Advances in Crop Science and Technology
ISSN: 2329-8863
Research Article Open Access

Yield Estimation and Sensitivity Analysis of Maize (*Zea Mays L.*) Cultivars Using DSSAT Software in Assosa, Western Ethiopia

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Abstract

An experiment was conducted in the Assosa university farm during 2019 and 2020 on maize cultivars with the objective of calibrating and validating maize cultivar coefficients using DSSAT software version 4.7.5. Five-cultivar coefficient was calibrated and evaluated using 2019 and validated using the 2020 crop data. The Genetic coefficient among cultivar showed, SHONE is highest in grain filling rate, while SHONE, BH545 and MH138 are highest in delay in development due to photo-period sensitivity, and highest in the number of kernels. Normalized difference RMSE (nRMSE) was Zero for days to anthesis, days to maturity and grain yield, while it was between 0-20% for leaf number and dry biomass yield as calculated by DSSAT during calibration. Time serious crop growth showed higher R2 (>90) and d-stat (>85) for most measured crop parameters during validation. The calibration results of 2019 showed that the observed and simulated values of maize cultivars are similar with ratio of near 1, for at least five measured values: days to anthesis, physiological maturity, dry biomass yield, grain yield and unit grain weight. The sensitivity analysis also showed that the performance of the different cultivars can vary depending on the climatic condition that could occur in study site. The day of planting when changed, starting from May 1 through to May 10 and May 20 continuously, increased the grain and dry biomass yield, but yield on May 1 was lower compared to actual time of planting (June 1-15), while planting in June 25 decreased the grain and biomass yields. Under stress conditions improving the plant density between 9-12 plant per m2 and the date of planting to May 10 to 20 could increase the yield of maize cultivars. The more cultivar coefficients are well calibrated and validated the more the yield estimation of the DSSAT software.

Keywords: Maize cultivars; Calibration; Validation; Sensitivity; Plant density; Date of planting

Introduction

DSSAT is one best crop simulation software, which is showing best promises in yield estimation and yield prediction over long time enabling decision support to different parties (Abera et al., 2018; Hoogenboom, et al.2012). DSSAT Software package has gone through different progress since its development with only few crops and four crop models (CERES maize, CERES-wheat, SOYGROW, NUTGROW) (Jone et al., 2003; Kaleita et al., 2020) to more than 42 crops and addition of new modules (Kaleita et al., 2008; Sachin et al., 2019; Abayechaw, 2021). Its advancement for use in many operating systems (Thorp et al., 2011), data interchange system and its ability to be integrated with different software (Dzotzi et al., 2013; Thorp et al., 2008) inclusion of new modules (Kaleita et al., 2020) used in precision agriculture (Paz et al., 2001a, 2003; Thorp et al., 2008) and with its betterment in the challenges in formatting input and output files (Kaleita et al., 2008) it has become more user friendly, and is well validated for a number of regions and crops (Throp et al., 2008) [1].

In the same line as the progress in DSSAT developers the progress that demand in the users of DSSAT in the agricultural sector should also be in line by evaluating and validating the different new interfaces of DSSAT added from time to time and covering most areas of the agricultural ecosystem while, adjusting crop coefficients of cultivars is needed for its efficient utilization (Hoogmboom et al., 2020) [2]. The demand continues in evaluation and validation of crop parameters for various crop genes by environment interactions so that we can address the different combination of effects from changes occurring on the environment (Abera et al., 2018) and changes occurring by varying different technologies (Thorp et al., 2008) and at the end it will be possible to find ways to modify or optimize the models within DSSAT for our local condition and specific crop (Jing-yi et al., 2012) [3].

Environmental changes that arise due to climate change and variability across agro-ecosystems (Abera et al., 2018) as well as the differential potentials of crop cultivars across different agroecologies, technologies used in the management practices are the major causes (Jone et al., 2003) for fluctuations and yield gap problems that are widely seen in most cropping systems and have predicted future impact on the crops productivity (Abera et al., 2018; Mulune et al., 2015) [4]. For example in Ethiopia climate change perdition across time between 2010-2099 showed a decrease in maize yield by more than 24 % at the end of the century. The use of adaptation strategies, such as, the best cultivar of maize and change in the date of planting will have a salvaging effect up to 12% yield reduction during predicted years of 2012 -2040 (Eulenstein et al., 2017). Being at the start of long term climate change predictions this study is done with the objective of Evaluating and validating different cultivars using DSSAT-CSM, while testing the maize cultivar sensitivity based on some anticipated climate change scenarios [5].

