Article

Potential distribution of two leguminous species in the microbasin Tula, Mexico

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Abstract

Macroptilium atropurpureum (DC.) Urb and *Vicia sativa* L. are two forage species with potential for the rehabilitation of soils that tolerate drought, compete with unwanted plants and fix nitrogen. However, its potential distribution in Mexico and the convenient areas to introduce them are unknown. The objective of the present work was to evaluate the potential geographical distribution of *M. atropurpureum* and *V. sativa*, in the Tula micro-basin, Mexico using the BIOCLIM ecological niche model, to determine their optimal growth zones, for soil rehabilitation purposes. For the modeling, 15 bioclimatic variables were used, as well as 19 records of the presence of the species *V. sativa* and 219 of *M. atropurpureum*, obtained from the REMIB and MEXU databases. The modeling results indicated that the models, for *M. atropurpureum* and *V. sativa*, have a good predictive capacity, according to the values obtained from the Area under the Curve, AUC, with 0.801 and 0.967, respectively. The potential distribution of the *V. sativa* species ranged from low to very low, 96% of the surface of the micro-basin; while 97% of the surface for *M. atropurpureum* was very low and they registered a regular survival with 70% and 66%, respectively, in the experimental validation in the field. Due to the low distribution potential and their regular survival, the introduction of the two species was not considered an option for soil rehabilitation in the Tula microbasin.

Keywords: *Macroptilium atropurpureum*, *Vicia sativa*, Bioclim.

Introduction

In recent decades, the population of the 14 municipalities that make up the Tula microbasin has increased on average by 2% per year, with a population of 288 196 inhabitants in 2010 (INEGI, 2013a). In addition, the population density increased from 205 to 278 inhabitants km^{-2} (1990-2010), reaching 61 inhabitants km^{-2} above the national average (INEGI, 2013a). This has intensified the pressure on the region's natural resources, due to the demand for goods and services by society (Zamora *et al*., 2020).

In the area there has been a disorderly growth of urban areas, displacing agricultural and forestry areas, in addition to an increase in the area of extraction of construction materials (INEGI, 2017a, 2017b, 2017c), which has caused an increase in the land use change.

According to Zamora *et al*. 2020, in the period from 2000 to 2017 there was an increase of 4.17% agricultural areas in the Tula microbasin, this being an economic activity that deteriorate the soil resource, in addition in the microbasin there are abandoned areas due to the reduction or loss of its productivity, which according to Zavala-Cruz *et al*. (2011) implies that the soil resource is degraded. For this reason, it is necessary to look for alternative plant species that have optimal growth in the region and also allow the rehabilitation of degraded soils.

The *M. atropurpureum* species is located from the southern United States of America and Mexico to Central and South America, specifically in Brazil, Colombia, Ecuador and Perú (McVaugh, 1987). While, *V. sativa* L. is native to Europe, North Africa and West Asia and considered an exotic species in Mexico (Vibrans, 2009b).

Both species belong to the Fabaceae family, to the Faboideae sub family and are used for forage in Mexico (Vibrans, 2009a, 2009b). According to Lewis *et al*. (2005), the Fabaceae family has an extensive geographical distribution in the world; that is, 727 genera, with 19 327 species of cosmopolitan distribution, located mainly in warm and temperate regions. While, in Mexico, 1 851 species have been recognized (Sousa *et al*., 2001). *M. atropurpureum* and *V. sativa* are species that are characterized by tolerating drought, competing with unwanted plants and fixing nitrogen (La O *et al*., 2006; Flores *et al*., 2007).

However, to date, there is no information about their potential geographical distribution at the regional level, despite the fact that due to their characteristics it is possible to use them as multipurpose herbaceous plants. In Mexico, the species *M. atropurpureum* is located mainly in paddocks and roadsides and has been registered in 28 states, while *V. sativa* is located especially in oak pine forests and is registered in 8 states (Flores *et al*., 2007; Vibrans, 2009a, 2009b).

