OPEN ACCESS

ORIGINAL ARTICLE

Revista Ciencias Técnicas Agropecuarias 34
January-December 2025
ISSN 1010-2760, eISSN 2071-0054
Cu-ID: https://cu-id.com/2177/v34e27

Climate change and irrigation demand for rice (*Oriza sativa* L.) in Cuba

Cambio climático y demanda de riego del arroz (Oriza sativa L.) en Cuba

Julián Herrera-Puebla[1]*, Carmen Duarte-Díaz[1], Enrique Cisneros-Zayas[1] and Felicita González-Robaina[1]

[1]*Instituto de Investigaciones de Ingeniería Agrícola (IAgric).*
Carretera de Fontanar, km 2 1/2, Reparto Abel Santamaría, Boyeros, La Habana, Cuba.
E-mail: carmen.duarte@iagric.minag.gob.cu, enrique.cisneros@iagric.minag.gob.cu, felicita.gonzalez@iagric.minag.gob.cu

*Author for correspondence: Julián Herrera-Puebla, e-mail: julian.herrera@iagric.minag.gob.cu

ABSTRACT: Given the possible effects of climate change (CC), expressed in the increase in temperatures and the decrease in rainfall, it is expected among the main impacts motivated by CC for rice cultivation in the country the reduction of the crop area, due to the lower availability of water, lower quality crops and total magnitude. Taking into account the above, and the importance of this crop for the country, this work was proposed to study the effect of rainfall variations using the SSP1 2.6 climate scenario and three regional climate models (Hadgem3-gc31-ll-SSP12.6, Mpi-esm1-2-hr-SSP126 and Mri-esm2-0-SSP126), with climatic variables until the year 2050, using the CropWat 8.0 program to calculate irrigation demand at six sites distributed in the Western (2), Central (2) and Eastern (2) regions of the country. Regardless of the model studied for the evaluation of rainfall, there was a decrease in values from west to east, with averages of 1644, 1467,5 and 1239,1 mm year^{-1} for the western, central and eastern zones, respectively; water demand was higher in the Hadgem3-gc31 model with an average gross water demand of 1337,5 mm for the 6 sites studied for a 130 day cycle and 5,8 and 4,3 % higher for the Mpi-esm1-2hr-SSP126 and Mri-esm2-0-126 models, respectively. It is suggested that further studies on the subject be continued, including the possible effect of temperatures on the decrease of both the cycle and the yield of the crop.
Keywords: Climate Variability, Water Consumption, CropWat.

RESUMEN: Dado los posibles efectos del cambio climático (CC), expresados en el aumento de las temperaturas y la disminución de las lluvias, se prevé entre los principales impactos motivado por el CC para el cultivo del arroz en el país la reducción de la superficie de cultivo, debido a la menor disponibilidad de agua, cosechas de menor calidad y magnitud total. Teniendo en cuenta lo anterior, y la importancia de este cultivo para el país este trabajo se propuso estudiar el efecto de la variación de las lluvias utilizando el escenario climático SSP1 2.6 y tres modelos climáticos regionales (Hadgem3- gc31-ll-SSP12.6, Mpi-esm1-2-hr-SSP126 y Mri-esm2-0-SSP126), con variables climáticas hasta el año 2050, utilizando el programa CropWat 8.0 para el cálculo de la demanda de riego en seis sitios distribuidos en la región Occidental (2), Central (2) y Oriental (2) del país. Con independencia del modelo estudiado para la evaluación de las precipitaciones hubo una disminución de los valores desde occidente hacia el oriente, con promedios de 1644, 1467,5 y 1239,1 mm año^{-1} para la zona occidental, central y oriental, respectivamente; la demanda del agua fue superior en el modelo Hadgem3-gc31 con norma bruta promedio de los 6 sitios estudiados de 1337,5 mm para un ciclo de 130 días y superior en un 5,8 y 4,3 % para los modelos Mpi-esm1-2hr-SSP126 y Mri-esm2-0-126, respectivamente Se sugiere continuar los estudios sobre el tema incluyendo el posible efecto de las temperaturas en la disminución tanto del ciclo como del rendimiento del cultivo.
Palabras clave: variabilidad climática, consumo de agua, modelaje.

INTRODUCTION

Rice consumption in Cuba has been estimated at approximately 70 kg per capita annually, meaning the country demands approximately 700,000 tons of rice (Gutiérrez & Lau, 2019). Average paddy rice production for the years 2018-2022 was 297,281 tons, equivalent to approximately 134,000 tons of rice for consumption. For the same five-year period, the average annual rice import was 477,480 tons ONEI-Cuba (2022), this means that the country has needed to import an average of 78% of its rice consumption. The above figures indicate the importance of this crop for the country and the need to increase its production in order to minimize such a high volume of imports. This dilemma highlights the potential future impact of climate change on rice production in Cuba, especially in terms of whether or not it will be able to meet its water demand.

Received: 20/04/2025
Accepted: 18/09/2025
The authors of this work declare no conflict of interests.
Author contributions: Conceptualization: J. Herrera, C. Duarte, E. Cisneros, F. González. **Data curation:** J. Herrera, C. Duarte, E. Cisneros. **Formal analysis:** J. Herrera, C. Duarte, E. Cisneros. **Investigation:** J. Herrera, C. Duarte, E. Cisneros. **Methodology:** J. Herrera, C. Duarte, E. Cisneros, F. González. **Software:** J. Herrera, C. Duarte, E. Cisneros, F. González. **Supervision:** J. Herrera, C. Duarte. **Validation:** J. Herrera, C. Duarte, E. Cisneros. **Writing-original draft:** J. Herrera, C. Duarte, E. Cisneros. **Writing-review & editing:** J. Herrera, C. Duarte, E. Cisneros, F. González.

