ORIGINAL ARTICLE

Calibration and Validation of CSM-MANIHOT-Cassava Model for Cassava Crop (*Manihot esculenta* C.) at Different Plant Spacing in Holguín Province, Cuba

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Calibración y validación del modelo CSM-MANIHOT-Cassava en diferentes arreglos espaciales en la provincia Holguín, Cuba

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ABSTRACT: Cassava is a cultivation of marked importance at global level and it constitutes the nutritious base of more than 500 million people. In Cuba, it is cultivated in all the provinces of the country with significant production volumes, however, technologies that favor the presence of processes of degradation of the soils and limit their productive potentialities persist. The yields reached in Calixto García Municipality oscillate around 15 t.ha^{-1}, very below the national average. This investigation was developed with the objective of calibrating the CSM-MANIHOT-Cassava of the DSSAT v4.6 and validating the genetic coefficients in function of the yields for the clone "Señorita" under the conditions of Holguín Province. The experiments were carried out in two properties of the CCS "Julio Sanguily" in different plantation dates and using three space arrangements. For the validation, yields reached by producers in the study area in different campaigns were used and the values of the ***RMSEn*** were determined. The results of the validation showed values of ***RMSEn*** of 9.8% and 11.2% for the 2 campaigns used, it demonstrates the appropriate adjustment of the model and the feasibility of its utilization for cassava.

Keywords: Modeling, DSSAT, Genetic Coefficients, Yields, Cassava.

RESUMEN: La yuca es un cultivo de marcada importancia a nivel global y constituye la base alimenticia de más de 500 millones de personas. En Cuba se cultiva en todas las provincias del país con significativos volúmenes de producción, sin embargo, persisten tecnologías que favorecen la presencia de procesos de degradación del suelo y limita sus potencialidades productivas. Los rendimientos alcanzados en el municipio de Calixto García oscilan alrrededor de las 15 tha^{-1}, muy por debajo de la media nacional. Esta investigación se desarrolló con el objetivo de calibrar el modelo CSM-MANIHOT-Cassava del DSSAT v4.6 y validar los coeficientes genéticos en función de los rendimentos para el clon "Señorita" en las condiciones de Holguín. Se realizaron experimentos en dos fincas de la CCS Julio Sanguily en fechas de plantación diferentes y empleando tres arreglos espaciales. Para la validación se emplearon rendimientos alcanzados por productores en la zona de estudio en campañas diferentes y se determinaron los valores de la ***RMSEn.*** Los resultados de la validación mostraron valores de ***RMSEn*** de 9.8% y 11.2% para las dos campañas empleadas, ello demuestra el adecuado ajuste del modelo y la factibilidad de su empleo para la yuca.

Palabras clave: modelación, DSSAT, coeficientes genéticos, rendimientos, yuca.

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INTRODUCTION

Cassava (*Manihot esculenta* Crants) is a crop of marked global importance and constitutes the diet of more than 500 million people in tropical regions (CIAT-Colombia, 2013). Its world production, only surpassed by potatoes FAO (2020), shows an increasing trend and it is expected that by 2050, its consumption will exceed 8% compared to 2010, mainly in Latin America and the Caribbean (Rankine *et al.*, 2021; Scott, 2021; Lehmane *et al.*, 2022).

In Cuba, cassava is cultivated in all the provinces of the country. However, there are production technologies that cause the degradation of the soil resource and limit its productive potential (Mojena & Bertolí, 2000)).

In the municipality of Calixto García, the yields obtained with cassava are close to 15 t.ha-1 in the year 2020. These values do not exceed the average yield at the national level (ONEI-Cuba, 2021). Because of that, it is important to obtain alternatives for agricultural use according to the edaphoclimatic conditions of the agroecosystems. These should be aimed at achieving substantial increases in yields on degraded soils and under specific management conditions and changing climate change scenarios (IPCC, 2021; FAO, 2022).

In this sense, having tools related to crop simulation models is very useful (Moreno-Cadena *et al.*, 2020; 2021; Rodríguez-González *et al.*, 2020). Knowledge of the way in which the crop responds to variations in environmental conditions is an essential component for the design of adequate management strategies (Rodríguez-González *et al.*, 2018; González-Viera *et al.*, 2022). The determination of the genetic coefficients of a cultivar can be obtained from the appropriate calibration of the model (Choudhury *et al.*, 2018; Rodríguez-González *et al.*, 2018; Rankine *et al.*, 2021). The genetic coefficients of cassava clones produced in Cuba are not included in the DSSAT (Decision Support System for Agrotechnology Transfer) cultivar database.

