Botanical Sciences 97 (3): 263-290. 2019
DOI: 10.17129/botsci.2202

Received: February 1, 2019, accepted: May 29, 2019
On line first: 25/08/2019

Review/Revisión

The genus *Agave* in agroforestry systems of Mexico

El género *Agave* en los sistemas agroforestales de México

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Abstract
Background: The genus *Agave* L. is recognized for its wide distribution in Mexican ecosystems. Species have been described as multipurpose as part of agroforestry systems (AFS). There has not been a systematized, detailed analysis about its richness in AFS nor their ecological, economic and cultural relevance.
Questions: What is the *Agave* richness in Mexican AFS? What is their ecological, agronomical, economic and cultural relevance? What are the risks and perspectives for strengthening their role in AFS?
Species studied: 31 *Agave* species in Mexican AFS.
Study site and dates: AFS throughout Mexican territory. January to august 2018.
Methods: Systematization of published information, scientific reports, repositories, and our fieldwork, was performed. The data base "The genus *Agave* in AFS of Mexico" was created, containing information about *Agave* richness in AFS, ecological, economic and cultural relevance, as well as the current and future perspectives of the AFS they are included in.
Results: We recorded 31 species with 22 uses that were part of AFS practices (hedgerows, boundaries and live fences), in homegardens, terraces and agroforests in temperate, semiarid and sub-humid regions, managed by 12 cultural groups. The main benefits of agaves are soil retention, infiltration of water and satisfaction of socio-economic and cultural needs. The decrease of multipurpose species and functions was observed in relation with the commercialization of mezcal.
Conclusions: There has been ample recognition of AFS as settings for conservation and use of *Agave,* as well as the importance of the knowledge and management practices associated to agave species in AFS.
Keywords: Agrobiodiversity, conservation, exploitation, multipurpose species, mezcal, agaves.

Resumen
Antecedentes: El género *Agave* L. es reconocido por su amplia distribución en ecosistemas mexicanos y arraigo nacional. Descritos como especies multipropósito en sistemas agroforestales (SAF). No obstante, su importancia biocultural, hace falta aún un análisis sistematizado y detallado sobre la riqueza y relevancia del grupo en SAF mexicanos.
Preguntas: ¿Cuál es la riqueza del género *Agave* en SAF mexicanos?, ¿Cuál es la relevancia ecológica, agrícola, económica y cultural de estos taxa? ¿Cuáles son los riesgos y perspectivas del manejo de este grupo en SAF?
Especies en estudio: 31 especies del género en SAF mexicanos.
Sitio de estudio y fechas: Se revisaron sistemas agroforestales del territorio de México. Enero a agosto de 2018.
Métodos: Se integró información publicada, repositorios y registros de trabajo de campo, construyendo la base de datos "El género *Agave* en SAF de México" que sintetiza la riqueza de especies y relevancia en los SAF, así como las perspectivas para su manejo.
Resultados: Se registraron 31 especies con 22 usos, en prácticas agroforestales (franjas, linderos y cercas vivas) en huertos, terrazas, milpas y agrobosques en ambientes templados, semiáridos y subhúmedos, manejados por 12 grupos culturales. Los beneficios principales son reducción de la erosión e infiltración de agua y la satisfacción de necesidades socioeconómicas y culturales. Es notoria la disminución de las especies y la función multipropósito de éstas en SAF asociados con la comercialización de mezcal.
Conclusiones: Los SAF son relevantes escenarios de conservación y aprovechamiento del género, así como del conocimiento y prácticas locales asociadas a los beneficios.
Palabras clave: Agrobiodiversidad, aprovechamiento, conservación, especies multipropósito, magueyes, mezcales.

Since prehistoric times, diverse forms of agroforestry management of the landscapes have been practiced in Mexico, these include cultivation of nearly 200 native species of crops and the incipient management of a broad spectrum of wild species of plants, which complement diets and fulfill the needs of the societies that maintain them (Casas *et al.* 1996, 1997a, Moreno-Calles *et al.* 2013, 2016a, 2016b). In modern times, and particularly after the second half of the 20th century, the global dominant tendency has been to simplify these systems into intensive, technical monocultures, unchaining multiple negative socio-environmental impacts in the process. Among these impacts are the loss of Traditional Ecological Knowledge (TEK) and agrobiodiversity, and a high dependence on toxic agrochemicals (Altieri 2009, Altieri & Toledo 2011, Barkin & Suárez 1982, Emanuelli *et al.* 2009, Holt-Gimenez & Patel 2009, Godfray *et al*. 2010, Torres & Rojas 2015). An expression of this process in Mexico are the intensified agave plantations of the *haciendas pulqueras* during the 19th and part of the 20th centuries, as well as plantations associated to the growing agave spirits industry of tequila and mezcal, particularly since the end of the 20th century and up to the present (Ramírez-Rodríguez 2004, Valenzuela-Zapata & Macías-Macías 2014).

The genus *Agave* L. has been a very important group of resources for Mesoamerican and Aridoamerican cultures since prehistoric times (MacNeish 1967). Many ancient uses have prevailed in rural and peri-urban communities, among the most important food, construction, cordage, garments, fermented beverages, medicine, soil control and ceremonial uses can be mentioned. These resources have been crucial for the life and development of societies within the Mexican territory (Colunga-GarcíaMarín *et al.* 2007, 2017, Gentry 1982). Popularity of *Agave* spirits has increased in the last 30 years, both within national territory as well as abroad (Consejo Regulador del Mezcal 2015, Consejo Regulador del Tequila 2019, Delgado-Lemus *et al.* 2014a, Delgado-Lemus *et al*. 2014b, Torres-García *et al.* 2013, Torres-García *et al.* 2015a and b). The high demand of the tequila industry for raw materials has been characterized, among many socio-environmental injustices, by the devastation of hundreds of thousands of original forests, mainly in five Mexican states, for establishing intensive monocultures of *A. tequilana* (Bowen & Zapata 2009, Herrera-Pérez *et al.* 2017, Trejo-Salazar *et al.* 2016, Valenzuela-Zapata & Macías-Macías 2014). Since 1995, the expansion of these intensive monocultures has resulted in social conflicts and environmental problems, among them the loss of biodiversity and ecosystem benefits, the increasing pollution of soils and water, due to the large quantities of agrochemicals used in these plantations (Gil-Vega *et al*. 2001, Trejo *et al.* 2018). Pressure from this industry maintains these territories, where a single species predominates, dependent on the use of external inputs, to create what we have conceptualized as "blue deserts" *sensu* Altieri (2009).

Recently, new approaches have emerged from agroecology, which see Agroforestry Systems (AFS) as alternatives to the problems related to the production and conservation of biodiversity. In the last three decades there has been an increase in publications about the importance of agroforestry systems in the conservation of wild and cultivated species and their diversity. These publications also delve into environmental benefits, TEK, and sociocultural practices related to the management of AFS (Casas *et al.* 1996, 1997a, 1997b, Altieri 1999, Jose 2009, Blancas *et al.* 2010, Moreno-Calles *et al.* 2013, Moreno-Calles *et al.* 2016a, 2016b, Moreno-Calles *et al.* 2019, Vallejo-Ramos *et al.* 2018, Vallejo *et al.* 2019). Several research findings have registered the role that this type of agroecosystems have for subsistence, the economy and cultural identity of the peoples that practice and conserve them (Alcorn 1984, Nair 1985, Casas *et al.* 1994, Nair *et al.* 2008, Moreno-Calles *et al.* 2010, Jose *et al.* 2012, Somarriba *et al.* 2012, Moreno-Calles *et al.* 2013. Within the high diversity of wild and domesticated plant elements that are conserved, managed and utilized in these systems, *magueyes*, *mezcales* or *agaves*, as they may be called, are a group of resources with strong presence and a long relationship with the cultures of Mexico (Colunga-GarcíaMarín *et al.* 2007, Colunga-GarcíaMarín *et al.* 2017).

Agaves have in the Mexican territory the scenario with the highest species´ richness in the world, and also a wide distribution (García-Mendoza 2004). The majority of species fulfill multiple purposes, such as the satisfaction of primary and secondary needs, products directly consumed by households or exchanged by other products and constitute one of the main elements in the economy of families and communities of maguey managers (Delgado-Lemus *et al*. 2014b, Torres-García *et al.* 2015a, Torres-García *et al.* 2015b). Nevertheless, there is a need for an in-depth analysis of the information available, as well as of the experience amassed regarding the relationship between agroforestry systems and the genus *Agave* in Mexico. Such information is of high national priority, for it would help establish the basis to maintain, develop, and manage systems capable of giving the support needed for maintaining the balance between productive and human wellbeing purposes, biodiversity conservation, and environmental benefits. This study was performed in order to answer the following questions: What is the richness of *Agave* spp. in Mexican AFS?, What is the ecological, agronomical, and cultural relevance of taxa belonging to this genus in the AFS that host them?, What are the management perspectives for this group within AFS? The general objective of our research was to analyze the richness and relevance of the genus *Agave* in agroforestry systems in Mexico.