On the other hand, the factors that determine the presence of a species in a geographic area are, among others, abiotic conditions (climate, topography, edaphic conditions, etc.), that is, they are those that determine its ecological niche (Austin, 2002; Soberon and Nakamura, 2009). In the last 15 years, the development of programs for the modeling of ecological niches has been a new field of research with high growth (Kearney, 2006; Lobo *et al*., 2010).

These programs model, based on Hutchinson's ecological niche concept (Hutchinson, 1957; Guisan and Zimmermann, 2000; Elith *et al.*, 2010) relating the biological information of the species (presence-absence and abundance) and the environmental information (Soberon and Peterson, 2005; Soberon, 2007). BIOCLIM is one of the first algorithms used for the modeling of ecological niches, and is supported by envelope functions (Nix, 1986; Busby, 1991); that is, it identifies areas with climatic characteristics similar to the areas where the presence of a certain species has been registered, generating an ecological interval for the species according to the predictive variables (Palacios *et al.*, 2016).

Niche modeling with BIOCLIM has been used in several studies, including that of Finch *et al.* (2006) with invertebrates in Africa, Aguirre-Morales *et al.* (2016) with *Passiflora* subgenus *Astrophea* (Passifloreceae) in Colombia and Palacios *et al.* (2016) with *Prosopis laevigata* (Humb. Et Bonpl. Ex Willd) M. C. Johnston, in each study the potential distribution of the species was determined. Therefore, the objective of this research was to evaluate the potential geographical distribution of two forage legume species: *Macroptilium atropurpureum* (DC.) Urb and *Vicia sativa* L., in the Tula microbasin, Mexico; through the modeling of their respective ecological niches, using the BIOCLIM algorithm, to determine if they can have optimal growth in this region to be used as an alternative for soil rehabilitation.

Materials and methods

Location of area of study

The Tula micro-basin is located between the geographical coordinates: 19° 55' 31'' and 19° 34' 28'' north latitude and 98° 39' 59'' and 98° 28' 16'' west latitude with an area of 1 037.66 km^2 (Zamora *et al.*, 2020). It is made up of the states of Hidalgo (77%), the State of Mexico (18.03%) and Tlaxcala (4.8%) with a total of 14 municipalities.

The Tula microbasin belongs to the hydrological region 26. The Panuco River Basin and the physiographic province of the transverse Neovolcanic axis, has an altitudinal range of between 2 333 m and 3 223 masl. It has an average annual precipitation of 600 mm and an average annual temperature of 14 °C. The predominant soils are hyphalic pheozem (65% of the surface), litosol (11%) vertisol pelico (11%), cambisol eutric (9%) (INEGI, 2017a; 2017b, 2017c).

By having a wide climatic and edaphic variety, it allows the existence of different types of vegetation, among which are forests of tascate, pine, oak, crasicaule scrub, secondary vegetation, seasonal agriculture and irrigation agriculture (INEGI, 2017d).

Obtaining presence data

The records of the presence of the species *M. atropurpureum* and *V. sativa* were obtained from the database of the World Biodiversity Information Network (REMIB) and the National Herbarium of Mexico of the Institute of Biology, UNAM (MEXU), which They have been used in a large number of modeling studies of potential species distribution areas and ecological niche modeling (Herrera and Cortes, 2009; Martínez-Méndez *et al.*, 2016; Palacios *et al.*, 2016; Reynoso *et al.*, 2018).

The records of both species were purified, in order to eliminate repeated records or those that did not contain a coordinate system; through Geographic Information Systems (GIS) (Guisan and Zimmermann, 2000; Broennimann *et al*., 2012).

Environmental variables

To perform the distribution models of *M. atropurpureum* and *V. sativa*, 15 variables were used (Hijmans *et al*., 2005). 14 of them were derived from the monthly values of maximum temperature, minimum temperature and precipitation, obtained from the WorldClim Version 1.4 platform (http://www.worldclim.org/), which represent the conditions from 1970 to 2000. In addition to the INEGI digital elevation model (INEGI, 2013b) with a spatial resolution of 120 m, as a topographic variable (Table 1).

Table 1. Variables incorporated in the modeling of the ecological niches of V. sativa and M. atropurpureum.