MATERIAL AND METHODS

Study Site Description

The research was carried out in Calixto García Municipality, in Holguín Province (Figure 1). It is geographically located according to the South Cuba coordinate system at 20°53'58"N latitude and 76°26'51"W longitude and with an altitude of 104 m above sea level. In the territory, Sialitic Brown soils prevail with the presence of carbonates (Hernández *et al.*, 2015). The average annual temperature is 25.6°C and rainfall ranges between 800 mm and 1,200 mm per year, with long periods of drought (ONEI-Cuba, 2021).

Calibration

To determine the values of the genetic coefficients of the cassava clone "Señorita", the data of experiments developed in two farms of the CCS "Julio Sanguily" were taken. Planting was carried out on July 17 and December 20, 2020. A randomized block experimental design was used with three treatments and four repetitions, in 25 m^2 experimental plots. Three different spatial arrangements were used: 0.90 m x 0.90 m; 1.20 m x 0.70 m and 2.0 m x 0.60 m with a density of 12,345 plants ha^{-1}, 11,904 plants ha^{-1} and 8,333 plants ha^{-1}; respectively. The "Señorita" clone of acceptable rusticity, long cycle, erect habit and little branching was used (INIVIT, 2007). The planting was carried out by the manual method in the bottom of the furrow and the phytotechnical work was carried out as recommended by INIVIT, (2007) and without fertilization.

Data collection

The observations of the selected variables were made with a monthly frequency from 30 days after planting (DDP) through destructive sampling. The fresh mass and dry mass of each vegetative structure (leaves, petioles, stems, seeds, roots and tuberous roots) were determined separately and, with this, the dry mass of the aerial part (gm-2) was determined. Agricultural yield was obtained in each experimental plot and then estimated for one hectare, as recommended by Mojena and Bertolí (2000). The dry mass of the plant organs was determined using a Bonvoisin mechanical laboratory balance, model MB2610 with a capacity of 2 610 g and a precision of 0.1 g.

Preparation of the Input Files

Six input files were created to run the CSM-MANIHOT-Cassava model inserted in DSSAT v4.6: X file. A file, T file, soil file, climate file and genetic coefficients file. In files A and T, the values of the physiological variables observed in the experiments were stored and, later, they were compared with the values simulated by the model for calibration. The data on field conditions, experimental treatments and simulation options were stored in the X file. This file stores the crop production management data, separated into several sections. For the preparation of the climate file, the values of the meteorological variables (maximum temperatures, minimum temperatures, daily rainfall and solar radiation) of the months in which the experiments were carried out were utilized. The information was obtained from the Meteorological Station of La Jíquima, Calixto García Municipality, approximately 18 km away from the experimental area.

Model Calibration

To obtain the values of the genetic coefficients of the cassava clone "Señorita", the soil data of the two farms at two depths (0-10 cm) and (10-20 cm), the climatic data of the meteorological station from La Jíquima and the crop management data were obtained. They were entered into the DSSAT in the form of files according to the procedure described by Hoogenboom et al. (2019).

The CSM-MANIHOT-Cassava model for DSSAT needs to be calibrated by obtaining the genetic coefficients for the studied clone, adjusting the parameters related to the phenological aspects of the crop (B01ND, B12ND, B23ND, B34ND, B45ND, B56ND) and the parameters related to yield (SR#WT, LAXS, SLAS, LLIFA) whose definition is shown in Table 1. The accuracy of the parameters was evaluated by comparing the simulated values with those observed in relation to yield and harvest index. To determine the goodness of fit of the model, the root mean square of the error (RMSE) and the root mean square of the normalized error (RMSEn) were calculated, for which the following equations were used (Equations 1 and 2):

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

$$RMSEn = 100 * \frac{\sqrt{\sum_{i=1}^{n} \frac{(Si - Oi)^2}{n}}}{\bar{Ob}} \quad (2)$$

Where:

Si and Oi-simulated and observed values

n-is the number of observations

$\bar{Ob}$-mean of the Oi values

A simulation can be considered Excellent if the RMSEn is less than 10%, Good if it is between 10% and 20%, Fair if it is between 20% and 30%, and Poor if it is greater than 30% (Rodríguez et al. , 2020; Moreno et al., 2021; Poncharoen et al., 2021). For the calibration of the crop simulation model, data from the experiments from July 2020 and December 2021 were used.

Validation

The genetic coefficients resulting from the calibration were copied to the DSSAT.CUL file to apply them to the runs of the program and evaluate the model. It was validated using the yield data obtained by producers in the study area in February 2018 and May 2020 campaigns and comparing the results of the observed values with the values simulated by the model. The RMSE and RMSEn values were also calculated for these yields.

