Open Access Library Journal
2022, Volume 9, e9284
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Productive Zoning for the Corn Milpa System in *El Zapotal* Reserve Area of Tizimin Yucatan, Mexico

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How to cite this paper: de Jesús Cano-González, A., Ramírez-Jaramillo, G., Ramírez-Silva, J.H., Uzcanga-Pérez, N.G. and Lozano-Contreras, M.G. (2022) Productive Zoning for the Corn Milpa System in *El Zapotal* Reserve Area of Tizimin Yucatan, Mexico. *Open Access Library Journal*, **9**: e9284.
https://doi.org/10.4236/oalib.1109284

Received: September 5, 2022
Accepted: October 17, 2022
Published: October 20, 2022

Abstract

This work was carried out in the state of Yucatan, Mexico in *El Zapotal* reservation area. Corn is the main crop of the area cultivated in the Milpa Maya where shifting cultivation, based on the ancient slash-and-burn system, continues to be practiced by small farmers. Even though, the National Institute for Forestry, Agricultural and Livestock Research (INIFAP) has different technological components to be applied, the regionalized scope of these results has never been evaluated. The objective was to zone the reserve area for corn production (yield and surface), modeled with INIFAP technology and small farmers management, as a first step, before implementing a sound agroforestry program. For zoning, the Soil and Water Assessment Tool (SWAT) model was used to obtain the maps of the Homogeneous Response Units (HRU). The edaphic and climatic variables were included, as well as the physiological and management parameters of the crop to simulate and estimate crop performance. The potential yields and their corresponding areas, modeled with INIFAP technology, were the next: VERY LOW yield range from 0 to 1.68 $t \cdot h^{-1}$ (363 ha), LOW from 1.68 to 3.37 $t \cdot h^{-1}$ (3177 ha), MEDIUM from 3.37 to 5.06 $t \cdot h^{-1}$ (13,449 ha), HIGH 5.06 to 6.74 $t \cdot h^{-1}$ (39,550 ha), VERY HIGH from 6.74 to 8.40 $t \cdot h^{-1}$ (38,720 ha). With farmers' management, potential yields and surface were as follow: VERY LOW yield from 0 to 0.77 $t \cdot h^{-1}$ (12,199 ha), LOW from 0.77 to 1.55 $t \cdot h^{-1}$ (13,236 ha), MEDIUM from 1.55 to 2.32 $t \cdot h^{-1}$ (42,448 ha), HIGH from 2.32 to 3.09 $t \cdot h^{-1}$ (38,767 ha) and VERY HIGH from 3.09 at 3.87 $t \cdot h^{-1}$ (8609 ha). Yields can increase by more than 100% by using INIFAP technology.

Subject Areas

Agricultural Engineering

Keywords

SWAT, Shifting Cultivation, Deforestation, Ecosystems

1. Introduction

Currently, changes in land cover and use (CCUS) have accelerated the transformation of the geographic space [1]. Those changes are due to the conversion of the original land cover into agricultural, livestock and forestry activities [2] [3] [4].

In Mexico, during the last five decades, the land cover has changed dramatically, even above the world average, with activities related to deforestation, crop cultivation, grazing and urban areas [5].

The FAO (2004) [6] indicates that Mexico is the first country to deforestation with a rate of 775, 800 hectares per year. The impact on biodiversity and soil degradation is a worrying problem since ecosystem services are altered (support, provision, regulation and culture) affecting the ability of biological systems to support human needs [7] [8] [9].

At the global level, the most effective strategy to mitigate and prevent the effects on biodiversity is the establishment of Protected Natural Areas (PNA) [10] [11]. In Mexico, the PNA constitute one of the best-defined environmental public policy instruments with great legal certainty [12].

The PNAs are representative of the different ecosystems and cover approximately 12% of the national territory [10]. However, the 17% proposed as a target area, in a global compromise, is far to be reached [13] [14].

Despite their legal nature, the PNAs are still facing risks when the agricultural frontier is expanded [15] and the increasing population is demanding new urban areas with new communication routes and hydraulic infrastructure [5] [16] [17] [18].

In Yucatan, Mexico, deforestation and soil degradation is mainly due to corn cultivated under a nomadic shifting system (slash-and-burn) in the MILPA Maya and extensive cattle ranching. Pronatura-Peninsula de Yucatán, a Mexican non-profit civil organization [19] reports that the state of Yucatán has 869,528 degraded hectares. They acquired, in 2002, the property "*El Zapotal*" for conservation purposes. The *El Zapotal* has suffered drastic modifications due to human activities and natural events. In the 1950s, livestock was encouraged, reaching maximum devastation between 1970 and 1990 when many forest hectares were transformed into pastures [20].