Materials and methods

Information available on agaves in AFS was systematized through the construction of the database "El género *Agave* en Sistemas Agroforestales de México" (The genus *Agave* in Agroforestry Systems of Mexico) which includes information about the species and the relevant characteristics of the systems that host them, considering: 1) a description of the systems that host agaves, product of our own research; 2) an archive of the literature that is part of the database "Sistemas Agroforestales de México" (http://red-sam.org/index.php/lista-de-publicaciones-sobre-sistemas-agroforestales/) and a

typology of these systems developed by Moreno-Calles *et al.* (2013, 2016b); and 3), an update of the searches of specialized studies on the subject in the Web of Science, Science Direct, Google Scholar databases, and ProQuest Dissertations & Theses, as well as TesiUNAM repositories. The keywords included in the search were: agave/maguey + agroforestería, agave/maguey + agroforestal, agave/maguey + sistemas agrícolas tradicionales, agroecosistemas + agave/maguey (agave/maguey + agroforestry, agave/maguey + agroforestal, agave/maguey + traditional agricultural systems, agroecosystems+ agave/maguey). These searches were also carried out with the terms in English. This update focused on a search from 2012 to the present. The review of 146 records included in 75 studies integrated information regarding the role that each species plays in the hosting system, considering the following fields: a) scientific name (taking as a reference www.theplantlist.org), b) common name, c) type of agroforestry system (*sensu* Moreno-Calles *et al.* 2013), d) other systems where the species can be found with different management intensities, e) cultural group that manages the system, f) locality, state, g) agroforestry practice (*sensu* Moreno-Calles *et al.* 2011), h) ecological aspects and interactions, i) uses, j) ecological status/management (*sensu* Blancas *et al.* 2010), k) economic value, l) socio-cultural importance, m) density/intensity/dominance, n) evidence of domestication (*sensu* Colunga-GarcíaMarín *et al.* 2017, Figueredo-Urbina *et al.* 2017, Urbina *et al.* 2018).

Results

Agave *species present in agroforestry systems in Mexico.* Based on the information from the current research and the studies reviewed (75), 31 species and 4 intraspecific variants of the genus *Agave* were registered in agroforestry systems; 29 records specified the presence of agaves identifying only the genus. The species with the highest number of records is *Agave salmiana* Otto ex Salm Dyck, which included references to the variety *A. salmiana* var. *ferox* (K.Kock) Gentry and the subspecies *A. salmiana* subsp. *crassispina* (Trel.) Gentry, with 22 records in total, followed by *A. fourcroydes* Lem., which was registered 14 times. Other species registered, in descending order of frequency are: *A. angustifolia* Haw., *A. americana* L., *A. americana* var. *marginata* Trel. in L.H.Bailey, *A. tequilana* F.A.C. Weber, *A. marmorata* Roezl., *A. cupreata* Trel. & A. Berger, *A. sisalana* Perrine, *A. atrovirens* Karw., *A. mapisaga* Trel. in L.H.Bailey, *A. lechuguilla* Torr., *A. potatorum* Zucc., *A. scaposa* Gentry, *A. karwinskii* Zucc., *A. striata* Zucc, *A. striata* subsp. *falcata* (Engelm.) Gentry, *A. triangularis* Jacobi, *A. angustiarum* Trel., *A. asperrima* Jacobi, *A. rhodacantha* Trel., *A. promontorii* Trel., *A. peacockii* Croucher, *A. macroacantha* Zucc., *A. murpheyi* F.Gibson, *A. maximiliana* Baker, *A. inaequidens* K.Koch, *A.* aff. *weberi* J.F. Cels ex J.Poiss., *A. deserti* Engelm, *A. kerchovei* Lem., *A. cerulata* Trel, *A. celsii* Hook. and *A. aurea* Brandegee (see Figure 1 and Appendix 1).

Traditional agroforestry systems. Homegardens.- This is a type of agroforestry system generally found next to or very near the houses of the families that manage them. With an ancient history, which is crucial among the traditional production systems managed by household units in rural peasant zones. It is characterized by its high richness of native and exotic species diversity, and by its high complexity and structural variation (Ruenes-Morales & Montañez 2016). Such abundance and heterogeneity determine the existence of microhabitats that allow the conservation and use of the genetic resources

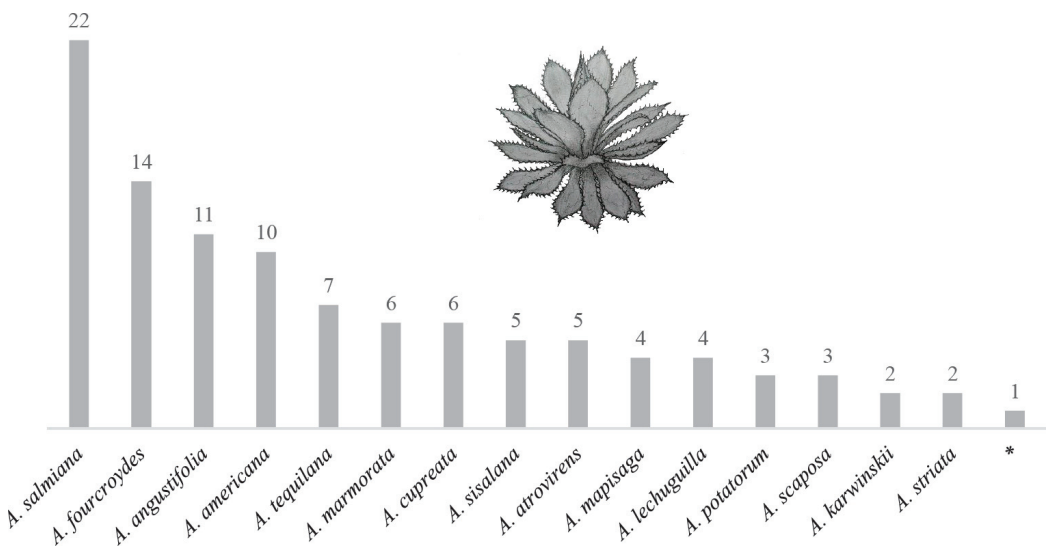

Figure 1. Species and number of studies that mention agave as part of an agroforestry system. *: *Agave triangularis*, *A. angustiarum*, *A. asperrima*, *A. rhodacantha*, *A. promontori*, *A. peacockii*, *A. macroacantha*, *A. murpheyi*, *A. maximiliana*, *A. inaequidens*, *A.* aff. *weberi*, *A. deserti*, *A. kerchovei*, *A. cerulata*, *A. celsii*, and *A. aurea* with only one report.

necessary for the self-sufficiency and incomes of the family's members, mainly women (Moreno-Calles *et al.* 2016a)

This system was the most common among the studies reviewed. *Agave* species were identified in 57 studies (13 species), of which *A. fourcroydes* was the most common with ten records; *A. angustifolia* with seven: *A. americana* with six; *A. tequilana* and *A. sisalana* five; *A. salmiana* four; *A. atrovirens* and *A. marmorata* two, and *A. angustiarum, A. lechuguilla, A. macroacantha,* and *A. striata* with one record each. Eleven records only specified the genus level. The cultural groups mentioned in these studies as managers of agave in their homegardens were the Maya of the state of Yucatan, Campeche, and Quintana Roo (22 homegardens) (Herrera-Castro 1994, Poot-Pool 2008, Cahuich-Campos 2012, Mariaca-Méndez 2012, Poot-Pool *et al.* 2012); Mestizo people from the states of Puebla, Chiapas, Nayarit, Tabasco, Mexico (13 homegardens) (Stienen 1990, Ruenes-Morales 1993, Tamayo-Ortega 1995, Gaytán-Ávila *et al*. 2001, Blanckaert *et al.* 2004, Pagaza-Calderón 2008, Rosales *et al*. 2008, Hernández-Soto 2009, Gómez-García 2011, Torres-Díaz 2011); the Nahua of Puebla (nine); the Chontal of Tabasco (four); the Tzotzil/Tzeltal from Chiapas (three) (Gutiérrez-Miranda 2003, Guerrero-Peñuelas 2007, Pérezgrovas-Garza 2011); the Mazahua of the State of Mexico (one); the Zapotec from Oaxaca (one) and the Totonac of Puebla (one).

A) Structural role of Agaves in homegardens.- Within these agroforestry systems agave density is mostly low, and may vary from one to dozens of individuals. The agaves within this system play different structural roles, such as that of blocking the passage of cattle or people, parting from agroforestry practices such as live fences or hedges, protecting the integrity of the homegarden and limiting the area that is considered as belonging to that family (Ffolliott 1998). Agaves can be found along the borders or places where they do not represent an obstacle for moving around the homegarden, given that these often grow to a considerable size, sometimes occupying from 1 to 3 m^2 or more, while homegardens usually cover relatively small areas (between 100 and 500 m^2), compared to other AFS in Mexico (1-4 ha). It is possible to find isolated individuals at the center of the homegarden (see Figure 2) or as part of vegetation islands.