RESULTS AND DISCUSSION

Calibration

The monthly evaluation and the systematic monitoring of the phenology of the crop provided the data for the calibration of the model for the Cuban cultivar “Señorita”.

The results obtained in the main variables in the two farms between the observed values (Oi) and the simulated values (Si) and the goodness-of-fit indicators of the RMSE and RMSEn models are shown in Table 2.

In general, for the three spatial arrangements in both planting dates, the predicted crop yields showed a good correspondence in relation to those observed with RMSE = 1 687.30 $kgha^{-1}$. A similar behavior was shown by the values of the harvest index with RMSE = 0.107. For these evaluated parameters, the RMSEn behaved with values between 10% and 12%, which demonstrates a good fit of the model. In Thailand, when determining the genetic coefficients for four cassava clones at various planting dates (May, June, and December 2016) using the DSSAT model, RMSEn values between 14.4% and 38.3% were achieved, higher than those obtained in this research

TABLE 1. Calibration of the genetic parameters for the cassava clone “Señorita”

Genetic parameter	Definition	Clone “Señorita”
B01ND	Thermal time coefficient number of nodes at the time of the first branching.	18.47
B12ND	Thermal time coefficient number of nodes at the time of the second branching.	68.06
B23ND	Thermal time coefficient number of nodes at the time of the third branching.	56.72
B34ND	Thermal time coefficient number of nodes at the time of the fourth branching.	125.20
B45ND	Thermal time coefficient number of nodes at the time of the fifth branching.	0.00
B56ND	Thermal time coefficient number of nodes at the time of the sixth branching.	0.00
SR#WT	Ratio between the number of tuberous roots and the mass of the aerial part of the plant.	0.550
SRFR	Fraction of maximum assimilates sent to be stored in the tuberous root.	6,705
LAXS	Maximum leaf area	295.0
SLAS	Specific leaf area	380.0
LLIFA	Accumulated thermal time between complete leaf expansion and the beginning of leaf senescence.	990
LPEFR	Leaf petiole fraction (blade fraction + petiole)	0.33
STFR.	Fraction of assimilates from the stem destined for the growth of the canopy of the plant	0.35

Source: Adapted from (Rodríguez et al., 2020).

(Poncharoen et al., 2021). Similarly, in recent studies developed in Jamaica evaluating this model to determine the benefits of irrigation potential for four cassava clones, Rankine et al. (2021) report RMSEn values between 18.2% and 24.0% in two of the clones evaluated, superior to those obtained in this investigation. In this sense, a study carried out to determine the most appropriate statistical indices to evaluate crop simulation models concludes that the RMSE and RMSEn indices are the ones that best show how much the simulations carried out by a model deviate, which is why they are considered the most appropriate to reflect the quality of the simulations of a model (Saldaña and Cotes, 2021). Figure 1 shows the behavior of the observed and simulated yield values in each of the spatial arrangements evaluated in the two experiments.

As we can seen in five of the six treatments, the yield values simulated by the model are higher than the yields observed in the field experiments, with the highest values corresponding to the spatial arrangements of 0.90 m x 0.90 m and 1.20 m x 0.60 m in the experiment planted in December 2020 with 17,377 kgha^{-1}. In this last treatment is where a greater difference between the observed and simulated yield values can be seen between the six treatments with a value of 2,611 kgha^{-1}. This indicator obtained the highest values in the experiment planted in December 2020 in the spatial arrangements of 0.90 m x 0.90 m with 16 561kgha^{-1} and 2.0 m x 0.60 m with 12 564 kgha^{-1} . The values obtained in the experiment planted in July 2020 in arrangements of 0.90 m x 0.90 m were 14,149 kgha^{-1} and in arrangements of 2.0 m x 0.60 m, 11,604 kgha^{-1}. These results are attributable to the fact that the experiment in December 2020 was planted at the optimal time for this crop in Cuba, so environmental factors exerted a greater influence on the development and growth of the crop. In the case of the 1.20 m x 0.70 m spatial arrangement, the yields obtained were very similar with 14,806 kgha^{-1} and 14,766 kgha^{-1}, for the experiments planted in July 2020 and December 2020, respectively. In studies carried out in Jamaica to determine the performance of four cassava genotypes using the DSSAT, Rankine et al. (2021) report differences between the observed and simulated yield values of up to 4 606 kgha^{-1}, which does not agree with the results of this research. On the other hand, in recent research carried out in Thailand, Photangtham et al. (2022), report that for yield, the values observed in the field experiments showed a tendency to decrease as larger spatial arrangements are used. Similar behavior is shown by the values simulated by the model; these results coincide with those obtained in this investigation.

