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USE OF A SIMULATION MODEL FOR PREDICTING THE BEHAVIOR OF SOME CEREAL CROPS UNDER THE CONDITIONS OF CUBA

Utilización de un modelo de simulación para la predicción del comportamiento de algunos cereales en las condiciones de Cuba

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ABSTRACT. A research was developed from 2008 to 2012, with the aim of applying modeling tools for the analysis of cereal crop production at different environments in Cuba. The institutions took part in it, were: INCA, INSMET, IS and IAgric. A total of 19 experiments were carried out in rice, maize, sorghum and wheat crops under different soil and climatic conditions, to obtain the required information to implement DSSAT version 3.5 Simulation Model. All information of soils where experiments were conducted was collected and introduced into the model file; besides, a daily climatic report was recorded at the meteorological stations of these experiments. All that information enabled to calibrate and validate the model for the experimental conditions; then, each crop yield was simulated under two future environments (2025 and 2050) using ECHAM model in a2 environment at every experimental site. Model calibration and validation showed the feasibility of its use under these experimental conditions, in order to predict yield and its components. Under the simulated environments, yields ranging between 63,8 and 22,9 % are reached, in relation to the average yield potential of experiments, depending on the crop and the simulated year. For the first time in the country, there is information of the aforementioned crops, to predict the behavior and yield of some cereal crops by using a simulation model as a tool for climatic change adaptation.

Key words: crops, physiological index, simulation models, yield

RESUMEN. Entre los años 2008 y 2012 se desarrolló una investigación, con el objetivo de aplicar herramientas de modelación para el análisis de la producción de cereales en distintos escenarios en Cuba. En el trabajo participaron las instituciones INCA, INSMET, IS e IAgric. Se ejecutaron un total de 19 experimentos en los cultivos de arroz, maíz, sorgo y trigo en diferentes condiciones edafo-climáticas, con el fin de obtener la información necesaria para introducir en el Modelo de Simulación DSSAT versión 3,5. Se recopiló toda la información de los suelos donde se ejecutaron los experimentos, lo que se introdujo en el fichero del modelo; además, se obtuvo la información diaria del clima en las estaciones meteorológicas donde se desarrollaron los experimentos. Con toda esa información se calibró y validó el modelo para las condiciones de estudio; posteriormente, se simuló el rendimiento de cada cultivo en dos escenarios futuros (2025 y 2050), utilizando el modelo ECHAM en el escenario a2, en cada sitio experimental. La calibración y validación del modelo demostró la factibilidad de su utilización en las condiciones de estudio, para la predicción del rendimiento y sus componentes. En los escenarios simulados se alcanzan rendimientos que oscilaron entre 63,8 y 22,9 %, en relación con el rendimiento medio potencial en los experimentos, en dependencia del cultivo y el año simulado. Por primera vez en el país, se cuenta con información de los cultivos anteriormente señalados, para poder predecir el comportamiento y rendimiento de algunos cereales, utilizando un modelo de simulación como herramienta para la adaptación al cambio climático.

Palabras clave: cultivos, indicadores fisiológicos, modelos de simulación, rendimiento

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INTRODUCTION

In a program of development of agriculture, as a first step should be to assess the natural resources available and have an outcome measure of the interaction between the environment and crops (1) to characterize the variability of this interaction both temporarily as space; ie have results that reveal the impact of environmental variables on crop productivity, know the limitations, to mitigate the effect of these limitations, measuring the environmental potential for different genetic materials and define the best production strategies to approach this potential (2).

The most important difference among plants is produced in the path of CO_2 fixation. C_4 plants convert sunlight into biomass with a higher efficiency than C_3 plants, which is given by the concentration of CO_2 around Rubisco (3).

Climate variability is one of the main sources of uncertainty and risk in many agricultural systems around the world (4). In this sense, agriculture is one of the most dependent and sensitive human activities to climate variations (5). The vulnerability of farming systems is not only a result of the temporal variability of climate, but also the inability to predict fully their behavior.

Simulation models of crop growth and analysis of soil-plant-atmosphere are important tools for modern agricultural research (6). A crop model represents a simple and concise manner the most important physiological and ecological processes that govern growth, using mathematical equations (7). The functioning understanding and the main factors evolution responsible for these conditions is acquired by comparing simulation results with experimental observations. These observations can be designed to validate the model, taking into account the weather, soil and crop management conditions, according to the implantation site (8). Once this first stage of the model validation, this can be used to help analyze and interpret different future sceneries product modifications that seek to achieve in crop management, changes in weather conditions or for forecasting performance, among others indicators (9).

