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ORIGINAL ARTICLE

Estimation of soybean (*Glicine max*) yield the SSP2-4.5 climate scenario

Estimación del rendimiento de la soya (*Glicine max*) para el escenario climático SSP2-4.5

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ABSTRACT: To analyze the different impacts of climate change and due to the high uncertainty regarding future climate conditions, it is advisable to work with scenarios, which are coherent and consistent descriptions of how the Earth's climate system can change in the future. The goal of this study is to predict the yields of soybean planted in Ferrallitic Red soil in the Alquízar region under the SSP2-4.5 climate change scenario of the Hadgem3, Mpi-esm1 and Mri-esm2 models with the use of the *AquaCrop* simulation model. To select the hydrological years, a study of a series of 28 years (2023-2050) was carried out for the period November-April (crop development period) for each model. The possibility of achieving potential yields between 2,72 and 3,27 t ha^{-1} and an agronomic water productivity that varies between 0,78-0,91 kg m^{-3} is evident in soybeans, if the crop is not subjected to any type of limitation except plant genetics, solar radiation, temperature, and rainfall is sufficient in this dry period. The highest average yields were simulated by the HadGEM3 model with 3,27 t ha^{-1}. If irrigation is applied only to guarantee soybean germination, reductions with respect to potential yield are estimated between 14-95%. The comparative study of yields in the SSP2-4.5 climate change scenario in the different models demonstrates the influence of these conditions on the crop response.

Keywords: Climatic Change, Modeling, Water Productivity.

RESUMEN: Para analizar los diferentes impactos del cambio climático y debido a la alta incertidumbre respecto a las condiciones climáticas futuras se aconseja trabajar con escenarios, los cuales son descripciones coherentes y consistentes de cómo el sistema climático de la Tierra puede cambiar en el futuro. El objetivo de este estudio es predecir los rendimientos de la soya sembrado en suelo Ferralítico Rojo en la región de Alquízar ante el escenario de cambio climático SSP2-4.5 de los modelos Hadgem3, Mpi-esm1 y Mri-esm2 con la utilización del modelo de simulación *AquaCrop*. Para la selección de los años hidrológicos se realizó el estudio de una serie de 28 años (2023-2050) para el periodo noviembre-abril (periodo de desarrollo del cultivo) de cada modelo. Se evidencia la posibilidad de alcanzar en la soya rendimientos potenciales entre 2,72 y 3,27 t ha^{-1} y una productividad agronómica del agua que varía entre 0,78-0,91 kg m^{-3}, si el cultivo no se somete a ningún tipo de limitación salvo la genética vegetal, la radiación solar, la temperatura y las precipitaciones son suficiente en este periodo poco lluvioso. Los mayores rendimientos como promedio fueron simulados por el modelo HadGEM3 con 3,27 t ha^{-1}. Si se aplica riego solo para garantizar la germinación de la soya se estiman reducciones con respecto al rendimiento potencial entre 14-95%. El estudio comparativo de los rendimientos en el escenario de cambio climático SSP2-4.5 en los diferentes modelos demuestra la influencia de estas condiciones en la respuesta del cultivo.

Palabras clave: cambio climático, modelación, productividad del agua.

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INTRODUCTION

Climate change scenarios are coherent and consistent descriptions of how the Earth's climate system may change in the future (Escoto *et al.*, 2017). In order to improve the analysis framework, the assessment of climate change impacts and to achieve a more interdisciplinary view in recent years new scenarios have been developed (IPCC, 2014).

The SSPs (Shared Socio Economic Pathways) describe 5 alternative pathways of society according to the implementation or absence of policies to curb climate change, contemplating different development and emissions options in the year 2100 (SSP1, SSP2, SSP3, SSP4 and SSP5) (Escoto *et al.*, 2017; OFA & CC, 2023).

According to Morán & Novillo (2022) the SSP2 scenario assumes an intermediate level of challenges, where its assumptions lie between those corresponding to SSP1 (with sustainability narrative, low levels of mitigation and adaptation challenges) and SSP3 (with fragmentation narrative, high level of adaptation and mitigation challenges).