The Third National Communication to the United Nations Framework Convention on Climate Change (CITMA-Cuba, 2020), predicts that among the main impacts of climate change on rice cultivation in the country are a reduction in the cultivated area, resulting in lower water availability, lower-quality harvests, and lower overall magnitude. Furthermore, according to Hervis *et al.* (2019), the most significant potential impacts on agricultural development focus on climatic variables such as temperature and precipitation, at different time scales and depending on the region. Future local changes will increase the average annual temperature by 1.0°C and the average annual minimum temperature by 2.0°C. The IPCC (Intergovernmental Panel on Climate Change), in its sixth report, defines shared socioeconomic pathways (SSPs), which replace the so-called Representative Concentration Pathways (RPCs), these shared socioeconomic pathways (SSPs) as modeled scenarios, which are used to explore future emissions, climate change, impacts, possible mitigation and adaptation strategies, in addition, the corresponding future projection of greenhouse gas emissions and land use change is linked under the argument of the reference SSP as a new and improved version of the RCPs (Environment and Climate Change Canada, 2023).

In particular, SSP1-2.6 is a scenario starting in 2015 with low GHG emissions and decreasing CO_2 emissions to net-zero emissions around or after 2050, followed by varying levels of net-negative CO_2 emissions (Januta, 2021). It is an optimistic scenario developed to simulate developments compatible with the 2°C target (global warming of 2°C is unlikely to exceed, estimated temperature: 1.5°C), on the way to a sustainable and green world (IPCC, 2021).

In studies on future water demand for rice crops in various countries (Gilanipour & Gholizadeh, 2016; Kyu & Truong, 2018; Hastarai *et al.,* 2022; Agrawal *et al.,* 2023 among others), the CropWat program developed by Smith (1992), has been widely used in its most modern version CropWat 8.0 (FAO, 2008). The CropWat program calculates potential evapotranspiration using the Penman-Monteith equation, for which it requires data on maximum and minimum temperature, relative humidity, wind speed, and sunshine; from these data and using the crop coefficient, it can calculate crop evapotranspiration for the selected site. In addition, it requires rainfall and soil data, the latter data, in the case of rice, demands a different treatment than the rest of the crops, taking into account that rice is grown in most of the world using flood irrigation. All of this data is processed in different subroutines, which the program then combines to calculate irrigation demand and schedule irrigation (FAO, 2009).

With this in mind, this study aimed to study the effect of rainfall variation using the SSP1 2.6 climate scenario and three regional climate models (Hadgem3-gc31-ll-SSP1 2.6, Mpi-esm1-2-hr-SSP126, and Mri-esm2-0-SSP126), with climate variables up to the year 2050. CropWat 8.0 FAO (2008). was used to calculate irrigation demand.

MATERIALS AND METHODS

Table 1 shows the location of the study sites. The geographic coordinates shown correspond to the location of the meteorological station used.

Rainfall

In order to organize the data required by the different subroutines of the CropWat program, an analysis was conducted of rainfall in the country's main rice-growing regions (Table 1) for the period 2022-2050. This analysis was performed for three models and the same SSP1 2.6 scenario:

- Hadgem3-gc31-ll-SSP1 2.6 (model 1)
- Mpi-esm1-2-hr-SSP126 (model 2)
- Mri-esm2-0-SSP126 (model 3)

For the rainfall analysis, according to Aleman *et al.,* 2020), three rice growing cycles were considered: Cold (December-May, 150-day cycle), Pre-spring (May-September, 140-day cycle), and Spring (July-October, 110-day cycle). The rainfall data were sorted by month within each year, and the rainfall for each crop cycle was calculated for the country's main rice-growing regions over the 29 years studied. This data is shown in Table 1.

The rainfall data, sorted as described above, were analyzed for subsequent use in calculating crop water demand, following the procedure outlined by FAO (2016). for use in the CropWat 8.0 program.

Table 1. Study sites

Site	**Province**	**Coordinates**		**Altitude (m)**
		North	**West**	
Los Palacios	Pinar del Río	22°33’47”	83°18’26”	47
Corojal	Artemisa	23º 29’ 4,1”	83º 24’ 6,26”	38
Sur del l Jibaro	Sancti Spiritus	21°46´18,03"	79°16´6,22"	41
Vertientes	Camagüey	21° 52´68	78° 22´58	32
Jucarito	Granma	20°40´6,76"	76°33´10,12"	37
Yara		20°13´38,59"	76°57´3,40"	41

Soils

Martínez *et al.* (2017), distributed the predominant soil types in the different rice-growing areas in each province, which is shown in Table 2.

Ascanio *et al.* (1980) based on the Second Genetic Classification of Cuban Soils, grouped Cuban rice soils into 7 types, as shown in Table 2. Martínez *et al.* (2017), distributed these soil types across different rice-growing areas in each province.

Based on the data of rice´s soils physical properties existing in the IAgric database, and the works of Simeón (1979), Ascanio *et al.* (1980) and Cid *et al.* (2012), the file of properties of these soils was prepared according to each site, where the predominant soil types in each one were taken from the 1:25 000 soil map of each of the provinces where the study sites are located. According to the soil distribution shown in Table 2, and the three categories into which Samaké (1998), grouped them according to its infiltration capacity, Table 3 was prepared, which shows the soil parameters used in the soil module of the CropWat program for each site considered in the study.

