academicresearchJournals

Vol. 9(2), pp. 69-78, February 2021
DOI: 10.14662/ARJASR2021.030

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

Calibration and Evaluation of CSM-Cropgro- Faba Bean Model in Highlands of Ethiopia

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Accepted 1 February 2021

Field experiments were conducted during the 2014/15 and 2015/16 cropping season at Holetta, Kulmsa, Ambo, Agricultural Research centers and Kuyu testing site of Holetta. The cultivars namely, Gora, Gebelcho, Dagem and Walki released for Nitisols and vetisols were used to calibrate and evaluate CSM-CROPGRO- faba bean model in Ethiopia. The model inputs (crop management information, soil and daily weather data including maximum and minimum air temperatures, precipitation and solar radiation were used for calibrate and evaluation of CSM- CROPGRO- faba bean model in Ethiopia. The statistical indices used to measure model performance during calibration for days to flowering, days to maturity and grain yield showed a good agreement between the measured and simulated values. The performance of the calibrated model was also evaluated against the independent data set of experiments carried out in 2015 cropping season. The model evaluation indicated a good agreement between measured and simulated days to flowering (RMSE = 4 days; d = 0.92), maturity (RMSE = 7 days; d =0.93), and grain yield (RMSE= 0.6 t ha^{-1}; d = 0.8).In general, the current crop simulation model obtained after calibration and evaluation can be use in model applications o assess water- limited and potential yield, yield gaps and in closing yield gaps. Such information can assist plant breeder in the recommendation of cultivars to the target environment and determine management practices in both nitisols and vertisols. The objective of this study was to calibrate and evaluate CSM-CROPGRO-Faba bean model to estimate cultivar genetic coefficient in the highlands of Ethiopia

Keywords: *Crop modeling, Cultivar coefficients, DSSAT, faba bean*

Cite this article as: Wondafrash.M., Kindie T., Mezegebu G., Ahmed. S., Amsalu N., Fasil M. (2021).Calibration and Evaluation of CSM-Cropgro- Faba Bean Model in Highlands of Ethiopia. Acad. Res. J. Agri. Sci. Res. 9(2): 69-78

INTRODUCTION

In Ethiopia to increase faba bean production and productivity a new approach required like crop models. Crop simulation models to be used to simulate growth, development and yield of crops,

However, a critical first step is to know model is a function of environment (particularly weather, soil) and agronomic management practices (Boote et al., 2001). Thus, models need to be properly calibrated and evaluated before they are used for simulation (Mote et al., 2016). Model calibration is the adjustment of cultivar-specific parameters (genetic coefficients) so that simulated values compare fairly well with observed ones (Waha et al., 2013).Whereas, model evaluation involves comparison of outputs of a calibrated model with an independent data set and determination of suitability for application of the model according to our objectives.

The cultivar- specific parameters (genetic coefficients) define the growth and development of individual genotypes (Hunt et al., 1993; Boote et al., 2003). Cultivar coefficients are one of crop model inputs that account for cultivar differences of a certain crop. They allow the models to simulate the growth and development of a crop cultivar under different growing environmental conditions, taking into account the genotype by environment interaction (Hoogenboom et al., 1992).

Cultivars are represented by a group of genetic coefficients derived from calibrations using data from field experiments. These coefficients describe the genotype characteristics in response to soil and climate conditions, affecting phenology, accumulation of biomass and partitioning of assimilates. To simulate crop phenology, CROPGRO defines 18 stages, each one set when a photo thermal accumulator is reached (Jones et al., 1998).

Simulation models after calibration and evaluation with experimental data can be used to quantify water -limited yield, potential yield and yield gap; and explore crop management options as well as understand climate change impacts on adaptation options. Models can also be used to forecast yields prior to harvest and extrapolate the results obtained from different seasons, locations and management practices (Matthews et al., 2013). Measured data from contrasting growing environments for a given crop cultivar are considered to be more suitable for model calibration and validation (He et al., 2017).

