FOLIA 392

Annales Universitatis Paedagogicae Cracoviensis

Studia Geographica 20 (2023)

ISSN 2084–5456

DOI 10.24917/20845456.20.10

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Areas with agricultural suitability for corn cultivation State of Mexiconcy

Abstract

Ensuring access to food as a priority of the sustainable development objectives requires immediate attention to crops; motivated by this, the present study shows the results of the identification of agricultural suitability zones, specifically in the cultivation of corn in the State of Mexico, using the multi-criteria evaluation (MCE) that allows to model the territorial reality and execute the spatial process with the most important variables in the growth those crops. The identification of the processes and their regional problems gave guidelines for the weighting of each of them and define their criteria for the optimal growth of the plant. The study was carried out with the assignment of weights to the variables of altitude, temperature, precipitation, slopes and edaphology according to research on their degree of influence and dependence among them; the result is the areas with the greatest agricultural suitability for the cultivation of corn in the State of Mexico (with restriction of protected natural areas and urban areas), with a timely verification of the already existing crops and improve decision making by expanding the territory with the greatest probability of optimization and crops' yield. This methodology proposal is intended to be replicable to other crops and/or areas in which the processes and patterns that modify the characteristics of areas from a crop to high yield are recognized.

Keywords: *Corn, fitness, MCE, model*

Sugerowana cytacja / suggested citation: Mortera Martínez Nancy, Zepeda Mondragón Francisco, Canchola Pantoja Yered Gybram, Cortez Núñez Jocelyn Alejandra (2023). Areas with agricultural suitability for corn cultivation State of Mexico . Annales Universitatis Paedagogicae Cracoviensis Studia Geographica, 20, 127–143, doi: 10.24917/20845456.20.10

Introduction

Corn has a long history in Mexico and Latin America as it is an important crop in agriculture, which makes the study of agricultural suitability a reference for planting and thus guaranteeing good production. Mexico, as a country, is one of the places with greatest genetic diversity, since the plant has evolved naturally for thousands of years; corn in Mexico can adjust to various climatic and soil conditions and in recent years it has undergone important changes.

The agroecological regionalization of corn involves dividing a geographic area into smaller regions based on its agroecological factors such as climate, soil, topography, and other natural elements that influence the cultivation of corn. This allows better understanding of local conditions and the adoption of agricultural practices as well as unique characteristics of each region rather than applying uniform approaches across a large area.

To make decisions in territorial planning and agricultural management, it is essential to evaluate the suitability of the land; multicriteria methods as part of a spatial modeling process are approaches that allow to consider different variables using spatial data and attributes in geographic information systems as evaluation tools.

The work applies the lineal summation method with Boolean layers of temperature, precipitation, altitude, land use and edaphology with the ideal criteria for the growth of corn, restricting protected natural areas, urban areas, and land use, resulting in optimal areas for sowing corn grain. The objective was to determine, through multi-criteria evaluation, the areas of agricultural suitability for corn cultivation in the State of Mexico to improve sustainable and efficient agricultural management.

Materials and methods

Study area

The State of Mexico is located on the Mexican plateau, in the central portion of the Mexican Republic, it is between the meridians 98° 36' and 100° 37' west longitude of the Greenwich meridian and the parallels 18° 22' and 20 ° 17' north latitude. The territorial extension of the entity is 22,499.95 km2, which represents 1.1% of the national territory, which is why it occupies 25th place in terms of surface area, compared to the other federal

entities in the country. The State of Mexico borders to the north with the states of Querétaro and Hidalgo; to the east with the states of Puebla and Tlaxcala; to the south with the states of Morelos and Guerrero; and to the west with the state of Michoacán de Ocampo and a small portion of Guerrero. It also limits with Mexico City, surrounding it in its northern, eastern and western portions (Figure 1) (Dirección General de Ordenamiento e Impacto Ambiental, 2022).

The relief of the entity is characterized by presenting two large regions: one with 76% of mountains and hills of the state territory; and another, where plains, valleys and plateaus are found in 24% of the territory. This spatial heterogeneity provides a variety of altitudes, rock types, soils, climates, vegetation, flora, fauna and landscapes characteristic of the state territory. In general, the State of Mexico presents an average slope of 20.23%. with an accumulated annual precipitation of 900 mm in the rainy period and an average temperature in the warmest part of 25°C and temperature of 3°C in the coldest month. Climatic factors impact the feozem, andosol, and cambisol soils, with 50% of the total having agricultural surfaces and 18% of surfaces covered with forests (IEECC, 2021).

Figure 1. Localization study zone

Source: own elaboration 2024.

