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Article

# Tecnologías agroforestales para una Selva Baja Caducifolia: propuesta metodológica

# Agroforest technologies for a tropical dry forest: a methodological proposal

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**Resumen**

El diseño e implementación de tecnologías agroforestales presenta diversos problemas, debido a la complejidad de las mismas y a la falta de paquetes de tecnología en México. El objetivo de este trabajo fue proponer una metodología de evaluación de tierras, para diseñar tecnologías agroforestales en el ejido Ajuchitlán, Tlaquiltenango, Morelos. El método consistió en el diagnóstico de los aspectos biofísicos y agroforestales para definir unidades básicas relativamente homogéneas (UP), identificar las especies más representativas y detectar las principales limitantes. Se realizaron entrevistas semiestructuradas a los productores para conocer otras restricciones, determinar su principal interés económico y seleccionar las especies arbóreas y arbustivas preferidas para el diseño de las tecnologías agroforestales, así como evaluar la viabilidad económica de las mismas. La vegetación secundaria de selva baja caducifolia en sus diferentes densidades, condiciones climáticas y fisiográficas fue la unidad del paisaje (UP) que representó el uso con mayor superficie en la región. Las limitantes detectadas fueron: cercado en las zonas agrícolas y de pastizal, degradación del suelo en la parte alta del área de estudio y disminución de la diversidad vegetal en las unidades de tierra con baja densidad arbórea. Las tecnologías agroforestales propuestas fueron cercas vivas en la zona agrícola-ganadera, barreras vivas en la parte alta y enriquecimiento de acahuales en la unidad de tierra con baja densidad arbórea. El buen manejo silvícola de las tecnologías sugeridas puede incrementar los ingresos económicos de los agricultores, principalmente, por la venta de leña. Esta investigación contribuye a obtener información local de la zona.

**Palabras clave:** Barreras vivas, caracterización biofísica, cercas vivas, enriquecimiento de acahuales, evaluación de tierras, inventario forestal.

**Abstract**

The design and implementation of agroforestry technologies has some problems due to their complexity and the lack of technology packages in Mexico. The aim of this work was to propose a land evaluation methodology, to design appropriate agroforestry technologies in the *ejido* of *Ajuchitlán*, *Tlaquiltenango*, *Morelos*. The method consisted in the diagnosis of biophysical and agroforestry aspects to define relatively homogeneous basic units (UP), identify the most representative species and detect the main limitations. Semi-structured interviews were conducted with producers to learn about other limitations, determine their main economic interest and select the preferred tree and shrub species for the design of agroforestry technologies and assess their economic viability. The secondary vegetation of the low deciduous forest in its different densities, climatic and physiographic conditions was the UP that represented the use with the largest area in the region. The limitations detected were: fencing in agricultural and grassland areas, degradation of the soil in the upper part of the study area and reduction of plant diversity in land units with low tree density. The proposed agroforestry technologies were live fences in the agricultural-livestock area, live barriers in the upper part and secondary vegetation enrichment in the unit of land with low tree density. Good silvicultural management of the proposed technologies can increase the economic income of farmers, mainly through the sale of firewood. This research helps to obtain local information about the area.

**Key words:** Live barriers, biophysical characterization, live fences, secondary vegetation enrichment, forest inventory, land evaluation.

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# Introduction

There are several problems that directly affect the design and implementation of agroforest technologies in the different agricultural production systems, which is mainly due to the complex nature of agroforest, the lack of proven technology packages and the adoption and acceptance by of the producers (Soto *et al*., 2008). For a good design of these technologies it is essential to have information regarding biophysical, agroforest social and economic aspects (Raintree, 1987).

Müller and Scherr (1990) mentioned that the biophysical characteristics of the project area (climate, elevation, soils and topography) are the most important factors. However, in Mexico there are no precise data for small areas with rugged relief, which may mean that the proposed agroforest technologies are not the most appropriate for the specific conditions of the site, including the selection of shrub, herbaceous and tree species.

The landscape planning method proposed by Duchart *et al.* (1989) can fill that gap by being able to compensate through the use of Geographic Information Systems (GIS), Google Earth ™ and other mapping and spatial analysis tools (Taylor *et al.,* 2010; Fagerholm *et al*., 2013). In this way, the forms of land use can provide immediate benefits to the local population and, at the same time, favor the conservation or recovery of the productive capacity of the systems of the different units of the landscape.

With the parametric method of classification of the landscape, it is possible to superimpose thematic maps on biophysical features, geomorphic forms, climate, river systems, drainage, soils and vegetation cover (Soto and Pintó, 2010). By creating a composite map where you can distinguish landscape units with similar characteristics (Campos *et al.,* 2010; Wang and Yang, 2012). With the above, it is possible to identify appropriate places for the design and establishment of more appropriate agroforest technologies, without neglecting the social and economic aspect of resource owners (Ruiz and Soto, 2015).

The deciduous rainforest is an ecosystem under strong pressure for human activities in Mexico. Mainly due to the extraction of firewood and intensive livestock (Yescas *et* *al.,* 2017). This generates pressure on the plant resource, causing soil degradation and loss of plant diversity. The use and implementation of agroforest technologies can reduce pressure on forest resources and meet the economic needs of producers.

Therefore, the objective of this work was to propose a methodology for land evaluation, with the purpose of designing appropriate agroforest technologies in the *Ajuchitlán* ejido*, Tlaquiltenango, Morelos* State. The method consisted of the diagnosis of biophysical, agroforest, social participation and economic valuation aspects. The detailed diagnosis of the biophysical medium was made by means of a modification to the parametric method of landscape classification to obtain relatively homogeneous basic units (UP, for its acroym in Spanish). The agroforest diagnosis consisted of identifying the most representative species and detecting the main limitations of the UP. In order to include social participation, semi-structured interviews were conducted with producers to learn about other limitations, determine their main economic interest and select the preferred tree and shrub species for the design of agroforest technologies. Subsequently, their economic viability was assessed by calculating the costs of establishment and benefits from the sale of firewood.