Key	Environmental variable
BIO1	Average annual temperature
BIO2	Average daytime temperature range (monthly mean (maximum temperature-minimum temperature))
BIO3	Isothermality (BIO2 / BIO7)∗(100)
BIO4	Seasonality of temperature (standard deviation ∗ 100)
BIO5	Maximum temperature of the month plus heating
BIO6	Minimum temperature of the coldest month
BIO7	Annual temperature range (BIO5-BIO6)
BIO10	Average temperature of the warmest quarter
BIO11	Average temperature of the coldest quarter
BIO12	Total annual precipitation
BIO13	Precipitation of the wettest month
BIO14	Driest month precipitation
BIO15	Seasonality of precipitation (Coefficient of variation)
BIO16	Precipitation of the wettest quarter
BIO17	Driest quarter precipitation
Alt	Altitude (m)

DIVA-GIS modeling

The analysis of potential geographic distribution of both species was performed with the DIVA-GIS ver. 7.5.0, using the BIOCLIM algorithm. To use this program, it was necessary to homogenize the layers to a standard size of 21.16 km^2 and they were cut with the pre-established limit of the Mexican Republic, using the QGIS 2.14.3 program (Martínez-Méndez *et al*., 2016; Reynoso *et al*., 2018). Once the modeling was done, the layer was cut with the limit of the Tula microbasin. To determine the estimated fitness for development of both species, the scale proposed by Palacios *et al*. (2016) that includes 6 intervals: null, very low, low, medium, good, optimal.

Statistical validation

The predictive ability of a model is evaluated with a presence dataset independent of the one used to calibrate the model (Guisan and Zimmermann, 2000). The receiver operated curve (ROC) assesses the predictive ability of distribution models by means of the area under the curve (AUC), which measures the model's ability to correctly classify a species as present or absent (Hanley and McNeil, 1982).

AUC values can be interpreted as the probability that, when a point of presence and one of absence are randomly selected, the point of presence will have a higher suitability or probability value on the model. According to Araujo and Guisan (2006), the AUC values to classify the precision of the models is: 0.5-0.6= insufficient; 0.61-0.7= poor; 0.71-0.8= regular; 0.81-0.9= good; 0.91-1= excellent. Although, AUC values between 0.7 and 0.9 are considered models with good precision (Peterson *et al*., 2001).

Field survival assessment

According to Ramírez (2011), the evaluation of survival in the field allows obtaining a quantitative measure of the success of the plantation under the influence of site factors. The survival assessment of the *V. sativa* and *M. atropurpurem* species was carried out during the years 2018 and 2019, in the common de San Felipe Teotitlan, which covers part of the municipalities of Axapusco and Nopaltepec, in the State of Mexico, within the Tula micro-basin (Figure 1), the experiment was carried out in an area 20 x 55 m wide and long, respectively, located between the geographical coordinates of 19° 50' 24 and 19° 49' 00'' latitude. north and 98° 42' 00'' west longitude,
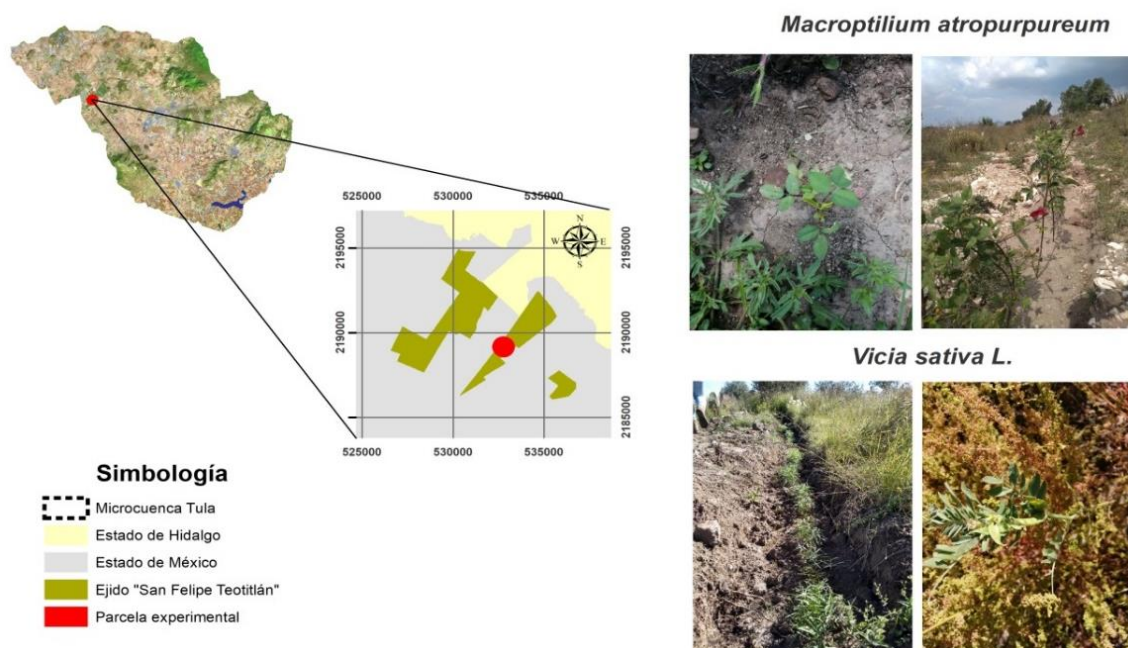