Materials and Methods

Description of the Study Site

The experiment was conducted for two seasons in a warm sub-humid lowlands agro-ecology possessing one altitude feature in the region. The major agroecology covering vast area of the region are

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Received: 01-Apr-2024, Manuscript No: acst-24-135773, **Editor Assigned:** 04-Apr-2024, pre QC No: acst-24-135773 (PQ), **Reviewed:** 18-Apr-2024, QC No: acst-24-135773, **Revised:** 22- Apr-2024, Manuscript No: acst-24-135773 (R), **Published:** 29-Apr-2024, DOI: 10.4172/2329-8863.1000691

Citation: Hailu BT (2024) Yield Estimation and Sensitivity Analysis of Maize (*Zea Mays L.*) Cultivars Using DSSAT Software in Assosa, Western Ethiopia. Adv Crop Sci Tech 12: 691.

the warm moist lowlands and warm sub-humid lowlands having distribution in all the Zones and most districts. Assosa district is selected to represent warm moist lowlands agroecology. The study site is geographically located at 34o 31'E longitude and 10o04'N latitude with an altitude 1580 meters and it is approximately 660 km west of the capital, Addis Ababa [6].

Description of the study materials

Five maize varieties adapted to the agroecology, which are high yielding; resistant to disease and recently released varieties, were selected for the study. Based on the selection criteria the five varieties were, Shone (Pioneer), Melkasa6, MH138, BH545 and local variety. Blended NPS and KCl (60% K) fertilizer was used to supply the three major nutrients, nitrogen, phosphorus and potassium and one micro-nutrient which is deficient in the soil of the study site (Table 1) [7].

Soil Sample and sampling methods

Soil samples were taken from the whole field at 10 points and from 4 depths (0-20, 20-40, 40-60 and 60-80 cm) before treatment application and from each plot at 3 points diagonally after crop harvest from 30 cm depth of and samples from the similar experimental unit were composited [8].

Soil physical properties like soil texture and soil dry bulk density, accompanied by chemical properties were tested following standard methods, in the Assosa University Soil Lab. Soil texture were determined using density method proposed by Bouyoucos (2003); the dry bulk density were measured by core sampling method of Black (2003); the soil pH (1:2.5) by pH meter (potentiometric analysis) (Jackson, 2003); the percent organic carbon content using wet potassium dichromate oxidation method (Walkley and Black, 2003); while the exchangeable K was measured by flame photometer; total N by kjeldahl digestion method (Jackson, 2003); and available P by Bray No 1 method (Bray et al., 1945) [9].

Treatments and design of the experiments

The five cultivars of maize SHONE (Pioneer), MELKASA6, MH138, BH545; and one local cultivar that was planted under two nutrient condition one with (NPS and KCl) and the second one without (NPS and KCl) fertilizers. The four cultivars and the local cultivar with two nutrient situations were planted for two seasons as single factor experiment. The six (6) treatments was, planted on plot size of 4.5 m x 4.5 m with plant spacing of 75 cm and 30 cm between rows and between plants on a row, respectively, for all the cultivars. The experiment was laid in RCBD design, with three replications.

Data collected

Crop data

Data on days to emergence, days to anthesis and silking and days to physiological maturity; and crop data on four important stages was measured to calculate the genetic parameter, like P1, P2, P5, G2, G3 and PHINT at each leaf appearance. P1 is the thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days, oC day, above a base temperature of 8 oC) during which the plant is not responsive to changes in photoperiod. P2 is the extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h). P5 is the thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 oC). G2 is Maximum possible number of kernels per plant. G3 kernel filling rate during the linear grain filling stage and under optimum conditions (mg day−1). And PHINT is the Phyllochron interval; the interval in thermal time (degree days) between successive leaf tip appearances, to record the phyllochron the plants were observed every day starting from emergence until flowering [10].

