Colegio de Postgraduados

Areas with agroecological potential for *Agave cupreata* (Trel. & Berger) plantations in Guerrero, Mexico

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ABSTRACT

Objective: to determine areas with agroecological potential for *Agave cupreata* (Trel. & Berger) plantations in the state of Guerrero, Mexico.

Design/Methodology/Approach: fifty-four specimens of *A. cupreata* were characterized. For each specimen, phenotypical, agroclimatic and agroecological data were recorded. Information from 123 herbarium specimens and information available in the literature were consulted. In addition, representatives of the State Council of Mezcal in Guerrero and other companies were interviewed, in order to identify possible areas excluded in the field. As well as in the specimens reviewed at the herbarium, which were validated with field observations. This information was processed in ArcGIS© version 10.3.1 (Esri Inc., 1999-2015, United States), with which a geographic information system was built and the distribution map was obtained, as well as the soil and climate and agroecological requirements of *A. cupreata* in the state of Guerrero. This information allowed the delimitation of the optimal, suboptimal and marginal areas for establishing agave plants. The validation of the information was made through field trips to specific areas to validate the agroecological variables of the potential areas defined in this study.

Results: areas comprising 673 084.16 ha with optimal agroecological potential, and 1 942 072.86 ha with suboptimal potential were determined.

Limitations/Implications of the study: it is suggested to complement with studies on productivity, population ecology, intra- and inter population genetic variability, in plantations and natural population (called in Mexico 'magueyeras') of *A. cupreata*.

Findings/Conclusions: in the state of Guerrero (Mexico), North, Central and Mountain regions were those with the highest number of optimal areas, which coincides with the areas where *mezcal* (a strong and dry alcoholic beverage distilled from the sap of *Agave* plants) production is concentrated.

Keywords: broad-leaf maguey, *mezcal*, ecological distribution analysis, geographic information system.

INTRODUCTION

In Mexico, the high demand for agave species for mezcal production has led to the degradation or loss of numerous *Agave* populations, so sustainable management is required to avoid extinction risk (Torres *et al*., 2015). The broad-leaf (Ancho, Papalome or Chino) maguey (*Agave cupreata* Trel. & Berger) is endemic to the Mexican states of Guerrero, Michoacán, and Oaxaca. The International Union for Conservation of Nature (IUCN) has placed this species in the "endangered" category because its population rates have decreased by 50% in the last 30 years. This situation may increase as the demand for mezcal of this species increases (Torres-García *et al*., 2020).

Guerrero is, by tradition, a mezcal producing Mexican state; mainly from species, *Agave angustifolia* Haw and *Agave cupreata* Trel. *et* Berger (Barrientos Rivera *et al*., 2020). Mexico's Agri-Food and Fisheries Information Service–SIAP reported that Guerrero produced 39 033.81 tons (Megagrams, Mg) of maguey, with a production value of $ 202 771 000 Mexican pesos ($ MXN) (SIAP, 2022). However, the lack of information related to standards that define the optimal places for the establishment of these plantations, and the environmental impacts associated with the lack of planning in crops can generate problems of oversupply of this resource in the medium term (Lucio-López, 2022).

Due to the economic and cultural importance, and commercial pressures to which wild populations of *A. cupreata* are subjected, the objective of this study was to determine the ideal sites in the state of Guerrero for establishing plantations of this species; in order to avoid the deforestation of tropical forests in those unsuitable sites for agave establishment.

MATERIALS AND METHODS

Study, sampling and distribution area of *Agave cupreata*

The study area is located in southern Mexico, in the state of Guerrero, which has an area of 63 564.87 km^2 (INEGI, 2022). Twenty-two field trips were made in the North and Central regions of Guerrero between March 2021 and May 2023. A total of 54 specimens were characterized according to the methodology of Huerta-Zavala *et al*. (2019), of which 26 were deposited in the UAGC and MEXU herbariums. The analysis was complemented with information from 123 specimens of *A. cupreata* found in the collections of MEXU, ENCB, and UAGC herbariums, whose information is available in the literature. In addition, nine interviews were conducted with representatives of the Mezcal Council in the state of Guerrero and with members of the companies Mezcalli del Sur, Mezcal Al Centavo and Sanzekan Tinemi, in order to identify possible areas excluded in the field visits and those mentioned in the herbarium reviews. This information was processed in ArcGIS© ver. 10.3.1 (Esri Inc., 1999-2015, United States) for integrating the distribution map of *Agave cupreata* in Guerrero.