Figure 1. Location of the experimental area for the introduction of species in common San Felipe Teotitlan, Mexico.

The implementation of the experiment consisted of producing seedlings of *M. atropurpurem*, which is a perennial species, in the greenhouse of the Department of Animal Husbandry at the Autonomous University Chapingo (UACH), during the period from May to July 2018. Also, it was carried out the preparation of the ground, beginning with the breaking of the ground to contour lines with a spacing of 11 m, and the opening of trenches of 20 x 0.3 x 0.2 m in length, width and depth, respectively.

Subsequently, the trenches were filled with soil from the region and zeolite (0.5 kg plant^{-1}), due to the presence of stone and tepetate in the first 0.15 m depth. Finally, the *M. atropurpurem* seedlings were transplanted during the first week of August at a distance of 0.2 m between each plant, in the first 10 meters of the trench. It is worth mentioning that *V. sativa*, which is an annual species, was planted directly in the field in the remaining 10 meters of the trench, in the same period and at the same distance.

In December 2018, survival was assessed, defined as the number of seedlings that survived at the end of the follow-up control, with respect to the number of plants at the start of the study, this value is expressed as a percentage (Ramos-Font *et al*., 2015). In the month of June 2019, all the dead plants were replaced, this time the seeding was direct in both species and survival was evaluated, in the month of October 2019.

Results and discussion

The presence records obtained from the MEXU and REMIB databases for the species *M. atropurpureum* were 219 after the purification process of the 856 records with the QGIS 2.14.3 software and for the species *V. sativa* 19 records were obtained after debugging the 124 records.

The presence records indicated that *M. atropurpurem* has a wide distribution in Mexico, and was mainly identified in the states of Oaxaca (68 records), Puebla (29), Campeche (25) and Chiapas (20), which coincides with what reported by Vibrans (2009a). While *V. sativa* was registered in seven states, with the State of Mexico (9 records) having the most records, which coincides with what was reported by Vibrans (2009b); Flores *et al*. (2007) (Figure 2).
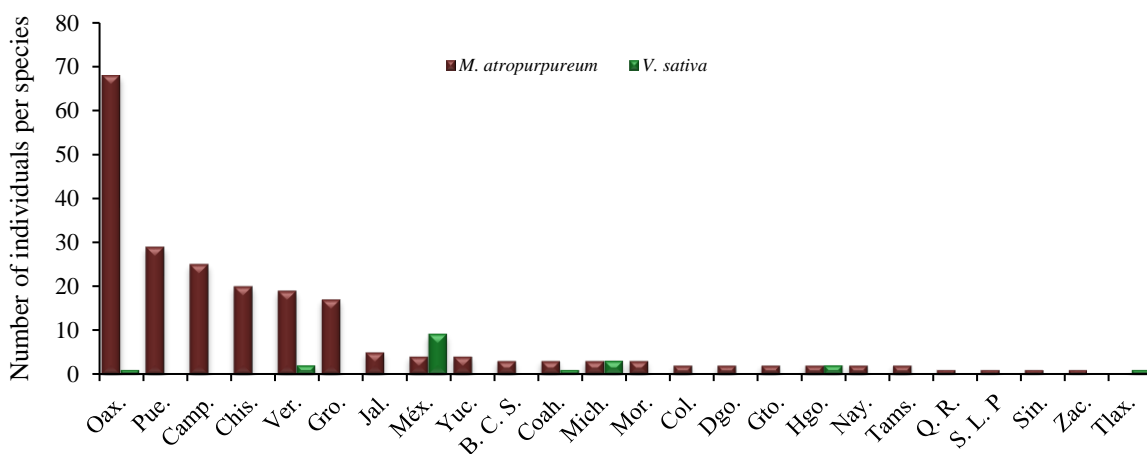