Growths of maize such as the leaf area index and plant height were recorded at each full appearance of new leaves until the end of leaf growth and start of flowering. Plant samples were selected from the central plant rows for measuring the LAI and the plant height. Yield component data were also measured at physiological maturity, while the grain yield and final dry biomass yield were taken at time of full maturity. All plant parts (leaves, stalk and the husk) were separated dried and summed up for dry biomass yield [11].

Climate and soil data

A 40 year data between (1980-2020) on five climate variables, solar radiation, maximum temperature, minimum temperature, relative humidity and rainfall was collected from Ethiopian meteorology agency of Benishangul Gomez region, however because of high numbers of missing data between (1980-2000) only 20 year data between (2000-2020) was used for the calibration and validation purpose as completeness of climate data is more important than the numbers of years (Hognboom, et al., 2012).

During the period of the experiment in the 2019 the amount of rainfall in the growing period was 967 mm which is slightly lower than the rain fall amount in the growing period of 2020 experiment year 987 mm. The min and max temperature during 2019 was slightly higher than 2020 in the growing period the different climatic variable in the two growing period (Figure 1,2).

Soil analysis was made by taking soil samples from four depths of 0–20, 20–40, 40–60, and 60–80 and 80-100 cm and soil physical properties like: texture, dry bulk density, and some soil chemical properties, such as pH, Organic carbon, Total N, available P, available K were taken before and after the experiment [12].

Data analysis

Crop data in the first season, was used to calibrate the CERES maize model of DSSAT software version 4.7.5, while in the second season the

Table 1: Descriptions of Maize varieties selected for the study.

Variety	Year release	Source of Germplasm	Altitude(m)	Rain fall (mm)	Days to Maturity	Yield (t ha^{-1})	
						Research Station	Farmers field
SHONE	2006	Pioneer	1000-2000	800-1200	-	70-110	65-80
Melkas6	2011	Bako RC	1000-1700	1000-1200	145	65-70	45-50
MH138							
BH545	2002	EIAR	1700-2400	1000-1200	165	90-120	60-80
Local	-	-	-	-	-	-	-

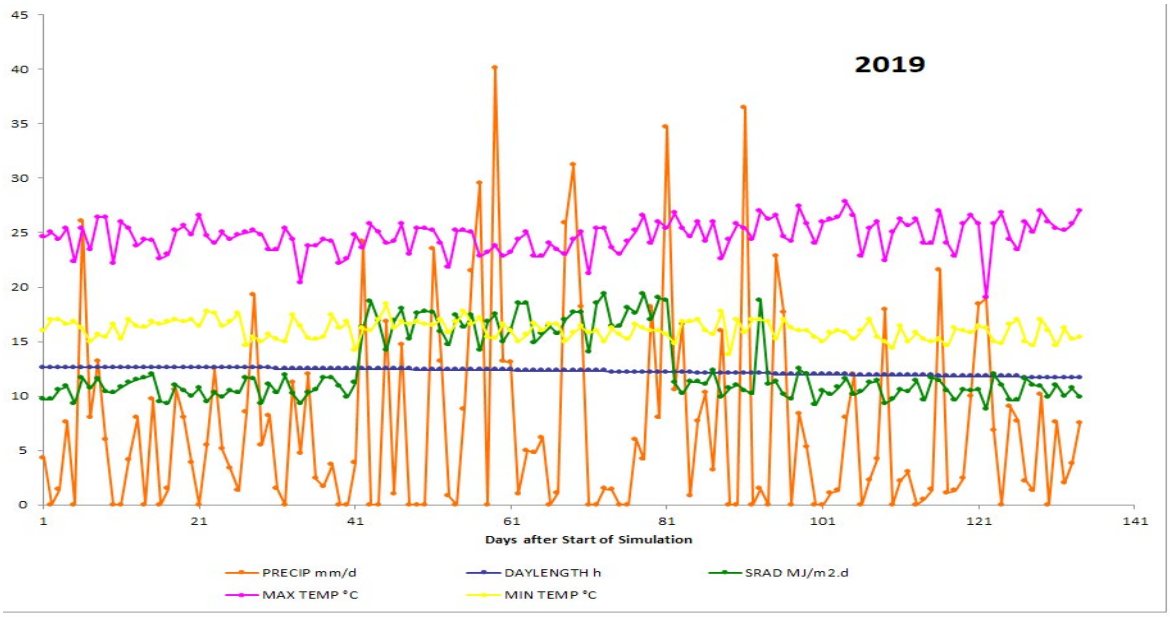

Figure 1: The weather condition in the growing period of 2019.

