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Areas with Potential for Commercial Timber Plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. in Michoacán, México

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Abstract

Michoacán has a deforested area of 525,260 ha, representing 52,526 ha per year, mainly caused by anthropogenic disturbances such as agricultural burning and forest fires (50%), change of use of land for extensive livestock farming (28%), agriculture (17%) and illegal logging (5%). The establishment of forest plantations is an alternative for reducing the pressure on natural forests and creating options for sustainable development and diversification of production and conversion of land for agricultural and livestock fragmented for forestry purposes. The aim of this study was to determine the potential areas for commercial forest plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. in the State of Michoacán, México, through the use of Geographic information systems (GIS). Areas were identified using IDRISI 32, and ArcView software. Screening variables include annual temperature, annual precipitation, land use, soil type, elevation and slope. Products obtained were field verified. Two maps where potential areas for the establishment of commercial forest plantations of *E. cyclocarpum* shown were obtained. Potential areas for commercial forest plantation establishment are (0% - 15% slope) for commercial forest plantations mechanized was 57,227 ha and (15% - 30% slope) for manual plantations was 6273 ha. The total area in the state with potential for the establishment of the species in the study was 63,500 ha.

Keywords

Potential Areas, Michoacán, *Enterolobium cyclocarpum,*
Commercial Forest Plantations, Geographic Information System

1. Introduction

Mexico ranks 10th place in the world as for the rich diversity in its natural forests. Mexican forests cover 141.7 million ha. Timberland in Mexico amounts to 56.7 million ha. Temperate forests occupy 30.4 million ha, and 26.4 million ha are covered by tropical forests (FAO, 2000). Despite its considerable forestry potential, the country faces serious and complex problems such as deforestation and erosion of large land areas. Deforestation has been the direct result of illegal logging, forest fires, and changes in land use. In the 2000-2005 period, deforestation averaged a net annual loss of 314,000 ha (CONAFOR, 2005).

The state of Michoacán is endowed with 59,864 km^2 of territory, which amounts to 3.04% of the national territory. Its natural wealth takes Michoacán to 5th place as for its national biodiversity. Timberlands represent nearly 2,602,727 ha. They contain 1,544,353 ha of temperate forests, 1,058,374 ha of tropical forests, and 247,846 ha of arid lands, wetlands and saline environments. Michoacán has 1,355,878 ha of degraded areas, even though it is a region with a tradition in forestry. Deforestation, illegal logging, over-exploitation, forest fires, pests and diseases are the forces behind the deforestation rate of 30,000 ha per year (COFOM, 2003). This condition can only be reversed by reforestation with forest tree species, which can be adapted to the zone or limiting the areas of choice using the Geographic Information System (GIS) (Sáenz et al., 2000). The GIS is a convenient tool that facilitates geographic features location and delimitation. Carmona and Monsalve (1999) explain that it is a system composed of hardware, software and procedures designed to handle spatially explicit objects and data processing such as input, administration, processing, analysis, modeling, and plotting. GIS helps solve complex problems in planning and management. The United Nations Food and Agriculture Organization (FAO, 2000) defines as GIS those computer systems used for data storage, summarization and retrieval. GIS data management, according to FAO, is carried out with specially designed programs that handle both geographic attributes and spatial information. Moreno and Moreno (1995) point out that the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) have conducted research at national level using GIS since 1991. The study of the productive potential of crops is frequently carried out using GIS. This research has enriched and promoted the use of INIFAP's geographic data bank. The results have provided grounds for decision on the plans for land use. Michoacán forest plantations have become testing grounds for a great variety of conifers and hardwoods: *Pinus michoacana* Martínez and *P. oocarpa* (INIFAP, 1993); *Abies religiosa* (Kunth) Schltdl. & Cham, *Pinus pseudostrobus* Lindl. *P. michoacana*, *P. montezumae, P. teocote, P. oocarpa, P. ayacahuite, P. lawsonii*, *P. herrerae*, *P. cembroides*, *P. radiata*, *P. greggii*, *P. engelmannii*, *P. arizonica P. durangensis* and *P. chihuahuana* (Martínez & Prieto, 2011; Muñoz et al., 2011; Sáenz et al., 2010); and other shrub species of arid land of the state of Coahuila as *Nolina cespitifera* Trel. (Martínez & Castillo, 2007) *Agave lechuguilla* Torr. (Castillo et al., 2014). The usual findings are characterized by poor survival and limited growth, due to various reasons such as: lack of a specific reason for planting, wrong

selection of species and stocking and limited silvicultural tending (Sáenz et al., 2000).