Even though the National Institute for Forestry, Agricultural and Livestock Research (INIFAP) has technologies to improve yields on the milpa Maya, the regionalized scope of these results needs an evaluation, before launching a sound reforestation program. The objective of this work was to zone the reserve area for corn production (yields and surface), modeled with both INIFAP technology and small farmers' management.

2. Materials and Methods

2.1. Study Area

The study was carried out in the private reserve area of *El Zapotal*, with approximately 56,250 hectares managed by the non-governmental organization Pronatura-Peninsula de Yucatán (PPY) acquired in 2002 for conservation purposes. The reserve is located in the community of Nuevo Tesoco in the northeastern part of the PY (between 21˚18'36"N, 87˚33'47"W), in the municipality of Tizimín, Yucatán (**Figure 1**).

The reserve is part of a wetland system that includes three coastal reserves: Bocas de Dzilam State Reserve (REBD) and RBRL (both in Yucatán), and the Yum Balam Flora and Fauna Protection Area (APFFYB, in Quintana Roo), that together cover more than 200 kilometers of coastline and contain approximately 140,000 hectares of medium sub-evergreen forest [21] and wetlands. The climate is predominantly warm sub-humid. The dry season lasts from December to May and the rainy season from June to November.

2.2. Homogeneous Response Units (HRU's)

For the delineation of sub-basins the runoff and basin maps, and the Digital Elevation Model (DEM) of the National Institute of Statistics and Geography (INEGI) were used. The generated sub-basin maps were enriched with soils, land use and slope intervals information reported by INEGI (Soil map scale 1:250,000).

To determine land use, a raster format mask was generated in order to delimit the agricultural frontier. For the generation of the slope intervals, five categories were considered (0 - 3, 3 - 8, 8 - 15, 15 - 30 and > 30%) based on the DEM. The inputs described were used to generate the evaluation units, which in the SWAT model (Soil Water Assessment Tool) are called Homogeneous Response Units (HRU's). The HRU's are areas (**Figure 1**) belonging to the same sub-basin, presenting internal homogeneity with respect to inputs (slope, soil and land use).

2.3. Generation of URH's Maps

To obtain the maps of the Homogeneous Response Units (HRUs), beside the edaphic and climatic variables, the physiological and crop management parameters were included to simulate and estimate the yield.

Regarding the soils, the database contains 171 soil subunits, classified according to the World Reference Base (WRB). The historical data of climate were taken from 1074 weather stations including precipitation, maximum and minimum temperature, among others, from 1912 to 2010. Monthly statistical data

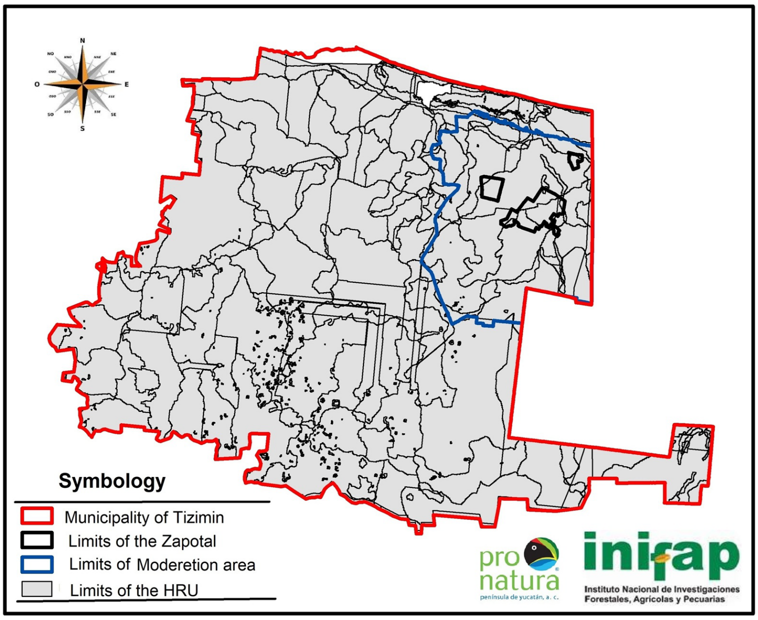

Figure 1. Geographical location of the Zapotal Reserve and HRU's limits.

were calculated with the climate generator of the Environment Policy Integrated Climate (EPIC) model [22].

For the simulation process, the model Soil and Water Assessment Tool (SWAT) evaluates each weather station based on its proximity to the centroid of each sub-basin generated by the model. Regarding to the physiological parameters and crop management, SWAT uses an internal database structure to capture all crop variables [23].