## Materials and Methods

The study was carried out in *Ajuchitlán ejido* which belongs to *Tlaquiltenango* municipality south of the *Sierra de Huautla, Morelos* State. It is located between 18°25'20" to 18°29’52” N and 98°54'42" to 98°58’54” O, within the *Eje Volcánico Transversal* and the *Sierra Madre del Sur* provinces; as well as the subprovinces of *Sierra del Sur de Puebla and Sierra and Valles* of *Guerrero* state (INEGI, 2009). It has 2 686 ha and its geographic relief is rugged and its altitudinal range is from 1 000 to 1 800 m. The predominant vegetation is the low deciduous forest (Miranda and Hernández, 1963).

The method consisted of the diagnosis of the biophysical and agroforest aspects, considering the social participation for the design of agroforest technologies and the calculation of their economic viability (Raintree, 1987).

## Detailed diagnosis of the biophysical environment

The parametric method of landscape classification (Duchart *et al.,* 1989) was used to obtain relatively homogeneous basic units of the territory (UP) that resulted from the superposition of the thematic maps of physiography, climate, land use and vegetation. To each basic unit was assigned a name for the use of soil and vegetation, followed by the type of climate and finally with the geoform of the land.

To design the physiographic map, terrain forms, slope and altitude were taken into account. The climate map was prepared based on the methodology of Gómez *et al.* (2008), for which 23 meteorological stations with complete data of at least 20 years were selected (IMTA, 2013). The temperature map was generated using the simple linear interpolation method to obtain specific monthly and annual average temperature data for the study area (Gómez *et al*., 2008).

**Table 1.** Selected weather stations with complete data of at least 20 years in areas near *Ajuchitlán, Tlaquiltenango, Morelos*.

| Key | Name | State | Latitude | Longitude | Altitude (masl) |
|---|---|---|---|---|---|
| 12030 | *Chaucingo, Huitzuco* | *Guerrero* | 18.28 | -99.11 | 830 |
| 12115 | *Huitzuco, Huitzuco* | *Guerrero* | 18.30 | -99.33 | 940 |
| 12081 | *Taxco, Taxco* | *Guerrero* | 18.36 | -99.61 | 1 800 |
| 12126 | *Tlacotepec* | *Guerrero* | 17.78 | -99.96 | 1 802 |
| 12117 | *Ixcateopan, Cuahutemoc* | *Guerrero* | 17.51 | -99.75 | 1 820 |
| 17007 | *Huajintlan, Amacuzac* | *Morelos* | 18.63 | -98.96 | 1 049 |
| 17008 | *Huautla, Tlalquiltenango* | *Morelos* | 18.43 | -99.03 | 971 |
| 17015 | *Tepalcingo, Tepalcingo* | *Morelos* | 18.60 | -98.85 | 1 200 |
| 17016 | *Tequesquitengo, Jojutla* | *Morelos* | 18.60 | -99.25 | 970 |
| 17019 | *Tilzapotla, Puente de Ixtla* | *Morelos* | 18.50 | -99.26 | 950 |
| 17042 | *Zacatepec, Zacatepec* | *Morelos* | 18.65 | -99.18 | 1 226 |
| 17031 | *Jojutla de Juárez (Smn)* | *Morelos* | 18.60 | -99.18 | 891 |
| 17032 | *San Gabriel, Amacuzac* | *Morelos* | 18.61 | -99.35 | 1 008 |
| 17033 | *Xicatlacotla, (Cfe)* | *Morelos* | 18.58 | -99.20 | 1 000 |
| 17036 | *Lagunillas de Rayón, Dge* | *Morelos* | 18.48 | -98.71 | 1 100 |
| 17038 | *Nexpa, Tlaquiltenango* | *Morelos* | 18.51 | -99.13 | 1 200 |
| 17056 | *San Pablo Hidalgo,* | *Morelos* | 18.58 | -99.03 | 955 |
| 17057 | *El Limón, Tepalcingo* | *Morelos* | 18.51 | -98.93 | 1 650 |
| 17076 | *Puente de Ixtla* | *Morelos* | 18.61 | -99.31 | 899 |
| 21050 | *Jolalpan, Jolalpan (Smn)* | *Puebla* | 18.31 | -98.81 | 820 |
| 21116 | *Chiautla de Tapia, (Smn)* | *Puebla* | 18.28 | -98.60 | 1 025 |
| 21177 | *Tepexco, Tepexco (Dge)* | *Puebla* | 18.56 | -98.71 | 1 150 |
| 17021 | *Tlacualera, Tlacualera* | *Morelos* | 18.61 | -98.95 | 1 560 |

Source: IMTA, 2013.

The mapping of the average annual rainfall was based on the graphic method, establishing analogies of the areas with meteorological stations with which they have no information. The selected weather stations were geographically located according to their coordinates in the ArcMap 10.1 Geographic Information System; its annual average precipitation value was included in a digital elevation model map with contour lines. The impact of the relief on the meteorological systems that generate the precipitation was analyzed and, expressed in the value of the annual average precipitation at each geographical point with information, the annual average isohyetal lines were drawn up at 100 mm intervals, starting from those that have more elements to delimit their location. Subsequently, the isohyetal lines plotted on a false color map denoting the vegetation cover were overlaid and to which the polygons were added with data on the types of land use and vegetation; isohyetal lines were adjusted based on the association that precipitation may have with vegetation cover (Gómez *et al.*, 2008).

The average monthly precipitation was estimated through an analysis of the distribution of regional precipitation from the annual average precipitation intervals (Gómez *et al*., 2008).

The annual average temperature and precipitation maps were put together to define areas of climatic influence (AIC). In each AIC, the monthly and annual mean temperature and precipitation values were estimated. Subsequently, the type of climate was determined using the Köppen Classification System modified by García (García, 2004).

To identify all land and vegetation uses of the study area, we worked with the INEGI Series VI polygons (Inegi, 2016), in which the boundaries were redefined and detailed with greater precision by means of Google Earth satellite images (2018) at a scale of 1: 10 000.

Based on the satellite images, the tree density of the polygons of the secondary deciduous forest vegetation consigned by the INEGI Series referred to as high, medium and low was classified. Likewise, new polygons of roza-tomb-burning agriculture and mechanized agriculture were generated. For this, the results of previous work carried out in the study area were considered (Uribe *et al*., 2015).