An alternative may be *Enterolobium cyclocarpum* (Jacq.) Griseb. Fabaceae (Tropicos, 2016). *E. cyclocarpum* has been used in ecological restoration programs for degraded ecosystems, soil conservation and erosion control (Vázquez et al., 1999). Studies on growth and volumetric efficiency in plantations of this species are reporting 15 to 30 m^3/ha/year, depending on the density and technical turning, could conservatively grow, in 20 years of age, to a total estimated volume of 130 m^3/ha (Manzanilla et al., 2001). The wood obtained from this species has a wide variety of uses as in the manufacture of staves, trimmings, agricultural devices such as carts, carpentry and helps in the production of panels, fine furniture, interior building materials, kitchenettes, halls, mills, fittings, closets, and thermal insulation (Pennington & Sarukhán, 1998; Manzanilla et al., 2001). The *E. cyclocarpum* species is native from America and is characteristic in places where the vegetation has been damaged. Usually grows in areas with a high degree of tampering (changes in land use, clearing for agriculture, etcetera), especially in humid tropics and sub-humid, low altitude in Mexico and Central America. This species is not related to any kind of primary vegetation; however, you can find it in forests, tropical deciduous forest galleries, and as secondary vegetation in the tropical evergreen forest (Vázquez et al., 1999; CONABIO, 2008). The object of this paper was to locate and determine potential areas for commercial forest plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. in Michoacán, through the use of geographic information systems (GIS).

2. Materials and Methods

2.1. Study Area

The state of Michoacán in Western Mexico was the study area. Coordinates for Michoacán are 100˚04'45"W to 103˚44'49" W, and 20˚23'43"N to 18˚09'47"N. Michoacán territory expands 59,864 km^2, and it is Northwest of Guerrero, North of the Pacific Ocean, South from Guanajuato and Querétaro, and East of Colima and Jalisco. Michoacán is administratively divided into 113 municipalities (INEGI, 2012; COFOM, 2014) (**Figure 1**).

The climate in Michoacán is affected by one main geographic factor: the changes in elevation caused by rough topography. Michoacán is characterized by a series of mountain ranges parallel to the coastline. Climate patterns tend to be predominantly sub-humid with summer rains and a sharp winter dry season. Predominant soils in the state are the result of volcanic ash (Andosols). These soils are found at Eje Neovolcánico and Sierra Madre del Sur. In this edaphic province, Vertisols also appear in ranges and valleys. On hills and mountains, Leptosols, Luvisols, and Feozems might be present. Andosols dominate the MesetaTarasca. Soils from Sierra Mil Cumbres at high elevation sites are also Andosols. Acrisols and Luvisols are found at piedmonts, creeks and valleys. Feozems normally can be seen at the edge of crop lands. Low lands and flat ground places with non-irrigated and irrigated agriculture, or natural vegetation of subtropical woodlands and grasslands tend to be Vertisols. Leptosols are distributed in

