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Article

Potential surface areas for forest plantations of *Brosimum alicastrum* Sw. for restoration purposes

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Abstract:

Restoration forest plantations are an alternative to recover degraded land and prevent erosion, as well as the reconversion to forest use of dismantled soils for agricultural and livestock purposes. The objective of this study was to determine the potential areas of forest plantations with *Brosimum alicastrum*, for restoration purposes in the state of *Michoacán*, through the use of geographic information systems. The delimitation of the areas was done with the programs IDRISI 32 and ArcView, and the environmental requirements of the species. The variables considered were precipitation, temperature, soil, altitude and slope. Twelve maps were generated in total, 10 for five regions and two for the state, showing the potential areas for the establishment of forest plantations for the restoration of this species in slope ranges of 0-15 % (mechanized) and 15 -30 % (not mechanized). The total area with potential to establish plantations for restoration purposes in the entity was 86 408 ha, of these 71 687 ha correspond to slopes of 0-15 %, and 14 721 ha in slopes of 15-30 %. The plantations can be established in the region: IV *Oriente*, V *Tepalcatepec*, VIII *Tierra Caliente*, IX *Sierra Costa* and X *Infiernillo*. The dry tropic of the state of *Michoacán* due to its ecological, geological, physiographic, and topographic characteristics, presents favorable conditions for the potential development of forest plantations of restoration with *Brosimum alicastrum*.

Key words: *Brosimum alicastrum* Sw., tropical plantations, productive potential, agroecological requirements, restoration of ecosystems, Geographic Information Systems.

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Introduction

In the state of *Michoacán*, the priority surface for reforestation consists of eroded areas and induced grasslands adding up to 641 971 ha, equivalent to 10.9 % of the surface of the state (Cofom, 2014). Due to the existing need of reestablishing the capacity of the forest ecosystems to generate environmental services and productive activities based on a sustainable exploitation, the recovery of those areas that were covered by vegetation through active reforestation and through soil restoration is crucial (Conafor, 2007).

Because of its ecological, geological, physiographic and topographic characteristics, *Michoacán* exhibits favorable conditions for the development of forest plantations with various species (Muñoz *et al.*, 2012); one of these, *Brosimum alicastrum* Sw., is an alternative for the restoration of dry tropical ecosystems that may also benefit the rural communities through its various uses.

Brosimum alicastrum, Moraceae (Trópicos, 2017), breadnut, known in the region as *ramón*, is native to the tropical regions of the American continent; it grows in areas with warm, semi-warm, tropical and temperate climates, at altitudes ranging between 10 and 1 600 masl; it is a wild species associated to various types of vegetation (Pellicer, 2005; Batis *et al.,* 1999).

In the low deciduous rainforest, it is considered to have a high fodder potential, though at the same time it provides important environmental services, such as the conservation of the soil and the control of erosion, and counteracts the effects of strong winds; it is also used for the recovery of degraded lands (Peters and Pardo, 1982; Batis *et al.,* 1999; Carranza-Montaño *et al*., 2003; CNIC, 2005). It is used as a living hedge in agro-habitats, a windbreaking barrier, shade and a shelter for wildlife. Furthermore, its wood is used for the manufacture of sheets, floor boards, parquet, packing crates, saddles and tool handles; due to its aesthetic characteristics of hardness and dimensional stability, it can be used in the manufacture of furniture (carpentry), agricultural utensils, timber dado linings, sports items (bowling ninepins), broomsticks and shoe trees (Zavala, 1999; MAE and FAO, 2014; CIBTS, 2016).

In order to select the most adequate species for each site or geographical region, it is essential to contrast the agro-ecological requirements of the studied taxon with the environmental characteristics of the selected region (Martínez, 1999; Rueda *et al.*, 2013). Through the use of Geographic Information Systems it is possible to group the environmental factors and their interactions, and thus to define the regions where the conditions exist for achieving feasible results. Experience shows that this technique is useful for making decisions on ecological zoning plans, the monitoring of forest resources, and the diagnosis of the productive potential and of the areas in risk of deterioration.

Recent maps of the productive potential for forest species were generated using geographic information systems supported by such software as ArcGIS and IDRISI, having previously defined the environmental requirements of these species, including annual precipitation, mean annual temperature, altitude, slope, climate, soil type and land use (Rueda *et al.*, 2006 and 2007; Díaz, 2007; Muñoz *et al.*, 2016a, 2016b); this process included the georeferenced analysis of these requirements, the most restrictive of which have often been related to altitude, soil type, land use, and climate, such as temperature and precipitation, for *Pinus* spp. and *Eucalyptus* spp. (Flores and Moreno, 1994; Flores *et al.*, 1997); the chemical phases of the soil, for *Abies religiosa* (Kunth) Schltdl. *et* Cham, and the minimum temperature and a soil without physical phases, for *Turnera diffusa* (Meza, 2003).

The aim of the present study was to determine the potential area for the establishment of *Brosimum alicastrum* plantations for restorative purposes in the state of *Michoacán*, through the use of geographic information systems.

Materials and Methods

Description of the study area. The state of *Michoacán* is located in the western portion of the country, between the coordinates 20°23'43'' - 18°09' 47'' N and 100°04'45'' - 103°44'49'' W, has a territory of 59 864 km^2, formed by 113 municipalities. The *Comisión Forestal del Estado de Michoacán* (Forestry Commission of the State of *Michoacán*) (Cofom) divides it into 10 forest regions (Figure 1): I *Lerma-Chapala*, II *Bajío*, III *Cuitzeo*, IV *Oriente*, V *Tepalcatepec,* VI *Meseta Purépecha*, VII *Pátzcuaro-Zirahuen*, VIII *Tierra Caliente*, IX *Sierra Costa* and X *Infiernillo* (Table 1) (Cofom, 2014).

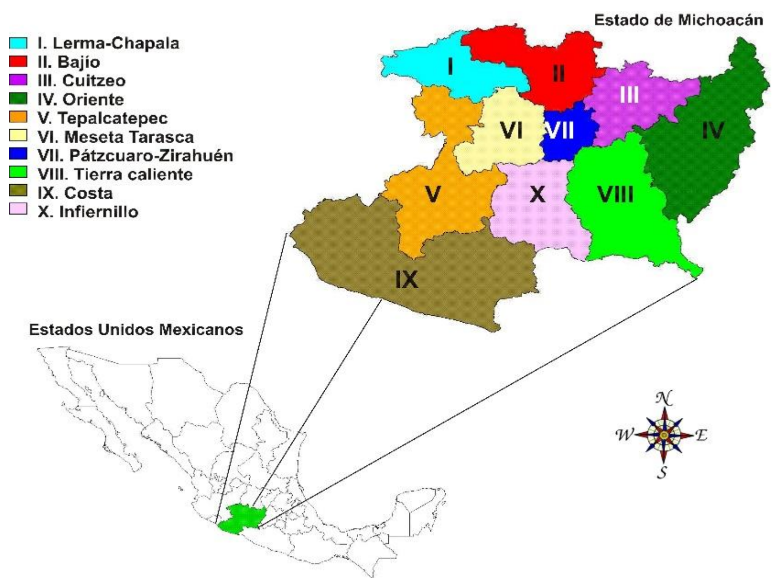


Figure 1. Location of the study area.

Table 1. Regionalization of the state of *Michoacán* according to the Forestry Commission of the State of *Michoacán*.

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, Paníndicuaro, 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*	*Angangueo, 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.*

Source: (Cofom, 2014).

The distribution of the climates in the state is strongly related to the altimetric contrasts of the relief; it includes the following types: A (w), warm subhumid; A (C) (m),semi-warm humid; A (C) (w), semi-warm subhumid, C (m), temperate humid; C (w), temperate subhumid; C (E) (m), semi-cold humid; and BS1 (h), dry and semi-dry, very warm and warm. The mean monthly temperatures vary from 13 to 29 °C; the highest temperatures occur in the regions of the Coast and *Tierra Caliente*, particularly in the areas with the lowest altitude, where the mean annual values reach extremes closer to 30 °C; the lower temperatures range between 27 and 48 °C, and the minimum extreme temperatures, between -7 and 18 °C. The precipitation ranges between 600 and 1 600 mm per year (Inegi, 1985; Anguiano *et al*., 2007).