In particular, SSP2-4.5 as an update of the RCP4.5 scenario, with an additional radiative forcing of 4.5 W/m² by the year 2100 represents the average trajectory of future greenhouse gas emissions. This scenario assumes that climate protection measures are being taken. The average percent change in precipitation for the SSP2-4.5 scenario diverges in the mid-horizon projection centered at 2050, and remains between 0 and +20% until 2080 where a +45% change is present indicating that there is an increase in precipitation. Meanwhile, the average temperature change in the projections for the mid-horizon centered on 2050 is +1°C and for the distant horizon 2085 it is +1.6°C, showing that in this scenario the increase in air temperature is notable (Bruno, 2023).

According to IPCC (2021) this scenario (SSP2-4.5) presents intermediate GHG emissions and CO_2 emissions that remain around current levels until mid-century, and it is highly probable that global warming of 2 °C will be exceeded.

In Cuba, studies developed by Planos *et al.* (2012) showed that important climatic variations have been observed, among which the following can be cited: "a tendency to increase precipitation in the seasonal period with little rainfall is evident. The differences between the mean and median values reaffirm the increase in extreme anomalies in the western and central part of the country".

Dynamic simulation models allow investigating the consequences of possible future scenarios and prepare for changes before they occur. The *AquaCrop* model released by FAO Raes *et al.* (2012) can be used as a computational tool to analyze different agricultural contexts in different cycles and locations. This new FAO proposal will provide practitioners with a more robust tool for: assessing the incidence of water scarcity on crop production, investigating the impact of climate change on crop yields, improving management strategies to increase productivity and water savings, among others (Steduto *et al.*, 2009).

Boligon *et al.* (2017) relied on the *AquaCrop* model to analyze the agronomic performance of soybean (Glicine max) under different climate scenarios in Brazil. They simulated cycle length, water productivity based on evapotranspiration, irrigation requirements and harvest index under different climate scenarios, with short- (2016-2035) and medium-term (2046-2065) projections. Soybean cycle length tends to decrease in colder regions, while water productivity should increase even without irrigation demands in these future scenarios.

The *Aquacrop* model was validated by Morla & Giayetto (2012) for soybean in the Río Cuarto region, in south-central Córdoba, Argentina. Yields of 1,9, 3,1 and 5,3 t ha^{-1} were simulated for dry, medium and wet year, respectively.

González *et al.* (2019) calibrated and validated the *AquaCrop* model for soybean on Ferrallitic Red soil in Alquízar, Artemisa province, Cuba. The results of the model calibration allowed optimizing the fundamental soil and crop parameters for its application in the study conditions.

Isla (2019) used the *AquaCrop* model to predict optimal planting dates and soybean yields in compacted Ferrallitic Red soil in the Havana-Matanzas Plain under B2 climate change scenarios. The results show the model as a viable alternative to select optimal planting dates, reproduce the phenology and productivity of the crop under different management scenarios and climatic variability.

The goal of this study is to predict soybean yields sown in Ferrallitic Red soil in the Alquízar region under the SSP2-4.5 climate change scenario of the Hadgem3, Mpi-esm1 and Mri-esm2 models with the use of the *AquaCrop* simulation model.

MATERIALS AND METHODS

Location of the study area

The model was calibrated and validated for soybean cultivation by González *et al.* (2019) with data from field experiments conducted during the winter season (January-April) in the period 1980-1990, under a sprinkler irrigation system at the Experimental Station of the Agricultural Engineering Research Institute (IAgric) in Alquízar, coordinates: Latitude 22º 46' N and Longitude 82º 36' W, elevation above mean sea level 6 m, 12 km from the coast.

These experiments were carried out with the objective of studying the water requirements and response to water of the soybean variety G-7R-315 (Castellanos *et al.*, 1984). The planting date was 6 January, with threshold temperatures from 10 to 30 °C, maturity was reached 112 days after planting, the population density was 370 370 plants ha^{-1} and the maximum yield was 3,49 t ha^{-1}.

The input parameters of the soybean crop to the *AquaCrop* model, obtained in previous studies by González *et al.* (2019), served as input to all the simulations performed in this study. The harvest index (HI) considered for soybean was 35%, this value is in the range (0,3 to 0,5) proposed by (Wani *et al.*, 2012).

The fundamental physical properties for each layer of the compacted Red Ferrallitic soil profile have been updated by Cid *et al.* (2011) and published by González *et al.* (2019); and form the soil file that was used for all model runs.