Crop coefficients

Crop coefficients (KC) were calculated for the study sites based on the Kc proposed by Herrera-Puebla et al. (2020) for the western region of Cuba, using the methodology proposed by Allen *et al.* (2006). To calculate the initial Kc, in their methodology, Allen *et al.* (2006), established that for rice grown in flooded fields with a water depth of 0.10-0.20 m, the ETc value during the initial stage will consist primarily of evaporation from the water surface. The Kc value included by the aforementioned authors is 1.05 for a sub-humid climate with light to moderate winds. However, for the conditions of western Cuba, Herrera-Puebla *et al.* (2020), found an initial Kc value of 0.8, which was used to extrapolate the mean and final coefficients for the sites where irrigation demand will be calculated. Table 4 shows the crop coefficients for each study site and their comparison with the Kc proposed by Allen *et al.* (2006).

Table 2. Predominant soil types in Cuban rice-growing areas and distribution by province Ascanio *et al.* (1980) and Martínez *et al.* (2017)

Types	soils	Rice areas	Soils infiltration groups according to Samaké (1998)
I	Dark gleyed and humic plastics, typical gley (heavy clay texture)	Matanzas, Sancti Spiritus Granma.	I
II	Dark gleyed and gleyzous plastics	Artemisa y Mayabeque	II
III	GleyFerraliticos	Pinar del Río y Camagüey	III
IV	Dark gleyzoid plastics (granular structure up to 40 cm)	Matanzas, Sancti Spiritus Granma.	I
V	Typical humicgley (loamy texture)	Granma	I
VI	Yellowish quartzite gley, laterized	Pinar del Río, Camaguey	III
VII	Typical yellowish quartzite	Pinar del Rio, Artemisa	III

Table 3. Parameters to be used in the "soils" module of the CropWat 8.0 program to calculate irrigation demand in rice

Parameter	Group I	Group II	Group III
	Matanzas, Sancti Spíritus, Granma	Artemisa, Mayabeque	Pinar del Río, Camagüey
Total Available water (TAW)	270	250	170
Maximum Infiltration rate (mm/day)	17	17	43
Maximum rooting depth (cm)	50	50	50
Initial soil moisture depletion (% de ADT (%)	100	100	100
Initial available soil moisture (mm/m)	0	0	0
Drainable Porosity () %	5	9	9
Critical depletion for puddle cracking(fraction)	0,6	0,6	0,6
Maximum percolation rate after puddling(mm/day)	2,6	2,6	2,6
Water availability at planting (% of saturation)	0	0	0
Maximum water depth (mm)	100	10	10

Table 4. Crop coefficients (Kc) for the different sites

	Allen *et al.* (2006)	**Paso Real y Corojal**	**La Sierpe y Sur del Jibaro**	**Vertientes**	**Jucarito**	**Yara y Veguitas**	**Kc average**
			Winter planting				
$Kc_{initial}$	1,1	0,80	0,80	0,80	0,80	0,80	0,80
Kc_{medium}	1,2	1,40	1,30	1,30	1,30	1,13	1,29
Kc_{final}	1,05	1,3	1,18	1,19	1,23	1,23	1,23
			Spring planting				
$Kc_{initial}$	1,1	0,80	0,80	0,80	0,80	0,80	0,80
Kc_{medium}	1,2	1,33	1,40	1,30	1,31	1,21	1,31
Kc_{final}	1,05	1,23	1,30	1,20	1,21	1,17	1,22

RESULTS AND DISCUSSION

Rainfall Analysis

Figure 1 shows the behavior of annual and seasonal rainfall for each scenario at every studied sites. It can be observed that, regardless of the model, rainfall decreases from west to east, with average values for the three models of 1644, 1467.5, and 1239.1 mm yr^{-1} for the western, central, and eastern zones, respectively. The coefficient of variation (C.V.) for annual rainfall is also much lower in the western and central zones than in the eastern zones, indicating greater consistency in the average values for this region. In the western zone, scenario 2 (Mpi-esm1-2-hr-SSP126) showed the highest average annual rainfall values (1715,2 mm year^{-1}), while in the eastern region, the highest values corresponded to Hadgem3-gc3SSP126 model (1287,2 mm). In the central zone, scenarios 1 and 2 had similar annual rainfall values (1456,5 mm year^{-1}); in all the studied sites, the mean annual rainfall was 1456,5 mm year^{-1}.

Also during the rainy season, rainfall in the west and center, as well as the CV, show higher values than the eastern region in all three models studied. However, for the dry season, only in model 1 (model Hadgem3-gc31-ll-SSP1 2.6) is there a clear superiority in rainfall values for the western region, although it also presents the highest CV values.

The behavior of the average monthly rainfall for all the sites studied and for each scenario is shown in Figure 2.

For all models, the lowest rainfall values are found in the months of November to April, corresponding to the dry season, and the highest in the months of May to October. A decrease in rainfall can be observed in the months of July and August, equivalent to 30%, 20%, and 20% for models 1, 2, and 3, respectively, relative to the total rainfall that would occur during the remaining months of the rainy season. This period, known as the cold season, according to Carrazana *et al.* (2013), is characterized by the longest growth cycle and expression of yield potential.