17 soil units are present: Acrisol, Andosol, Cambisol, Castañozem, Phaeozem, Fluvisol, Gleysol, Histosol, Lithosol, Luvisol, Planosol, Ranker, Regosol, Rendzina, Solonchak, Vertisol, and Xerosol; the volcanic soils (andosols) are located in the Transversal Neovolcanic Axis in the Southern *Sierra Madre*. In the lower parts of the region of the *Balsas* Depression are vertisols, gleysols, rendzinas, fluvisols, lithosols and regosols (Cofom, 2014; Inafed, 2016).

Natural distribution and environmental requirements. An extensive bibliographical revision was carried out for the obtainment of the natural distribution and the environmental requirements of *B. alicastrum* (Rzedowski, 1981; Chavelas and Dewall, 1988; Vega 1989; Von Carlowitz *et al*., 1991; Batis *et al*., 1999; Vega *et al.,* 2003; CNIC, 2005; Pellicer, 2005; SIRE, 2005). General information regarding the conditions of the dry tropic of the state was obtained and systematized, and the requirements for *B. alicastrum* were subsequently determined.

The environmental requirements for the estimation of the potential areas were: altitude, total annual precipitation, mean annual temperature, slope, soil type and land use (Table 2).

Table 2. Environmental requirements of *Brosimum alicastrum* Sw. for the determination of the potential areas for restorative forest plantations in the state of *Michoacán*.

Altitude (masl)	**Precipitation (mm)**	**Mean Annual Temperature (°C)**	**Type of Soil**
0-800	800-1200	23-31	Vertisol and Rendzina

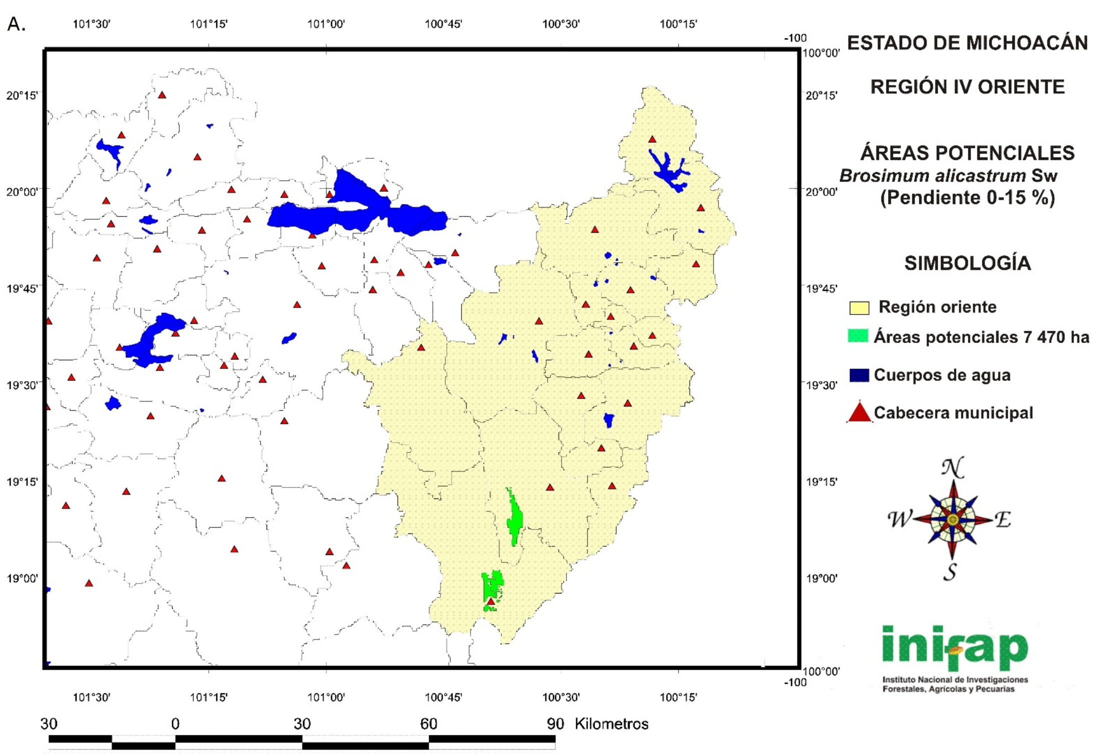
Development of maps of the potential areas. The potential areas were delimited by using the *IDRISI* 32 ver. 4.0 software (Eastman *et al*., 2009), which works with Geographic Information Systems (GIS), and the cartographic and climatic digital information generated by INIFAP. The maps were developed using the RECLASS command, which discarded those areas in the region that did not meet the specific characteristics for the species of interest. For this purpose, a stratification system of the potential areas was designed based on the following categories and levels of aptitude: Not apt = 0, comprises those areas that do not exhibit favorable conditions for the development and growth of the studied species and areas; Apt = 1, comprises those areas that ensure the adaptation of the species, as they exhibit conditions that are favorable to its development. These coverages individually contain the interval of each variable associated to distribution. The images thus obtained were superimposed using the OVERLAY command (which is accessed by clicking on the Analysis/DataQuery/Overlay menu). In this manner the potential areas for the taxon were obtained. The surface of these areas was estimated using the AREA command. The images in the RASTER format were converted to a vector with the REFORMAT command. Each image was exported to a shapefile format in order to work in SIG ArcView version 3.2 (Zeiler, 1999), which was used to generate images at the scales of 1: 100 000 and 1:250 000.

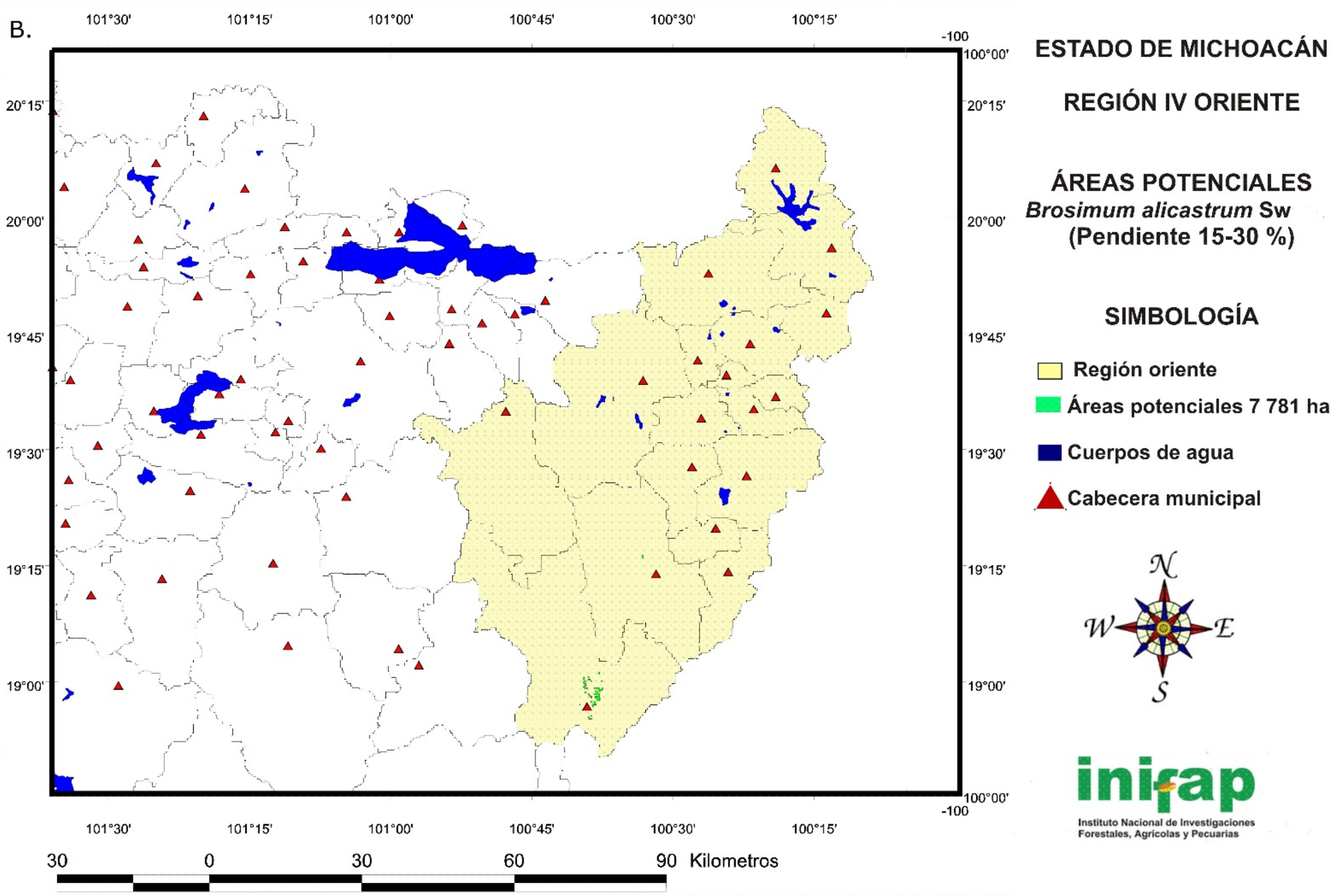
In-field verification. The generated maps were verified by means of a survey of the verification sites, both with and without forest vegetation; this was done with the purpose of corroborating whether or not the developed maps coincided with the reality of the terrain. This activity included the following actions: first, a questionnaire was developed to collect the information regarded as relevant for the assessment and characterization of each verification site. Then, based on the generated maps by forest regions, the sites were located and georeferenced with GPS; this made it possible to compare the environmental demands of the studied species with the actual existence of the area or of the location marked as potential. Furthermore, the location of the sampling sites in the plantations established in previous years was verified in order to determine whether they are within or outside the potential areas determined in this study. Furthermore, samples of the soil were collected from certain verification sites and sent for physicochemical analysis to a soil laboratory BELTEC, S. de R.L. in *Uruapan*, *Michoacán*, in order to compare the results with the characteristics of the soil cited in the literature as soil requirements of *B. alicastrum*.