In Ethiopia, use of process-based faba bean crop simulation model was not practiced particularly on faba bean and specific parameters for faba bean cultivars have not been determined before. Hence, it is difficult to predict the yield, to study genotype x environment x management interaction, support the recommendation of new varieties in the target growing environments, and to estimate water- limited yield, yield potential, yield gap and management practices .Therefore, the main objective of this study was to calibrate and evaluate the CSM-CROPGRO-faba bean model to estimate cultivar genetic coefficient of four released faba bean cultivars namely Gora, Gebelcho, Dagem and Walki with field experimental data from nitisols and Vertisols in the highlands of Ethiopia.

MATERIALS AND METHODS

Description of the study sites

The study was conducted at four locations: Holetta, Kulumsa, representing, the Nitisols, and Ambo, and Kuyu are representing the Vertisols faba bean growing environments (Table 1). The experiments were conducted during the 2014/15 and 2015/16 cropping seasons in rainfed and supplemental irrigation.

Field experiments and trial management

In the present study, CROPGRO-faba bean model was used to simulate the growth and yield of faba bean bean (*Vicia faba* L.). Crop phenological and yield data for model calibration and evaluation were obtained from field experiments conducted in four locations with different soils and contrasting climatic conditions. Rainfed experiments were conducted at Holetta Kulumsa Ambo and Kuyu during the Meher seasons of 2014/15 and 2015/16. Two improved faba bean cultivars namely, Gora (EH91026-8-2 X BPL44-1), and Gebelcho (ILB4726 X 75TA26026-1-2) were planted on nitisols of Holeta and Kulumsa whereas Dagem (Grar jarso 89-8) and Walki (ILB4726 X 75TA26026-1-2) cultivars were planted on Broad bed and Furrow (BBF) to drain the excess water from the field in vertisols of Ambo and Kuyu. Both soils were considered represent the major soil types of faba bean grown in highlands of Ethiopia. The plots were non-replicated with a plot size of 100 m^2 with 40 cm spacing between rows and 10 cm spacing between plants. The experiment at Holetta was repeated in the small rainy season (February-April) using supplemental irrigation with 30 cm spacing between rows and 10 cm spacing between plants. The experiments were managed under optimum management practices to avoid stresses from nutrients, weeds, insect pests and diseases. The minimum data set required for model calibration including dates to flowering, and maturity as well as yield and biomass were recorded from all locations.

Data collected

Soil data

Soil physical and chemical properties data were collected from Holetta, Kulumsa, Ambo, and Kuyu locations where the field experiments were conducted in 2014 and 2015 cropping season. Soil samples were collected prior to planting and at the depths of 0-20 and 20-40 cm top and subsoils. Four sub-samples were randomly taken from each sampling depth and each site to make a composite sample. The composite soil samples were air-dried and ground to pass- through 0.2 mm sieve for analysis at Holetta Agricultural Research

Center (HARC) Soil and Plant Tissue Analysis Laboratory, Ethiopia. The soil samples were analyzed for pH, in H_2O with a liquid solid ration of 1:1 (Black ,1965) ; organic carbon (OC); total nitrogen (TN) by using Kjeldahl method (Bremner and Mulvaney, 1982 available phosphorus (P) determined using Bray-II and Olsen methods (Bray and Kurz, 1945; Potassium (K), Cation Exchange capacity (CEC), and exchangeable cations (EC) (Table 2).

