Variations of the agroecological potential of *Moringa oleifera* Lam., in the presence of climate change scenarios in Veracruz, Mexico

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ABSTRACT

Objective: This research aimed to identify variations in areas with agroecological potential for *Moringa oleifera* Lam. (Moringa) cultivation, derived from the effects of climate change to the near horizon of 2039 in the state of Veracruz, Mexico.

Design/methodology/approach: The future scenario considered the current agroecological potential in the State and the general circulation model (GCM) HADGEM2-ES for the RCP8.5 scenario projected to the near future, 2039, with five categories: Very High, High, Medium, Low, and Very Low potential.

Results: An area with a Very High category of 1,057,415 hectares (ha) was identified, which corresponds to an expansion of 4.9% with respect to the current size. It was determined that climate change favors the cultivation of Moringa in three areas of the state. The most significant variation with an increase in the Very High category (115.58%) was identified in southern Veracruz, followed by the central area (110.17%). The greatest decrease (−4.53%) occurred in the north of the state.

Limitations on study/implications: Only the regions with Very High potential were identified, without considering those with High, Medium, Low, and Very Low agroecological potential.

Findings/conclusions: The projections under climate change conditions to the horizon of 2039 highlight the expansion of regions with Very High potential for cultivating the species in 19% of the Veracruz territory.

Keywords: Resilient crops, general circulation models, very high potential.

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INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change (CC) as a variation in climate caused, directly or indirectly, by human activity that modifies the composition of the global atmosphere (Naciones Unidas, 1992).

Image by rsk585823 at Pixabay

Therefore, the current agricultural practices should adapt to the environmental and CC dynamics, with resilient species as potential resources for food production and financial income in tropical regions. Within this context, *Moringa oleifera* Lam. (Moringa) stands out due to its adaptability to rough conditions and fluctuations in temperature and rainfall (Holguín *et al.*, 2018). Nevertheless, assessments of the future behavior of any crop require studies for the construction of CC scenarios, where different contexts of greenhouse gas (GHG) emissions are used to evaluate global concentrations and radiative forcing; and, thus, to obtain models of the temperature increments in different time horizons (Manzanilla *et al.*, 2018).

The resource available to study climate is the set of General Circulation Models (GCM), which are the basis for constructing scenarios and future projections of CC. In regional studies, the information from the GCM is considered and complemented with regional and local climate factors (Conde and Gay, 2008).

Within this framework, the state of Veracruz presently stands out due to its high potential for Moringa cultivation (Carrión-Delgado *et al.*, 2022). However, it is necessary to know the impact that CC would have on the current potential of the crop according to climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC).

Therefore, this study aimed to identify the changes in the areas with agroecological potential for the cultivation of *Moringa oleifera*, derived from the effects of climate change to the near horizon of 2039 in the state of Veracruz, Mexico.

MATERIALS AND METHODS

The data were collected from two sources: 1) The studies carried out by Carrión-Delgado *et al.* (2021 and 2022) (Table 1), which show georeferentiation and soil samples collected which served as a basis for the elaboration of climate layers and current environmental factors. 2) The Climate Atlas of Mexico (*Atlas Climático de México*, ACDM).

The scenarios elaborated by the IPCC (2000) to determine the future behavior of climate are A1, B1, A2, and B2, where A1 and B1 assume development at the global level while scenarios A2 and B2 are at the local level. Thus, the cartography to evaluate the distribution under CC change conditions was supported by scenario A2. Likewise, the local scenario A2 (Very High), the most extreme, was used under the assumption of a lack of actions for

Table 1. Agroclimatic characteristics from georeferenced data, interviews with producers, and soil sample collected in municipalities where Moringa is cultivated in Veracruz, Mexico.

Variable	Emiliano Zapata	Soledad de Doblado	Cosamaloapan
Temperature intervals (C°)	19-30	19-32	22-32
Altitude (masl)	827	103	10
Accumulated annual precipitation (mm)	894	887	1307
Types of soil	Phaeozem	Phaeozem	Vertisol
Soil pH	6.15-6.83	7.63-7.99	6.6-6.9
Soil texture	Clay-loam	Clay-loam	Clay

Carrión-Delgado *et al.*, 2022.