To generate the model of crop biomass, different sensitive crop management parameters were introduced into the model such as: initial crop cycle and harvest dates, fertilization dose and other agricultural practices.

At the end, a yield map ($t \cdot ha^{-1}$), classified into five categories (very low, low, medium, high, very high) was generated using the Equal Interval Classification Data (EICD) method which divides attribute values into equal-sized ranges.

2.4. INIFAP Technology and Producer Management

The technology is a determining factor for high corn productivity in the Milpa may a system. The INIFAP's technology on which the model was based are the next: 1) Deep and well drained soils. 2) Use of High Quality Protein Improved Native Maize (QPM). 3) Use of open-pollinated varieties, which can be used yearly by farmers after selecting it. 4) Increasing number of plants per hectare, up to 50%, (60 instead of 30 to 40 thousand). 5) To cope with the corn nutrition, a combination of bio (Mycorrhizal fungi and *Azospirillum* bacteria) and chemical (130 kg Urea for nitrogen and 100 kg of Triple Super-phosphate for phosphorus) fertilizers is considered. Land preparation by using slash-and-burn, weed and pest control and harvesting process, by hand, were the same for both INIFAP and the may an small corn producers.

On the other hand, the local small farmers are still using very low productive creole corn varieties, not including any chemical fertilizers and the planting density ranges from 30 to 40 thousand plants·ha^{-1}.

Figure 2 shows an INIFAP plot and **Figure 3** shows the plot of a Mayan small farmer; both with contrasting population densities. The optimal planting density, in all crops, should be oriented towards avoiding very low densities that limit the potential yield per unit area. Low populations cause considerable loss of moisture in the soil and favor the development of weeds. Population density is the most important controllable factor to obtain higher yields. In maize, it exerts a high influence on grain yield and agronomic characteristics, since grain yield increases with population density, until reaching a maximum point.

3. Results

In the *El Zapotal* reserve area, corn is mainly cultivated in a slash-and-burn system, and in different social, economic and environmental contexts [24].

3.1. Productive Zoning with INIFAP Technology

In the case of the productive zoning with INIFAP technology, the model considered the following yields and corresponding surface as shown in **Figure 4**:

VERY LOW yield range from 0 to 1.68 t·h^{-1} (363 ha), LOW from 1.68 to 3.37 t·h^{-1} (3177 ha), MEDIUM from 3.37 to 5.06 t·ha^{-1} (13,449 ha), HIGH 5.06 to 6.74 t·ha^{-1} (39,550 ha), VERY HIGH from 6.74 to 8.40 t·ha^{-1} (38,720 ha).

3.2. Productive Zoning of Corn with Producer Management

The study determined (**Figure 5**) the next potential yields and its corresponding areas: VERY LOW YIELD from 0 to 0.77 t·h^{-1} (12,199 ha), LOW from 0.77 to 1.55 t·h^{-1} (13,236 ha), MEDIUM from 1.55 to 2.32 t·h^{-1} (42,448 ha), HIGH from 2.32 to 3.09 t·h^{-1} (38,767 ha) and VERY HIGH from 3.09 at 3.87 t·h^{-1} (8609 ha).

Figure 2. INIFAP technology with high plant density.

Figure 3. Traditional small farmers' management with low plant density.

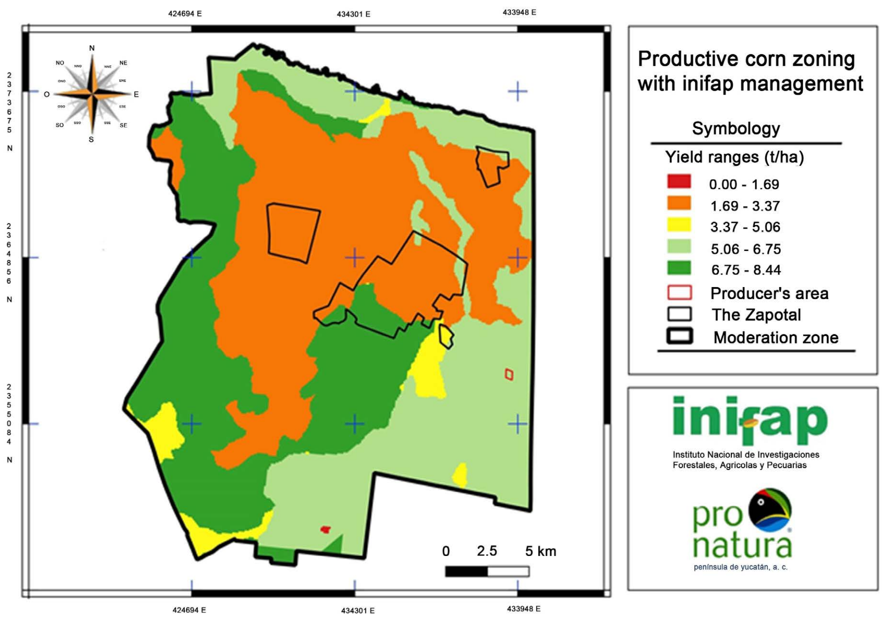

Figure 4. Productive zoning for corn with inifap management in the zone of influence of *El Zapotal* conservation area.