Figure 2. States with georeferenced records of *V. sativa* and *M. atropurpurem* in Mex.

According to the values obtained from the records for *V. sativa* and *M. atropurpurem*, the ranges of the environmental variables in which the largest number of individuals have been reported nationwide were obtained. For *V. sativa*, the average annual temperature range obtained was from 13.8 to 17.3 °C (Table 2), this range indicates that it does not tolerate cold for optimal growth, as mentioned by Alfonso (2007).

Table 2. Bioclimatic intervals of the areas in which the presence of *V. sativa* and *M. atropurpurem* is recorded in Mexico.

Environmental variable	*V. sativa*		*M. atropurpureum*	
	Interval	Int. higher frequency	Interval	Int. higher frequency
Annual mean temperature (°C)	6.9-24.1	13.8-17.3	12.3-27.6	24.5-27.6
Average daytime t. range (° C)	9.9-18.1	14.8-16.4	3.2-19.8	9.8-13.1
Isothermality	57.7-74.5	67.8-71.2	23.9-83.7	59.8-71.7
Seasonality of the t.	124.6-351.5	170-215.4	59.7-788	205.4-351
T. max. warmest month (° C)	15.8-35.9	23.8-27.9	21.7-40	32.7-36.3
T. min. coldest month (° C)	-1.5-12	1.2-3.9	-2.9-20.1	15.5-20.1
Annual t. range (° C)	16.8-26	22.3-24.2	13.2-38.6	18.3-23.4
Warmest quarter mean t. (° C)	8.4-27.6	16.1-20	14-31.1	27.6-31.1
Coldest quarter mean t. (° C)	5.4-21.3	8.6-11.8	6.8-26.5	18.6-22.6
Total annual precipitation (mm)	531-1981	821-1111	70-3386	733.2-1396.4
P. of the wettest month (mm)	92-404	216.8-279.2	16-638	140.4-264.8
P. of the driest month (mm)	2-45	2-10	0-99	0-19.8
P. seasonality (mm)	70.8-113.1	96.2-104.7	52.3-136.2	102.6-119.4
P. of the wettest quarter (mm)	266-1068	586.8-747.2	35-1693	366.6-698.2
P. of the driest quarter (mm)	17-142	17-42	0-327	0-65.4

Regarding the precipitation range of the sites in which it obtained the highest frequency of presence, it was from 821 to 1111 mm, with a general interval of 531 to 1 981 mm, a range that differs from that reported by Flores *et al*. (2007), who indicate that it grows and develops from 200 to 400 mm because the species withstands water stress.

For the *M. atropurpurem* species, the highest number of individuals were found at an average annual temperature of 24.5 to 27.6 °C, indicating that it has a lower tolerance at the cold than the *V. sativa* species. While, the annual precipitation range was from 733.2 to 1 396.4 mm, a range that is within the range 650-1 500 mm reported by Vibrans (2009a) for this species and between that reported by (Guerrero *et al*., 2009) 650 at 1 750 mm, the general range obtained was from 70 to 3 386 mm, which explains its extensive distribution in Mexico and its tolerance to water stress.