Multicriteria Evaluation (MCE)

Aptitude is the ability to develop a specific activity (in this case, corn planting) in the same geographical space, which obtains advantages from the geographical conditions and the interrelationships with the elements of the space. Land suitability studies are determined from agroecological regionalization, which refers to a division of the surface into smaller units that have similar characteristics, related to that condition and it results in the potential production with the environmental impact (IEECC, 2021).

The present work considers the multi-criteria approach which provides a comprehensive evaluation of land suitability, considering different factors and allowing decision making with more information for land use planning. The multi-criteria evaluation (MCE) offers a set of procedures and tools to model the territorial reality, which is supported by the structural analysis of systems in order to understand its functioning, that is, its elements its interactions and the result of a “whole” (Manzano Solis, Pineda Jaimes, & Gomez-Alborez, 2019).

In situations where there are several factors to consider and different objectives or perspectives, there must be a balance, this approach is useful for making decisions in locating and planting corn crops in areas with agricultural suitability.

The results are also useful and economical tools where the multiplication of the normalized scores by the assigned weights and the sum of these products can be included in this methodology.

By synthesizing the variables that determine the productivity of the corn crop, the MCE methodology will provide a framework to evaluate and zone the crop.

Spatial Modeling Process with MCE

Evaluating the suitability of the land for growing corn using MCE involves simultaneously considering several criteria to determine suitable areas, so a step-by-step approach is given using this method in spatial modeling.

Identification of processes

The corn cultivation process includes a series of stages, from soil preparation to harvest, in which different requirements take part within a system.

The problems of growing corn can vary depending on the region, climate, agricultural techniques and other factors. However, corn farmers may encounter some common difficulties such as climatic conditions, soil loss, pests and diseases, water management, high input costs, access to technology or even socioeconomic factors, which (IICA, Instituto Interamericano de Cooperación para la Agricultura, 2020) includes as "edaphoclimatic factors" in which corn, as a plant with a high capacity-respond to environmental opportunities, prioritizes water, soil and the plant's own adaptation for its optimal growth. (Table 1)

Table 1. Edaphoclimatic factors of corn

Adaptation	Soil	Water
Vegetative development up to 5 meters. height Altitudes greater than 1,000 meters above sea level Good performance 0 to 900 meters above sea level, Plant height from 2 to 2.65 meters.	Medium texture soil (loams). Fertile Well drained, Deep high water retention capacity. pH between 5.5 and 7.8	NO water stress or drought during the early stages of growth (15 to 30 days).

Own elaboration based on: (IICA, Instituto Interamericano de Cooperación para la Agricultura, 2020) (Fassio, Carriquiry, Tojo, & Romero, 1998)

Identification of variables and criteria

As variables are measurable, controlled or manipulated elements in a study, the identification of variables is a crucial step in any investigation or analysis, so determining the processes in advance generates the system line that interweaves the requirements of corn cultivation.

During this cultivation, the 3 important stages of corn are distributed throughout: Emergency Phase (May), Flowering Phase (July) and Maturity Phase (October), in addition to the fallow land (land preparation) in January and its harvest in November, so it is an annual process. (Jasso Miranda, Soria Ruiz, & Antonio Nemiga, 2022)

By clearly identifying and defining these variables, it contributes to the validity and reliability of the results obtained. The selection of the variables will depend on our research objective: determining areas of agricultural suitability for corn cultivation. Not only are the variables of this research supported by direct observation with corn cultivation in the field, but also with specialized readings. (Aguilar Carpio, Escalante Estrada, & Aguilar, Mariscal, 2015).

Based on the determination that Sotelo, Ruiz, Cruz, Bello, Gonzalez, Hernandez, & Moreno, Sanchez, made in 2016 on the optimal growth of corn, values are determined for this study:

Plant adaptation (DEM, Altitude):

Since climatic conditions vary with altitude and affect various aspects of plant growth, altitude can have a significant impact on corn cultivation, so the following values were considered (Table 2)

Table 2. Plant adaptation criteria (dem, altitude)

Variable	Criterion
ALTITUDE	1800 to 2500 meters above sea level
DEM	Digital Elevation Model

Source: Sotelo,2016

Soil (Edaphology and slopes)

Edaphology studies soil in relation to plants and their environment. Since corn depends greatly on soil characteristics, edaphology plays an important role in the growth and plants' development.