## Agroforest diagnosis

In each UP a forest inventory was made to identify the species that best develop in each of them. Three 400 $m^2$ circular shape sampling plots were established in each UP, with a radius of 11.28 m. Trees and shrubs with a normal diameter> 2.5 cm were recorded throughout the sampling surface. For trees, the normal diameter was measured at 1.30 m. The diameter of the bushes was measured at 15 cm above the ground. The height of the trees and shrubs was determined with a 43890 Haga altimeter, and the diameters with a 283D Forestry Suppliers cloth diametric tape.

The Importance Value Index (IVI) was calculatd with the folwing formula (Mueller-Dumbois y Ellenberg, 1974):

$$VI = \{[Dominance\ + Frequency\ + Abundance]/3\} * 100$$

Where:

*VI*= Importance Value of the *i* species

*Dominance* = Basimetric area of the *i* species / ∑ basimetric area of all the species

*Frecuence* = Number of plots in which the *i* species is present / total number of plots

*Abundance* = Number of individuals of the *i* species/ total number of individuals of the whole sampled area

Based on what was observed in the field and in previous studies in the area (Uribe *et al.,* 2015; Burgos *et al.,* 2017; Yescas *et al*., 2017), those UPs that had two or more limitations described in Table 2 were selected, to give a possible solution through the implementation of agroforest technologies, with special interest in increasing the low productivity of the system.

**Table 2.** Description of the limitations considered for the selection of the UP for the design of agroforest technologies in *Ajuchitlan, Tlaquiltenango, Morelos.*

| Limiting condition | Description |
|---|---|
| Soil deterioration | Bare ground with gullies, gutters and *edones* |
| Low tree and scrub diversity | Tree and scrub cover < 25 % |
| Conventional agriculture<br>Intensive grazing | Excesive use of nitrogen fertilizers |

## Social contribution

There were 32 semi-structured interviews that represented 80 % of the total producers in the study area. The interviews were prepared based on the Diagnostic and Design Methodology (Raintree, 1987) which was adapted to the conditions of the region and the purpose of this research. The questions focused on the identification of other possible limitations in each UP, as well as in the main economic interest on the part of the producers; in a similar way, the preference of tree and shrub species of multiple uses for the design of agroforest technologies was asked too.

## Design of agroforest technologies

The main limitations of each UP, the tree and shrub species of multiple uses indicated by the producers with special interest to the economic aspects and with representativeness in the landscape through the value of importance (VI) were considered. Aspects of physiography and climate were included in order to ensure adequate development in the field of these taxa.

Based on the literature review (Chacón and Harvey, 2006; Soto-Pintó *et al*., 2011; Bolaños *et al*., 2013) the morphology of each species studied was determined, the density of trees per hectare was established, as well as the spatial arrangement of trees in each technology.

## Evaluation of the economic viability of agroforest technologies

The total cost per hectare of the establishment of the proposed agroforest technologies was calculated through the charge for labor, charge for machinery and equipment, and charge for consumption. These charges were obtained from the concept and performance catalog of the National Forestry Commission (Conafor, 2014), in which the current cost per wage and per tool to be used was modified. It is worth mentioning that the cost estimate was for April 2019, when the average exchange rate was $ 19.00 Mexican pesos per US dollar.

If the main economic interest of the producers is the sale of firewood, the economic benefits were estimated only for such activity. It was considered that the planting of the species proposed in each technology will be taken care of by the producers in the early stages and based on what is defined by the National Forestry Commission, the total volume of the tree was estimated at the age of 20, to obtain the number of wood loads per tree, under the assumption that there will be a 10 % mortality of trees planted in each technology (Conafor, 2013).

The volume was multiplied by the local cost of firewood load. The load of firewood is equivalent to 0.17 $m^3$, so 1 $m^3$ of firewood contains 5.8 loads. According to Vázquez et al. (2017) its cost depends on the type of species, and varies between $ 85.00 Mexican pesos and $ 100.00 Mexican pesos, which is equivalent to US $ 4.47-5.26.

# Results and Discussion

## Detailed diagnosis of the biophysical medium

It is recognized that 42 % of the surface of the study area has moderately sloping slopes with slopes between 2 and 8 %, at altitudes of 1 200-1 400 m (Table 3) (Figure 1).

**Table 3.** Dominant characteristics of the delimited geoforms in *Ajuchitlán, Tlaquiltenango, Morelos.*

| Description of the Geoform | Altitudinal range (msnm) | Slope range (%) | Area (ha) | Percentage (%) |
|---|---|---|---|---|
| Almost flat river valley | 1 000-1 200 | 0-2 | 547 | 20.36 |
| Mildly inclined hillside | 1 200-1 400 | 2-8 | 1130 | 42.09 |
| Inclined hillside | 1 400-1 600 | 8-15 | 758 | 28.21 |
| Hillside peak | 1 600-1 800 | 0-2 | 251 | 9.34 |