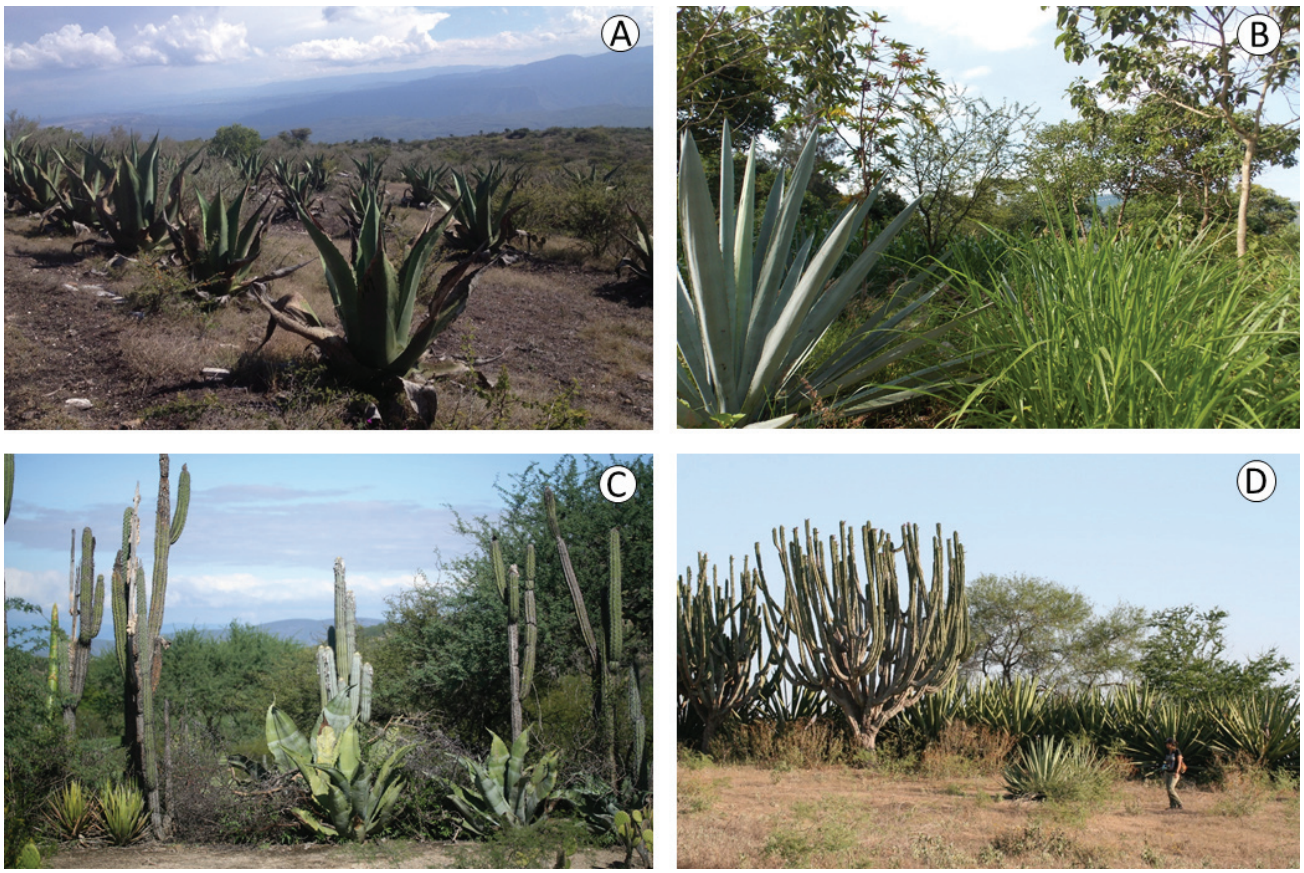

Figure 2. *Agave* species and general management strategies in agroforestry systems. A) *Metepantle* in the municipality of Zacualtipán, Hidalgo (Photo: G. Álvarez), B) *A. americana* in a family homegarden in the municipality of Tlahuiltoltepec, Oaxaca (Photo: A.I. Moreno-Calles), C) *A. triangularis* and *A. marmorata* as part of a live fence in a AFS in a semiarid zone in Zapotitlán de las Salinas, Puebla. (Photo: I. Torres-García), D) Live fences and island of *A. rhodacantha* in an agrosilvopastoral system in Zapotitlán de Vadillo, Jalisco. (Photo: I. Torres-García).

B) Ecological-functional role of Agaves in homegardens.- Agaves retain soil and humidity, promoting the infiltration of water into the ground. When they are allowed to flowering, they act as attractors of melliferous species (bees) and beneficial nectarivorous species (birds, bats, and other small mammals) both necessary to increase the productivity and fructification of other important species that compose the system, such as fruiting trees. Similarly, they are the habitat for animal species such as reptiles (mainly small lizards and snakes, see Figure 3), which control insect plagues and rodents inside the system.

C) Utilitarian attributes of Agaves in homegardens.- In total 16 use categories were reported, eight have two or more records, being the most mentioned the ornamental, followed by medicinal, edible, and obtaining of fiber as the most important (see Figure 4 and Appendix 1). The majority of the *Agave* species registered have mainly an ornamental use with an aesthetic role in the system; there are other important uses as well, such as the medicinal and edible uses, given their immediate availability and accessibility as a constant element of homegardens. In Mayan homegardens flowering stalks and fibers are used as materials for constructing ka´anche, a sort of traditional seed-bed or elevated horticultural pots characteristic of this region, used for the production of vegetables. Some uses represent an economic incomen this category it is possible to include the commercialization of *pulque*, fiber extraction, processing and commercialization of crafts such as necklaces and rosaries, as well as articles of common use such as *morrales* (bags) and *mecapales* (a sort of rope implement made of agave fiber that is used to carry bulks on the back and which is borne on the forehead). In this system, it is possible to find the presence of species that have been cultivated and selected for a long time, and evident domestication syndromes are present, such as gigantism of the leaves, fibers and the whole individual, as well as a high concentration of carbohydrates. Species such as *A. fourcroydes*, *A. angustifolia,* and *A. tequilana* are part of a complex of species for which there is information about their domestication processes and the relationship with their wild relatives.

D) Management. Those individuals that are established and maintained in homegardens, in the case of domesticated species are mostly transplanted from adjacent homegardens or from shoots of individuals that have flowered. Due to their monocarpic reproduction, agaves die after flowering and are then reproduced through stoloniferous or bulbil shoots. In

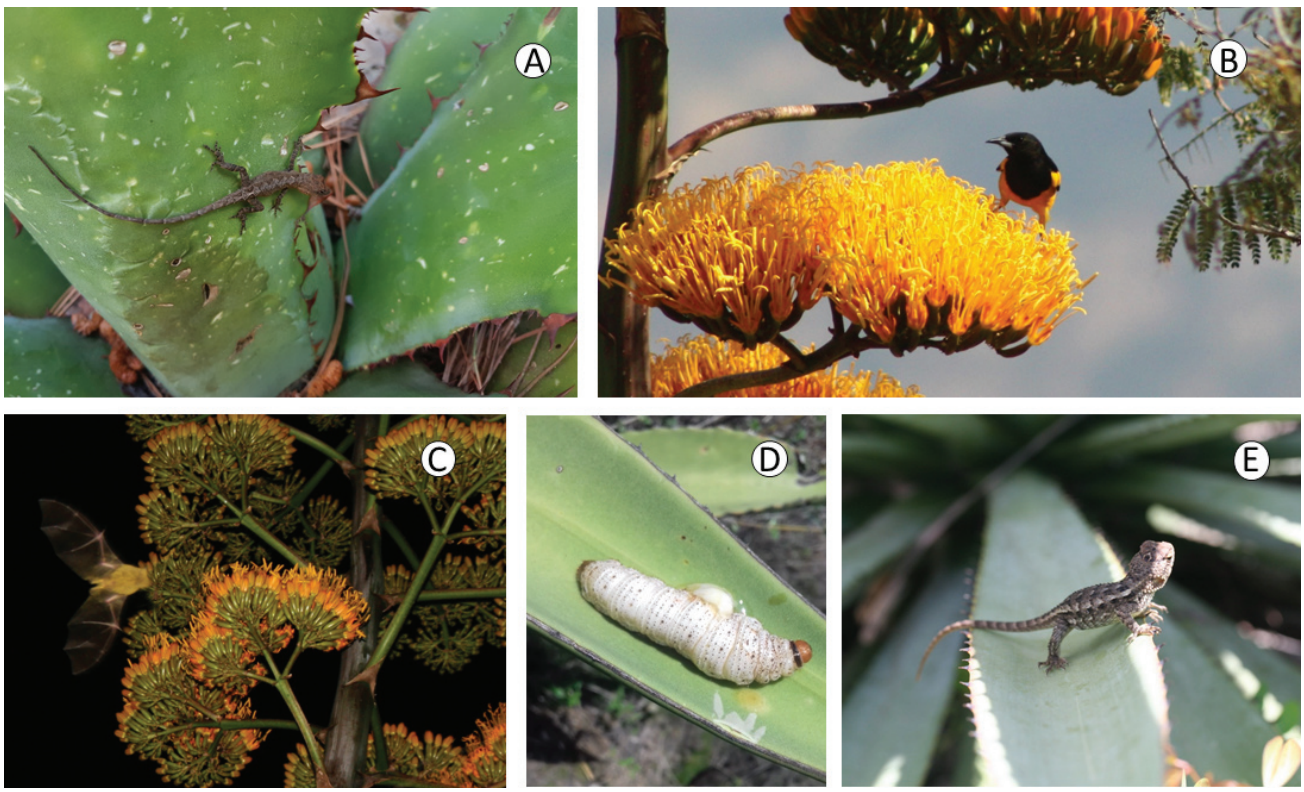

Figure 3. Ecological interactions of agave in agroforestry systems. A) *Anolis nebulosus* in *Agave cupreata*, municipality of Tzitzio, Michoacán (Photo: I. Torres-García), B) *Icterus wagleri* feeding on an inflorescence of *A. cupreata* in the municipality of Tzitzio (Photo: C. Ojeda), C) *Leptonycteris* sp. Feeding on the inflorescences of *A. cupreata* in the Tzitzio municipality (Photo: I. Torres-García), D) *Aegiale hesperiaris* in *A. scaposa* in the municipality of Caltepec, Puebla (Photo: M. A. Negrellos-Balderas) and E) *Sceloporus* sp. in *A. angustifolia* in Zapotitlán de Vadillo (Photo: I. Torres-García).