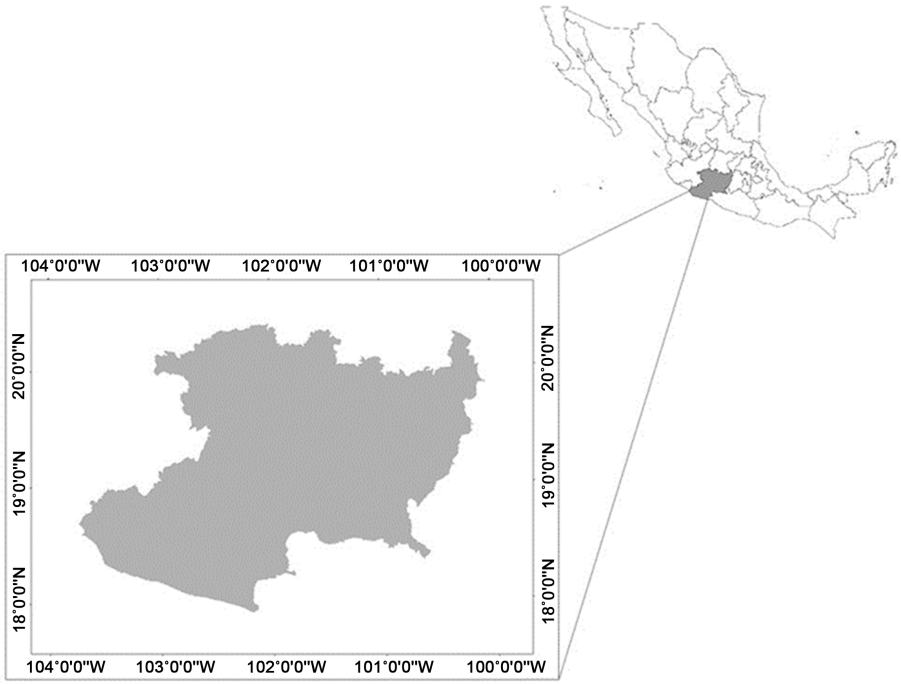

Figure 1. Geographic location of Michoacán, the study area.

random patterns associated to steep terrain and rocky outcrops.

Subdivision of the Study Area

Michoacán state is divided in 113 counties, which for this study purposes was subdivided in ten regions and were defined according the regionalization of the Forestry Commission of state of Michoacán (COFOM, 2014), which are shown in Table 1.

2.2. Natural Distribution and Environmental Requirements to Determine Potential Areas of *Enterolobium cyclocarpum* (Jacq.) Griseb

To obtain the natural distribution and environmental requirements from *E. cyclocarpum*, an extensive research of written material was conducted. The findings show the climate where *E. cyclocarpum* is located to be warm humid (SEDER, 1995) with an annual rainfall of 750 to 2500 mm, average annual temperature between 22˚C - 32˚C; at altitudes ranging from 0 to 1600 m and Regosol and Cambisol soil types, though it develops best in Vertisol soils (SEDER, 1995; CNIC, 2005; Manzanilla et al., 2001; Rueda et al., 2007). The information was gathered mostly considering the dry tropical conditions found in the state of Michoacán, and once the information was systemized, the environmental requirements for *E. cyclocarpum* was determining the potential areas for commercial forest plantations were determined, based on altitude, total annual precipitation, average annual temperature, soil type and slope. The research scheme for potential areas chose sites meeting the following environmental features for *E. cyclocarpum:* elevation, total annual rainfall, annual average temperature, soil type and slope (Table 2).

Table 1. Municipalities and Michoacán forest regions, according to the forestry commission of the state of Michoacán (COFOM, 2014).