Based on the elements outlined above the present work was developed with the aim of applying modeling tools for the analysis of plant-environment-operation responses at various stages of the cereal crop production in Cuba, that will address current issues of their production sustainability as well as the possibility of providing this tool to the study of current and future scenarios.

MATERIALS AND METHODS

Twenty one experiments were performed at different planting dates at three sites in the country with different conditions of climate and soil. Experiments and characteristics of each site are listed in Tables I and II.

The experiments were conducted at different times of the year and a set of indicators were evaluated in order to obtain the information necessary for the System Decision Support Model for Transfer of Agrotechnology (DSSAT), the most used in the world (11).

Table I. Experiments developed

Cultivations	Places	Number of experiments	Varieties used
Rice	Los Palacios Pinar del Río	4	LP-5
Corn	Tapaste, Mayabeque	4	P-7928
	Guantánamo	1	“
Sorghum	Tapaste, Mayabeque	4	ISIAP Dorado
	Los Palacios Pinar del Río	1	“
	Guantánamo	1	“
Wheat	Tapaste, Mayabeque	4	10TH-4
	Los Palacios Pinar del Río	1	“
	Guantánamo	1	“

Table II. Characteristics of the experimental locations

Location	Latitude N	Longitude W	Altitude (m s. n. m.)	Temperature mean (ºC)	Precipitations (mm)	Soils*
Los Palacios	22º 33'	83º 18'	43,97	25,5	1289	Nodular ferruginous hydromorphic gley humic petroferric
Tapaste	23º 01'	82º 08'	120,043	24,6	1513	Compated hydrated red ferralitic
Guantánamo	20º 08'	75º 14'	55,06	26,5	1274	Sialitic fluffy brown carbonated

*The classification of Cuba´s soil was used (10)

The indicators were assessed at the time that the different phenological stages of cultivation occurred, the dry mass of each organ, leaf area and yield (tons of dry matter per hectare) and its components. In addition, the soil analyzes of in each experiment and the contents of N, P and K in each organ of the plant at the end of the harvest were made. With all this information databases needed to make to the model in each culture were prepared. Soil files that were studied were also created; regarding weather information, it was featured basis of daily data from weather stations from Tapaste, San Diego de los Baños in Pinar del Rio and Guantanamo. Daily weather information around the country were also available, the estimated until 2099, prepared by the Institute of Meteorology, using the ECHAM simulation model in the a2 scenario (high emissions of greenhouse gases), which was used to simulate the behavior of crops in two future scenarios (2025 and 2050).

Genetic coefficients P_1 were obtained (accumulated temperature from emergence to the issuance of the spike), P_5 (accumulated temperature since the beginning of grain filling to physiological maturity) and G_3 (rate of grain filling during linear growth stage under optimal conditions); moreover, the different variables containing 3.5 v DSSAT model files A (average values of performance data for an experiment), T (field data for an experiment) and X (experimental data were calculated, conditions and crop management and controls simulation). To assess the validity of the model, two indicators of efficiency, RMSE (Residual Mean Square Error) and d (acceptance rate) were used, comparing observed values with simulated[A]; the formulas for calculating these indicators were:

$$RMSE = \sqrt{1/n \sum (S_i - O_i)^2}$$

$$d = 1.0 - \sum (S_i - O_i)2 / \sum | (S_i - O_x)| + | (O_i - O_x)^2$$

Where:

S_i is the simulated value, O_i is, the observed value and n is, the pairs of values number. The indicator “d” ranges from 0 (bad prediction) and 1 (perfect prediction).

RESULTS AND DISCUSSION

As shown in Table III, yields were high compared with those reported for Cuba[B, C] (12), indicating that the conditions where the different cultures grew, were not limiting for growth and production; Besides, the feasibility of achieving good yields in the country is demonstrated.

Table III. Average yield achieved by the different cultures in experiments and reported to the conditions of Cuba

Cultivations	Yields (t ha^{-1})	
	Experiments	Reported to Cuba
Rice	5,6	5,8[D]
Corn	7,3	4
Sorghum	4,2	3,8
Wheat	3,7	2 - 3

In the analysis of the model output, the indicators: flowering date, date of physiological maturity, yield, weight of a grain, grains m^{-2}, grains spike^{-1} or cob^{-1}, leaf area index (LAI) and harvest index (IC) showed the greatest similarity between simulated and observed values; The opposite was true with the nitrogen indicators anthesis biomass, grain nitrogen, total biomass nitrogen and nitrogen in stem. For this reason, only the analysis Residual Mean Square Error (RMSE) and acceptance index (d) was made in the first indicators identified. These results indicate, at least for the conditions studied, the DSSAT model has better prediction for yield and its components and some physiological indicators, not for respect to the content of nitrogen; however, it is necessary to continue in this direction as this is vital element for crops.