Figure 4. Main uses of agave in agroforestry and agroforest systems. A) *Agave triangularis* being used to delimit a plot (Photo: I. Torres-García), B) *Condachos*, *Aegiale hesperiaris*, roasting on a grill, municipality of Caltepec, Puebla (Photo: M.A. Negrellos-Balderas), C) *Agave marmorata* used as a live fence, municipality of Zapotitlán de las Salinas, Puebla, D) Walls of traditional housing made with inflorescences of *A. scaposa*, Municipality of Concepción Buenavista, Oaxaca, E) Goat *barbacoa* baked using leaves of *A. salmiana* var. *ferox,* municipality of Concepción Buenavista, Oaxaca, F) Distillation of mezcal made with *A. cupreata* in the municipality of Tzitzio, Michoacán (Photos: I. Torres-García).

the case of wild species, individuals come from the adjacent ecosystems, and are cultivated primarily through transplanting the complete juvenile individuals that are of interest to people. The transplant location depends on the design of each homegarden and the function that transplanted agaves have as part of the system.

Agroforestry terraces.- This AFS is embankment-based structure located on the slopes of hills and mountains has contributed to its archeological identification in several zones of the country (Moreno-Calles *et al*. 2013, 2016b, and Gonzáles-Jácome 2016). The architecture of this system allows the conservation of soil and water trough of the roots of the useful trees and agaves, perennial bushes, and others, growing in board terraces allowing intensive annual and perennial management crops.

This system was mentioned in 21 of the studies reviewed in which five species are mentioned; among them, *Agave salmiana* was the most frequently referred to followed by *A. americana A. atrovirens*, *A. salmiana* var. *ferox,* and *A. mapisaga*. Seven studies identified the agaves only at the genus level, eight focused on the study of *metepantles* or terraces with agaves from the historic or prehistoric point of view, presenting palynological evidence, archeological evidence (as instruments to extract *aguamiel*), and archaeobotanical evidence (as remains of roasting pits with agave fibers associated with this type of agroforestry system in various parts of the country). Places such as the Teotihuacan Valley, Ixtapalapa, and Ixtacuixtla in Tlaxcala in central Mexico, but also in places in the north of Mexico, such as Parras de la Fuente, in Coahuila, La Quemada, in Zacatecas, and Cerro Juanaqueña in Chihuahua, are all places with a record of this agroforestry practice, all of them importantly including the presence of agaves. Through their roots, agaves confer stability to the terraces, which were usually established on slopes highly susceptible to erosion. This system was practiced in areas that were under high demographic pressure. Such was the case of the Aztec settlement in the Valley of Mexico, in which thousands of people lived before the arrival of the Spaniards. One of the explanations for how this human settlement survived highlights the intensive establishment of this system.

A) Structural role of agaves in agroforestry terraces.- Depending on their extension, terraces can host hundreds or thousands of individuals which are generally planted in lines following the level curves. Among the functions of agaves are, first of all, the limits created by the succulent and armed

rosettes, which at the same time intercept and diminish the effect of rain on soil, allowing in this way the infiltration of water into the ground. Adding on to these effects, there is the strong hold of superficial roots (see Figure 2), which contribute to the effective prevention of erosion and to the conservation of the architecture of terraces.

B) Ecological-functional role of agaves in agroforestry terraces.- Some species of *Agave* in these systems are hosts to larvae of some lepidopteran species. These larvae have specialized to hatch, feed, grow, and find refuge on the tissues of agaves and depend completely on their existence to complete their life cycle. These larvae have been used as food by many cultures. In agaves other animals such as rodents, lagomorphs, and some reptiles also find shelter and when agaves bloom, they provide food to several insect, bat and bird species. The flowering stalks are perching and nesting sites for many bird species (see Figure 3). Some species defecate plant propagules that could be incorporated to the system.

C) Utilitarian attributes of agaves in agroforestry terraces.- These systems integrate the cultivation of diverse grains that are sown in the terrace structure under the shelter of agaves, therefore this structural component is at the same time a source of multiple resources. Regarding this issue the most important uses reported were *aguamiel* and fermented beverage (*pulque*), edible, fuel and provision of edible insects the most important ones (Figure 4) (Blanton 1972, Martínez-Saldaña *et al.* 1993, Hard *et al.* 1999, Martínez-Saldaña 2007, Borejsza *et al.* 2008). In the past, large *metepantle* extensions were linked to great civilizations. The gathering of *aguamiel* in these systems represented a source of water in those relatively semiarid zones of the Mexican Plateau, as well as a source of food with high nutritional content. Moreover, the flowering stalks were elements for construction, while the thorns and teeth were employed to produce sharp instruments for sewing and performing rituals. The fibers were used to spin and sew textiles, the leaves for construction of roofs in the manner of tiles and when dry, these same leaves could be used as fuel for cooking food. Such was the versatility and importance of this resource that the plant was worshipped and even deified in the Aztec worldview. In contemporary times, the gathering of *aguamiel* and *pulque* for commercialization has radically diminished since the second half of the past century (Álvarez-Ríos 2015). Nevertheless, currently these systems can be found in large extensions within the country in the states of Tlaxcala and Hidalgo, where resources such as *aguamiel* and *pulque* are collected, as well as edible insects for direct consumption by households and for commercialization. Another activity that characterizes this region is the use of agave leaves to prepare *barbacoa de borrego* (sheep barbecue), being sheep, a traditional animal managed in this area. The *barbacoa* is prepared in a pit oven in which the meat is covered with agave leaves, which serve as insulation from the direct heat of the ashes and give this regional dish a special taste.

D) Management.- The multiple individuals of agave that integrate this AFS have been obtained, selected and propagated asexually, through transplanting of stoloniferous shoots of the mother plants that were used and whose lifecycle has come to an end. This type of management is practiced in the case of domesticated species and their varieties: exchange of plants of other regions with similar management is performed by inhabitants with the intention of incorporating variants with different attributes. In the case of wild species, juvenile individuals may be transplanted from the surrounding ecosystems or may be tolerated at the moment of removing vegetation in order to cultivate other crops, and also transplanted in the same field to form the contention lines that form the terraces.

Agroforestry systems in semiarid zones: *Melgas*, *apantles* and *coaxustles* in the Tehuacán Valley, Puebla.- This type of AFS was recorded in 7 studies and included the presence of species like *Agave salmiana* var. *ferox, A. scaposa, A. marmorata,* and *A. potatorum,* with at least 9 use categories (see Appendix 1. It is in the semiarid zones of the Tehuacán-Cuicatlán Biosphere Reserve, which is inhabited by communities of Popolocan and Nahuatl ascent. All *Agave* species mentioned grow wild in the ecosystems within community territory. In these agroecosystems, a considerable number of individuals from species that form part of native forests are tolerated, promoted and/or protected due to the different benefits that can be obtained from them, agaves being the most precious elements.