Soil profile data was obtained from locations where the field experiment executed across all available horizons including bulk density, soil texture percent silt and clay, organic matter (OM), total nitrogen (TN), root growth factor (RGF), pH, and Cation exchange capacity (CEC), P and K. In addition, the soil parameter used in determination of soil water balance dynamics such as drained upper limit (DUL)/field capacity Soil water content at drained upper limit in soil layer L (cm3[water]/cm3[soil]),, lower limit (LL)/ permanent wilting point Soil water content in soil layer L (cm3[water]/cm3[soil])), and soil water content in layer L at saturation (SAT) (cm3[water]/cm3[soil]) (Abebe,1998; Tolosa, 2006; Sahlemedhin and Abayneh, 2003) (Table 1).Soil water dynamics such as drained upper limit (DUL), lower limit (LL) of soil water content (cm^3[water]/cm^3[soil]),and saturated water content (SAT) (cm^3[water]/cm^3[soil]), were estimated from soil physical properties data such as soil texture (percentage of sand, silt and clay), soil organic matter content and soil bulk densities and etc., in to a soil file creation utility program of the DSSAT v4.6 software (Table 2).

Weather data

Daily weather data of maximum and minimum temperatures and rainfall for the period 1980 to 2009 were obtained from National Meteorological Agency of Ethiopia for the selected sites namely Ambo, Holetta, Kulumsa and Kuyu. Daily solar radiation was taken from the National Aeronautics and Space Administration for Climatology Resource for Agro-climatology (NASA POWER) (Stackhouse, 2010, http://power.larc.nasa.gov) (Table.1)

Table 1. Description of the four field experimental locations

Parameters	Holetta	Kulumsa	Ambo	Kuyu
Altitude (m)	2400	2200	2090	2400
Latitude (decimal degrees)	9.3	8.133	8.967	9.05
Longitude (decimal degrees)	38.3	39.133	37.867	38.05
Annual rainfall (mm)	1064.5	797.5	1165	1166.4
Growing season Rainfall(mm)	779.4	513.1	830.5	861.4
Mean minimum temperature (^oC)	6.4	10.0	11.7	6.4
maximum temperature (^oC)	22.5	23.0	25.4	22.5
Daily solar radiation (MJ/(m^2day))	21.7	21.2	21.0	21.6
Soil type	Nitisols	Nitisols	Vertisols	Vertisols

Data source: Holetta, Kulumsa, and Ambo Agricultural Research Centers weather report

Table 2. Soil profile data used for model input at four experimental locations

Depth (cm)	DUL	LL	SAT	pH (H_2O)	BD (g cm^{-3})	CEC cmol/kg	K ppm	P ppm
		Ambo						
13	0.189	0.092	0.468	6.2	1.36	1.0	15.0	0.96
45	0.148	0.077	0.477	6.5	1.33	0.56	14.2	0.97
78	0.163	0.084	0.48	6.8	1.37	0.29	11.7	1.03
110	0.177	0.088	0.483	6.8	1.48	0.15	13.6	1.18
153	0.157	0.085	0.46	7.1	1.56	0.07	9.8	1.25
187	0.155	0.109	0.474	7.2	1.59	0.03	10.7	1.48
200	0.155	0.109	0.471	7.1	1.52	0.024	12.2	1.47
			Holetta					
20	0.339	0.13	0.45	5.4	1.36	0.82	29.9	328
40	0.347	0.13	0.45	6.0	1.60	0.55	31.4	250
80	0.345	0.13	0.44	6.0	1.26	0.30	25.0	438
120	0.332	0.13	0.43	6.0	1.26	0.07	24.7	344
			Kulumsa					
25	0.409	0.20	0.52	5.9	1.16	0.79	31.4	2.03
45	0.426	0.22	0.53	6.4	1.15	0.50	32.6	1.41
70	0.469	0.26	0.54	6.4	1.13	0.32	37.4	1.38
115	0.529	0.31	0.55	7.0	1.10	0.16	39.0	1.56
145	0.529	0.31	0.55	7.4	1.10	0.07	39.2	1.69
185	0.369	0.17	0.51	7.8	1.19	0.04	46.6	2.19
			Kuyu					
17	0.438	0.137	0.518	5.3	1.28	0.84	52.3	1.04
41	0.459	0.349	0.533	5.7	1.24	0.55	64.2	1.07
94	0.458	0.349	0.538	6.3	1.23	0.26	65.9	1.03
129	0.46	0.349	0.531	6.9	1.24	0.12	70.4	0.10
188	0.457	0.457	0.542	6.5	1.21	0.042	72.8	1.06