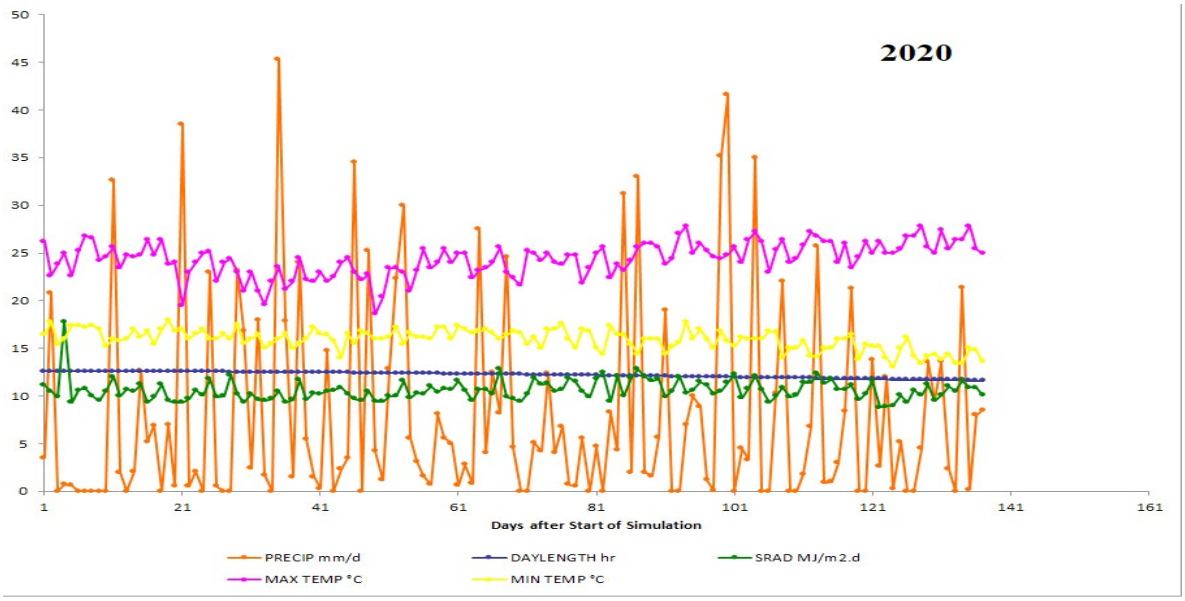

Figure 2: The weather condition in the growing period during 2020.

crop data were used to validate using the statistic root means squared error (RMSE), Normalized difference RMSE (nRMSE), mean absolute error (MAE), index of agreement (d) of DSSAT (Yang et al., 2014). Then crop growth and yield of maize scenarios were estimated by changing climatic variables that approximate the El-nino periods of historic El nino years, and different adaptation strategies were tested based on changes in the length of growing period and maize varieties using the DSSAT software.

Result and Discussion

Soil Test Results

The soil analysis across five depth showed that the dry bulk density increased downward in the range between 2.00 - 2.20, while the soil pH; organic carbon, total nitrogen and available phosphorus decreased across depth within range between, 5.50-5.30, 2.84-0.62, 0.49-0.12, and 27.0-25.2 respectively, while the available potassium increased downward from 0.5-0.8 (Table 2).

Evaluation of calibrated result

Calibration of five maize varieties using the DSSAT Software: the days to anthesis, the days to physiological maturity, grain yield, harvest index, unit grain weight, and kernels number are simulated with acceptable RSME and d-stat values, higher R2 values and within the ranges of crop coefficient limits.

The minimum and maximum DSSAT-CSM crop coefficients and the new calibrated coefficients of the five cultivars of maize are shown. Comparison of the cultivars from the genetic coefficient may show that variety SHONE is the highest in grain filling rate, while it

Table 2: Initial soil characteristics of experimental field.