Within these systems, agaves have the main function of limiting plots of land and constitute live fences to prevent the passage of cattle into the *milpa* (Figure 2). *Agave potatorum* (papalometl) and *A. marmorata* (pitzometl) are used in the community to produce alcoholic beverages like mezcal and *pulque* which have in recent years diminished due to extraction of individuals from populations of these species. Therefore, the authorities of the Biosphere Reserve have intervened to influence the communitarian authorities so as to establish a prohibition of extraction/felling of *A. potatorum.* Available literature reports that in some AFS of the Tehuacán Valley there exist the necessary conditions for this species to grow, given the species needs for nursing plants to germinate and establishment (Rangel-Landa *et al.* 2015). It is within these systems where various species with different nursing qualities can be found, such as diverse bush species that are tolerated as part of agroforestry practices. These systems are also propitious spaces for seed dispersal by animals. The existence of proper conditions is very important for the conservation of these delicate interactions. Wild and cultivated agave extraction for mezcal production and sale has high cultural importance in this community, for it is not only consumed in patronal fests, but also as a remedy or stimulant for the hard labor in the fields. There is high demand for mezcal produced in this locality, and it has already a regional market, which means economic incomes for the families that produce it (Torres-García 2009, Moreno-Calles & Casas 2010, Torres-García *et al.* 2013, Delgado-Lemus *et al.* 2014a, Torres-García *et al.* 2015b). *Agave marmorata* is employed to make cough syrup, *pulque* and mezcal, the flowering scapes are used in Easter to adorn churches, houses, and streets, as well as for making bird nests in houses; flowers are also consumed (the flower buds are called *cacayas*) and

leaves are used as fuel (*mezontete*). Another singular species in these ASF is *A. scaposa*, a common species that is generally found as part of agroforestry practices like hedgerows and live fences, with the main purpose of retaining soil. This species has the highest abundance dominance in milpa-chichipera ASF. Also, its floral scapes are highly appreciated for house construction due to a scarcity of trees with straight trunks (Figure 4). In San Luis Atolotitlán, there exist rules that establish that in order to cut a flowering stalk, it needs to have blossomed and freed its seed, allowing for its natural regeneration, considering the biotic interactions as well that occur in the flower, which is visited by multiple nectarivorous species of insects, birds, and bats. It is also very important for the culinary culture of this community, since it is the habitat of a highly appreciated edible insect called *condacho,* of the species *Aegiale hesperiaris* Walker. These larvae can be found in the inner part of the succulent base of the leaves of this agave, and to extract them it is necessary to cut the leaves with much care so as not to harm the larvae. In this process agaves, which are in general those that have not blossomed, may be harmed, causing their death. Given these risks, rules were established by the community, allowing for the extraction of these larvae only one or two days in the year in the month of June (Figure 3 and 4) (Moreno-Calles & Casas 2010, Moreno-Calles *et al.* 2011, Moreno-Calles *et al.* 2016a).

Newly established agroforestry systems. Agrosilvopastoral systems and agaves in Jalisco.- On the foothills of the Nevado de Colima and the Volcán de Fuego in the Zapotitlán de Vadillo municipality in the community with the same name, it is possible to find some experiences of integrated management of mezcal agaves. This region continues a tradition of more than 300 years in the production of mezcal, *tuxca* or mezcal wine, spirits based on the fermentation of two species, one wild *Agave angustifolia* and the other with incipient domestication *A. rhodacantha.* In the beginning of the past century mezcal production in the zone was sustained by the extraction of wild agave populations in the tropical dry forest of the region, mainly *A. angustifolia*. It was during the 1990´s that these wild populations began to diminish. Considering this fact many families began to select plants with attributes desired for mezcal production and took them from wild habitats to cultivate them in their agricultural systems. A particular experience in Zapotitlán de Vadillo is that of one family that has developed an integral cultivation system that alternates around 14 wild varieties of *A. angustifolia* with corn, bean, squash, and other annual products, as well as with other forest elements that have been tolerated within parcels, such as *pitayas* (*Stenocereus queretaroensis* (F.A.C.Weber Buxb) which provide edible fruits, *mezquites* (*Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M.C.Johnst., species whose sweet pods are used as forage or for human consumption, among other uses and *huamúchiles* (*Pithecellobium dulce* (Roxb.) Benth.), which are trees that provide shade to people and cattle (Figure 2). These areas are also used by goats that feed on the multiple weeds and forage that grows in this system. Of the two agave species present in this system, around 14 varieties of *A. angustifolia,* have been identified as having been obtained from the wild, and reproduced in this system through stoloniferous shoots, and transplanted in lines of only one variety (Vargas-Ponce *et al.* 2007, Vargas-Ponce *et al.* 2009). There are two varieties of *A. rhodacantha* identified by people, who mention that they are only known as cultivated varieties, and these have evidence of domestication, mainly due to the size of individuals, the length of their leaves and the use that they had in past times for fiber provision. Their traditional names also evidence their use, because they are commonly known as *ixtero verde* (*ixte* or *ixtle* is another way of naming the fibers that come from *Agave*) and *ixtero amarillo*. Seven use categories have been registered for this species, the most important being mezcal production, followed by their use as live fences, food, condiment for *barbacoa*, medicinal, fiber and as a fermented drink (see Appendix 1). Currently, mezcal production in this region depends mainly in the production of agaves from agricultural lands that were established as a response to the shortage in the past. The production of mezcal wine or *tuxca* in this region is also a cultural activity of economic importance that has prevailed for many generations and in recent years, has reached commercialization channels at the local and national levels.

Agave agroforests in western Mexico.- This type of management has been observed and documented for species such as *A. cupreata, A. inaequidens,* and *A. maximiliana.* Although these are multipurpose species, they are currently used mainly for the preparing of spirits from mezcal and *raicilla* in Michoacán and Jalisco, respectively. This type of management has evolved in recent years. Spirit producers and managers of these species remark that mezcal in Michoacán and *raicilla* in Jalisco have been produced for at least 300 years. However, these species only started to be reproduced and cultivated in the past 15 to 20 years through sexual propagules, the only effective form of reproduction for species of the Crenatae group. The main reason why people started growing this crop was as a response to market pressure which caused the decrease in wild populations, as well as the growth in the number of producers in these zones.

In the case of *Agave cupreata* in the state of Michoacán, the cultivation of this species began approximately 20 years ago, mainly in the municipalities of Madero, Charo, Tzitzio, and Morelia. Cultivation of *A. cupreata* in this region was a reaction to pressure over the resource, which was used for making mezcal, and this activity determined a critical decrease of its wild populations. Experimentation with plant production in nurseries through seed sowing, started in the municipality of Madero. The tendency was to establish monocultures, similarly to *A. tequilana*; however, there are other cases in the region principally in Tzitzio and Charo, where *A. cupreata* is spread through agroforestry practices, through seeds in rustic nurseries. The main purpose of the plants grown in these nurseries is to reforest through plantations with a very high density of agaves, in places found on the transition between oak-pine forests and tropical dry forest, where relicts populations of these species can be found, and can be taken as a sign of the ideal habitat for production of this agave species. In these forest areas clearings

of bushy species take place and some tree species have been tolerated, such as *tepehuajes* (*Lysiloma* spp.), *papelillos* and *copales* (*Bursera* spp.), anonas (*Annona* sp.), *palo dulce* (*Eysenhardtia polystachya* (Ortega) Sarg.), and palms (*Brahea pimo* Becc.) among others (Figure 5). Cattle are also allowed to feed in these systems, having the care of letting cattle feed where agaves already have a proper age, size, and configuration that allow it to resist being stepped-on by cattle. Although the predominant use in of *A. cupreata* in Michoacán in the present is the production and marketing of mezcal, nine other categories of use have been registered (see Appendix 1). In order of importance these are: as food, medicinal uses of the baked or grilled stem, the use of flowers as attractors for deer hunting, as live fences, ornamental, and ceremonial uses, and as a diversity of instruments and utensils (nests for little parrots, seats, thorns to take out splinters, caps for bottles). The bagasse that remains from mezcal production is used as a biofertilizer. Another highly demanded use is the commercialization of juvenile plants for the establishment of plantations to make mezcal, and the commercialization of seed, a product that can cost between US$210 and US$263 ($4000 and $5000 Mexican pesos) per kilo.

Agave inaequidens has a similar history. In the municipalities of Indaparapeo and Queréndaro -with around 40 maguey managers and mezcal producers- around 20 years ago producers began to establish monocultures of agave as a response to the shortage of wild agave due to a faster extraction-to-regeneration rate, following the production tendency of tequila maguey. Nevertheless, there exist wild populations managed *in situ* which are reforested with individuals produced in rustic nurseries. Several management practices contribute to the conservation of this species. Among these practices it is possible to find the tolerance of agaves when clearing the underbrush in forest patches of pine-oak and pine-fir, the protection or promotion of specific individuals when transplanting to sites with better conditions for growth, and the dispersion of seeds by scattering on favorable sites for germination –in total 10 types of *in situ* management practices (Figure 5). A total of 16 use categories and 34 specific uses have been registered for this species of which the most important by order of mention is the making of mezcal, which has had a boom in the past 10 years (see Appendix 1). However, to a lesser extent it also has edible and medicinal uses, it is used as insulation and as condiment for