Region	Municipalities
I. Lerma-Chapala	Briseñas, Chavinda, Cojumatlán, Ixtlán, Jacona, Jiquilpan, Marcos Castellanos, Pajacuarán, Purépero, Sahuayo, Tangamandapio, Tangancícuaro, Tlazazalca, Venustiano Carranza, Villamar, Vista Hermosa, Zamora.
II. Bajío	Angamacutiro, Coeneo, Churintzio, Ecuandureo, Huaniqueo, Jiménez, José Sixto Verduzco, Morelos, Numarán, Penjamillo, La Piedad, Panindicuaro, Puruándiro, Tanhuato, Yurécuaro, Zináparo, Zacapu.
III. Cuitzeo	Acuitzio, Álvaro Obregón, Copándaro, Cuitzeo, Charo, Chucándiro, Huandacareo, Indaparapeo, Morelia, Queréndaro, Santa Ana Maya, Tarímbaro, Zinapécuaro.
IV. Oriente	Angangeo, Aporo, Contepec, Epitacio Huerta, Hidalgo, Irimbo, Juárez, Jungapeo, Maravatío, Ocampo, Senguio, Susupuato, Tlalpujahua, Tuxpan, Tuzantla, Tiquicheo, Tzitzio, Zitácuaro.
V. Tepalcatepec	Aguililla, Apatzingán, Buenavista, Cotija, Tepalcatepec, Tingüindín, Tocumbo, Parácuaro, Peribán, Los Reyes.
VI. Meseta Tarasca	Charapan, Cherán, Chilchota, Nahuatzen, Nuevo Parangaricutiro, Paracho, Tancítaro, Taretan, Tingambato, Uruapan, Ziracuaretiro.
VII. Pátzcuaro-Zirahuén	Erongarícuaro, Huiramba, Lagunillas, Pátzcuaro, Quiroga, Salvador Escalante, Tzintzuntzan.
VIII. Tierra Caliente	Parácuaro, Huetamo, Madero, Nocupétaro, San Lucas, Tacámbaro, Turicato.
IX. Costa	Aquila, Arteaga, Coahuayana, Coalcomán, Chinicuila, Lázaro Cárdenas, Tumbiscatío.
X. Infiernillo	Ario de Rosales, Churumuco, La Huacana, Gabriel Zamora, Múgica, Nuevo Urecho.

Table 2. Environmental requirements considered to assess sites potentially suitable for commercial forest plantations of *Enterolobium-cyclocarpum* (Jacq.) Griseb. in Michoacán, México.

Environmental requirement	Optima requirement
Elevation (msnm)	0 - 800
Annual rainfall (mm)	800 - 1200
Annual average temperature (˚C)	20 - 32
Soil type	Vertisol
Slope	0% - 15% and 15% - 30%

2.3. Determining Areas of Potential Maps

IDRISI 32 (2.0) (Eastman, 1999) software was used to produce maps and estimates of area with potential for commercial forest plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. IDRISI is one of many commercial software products that handle GIS databases, as well as charts, imagery and climate digital information from National Institute of Forestry, Agriculture and Livestock Research were used. The Digital Elevation Model (DEM) employed had a 360 m × 360 m resolution, equivalent to 12.96 ha, that is, each pixel (cell) covers this area; all variables were measured within this spatial frame. Screening sorted sites using Reclass command. Excludes pixels that do not meet stated species habitat criteria. A hierarchical screening sequence was designed for this purpose, according to the following categories or fitness classes: Unsuitable = 0 Sites lacking required ecological features for growth and development of the studied taxon. Suitable = 1 Sites that offer the required ecological features for a certain species.

GIS thematic layers displayed each variable and its range of values spread throughout the geographic distribution range of *E. cyclocarpum.* These layers were, then joined

through Overlay command. The resulting product represents the potential areas in Raster format. Command Area produced a quantitative estimate of potential area. IDRISI command Reformat was used to convert to vectorial format, and then exporting it to Shapefile for further work on ARCVIEW 3.2. GIS software for rendering 1:100,000 and 1:250,000 scale outputs.

2.4. Validation of Potential Areas

Selected sites within the potential zones of the studied specie were visited in the field to assess the existence of suitable ecologic conditions to favor for the establishment and development of *E. cyclocarpum* plantations, and therefore considered suitable for commercial forest plantations, for it were chosen randomly and were georeferenced data accurately in selected areas.

3. Results and Discussion

According to the methodology used and the agro-ecological requirements for *E. cyclocarpum* growth, the required characteristics are: elevation, total annual precipitation, average annual temperature, slope, land use, and soil type, two maps were produced which show the sites and potential areas for plantations and developing of *E. cyclocarpum*. The first map shows a slope ranging between 0% to 15% and is indicate for mechanized plantations, and the other map shows a slope with an inclination of 15% to 30%, where manual planting is best in these conditions.