Initial soil characteristics of some physical and chemical properties						
Soil depth (cm)	**Bulk density (g cm^{-3})**	**pH (H_2O)**	**Organic carbon (%)**	**Total N (%)**	**Available P (mg kg^{-1})**	**Available K (cmol kg^{-1})**
0-20	2	5.5	2.48	0.49	27	0.5
20-40	2.1	5.4	1.8	0.36	25.7	0.6
40-60	2.1	5.4	1.87	0.37	25.2	0.7
60-80	2.2	5.3	1.17	0.23	25.6	0.8
80-100	2.1	5.3	0.62	0.12	25.2	0.8

Table 3: CSM-CERES cultivar coefficient limits and maize cultivars coefficient.

G.cof.	MIN	MAX	SHONE	MELKASA6	MH138	BH545	L-ASOSA
P1	5	480	260	240	282	285.4	278.7
P2	0	2	0.405	0.248	0.399	0.365	0.398
P5	390	999	656	661.7	546.2	575	562.8
G2	248	990	999	318.1	999	1292	900
G3	4.4	16.5	9	6	8.5	8	8.5
PHINT	30	75	44.92	52.01	53.11	51.45	57.37

Table 4: Normalized RMSE obtained from DSSAT during calibration.

Varieties	RMSE (percentage) based on crop parameters in Maize rules file				
	Anthesis	**Maturity**	**Grain yield**	**Leaf number**	**Biomass yield**
SHONE	0.00%	0.00%	0.00%	1.56%	20.33%
MELKASA6	0.00%	0.00%	0.00%	18.25%	5.40%
BH545	0.00%	0.75%	0.00%	0.00%	24.81%
MH138	0.00%	0.00%	0.00%	0.06%	13.12%
L-ASSOSA	0.00%	0.00%	0.00%	10.18%	20.36%

Table 5: RMSE, R^2 and d-stat values used to evaluate simulated maize in 2019.

	Mean							
Variable Name	**Observed**	**Simulated**	**Ratio**	**r-Square**	**Mean Diff.**	**MAD**	**RMSE**	**d-Stat.**
Emergence day	6	7	1.17		1	1	1	0
Anthesis day	84	85	1.01	0.79	1	1	1.68	0.93
Maturity day	132	132	1	0.89	0	0	0.41	0.97
Tops wt t/ha	11.01	9.79	0.96	0.77	-1218	2397	2592.14	0.77
Mat Yield t/ha	3.39	4.63	1.43	0.74	1238	1341	1502.4	0.79
Weight g/unit	0.28	0.25	0.91	0.75	-0.03	0.03	0.03	0.85
Leaf number #	15.17	18.75	1.25	0.26	3.58	3.58	3.81	0.38
LAI maximum	3.09	2.25	0.78	0.02	-0.83	0.86	1.14	0.5
Harvest index	0.3	0.46	1.51	0.03	0.15	0.18	0.18	0.21

was the second in number of kernels compared to BH545 and MH138, the delay in development due to photo period sensitivity is higher for SHONE and MELKASA6 compared to the other three MH138, BH545 and L_ASOSA (Table 3).

The normalized RMSE (nRMSE) for each cultivar based on the five parameters found in the rules file was zero(0) for anthesis, maturity date and grain yield and it ranged between zero(0) and 20 for leaf numbers and biomass yield as calculated with in DSSAT internal statistics and taken during calibration. The values indicated that the former three parameters were estimated as excellent, while it was very good and good for next two parameters. It is suggested that if the nRMSE is less than 10% the simulation is considered excellent; good if it is between 10 and 20%, fair if it is between 20 and 30% otherwise poor if greater than 30% (Jamieson et al., 1991) (Table 4).

The statistics in the evaluation output for all measured crop parameters high values in the R2, d-stat values, while lower values in the RMSE values support the same, which is sufficient evidence that the genetic coefficients can represent the characteristics of cultivars in target (Table 5) [13].

Evaluation of the measured crop parameters during the 2019 between the observed and simulated value cross the origin of the coordinate plane with the indication that there is similarity between the observed and simulated values (Figure 3).