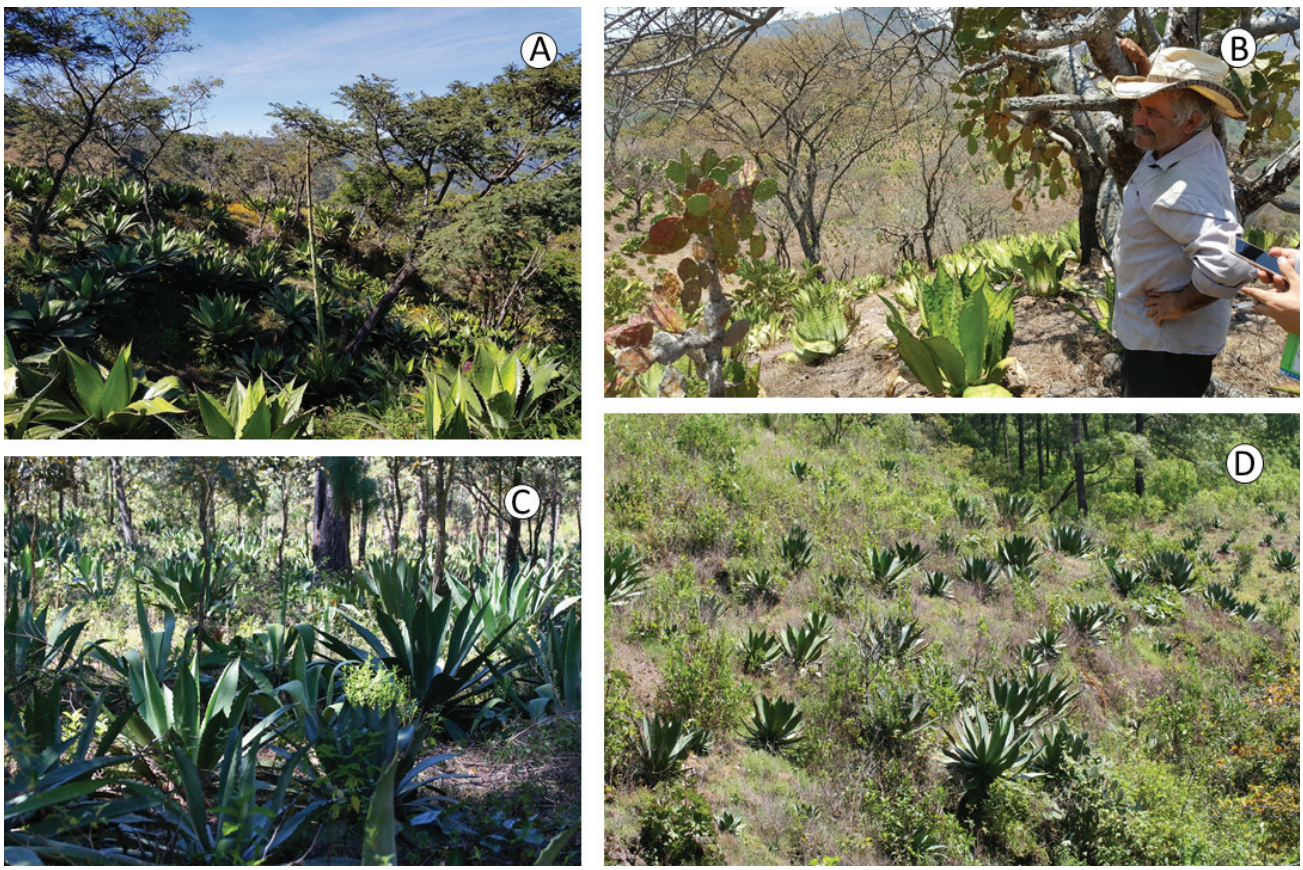

Figure 5. Agave agroforests. A, B) *Agave cupreata* agroforests in the municipality of Tzitzio and Charo, Michoacán, C) Agroforests of *A. maximiliana* in the municipality of Mascota, Jalisco, D) Agroforests of *A. inaequidens* in the municipality of Queréndaro, Michoacán (Photos: I. Torres-García).

making *barbacoa,* as veterinary medicine, for the extraction of *aguamiel* and *pulque*, as live fences, forage, construction material, fiber extraction, sale of juvenile agave, erosion control, as bait to attract deer for hunting, for ornamental uses, and as utensils (Torres-García *et al.* 2015a).

In the case of *Agave maximiliana* in the region of Mascota, Jalisco, registries mention that 15 years ago the rates of extraction of wild populations of this species determined its critical decrease, promoting the establishment of commercial monocultures in deforested areas and abandoned agricultural lands. Some managers have established agroforests with agaves such as the ones mentioned above; these sites result from the clearing of forests and the planting of juvenile agave that have been grown in rustic nurseries in pine-oak forest zones (Figure 5). Inhabitants recognize the incidence of frost in the zone, a fact that affects species found in open areas with no canopy cover. It is in these areas that inhabitants have established this crop, trying to reproduce the natural conditions of the populations that grow under tree canopy in order to keep them from frost. For this species, 11 use categories have been registered, of which the most important is the making and marketing of *raicilla*, (a spirit that is going through a market boom) followed by uses as medicine, fuel, forage, marketing, and bartering, as fertilizer, as ornament, as insulation and condiment, as a fermented drink, to retain soil and as bait for deer hunting (Huerta-Galván 2018).

Agave agroforest management in Guerrero. In the Mountain region of Chilapa, Guerrero, there exists a management experience that has been developing for many years. This experience has been the fruit of the interaction between the community of Nahuatl mezcal producers of Acateyahualco, Guerrero and the non-governmental organization GEA A.C. (Grupo de Estudios Ambientales y Sociales). GEA has nearly 20 years carrying out arduous participatory action research that has had a positive impact in the community´s management of their territory and its natural resources. This community has developed an important management strategy, based on ecological information generated through demographic studies of the local wild *Agave cupreata* populations, which integrates the biological and reproductive dimension of this species in the design and application of annual systematic monitoring schemes. Indicators regarding the structure of wild agave populations are analyzed in community assemblies. In this way, the community decides how many mature agaves can be extracted based on the harvest thresholds established in the demographic models; that is harvesting that does not alter the recruitment rates in order to allow for population equilibrium. This monitoring scheme allows maguey to be harvested in a period of one year, and it specifies that it can only be processed by the community of Acateyahualco to satisfy its demand of mezcal. At the same time, the community practices a rotation system of the extraction sites, by establishing different stands within natural vegetation, where they carry extraction and monitoring. This extraction model implies that the sites where extraction happens must be shifted over time in order to assure that natural regeneration of the species happens in its natural habitat, allowing individuals to naturally blossom and disperse their seeds. They also have a systematized management of the cattle that grazes on this territory. The management of cattle assures seed production, dispersion, and establishment of new agave generations, at the same time that pollination processes are promoted. On one hand, the restriction of cattle to enter plots where mezcal seeds are germinating protects these seeds from being eaten. On the other hand, this restriction allows tender inflorescences to blossom in order to let pollination processes occur. When seeds germinate and there are seedlings on the fields, cattle may step over these seedlings, so the entrance of cattle into these stands during these susceptible stages is restricted. This species is mainly pollinized by bats of the genus *Leptonycteris* and given that this agave does not produce stoloniferous shoots, seeds are the only way it can reproduce. This is an example of community management of a collective resource through a very interesting collaboration between Academia, NGOs and rural communities to sustainably manage natural resources, ecosystems and territories (Illsley *et al.* 2007, Martin *et al.* 2011, Illsley *et al*. 2018). Forest areas next to this community are being conserved for being the natural habitat of *Agave cupreata.* This action contributes significantly to the conservation of diversity of accompanying species and ecosystem benefits that are determinant to the quality of life of the community. Mezcal is a very important part of local and regional culture: it is consumed in patronal fests and is one of the few cultural activities that determine a tangible economic income for the inhabitants of this community.

Discussion

In total, our study identified 31 species of *Agave* (of the 210 described, according to García-Mendoza *et al.* 2019), within traditional AFS and newly established AFS in Mexico; that is, 11 percent of total *Agave* richness. However, these are preliminary and surely underestimated data, for the research efforts have to the present focused on specific regions and ethnic groups, leaving out others that also have an important history of AFS and agave management. Moreover, adding to this bias in the regions and ethnic groups studied, the lack of studies regarding AFS and agaves is also because studies that concentrate on these topics are only very recently gaining importance and being performed (Moreno-Calles *et al.* 2016b). Other problems also limit the analysis efforts of this study, such as the lack of studies that identify agaves to the species level. An explanation for this can be that *Agave* species are hardly collected to be put in a herbarium, or that the sampling does not always coincide with the presence of floral structures, and above all, that the preparation of herbarium samples requires dedication and specialized techniques, or that species under agroforestry management are not of interest to wider groups of researchers. The lack of herbarium material makes it difficult to identify species, moreover when these are domesticated cultivars.

Agave are indisputably one of the most important groups of resources for the survival and development of Aridoamerican and Mesoamerican cultures. Just as Gentry (1982)

reported in his works dedicated to this group of plants, focusing on the symbiosis Agave-human, the present study also reports this symbiosis, which is reflected in the multiple utilitarian, cultural, evolutionary and socioeconomic expressions studied. *Magueyes*, *agaves*, *mezcales*, *lechuguillas*, among others (*Agave* spp.), have an elevated number of uses (22) at the local level compared to other plant species. Agaves are a crucial part of the lives of the communities, providing nutrition, energy production, construction, making of medicinal remedies, as well as an important base for the generation of economic resources needed in a rural context. It is of interest that in Figure 6 these species have a greater number of uses in agroforestry milpas, family homegardens and terraces in comparison to agroforest*s* destined to produce mezcal. This tendency is worrisome because it not only represents the loss of ecological and biocultural richness, it also represents the loss of the multiple functions of these species as they are integrated into global emerging markets, as is the case for mezcal, edible insects or the so-called superfoods markets, as in the case of agave syrup. This situation poses a dilemma about the production models where the satisfaction of local rural necessities (food, health, housing, fuel, preservation of soil and water) competes with the global urban "necessities" like recreation with alcoholic beverages or alternative nutrition through so-called "superfoods". Many species show clear signs of domestication and the archaeobotanical, paleontological, historic, and contemporary and actual evidences suggest a long history of their importance within agricultural, forest and agroforestry systems. According to our work, 12 of the 64 existing cultural groups present in the territory (Boege 2008) have incorporated and maintained agaves in ethnoagroforestry systems and various mestizo groups also use these elements as part of their management systems. It is possible that due to the wide distribution of this genus of plants in Mexico many more cultures use them in their agri-food systems.

