

EcoCrop model approach for agroclimatic suitability of rice (*Oryza sativa* L.) cultivation

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ABSTRACT

Objective: To evaluate the suitability of commercial rice (*Oryza sativa* L.) cultivation in the state of Tabasco, Mexico; using the EcoCrop model to improve policy decisions on the crop.

Design/methodology/approach: A crop suitability analysis was carried out for the state of Tabasco using the EcoCrop model. The data for the variables of temperature, solar radiation, humidity and precipitation were taken from the WorldClim database (2023) for the period 1960-2010, with a spatial resolution of 1 km². The soil information was downloaded from INEGI (2023). The modeling was carried out in R studio with the terra, geodata and Recocrop libraries.

Results: The capacity of the area at a regional level to supply the national demand for rice was determined. The model predicted a high climatic suitability of rice in areas where it grows optimally.

Limitations on study/implications: It is suggested that simulation be explored for future situations of the areas currently identified in Tabasco for establishing rice cultivation.

Findings/conclusions: The considerable potential of this approach to assess global and regional food security problems and general climatic constraints is highlighted.

Keywords: Crop suitability, agroclimatic zones, ecocrop, *Oryza sativa*.

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INTRODUCTION

Rice is the world's most important staple food, feeding more people than any other crop (Fulkagawa, 2019; USDA, 2022). The International Rice Research Institute (IRRI) in the Philippines has reported that rice feeds 4 billion people, or 56% of the world's population (IRRI, 2024), making it the most important crop on the planet (Muthayya *et al.*, 2014; FAOSTAT, 2023). In Mexico, with the current agricultural policies, it has begun

to promote various basic grains such as rice cultivation to achieve food sovereignty. Under this context, it is important to define the potential areas where rice cultivation can grow and provide that information to decision makers and politicians (Tello and Corral, 2023; AGRICULTURE, 2024).

The state of Tabasco during the period 1980-1985, managed to have up to 15 thousand hectares of rice established (Jiménez-Chong *et al.*, 2017), however, due to a series of problems, mainly low profitability forced this crop to stop being planted and depend on imports in about 95% from USA (Hernández-Aragón *et al.*, 2016; Pureco *et al.*, 2017; SE, 2024). The soil and/or land of different geographical areas do not have the same suitability for crops; therefore, the development of spatial modeling to evaluate land suitability by integrating different techniques and diverse agroclimatic requirements, allows the development of strategic actions that protect water resources and land, and thus implement sustainable agricultural systems (García *et al.*, 2021). Therefore, the agricultural-environmental suitability analysis contributes to adequate land use planning and distribution, as well as to sustainable agriculture (Córdova-Sánchez *et al.*, 2023; Olvera-Rincón *et al.*, 2024).

The EcoCrop model uses the FAO EcoCrop database, which compiles the environmental requirements of an extensive list of plant species and can be used to identify potential crops in a specific environment (Dhanya *et al.*, 2023). This model allows zoning and spatial analysis of the agroecological suitability of particular crops. The EcoCrop model is used to predict the adaptation of a particular crop considering temperature and precipitation thresholds over a geographic region (Yarlequé *et al.*, 2024). The model calculates the suitability index for temperature and precipitation independently, and then integrates both to obtain a final suitability rating from very suitable to unsuitable zones. In this work, the climatic and edaphic layers were integrated to further delimit the analyses of the Ecocrop model as an alternative to agroecological zoning. The main objective of the research was to evaluate the suitability of commercial rice cultivation in the state of Tabasco, Mexico, using the EcoCrop model to improve policy decisions on rice cultivation.