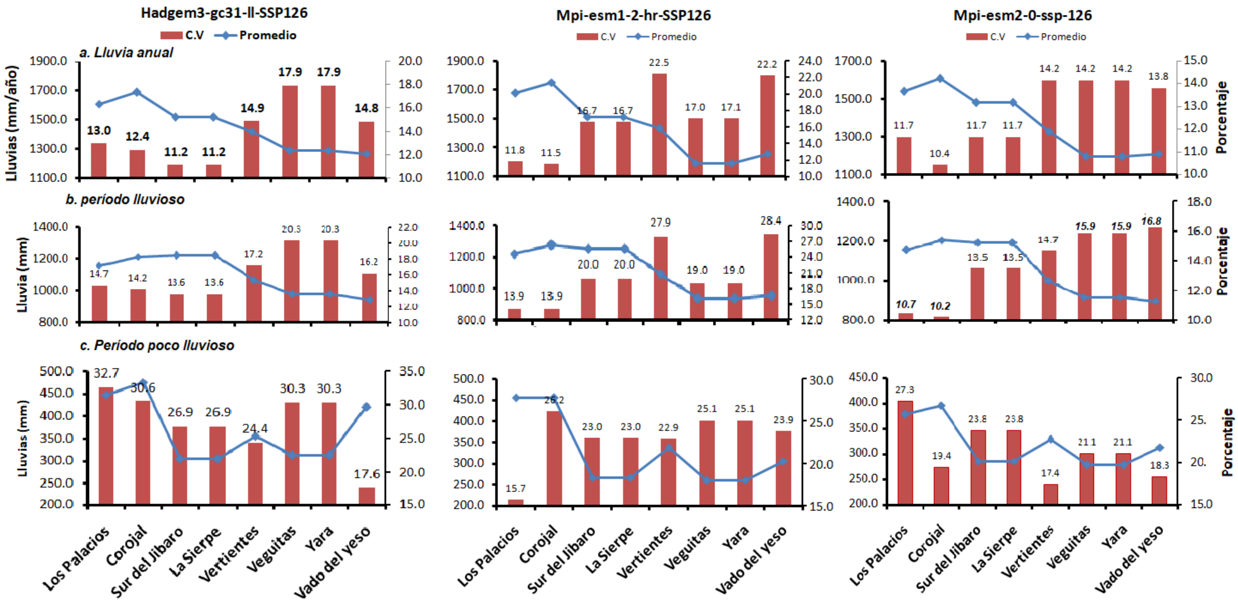

Figure 1. Average annual and seasonal rainfall in the three scenarios for each of the sites under study.

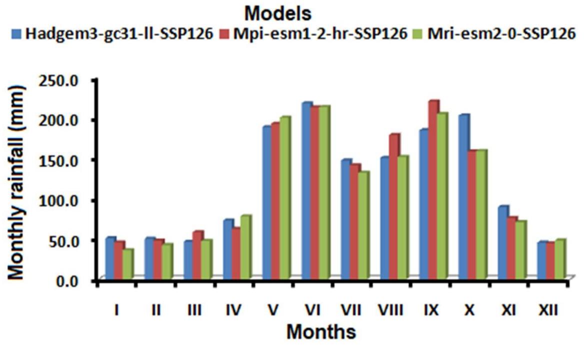

Figure 2. Average monthly rainfall for all sites for the three models studied.

These factors are influenced by the behavior of temperatures and solar radiation. It also corresponds to the highest water demand due to a longer growth cycle and the rainy season.

Figure 3 shows the rainfall values for each planting period, scenario, and site; As expected, rainfall values in period 1 (Figure 3a, sowing in December and cycle length of 150 days), which correspond to the dry season, show the lowest total rainfall, regardless of site or model. Period 2 (Figure 3b), where crop growth coincides with the rainy season, shows the highest accumulated precipitation, also independent of site and scenario. Period 3 (Figure 3c) shows an intermediate situation between the two previous periods.

Table 5 shows the calculated values for the probability of rainfall for the western and central regions and the eastern region. As Table 5 shows, there are differences, albeit slight, between the coefficients for each site and planting season. This is because Kc depends on both climatic conditions (potential evapotranspiration) and crop development, which determines crop evapotranspiration.

From the results obtained, in terms of rainfall parameters, crop coefficients and soil properties of the different sites where the future water demand for rice will be determined according to the SSP1 2.6 scenario and the 3 models studied, the great variation in rainfall between regions is observed, where it is shown that regardless of the model there is a decrease in rainfall values from west to east, with average values for the three scenarios 1644, 1467,5 and 1239,1 mm year^{-1} for the western, central and eastern areas respectively, which together with the variations in Kc and soil types between sites will impose variations in the irrigation demand of the crop.

The variations in rainfall probabilities between years, regions, and models demonstrate the appropriateness of choosing rainfall from the period in which the crop is planted rather than the climatic or hydrological year.

Since the planting period, corresponding to the so-called "cold period," is when the highest yields are obtained and where the greatest water demands also occur, it was decided, when calculating future crop water demands, to work only with this period, since any water demand planning for a rice irrigation system project would include the demand for this cycle.

Water Balance

The water balance shown in Figure 4 was calculated from the ETo values calculated using the Penman-Monteith equation (Allen *et al.,* 2006) and the monthly rainfall for each model and site.