adaptation and mitigation in the presence of the effects of CC. The definition of climate layers and future environmental factors was carried out with precipitation and temperature data from the ACDM (Centro de Ciencias de la Atmósfera, 2018), contained in the Daily Climatological Base (DCB) from 1902 to 2011 with a spatial resolution of 1 km×1 km (Fernández *et al.*, 2014). The CC scenarios for the state of Veracruz were structured using a GCM based on the most favorable results obtained from the performance and spatial resolution for the region of Mexico (Conde & Gay, 2008), and the HADGEM2-ES model (Met Office Hadley) was chosen, with a spatial resolution of 1 km×1 km and the scenario with the highest level of GHG emissions (RCP8.5) to the near horizon of 2039. The climate layers of average monthly temperature (°C) and accumulated precipitation (mm) were downloaded from the GCM HADGEM2-ES, with a high spatial resolution of 1 km×1 km, sampled at a spatial scale of 30 m×pixel and with its corresponding topographic effect (UNIATMOS, 2021).

As suggested by Carrión-Delgado *et al.* (2022), the source maps were obtained with the ArcGis® Version: 10.7.1 tools; the values with the most significant adjustments in the raster images were interpolated, the values were classified for the variables, and the shape files were generated for the minimum and maximum annual temperature, the minimum and maximum annual rainfall in the adequate interval for the cultivation of Moringa in the state of Veracruz. The criteria established by Carrión-Delgado *et al.* (2022) were considered again for the future scenarios, with five categories: Very High, High, Medium, Low, and Very Low. The classification of each category was based on the evaluation of five variables: soil type, annual accumulated rainfall, agriculture and livestock land use, altitude, and minimum and maximum temperature. The areas categorized as Very High were those that passed the requirement of the five variables; those with High passed four; and those in the category Very Low were the ones that passed only one variable (Table 2).

The Very High category was the most important in this study. Because of this, the potential of Moringa for the scenario described was obtained as a result of the difference between the reference climate period and the future climate scenario (Fernández *et al.*, 2015); that is, from the subtraction of the layers of the current territorial potential minus the future one from MGC HADGEM2-ES. This analysis reflected the impact of CC on the modeled system, and the cartographic representation allowed identifying the variations

Table 2. Categories for the identification of areas with agroecological potential for the cultivation of *Moringa oleifera* Lam.

Number of variables	Category				
	Very low	Low	Medium	High	Very high
1	X	X	X	X	X
2	X	X	X	X	X
3		X	X	X	X
4			X	X	X
5				X	X
Total	1	2	3	4	5

Carrión-Delgado *et al.*, 2022.

of the areas with increment or decrement of agroecological potential to the time horizon 2039 for scenarios RCP8.5 (Fernández *et al.*, 2015; Trejo, 2016).

RESULTS AND DISCUSSION

Figure 1 shows the current distribution of the potential cultivation of Moringa in the state of Veracruz.

Table 3 shows the assessment of the current agroecological potential and the future projection. Table 3 (a) exposes the values of the current agroecological potential for the cultivation of Moringa in the territory of Veracruz (Carrión-Delgado *et al.*, 2022), while 3(b) shows the agroecological potential projected to 2039 under the non-conservationist scenario of RCP8.5 (A2).