Results and Discussion

Two maps showing the potential areas for *B. alicastrum* were generated. Non-mechanized plantations (15 to 30 % slope) are those in which the furrows where the trees will be planted are dug manually, and the mechanized plantations (0 to 15 % slope) are those in which the furrows are made using machinery; mechanization accelerates the planting process but requires the investment of capital.

Maps of the potential areas. In the IV *Oriente* region, the municipalities that comprise potential areas with a 0-15 % slope are *Tuzantla* and *Tiquicheo*, with a total of 7 470 ha, while the potential areas in sites with 15-30 % slopes in *Tiquicheo* cover a surface of 778 ha (Figure 2).





Áreas potenciales = Potential areas; *Pendiente* = Slope; *Simbología* = Symbology; *Región oriente* = Eastern region; *Cuerpo de agua* = Waterbody; *Cabecera municipal* = Municipality

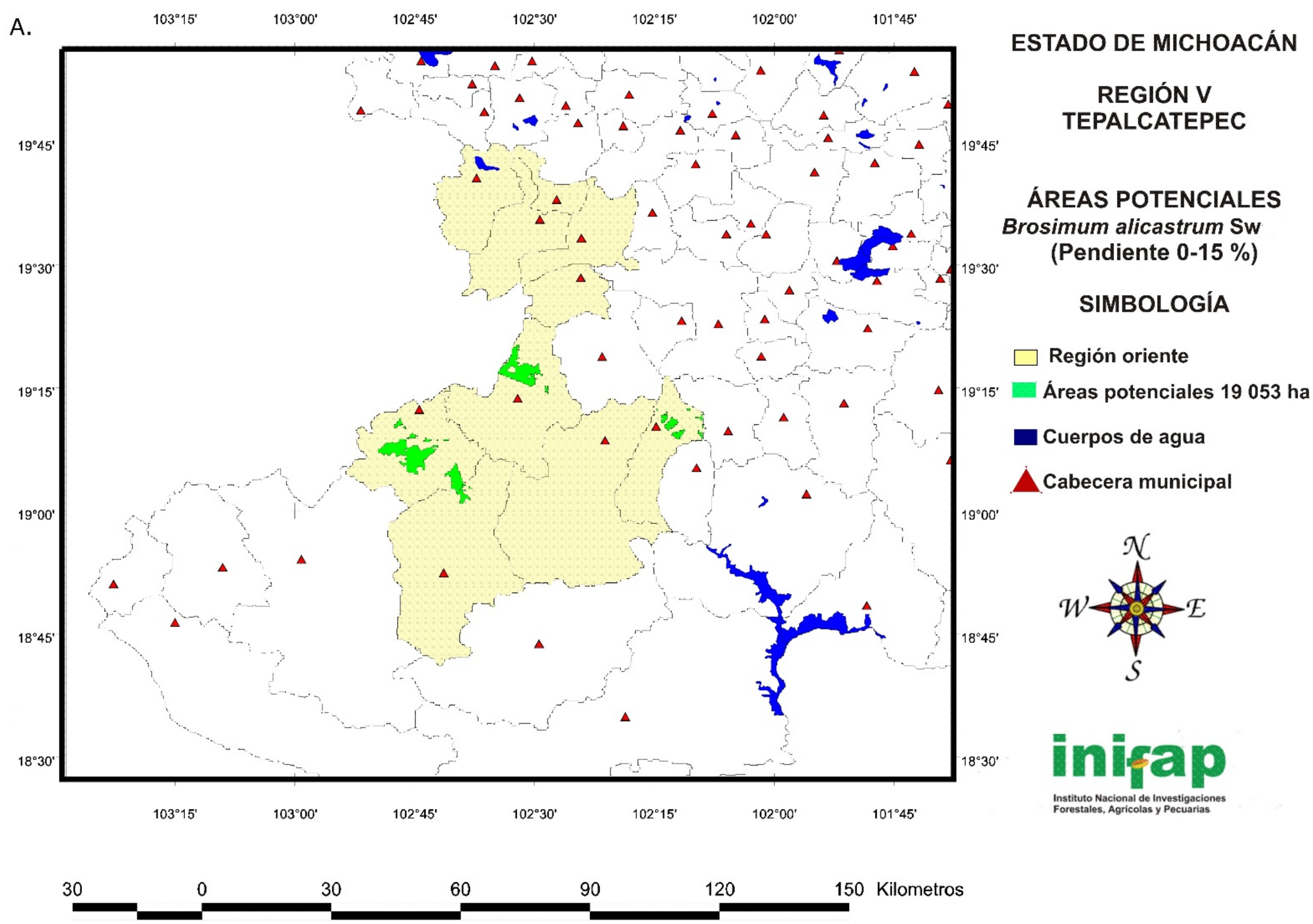
Figure 2. A. Potential areas (0-15 % slope), B. Potential areas (15-30 % slope) for restorative forest plantations of *Brosimum alicastrum* Sw., in the IV *Oriente* region of the state of *Michoacán*.

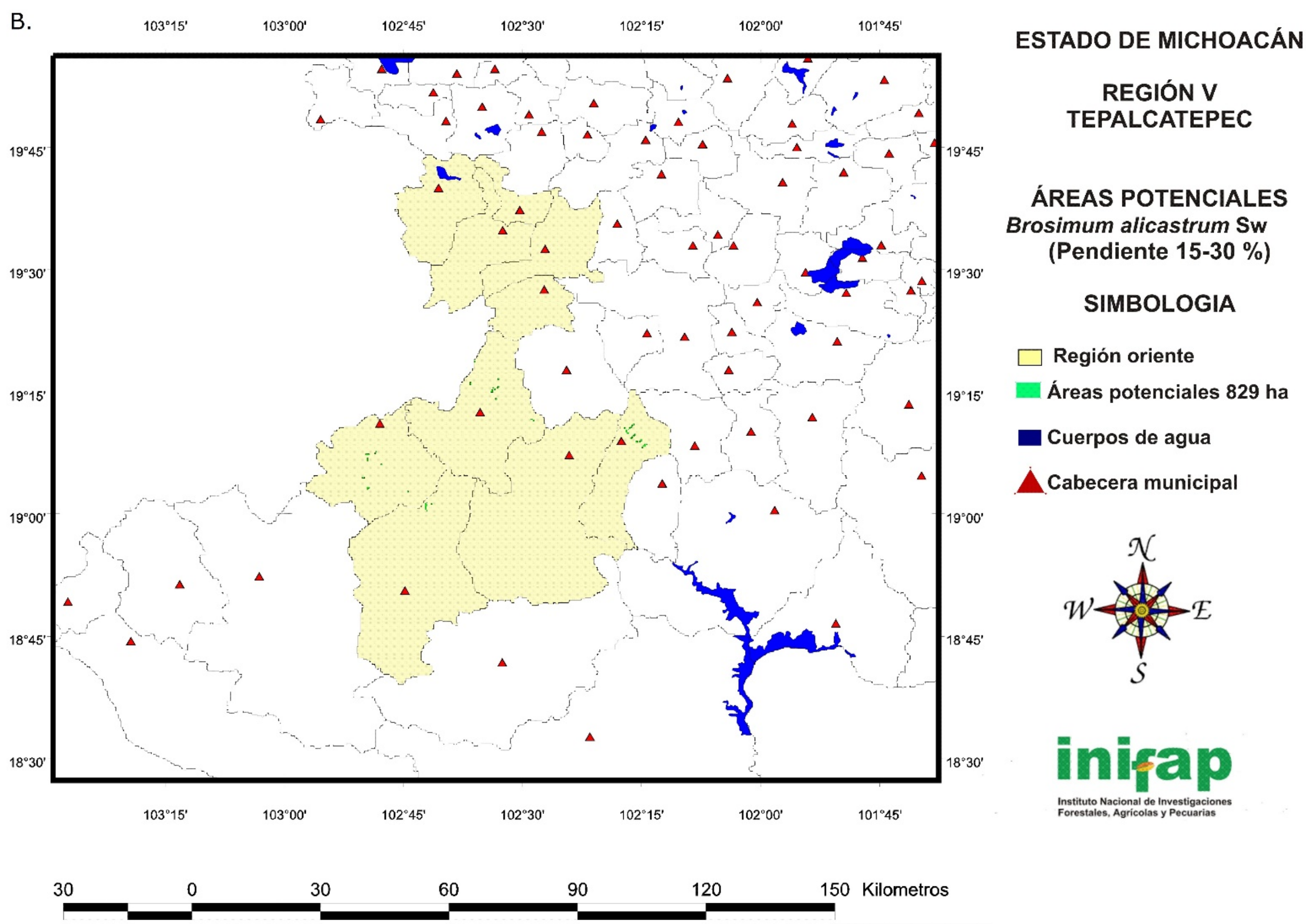
The presence of a small surface area with potential (8 248 ha) located in both slopes is mainly due to the fact that most of the municipalities that conform it have a temperate-cold climate, and only the municipalities of *Tuzantla* and