Processing and extraction of climate change information

To obtain this data, the climatic values of the SSP2-4.5 scenario of the Hadgem3 (Hadley Centre Global Environment Model version 3), Mpi-esm1 (Max Planck Institute Earth System Model) and Mri-esm2 (Meteorological Research Institute) models, which has a resolution of 125 x 125 km, were used. The following variables were taken: maximum and minimum temperature, relative humidity, wind speed and precipitation, which represent the future climate for the study area, according to the recommendations of the Instituto de Meteorología-Cuba (2023).

For the selection of the hydrological years, a series of 28 years (2023-2050) was studied for the November-April period (seasonal period with little rainfall that coincides with the development stage of the soybean studied) for each model, where the empirical probability was determined from the expression:

$$P = (m - 0.3 / n + 0.4) \times 100$$

m: order number.

n: number of members of the series.

Each of the periods of the series were classified according to their respective probability. The 25% probability denotes a wet year, 50% medium and 75% dry, according to Pérez & Álvarez (2005).

Crop Management Module

For the simulation, crop management was considered under optimal conditions of water and nutrient availability and the only variables that affected the development were the climatic conditions of the SSP2-4.5 climate scenario and the 3 selected models (Hadgem3, Mpi-esm1 and Mri-esm2). We chose not to evaluate in particular any growth reduction associated with the level of fertilization, avoiding the greater complexity involved in analyzing the interaction between water availability and crop nutrition.

Irrigation management

The program CROPWAT version 8.0 was used to estimate soybean water requirements and irrigation management for each climatic period considering the SSP2-4.5 scenario of the Hadgem3, Mpi and Mri-esm2 models. This software allows irrigation schedules to be managed under both rainfed and irrigated conditions, so it was used to determine the reference evapotranspiration by the FAO Penman-Monteith method.

Initial conditions

A soil water content of 0,35 cm^3 cm^{-3} was considered, which represents 90% of the soil water content at field capacity 0,39 cm^3 cm^{-3} to a depth of 0,40 m.

Applications

The adjusted potential production was simulated for the SSP2-4.5 scenario of the Hadgem3, Mpi-esm1 and Mri-esm2 models in the three selected years 2023-2050 (wet, medium and dry). The results presented correspond to the outputs of the *AquaCrop* model once the changes in climate that are expected according to the contemplated climate change scenario have been incorporated. Soybean production was then simulated by applying irrigation only to guarantee the germination of this crop for the SSP2-4.5 scenario, comparing the outputs of the 3 models.

RESULTS AND DISCUSSION

Using the climate values of the SSP2-4.5 scenario from the HadGEM3, Mpi-esm1 and Mri-esm2 models, the results representing the future climate for the study area for each of the models are presented.

Table 1 shows the selection of the hydrological years according to their respective probability (probability 25% denotes a wet year, 50% medium and 75% dry) for the period 2023-2050 (November-April, crop development period) and precipitation values for the SSP2-4.5 scenario and the Hadgem3, Mpi-esm1 and Mri-esm2 models.

Under the SSP2-4.5 scenario, it can be observed that the behavior of precipitation varied between 319,73-532,67 mm for the period studied, differing by model. For the period of crop development (November-April), the Hadgem3 and Mpi-esm1 models estimate precipitation values higher than the Mri-esm2 model by 5-18%, with the greatest differences for the 50% probability of occurrence (13 and 18%).

TABLE 1. Selection of hydrological years according to their respective probability (probability 25% denotes a wet year, 50% average and 75% dry) for the period 2023-2050

Prob. (%)	**Models**					
	Hadgem3		**Mpi-esm1**		**Mri-esm2**	
	Year	**Rainfall (mm)**	**Year**	**Rainfall (mm)**	**Year**	**Rainfall (mm)**
25	2043-2044	532,67	2034-2035	567,36	2038-2039	482,80
50	2029-2030	446,85	2030-2031	421,25	2042-2043	366,02
75	2030-2031	339,27	2040-2041	346,89	2034-2035	319,73

Figure 1 compares the annual precipitation estimated under the SSP2-4.5 scenario for the period 2023-2050 for the three models studied, it can be observed that the behavior of precipitation varied between 1241,7 and 2216,18 mm per year. Of the 3 models, the Mpi-esm1 model estimates the highest precipitation values in 17 of the 28 years studied, and in 23 years values above 1500 mm. The HadGEM3 model estimates 9 years below 1500 mm. The maximum value is estimated by the Mri-esm2 model with 2216,18 mm for the year 2037, while in 10 years the precipitation estimates were less than 1500 mm.