The normalized RMSE (nRMSE) difference in percent between observed and simulated was less than 10% for pheology maize: days to anthesis (0.024%), days to physiological maturity (0.00%), days to emergency (2.38%,) while growth and yield of maize: leaf number (5.57%), LAI 7.97%, grain weight (2.22%), grain yield at maturity (5.46%) and top weights/dry biomass yield (6.16%), but harvest index showed high difference (22.45%) compared to all others during calibration year (2019). During the validation year (2020) the phenology of maize: days to emergence (2.38%), days to anthesis (2.29%), physiological maturity (0.026%); while the growth and yield of maize: the leaf number (4.41%), the LAI (16.57%), the grain weight (5.17%), grain yield at maturity (2.15%), top weight/dry biomass yield (9.37%), in similar manner the harvest index (14.33%) showed a greater than 10% variability as in the

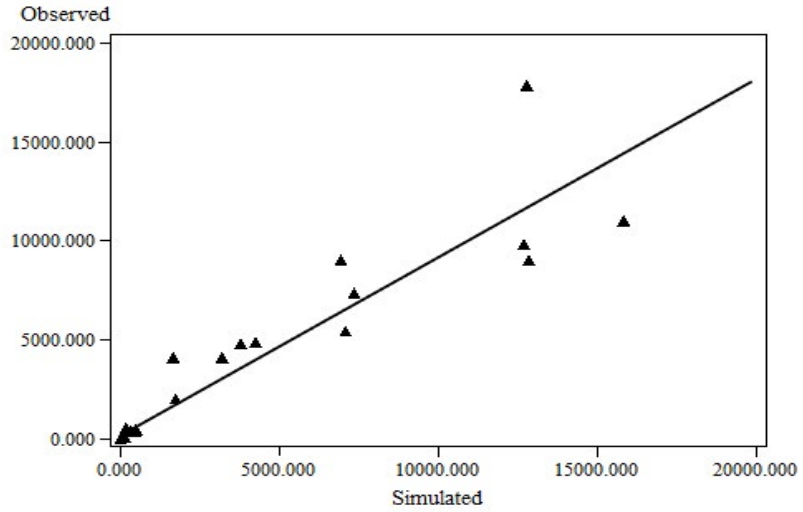

Figure 3: Evaluation of Observed vs. Simulated values of all crop parameters (days to emergence, canopy height, leaf number, leaf area index, days to physiological maturity, dry biomass yield, grain yield, number of grains per ear, unit grain weight).

Table 6: Measured vs. simulated values (calibration) of the six cultivars of maize during 2019.

Measured parameter	SHONE		MELKASA6		MH138		BH545		L_ASOSA	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
Emergence	7	6	7	6	7	6	7	6	7	6
Anthesis	81	81	80	80	86	86	86	87	88	88
Phy. Maturity	133	133	133	133	130	130	132	132	133	133
G.Yield (kg /ha)	7118	5460	1956	2040	4888	3770	4981	4250	4211	3190
Unit G.wet (g/unit)	0.333	0.343	0.222	0.229	0.247	0.275	0.24	0.247	0.246	0.309
Grain no. (no/unit)	485.8	401.7	200.3	563.5	450.7	498.1	471.7	470.7	388.3	380.6
Dry biomas (kg/ha)	13068	17860	7722	7340	10136	12670	11271	15800	9285	12820
LAI, maximum	2.87	2.76	2.14	2.02	2.31	4.23	2.7	3.68	2.05	3.49
Harvest Index	0.545	0.307	0.253	0.253	0.482	0.229	0.442	0.269	0.454	0.25
Leaf No at mat.	20.7	16	17.76	12	18.82	16	20.43	16	17.82	16

calibration year. In both calibration and validation year all parameter showed less than 10% different except for harvest index in the first year and LAI and harvest index in the second year.

The nRMSE comparison between Calibrated vs. Validated show that values for validated year are higher in six measured parameters among nine. This can be an indication that better estimation was done during the calibration than validation year hence. Improving high values seen in the harvest index during the calibration year by improving the genetic coefficient could improve the simulation during validation. The R2 and d-stat values are greater than 0.70 for at least four parameter in the calibration year (2019) compared to the validation year (2020) which showed less values for most parameters, exhibiting variability in yield estimation.