Homegardens represent one of the oldest, and most intimate agroforestry management systems, given that in general they are adjacent to houses and they play many roles, from aesthetics, ornamental and utilitarian purposes, such as serving as food and medicine. González-Jácome (2009), determined that homegardens are living laboratories where selection processes and hybridization processes may have taken place, for it is in these places where species with disjunctive distributions found and coincided with each other. These AFS are generally vast in diversity and surely, processes like the ones mentioned above took place in these places. In this context, one of the species most documented for the Mexican Southeast is *Agave fourcroydes*, species that is recognized as the product of the domestication of *A. angustifola* (Colunga-GarcíaMarín & May-Pat 1997, Colunga-GarcíaMarín & Zizumbo-Villarreal 2004).

Terraces like homegardens, are systems with an ancient history in several regions and cultures in our country. There is palynological and archaeological evidence of this extensive practice related to the development of some highly populated Mesoamerican cultures (Blanton 1972, Evans 1990, Trombold & Israde-Alcantara 2005, Borejsza *et al.* 2008). Nevertheless, the extension and use of this type of system has diminished at a significant and accelerated rate since the last half of the 20th century. The main reason for this is the decay in the consumption of *pulque* in a number of places in Mexico, but mainly in Mexico City (Álvarez-Ríos 2015). The theft of the cuticle of the *maguey pulquero* leaves for the making of *mixiotes* also discourages managers of this species (Moreno-Calles *et al.* 2016b).

The existence of a gradient of management applied to different species of *Agave* registered in agroforestry systems is evident. This gradient can be observed from *in situ* to *ex situ* management (Casas *et al.* 2007, Blancas *et al.* 2010), which also expresses a complexity gradient. *In situ* management; in the case of community forest management, no reforestation nor complex manipulation actions are performed; the work is already strategic, since it incorporates ecological techniques appropriated by inhabitants, and a decision-making process through the community assembly, to decide the extraction rates based on models. Under this management regime, the forest is not radically impacted, only when mature individuals are harvested, and while transporting them to the places where mezcal is produced. In agroforests, there is an impact directed mainly at the understory vegetation in order to establish agave produced in nurseries, which implies greater effort and planning, besides harvesting. *Ex situ* management: it is in homegardens and terraces where managers apply a greater complexity of management practices, since these are environments with a high presence of domesticated and cultivated species. These places also count with several tolerated wild species, as well as wild elements that have been either transplanted, tolerated or promoted, from adjacent natural systems into these agroforestry systems. The presence of these tolerated or promoted wild species in homegardens and terraces also implies the accompanying development of agricultural labors and the maintenance of lines or borders of agave within these systems.

Challenges and perspectives in the management of Agave in AFS in Mexico. The loss of *Agave* species and the abandonment of these agroforestry systems is a phenomenon related to multiple factors, some of them associated to migration and transculturation. The collective TEK of communities has suffered losses, and above all the loss of the practice of this knowledge. Another determining factor for the abandonment in the use of agave, mainly the fibers, a very important use in the past centuries, has been caused by the production of cordage by the hydrocarbon industry, polyethylene, etc. This industry came to displace the making of cordage made with agave in practically the entire Mexican territory and determined the fall of a very important economic activity for the Yucatán peninsula in the past century. However, the preservation of *Agave fourcroydes* in family homegardens is an example of how cultures treasure resources, those same resources that may have been displaced by market tendencies and which are maintained and managed in these environments due to utilitarian and aesthetic reasons, although at a smaller scale, but fulfilling biocultural and ecological functions in the present.

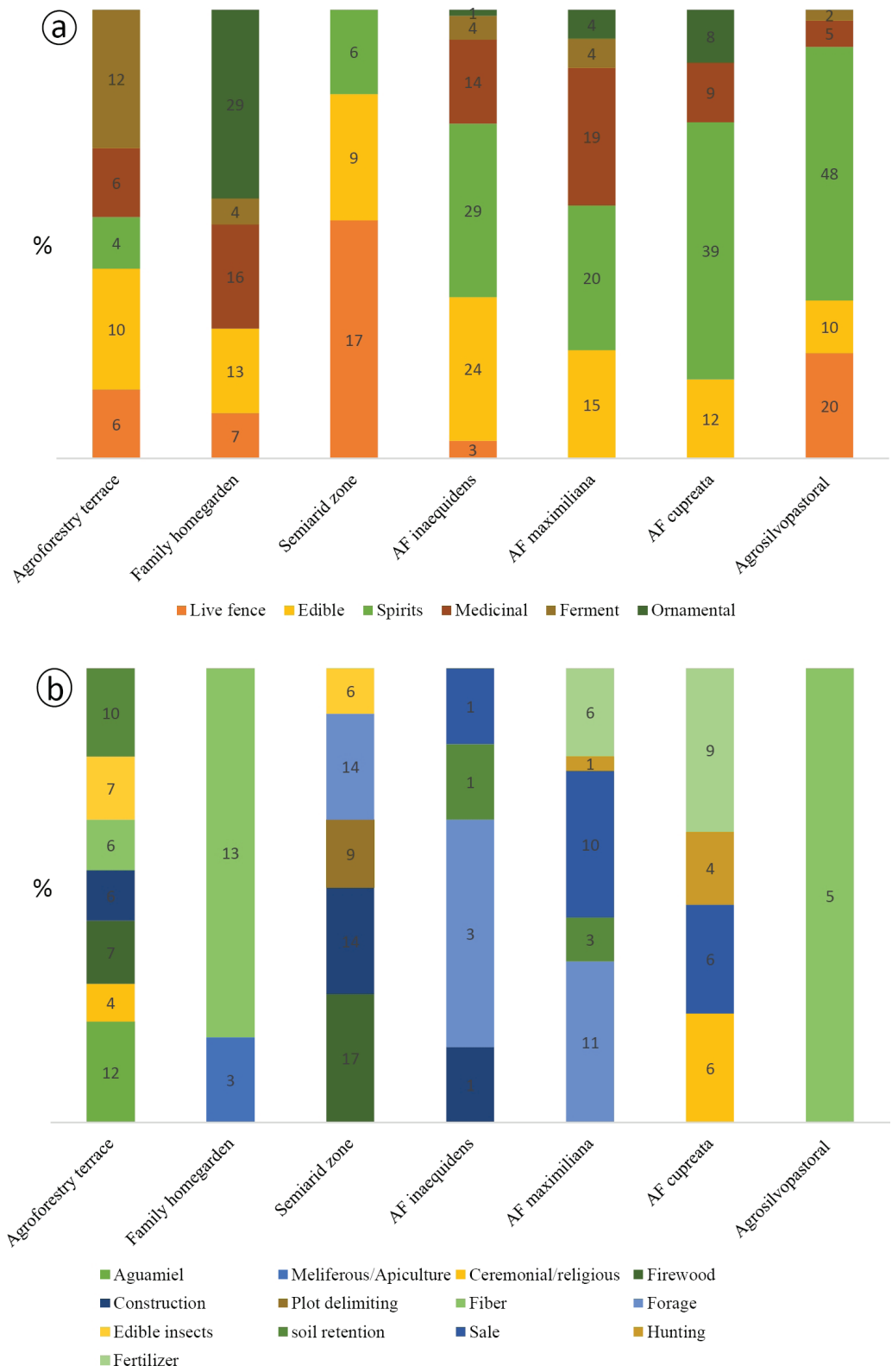

Figure 6. Comparison of the percentages of mentions of the registered use categories in this study for agave present in various agroforestry systems. For comparison purposes they were separated into: a) use categories with the highest number of mentions, b) use categories with the least number of mentions.

The crisis of distilled spirits in Mexico, the market tendencies and the boom in mezcal demand are determining the establishment of monocultures, which are systems that in the long term become dependent on agrotoxics, and determine many biological, environmental and sociocultural losses. The establishment of new agroforestry and forest management forms described in this study are alternatives to produce raw material for this industry. They also promote the conservation of part or the whole of biodiversity of the ecosystems where they are found. At the same time, all this biodiversity represents an opportunity for designing future strategies for management and conservation of such valuable genetic resources. The market tendencies could recognize –through labeling and publicity- those spirits that come from these types of management.

The recognition, valuation and promotion of this important group of resources within these management systems, beyond the production of spirits, is very important in the effort to guarantee the availability of the different types of foods and raw materials for productive activities. As well as considering the sub-products that are disposed of in the production of spirits, such as leaves, bagasses, and vinasses. The leaves are left in the fields were harvesting of the agave heads occur, bagasses are the fibers that are disposed after distillation (Martínez-Gutiérrez *et al.* 2015) and vinasses are acidic liquids that are also disposed, mainly to water bodies, after distillation (Robles-González *et al.* 2012). These sub-products which represent a development potential in agriculture, food, and pharmaceuticals and an alternative to complement the economy of producers (López-Romero *et al.* 2018). Likewise, it is important to guarantee the preservation of important elements of the identity of the communities and cultural groups that host this diversity.