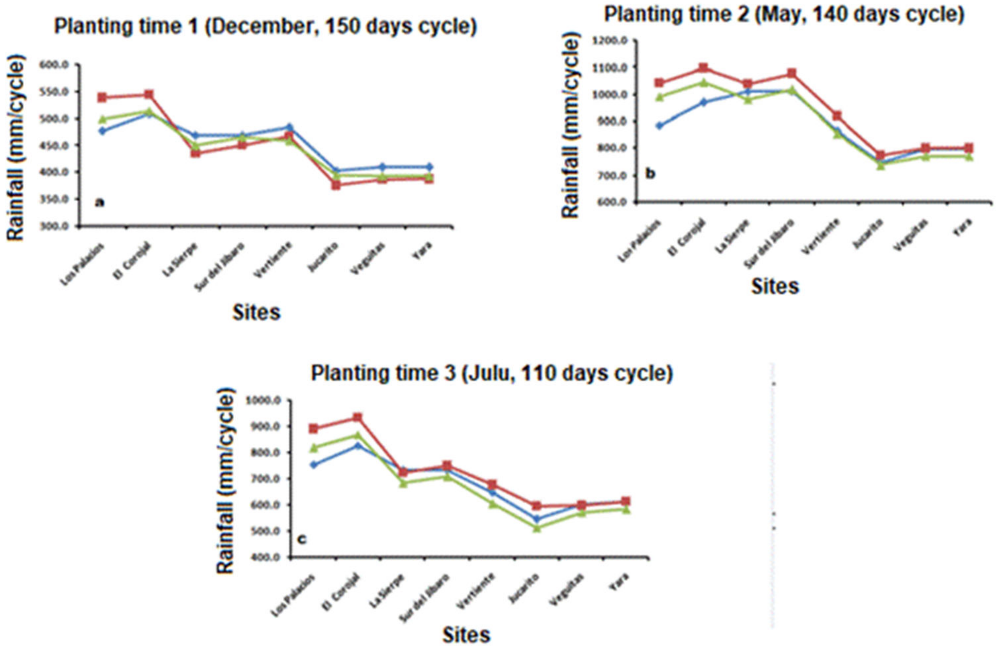

Figure 3. Average rainfall values for each planting season, scenario, and location.

Table 5. Rainfall Probability´s values for the years, wet (25%), medium (50%) and dry (75%) for the different sites, planting season and scenario

Sitio	**Época**	**Meses**	**P (%)**	**Modelos**					
				Hadgem-gc31-II SSP-1.26		**Mpi.esn-1-2-hr SSP-1.26**		**Mpi.esn-2-0-hr SSP-1.26**	
				Año	**Lluvia total (mm)**	**Año**	**Lluvia total (mm)**	**Año**	**Lluvia total (mm)**
				Región Occidental					
Los Palacios	1	dic-mayo	25	2040	556,1	2029	599,9	2040	556,1
	1		50	2033	462,5	2035	507,7	2033	462,5
	1		75	2041	407,7	2037	453,8	2041	407,7
	2	mayo-sept.	25	2029	985,3	2039	1113,8	2046	1057,8
	2		50	2036	878,5	2032	1002,2	2048	962,1
	2		75	2047	816,1	2037	936,9	2033	906,2
	3	julio-nov	25	2042	852,9	2029	956,3	2049	861,8
	3		50	2023	744,7	2039	855,8	2047	794,5
	3		75	2045	681,5	2042	797,0	2041	755,2
Corojal	1	dic-mayo	25	2028	557,6	2029	603,8	2040	550,4
	1		50	2037	482,1	2035	514,3	2042	473,5
	1		75	2024	437,9	2037	462,0	2050	428,5
	2	mayo-sept.	25	2039	1038,3	2048	1171,1	2032	1093,3
	2		50	2036	931,5	2041	1057,4	2050	1002,5
	2		75	2033	869,1	2044	990,9	2042	949,4
	3	julio-nov	25	2042	899,9	2027	998,3	2026	909,6
	3		50	2024	791,7	2045	897,8	2048	835,4
	3		75	2047	728,5	2042	839,0	2045	792,0
				Región Central					
Sur del Jibaro	1	dic-mayo	25	2043	503,5	2039	478,5	2029	499,9
	1		50	2026	449,4	2030	437,6	2047	445,9
	1		75	2038	417,7	2041	413,7	2036	414,4
	2	mayo-sept.	25	2039	1076,4	2027	1189,5	2050	1073,5
	2		50	2026	979,3	2041	1016,9	2036	983,4
	2		75	2032	922,6	2047	915,9	2023	930,7
	3	julio-nov	25	2028	800,5	2034	854,6	2037	756,7
	3		50	2042	700,7	2027	691,7	2029	679,8
	3		75	2048	642,3	2041	596,4	2032	634,8
La Sierpe	1	dic-mayo	25	2043	503,5	2039	477,2	2039	499,9
	1		50	2026	449,4	2038	436,0	2047	445,9
	1		75	2038	417,7	2041	411,9	2046	414,4
	2	mayo-sept.	25	2039	1076,4	2027	1189,5	2050	1073,5
	2		50	2026	979,3	2041	1016,9	2036	983,4
	2		75	2032	922,6	2047	915,9	2023	930,7
	3	julio-nov	25	2028	800,5	2029	854,6	2037	756,7
	3		50	2042	700,7	2027	691,7	2027	679,8
	3		75	2048	642,3	2041	596,4	2032	634,8

Sitio	Época	Meses	P (%)	Modelos					
				Hadgem-gc31-II SSP-1.26		Mpi.esn-1-2-hr SSP-1.26		Mpi.esn-2-0-hr SSP-1.26	
				Año	Lluvia total (mm)	Año	Lluvia total (mm)	Año	Lluvia total (mm)
				Region Oriental					
Vertientes	1	dic-mayo	25	2043	521,9	2046	506,1	2048	486,3
	1		50	2038	461,7	2027	444,2	2040	443,4
	1		75	2036	426,5	2042	407,9	2035	418,2
	2	mayo-sept.	25	2033	937,1	2025	1054,9	2026	919,5
	2		50	2050	823,4	2032	845,6	2036	819,7
	2		75	2036	756,9	2024	723,1	2047	761,3
	3	julio-nov	25	2047	723,1	2027	811,6	2029	646,5
	3		50	2041	609,4	2032	604,3	2048	579,6
	3		75	2038	542,9	2043	483,1	2030	540,5
Jucarito	1	dic-mayo	25	2032	455,5	2032	432,8	2034	440,8
	1		50	2033	395,5	2031	364,2	2026	390,6
	1		75	2036	360,4	2039	324,1	2035	361,2
	2	mayo-sept.	25	2041	828,9	2029	919,5	2029	823,8
	2		50	2045	736,7	2034	730,9	2038	728,1
	2		75	2036	682,8	2026	620,6	2040	672,2
	3	julio-nov	25	2024	623,5	2023	733,7	2039	572,0
	3		50	2032	533,4	2032	555,6	2049	509,5
	3		75	2045	480,7	2043	451,4	2033	473,0
Yara	1	dic-mayo	25	2025	444,1	2041	426,8	2033	416,8
	1		50	2045	389,4	2026	364,9	2026	379,7
	1		75	2026	357,3	2036	328,6	2035	358,0
	2	mayo-sept.	25	2041	878,9	2023	882,5	2026	835,4
	2		50	2050	752,1	2033	754,3	2037	732,1
	2		75	2036	677,9	2048	679,3	2038	671,7
	3	julio-nov	25	2042	694,2	2035	679,3	2026	641,9
	3		50	2035	568,0	2031	572,5	2030	549,7
	3		75	2026	494,2	2044	510,1	2025	495,8