Phenology, grow and yield between Observed vs. Simulated

The calibration results of 2019 showed that the observed and simulated values of maize cultivars are very near to each other with ratio of near 1, for at least four measured values of days to emergence, anthesis day, physiological maturity and the dry biomass yield for which they are simulated below the observed values, except days to emergence, while grain yield and number of leaves are also have ration near to 1, for which they are simulated above the observed values. The unit grain weight at maturity showed nearly equal values for two cultivars SHONE (0.335 and 0.343 g) AND MELKASA6 (0.239 and 0.229 g) for observed vs. simulated values, but there were slight variability for the other three varieties. The values presented in table are for cultivars which are treated the same, but the second cultivar L_ ASOSA, was treated differently (no fertilizer) compared to L_ASOSA in the table and the simulation values are not presented here. The grain number at maturity, the dry biomass yield, LAI, HI and leaf number at maturity are not very well simulated for some cultivars than the others; for example, grain number per shoot is simulated well for MH138 (7 grains above), BH 545 (20 grains above) and L-¬_ASOSA (15 grains below) measured data. The LAI is 0.7 lower that the measured value for MELKASA6, while higher for other cultivars. The leaf number at maturity matched between observed and simulated values for the cultivar SHONE, while not good for others. The top weight is among poorly simulated character for all cultivar in both evaluation and validation years. There is much similarity in simulation between the evaluation and validation years, however in validation year the phenology and yield estimation were lower for some cultivars like MELKASA6, which also showed simulation of grain yield much below the observed value (Table 6,7).

Table 7: Measured vs. simulated values (validation) of six cultivars of maize during 2020.

Measured parameter	SHONE		MELKASA6		MH138		BH545		L_ASOSA	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
Emergence	7	6	7	6	7	6	7	6	7	6
Anthesis	81	81	81	76	89	80	87	88	91	83
Phy. Maturity	134	133	135	133	133	130	133	132	136	133
G.Yield (kg /ha)	6430	5630	1695	3883	4362	4673	4522	3423	3992	3473
Unit G.wet (g/unit)	0.333	0.361	0.222	0.304	0.246	0.286	0.24	0.305	0.255	0.342
Grain no. (no/unit)	438.8	483	173.5	478.1	402	520.8	428.3	459.4	355.8	414.7
Dry biomas (kg/ha)	11317	16823	6466	9976	9033	11456	9865	12743	8482	12213
LAI, maximum	2.29	3.11	1.69	2.95	1.98	3.43	2.21	2.39	1.79	3.27
Harvest Index	0.568	0.335	0.262	0.338	0.48	0.409	0.458	0.272	0.471	0.301
Leaf No at mat.	20.13	16	17.46	15	18.76	15	19.89	15	17.75	16

Table 8: Sensitivity analysis in planting date simulated on maize phenology for 2020.

	Planting date response of maize cultivars							
Cultivar	10-May	20-May	14-Jun	24-Jun	10-May	20-May	14-Jun	24-Jun
	Days to Anthesis				Days to Physiological mat			
SHONE	77	79	81	82	131	132	134	135
MELKASA6	78	80	81	83	133	133	135	136
MH138	86	87	89	89	130	131	133	133
BH545	83	85	87	89	131	131	133	136
L_ASOSA	88	88	91	90	133	134	136	137

Table 9: Sensitivity analysis in planting date simulated on yield for 2020.

	Planting date response of maize cultivars							
Cultivar	**10-May**	**20-May**	**14-Jun**	**24-Jun**	**10-May**	**20-May**	**14-Jun**	**24-Jun**
	Grain yield				Dry biomass yield			
SHONE	6359	6381	6430	6281	12699	11993	11317	11159
MELKASA6	1741	1735	1695	1746	6751	9132	6466	6684
MH138	4408	4308	4362	4388	10116	9359	9033	9246
BH545	4735	4513	4522	4697	11022	10108	9865	10401
L_ASOSA	4119	4011	3992	3996	9542	8741	8482	8767

Sensitivity analysis on the planting date and plant spacing

Date of Planting

Changing time of planting known in the area from June 1-15 to a different date of planting between May 1 to June 30 showed a change both in phenology and yield of maize. When the planting date is shifted 1 month before the known time sowing in the site June 1-15 the phenology as well as the yield of maize decreased. Increasing the panting date between May 10 to May 20 the phenology and the yield increased compared to May 1 planting, but without difference between the two days of planting (May 10 and May 20), however, planting date when shifted to June 24 the phenology are approximately similar to the known planting date of the site, but the grain yield and dry biomass decreased for both calibrated and validated simulations in 2019 and 2020, data presented here is only validation year. Therefore, the time of planting of the area could still be as appropriate using the DSSAT model, but with changes in the climate changes or fluctuation the panting date between May 10 to end of May could be beneficial during the occurrence of short rains due to El Nion (Table 8,9).