In Table IV the results of model validation are presented; it can be seen, first, how the value of “d” varies between 0,84 and 0,99, indicating a good fit, assuming that as long as this indicator approaches the unit is a greater prediction model.

Concerning to RMSE values, indicating the range in which the simulated values vary in relation to the observed ones, these were highlighted in allowable levels.

In this respect, similar results are reported in different working conditions and in cereals (13, 14), highlighting the values of “d” above 0,90 that are suitable and indicate a good prediction model.

[A] Rodríguez, E.; Pérez, P.; Grande, O. y Torres, M. *Guía técnica para la producción de maíz* (*Zea mays L.*). Inst. Instituto de Investigaciones de Granos, La Habana, Cuba, 2013, p. 29.

[B] Canet, R.; Rivero, L. y Armenteros, M. A. *Guía técnica para el cultivo del sorgo* (*Sorghum bicolor L. Moench*). La Habana, Cuba, 2013, p. 36.

[C] INIFAT. *Instructivo Técnico del Trigo*. La Habana, Cuba, 2003, p. 23.

[D] Maqueira, L. *Relación de los procesos fisiológicos del desarrollo y de variables meteorológicas, con la formación del rendimiento en el cultivo del arroz* (*Oryza sativa* L.) *en los Palacios, Pinar del Río*. Tesis de Doctorado, 2014, 191 p.

These results confirm that the DSSAT model can be used for the conditions of Cuba in the performance indicators and their components, as well as physiological variables listed in the table. In Figures 1, 2, 3 and 4, examples of the estimates for each crop, simulating planting dates in each month of the year yields are presented; as can be seen in all cases is expected yield reduction in both years, in connection with the performance achieved in each of experiments, with greater reductions in 2050, which is mainly due to increased average temperature, according to predictions; everywhere there was a similar behavior for each crop

The simulated yields compared to average yields in experiments developed in this work, decrease depending on the year and the crop (Tables V, VI, VII and VIII). Outliers are in the cultivation of wheat, which ranged from 74,9 % in 2025 and 22,9 % in 2050, while the behavior of the remaining three crops (rice, maize and sorghum) showed similar reductions, ranging between 63,8 and 34,7 %; it is important to note that corn and sorghum are C_4 cycle plants, which makes them more efficient in dry matter production per unit of water transpired; in the case of rice, even though it is the C_3 cycle, it is a native of tropical climate and temperature requirements regarding plant are relatively high.

An important element to consider is that, as shown in the above-mentioned figures, minor yield reductions occur in the less warm months, which suggests the possibility of changing planting dates, taking into account the temperature increases in the coming years until the end of this century. The differences between sites are also influenced by the soil characteristics of each place.

Table IV. Summary adjustment of model evaluated indicators

Indicator	RMSE				d			
	Rice	Corn	Sorghum	Wheat	Rice	Corn	Sorghum	Wheat
Flowering date	2,1	1,9	2,6	8,7	0,99	0,99	0,99	0,94
Physiological maturity	2,6	0,71	1,12	10,3	0,99	0,99	0,99	0,96
Yield	305,2	22,5	723,7	485,8	0,99	0,99	0,98	0,96
Weight of a grain	0,0001	0,001	0,0003	0,0001	0,99	0,99	0,99	0,99
Grain m^2	1747	3,39	2698	1759	0,99	0,99	0,98	0,96
Grains per spike or cob	65,6	0,001	304,3	7,7	0,97	0,99	0,95	0,87
Maximum LAI	0,27	4,2	2	0,7	0,96	0,84	0,94	0,98
Biomass in anthesis	1211	1957	2803	700	0,95	0,92	0,89	0,99
Biomass physiological maturity	986	2430	3538	1142	0,99	0,98	0,97	0,97
Harvest index	0,08	0,07	0,12	0,02	0,97	0,98	0,94	0,98