The degree of slope in corn cultivation is a crucial topographic factor that can affect crop yield and a variety of aspects of agricultural management, as, for example, it influences soil drainage, machinery entry or erosion. (Table 3)

Table 3. Soil criteria (peedafology and slopes)

Variable	Criterion
EDAPHOLOGY	Andosol Feozem Vertisol Fluvisol
SLOPE	0 to 10 degrees

Source: Sotelo,2016

Water (Temperature and Precipitation)

Temperature and the amount of precipitation are two important climatic factors that have a direct impact on corn cultivation. Precipitation has an impact on many aspects of the life cycle of plants, including crop performance, such as growth and adaptation to climate change; on the other hand, excess at certain stages can be harmful.

Another important environmental factor that significantly influences the development and yield of the corn crop is air temperature, it influences the development of corn plants throughout the life cycle; since extreme heat and cold can negatively affect corn yield, temperatures must be taken into account both day and night. (Table 4).

Table 4. Water criteria (precipitation and temperature)

Variable	Criterion
PRECIPITATION	500 to 1400mm
AVERAGE TEMPERATURE	15 to 22(°C)

Source: Sotelo,2016.

Model construction

To create research models that represent real-world phenomena, *non-definitiveness* must be considered, as information is obtained and processed, it needs adjustments and improvements to reflect the topic more accurately to be delimited. The first step before modeling is to recognize the spatial components of the problem to be modeled, it usually begins by examining the expected result using a dissection and how the pieces fit to the subject, this allows us to make a basic estimate of future and juxtaposed relationships; in the second step, recognize the visible patterns, and in the third, the patterns that are hidden behind the optimal corn growth process.

Simplified representations of reality that help us understand and analyze complex phenomena are known as models. In the context of models, abstraction refers to the selective simplification of details to focus on key and relevant elements. Below is the conceptual model (Figure 2) which lists the variables involved and the restriction of areas. (PNA: Protected Natural Area and UZ: Urban Zone).

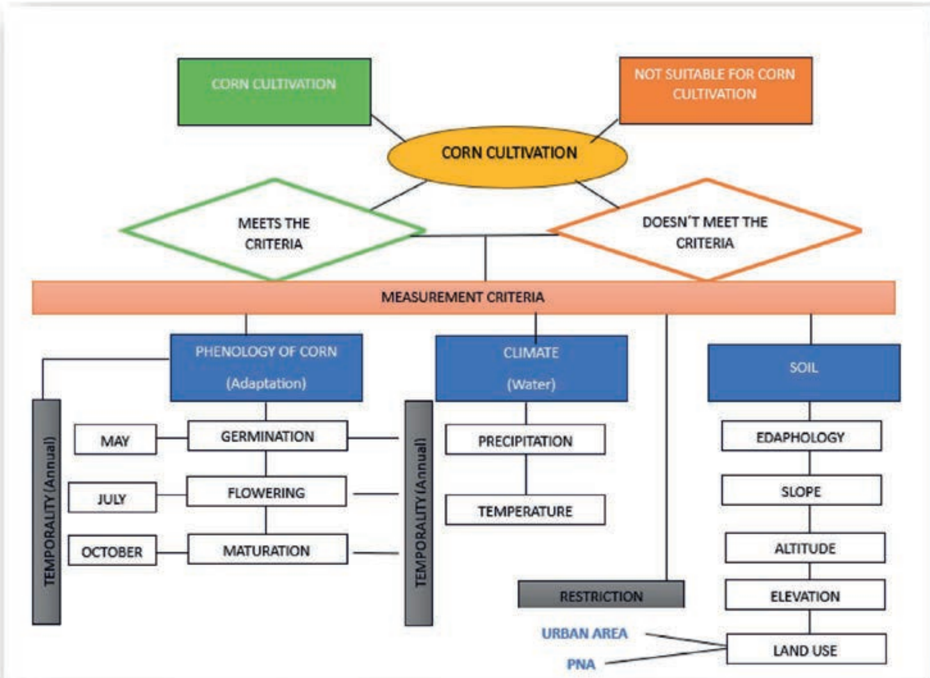

Figure 2. Conceptual model

Source: Own elaboration, 2024.