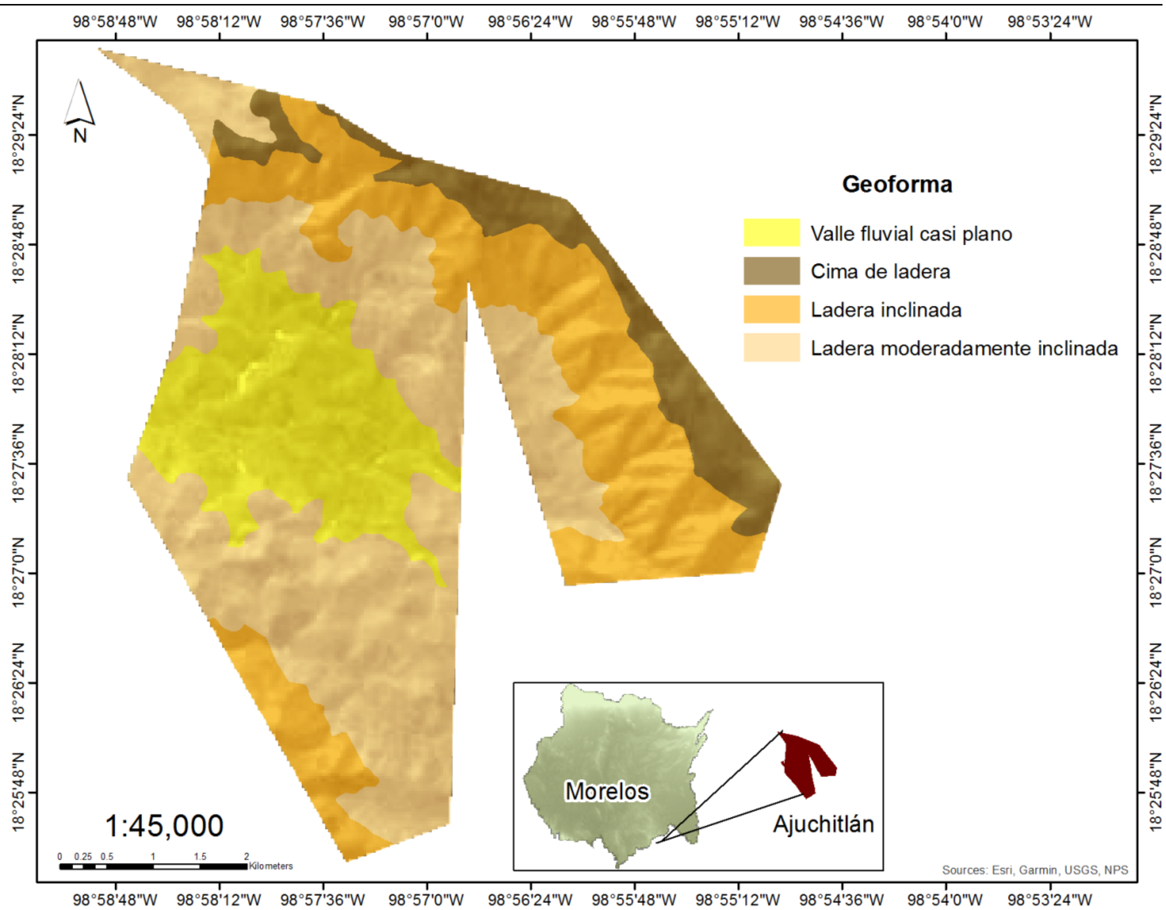



**Figure 1.** Spatial distribution of the delimited geoforms in *Ajuchitlán, Tlaquiltenango, Morelos.*

14 areas of climatic influence were delimited and three different climates were determined in the area evaluated (Figure 2). The warm climate, the driest of the subhumid ones, with a summer rainfall regime [$Aw_0$(w)(i')g] has a greater predominance in the area, and is presented in 53.47 % of the total area studied (1 436 ha); it is located in the river valley and the surrounding areas of moderately sloping slopes of the western part.

On the sloping slopes, there is a gradient of greater precipitation, where the weather is warm, the normal of the sub-humid ones and with summer rainfall [$Aw_1$(w)(i')], the surface with this climate is of 609 ha (22.65 %). At the top of the slopes, the climate is characterized as semi-warm of the warm group, the normal of the subhumid and summer rainfall regime [A(C)$w_1$(w)(i')g], with an area of 641 ha (23.88 %).