† DUL, drained upper limit or field capacity of soil ; LL, Soil water content lower limit or permanent wilting point ; SAT, Saturated soil water content ((cm^3[water]/cm^3 [soil]) (calculated by DSSAT 4.6 program**)**; pH, pH in water; BD, bulk density; p, Phosphorous ; K, Potassium ;CEC, Cation exchange capacity; Data source: (Debele, 1985**,** Abebe,1998;Tolosa, 2006; Sahlemedhin and Abayneh, 2003)

Data Analysis

Cultivar coefficient estimation

The calibration and testing of the DSSAT-CROPGRO-faba bean model for the experimental conditions were performed by adjusting genetic coefficients that characterize the essential aspects of faba bean, as recommended by Jones et al, 2003. The Genetic coefficients of each cultivar were determined iteratively by executing the model with approximate coefficients, comparing model output with actual data and then re-adjusting the coefficients and repeating the process until acceptable fits are obtained.

RESULTS AND DISCUSSION

Soil Analysis

According to Tadese, 1991 the pH was classified as strongly acidic for Hoetta moderately acid for Kulumsa and Kuyu and neutral for Ambo. Values of OC and TN content of the soil were rated as low for Holetta and Ambo but moderate for Kulumsa and Kuyu. Thus, soil reclamation and amendment is important for Holetta. Besides, addition of single and/or combined fertilizers at the right rate might be required whenever there is nutrient deficiency in the study sites.

Cultivar coefficient and model evaluation

The cultivar coefficients estimated through the calibration process for four faba bean cultivars studied are presented in Table 3.3. The genetic coefficients were sensitive enough to capture the differences among cutivars. The cultivars specifically differ in the period between plant emergence and flower appearance (R1). The statistical indices used to measure model performance during calibration for days to flowering, days to maturity and grain yield showed a good agreement between the measured and simulated values (Figure 1).

The performance of the calibrated model was also evaluated against the independent data set of experiments carried out in 2015 crop season by comparing simulated output and observed data. The model evaluation (Fig. 2) indicated a good agreement between measured and simulated days to flowering (RMSE = 4 days; d= 0.92), maturity (RMSE= 7 days; d= 0.93), and grain yield (RMSE= 0.6 t ha^{-1}; d = 0.8). The performance of the CROPGRO– faba bean model in the current study is similar to the one reported for CROPGR-chickpea and CROPGRO-dry bean in Ethiopia (Tesfaye and Walker, 2006) indicating the ability of the model in simulating the phenology and yield of legume crops in Ethiopia. Similarly, Boote et al. (2002) at Cordoba, Spain revealed using Alameda and Brocal faba bean cultivars with application of furrow irrigation as necessary ,to avoid water deficit and made comparison between observed ,and simulated of flowering (83.7, 82.7), maturity (162.7, 160.7) and grain yield (t ha^{-1}) (6.3, 6.5 and with RMSE of 3, 2.2, and 370, respectively.

Table 3. Chemical characteristics of top soil (0-40cm depth) before planting field experiments, 2014/15 cropping season