The ranges of the environmental variables obtained for Mexico and the climatic information of the Tula micro-basin, which has an average annual temperature of 14 °C and an average annual precipitation of 600 mm (INEGI, 2017a, 2017b, 2017c), indicate that *V. sativa* according to

temperature if you can have adequate growth. However, in the micro-basin there is not an optimal precipitation for the optimal growth of this species. In the case of *M. atropurpurem*, the micro-basin does not have an average annual temperature or an average annual precipitation adequate for its optimal growth.

The results obtained from the potential geographical distribution by modeling with BIOCLIM, for the species *V. sativa*, indicates that the micro-basin has a total area of 41.51 km^2 with zero potential, which is equivalent to 4% of the surface, while 996.15 km^2 (96%) have potential; of this surface, 21% (209.19 km^2) corresponds to low potential and 79% (786.96 km^2) corresponds to a very low potential (Figure 3).
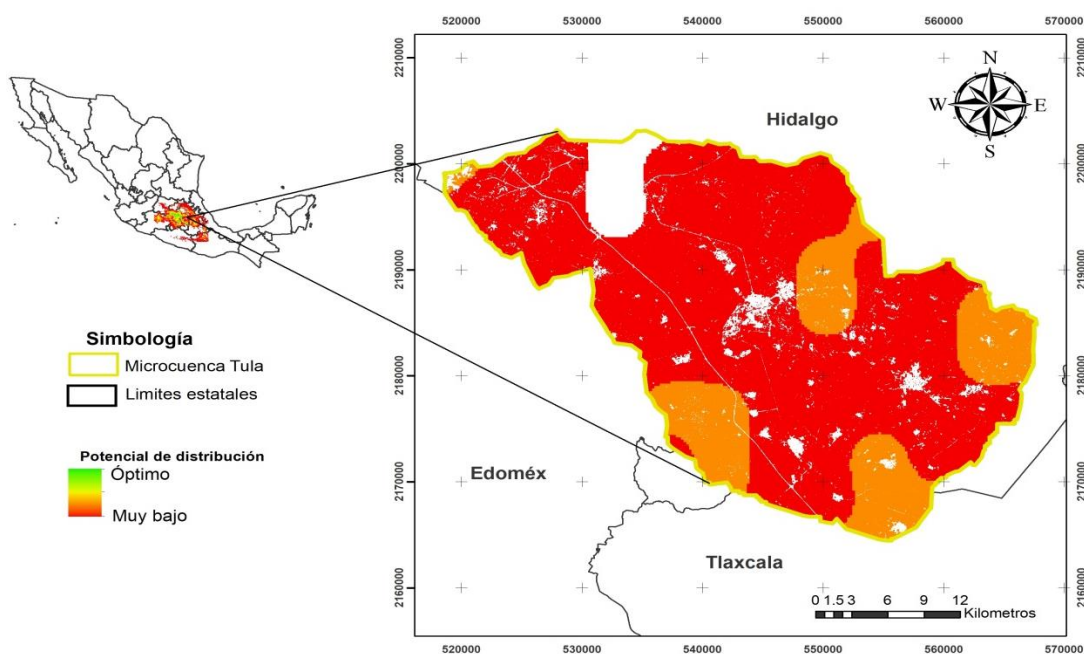

Figure 3. Potential distribution of *V. sativa* in the Tula microbasin, Mexico.

This indicates that in the micro-basin the species will develop but will not reach its optimal growth and therefore yield, since the species requires a higher average annual rainfall. The potential geographical distribution of the *M. atropurpureum* species in the micro-basin was 3% (31.12 km^2) with zero potential and 97% (1 006.53 km^2) with very low potential (Figure 4), indicating that the species it will not have optimal growth in this region, because it requires a higher temperature and annual average precipitation.