MATERIALS AND METHOD

Study area. The state of Tabasco is located in the southeast of Mexico, south of the Gulf of Mexico, between the extreme latitudes 18° 39' 07" N to the north and 17° 20' 24" N to the south, and between longitudes 90° 59' 16" W to the east and 94° 07' 40" W to the west. It borders the Gulf of Mexico to the north, Campeche to the northeast, Guatemala to the east and southeast, Chiapas to the south, and Veracruz to the west (Salgado-Velázquez *et al.*, 2020). The continental surface of the state covers 24 694.60 km², which represents 1.3% of the national territory, placing it in 24th place with respect to the states with the greatest extension, however, it hosts on average 23% of the national biodiversity of vertebrates and 53% of the nation's freshwater wetlands (CONABIO, 2024). Tabasco's location in the tropical zone, its low elevation with respect to sea level and its proximity to the Gulf of Mexico along 191 kilometers (km) of coastline (Figure 1), determine the development of warm climates with maritime influence. The humid tropical climate is a very unique characteristic of the region. Temperatures range from 15 °C in the coldest months (January and December) to 44 °C in the hottest months; the average temperature



Figure 1. Geographic location of the State of Tabasco. Own elaboration with data from INEGI (2024).

is 26 °C, which due to the low altitude in relation to sea level remains constant. Annual precipitation ranges from 1800 to 3500 mm, with a dry season from April to May and a rainy season from August to October (CONAGUA, 2024).

Database. The EcoCrop model uses the FAO ecocrop database and requires mainly climatic data of minimum and maximum temperature (°C), precipitation (mm/month), wind speed (m/s) and solar radiation (W/m^2) for the region. For this purpose, the WorldClim2 database (Fick and Hijmans, 2017), in a 3-minute grid (1 km spatial resolution), was used in the R studio GIS environment for climate data. The edaphic layer was downloaded from INEGI for Tabasco with a resolution of 1 km, which was integrated in the model. FAO threshold values for growing season, maximum and minimum temperatures, and precipitation for rice cultivation (Hunter and Crespo, 2019) were considered in the EcoCrop model (Table 1).

Data extraction in R. Gridded (2-5 m) climate data from WorldClim were downloaded, extracted into a dedicated folder and also imported into the EcoCrop module. WorldClim is a global gridded dataset with monthly climatological means of maximum, minimum and mean temperatures, and total precipitation, developed by thin-plate spline interpolation from long-term (1950-2010) weather station records (Ramírez *et al.*, 2014). The R studio libraries geodata, ecocrop, terra were used. The geodata library allows the manipulation of climate variable files in raster format. The ecocrop library allows accessing the database of optimal growing conditions of crops and processing the modeling. The terra library was used to manipulate and edit the layers resulting from the modeling.

Table 1. EcoCrop parameters used for analysis of crop suitability for rice.

Parameters	Rice	Units
Gmin	110	Days of growth
Gmax	180	
Tkmp	40	°C×10
Tmin	110	
Topmin	210	
Topmax	280	
Tmax	340	
Rmin	950	mm
Ropmin	1500	
Ropmax	2000	
Rmax	3900	

Modeling of suitable zones with Ecocrop in R. Once the climatic and soil layers were processed, and the mask was applied to the state of Tabasco with the Recocrop function of the Ecocrop library, the raster files were loaded into the model to generate the suitable zones for rice cultivation. Finally, the generated map was visualized and saved as an image using the ggplot2 library. Likewise, the areas of each zone were quantified. Agroclimatological suitability zones were classified as not suitable, moderately suitable, suitable and very suitable (Chhogyel *et al.*, 2018). Therefore, a quantile class partitioning was performed by means of the break class quantile function to generate the classes based on the model score (Møller *et al.*, 2021).

RESULTS AND DISCUSSION

Climatic variables for Tabasco. Figure 2 shows the climatic variables used in the Ecocrop modeling, in monthly average values for the period 1950-2010.

It is observed that for the period 1950-2010 the average behavior of precipitation, temperatures and solar radiation show trends according to the geography of the state of Tabasco. The southern part of Tabasco has the highest precipitation (3500 mm), the lowest temperatures (<20 °C) and wind speed (<2 m/s). The highest wind speed occurs in the northern part close to the coast. The highest solar radiation values are present in the eastern part of the state, especially in the Los Ríos region (Navarro *et al.*, 2022).