Tiquicheo have a tropical climate with Vertisol soil and a mean annual precipitation of 700 to 1 000 mm, as well as an altitude gradient below 1 000 m.

In Region V *Tepalcatepec*, the potential areas with a 0-15 % slope correspond to the *Aguililla*, *Buenavista*, *Tepalcatepec* and *Parácuaro* municipalities, with a total of 19 053 ha; the 15-30 % slopes correspond to *Aguililla*, *Buenavista*, *Tepalcatepec* and *Parácuaro*, with 829 ha (Figure 3).

A.



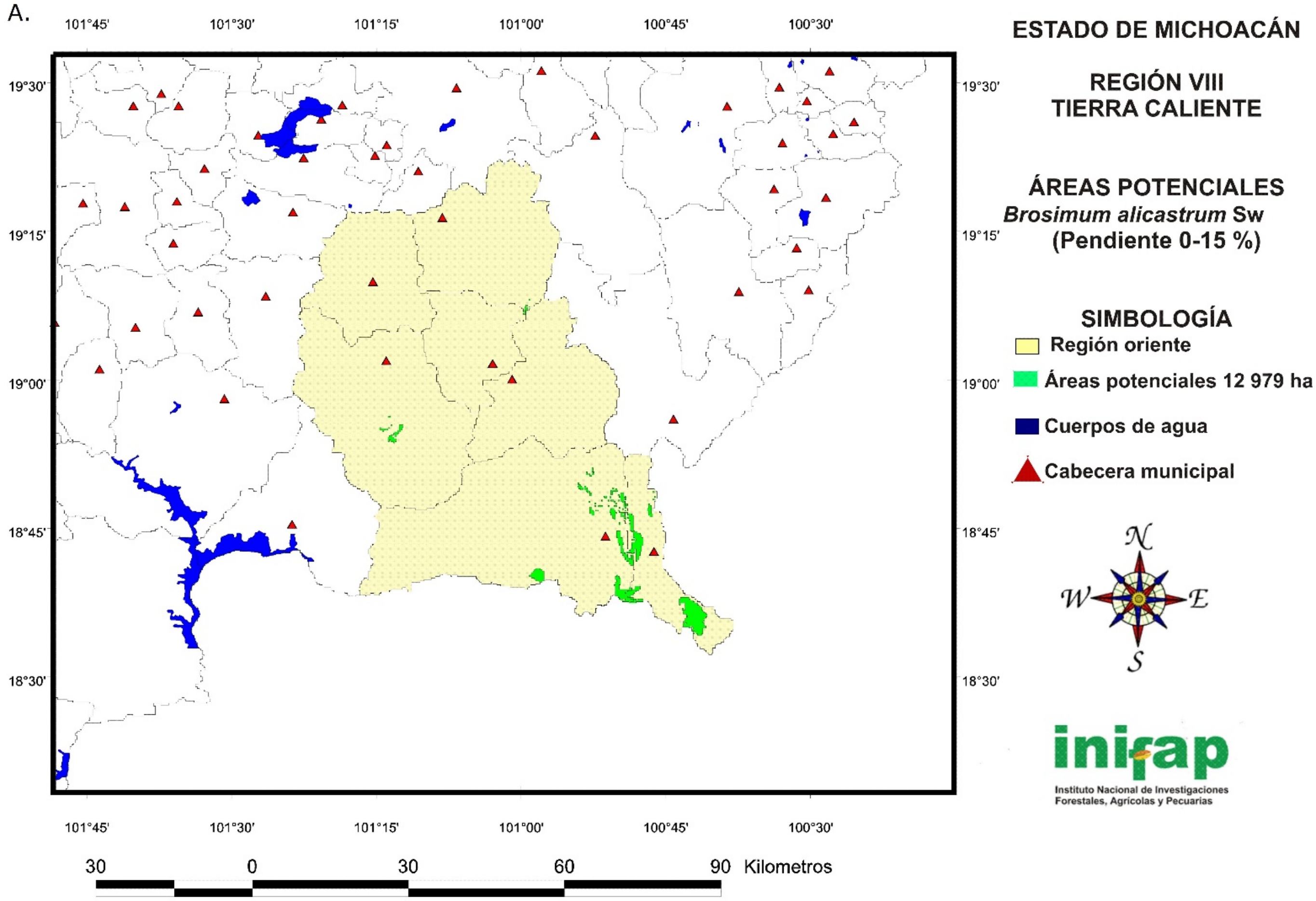


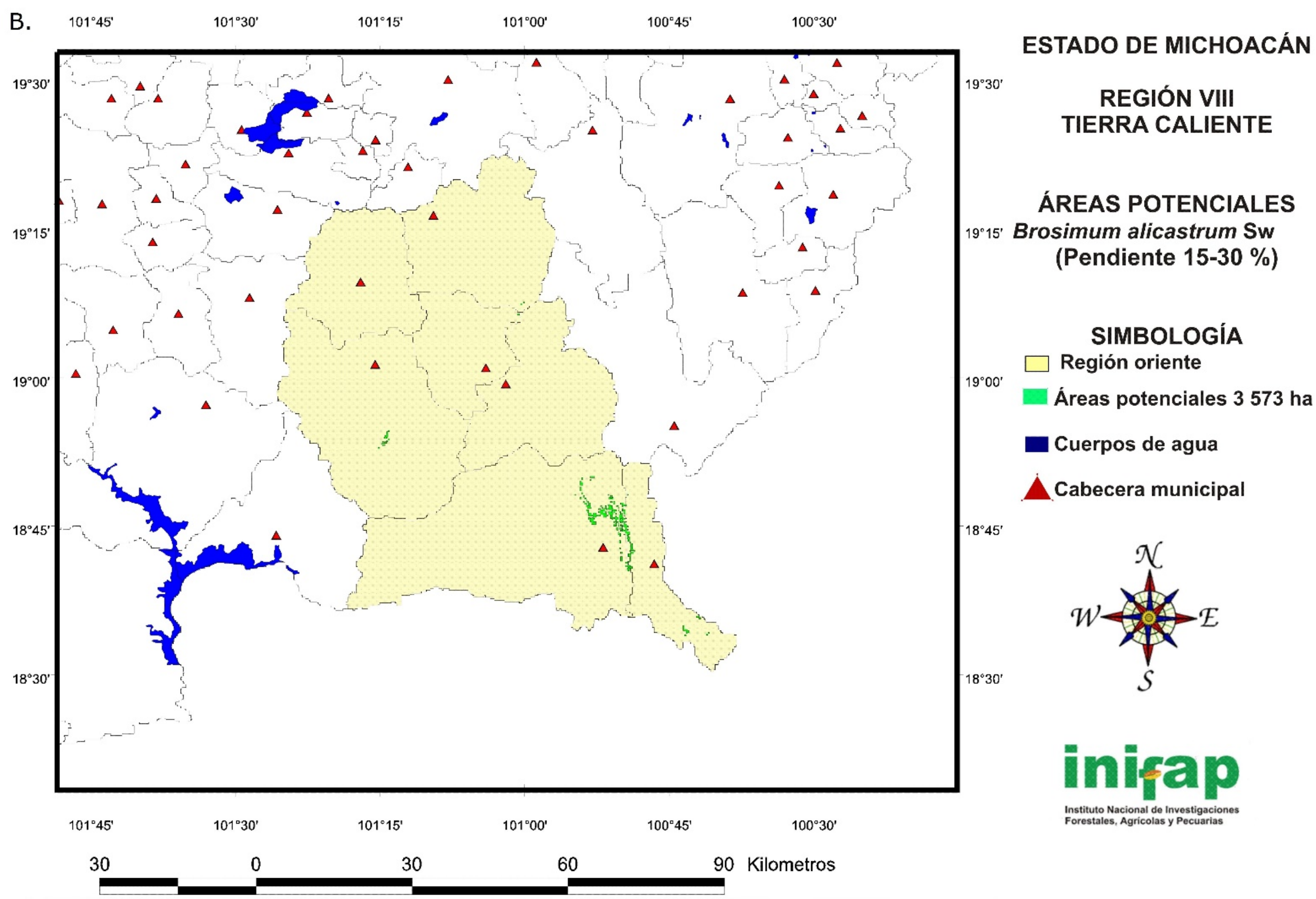
Áreas potenciales = Potential areas; *Pendiente* = Slope; *Simbología* = Symbology; *Región oriente* = Eastern region; *Cuerpo de agua* = Waterbody; *Cabecera municipal* = Municipality