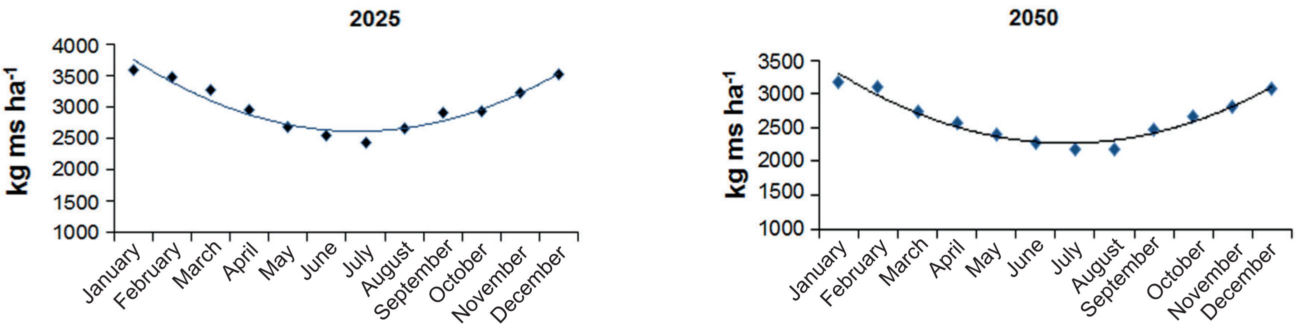

Figure 1. Simulated yields in the rice cultivation in monthly sowing date in Los Palacios

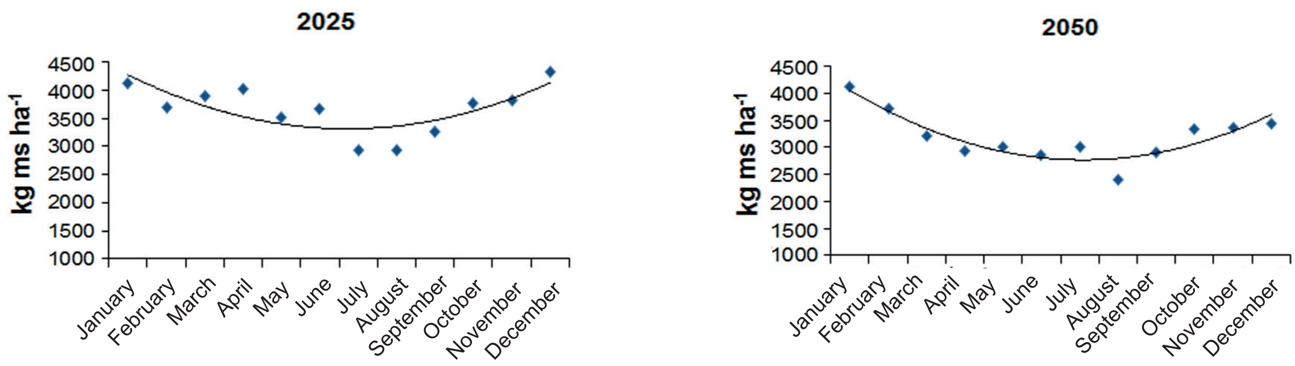

Figure 2. Simulated yields in the cultivation of corn in monthly planting dates in Tapaste

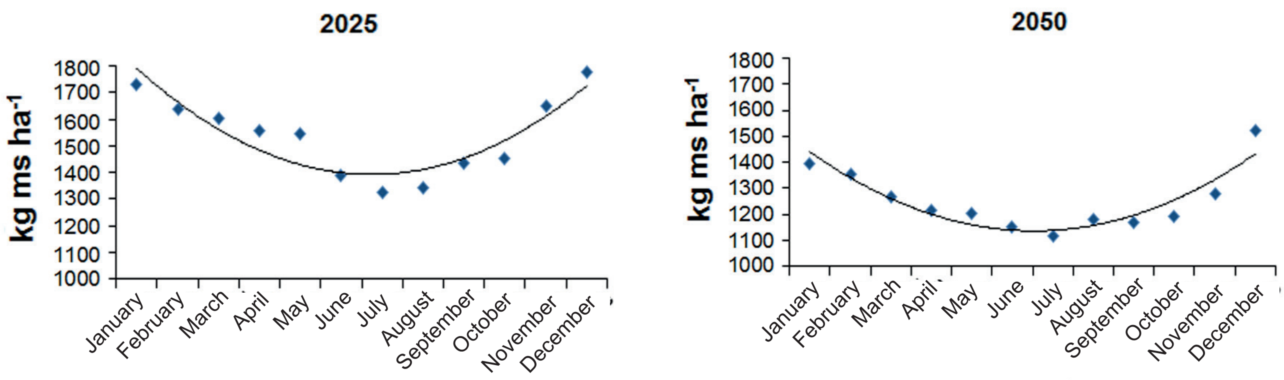

Figure 3. Simulated yields in the cultivation of sorghum in monthly planting dates in