EcoCrop model for Tabasco. Figure 3 shows the regionalization of suitable areas for rice cultivation according to the results of the EcoCrop model (FAO, 2023). Four classes are highlighted: not suitable, moderately suitable, suitable and very suitable (Heinz *et al.*, 2024).

The areas with the best conditions for the establishment of rice cultivation, according to their level of aptitude, are concentrated in the Chontalpa region, mainly in the municipalities of Cárdenas (66,235 ha), Huimanguillo (25,245 ha), Cunduacán (51,658 ha) and Comalcalco (38,875 ha); in the Los Ríos region, with Balancán (31, 611 ha) and Jonuta (34, 125 ha); and in Centro (10, 147 ha) (Figure 3), representing 10.3% (258,696 ha)

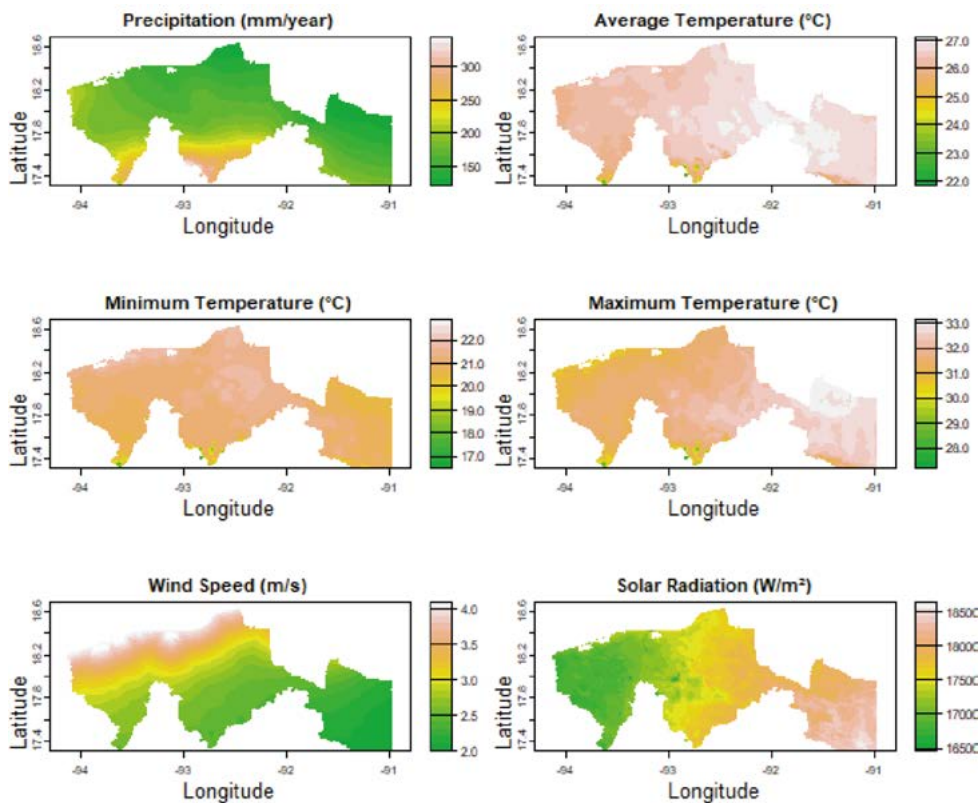


Figure 2. Monthly averages of climate variables for Tabasco for the period 1950-2010 from the WorldClim database.