Estimates of the 28-year annual average for the HadGEM3 model are 1619,23 mm, while the Mpi-esm1 model estimates 1714,57 mm and the Mri-esm2 model 1596,19 mm, all between 16 and 22% above the current annual average of 1335 mm for Cuba according to the new isoietic model (Servicio Hidrológico Nacional, 2006).

Figure 2 shows the water balance in the defined growing period for soybean (November-April) between 2023-2050 for SSP2-4.5 of the Hadgem3 model. Despite the fact that in the selected years the annual rainfall exceeds 1400 mm in the three models, the same behavior is not observed in the soybean growing period. As shown in Figure 4A in the wet hydrological year (25% probability of precipitation occurrence), only in the months of December and January, precipitation exceeds crop evapotranspiration, in 50% and 75% of probability only in one month, so a greater number of irrigations could be expected together with a higher total net standard for this SSP2-4.5 scenario.

Tables 2, 3 and 4 present the results obtained in Cropwat for water requirements and irrigation management for soybean cultivation for the SSP2-4.5 scenario of the HadGEM3, Mpi-esm1 and Mri-esm2 models.

The number of irrigations for soybean varied between 9 and 10 irrigations with partial norms between 24 and 30 mm and total norms between 246,2 and 272,7 mm, depending on the year and the model used.

The results obtained by Castellanos *et al.* (1984), for a planting season similar to that of this study, report that it was necessary to apply 14 irrigations with a total net norm of 259 mm and a rainfall of 117,6 mm. They also report that in order to obtain high yields in Red Ferrallitic soils, moisture before irrigation should not fall below 85% of the Cc in the 0-40 cm depth layer.

Table 5 shows the results of the simulation with Aquacrop for soybean. First, a potential production was simulated, maximum possible yield without any constraints except plant genetics, solar radiation and temperature, adjusted for the SSP24.5 scenario and the HadGEM3, Mpi-esm1 and Mri-esm2 models in the three selected years of the 2023-2050 period (wet, medium and dry).

Yield values (2.72-3.27 t ha^{-1}) and water productivity (0.78-0.91 kg m^{-3}) are in the range published in previous works by González *et al.* (2014) and González *et al.* (2015).In the particular case of yield in field experiments that served as a source for model calibration (Castellanos *et al.*, 1984),

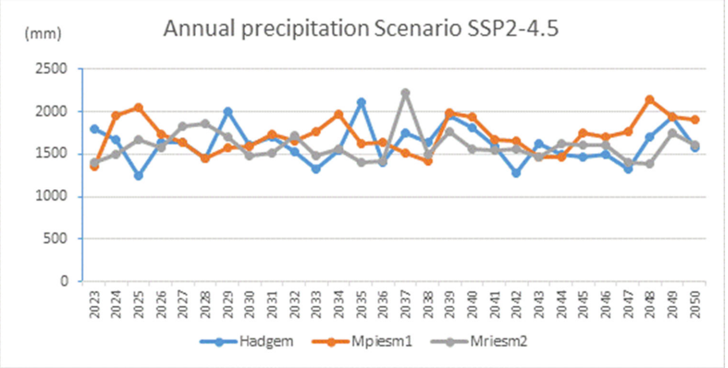
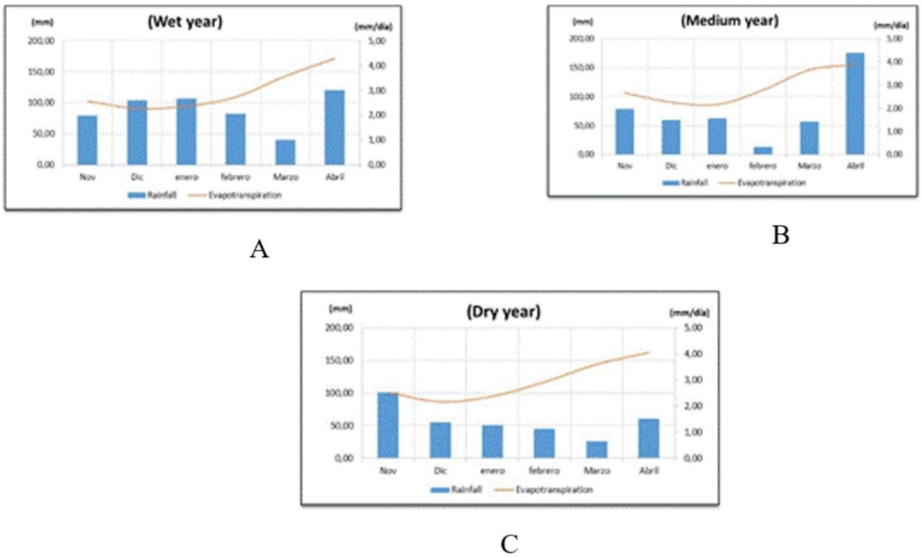