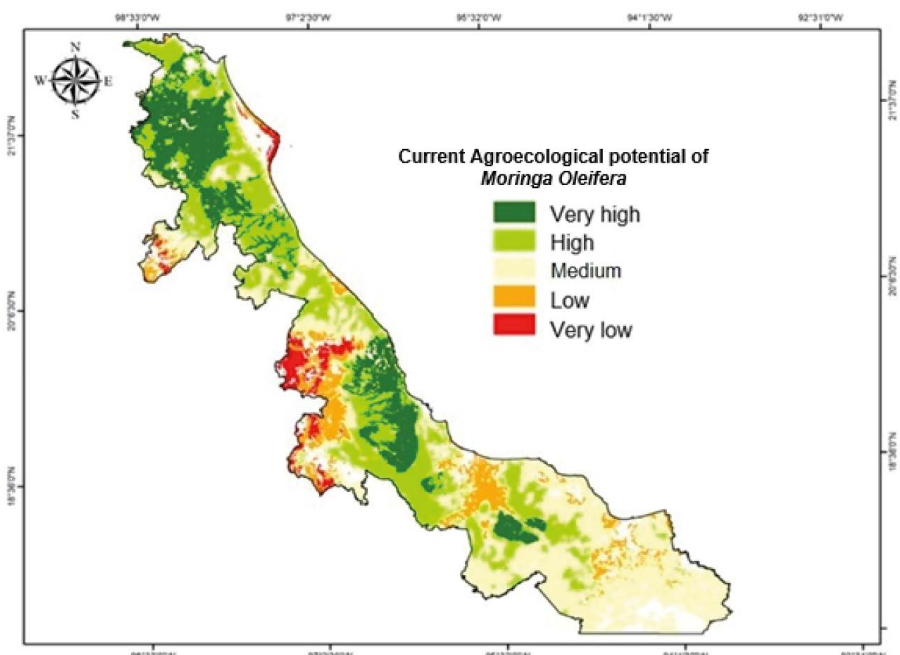

Figure 1. Current agroecological potential of Moringa in the state of Veracruz, Mexico (Carrión-Delgado *et al.*, 2022).

Table 3. Surface with agroecological potential for the cultivation of Moringa in the state of Veracruz: a) current and b) projected under scenario RCP8.5 to 2039.

Category	Current surface (ha)[†]	%	Projected surface (ha)	%
Very low	1,008,119	18.4	1,057,415	19.3
Low	1,602,381	29.3	1,600,814	29.3
Medium	2,049,887	37.5	2,000,107	36.6
High	639,212	11.7	648,081	11.8
Very high	170,551	3.1	165,157	3.0
TOTAL	5,470,148	100	5,471,575	100

[†]Carrión-Delgado *et al.* (2022).

The results obtained with the HADGEM2-ES Model under CC scenarios evidenced a significant variation: a territorial incrment in the agroecological potential for Moringa cultivation. The variations in agroclimatic conditions impacted the spatial dimensions (number of ha). Similarly, they will affect both the growth of the crop and biomass production, as mentioned by Meza-Carranco *et al.* (2016).

On the other hand, when contrasting the distribution of the current agroecological potential with the scenario RCP8.5 projected to the horizon of 2039, the findings show that the most significant increment was found in the category Very High (2.4%) and, to a lower proportion, in the Low (0.7%). The Very Low (−1.6%) was the most significant decrement, followed by the Medium (−1.2%).

Figure 2 indicates the spatial distribution of Moringa in its different categories, with MGC HADGEM2-ES under scenario RCP8.5 (A2), projected to horizon 2039. Three areas of larger spatial dimension were obtained regarding the Very High category. The first is located to the south (Los Tuxtlas, Olmeca, and Papaloapan), between the state of Oaxaca and the Gulf of Mexico (Table 4), with an extension of 92,782 ha and 115.58% of expansion compared to the current potential. The second is located in the center (Sotavento, Capital, Nautla, and Altas Montañas), in the central part of the state, neighboring the Gulf of Mexico and with a projected area of 347,026 ha, presenting 110.17% of expansion compared to the current state. Finally, the third is located to the north (Totonaca, Huasteca Alta, Huasteca baja) of the state, neighboring the states of San Luis Potosí, Hidalgo, and Puebla, with a projected extension of 617,492 ha that presented a decrease of −4.53% compared to the current status. These results agree with Rueda-Magaña and Gay-García