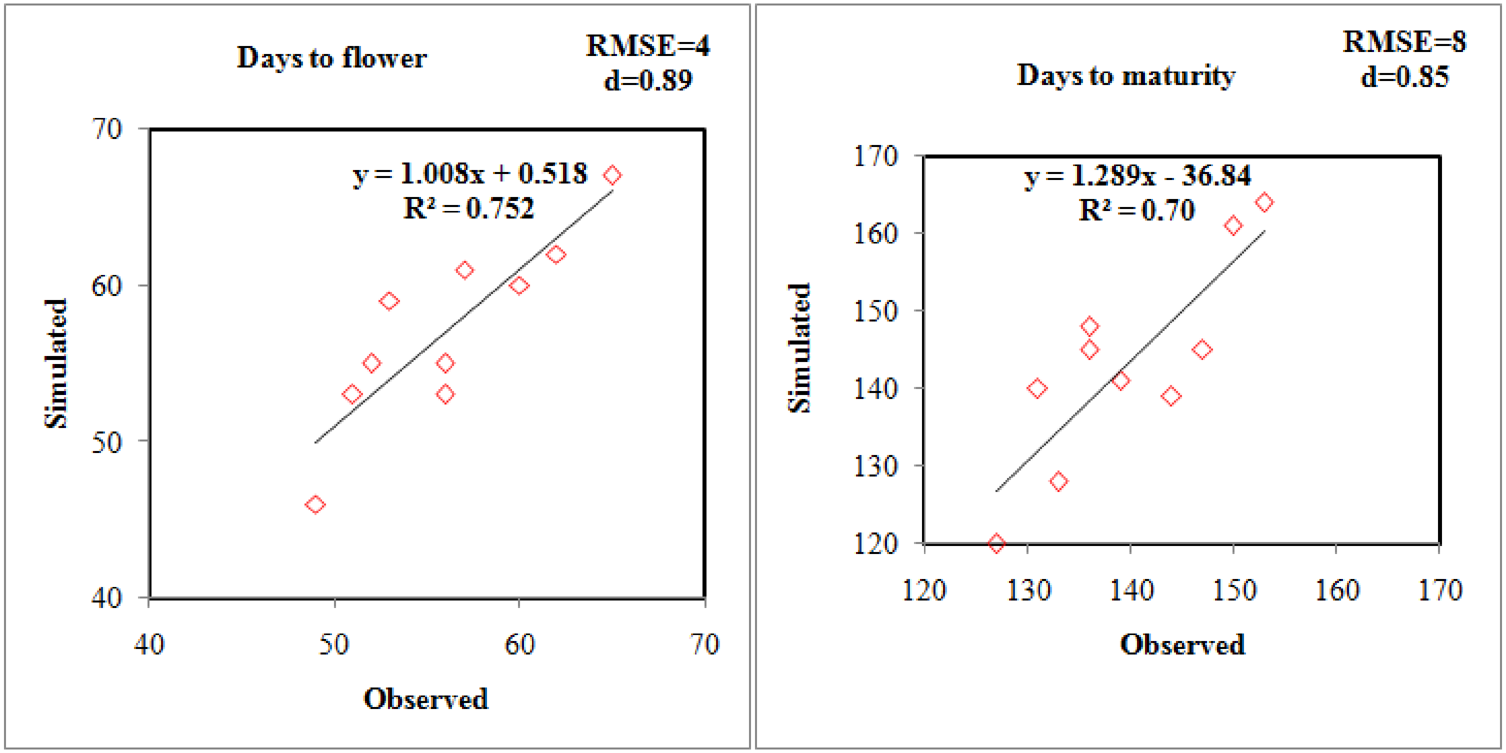
Locations	pH (H_2O)	OC (%)	TN (%)	average P (ppm)	Average K (Meq/100g)	CEC (Meq/100g)
Holetta (Supplemental irrigation)	5.1	1.1	0.1	28.5	0.6	22.3
Holetta-rainfed	5.1	1.3	0.1	17.1	0.9	22.0
Kulumsa-Rainfed	5.9	2.4	0.2	7.1	1.5	35.3
Ambo-Rainfed	7.3	1.1	0.1	15.2	0.8	60.6
Kuyu-Rainfed	5.4	2.2	0.2	7.9	0.4	41.4

PH, pH in water; OC, organic carbon; TN, Total nitrogen; CEC,Cation exchange capacity.
Data source: Holetta Agricultural Research Center (HARC) Soil and Plant Tissue Analysis Laboratory