Maps potential areas for *Enterolobium cyclocarpum* (Jacq.) Griseb.

Two maps were drawn from the GIS analysis. This maps show the potential areas for the establishment of commercial forest plantations of *E. cyclocarpum* according within a two slope range proposal. First slope range (0% - 15%) where mechanized plantations have greater potential for planting *E. cyclocarpum,* equivalent to 57,227 ha and are located in the IV (Oriente), V (Tepalcatepec), VII (Tierra Caliente), IX (Sierra Costa) and X (Infiernillo) regions (**Figure 2**).

The other map obtained shows potential areas for establishing new commercial forestry plantations non-mechanized or manual plantations of *E. cyclocarpum* on a slope range of 15% - 30% which is a 6273 ha area and are located in the IV Oriente, V Tepalcatepec, VII Tierra Caliente, IX Sierra Costa y X Infiernillo regions (**Figure 3**).

The total surface considering the range of both slopes (0% - 15% and 15% - 30%) adds up to 63,500 ha and showed potential for establishing new commercial forestry plantations with *E. cyclocarpum* in the state of Michoacán, and are mostly distributed in the V, VII, IX, X regions (Tepalcatepec, Tierra Caliente, Sierra and Costa Infiernillo, respectively), with 43,967 ha. The lower height range was taken in reference to sea level, which is the same as for SEDER (1995) and the upper limit, 800 m, which is slightly less than that found by SEDER (1995) and other authors for 1200 m.

The results are similar to those reported by Rueda et al. (2007), who used the same variables for his work, to generate maps of potential areas for forest plantations of 11 species of pine and six tropical species in the state of Jalisco. It also matches those of