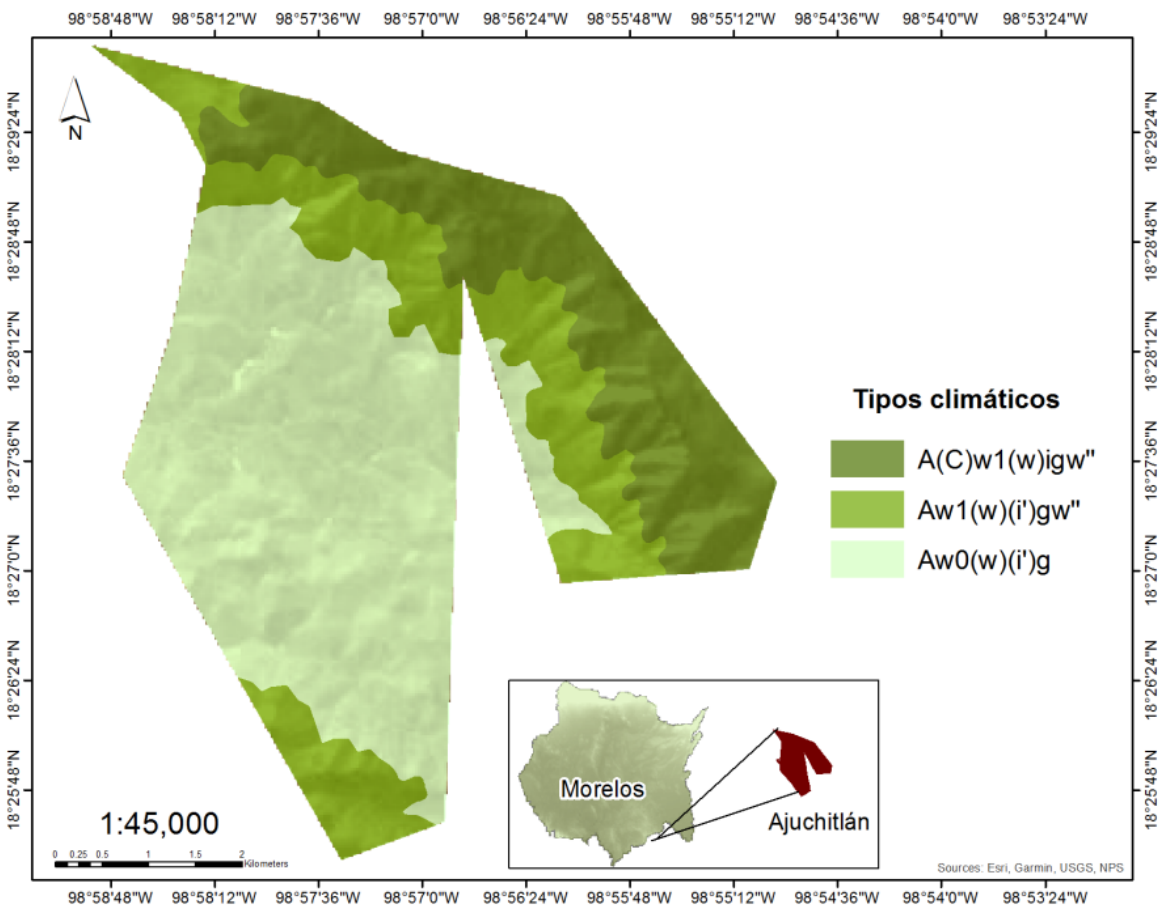
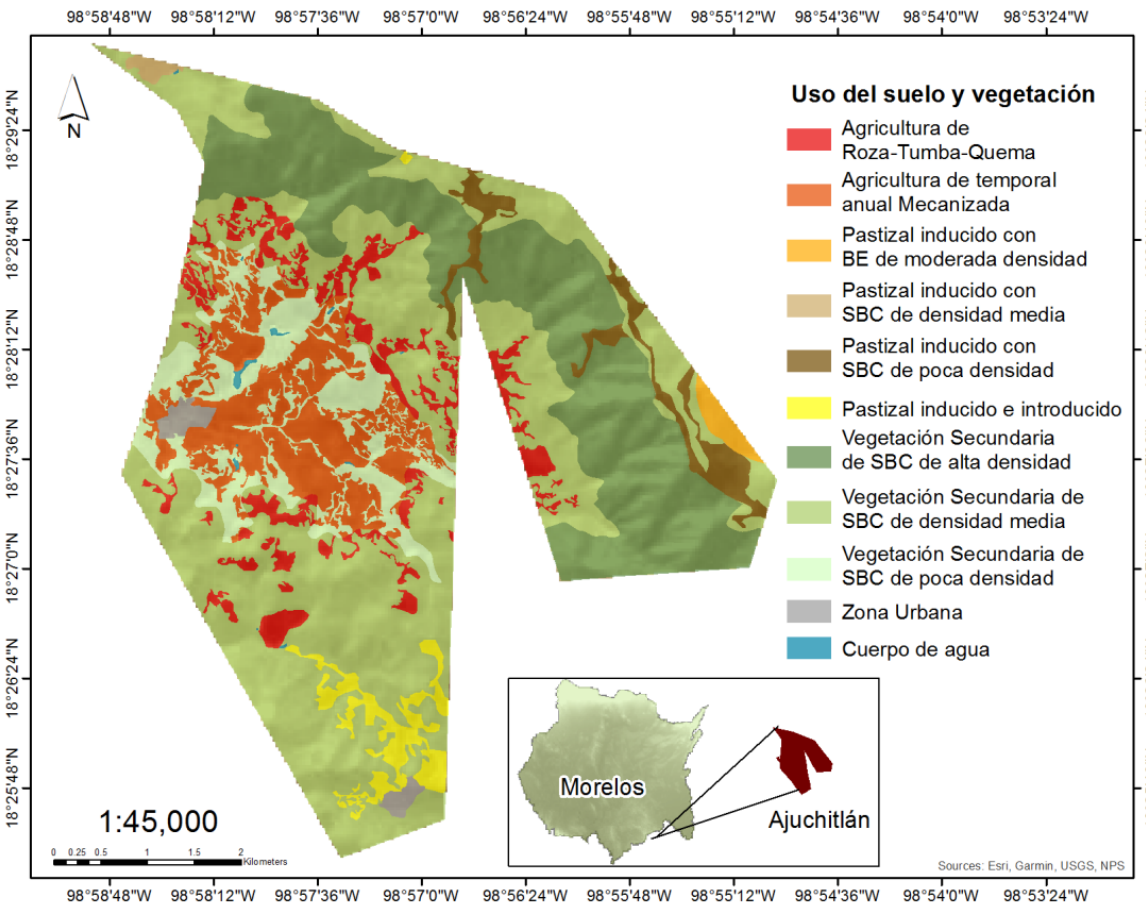



**Figure 2.** Spatial distribution of the climatic types found in *Ajuchitlán, Tlaquiltenango, Morelos.*

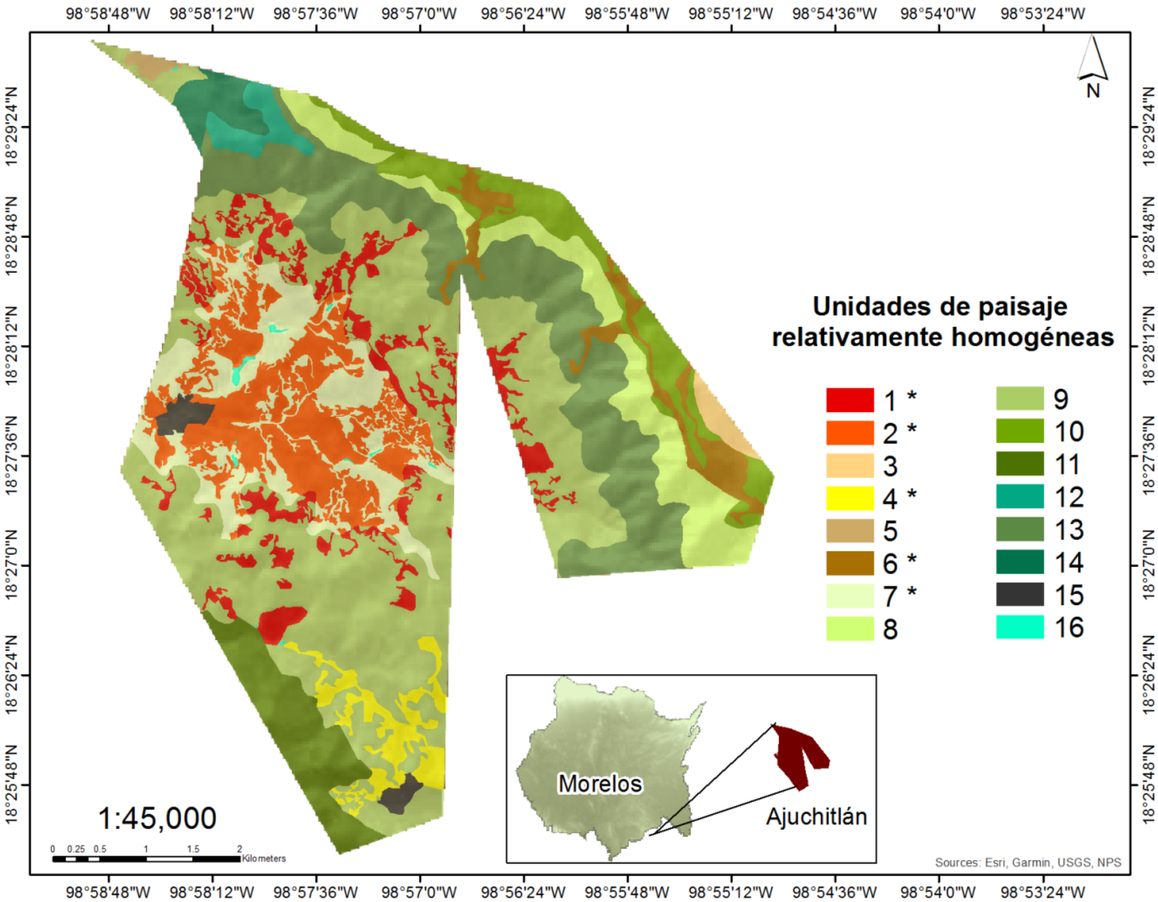
Regarding the use of soil and vegetation, 11 types were delimited in the study area. The secondary vegetation of low deciduous forest (SBC) of medium density (42.30 %) predominates. The area dedicated to agriculture and grassland accounts for 19.30 % of the total (Figure 3).