Plant population (plant spacing)

The plant spacing was made for the corresponding plant population without changing on row spacing, but making change only on plant spacing (Table 10).

Changing the plant spacing (plant desity), from 4.4 plants m-2 to 5.3 and up to 12 plants m-2 consciously increased the grain yield and biomass yield without change on the phenology of maize (days to anthesis, days to physiological maturity). However, increasing the plant density to 14 plants m-2 decreased the grain, but kept increasing the dry biomass yield of maize cultivars, during both evaluation years (2019) and validation year (2020) data presented here is only validation year (Table 11,12) [14].

Conclutions

The R2, RMSE and d-stat values are used for comparison for the maize cultivars responses. During the Calibration year the R2 values are higher for five responses of the maize cultivars with higher correlation coefficient and r values, the RMSE and Index of agreement (d) value are within the acceptable range for five responses: Anthesis, Physiological maturity, Unit grain weight, Dry biomass yield, Grain yield at maturity, for both calibrated and validated years (2019 and 2020). The calibration result genetic coefficient during 2019 showed that the observed and simulated values of maize cultivars are similar with ratio of near 1 to most of measured parameter. The validation result showed similar trend as the calibration result, but with higher RMSE, and lower d-stat values and with comparatively higher difference between observed and simulated values compared to the calibration result.

Sensitivity test with different time of planting scenario different from June 1-15 to May 1 through to June 30 showed a change both

Table 10: Plant population per meter square and its corresponding plant spacing.

Plant population in 1 m^2	Area in m^2 used per plant	Pant spacing (m x m)
5.3	0.188	0.75 x 0.25
6.2	0.161	0.75 x 0.21
7.4	0.135	0.75 x 0.18
8	0.125	0.75 x 0.16
9	0.111	0.75 x 0.15
12	0.083	0.75 x 0.11
14	0.071	0.75 x 0.095

Table 11: Sensitivity analysis in population density simulated on phenology for 2020.

	Population Density (5.3, 6.2, 7.2, 8, 9, 12, 14 plant m^{-2}) maize cultivars							
Cultivar	5.3	9	12	14	5.3	9	12	14
	Days to Anthesis				Days to Physiological mat			
SHONE	77	79	81	82	131	132	134	135
MELKASA6	78	80	81	83	133	133	135	136
MH138	86	87	89	89	130	131	133	133
BH545	83	85	87	89	131	131	133	136
L_ASOSA	88	88	91	90	133	134	136	137

Table 12: Sensitivity analysis in population density simulated on yield for 2020.

	Population Density (5.3, 6.2, 7.2, 8, 9, 12, 14 plant m^{-2}) maize cultivars							
Cultivar	5.3	9	12	14	5.3	9	12	14
	Grain yield				Dry biomass yield			
SHONE	6947	8336	8984	6644	12548	15844	17051	17521
MELKASA6	1901	2547	2972	2697	7384	10033	11434	12157
MH138	4782	5893	6466	4824	10233	13654	15107	15655
BH545	4914	5944	6419	4814	11086	14551	15815	16328
L_ASOSA	4398	5560	6167	4712	9613	13174	14755	15443

in phenology and yield of maize. When the planting date is shifted 1 month before the known time of sowing in the site June 1-15 the phenology as well as the yield of maize decreased, but increasing the panting date between May 10 to May 20 the phenology and the yield increased compared to May 1 planting, but without difference between the two days of planting (May 10 and May 20). Changing the planting density between 4.4 plant per m2 to 12 plant per m2 could also be advantageous by predicting and mutching with the future climate condition of the site to increase grain yield, but increasing plant density above 14 plants per m2 could increase the dry biomass yield but not the grain yield.

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