As can be seen in Figure 4, in all models under the same SSP1 2.6 scenario, there is a marked imbalance between rainfall and ETo in the months corresponding to the dry season. While in the western and central regions this deficit disappears starting in May, in the eastern region, Models 1 and 3 maintain this throughout the year, while in Model 2, it disappears from August to November.

Crop Evapotranspiration

According to Bouman *et al.* (2012), the ETc for a rice crop cycle varies between 400 and 700 mm in the tropics and 800 to 1100 mm in temperate regions, representing 56 to 53% of the total water delivered to the crop, according to Renault (2004). Halfway through the crop cycle, when the crop is fully covered, rice evapotranspires at a rate slightly higher than the reference evapotranspiration (ET0), with average daily ET rates of 4-5 mm day^{-1} in the tropical wet season and 6-7 mm day^{-1} in the tropical dry season, but which can reach 10-11 mm day^{-1} in arid regions (Bouman *et al.,* 2012),

For Cuban conditions, Herrera-Puebla *et al.* (2019), reviewed studies on this parameter in Cuba and showed values ranging from 657 to 1173 mm/crop cycle. These authors also compared the results of lysimeter studies and data estimated using the CropWat program for the Los Palacios region (Pinar del Río).

Figure 5 shows the average crop evapotranspiration (ETc), in each model, for the total of a 130-day cycle in rice grown in the so-called cold season.

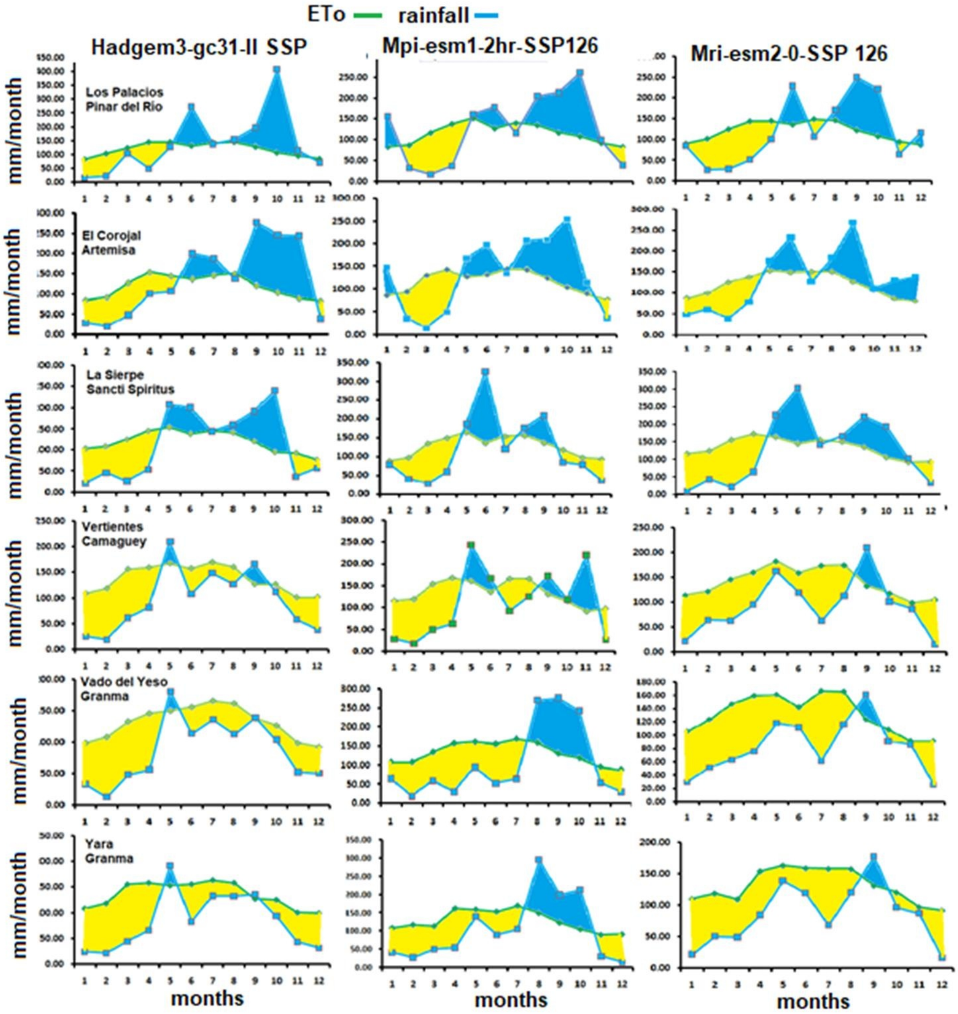

Figure 4. Annual water balance for each model and site studied.

The values in Figure 5, show that rice´s ETc for the study period is within the values obtained both globally and nationally. The Mpi-esm1-2-hr-SSP126 model (model 2) showed the lowest ETc values, 3,9% and 8,3% lower than models 1 and 3, respectively.