SBC = Low Deciduous Forest; BE = Oak forest.

**Figure 3.** Spatial distribution of the climatic types found in *Ajuchitlán, Tlaquiltenango, Morelos.*

By integrating the three thematic maps of physiography, climate and land use and vegetation, 14 UP were obtained, of which, the secondary vegetation of SBC in its different densities and climatic conditions, as well as physiographic, represent the use with greater surface area in the region, both for livestock and for the community (Figure 4). This is because during the rainy season, natural vegetation is the only source of food for livestock, which decreases the expenses of the producers (Uribe *et al.,* 2015).




1. Slash and burn agriculture in an $Aw_0(w)(i')g$ climate on a moderately sloping slope; 2. Mechanized annual temporary agriculture in an $Aw_0(w)(i')g$ climate in an almost flat river valley; 3. Grassland induced with medium density BE in a climate $A(C)w_1(w)(i')g$ on a hillside peak; 4. Grassland induced and introduced in an $Aw_0(w)(i')g$ climate on a moderately sloping slope; 5. Grassland induced with medium density SBC in an $Aw_0(w)(i')g$ climate on a moderately sloping slope; 6. Grassland induced with low density SBC in a climate $A(C)w_1(w)(i')g$ on a hilltop; 7. Secondary vegetation of low-density SBC in an $Aw_0(w)(i')g$ climate in an almost flat river valley; 8. Secondary vegetation of high density SBC in an $Aw_1(w)(i')g$ climate on a sloping slope; 9. Secondary vegetation of medium-density SBC in an $Aw_0$ (w) (i´) g climate on a moderately sloping slope; 10. Secondary vegetation of medium-density SBC in a climate $A(C)w_1(w)(i')g$ on a hilltop; 11. Secondary vegetation of medium-density SBC in an $Aw_0(w)(i')g$ climate on a sloping slope; 12. Secondary vegetation of high density SBC in an $Aw_1(w)(i')g$ climate on a hillside summit; 13.

Secondary vegetation of high density SBC in an $Aw_1(w)(i')g$ climate on a sloping slope; 14. Secondary vegetation of high density SBC in an $Aw_1(w)(i')g$ climate on a moderately sloping slope; 15. Urban Zone; 16. Body of water.

SBC = Low Deciduous Forest; BE = Oak Forest; * UP selected for the design of agroforest technologies.

**Figure 4**. Spatial distribution of Relatively Homogeneous Landscape Units (UP) in *Ajuchitlán, Tlaquiltenango, Morelos*.

## Agroforest diagnosis

64 tree and shrub species were identified. The species with the highest importance value per landscape unit are shown in Table 4. These results are similar to those of Hernández et al. (2011) in a study carried out in *Ajuchitlán*, where they determined that the most important species are *ixtumeca* (*Euphorbia schlechten* Boiss), *tlahuitol* (*Lysiloma divaricata* (Jacq.) McBride) and *tecolhuixtle* (*Mimosa benthami* JF Macbr) they represent 37.29 % of the total importance value index.

**Table 4**. Species with the highest importance value (VI) in percentage in each unit of relatively homogeneous landscape (UP).

| Rather homogeneous Landscape Unit (UP) | Species | IVI (%) |
|---|---|---|
| 3 | *Quercus magnoliifolia* Née | 22.39 |
| 8 | *Quercus magnoliifolia* Née | 9.61 |
| 7 | *Acacia cochliacantha* Willd. | 65.41 |
| 11 | *Lysiloma divaricata* (Jacq.) J. F. McBride | 13.95 |
| 13 | *Eysenhardtia polystachya* (Ortega) Sarg. | 21.28 |
| 10 | *Mimosa benthamii* J.F.McBride | 12.97 |
| 12 | *Lysiloma divaricata* (Jacq.) J. F. McBride | 12.12 |
| 14 | *Guazuma ulmifolia* Lam. | 11.37 |
| 5 | *Guazuma ulmifolia* Lam. | 9.90 |
| 9 | *Bursera bipinnata* (DC.) Engel. | 7.31 |
| 6 | *Lysiloma acapulcensis* (Kunth) Benth. | 7.12 |

The UP selected for the design of agroforest technologies were: slash and burn agriculture (1), mechanized annual temporary agriculture (2), induced and introduced grassland (4), grassland with low-density SBC at the top of the slope (6) and secondary vegetation of low density SBC in the river valley (7).

It was observed that the main limitation in the first three UPs (1, 2 and 4) is the use of conventional agriculture and grassland with intensive use of nitrogen fertilizers. In semi-structured interviews and field trips, limitations were recognized in fencing with dead posts, due to its high cost of establishment and maintenance (Uribe *et al*., 2015). This is due to the fact that the area is clearly cattle-raising, which generates pressure for tree species that are used as poles to make dead fences in small and fractional plots with an average area of 1 ha.