FIGURE 1. Comparison between annual precipitation for the period 2023-2050 under the SSP2-4.5 scenario of the HadGEM3, Mpi-esm1 and Mri-esm2 models.



A

B

C

FIGURE 2. Water balance in the November-April period between 2023-2050 for the SSP2-4.5 scenario of the Hadgem3 model in the study area.

TABLE 2. Water requirements and irrigation management for soybean crop for the SSP2-4.5 scenario of the HadGEM3 model in the analyzed periods, according to the Cropwat software

Wet (2043-2044)		**Medium (2029-2030)**		**Dry (2030-2031)**	
Day	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**
1	26,4	1	26,3	1	26,3
35	25,6	35	26,2	32	25,0
48	27,6	45	28,5	45	26,2
59	28,0	55	27,2	56	28,1
68	26,4	65	28,6	65	29,1
76	28,1	74	27,1	74	29,5
84	28,5	83	26,9	83	27,1
93	29,8	91	28,3	91	29,0
101	26,7	100	29,0	99	26,6
Total net irrigation duty (mm)	**247,2**		**248,2**		**246,9**
Irrigation number	**9**		**9**		**9**

TABLE 3. Water requirements and irrigation management for soybean crop for the SSP2-4.5 scenario of the Mpi-esm1 model in the analyzed periods, according to the Cropwat software

Wet (2034-2035)		**Medium (2030-2031)**		**Dry (2040-2041)**	
Day	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**
1	26,4	1	26,3	1	26,3
35	26,0	21	24,0	35	25,7
48	28,6	41	27,9	48	28,5
59	27,0	54	27,5	59	27,8
69	27,0	65	29,3	69	28,2
79	28,9	75	29,6	78	26,2
87	27,6	84	27,3	86	27,2
95	28,0	93	28,1	95	28,7
105	26,7	103	27,5	106	28,0
Total net irrigation duty (mm)	**246,2**		**247,4**		**246,6**
Irrigation number	**9**		**9**		**9**

TABLE 4. Water requirements and irrigation management for soybean crop for the SSP2-4.5 scenario of the Mri-esm2 model in the analyzed periods, according to the Cropwat software

Wet (2038-2039)		**Medium (2042-2043)**		**Dry (2034-2035)**	
Day	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**	**Day**	**Irrigation duty (mm)**
1	26,4	1	26,3	1	26,3
32	25,5	35	25,7	28	25,3
46	28,9	47	26,2	42	27,4
58	26,7	58	27,1	52	27,6
68	29,5	66	26,8	62	26,7
76	28,5	73	26,4	70	26,4
84	27,4	82	27,4	78	27,7
93	28,3	90	29,5	86	28,6
103	27,6	99	27,3	95	30,0
		111	26,2	105	26,9
Total net irrigation duty (mm)	**248,7**		**268,9**		**272,7**
Irrigation number	**9**		**10**		**10**

TABLE 5. Simulation results with *AquaCrop* for the SSP2-4.5 scenario and the HadGEM3, Mpi-esm1 and Mri-esm2 models, in the selected periods, for the soybean crop