Figure 3. A. Potential areas (0-15 % slope), B. Potential areas (15-30 % slope) for restorative forest plantations of *Brosimum alicastrum* Sw., in the region V *Tepalcatepec* in the state of *Michoacán*.

In Region VIII *Tierra Caliente*, the municipalities with potential areas with a 0-15 % slope are *San Lucas, Huetamo, Turicato, Madero, Nocupétaro* and *Carácuaro,* with a total of 12 979 ha; those with a 15-30 % slope are located in *San Lucas, Huetamo, Turicato, Madero* and *Nocupétaro*, with a total of 3 572 ha (Figure 4).

A.



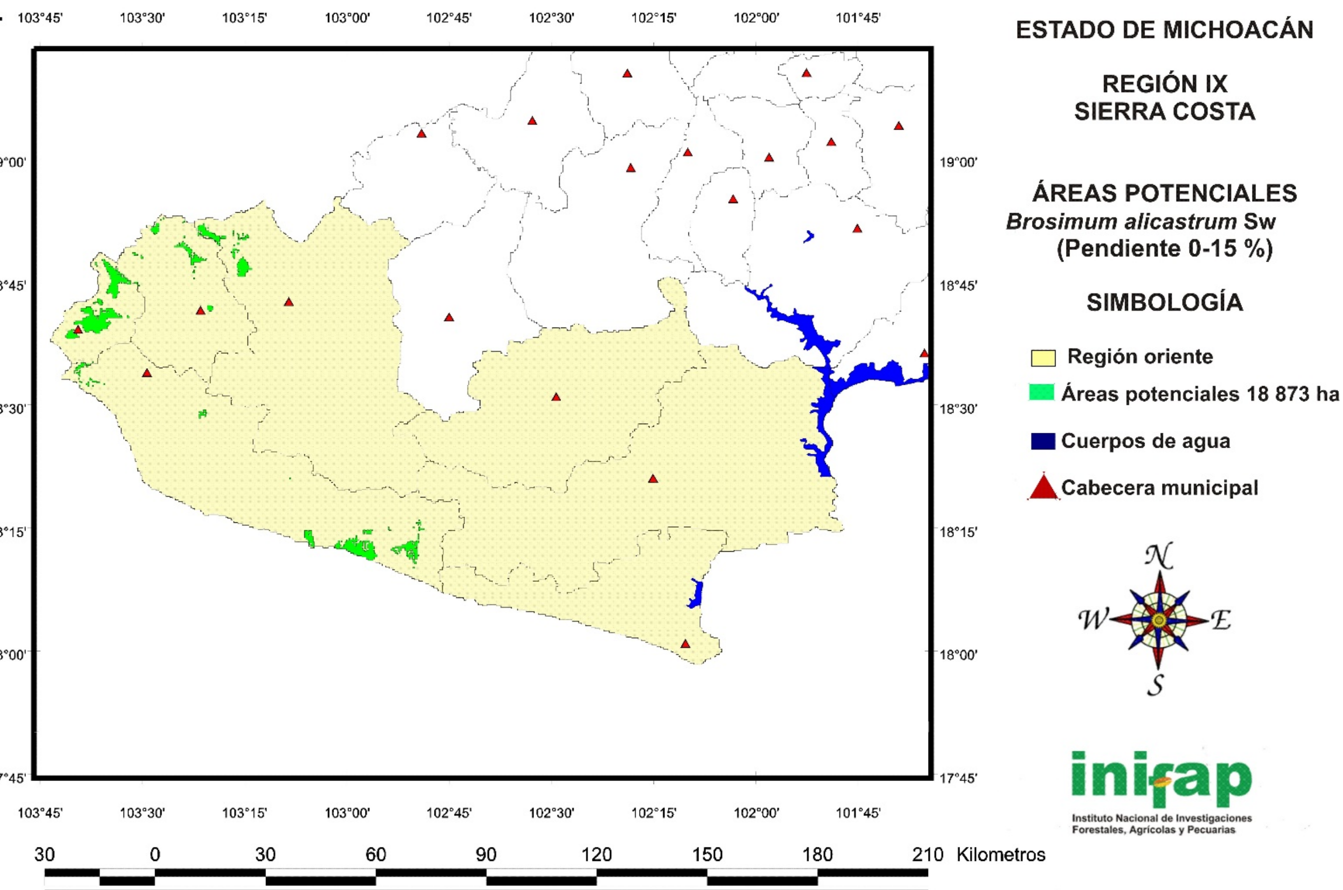


Áreas potenciales = Potential areas; *Pendiente* = Slope; *Simbología* = Symbology; *Región oriente* = Eastern region; *Cuerpo de agua* = Waterbody; *Cabecera municipal* = Municipality