In UP 6 there is soil degradation caused mainly by water erosion. In UP 7, low tree density was observed, which can cause soil loss if proper management tasks are not applied.

## Design of agroforest technologies

## Live fences

In the UP with pasture and agriculture (1, 2 and 4) the establishment of living fences is recommended, which according to Harvey *et al.* (2005) are multi-purpose trees planted in rows, managed by farmers. They are used to divide pastures and protect crops from animals, or to mark the boundaries of plots, which helps maintain the landscape and connectivity of the agricultural-livestock region (Chacón and Harvey, 2006). Because the properties are small and divided, no other type of agroforest technology is recommended.

For the establishment of living fences it is suggested to incorporate the following species: *Gliricidia sepium* (Jacq.) Kunth ex Walp. or kill rat; *Acacia cochiacantha* Willd. or brown *cubata*; *Mimosa benthamii* or *tecolhuixtle* and *Guazuma ulmifolia* Lam. or *cuaulote*.

These species are of multiple use and have a high value of importance. They develop properly in the almost flat river valley and on moderately sloping slopes with the $Aw_0(w)(i')g$ climate type. They can be used to sell firewood once they have reached the desired development, since they are appreciated by the villagers (Vázquez *et al.,* 2017).

For its establishment in the field, a spacing of 4 m between the plant is proposed, interspersing a dead pole every two meters, with a density of 100 $ha^{-1}$ plants. A smaller separation could reduce crop yields, due to competition for light and nutrients. The barbed wire should be placed when the plants are well rooted and have a thickness of more than 15 cm in normal diameter (Chacón and Harvey, 2006).

According to Yescas *et al.* (2017) the establishment of living fences is one of the recommended technologies in the agricultural-livestock area of the low deciduous forest of the *Sierra de Huautla, Morelos*. This is because, in addition to serving as boundary delimitation, it can meet the needs of firewood for trees planted in such technology.

According to Cortez *et al.* (2017) the use of live fences may be an option to reduce the negative impacts of extensive livestock, loss of natural vegetation and soil degradation in the *Sierra de Huautla*. Likewise, Soto *et al.* (2008) mentioned that this technology has a beneficial effect on the soil by reducing erosion, management costs are low or zero and provide various products, among which the use for firewood and fodder.

## Live barriers

In UP 6 a high degree of erosion was observed. For this reason, it is recommended to apply the practice of living barriers, which will be used to control the loss of soil due to water erosion, which reduces the speed of runoff water downhill and thus the removal of the soil; it also favors that the soil particles settle in the upper part of the living bars and form natural terraces (Quinton and Rodríguez, 1999). With this strategy, the soil degradation process will stop and, over time, the productive potential of the land will increase.

Likewise, little diversity of species and an important presence of *ixtumeca* (*Euphorbia schlechten*) were identified, with an importance value of 27 %. This species is considered by the community as invasive, very aggressive and of little use. Therefore, it is recommended to use rustic species that serve to retain the soil and generate adequate conditions to restore long-term tree species that are useful. The carbon content on the site is expected to increase and gradually replace the *ixtumeca*.

The species proposed for this activity are *nopal* (*Opuntia lubrica* Griffiths) and Chinese copal, which develop properly on the top of the slope and in the type of climate $A(C)w_1(w)(i')g$. Although the cactus is not highly representative in this area (IVI 6 %), it can be a good option to be implemented in live barriers in areas with high erosion, because it is a rustic species and develops well in these conditions and It has a high survival (Bolaños *et al.,* 2013).

The Chinese copal (*Bursera bipinnata* DC. Engl.) is recommended from having a high value in the area (18 %) in addition to branching from ground level in its early stages. Likewise, it is a species highly prized by residents for its resin.

For the establishment in the field, the separation between cactus plants should be 20 cm from each other, along the contours with a distance between curves of 16.6 m (Bolaños *et al.,* 2013) and a planting density of 3 012 individuals ha$^{-1}$. The strips with prickly pearls and the strips with Chinese copal should be placed interleaved. Once established the plants will be pruned to give them structure.

In the *nopal* (*Opuntia* spp.) the main stems will be used to form the boards between plants that reduce or limit runoff. In the case of copal, the material removed in pruning will be accommodated between the plants to form boards. When the barriers are established, thinning will be carried out to allow the best development of the plants, taking care to keep the borders on the contour.

According to Zúñiga *et al.* (1993) the use of living barriers in some tropical regions of Mexico has been used successfully, which is why it is widely recommended in areas with soil degradation. It is expected that by using the living barriers in this UP, water erosion will be reduced, by means of the longitudinal decrease and the gradient of the slope; and soil moisture is increased to favor the good development of plants (Ruiz *et al.,* 2001).

## *Acahuales* enrichment

In UP 7, species enrichment is recommended using the improved *acahual* technology proposed by Soto-Pintó *et al.* (2011). The recommended species are tlahuitol, tepeguaje (*Lysiloma acapulcensis* (Kunth) Benth), *tecolhuixtle* and *cuaulote*. These species have a full development in the almost flat river valley with a kind of $Aw_0$ (w) (i´) g climate, which are the biophysical conditions where it is proposed to establish agroforest technology.

The species selected for this activity coincide with the results of Moreno and Paradowska (2009) who mention that the potential use of these species, apart from enriching the *acahuales* and generating environmental benefits, are preferred by the producers for the use of firewood and fodder in the low deciduous jungle of central *Veracruz*.

For the establishment of the plantation it is recommended to make gaps of 2 m wide in a direction perpendicular to the slope with a separation of 3 m between trees. Between line and line of trees 7 m of natural *acahual* are left, which forms a density of 476 $ha^{-1}$ trees. If trees larger than 20 cm in diameter are found, they should be left there (Soto-Pintó *et al.,* 2011).

According to Soto-Pintó *et al.* (2011) the enrichment of *acahuales* maintains the regeneration ability of natural vegetation and increases the potential of the soil by increasing coverage, biomass and productivity. This contributes to improve the environmental benefits and, therefore, the economic and social benefits (Canadell and Raupach, 2008).