Comparing the study sites, Figure 6 shows that regardless of the model, the highest ETc values are always found in the central region, with average values for the three models exceeding the values obtained in the western and eastern regions by 18,9% and 6,4%, respectively.

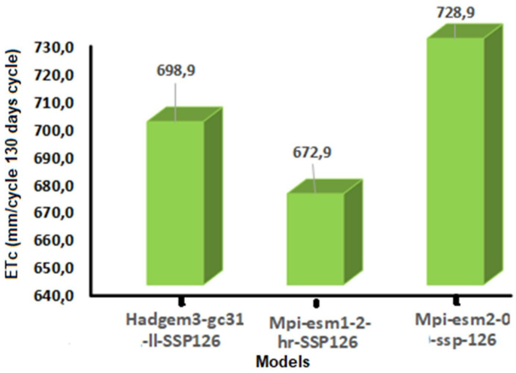

Figure 5. Average crop evapotranspiration in the three models for the SSP1 2.6 scenario.

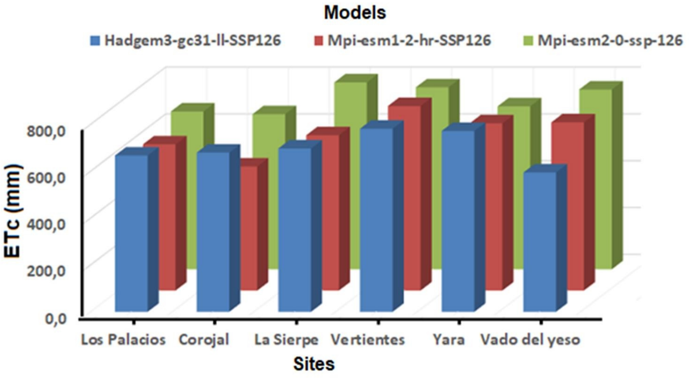

Figure 6. Crop evapotranspiration by model and site studied.

Water balance in rice cultivation

Rice irrigation water demands are closely related to the crop's unique water balance. The rice water balance can be briefly represented by the water balance formula Ding *et al.* (2017):

$$\Delta H = I + R - E - T - P - D \tag{1}$$

Where ΔH is the variation in water stored on the terrace, I is the water applied as irrigation, and R, E, T, P, and D represent rainfall, evaporation, transpiration, percolation, and surface drainage, respectively.

Figure 7 shows the components of the crop water balance according to the three climate models studied. Crop consumption losses plus percolation losses constitute the majority of the water that irrigation must replenish. As Figure 7 shows, rainfall accounts for a contribution of 15 to 17%, depending on the model considered.

Crop irrigation demand

As noted above, the amount of water to be applied as irrigation in rice crops depends on the ETc and percolation losses, since for agro technical reasons, the crop is maintained almost constantly with a water depth of 5-10 cm above the soil. The magnitude of this depth, expressed as the net irrigation rate, depends on the length of the crop cycle, climatic demand, and the soil infiltration capacity. Table 6 shows the gross irrigation demand values by site, for a 130-day crop cycle and cold sowing, i.e., sowing in December and harvesting in early May.

To calculate the gross irrigation, need as shown in Table 7, an overall irrigation system efficiency coefficient of 0,7 was used, equivalent to the efficiency required by an well designed and maintaining system according to INRH Standard 287/2015 (INRH-Cuba, 2015).

The same Standard establishes net irrigation requirements for rice ranging from 1128 to 1186 mm by cycle, which reach gross values, taking into account a system efficiency of 70%, of 1611 to 1694 mm, well above the actual requirements of the crop. Therefore, for the purposes of the national water balance, a gross irrigation requirement of 1400 mm has been established.

Recent studies by Cisneros *et al.* (2023) for the sites Los Palacios, Corojal, and La Sierpe, using a 13-year historical rainfall and ETc series from 2008 to 2020 and rainfall occurrence probabilities within the crop cycle (130 days, December-May), produced the values shown in Table 7.

Comparing the ETc values shown in Table 7 with those in Figure 6, it can be seen that the ETc for the period studied in the three models increased on average by 32, 27, and 33% for Los Palacios, Corojal, and La Sierpe, respectively, while rainfall decreased by 4,4% and 15,2% in Los Palacios and Corojal and increased by 36,3% for La Sierpe.

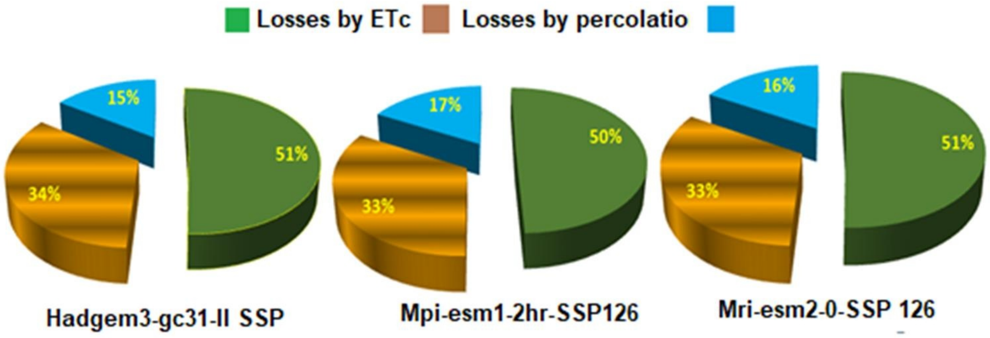

Figure 7. Components of the rice water balance for each model.