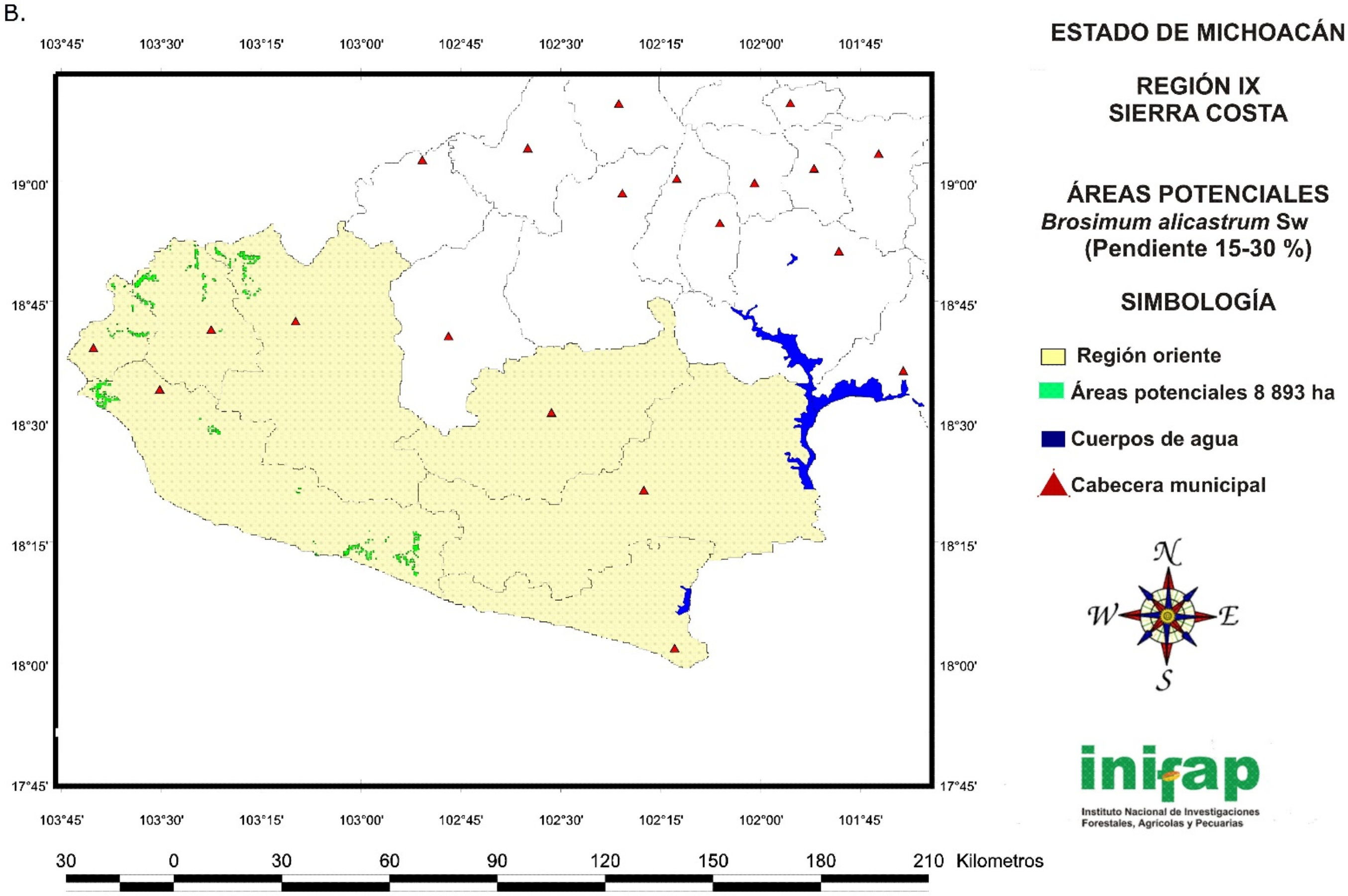
Figure 4. A. Potential areas (0-15% slope), B. Potential areas (15-30% slope) for restorative forest plantations of *Brosimum alicastrum* Sw., in region VIII *Tierra Caliente* in the state *Michoacán*.

In Region IX Coast, the municipalities with potential areas for the two slope intervals, 0-15 % and 15-30 %, are *Aquila, Coahuayana, Chinicuila* and *Coalcomán*, with 18 773 ha and 8 883 ha, respectively (Figure 5).

A.



B.

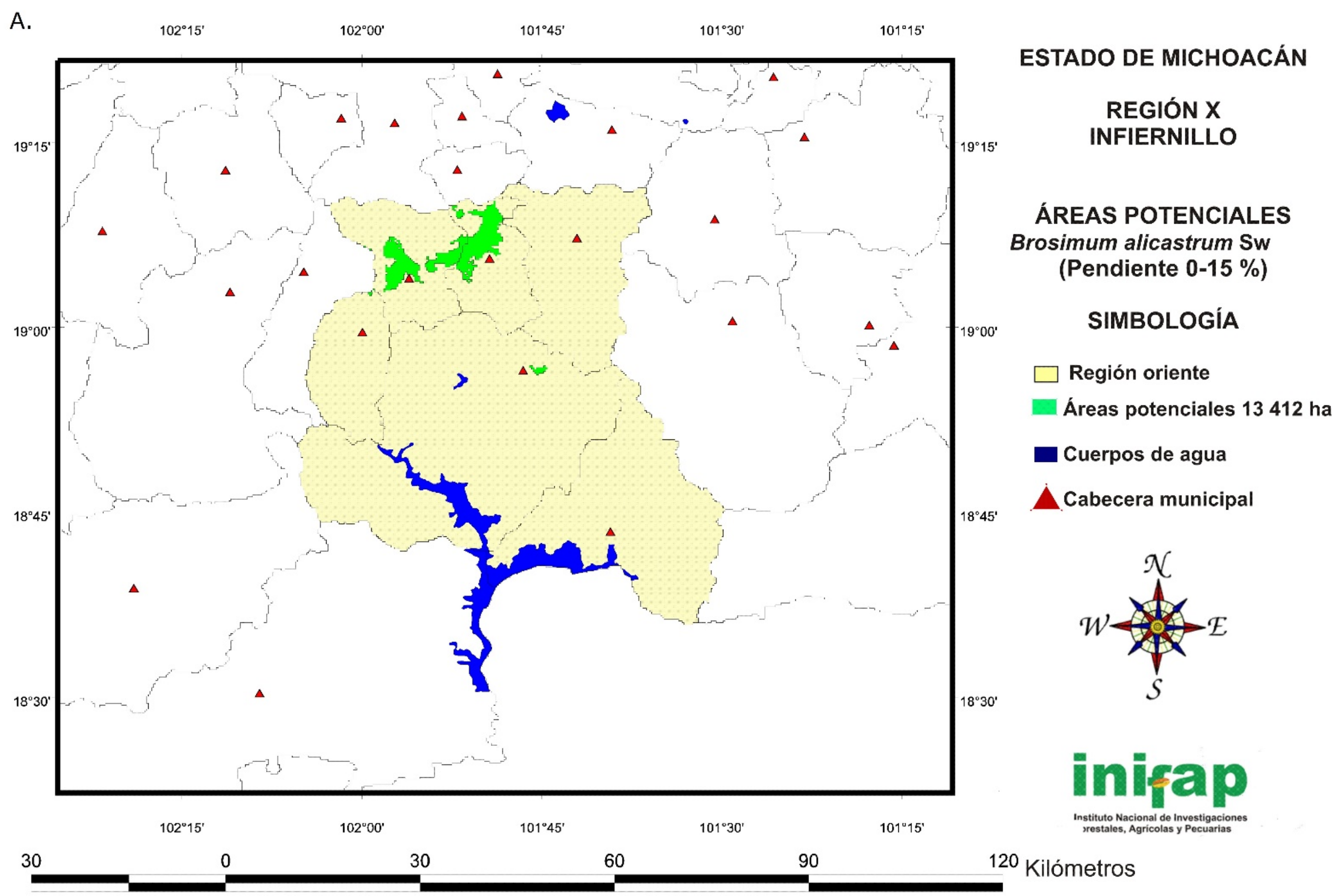


Áreas potenciales = Potential areas; *Pendiente* = Slope; *Simbología* = Symbology; *Región oriente* = Eastern region; *Cuerpo de agua* = Waterbody; *Cabecera municipal* = Municipality

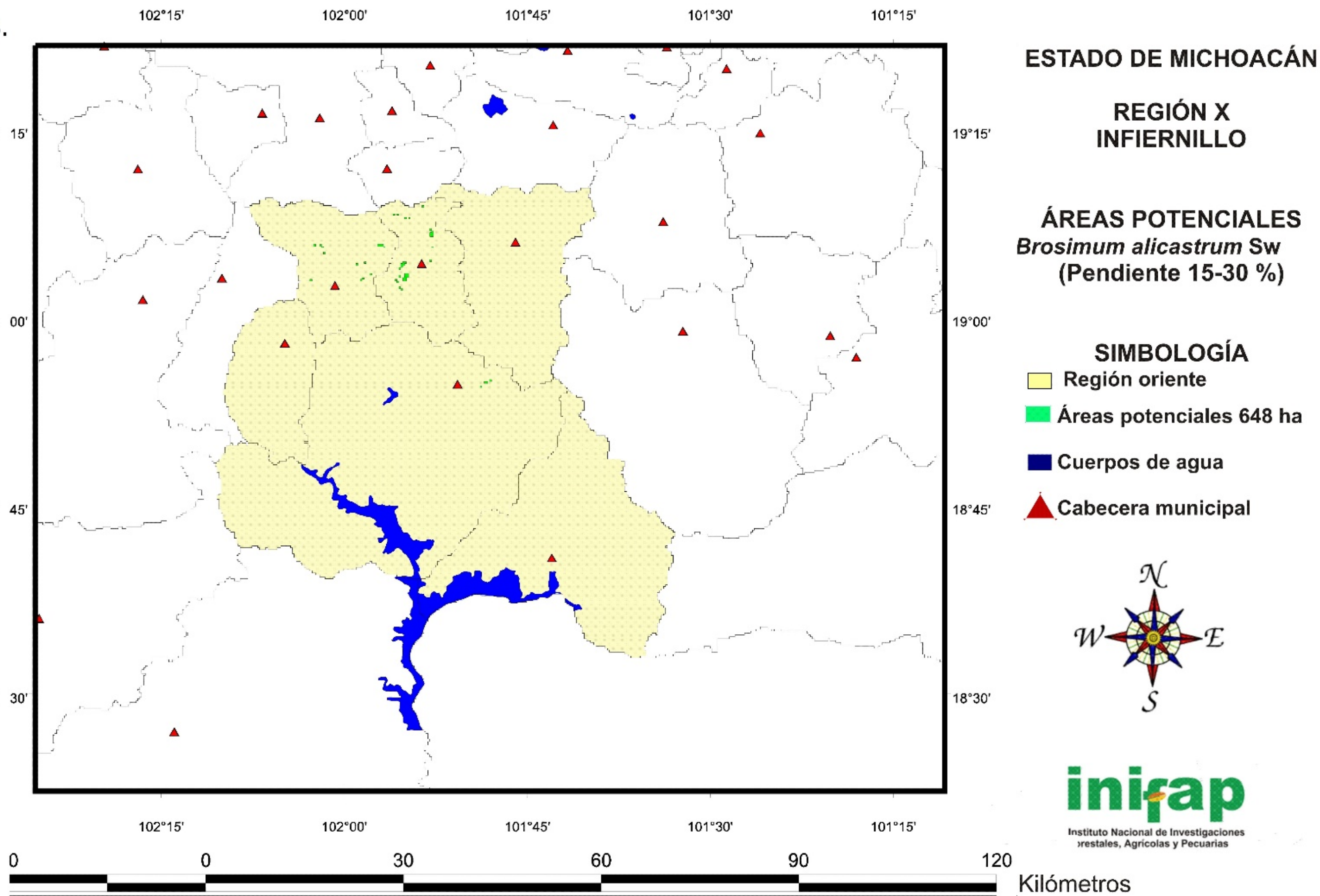
Figure 5. A. Potential areas (0-15 % slope), B. Potential areas (15-30 % slope) for restorative forest plantations of *Brosimum alicastrum* Sw., in region IX Coast in the state of *Michoacán*.