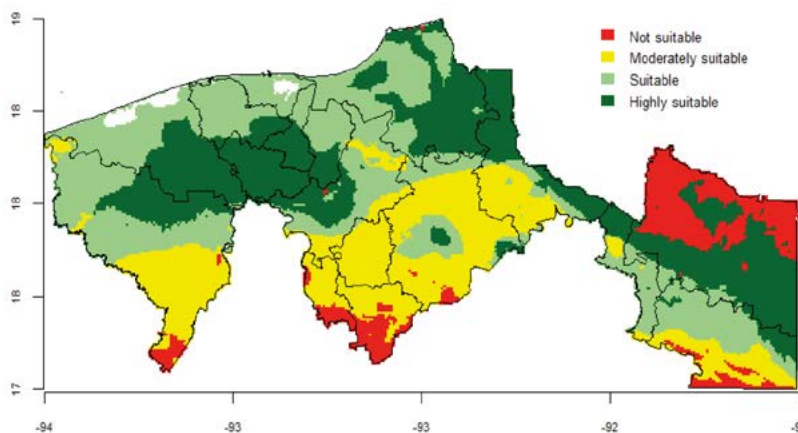


Figure 3. Suitable areas for rice cultivation in Tabasco using the EcoCrop model.

of the total area of the state, compared to the area currently planted, which is less than 0.2% (350 ha). The results obtained were similar to those reported by López *et al.* (2021), who identified similar municipalities with agroecological zoning for rice in Tabasco.

As shown in Figure 3, the state of Tabasco has different levels of suitability for rice cultivation. The 18.7% of the state does not present suitable conditions for cultivation, mainly in the northeastern part, since the minimum requirements for its development

are not met. In this case, it has low rainfall, high maximum temperatures and high solar radiation (Xu *et al.*, 2021). In 35% of the area has a conditioned suitability as moderately suitable due to the low annual rainfall, as well as the variation of temperatures and possible heat waves, which, although the crop could adapt in the early stages of development, its growth would be limited and the yield would be considerably reduced (Gao *et al.*, 2024). This is important given that the increase in temperatures leads to the more frequent appearance of insect pests that are transmitters of diseases, such as the rice leafhopper mite (*Steneotarsonemus spinki*), which carries the bacterium (*Burkholderia glumae*) that causes the disease and is considered the most destructive of rice (Salazar-Santiago *et al.*, 2022). For this reason, INIFAP is currently concentrating its efforts on genetic improvement with resistance to biotic and abiotic factors (Barrios-Gómez *et al.*, 2023; Hernández-Aragón *et al.*, 2023).

It is important to point out that the rice production systems in the areas identified as suitable are in accordance with the resources available in the areas and for the purposes required, so that the advantages offered by this crop can be exploited. Likewise, improvements must be made in agronomic management given that yields are low despite the fact that some rice plots are established in the very suitable areas (Jiménez-Chong *et al.*, 2017).

The model developed in this work represents an advance towards the automation of meteorological processes and the application of geographic information systems (GIS) in the R environment, facilitating the management of large amounts of data and their spatial analysis, as well as optimizing the time required to perform similar studies for different crops.

Import reduction forecast

With INEGI (2024) data for total population and FIRA (2024) data for *per capita* consumption, the total national rice requirement would be:

$$Cnal = Pobot \times cpc$$

Where: $Cnal$ =national consumption; $Pobot$ =total population and cpc =*per capita* consumption: $(130,232,645 \times 9.0) = 1,172.1$ thousand tons. The latter leads us to the fact that, when determining the national rice consumption in 2024 at 1,134.1 thousand tons, in the state of Tabasco, 258.7 thousand hectares susceptible to be planted were identified with medium and high productive potential. The main municipality with high productive potential was Cárdenas with 25% of the area, representing 66.23 thousand hectares. Under this scenario, 776.1 thousand tons of rice could be contributed (with an average yield of 3 t ha^{-1}), which would have represented 67% in the reduction of rice imports and would benefit the rice trade balance (López *et al.*, 2021).

CONCLUSIONS

The proposed land suitability assessment model considered agroclimatic variables determining the suitability of a crop in a specific area. The considerable potential of

this approach for assessing global and regional food security issues and general climatic constraints is highlighted. Site suitability analysis will be useful to optimize expenditures and increase the level of income in a region, and the EcoCrop model can be applied on a regional or global scale to assess the climatic suitability of a specific crop. Tabasco has the potential to produce rice crops and significantly reduce imports to achieve national food sovereignty.

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