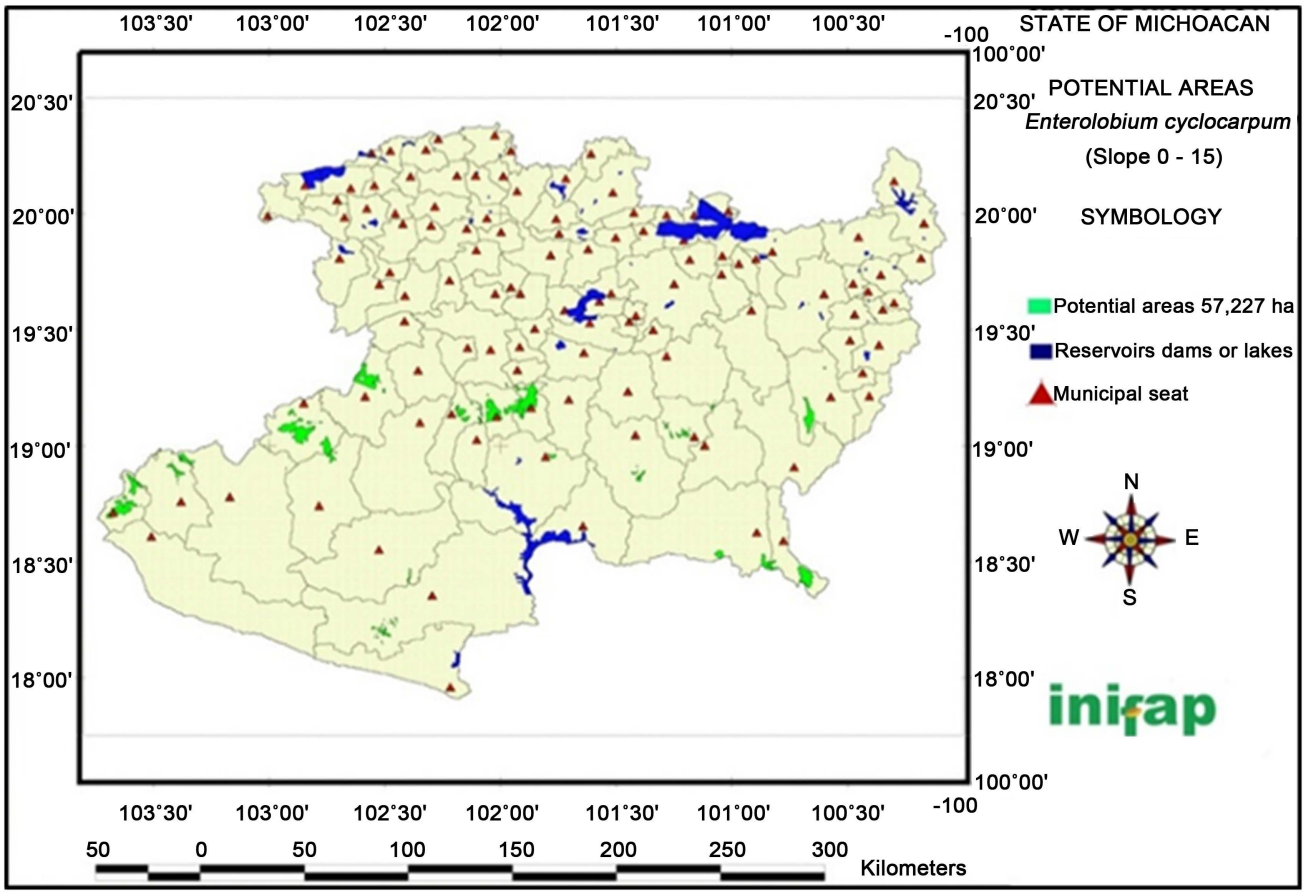

Figure 2. Areas with potential for mechanized establishment of commercial plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. in Michoacán, México(slope 0% to 15%).

Sáenz et al. (2000), who, using the same variables, determined the potential areas in the eastern region of Michoacán, for plantations with *Abies religiosa*, *Pinus pseudostrobus*, *P. michoacana*, *P. montezumae*, *P. teocote*, *P. oocarpa*, *P. ayacahuite*, *P. lawsonii* and *P. herrerae*.

Similarly, and consistent with Sáenz et al. (2007, 2011), is their finding of potential areas for commercial forest plantations of *Pinus pseudostrobus*, *P. michoacana*, *P. lawsonii* and *P. montezumae* combined with forage species in the basin of Lake Cuitzeo, in Michoacán. Furthermore, and consistent with Meza (2003) to locate potential areas for the establishment of plantations of damiana (*Turnera diffusa* Willd), and as indicated by the National Institute of Forestry, Agriculture and Livestock (INIFAP) in their assessment to determine potential areas in the state of Michoacán, considering the same variables (altitude, precipitation, mean annual temperature, slope, uses and soil type, and using the same GIS).

The potential areas determined by GIS maps and verified against the ecological requirements show results with a high level of accuracy (100%) between map sites and ecological sites, so the sampled sites match in soil type and altitude requirements for commercial plantations of *E. cyclocarpum* (Table 3).