Determination of potential areas

The determination of the potential areas for the cultivation of *A. cupreata* was first done by obtaining information from the different field specimens described and published in the National Commission for the Knowledge and Use of Biodiversity digital catalog (CONABIO, 2016; 2020), coupled with the cartography of the National Institute of Statistics and Geography (INEGI, 2016, 2020, 2021, 2024). Then, the geospatial information of each specimen was organized in a database with Microsoft Excel®; among them, agronomic factors (size of the specimens, weight, cultural works for crops or those in natural populations, the "magueyeras"); soil and climate factors (altitude, climate, rainfall, types and texture of soils); and agroecological factors (current land use, potential use of land and vegetation).

The database was integrated into a geographic information system (GIS) with ArcMap© 10.8, with which 12 thematic maps were generated and the soil and climatic and agroecological variables for this species were defined; with this, the categorization of three types of areas was obtained (optimal, suboptimal and marginal), according to the habit of the species (Huerta-Zavala *et al.*, 2019) (Table 1). The maps of the areas with soil and agroecological potential of *A. cupreata* were generated with the methodology proposed by Huerta-Zavala *et al.* (2019). The validation of the information was done through field visits to the sites that the cartographic system created categorized as optimal and suboptimal, in order to corroborate on site that these areas met the soil and climate and agroecological requirements for the good development of *A. cupreata*.

RESULTS AND DISCUSSION

Through the collection of specimens, field observations, and review of herbarium specimens, the presence of *Agave cupreata* was identified in 21 municipalities and 111 localities of Guerrero (Figure 1A). Table 1 presents the soil and climate and agroecological

Table 1. Soil and agroecological requirements of *Agave cupreata* in the state of Guerrero, Mexico.

Variable	Optimal	Suboptimal	Marginal
Altitude (m)	1300-1800	900-<1300 y >1800-2200	<900 y >2200
Slope (%)	5-15	3-<5 y >15-45	0-<3 y >45-90
Soil groups	Leptosol, Regosol and Phaeozem	Phaeozem, Luvisol and Calcisol	Cambisol, Fluvisol and vertizol
Soil texture	Loams, sandy loams or clay loams	Clay	Silty clay
pH	6.5-7.5	5.5-<6.5 y >7.5-8.0	<5.5 y >8
Climate Type	Warm subhumid and Semiwarm subhumid	Very warm semi-dry and Semi-warm humid and temperate humid	Very warm semi-dry, humid semi-warm and humid temperate
Temperature (°C)	20-28	13-<20 y >28-36	<13 y >36
Annual precipitation (mm)	900-1400	700-<900 y >1400-2000	<700 y >2000
Rainy days per year	80-105	55-<80 y >105-130	<55 y >130
Actual evapotranspiration (mm)	700-900	600-<700 y >900-1000	<600 y >1000
Days with hail per year	0	1-2	>3
Frost probability	<0.10	>0.10-0.15	>0.15
Land and vegetation uses	Annual, semi-permanent and permanent seasonal agriculture; palm grove and induced grassland; Sv low deciduous shrub forest; Sv oak forest weeds; Sv oak forest shrubs.	Sv arboreal and shrubby oak-pine forest; Sv tree of medium and low deciduous forest; Sv arboreal oak forest.	Sv herbaceous, shrubby and arboreal pine-oak forest; pine; pine-oak; Vs thorny semi-evergreen lowland forest shrub.