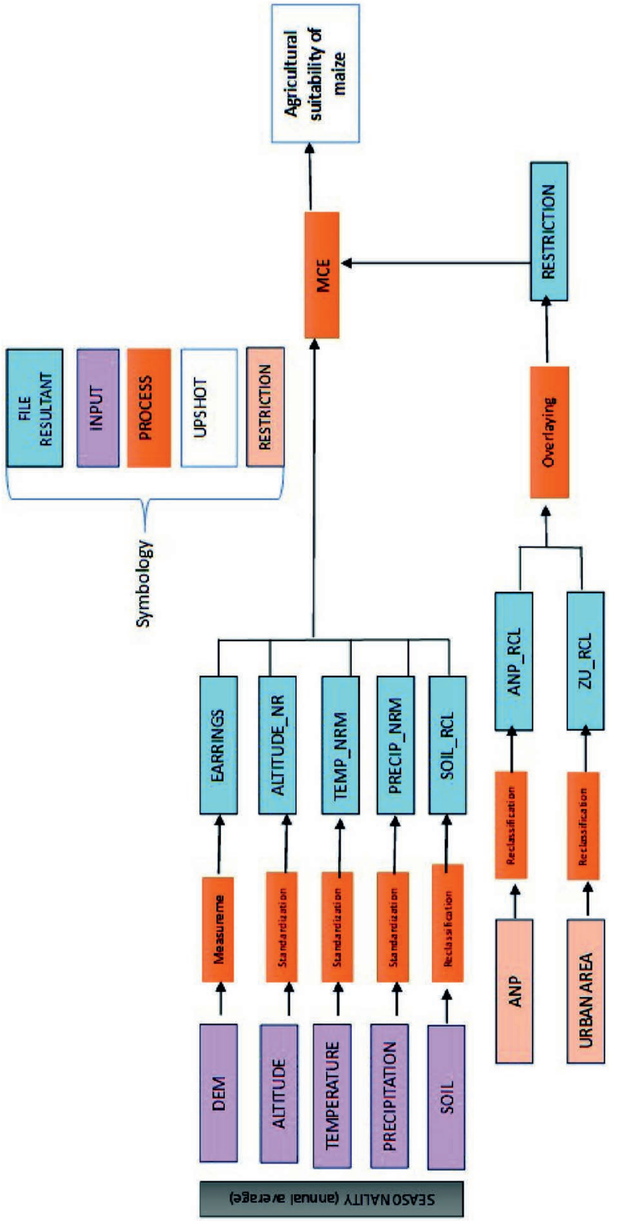

Figure 3. Logical model

Source: Own elaboration, 2024.

The second model presented is the logical model (Figure 3) which is the execution of the steps in the software to obtain the expected result. (TerrSET , *Spatial Decision Modeler*)

Data normalization

Standardization is the process of developing, applying and improving standards used in different scientific, industrial or economic activities to organize and improve them.(Galvez, Riquelme, 2016)

The goal of data normalization is a common process in statistical modeling and data analysis. It is adjusting the values of the variables on a similar scale. This is particularly in this research, the layers to be used are unified in a Boolean way since we are working with characteristics with different magnitudes or units.

This normalization is carried out using the ArcGIS tool, in which the original vector layers are cleaned of data by exporting only the criteria or variables to be used in the modeling. (Figure 4).

Another step for normalizing the information was taken on the raster layer exported from ArcGIS or source format. The TerrSet tool will result in Boolean layers, that is, binary values (1 or 0) according to the criteria that we occupy in each variable. This was the case for the layers of Protected Natural Areas and Urban Zones of the State, where 0 would be the zones delimited as a restriction in the MCE result. (Figure 5).

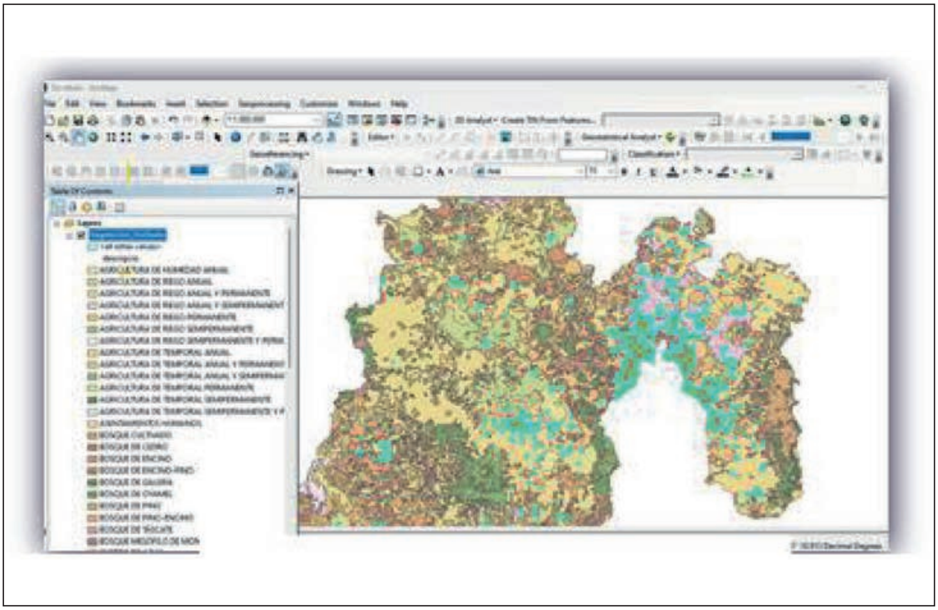

Figure 4. Data normalization

Source: own elaboration 2024.