Figure 2 shows the observed and simulated values of the harvest index for the two experiments.

TABLE 2. Behavior of the main variables in the calibration

Planting date	Spatial arrangement	Yield (kgha-1)		Harvest index	
		Oi	*Si*	*Oi*	*Si*
	0.90 m x 0.90 m	16,149	16,455	0.90	0.99
July 15, 2020	1,20 m x 0,70 m	14 806	16 455	0.88	0.99
	2,0 m x 0,60 m	13 862	11 604	0.90	0.99
	0.90 m x 0.90 m	16,561	17,377	0.90	0.99
Dec. 20, 2020	1,20 m x 0,70 m	14 766	17 377	0.88	0.99
	2,0 m x 0,60 m	12 564	13 863	0.90	0.99
RMSE			1 687.30		0.107
RMSIn			11.2%		10.7%

Source: Self-made.

FIGURE 1. Performance behavior in spatial arrangements for each experiment.

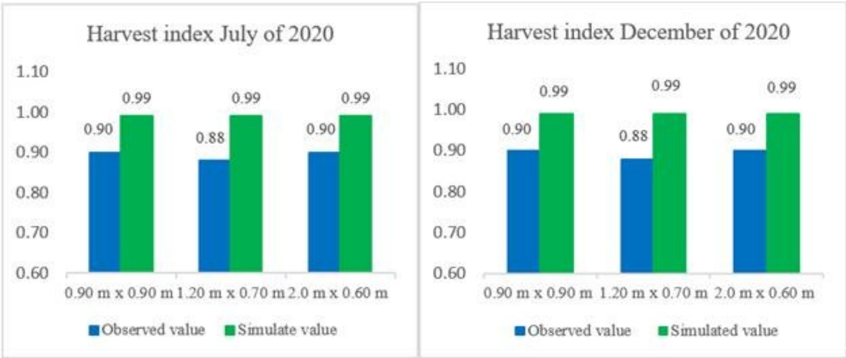

FIGURE 2. Observed and simulated values of the harvest index for the two experiments.

In this indicator, the observed values and the simulated values show a similar behavior, with the highest values corresponding to those simulated by the model for the three spatial arrangements with a harvest index of 0.99 for the two experiments. In the case of the observed values, it can be seen that the highest values are observed in the spatial arrangements of 0.90 m x 0.90 m and 2.0 m x 0.60 m with 0.90 and 0.90 for both farms, respectively. The lowest value observed for the harvest index is obtained in the spatial arrangement of 1.20 m x 0.70 m with a harvest index of 0.88.

Similar results were observed in Thailand when evaluating the potential of the DSSAT CSM-MANIHOT-Cassava to simulate the biomass of two cultivars in different spatial arrangements. Photangtham et al. (2022) report small differences between the observed values and those simulated by the model in this indicator, in the treatment without the application of irrigation for the two cultivars, in the different spatial arrangements used. On the other hand, Rankine et al. (2021) when evaluating the behavior of four cassava genotypes in Jamaica through the DSSAT, report very little variation between the observed and simulated values in this indicator.

Validation

The validation of the model was carried out by using the values of the genetic coefficients resulting from the calibration of the model and the comparison between the observed values and the simulated values of the yields in the campaigns of February 2018 and May 2020. The RMSE and RMSEn for both campaigns (Table 3).

The simulated yields were related to those observed for the two campaigns, in February 2018 campaign an RMSEn = 9.8% was obtained, and in May 2020 campaign an RMSEn = 11.2% was obtained. These results show the good fit of the DSSAT simulation model for cassava cultivation under the conditions of Holguín Province.

CONCLUSIONS

- The determination of the genetic coefficients of the cassava clone "Señorita" allowed establishing that the DSSAT model can be used to model the physiological components and the yield of this crop under Holguín conditions.
- The results of the validation showed RMSEn values of 9.8% and 11.2% for the two campaigns used, which demonstrates the good fit of the model and the feasibility of its use for cassava under Holguín conditions.
- The genetic parameters obtained in this study can be used for sensitivity analysis in the future and with this, propose management alternatives and use scenarios for cultivation in agroecosystems with similar edaphoclimatic characteristics.

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TABLE 3. Validation of the results of the DSSAT model for cassava

Indicators	February 2018 campaign		May 2020 campaign	
	Oi	*Si*	*Oi*	*Si*
Yield (kgha $^{-1}$)	18,730	16,882	15,280	16,994
RMSE	1 848		1 714	
RMSEn (%)	9.8		11.2	

Source: Self-made

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