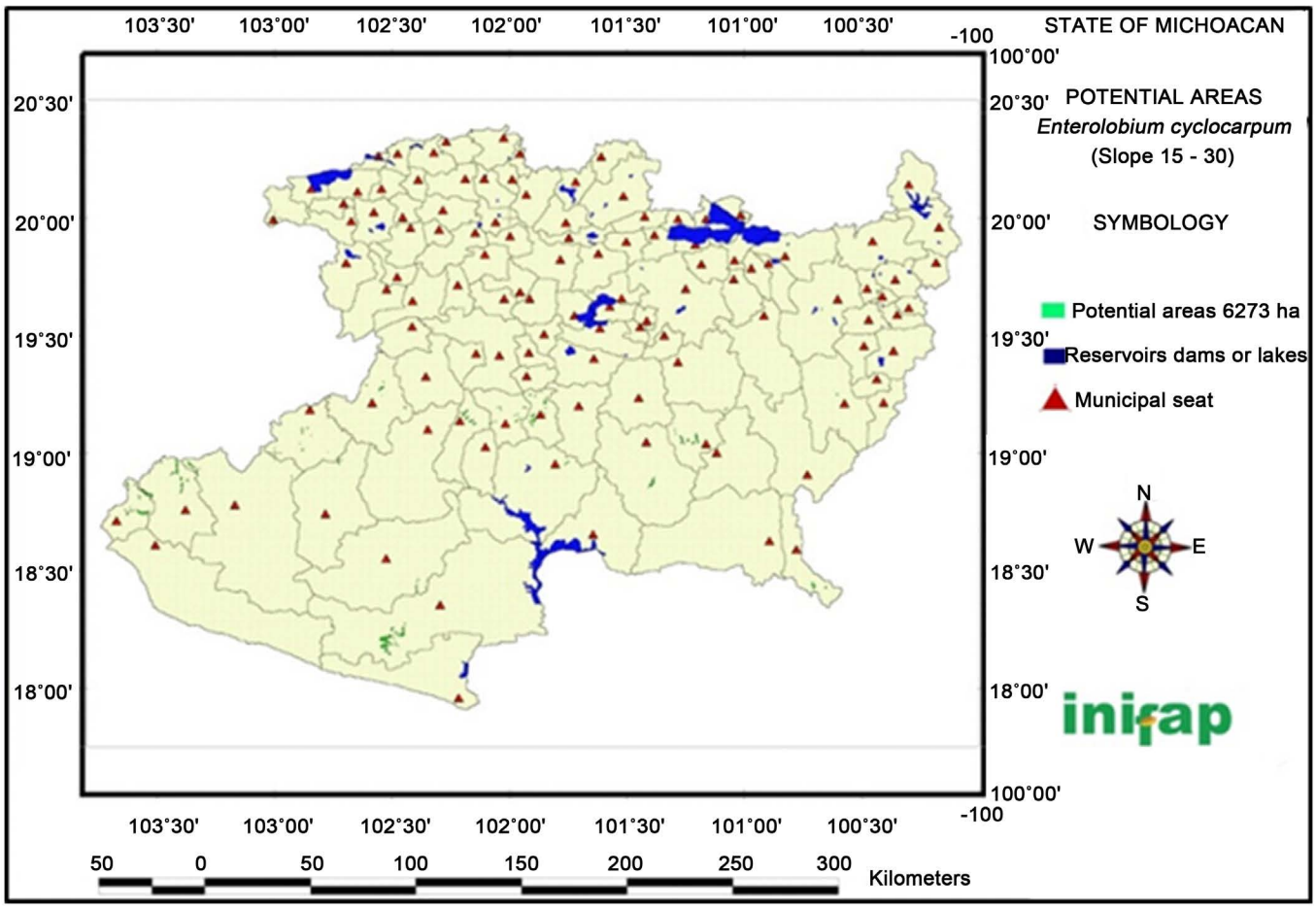

Figure 3. Sites with potential for non-mechanized establishment of commercial forest plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. in Michoacán, México (slopes 15% to 30%).

Table 3. Altitude, slope and soil type showing in validation sites for potential areas for commercial forest plantations *Enterolobium cyclocarpum* (Jacq.) Griseb. in the state of Michoacán.

Sample site	Municipality	Elevation (msnm)	Slope (%)	Soil type
1	San Lucas	440	0 - 15	Vertisol
2	Huetamo	433	0 - 15	Vertisol
3	Nuevo Urecho	625	15 - 30	Vertisol
4	Nuevo Urecho	514	0 - 15	Vertisol

4. Conclusion

The ecologic conditions in Michoacán are frequently favorable for successful establishment and development of commercial forest plantations of *Enterolobium cyclocarpum* (Jacq.) Griseb. where there are a totals area suitable for mechanized establishment of commercial plantations of *E. cyclocarpum* near of 57,227 ha low slope less than 15% and 6273 ha more in slopes upper 15%. Both superficies added 63,500 ha totals and V region (Tepalcatepec) presents 19,883 ha for new commercial forest plantations.

Geographic information systems are dependable tools in assessing the potential sites for growing forest species. Results have provided support to decisions on land use planning and establishment of commercial forest plantations of *E. cyclocarpum* in Michoacán.

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