## Economic viability of the proposed agroforest technologies

Table 5 shows the establishment costs per hectare of the technologies discussed. It is observed that the enrichment of *acahuales* turns out to be the cheapest to implement, mainly due to the fact that many inputs are not required, such as in live fences and barriers.

**Table 5.** Cost per hectare of establishment of the proposed technologies in *Ajuchitlán, Tlaquiltenango, Morelos*.

| Charge | Live fences | | *Acahual* enrichment | | Live barriers | |
|---|---|---|---|---|---|---|
| | Cost $ha^{-1}$ in Mexican pesos ($) | Cost $ha^{-1}$ in US dollars* ($) | Cost $ha^{-1}$ in Mexican pesos ($) | Cost $ha^{-1}$ in US dollars* ($) | Cost $ha^{-1}$ in Mexican pesos ($) | Cost $ha^{-1}$ in US dollars* ($) |
| Workforce | 1 201.01 | 63.21 | 2 115.67 | 111.35 | 2 171.79 | 114.30 |
| Machinery, equipment and tools | 16.30 | 0.86 | 30.58 | 1.61 | 13.02 | 0.69 |
| Supplies | 9 859.54 | 518.92 | 1 001.80 | 52.73 | 5 318.60 | 279.93 |
| Maintenance activities | 1 838.00 | 96.74 | 2 276.44 | 119.81 | 4 259.12 | 224.16 |
| Other charges | 128.66 | 6.77 | 495.52 | 26.08 | 0.00 | 0.00 |
| Total | 13 043.51 | 686.50 | 5 920.01 | 311.58 | 11 762.53 | 619.08 |

*Exchange rate= $19.00 Mexican pesos per US dollar

The costs per hectare obtained in this research are within the range calculated by Sáenz *et al.* (2010) ranging from $ 10 207 to $ 19 923 Mexican *pesos*, depending on agroforest technology. The implementation of agroforest technologies generates a considerable investment cost for the producers' economy, which varies depending on the fixed costs; as well as the current prices of inputs and labor. However, the long-term benefit, both economic and environmental, will make farmers recover their investment, which, although it can be paid for with their own resources, can also be financed totally or partially by government institutions.

As the main economic interest of the producers is the sale of firewood, the calculations were made only for this activity. It was determined that the economic benefit from the sale of firewood depends largely on the species. Because the volume is interrelated with the growth in diameter and height of the species. It is observed that the benefit is affected by the density of trees per hectare that is proposed, under the assumption that there will be 10 % mortality of trees planted in each technology (Table 6).

**Table 6.** Economic benefit in hectares per sale of firewood, according to the species to be used in each agroforest technology after 20 years established in *Ajuchitlán, Tlaquiltenango, Morelos*.

| Common name | Species | Live fnces ($ ha$^{-1}$) | | *Acahual* enrichment ($ ha$^{-1}$) | |
|---|---|---|---|---|---|
| | | Benefit in Mexican *pesos* | Benefit in dollars* | Benefit in Mexican *pesos* | Benefit in dollars* |
| *Tlahuitol* | *Lysiloma divaricata* (Jacq.) McBride | 0.00 | 0.00 | 207 004.39 | 10 894.97 |
| *Cuaulote* | *Guazuma ulmifolia* Lam. | 71 131.57 | 3 743.77 | 33 827.01 | 1 780.37 |
| *Tecolhuixtle* | *Mimosa benthami* (J.F.) McBride | 193 462.05 | 10 182.21 | 207 004.39 | 10 894.97 |
| *Cubata prieta* | *Acacia cochiacantha* Willd. | 105 113.99 | 5 532.32 | 0.00 | 0.00 |
| *Mata rata* | *Gliricidia sepium* (Jacq.) Walp. | 99 274.33 | 5 224.96 | 0.00 | 0.00 |
| *Tepeguaje* | *Lysiloma acapulcensis* (Kunth) Benth | 0.00 | 0.00 | 207 004.39 | 10 894.97 |
| Total | | 468 981.94 | 24 683.26 | 654 840.18 | 34 465.27 |

Source: Original making

*Exchange rate= $19.00 Mexican *pesos* per US dollar.

According to the results obtained, the sale of firewood turns out to have a high economic value. This is mainly due to the fact that firewood is considered by rural families as an indispensable natural resource for their way of life. Based upon the Food and Agriculture Organization of the United Nations (FAO) and the former Mexican Agriculture Department (Sagarpa) (FAO and Sagarpa, 2007) an average family needs about 500 kg of firewood annually to meet the needs of energy in cooking food, which implies an annual consumption of 8 m$^3$, equivalent to the extraction of 32 trees.

Because the extraction of firewood is practiced on a daily basis in the communities of *Morelos*, negatively affecting the forest resources of the deciduous forest (Yescas *et al.,* 2017), it is very important to generate and implement agroforest technologies with species that have quality dendroenergetics; It turns out to be a viable alternative that has both economic and environmental benefits. In this way, the pressure on those preferred species for firewood can be reduced and the negative impacts reduced.

# Conclusions

The parametric method of classification of the landscape allowed to generate the detailed diagnosis of the biophysical environment to obtain relatively homogeneous basic units of landscape that were fundamental to perform the agroforest diagnosis that served to identify the most representative species and detect the main limitations of the UP. Social participation was crucial to design the proposed technologies, which included local components of interest to producers and with the potential to improve the quality of these systems. Good silvicultural management of the proposed agroforest technologies can increase the economic income of the producers, mainly through the sale of firewood. However, it should not be ruled out that such technologies can generate economic benefits from payment for long-term environmental services. The results of this research contribute to obtaining local information for the good management of agricultural and forest land in the area. The methodology used can be replicated in any area of the country.

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**Conflict of interest**

The authors declare no conflict of interest.

**Contribution by author**

Patricia Ruiz García, Jesús David Gómez Díaz and Alejandro Ismael Monterroso Rivas: detailed description of the biophysical environment to obtain rather homogeneous landdscape units, determination of the agroforest opportunities and writing of the manuscript; Patricia Ruiz García and Miguel Uribe Gómez: design of agroforest technologies, economic viability evaluation and writing of the document.

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