Figure 5. Boolean restrictions

Criterion (exclude area)	
PROTECTED NATURAL AREA	URBAN AREAS

Source: own elaboration 2024.

GIS implementation of the model

The implementation of a model in a Geographic Information System (GIS) involves translating and applying the conceptual and logical model in a real environment, where geospatial data can be manipulated and analyzed; in this stage it is possible to modify these models to get closer to the desired results.

Once at check list (Figure 6) In the following steps, the suitability MCE model is assembled in TerrSet to locate the sites of greatest suitability for corn cultivation.

Spatial data is represented in the TerrSer software, and model execution testing begins in its spatial modeling tool (Spatial Decision Model), where ,in the order previously marked, the process input and execution result are found; likewise, the PNA and UZ restrictions are linked (Figure 7).

The available technique in GIS to achieve normalization is fuzzy logic, which due to the nature of the spatial data in the study, is considered the best option, carefully treated in TerrSet (fuzzy). (Manzano Solis, Pineda Jaimes, & Gomez-Alborez, 2019) In the spatial model of that software, the following criteria are selected with the study variables of agricultural suitability of corn (Figure 8):

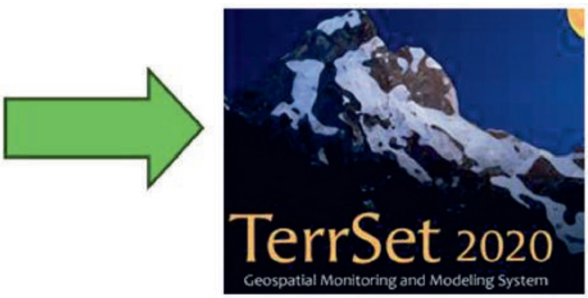

Figure 6. Pre-model check list

Source: own elaboration 2024.

