the CROPGRO model. Predicting lentil phenology is difficult for CROPGRO model, because of lack of understanding of sensitivity to temperature and photoperiod during development with sensitivity of lentil development rate to cool temperature decreasing after beginning seed filling duration and ultimately biomass accumulation (Grimm *et al.,* 1994).

CROPGRO chickpea model slightly under simulated the LAI during the both years of evaluation and validation with percent difference of -12.57 and -13.01 and during calibration -20.57% difference with RMSE of 0.48. Model under estimated results for LAI and phenology are in agreement with the results of Kumar *et al.* (2008) who worked on CROPGRO-Soybean for GS_2 variety at different sowing dates and plant population. Observed and simulated maturity having 12 days difference while observed and predicted LAI was 5.4 and 3.4 with deviation of 2 having RMSE of 0.5. Simulation using CROPGRO-chickpea under DSSAT was equally good in both evaluation and validation. So it appears from this study that CROPGRO chickpea model could be successfully used for lentil crop in the semi-arid conditions of Punjab. CROPGRO model under DSSAT may be used for generating future climate change scenarios under different climatic zones in Pakistan to assess the drastic effects of rising temperature, enhancing CO_2 and changing rainfall patterns in order to develop site specific mitigation and adaptation strategies.

In conclusion, model calibration and evaluation for growth, development and yield for promising cultivars of lentil at different Nitrogen doses proved to be satisfactorily under local climatic conditions of Pakistan and it can be very well validated under a set of independent data. CROPGRO chickpea model can be successfully used as a research tool to explore the effects of complex and alternate management decisions to sustain lentil production and evaluate the risks associated with adopting such decisions. There is a need in future to evaluate this model under variable climatic conditions and also to assess climate impact for food security in Pakistan.

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