Table 6. Net and gross norm values (mm) for a 130-day rice crop cycle at different sites and climate models

Sites	Climatic Models					
	Hadgem3-gc31-ll-SSP126		Mpi-esm1-2-hr-SSP126		Mpi-esm2-0-ssp-126	
	Irrigation needs (mm/crop cycle)		Irrigation needs (mm/crop cycle)		Irrigation needs (mm/crop cycle)	
	Net	Gross	Net	Gross	Net	Gross
Los Palacios	1026,8	1466,9	971,8	1388,3	1025,8	1465,4
Corojal	891,4	1273,4	982,4	1403,4	655,8	936,9
La Sierpe	840,9	1201,3	736,8	1052,6	951,1	1358,7
Vertientes	1061,2	1516,0	1049,7	1499,6	952,3	1360,4
Yara	962,0	1374,3	843,1	1204,4	849,1	1213,0
Jucarito	835,1	1193,0	747,4	1067,7	938,1	1279,1
Average		1337,5		1269,3		1279,1

Table 7. Rice water requirements for each studied site, based on the probabilities of rainfall occurrence for the planting season (December-May) 130 days Taken from Cisneros *et al.* (2023).

Sitio	Precipitation Probability (%)	Rainfall (mm)	ETc (mm)	Total Net Irrigation Requirement (mm)	Total Percolation Losses (mm)
Los Palacios Pinar del Rio	**75**	256,3	493,4	1023,88	580,4
EL Corojal Artemisa	**75**	287,0	488,0	891,80	415,5
La Sierpe Santi Espíritus	**75**	150,9	540,1	1027,78	411,8

The above values for these three sites suggest that, under the studied climate scenarios, an increase in crop ETc of approximately 30% can be expected, related to the expected increases in temperatures.

However, this increase in ETc does not always lead to an increase in crop irrigation demand, which, as shown in Figure 8a, is closely related to rainfall behavior (Figure b) in each model.

As shown in Figure 8a, in model 1 (Hadgem3-gc31-II-SSP1.26), irrigation demand decreases for the Corojal and La Sierpe sites, although rainfall is only higher at the La Sierpe site. In model 2 (Mpi-esm1-2hr-SSP126), for the Los Palacios site, there is a decrease in irrigation demand despite a slight decrease in rainfall, while for a greater difference in rainfall, irrigation demand increases at the Corojal site and at La Sierpe, in correspondence with the increase in rainfall, irrigation demand also decreases. Model 3 (Mri-esm2-0-1.26) shows an increase in the amount of rainfall for all sites and, correspondingly, the amount of water demanded for irrigation also decreases. These variations in irrigation demand are influenced not only by the total rainfall during the crop's growth period, but also by its distribution within this cycle, as well as by soil type.

Acharjee *et al.* (2017) in Bangladesh reported that ETo increased in the future, primarily due to rising temperatures, while potential rice water requirements (ETc) decreased by 6,5% and 10,9% for the RCP 4.5 and 8.5 scenarios, respectively, in 2050, and by 8,3% and 17,6% for these respective scenarios in 2080, compared to the 1980-2013 baseline.

CONCLUSIONS

- Independently of the climatic model use for the future rainfall´s evaluation, there is a diminution in the total annual rainfall´s values from west to the east, with average for the three models of 1644, 1467,5 and 1239,1 mm year^{-1} for the occidental, central and oriental zone, respectively.
- From the global climatic models study under SSP1-2.6 scenario, rice water demand was higher in the Hadgem3-gc31 model with an average gross water requirement for the 6 study sites of 1337,5 mm in a 130 days' rice growth cycle, it was 5,8 and 4,3% superior to the models Mpi-esm1-2hr-SSP126 y Mri-esm2-0-126, respectively.
- The expected effect of the increase in temperatures predicted in climate change studies for Cuba will undoubtedly lead to an increase in potential crop water consumption (ETc); however, the uncertain behavior of rainfall between sites and models for the SSP1-2.6 scenario leads to variability in crop irrigation demand, which is strongly influenced by the amount of rainfall within the cycle and by its distribution.
- Another possible source of variation in future crop irrigation demand, not studied in this result but reported by different authors, mainly in Asia, is the potential decrease in the crop cycle due to increased temperatures, which, in addition to decreasing water demand, could also lead to a decrease in crop yield, which should be the subject of future studies in Cuba

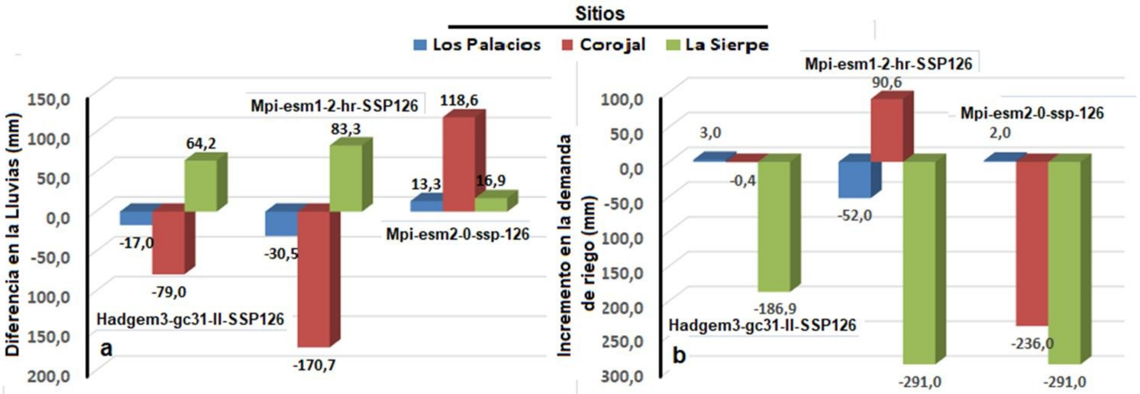

Figure 8. Differences in the amount of rainfall (a) in relation to the baseline (2008-2020) and variation in irrigation demand (b) for three sites according to the three climate models studied.

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