Models	**Year**	**Biomass (t ha^{-1})**	**Yield (t ha^{-1})**	**WP_{ET} (kg m^{-3})**	**ETo (mm)**	**Irrigation number**	**Duty (mm)**	**Rainfall (mm)**
HadGEM3	Wet (2043-2044)	9,27	**3,27**	**0,91**	367,0	9	247,2	329,1
	Medium (2029-2030)	8,79	3,03	0,90	352,2	9	248,2	275,6
	Dry (2030-2031)	9,09	2,95	0,81	366,0	9	246,9	165,8
Mpi-esm1	Wet (2034-2035)	8,82	2,93	0,85	351,4	9	246,2	385
	Medium (2030-2031)	8,87	2,92	0,85	354,9	9	247,4	226,7
	Dry (2040-2041)	9,21	2,97	0,86	354,6	9	246,6	149,1
Mri-esm2	Wet (2038-2039)	8,82	2,85	0,80	363,0	9	248,7	286,1
	Medium (2042-2043)	9,06	2,92	0,83	390	10	268,9	215,5
	Dry (2034-2035)	8,6	2,72	0,78	360,8	10	272,7	183,3

this varied between 0,42 for dry treatments and 3,49 t ha^{-1} for the best irrigation treatment, while productivity based on evapotranspiration obtained in this work was higher in all years than the average obtained by these authors cited above (0,67 kg m^{-3}).

The highest average yields, simulated with *Aquacrop*, were obtained with the climatic data of the HadGEM3 model with 3,27 t ha^{-1} (Figure 3). In the three years selected for this model, it was necessary to apply 9 irrigations to achieve yields higher than 2,95 t ha^{-1}. The possibility of achieving soybean yields of 3 t ha^{-1} is evident, even under the conditions imposed by climate change and provided that the crop does not have irrigation limitations, pest attacks, seed quality, among others.

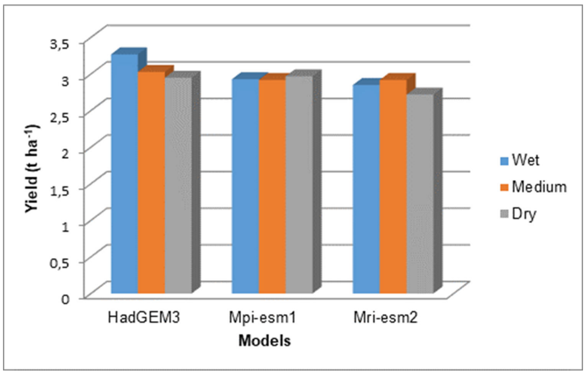


FIGURE 3. Comparison of HadGEM3, Mpi-esm1 and Mri-esm2 models used to predict soybean yield in the selected periods.

According to Merino (2006), soybean yields in Cuba range from 0,98 to 3 t ha^{-1}, depending on the variety used and the region. During the winter planting season and under conditions of brown soils with carbonates in the central zone of Cuba and with the cultivar Conquista, agricultural yields of 2,54 t ha^{-1} were achieved.

Figure 4 shows the outputs of the *Aquacrop* model for the SSP2-4.5 scenario of the Mri-esm2 model (2038-2039, wet year), where the lowest yield of the wet years of 2,85 t ha^{-1} was obtained, with 286,1 mm of precipitation and where it was necessary to apply 248,7 mm per irrigation. A decrease in transpiration was observed 50 days after planting the soybean, with 98% stomatal closure, apparently due to excess rainfall, since an irrigation of 28,9 mm was applied 46 days after planting the soybean and then it rained 5 days in a row, coinciding with the beginning of flowering.

Maximum yields are obtained when the crop can transpire at its maximum rate, i.e., when there is no stomatal closure and thus reduction in transpiration simultaneously with CO_2 assimilation. The rates of the latter two processes are strongly linked and therefore the calculation of transpiration through the crop canopy is a direct route to the calculation of crop assimilation (Isla, 2019).

According to Márquez and Enriquez (1984), cited by Herrera *et al.* (2011), in studies conducted under experimental conditions similar to this study, soybean is a crop that shows sensitivity to excess moisture, it can lose up to 20% of its yield with 48 hours and up to 40% with 72 hours of flooding; its productivity will then depend largely on good irrigation management. The effects of excess moisture result in a decrease in crop yields. The decrease in soybean yield with 4 days of flooding is in the order of 50% and the most severe losses occur in the vegetative-flowering stage.

When the soil is saturated for a prolonged period of time, the water fills all the pores, displacing the air. This causes the absence of oxygen in the soil and in most plants, cellular asphyxia at the root level, loss of root functionality, reduction of growth due to nitrogen deficiencies and if prolonged for a long time can cause the death of the plant (Gardner *et al.*, 1999).