Table 4. Cultivar coefficients of the four faba bean cultivars

Traits	Abbrev.	Unit	Cultivar			
			Gora	Gebelcho	Dagem	Walki
Critical short day length below which reproductive development progresses with no day length effect	CSDL	h	24	24	24	24
Slope of the relative response of development to photoperiod with time (positive for short day plants)	PPSEN	h	-0.31	-0.31	-0.31	-0.31
Development parameters						
Time between plant emergence and flower appearance (R1)	EM-FL	PT	18.5	19.5	21.5	24.5
Time between first flower and first pod (R3)	FL-SH	PT	10.9	11.5	11.5	11.5
Time between first flower and first seed (R5)	FL-SD	PT	21.0	22.0	21.0	23.0
Time between first seed (R5) and physiological maturity (R7)	SD-PM	PT	34.5	35.5	43.0	38.5
Time between first flower (R1) and end of leaf expansion	FL-LF	PT	46.0	48.0	46.5	47.0
Growth parameters						
Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light	LFMAX	mg CO2/m2s-1)	0.65	0.70	0.6	0.55
Specific leaf area of cultivar under standard growth conditions	SLAVR	Cm2/g	280	285	285	335
Maximum size of full leaf	SIZLF	Cm2	135	135	115	135
Maximum fraction of daily growth that is partitioned to seed shell	XFRT	-	0.6	0.6	0.6	0.6
Maximum weight per seed	WTPSD	g	0.70	0.8	0.4	0.7
Seed filling duration for pod set at standard growth conditions	SFDUR	PT	21.0	20.5	22.5	20.8
Average seed per pod under optimum growing conditions	SDPDV	seeds/pod	2.5	2.6	2.0	2.6
Time required for cultivar to reach final pod load under optimal conditions	PODUR	PT	20	20	22.0	20
Maximum shelling percentage [seed 100%/ (seed/pod)] at maturity (THRESH) (%)	THRSH	Threshing (%)	70	75	65	75.3
Fraction protein in seeds	SDPRO	g(protein)/g (seed)	0.315	0.315	0.315	0.315
Fraction oil in seeds	SDLIP	g(oil)/g(seed)	0.02	0.02	0.02	0.02

PT= Photo thermal days


Days to flower
RMSE=4
d=0.89
y = 1.008x + 0.518
R² = 0.752
Simulated
Observed
40
50
60
70
Days to maturity
RMSE=8
d=0.85
y = 1.289x - 36.84
R² = 0.70
Simulated
Observed
120
130
140
150
160
170