This larger surface with a potential to establish restorative plantations of *B. alicastrum* coincides with the ecological areas where the species is naturally distributed (medium sub perennial rainforest); furthermore, in 1979 Cotecoca registered this as the vegetation type with the best distribution along the Pacific Coast (3 757 850 ha). *B. alicastrum* is a dominant arboreal species in the medium sub perennial rainforest (Vega *et al., 2003).*

In Region X *Infiernillo*, the municipalities exhibiting potential areas with a 0-15 % slope are *Nuevo Urecho, Ario de Rosales, Gabriel Zamora* and *La Huacana*, with a total of 13 412 ha, while those with a 15-30 % slope occur in *Nuevo Urecho, Gabriel Zamora* and *La Huacana*, and cover a total of 648 ha (Figure 6).



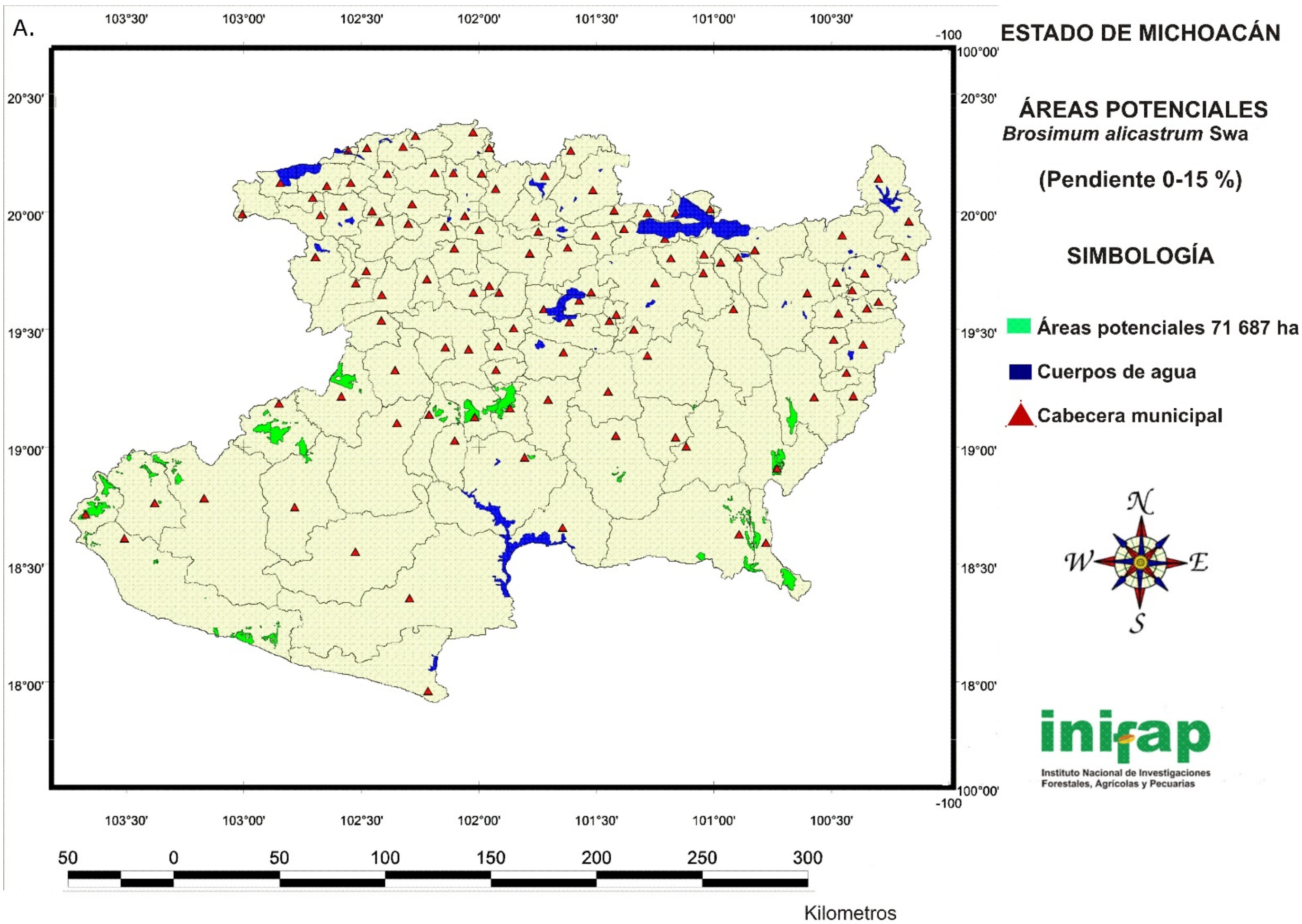
B.



Áreas potenciales = Potential areas; *Pendiente* = Slope; Simbología = Symbology; *Región oriente = Eastern region; Cuerpo de agua = Waterbody; Cabecera municipal* = Municipality

Figure 6. A. Potential areas (0-15 % slope), B. Potential areas (15-30 % slope) for restorative forest plantations of *Brosimum alicastrum* Sw., in region X *Infiernillo* in the state of *Michoacán*.

The potential areas for the establishment of restorative forest plantations of *B. alicastrum* using machinery for 0-15% slopes by forest region are located in: IV *Oriente* (7 470 ha), V *Tepaltepec* (19 053 ha), VIII *Tierra Caliente* (12 979 ha), IX *Sierra Costa* (18 773 ha) and X *Infiernillo* (13 412 ha). The potential surface area in the state is 71 687 ha (Figure 7).