Regarding the evaluation of the survival of the species in the field, which allows to quantitatively measure the success of the plantation under the influence of the factors of the site (Ramirez, 2011), during the year 2018, this was 100% for *M. atropurpurem* and 0% *V. sativa*, the latter value was attributed to the presence of wildlife. However, in the evaluation of the year 2019, both species recorded a regular survival, with 66% for the *M. atropurpurem* species and 70% for *V. sativa*.
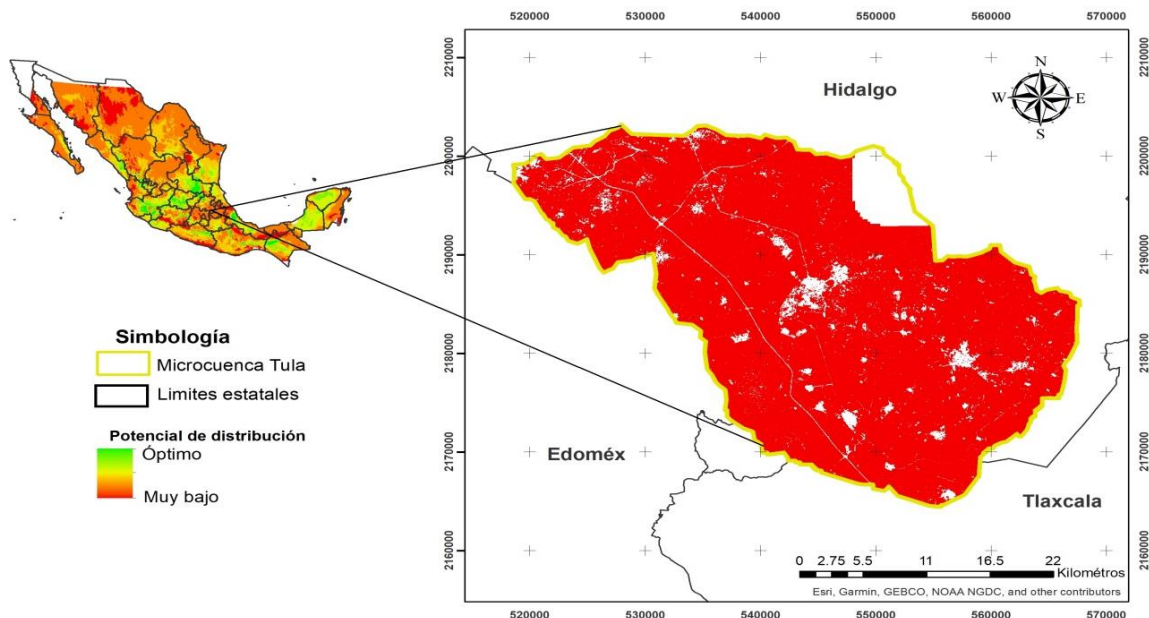
Figure 4. Potential distribution of *M*. *atropurpureum* in the Tula microbasin, Mexico.

This last species competed favorably against the annual herbaceous plants of the site and reached pod formation, while *M*. *atropurpurem* had a slow growth with a height less than 0.01 m in the vegetative state. It is worth mentioning that it is possible to improve their adaptation by improving the edaphic aspects as they did in Zacatecas with the *V*. *sativa* species, by applying auxiliary irrigation, fertilizing and controlling weeds (Flores *et al*., 2007; Flores *et al*., 2016). However, due to the costs involved, it is not recommended that they be used in projects for this region.

Finally, the AUC values, obtained for the validation of the prediction precision of the models, for *M*. *atropurpureum* and *V*. *sativa*, were 0.801 and 0.967 respectively, values that indicated that the models have a good prediction precision (Peterson *et al*., 2001; Araujo and Guisan, 2006; Phillips and Dudík, 2008).

Conclusions

The ecological niche models obtained with the BIOCLIM algorithm for the *M*. *atropurpurem* and *V*. *sativa* species have good prediction precision to obtain the potential distribution of the species. The low distribution potential obtained in the modeling and the regular survival of the leguminous species *M*. *atropurpurem* and *V*. *sativa* indicated that these species are not the most suitable to enter the Tula microbasin; however, studies are needed on the adaptation of these species to the region by improving the edaphic aspects of the introduction site.

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