Table 6 shows the results of the simulation with *Aquacrop* for soybean when irrigation (10 mm) was applied to guarantee germination, under the SSP2-4.5 scenario of the HadGEM3, Mpi-esm1 and Mri-esm2 models in the wet and medium years, as well as the yield reduction with respect to the potential obtained in each year shown in Table 5.

In the HadGEM3 model for the wet year (2043-2044) yields are estimated at 2,09 t ha^{-1} and biomass 7,02 t ha^{-1}, achieving a productivity of 0,68 kg m^{-3}, with reductions with respect to the potential yield of 36% (Figure 5).

At 20 days there is a stress of 100% canopy expansion and 31% stomatal closure, in all this period only 25,9 mm of rainfall. At 40 days 16% canopy expansion, at 80 days 63% stomatal closure and 16% early senescence and at 100 days 25% stomatal closure. Throughout the crop cycle, soybean was subjected to an average stress of 25% canopy expansion and 16% stomatal closure, significantly affecting yield.

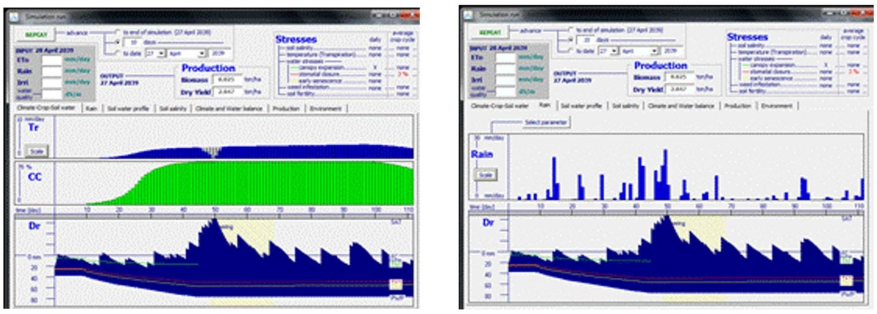


FIGURE 4. *Aquacrop* model output for potential soybean yield in the SSP2-4.5 scenario of the Mri-esm2 model (2038-2039, wet year).

TABLA 6. Simulation results with *AquaCrop* for the SSP2-4.5 scenario and the HadGEM3, Mpi-esm1 and Mri-esm2 models, in wet and medium years, as well as the yield reduction with respect to the potential for the soybean crop.

Models	Year	Biomass (t ha^{-1})	Yield (t ha^{-1})	WP_{ET} (kg m^{-3})	ETo (mm)	Rainfall (mm)	Yield reduction (%)
HadGEM3	Wet (2043-2044)	7,02	2,09	0,68	367,0	329,1	36
	Medium (2029-2030)	**2,03**	**0,148**	**0,12**	352,2	275,6	95
Mpi-esm1	Wet (2034-2035)	8,36	2,51	0,82	351,4	385,0	14
	Medium (2030-2031)	5,46	1,55	0,60	354,9	226,7	47
Mri-esm2	Wet (2038-2039)	7,5	2,22	0,74	363,0	286,1	22
	Medium (2042-2043)	2,66	0,32	0,22	390,0	215,5	89

For this same model but in the medium year (2029-2030) only a yield of 0,148 t ha^{-1} and biomass of 2,03 t ha^{-1} were achieved, with reductions with respect to the potential of 95% (Figure 6). This irrigation management, together with low and poorly distributed rainfall, caused water depletion in the soil during almost the entire period of crop development and marked levels of stress. From 30 days after soybean planting and up to 70 days, stress values between 66 and 100% inhibition of canopy expansion, 48-80% stomata closure and up to 39% acceleration of senescence were estimated as a response to water stress.

Soybean has two well-defined critical periods with respect to water requirement: from planting to emergence, and during the phase of formation and development of reproductive organs (flowering, pod formation and filling). In the germination phase, both deficit and excess moisture are detrimental to the uniformity of distribution and number of plants per unit area. During this period, excess water is much more limiting than deficit (Doorenbos & Kassam, 1986).

As shown in Figure 7, for the Mpi-esm1 model in the wet year (2034-2035), yield losses were only 14%, which occurred after 80 days after planting soybeans. At 100 and 110 days, stomata closure was 84% and the acceleration of senescence reached 50% as a response to water stress, in this period rainfall was less than 13 mm.