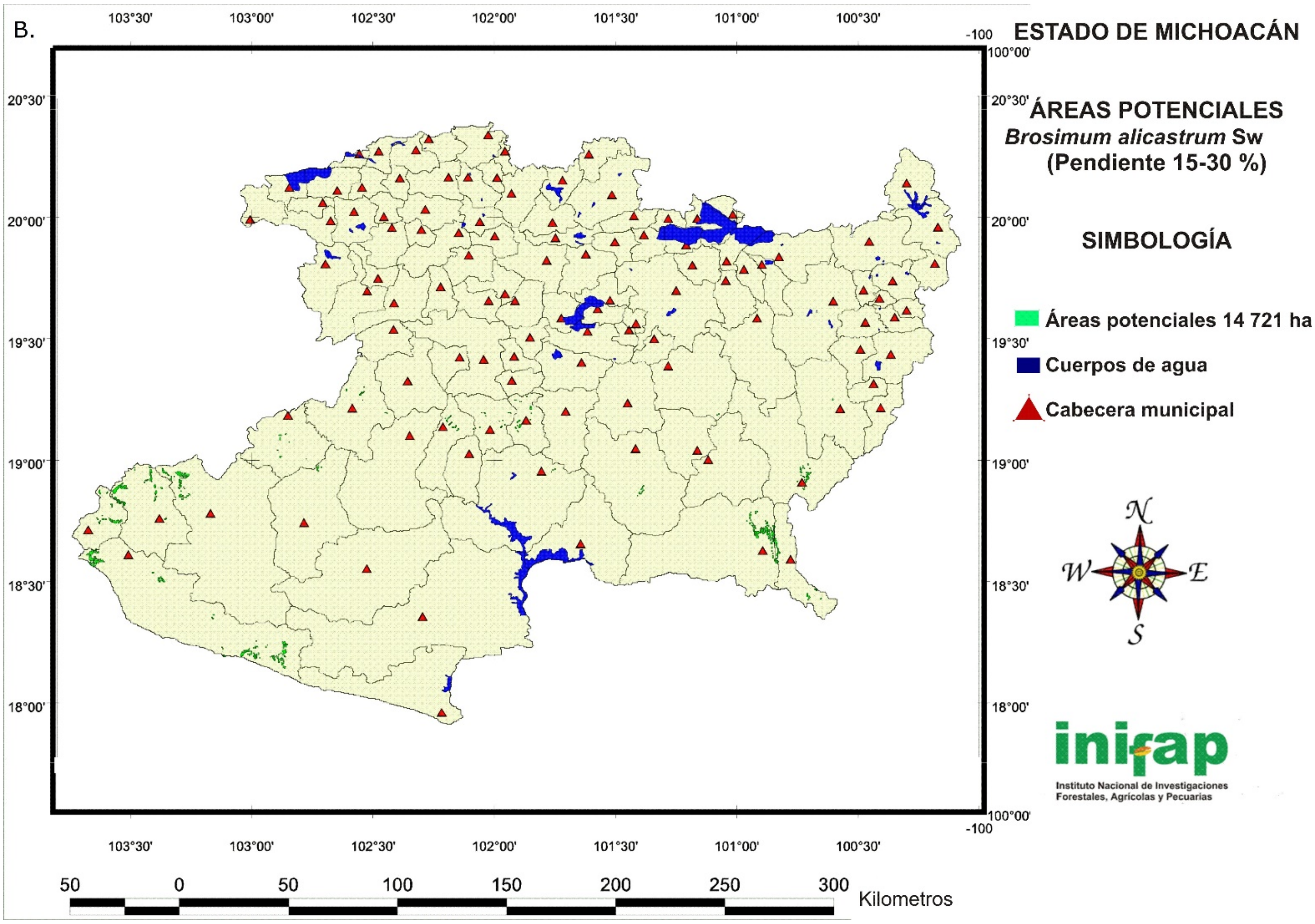


Figure 7. A. Potential areas for restorative forest plantations of *Brosimum alicastrum* Sw., with a 0-15 % slope, B. Potential areas with a 15-30 % slope in the state of *Michoacán*.

The potential areas for the establishment of non-mechanized or manual plantations of *B. alicastrum* at a state level in sites with a 15-30 % slope cover a total surface of 14 721 ha (Figure 7) and are located in the following regions: IV *Oriente* (778 ha), V *Tepalcatepec* (829 ha), VIII *Tierra Caliente* (3 573 ha), IX *Sierra Costa* (8 893 ha) and X *Infiernillo* (648 ha).

The total productive potential corresponds to 86 408 ha, mainly distributed in regions V and IX (*Tepalcatepec* and *Sierra Costa*), with 47 548 ha. The lowest limit of the altitude interval was considered to be the sea level, and the highest limit, up to 800 masl, as in the Pacific Coast (Vega *et al.*, 2003).

These results are similar to the ones cited by Rueda *et al.* (2006) and Rueda *et al*. (2007), who used the same variables to generate the maps of potential areas for forest plantations of 11 species of pine and six tropical species in the state of *Jalisco*. They also agree with those of Sáenz *et al.* (2000), authors who use similar edafoclimatic variables to determine the potential areas for plantations of *A. religiosa, P. pseudostrobus* Lindl.*, P. michoacana* Martínez*, P. montezumae* Lamb.*, P. teocote* Schiede ex Schltdl. & Cham., *P. oocarpa* Schiede ex Schltdl., *P. ayacahuite* Ehrenb. ex Schltdl., *P. lawsonii* Roezl ex Gordon and *P. herrerae* Martínez, in eastern *Michoacán*.

Likewise, they agree with the results registered by Sáenz *et al.* (2011a and 2012) for commercial forest plantations and for silvopastoral systems in *Michoacán*; with those of the study by Meza (2003) for the location of potential areas for the establishment of Damiana (*Turnera diffusa* Willd.) plantations, and with the results obtained by Sáenz *et al*. (2011b) and Muñoz *et al*. (2016a; 2016b), for determining potential areas of commercial forest plantations in the state of *Michoacán*.

As for the verification of the maps, the information obtained in field was confronted with the environmental requirements existing in the bibliography in order to establish the degree of reliability of the generated maps. The purpose was to corroborate whether or not an area defined as potential for the studied species corresponded to the climate and soil conditions cited by various authors

(Batis *et al*., 1999; Chavelas and Dewall, 1988; Von Carlowitz *et al*., 1991; SIRE, 2005; Vega *et al.,* 2003; Vega 1989; Rzedowski, 1981; CNIC, 2005; Pellicer, 2005).

The sampling of the four sites located in the municipalities of *San Lucas, Huetamo* and *Nuevo Urecho* confirm that the edafoclimatic conditions registered in these correspond to the soil type, slope, altitude and type of vegetation documented in the literature for *B. alicastrum*. However, they were insufficient, as the verification took place in only two of the five forest regions of *Michoacán* that had potentials to establish restorative plantations of this species (Table 3).

Table 3. Altitude, slope and soil type of the sampling sites for the verification of the potential areas for commercial plantations of *Brosimum alicastrum* Sw. in the state of *Michoacán*.

Site	Municipality	Altitude (masl)	Slope (%)	Type of soil
1	*San Lucas*	440	0-15	Vertisol
2	*Huetamo*	433	0-15	Vertisol, Cambisol and Rendzina
3	*Nuevo Urecho*	625	15-30	Vertisol, Rendzina and Planosol
4	*Nuevo Urecho*	514	0-15	Vertisol

The generation of maps of the potential areas together with the implementation of good reforestation practices with native species (Vanegas, 2016) will make it possible to restore the capacity of forest ecosystems to generate environmental services and productive activities through sustainable exploitation. It is crucial to recover those areas that were wooded in the past in the various forest regions of *Michoacán*.

This will also allow the reforestation of the priority surface area in the state, consisting of eroded areas and induced grasslands that add up to 641 971 ha, equivalent to 10.9 % of the total surface, and the prioritization of those forest regions with the largest total surface area registered by the *Comisión Forestal del Estado de Michoacán* (Forestry Commission of the State of *Michoacán*) through the *Inventario Forestal y de Suelos de Michoacán de Ocampo (*State Forestry and Soil Inventory of *Michoacán de Ocampo*), where there are plans to reforest the *Sierra Costa* region, 185 396 ha (29 %); *Oriente*, with 106 836 ha (17 %), and *Tierra Caliente*, with 96 284 ha (15 %) (Cofom, 2014).

Conclusions

The total surface with a potential for the reestablishment of *B. aliastrum* plantations with restoration purposes in the state of *Michoacán* is 86 408 ha; from these, 71 687 has correspond to 0-15 % slopes, and 14 721 ha, to 15-30 % slopes, distributed in the following regions: IV *Oriente*, V *Tepalcatepec*, VIII *Tierra Caliente*, IX *Sierra Costa* and X *Infiernillo*. Due to its ecological, geological, physiographic and topographic characteristics, the dry tropic of the entity exhibits favorable conditions for the development of the proposed plantations. The information generated is a guide for decision making in regard to the establishment of restorative forest plantations.

Acknowledgements

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

H. Jesús Muñoz Flores: development of the research, capture and analysis of the information, drafting and structuring of the manuscript; J. Trinidad Sáenz Reyes: support with the results and discussion of the manuscript; Agustín Rueda Sánchez: selection of the variables and review of the manuscript; Martín Gómez Cárdenas: field work and review of the manuscript; David Castillo Quiroz: general review of the document and final editing; Francisco Castillo Reyes: drafting and review of the abstract.