4. Discussion

The milpa system is a Mesoamerican agroecosystem whose main productive components are corn, beans, and squash. In this particular case, when modeling and zoning with SWAT the only crop considered was cornas the staple food of the farmers.

Population density is one of the main factors that the producers should modify to increase grain yields. If the producer uses a population density greater than the optimum, competition for light, water and nutrients, between corn plants, increases, and there is a reduction in root volume, number of ears, quantity and

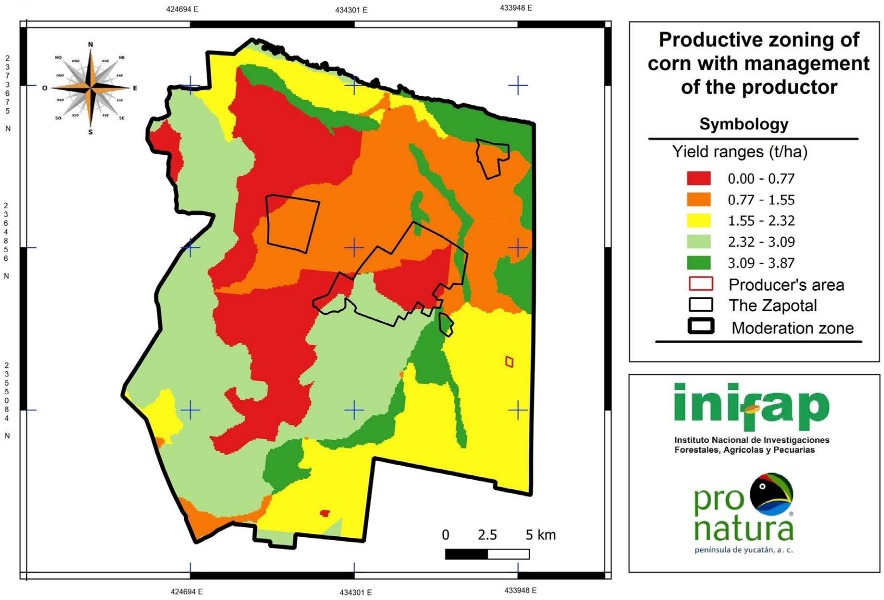

Figure 5. Productive zoning for corn with producer management in the zone of influence of *El Zpotal* conservation area.

quality of grain per plant with an induction for lodging; but on the other hand, low population densities cause problems with weeds or soil evaporation.

As it was mentioned, by Blanco-Valdes and González-Viera (2021) [25], the relationship between grain production and population density is complex, since the best response depends on soil condition, climate, cultural practices and genotype. The International Breeding Center of Maize and Wheat (CIMMYT) suggests optimal planting densities of 65,000 plants·ha^{-1}, for tropical maize genotypes as those recommended by INIFAP.

Work carried out on population densities, in hybrids, showed an increasing yield of 0.3 t·ha^{-1} by increasing the density from 50,000 to 62,500 plants·ha^{-1}.

5. Conclusion

Even though the National Institute for Forestry, Agricultural and Livestock Research (INIFAP) has developed different technological components, proper to the shifting cultivation system based on corn production, the overall technology needs to be evaluated at regional levels. After modeling, the potential yields and their corresponding surface of the reserve area of the *El Zapotal* using INIFAP technology and small farmer's management, it was concluded that there are different levels of corn production depending on the producers' management or INIFAP technology. In the case of the producers, the VERY HIGH productive corn potential ranged from 3.09 to 3.87 t·ha^{-1} in 8,609 hectares whilst with INIFAP technology the VERY HIGH ranged from 6.74 to 8.40 t·ha^{-1} in 38,720 hectares. Yields can increase by more than 100% by using INIFAP technology. The SWAT modeling system is appropriate to estimate potential yields after integrating different parameters such as climate, soil, crop phenology and technological management.

Acknowledgements

We thank Pronatura-Peninsula of Yucatan, a Mexican non-profit civil organization for financing this work as part of the project called: *Validation agroforestry models in the state of Yucatan.*

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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