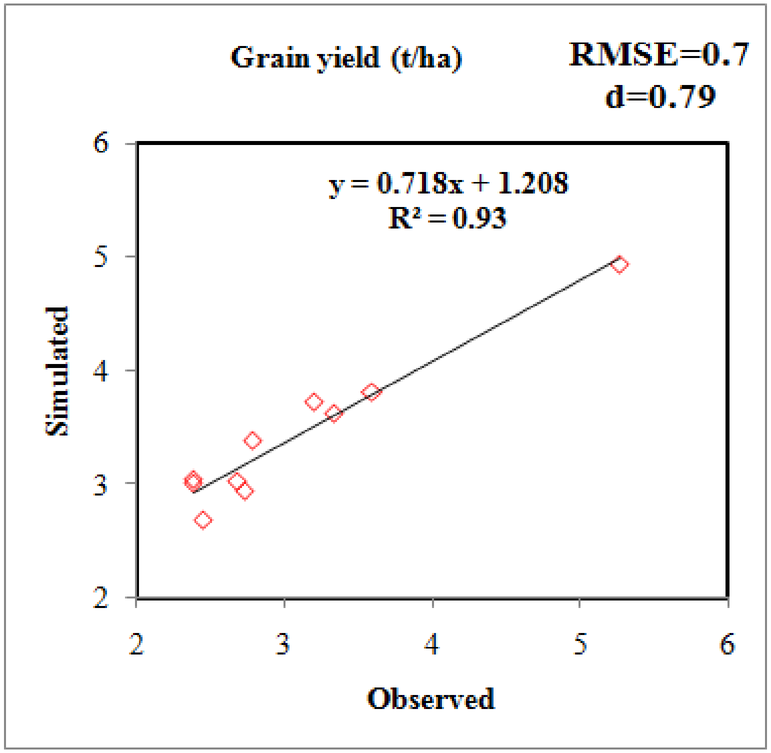


Figure 1. Relationship between measured and simulated number of days to flowering (left), days to physiological maturity (right) and grain yield (t ha^{-1}) (bottom) during the calibration phase. RMSE= root means square error, d= index of agreement

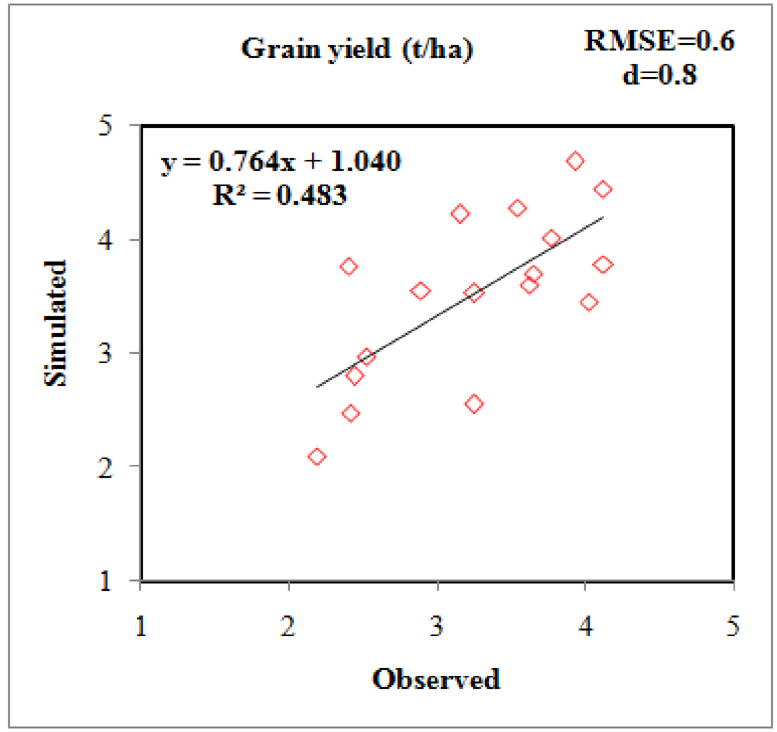


Figure 2. Relationship between measured and simulated number of days to flowering (left), days to physiological maturity (right) and grain yield (t ha^{-1}) (bottom) during evaluation phase RMSE= root means square error, d= index of agreement

CONCLUSION

The study showed that the DSSAT CROPGRO-Faba bean model is able to simulate crop phenology, grain yield, reasonably well for Nitisols and vertisols in the highlands of Ethiopia. The cultivar coefficients determined for the four released cultivars namely (Gebelcho, Gora, Dagem and Walki) can be adopted for crop model applications: such as to estimate water-limited yield, potential ,yield gap, determine management practices like an optimum planting date, planting density, fertilizer rate or cultivar choice also can be used to predict crop performance in sites where the crop has not been grown before, by predicting probabilities of grain yield levels for a given soil type and rainfall distribution.

ACKNOWLEDGEMENT

The financial support by the Ethiopian Institute of Agricultural Research (EIAR) and give the opportunity to the first author to pursue his PhD study highly appreciated. Moreover, the work was supported by Austria Development Agency fund provided to International Center for Agricultural Research in the Dry Areas (ICARDA), Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), and International Maize and Wheat Improvement Center (CIMMYT). We also would like to acknowledge for their financial and technical support and providing training.

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