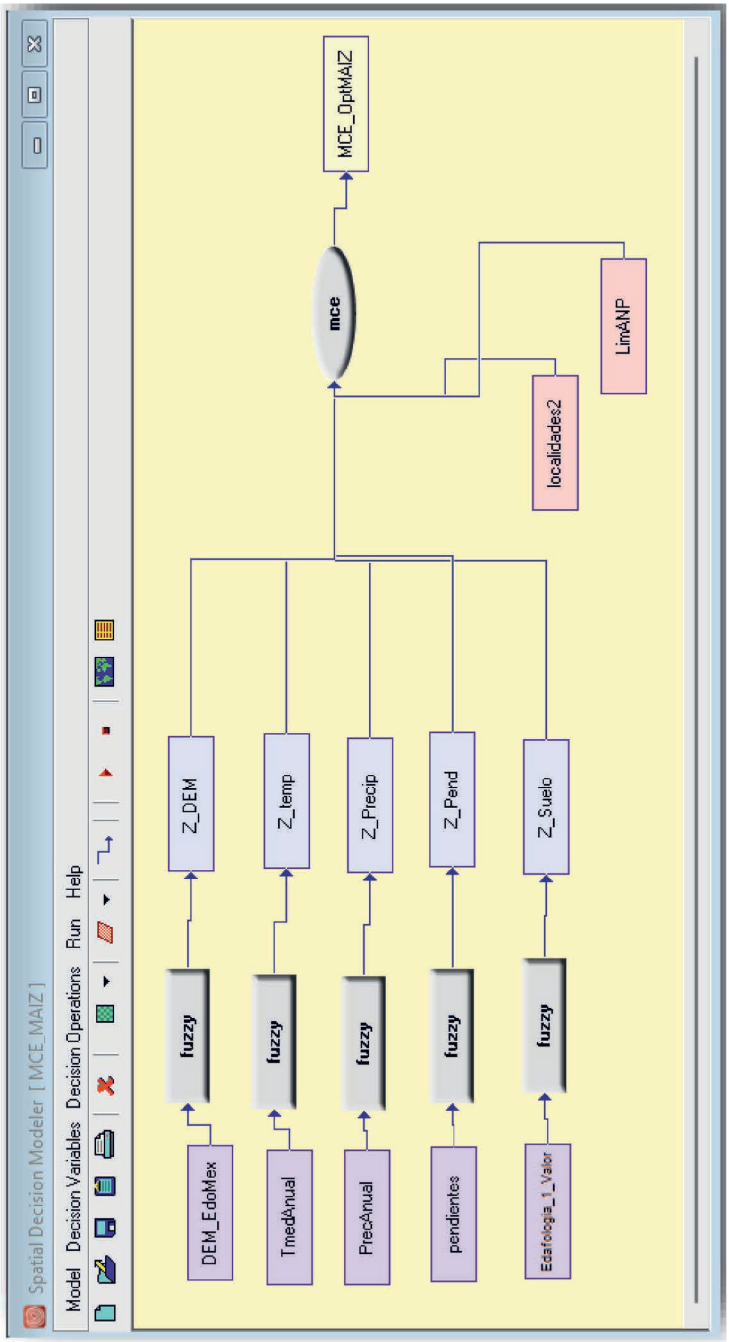

Figure 7. Spatial decision model

Source: own elaboration 2024.

Figure 8: Fuzzy criteria in spatial decision mod

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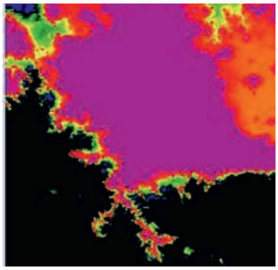
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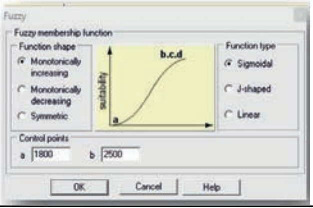
ALTITUDE
Defined optimal range:
From 1800 to 2500 meters above sea level



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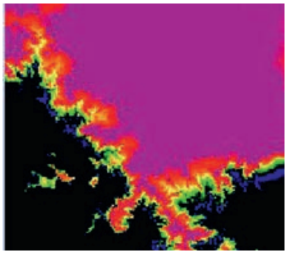
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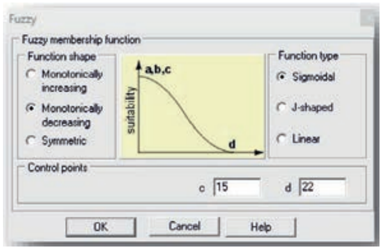
TEMPERATURE
Defined optimal range: From 15º to 22º C



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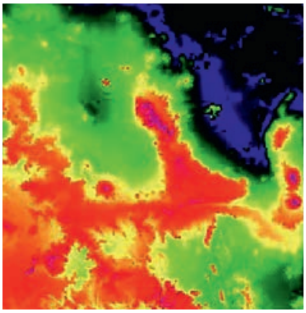
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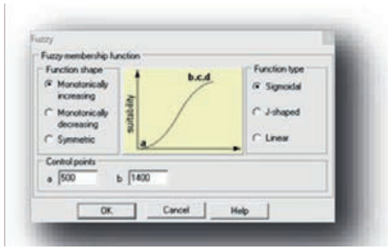
PRECIPITATION
Defined optimal range: From 500 to 1400 mm



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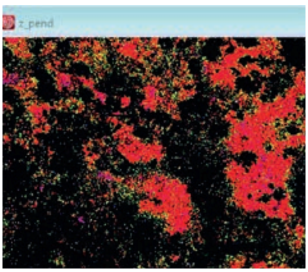

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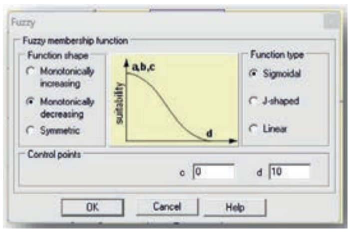
SLOPE
Defined optimal range: From 0º to 10º



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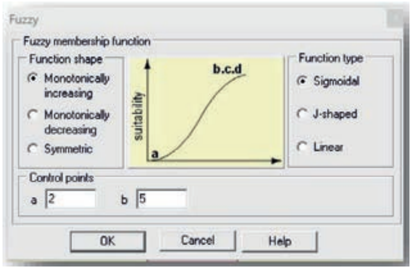
EDAPHOLOGY
Defined optimal range:
From 2 to 5
(Andosol, Feozem, Vertisol, Fluvisol) Note: In this raster layer, only the soil types are preprocessed according to the optimal criteria andthe classification is carried out with values from 2 to 5.



Source: own elaboration 2024.

Weight assignment

In multi-criteria evaluation, assigning importance to the different variables used in decision making is a crucial step. The weights show the relative value of each criterion compared to the others.