Sv: Secondary vegetation.

requirements identified for this species in the state of Guerrero. Altitude is one of the main variables that defines regional climatic conditions, whose optimal range for *A. cupreata* is between 1300 and 1800 m, where warm sub-humid and semi-warm sub-humid climates are found, with an annual rainfall between 900 and 1400 mm. The orography present in Guerrero favors a large number of areas with soil and climatic characteristics rated as optimal (18.20%, of the total state territory) and suboptimal (43.37%). In addition, there are those areas where the species grows under adverse or marginal conditions (Figure 1B).

Agroecological areas for *Agave cupreata*

We determined 673 084.16 ha (10.59% of the state territory) as of optimal agroecological potential; plus 1 942 072.86 ha (30.55% of the territory) with suboptimal potential; and other 24 019.63 ha (0.38% of the territory) with marginal potential (Figure 1C) for the establishment of *A. cupreata* plantations. The North, Central and Mountain regions were those with the highest number of optimal areas, while the North, Tierra Caliente and Central regions ranked second, and presented areas with suboptimal characteristics. Marginal areas were not accounted because in those sites the species does not express its whole productive potential (Figure 1D).

When grouping the optimal and suboptimal areas, the North, Central and Tierra Caliente regions presented the areas with the largest surface area, more than 71% of the

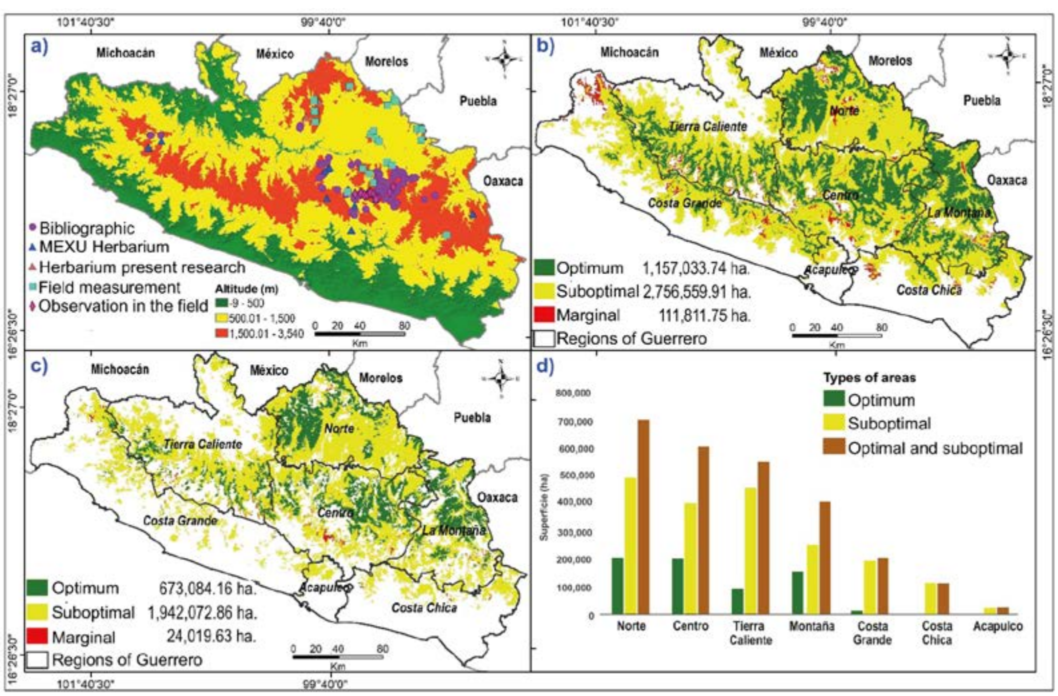

Figure 1. *Agave cupreata* in Guerrero (Mexico). A: natural distribution, according to data from the authors, complemented by Avendaño-Arrazate *et al.* (2015); Barrientos-Rivera *et al.* (2020); IIlsley Granich (2008); López-Serrano *et al.* (2021); Martínez-Palacios *et al.* (2011); Sáenz-Romero *et al.* (2012). B: soil and climate potential; C: agroecological potential, and D: areas defined as optimal, suboptimal and total agroecological potential by regions. Coordinate system: GCS, geographical. *Datum*: WGS 1984. Units: degrees.