FIGURE 5. Aquacrop model output for soybean yield in the SSP2-4.5 scenario of the HadGEM3 model for the wet year (2043-2044).

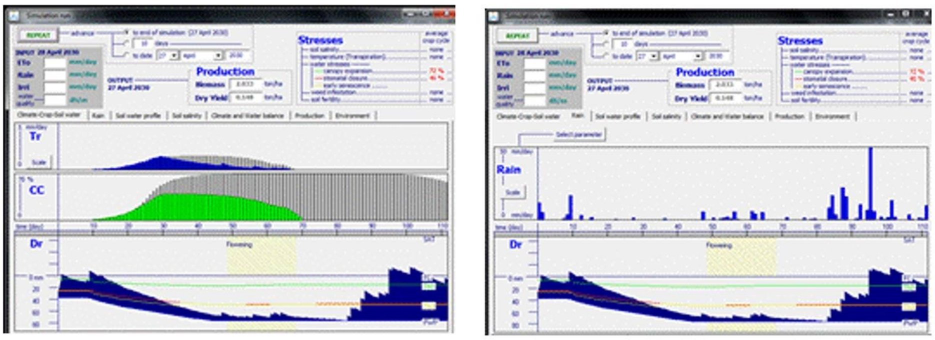


FIGURE 6. Aquacrop model output for soybean yield in the SSP2-4.5 scenario of the HadGEM3 model for the mid-year (2029-2030).

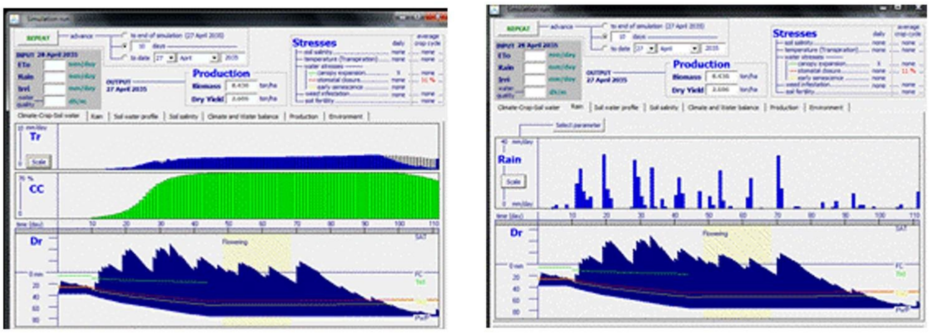


FIGURE 7. Aquacrop model output for soybean yield in the SSP2-4.5 scenario of the Mpi-esm1 model for the wet year (2034-2035).

CONCLUSIONS

- The behavior of annual precipitation under the SSP2-4.5 scenario of the HadGEM3, Mpi-esm1 and Mri-esm2 models varied between 1241,7 and 2216,18 mm. Of the 3 models Mpi-esm1 estimates the highest precipitation values in 17 of the 28 years studied, and in 23 years values above 1500 mm. The HadGEM3 model estimates 9 years below 1500 mm. The maximum value is estimated by the Mri-esm2 model with 2216,18 mm for the year 2037, while in 10 years the precipitation estimates were less than 1500 mm.
- The estimates of the 28-year annual average for the HadGEM3 model is 1619,23 mm, while the Mpi-esm1 model estimates 1714,57 mm and the Mri-esm2 1596,19 mm, all above the current annual average of 1335 mm for Cuba according to the new isoietic of Cuba, between 16 and 22%.
- Despite the fact that in the selected year's annual rainfall exceeds 1400 mm for the three models, in the growth period selected for the soybean crop (November-April), the same behavior is not observed. In general, in the year of probability of occurrence corresponding to 25%, only in the months of December and January does rainfall exceed crop evapotranspiration by 50 and 75% in only one month, so a greater number of irrigations could be expected together with a higher total net standard for this scenario.
- The simulated yield values show that soybean undergoes particular growth conditions during its biological cycle depending on rainfall behavior. These yield values can be considered as a reference of the productive capacity of the environment of the studied area and can be very useful in irrigation scheduling.
- If irrigation is applied only to guarantee soybean germination, under the SSP2-4.5 scenario of the HadGEM3, Mpi-esm1 and Mri-esm2 models, reductions with respect to potential yield are estimated between 14 and 95%.

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