For this corn suitability study, the direct weighting method was implemented, which is delegated to the experience of the executor and researcher; Although it is usually subjective, prior bibliographic consultation and direct field experience support the simple and fast method. The relative weight based on a sum equal to 1 depends strongly on the judgment and experience of the appraiser. (Carro, Paz & Gonzalez, Gomez, 2012).

The following image shows the degree of influence that a variable has with the rest (horizontal relationship) and the dependence between variables (vertical). The result shows an acceptable consistency (0.07) in the distribution of weights.

Model verification and validation

Verification is the process of ensuring that the model has been implemented correctly, checking its logic. Validation is proving that the final product meets the requirements when running the Spatial code. Decision Modeler is required either in isolation for unit testing or in various stages of integration. Automating these test suites is a huge built-in time saver. (Camacho, 2023)

This study brings the process to the MCE image result in the spatial modeler. Validation is itself determined whether the model correctly represents the

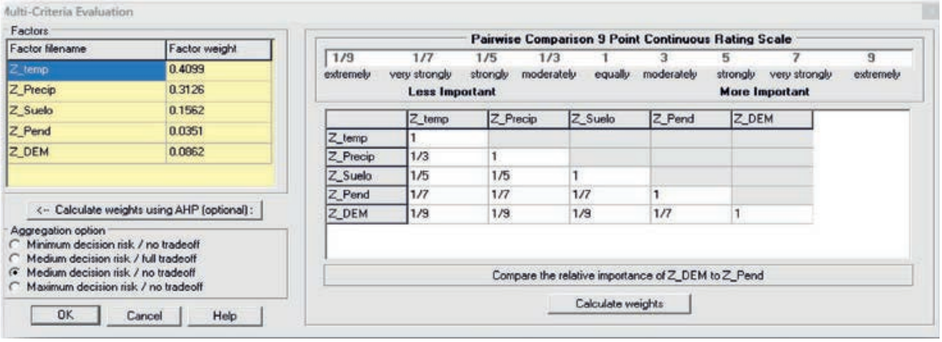
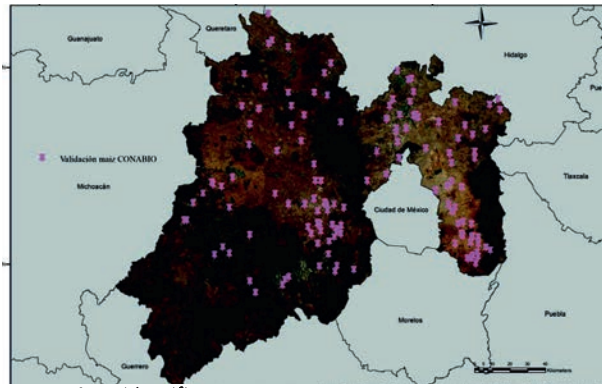


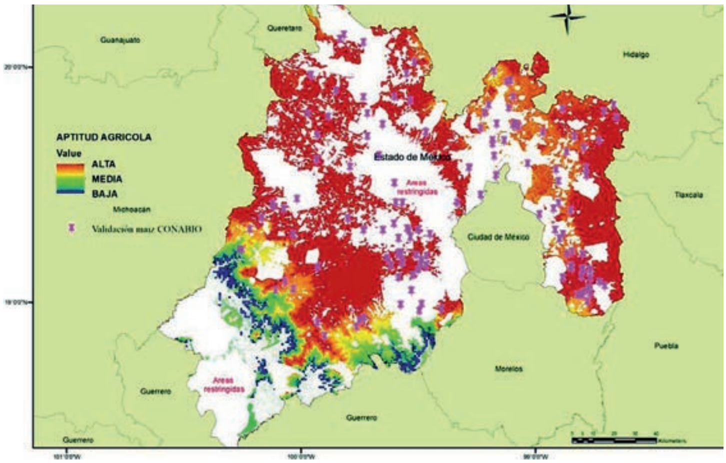
Figure 9: Weight allocation

Source: own elaboration 2024.