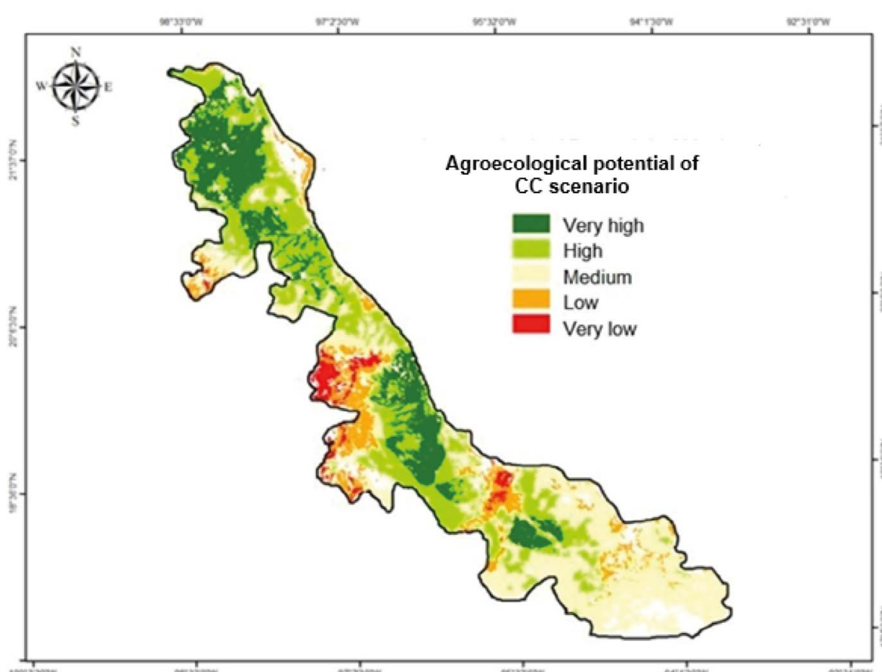

Figure 2. Agroecological potential of Moringa with MGC HADGESM2-ES, to the future horizon 2039 for the RCP8.5 scenario, in the state of Veracruz, Mexico.
Source: Prepared by de la Rosa-Portilla (2021).

Table 4. Estimated potential surface for the plantation of *Moringa oleífera* Lam. projected under scenario RCP8.5 to 2039 in the state of Veracruz.

Region	Municipalities	Surface (ha)	†%
Totonaca	Cazones de Herrera, Coatzintla+, Gutiérrez Zamora+, Papantla, Poza Rica de Hidalgo, Tecolutla+, Tihuatlán.	39,870	3.77
Huasteca Alta	Chalma, El Higo, Ozuluama de Mascareñas, Pánuco, Platón Sánchez, Pueblo Viejo, Tamalín+, Tamiahua+, Tampico Alto, Tantima, Tantoyuca, Tempoal.	471,486	44.59
Papaloapan	Ignacio de la Llave+, Isla, José Azueta, Juan Rodríguez Clara, Tres Valles+, Tierra Blanca.	66,893	6.33
Huasteca Baja	Álamo Temapache, Chicontepec, Cerro Azul, Chontla, Citlaltépetl, Ixcatepec, Ixhuatlán de Madero, Tepetzintla, Tuxpan.	106,136	10.04
Sotavento	Cotaxtla+, Jamapa+, La Antigua, Manlio Fabio Altamirano, Medellín de Bravo, Paso de Ovejas, Puente Nacional+, Soledad de Doblado, Tlalixcoyan, Úrsulo Galván, Veracruz	222,544	21.05
Nautla	Juchique de Ferrer, Martínez de la Torre+.	499	0.05
Capital	Actopan, Alto Lucero de Gutiérrez Barrios, Apazapan, Coatepec, Emiliano Zapata, Jalcomulco, Naolinco, Tepetlán+, Xalapa.	88,806	8.40
Olmeca	Acayucan, San Juan Evangelista+.	4,598	0.44
Las Altas Montañas	Camarón de Tejeda, Carrillo Puerto, Comapa, Cuitláhuac, Paso del Macho, Tenampa+, Tlaltetela, Zentla.	35,177	3.33
Los Tuxtlas	Hueyapan de Ocampo, San Andrés Tuxtla+, Santiago Tuxtla+.	21,407	2.02
	Total	1,057,415	100

†=Statewide percentage of the Very High category, + municipalities added to 2039.

(2002), who obtained more significant temperature changes in southeastern Mexico, with an increment no higher than 2.8 °C and a slight decrease in precipitation no higher than 10%. These climatologic variables will impact the agroecological potential, development, and production levels (Meza-Carranco *et al.*, 2016), favoring resilient crops like Moringa (Egea *et al.*, 2015).

Under the RCP8.5 scenario, the state of Veracruz presents a trend towards increasing temperature and decreasing rainfall in the south. These results agree with the GCM models obtained by Magaña *et al.* (1997), which showed an increase in temperature for the Gulf of Mexico zone at the end of the 21st century. Similarly, this agrees with Trejo (2016) regarding the expansion of the dry forest foreseen on the coast of the Gulf of Mexico due to the increments in temperatures and the decrements in rainfall in the south of the state.

CONCLUSIONS

The variations of areas with agroecological potential for the cultivation of *Moringa oleifera* under conditions of climate change to the near horizon of 2039 and scenario A2 (RCP8.5) tend to present higher agroecological potential towards the category of Very High in the state of Veracruz.

As a resilient species, Moringa can adapt and recover after disturbances under severe drought conditions, which could increase in broader regions of Veracruz. Therefore, its cultivation represents a great opportunity area as a source of income under the effects of climate change in the state of Veracruz.

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