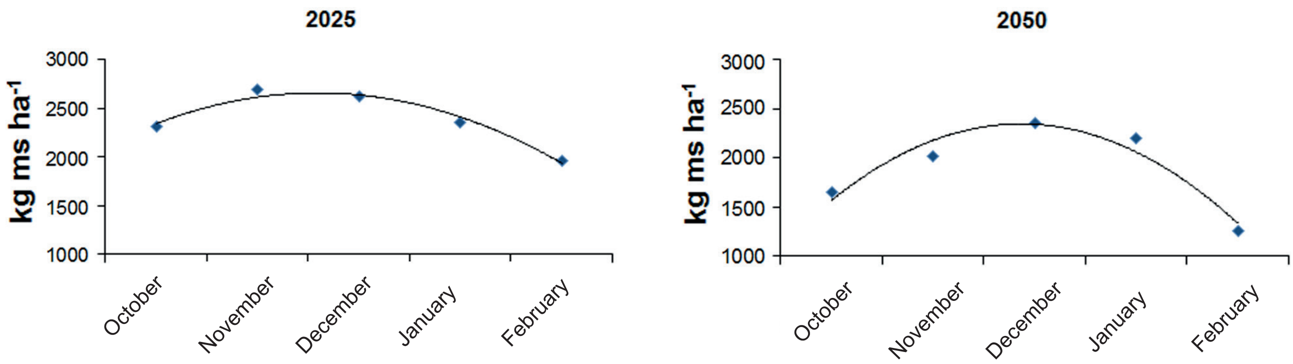

Figure 4. Simulated yields in the cultivation of wheat in monthly planting dates in Tapaste

Table V. Behavior rice yield

Experiments	Tapaste		Los Palacios		Guantánamo	
	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)
	4816	-	4816	-	4816	-
2025	2853	59,2	3087	64	2636	54,7
2050	2358	48,9	2654	55,1	1962	40,8

Table VI. Corn yield performance

Experimentos	Tapaste		Los Palacios		Guantánamo	
	kg dry mass ha^{-1}	(%)	kg dry mass ha^{-1}	(%)	kg dry mass ha^{-1}	(%)
	6300	-	6300	-	6300	-
2025	3660	58,1	3012	47,8	2835	45
2050	3192	50,7	2329	36,9	2243	34,7

Table VII. Sorghum yield performance

Experiments	Tapaste		Los Palacios		Guantánamo	
	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)
	3612	-	3612	-	3612	-
2025	2305	63,8	1753	47,5	1537	42,6
2050	2014	55,7	1473	40,8	1255	34,7

Table VIII. Wheat yield performance

Experiments	Tapaste		Los Palacios		Guantánamo	
	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)	Kg dry mass ha^{-1}	(%)
	3182	-	3182	-	3182	-
2025	2385	74,9	1732	54,4	943	29,6
2050	1893	59,5	1467	46,1	728	22,9

Performance is the end result of group interactions, where the genotype, climate, soil and crop management involved; the impact of the various parameters involved in these system variables define the phenology and crop yields (15).

The change in global weather patterns is one of the most serious environmental problems facing humanity today. Agriculture is one of the human activities most affected due to global warming, rising temperatures will cause crop development faster and shorter cycle, which in most cases is associated with the lower yields (16). Climate changes become less predictable crop productivity, which implies the need to develop more efficient cultivation systems (17); reduce vulnerability to climate change is the key to sustainable agriculture in the future (18).

Agricultural production will be significantly affected by climate change due to increasing atmospheric CO_2, which involve changes in temperature and precipitation. In a study on the cultivation of corn in Colorado, United States, showed that the increase in temperature is the major cause of the decline in yields (5); on the other hand, in the crop conditions in China, it is concluded that the total daily climatic variables radiation and air temperature have the greatest influence on the phenology and the potential (13) performance.

Greater efficiency in the use of radiation (directly related to the temperature) leads to higher values of the Rate Assimilation Net (RAN), which is simply the balance between photosynthesis, respiration and potential among the organs source and sink therefore higher yields (19) are reached.

One element that can be effective to make them less vulnerable to adverse conditions crops constitutes the change of planting date and harvesting annual crops (20), as changes in planting dates significantly affect growth and crop development, since it places the various stages of generation performance under different conditions of radiation, temperature and rainfall (21).

CONCLUSIONS

Importantly, the results of this study are a first approach to the use of simulation models in Cuba, as a tool to develop strategies for crop development studied in future scenaries and other growing conditions, so it is necessary continue working on this subject, which should be studied other varieties and especially having a greater number of experiments.

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