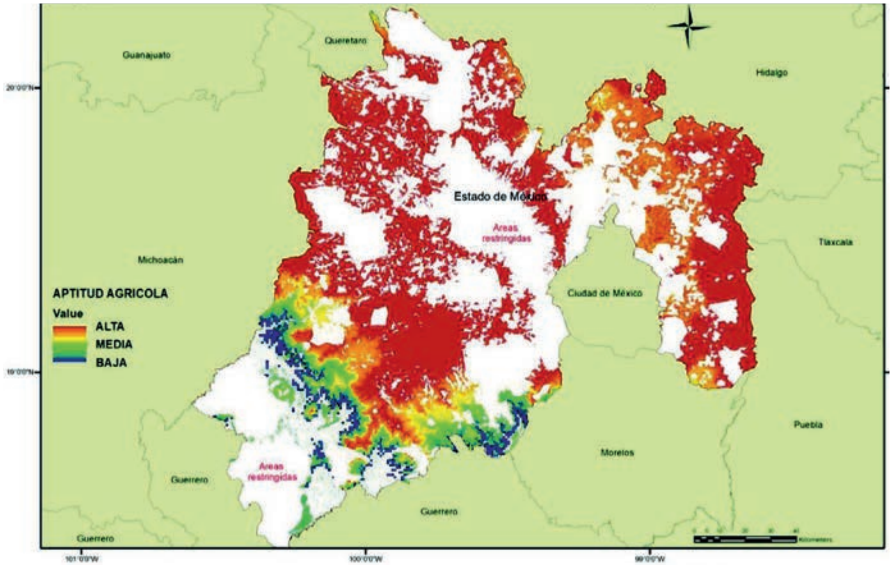
Map 1: Corn identifier

Source: own elaboration 2024.



Map 2: Conabio Validation

Source: own elaboration 2024.



Map 3: Corn Agricultural Suitability Areas

Source: own elaboration 2024.

real-world system that it is intended to simulate. In the verification it gives the raster image of having run the MCE in the spatial modeler. The reference parameter used to compare and evaluate the results is: the information from the CONABIO 2022 database, in which corn crops at the state level are indicated on the map (Map 1).

Results

as a result of the execution of the Spatial Decision Model the final raster layer is got, which delimits the areas of greatest and least agricultural suitability, visualizing it in a color palette, excluding the restrictions on Protected Natural Areas and Urban Zones. It is linked to the specific locations of CONABIO in terms of the species of georeferenced corn in the state, mostly coinciding. (Map 2). In the municipalities of the center and north of the State of Mexico, the colors with the greatest agricultural aptitude are displayed, highlighting Zinacantepec, Almoloya de Juárez, Amanalco, San Felipe del Progreso to Temascalcingo.

In the eastern part, bordering the states of Hidalgo and Puebla, the aptitude in the municipal territory of Otumba, Tepetlaoxtoc, Axapusco and Amecameca can be highlighted, which, despite its proximity to the city of altitude, leads to conservation and areas of high concentration of water, a vital element of sustainability (Map 2).

On the other hand, the southern area of the State of Mexico is contrasted, which is decreasing its capacity until it is nullified by the NPA. So, the municipalities not suitable for agriculture are Tlatlaya, Amatepec, Tejupilco and Luvianos. (Map 3).

Conclusions

Agricultural suitability is influenced by a variety of factors, but a high suitability indicates that conditions in that area are favorable for growing corn. To evaluate the agricultural suitability of corn, several factors were taken into account not only in the physical characteristics of the territory but also in the guidelines given by the multi-criteria Evaluation when choosing and assessing which of the different variables has the greatest weight and influence-dependence with the rest of the variables; the elements that are involved in the growth of the plant are dominant in their nutrient richness, as well as in the estimation of the harvest.

Although it has been said that climate change has caused changes in corn production, from geographical distribution to crop yields, temperature plays an important role and has priority in our weight calculation. In the State of Mexico crop variations have been modified by up to 4 o C in recent years.

The type of soil and its water retention properties has made the corn crop resistant to changes. Areas with soil types rich in organic matter such as andosols, feozem, vertisol, Fluvisol, or even areas within the state that are cultivated in planasol with good results are delimited.

It is known that the State of Mexico occupied 5th place nationally in forage corn in 2017 with a high production of almost 1 million 300 thousand tons. To adapt to new climatic conditions, farmers may have to change the varieties of corn they grow, as seen in the validation stage in which all corn species in the state were combined, already distributed in production. They are looking for varieties that are more resistant to heat stress, drought and other adverse conditions (CONABIO, 2022).

As corn is essential for the human and animal diet, modifications in its production can significantly affect food security, which implies carrying out studies such as this one, in which the weighting of the criteria prioritizes the effects of corn in the field and has an impact on the low production and the lack of interest in cultivation in the new generations.

The corn agricultural suitability map shows the conjugation of variables to optimize resources and a probability that in the temporality marked by the crop itself will reach high yield, since timely decisions were made to zone the crops according to their requirements.

This study of optimal areas applied to corn with MCE gives the guideline for the application to other crops; applying multicriteria evaluation to agriculture and territorial management, especially in the context of crops, can provide significant benefits such as resource optimization, profitability, adaptability to climate change, environmental sustainability, among others.

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