suitable areas. The municipalities with the largest optimal areas are Teloloapan (58,024.89 ha), Tlapa de Comonfort (35,883.54 ha), San Miguel Totolapan (33,196.62 ha), General Heliodoro Castillo (30,170.43 ha) and Chilapa de Álvarez (28,917.61 ha). Those with the largest suboptimal areas are San Miguel Totolapan (146 819.25 ha), Coyuca de Catalán (136 094.06 ha), Huitzuco de los Figueroa (118 580.55 ha), General Heliodoro Castillo (104 976.08 ha) and Teloloapan (90 255.16 ha). These are also the municipalities where mezcal production exists and thrives.

In the municipalities of Teloloapan, Tlapa de Comonfort, Heliodoro Castillo and Chilapa de Álvarez there are areas with large natural populations of *A. cupreata*, since in these sites there are optimal soil and climatic characteristics (altitude, soil types, climate and annual rainfall). Our soil and climate results are consistent with those obtained by other authors for this species (Martínez-Palacios *et al.*, 2011; Avendaño-Arrazate *et al.*, 2015; López-Serrano *et al.*, 2021). However, the optimal potential area calculated for the North and Central regions in this research (407 857.46 ha) differs from the results obtained by Olvera-Vargas *et al.* (2022) who calculated a potential area of 7800 ha for *A. cupreata* in these two regions using geomatic techniques.

Such a difference in total area may be due to the methodologies used, since these authors used field spectral radiometry signatures for the analysis of satellite photographs; these authors identified as potential, those areas where *A. cupreata* is present. On the other hand, in this research we determined the optimal areas through the analysis of the soil and climate and agroecological requirements of the species, which were verified in field observations and complemented with studies by Martín *et al.* (2011) and Barrientos-Rivera *et al.* (2020).

In regard to suboptimal areas, several authors have mentioned that in suboptimal areas for other agave species, there are edaphoclimatic limitations of some kind, such as water content, nutrients, or soil texture, which can be compensated by providing irrigation, organic or mineral fertilization (Reynoso-Santos *et al.*, 2016; Huerta-Zavala *et al.*, 2019). These principles are also applicable for the establishment of *A. cupreata* plantations in the suboptimal areas we determined in this study.

In determinig appropriate areas for the establishment of *A. cupreata* plantations, it is essential to care for and protect areas with native vegetation and to propose those spaces, that have already been negatively impacted by human activities (such as eroded areas, agricultural, livestock or with secondary vegetation), as suitable areas to implement productive reconversion strategies such as agroforestry models with maguey (Simonit *et al.*, 2020; Guzmán *et al.*, 2021; Olvera-Vargas *et al.*, 2022).

This would allow local producer families to diversify their productive areas, in which yields of up to 75 Mg ha^{-1} of agave could be achieved, depending on the species used (Simonit *et al.*, 2020). In addition to obtaining firewood and wood from various species such as white cedar (*Cupressus* sp.), juniper (*Juniperus* sp.), oak (*Quercus* sp.), guaje (*Leucaena* sp.), guamúchil (*Phytecellobium dulce* (Roxb.) Benth), mesquite (*Prosopis laevigata* Humb. & Bonpl. ex Willd.), and pine (*Pinus* sp.), in order to diversify and increase the economic income of families (Simonit *et al.*, 2020; Barrera-Cobos *et al.*, 2023). On the other hand, the use of other perennial and annual species contributes to improve the characteristics of the soils with the increase of organic matter content, nitrogen fixation, and the improvement of the texture, porosity, bulk density and water content of the soils (Simonit *et al.*, 2020).

CONCLUSIONS

A total of 673 084.16 ha were determined with optimal agroecological potential for the establishment of *Agave cupreata* plantations, which represent 10.59% of the state territory. This finding is relevant for the design of public policies related to the delimitation of specific areas for the establishment of *A. cupreata* plantations under less extensive agroecological models, which contribute to the conservation of natural areas with a different land use vocation in the state. Likewise, other areas that safeguard the genetic and phenotypic variability of the broad-leaf agave populations in Guerrero.

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