Agroforestry systems are spaces where wild and agricultural diversity coexist (Casas *et al.* 1997a, Moreno-Calles *et al.* 2013), and in Mexico, agaves are very important components of these systems. Commonly, Mesoamerican agaves constitute complexes of wild and domesticated taxa whose identity also represents a constant scientific challenge. In this way, including agaves in the agricultural or forest component is frequently very difficult. Domesticated agaves are part of the agricultural component, while wild agave is part of the forest component. This definition, the lack of research and the difficulty in identifying agave and their wild or domesticated status make it difficult to arrive at conclusions. This first approach allows to identify: (1) the structural, functional and cultural importance of *Agave* in agroforestry systems, (2) the importance of such spaces for the conservation of these species (wild and domesticated) and agave varieties, ergo, their role in *in situ* conservation of these genetic resources, (3) the need to do in-depth research about the composition of these systems and the related links to agave management, (4) the importance of going in-depth into the management techniques for agave in these systems as a basis to take advantage of the techniques developed traditionally in conservation programs in forests and agroforestry systems, (5) the value of studying these systems as referents of their value in the conservation of biodiversity and of biocultural heritage.

Acknowledgements

We thank the Dirección General de Asuntos del Personal Académico (DGAPA) for the postdoctoral scholarship awarded to the first author. We also thank the Consejo de Ciencia y Tecnología (CONACYT) and Red Temática de Sistemas Agroforestales de México (RedSAM) Project 293348 and la Red de Productos Forestales No Maderables (RED-PFNM), project 293914, for the support provided to this research. To the National Autonomous University of Mexico (UNAM) for the academic and technical support and for the resources received through the DGAPA PAPIIT IN200417 and IN206217, the DGAPA PAPIME PE209517 projects.

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Associated editor: José Arturo de Nova Vazquez

Author contribution: ITG: Coordination, design of the research, sampling, systematization and interpretation of information, writing and revision of manuscript. AIMC: Conception, coordination, design of the research, writing and revision of manuscript. AC: Research design, writing and revision of manuscript. JB: Research design, writing and revision of manuscript. FJRS: Sampling and systematization of information, writing and revision of manuscript.

Appendix 1. *Agave* species present in agroforestry systems in Mexico (S/R no record).

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. americana var. *marginata*	maguey pinto	Homegarden	Nahua	Coyomeapan	Puebla	crop	Ornamental	Larios *et al.* 2013
A. americana	maguey	Homegarden	Maya		Yucatán			Mariaca-Méndez 2012
A. americana	maguey	Homegarden	Maya		Quintana Roo			Mariaca-Méndez 2012
A. americana		Metepantle	Otomí (Hñähñú)	El Botho, found in the Alto Mezquital region	Hidalgo	terraces	Edible, fuel, *aguamiel*	Pérez-Botho *et al.* 2015
A. americana	maguey manso	Metepantle		Ixtacuixtla	Tlaxcala	terraces, hedges	Gathering of gusano blanco and chinicuil, soil retention, *aguamiel*, pulque, construction fiber (iscapul)	Pérez-Sánchez 2012
A. americana		Homegarden	Maya	Pomuch, Mpio Hecelchakán	Campeche		Ornamental	Poot-Pool *et al.* 2012
A. americana	maguey			Comitán	Chiapas		Distilled spirits	Reynoso-Santos *et al.* 2016
A. americana	maguey	Homegarden	Mestizo	Adolfo López Mateos and el Ahuacate	Nayarit		Edible and live fence	Ruenes-Morales 1993
A. americana	maguey, mexcaltenechtly	Homegarden		Coyomeapan	Puebla	crop	Edible	Larios *et al.* 2013
A. angustiarum	cacaya	Homegarden	Mestizo/Nahua	Coxcatlán	Puebla	homegarden	Edible flowers	Hernández-Soto 2009
A. angustifolia	ixtle	Agrosilvopastoral	Mestizo	El Limón, Paso de Ovejas municipality	Veracruz	hedges	Possibly live fence	Bautista-Tolentino *et al.* 2011
A. angustifolia	agave	Homegarden	Mestizo	Ejido Sinaloa 1ra Sección, Cárdenas	Tabasco		Ornamental, to hang clothes	Gómez-García *et al.* 2016
A. angustifolia	ki	Homegarden	Maya	X-uilub, Municipio de Valladolid	Yucatán	homegarden	Utensil, medicinal, fiber	Herrera-Castro 1994
A. angustifolia		Homegarden	Tsotsil/Tseltal		Chiapas		Ornamental	Mariaca-Méndez 2012
A. angustifolia		Homegarden	Chontal		Tabasco		Craft making (necklesses and rosaries), Construction, Domestic uses (soap), ornamental, tools, insecticide, medicinal	Mariaca-Méndez 2012
A. angustifolia		Homegarden	Maya		Yucatán			Mariaca-Méndez 2012
A. angustifolia		Homegarden	Maya		Quintana Roo			Mariaca-Méndez 2012

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. angustifolia		Homegarden	Maya		Campeche			Mariaca-Méndez 2012
A. angustifolia		Temperate zones			Tlaxcala			Xochitiotzin-Hernández 2005
A. angustifolia	lineño many varieties	Agrosilvopastoral	Mestizo	Zapotitlán de Vadillo	Jalisco	agriculture mixed, milpa-agave pitayas-mezquite	Distilled spirits (mezcal), food, live fence, construction, forage, medicine, ornamental, ritual (mezcal)	Vargas-Ponce *et al.* 2009
A. angustifolia		Arid zones			México	recently crops, before they were extracted wild		Altieri & Merrick 1987
A. asperrima	maguey	Arid zones		Chihuahua desert	Chihuahua	Live fence	Live fence, forage, medicine, pest control, aesthetic value	López-Yáñez 1990
A. atrovirens		Homegarden	Mestizo	San Miguel Tlaixpan, Texcoco	Estado de México		Drink, medicinal	Gaytán-Ávila *et al.* 2001
A. atrovirens	maguey pulquero	Temperate zones			Tlaxcala	hedges	Pulque	Xochitiotzin-Hernández 2005
A. atrovirens		Metepantle	Tlaxcaltecas (Nahua)		Tlaxcala			Martínez-Saldaña & Romero-Contreras 1993
A. atrovirens		Metepantle	Mexica (Nahua)	Valle de Teotihuacán	México	terraces	Food, *aguamiel*, *pulque*, fibers (textiles), live fence, fuel, fertilizer, medicinal, construction, forage	Evans 1990
A. atrovirens		Homegarden	Mestizo, Totonac and Nahua	Tlacuilotepec	Puebla		Ornamental	Pagaza-Calderón 2008
A. aurea		Arid zones		San Ignacio, El Pilar	Baja California			Arriaga & Rodríguez-Estrella 1997
A. cerulata		Arid zones		San Ignacio	Baja California			Arriaga & Rodríguez-Estrella 1997
A. convallis	jabalí	Managed forests,agroforests	Zapotec	San Dionisio Ocotepec	Oaxaca			This study
A. cupreata	maguey mezcalero / yaave ndishi	Long fallow	Mixtec	Alcozauca	Guerrero		Fibers	Casas *et al.* 1994
A. cupreata	papalote	Managed forests, agroforests	Nahuatl	Zitlatla, Ahuacuotzingo, Chilapa	Guerrero		Mezcal	Illsley *et al.* 2007

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. cupreata	papalote	Managed forests, agroforests	Nahuatl	Zitlatla, Ahuacuotzingo, Chilapa	Guerrero		Mezcal	Illsley *et al.* 2007
A. cupreata	papalote	Managed forests, agroforests	Nahuatl	Zitlatla, Ahuacuotzingo, Chilapa	Guerrero		Mezcal	Illsley et al. 2007
A. cupreata	chino	Managed forests, agroforests	Mestizo	Tzitzio	Michoacán	greenhouses and reforestation in wild sites where agave populations already existed	Mezcal, food	This study
A. cupreata	chino	Agrosilvopastoril	Mestizo	Tzitzio	Michoacán	Agave crops with forest elements and cattle	Mezcal, food	Martínez-Palacios *et al.* 2015
A. desertii	´a´ud / agave del desierto	Arid zones	Papago	Quitovac	Sonora		Edible, fiber	Nabhan *et al.* 1982
A. fourcroydes	henequén verde / kij	Homegarden	Maya	X-Mejía, Hopelchén	Campeche		Medicinal	Cahuich-Campos 2012
A. fourcroydes	sisal	Long fallow	Maya		Guatemala			Caso-Barrera & Aliphat-Fernández 2006
A. fourcroydes	henequén	Homegarden	Maya	Temax	Yucatán	homegarden	Fibers	García-deMiguel 2000
A. fourcroydes	ki, ch´eelem	Homegarden	Maya	X-uilub, Municipio de Valladolid	Yucatán	homegarden	Utensils, medicinal, fibers	Herrera-Castro 1994
A. fourcroydes	henequén	Long fallow	Mestizo	Ciudad Victoria	Tamaulipas	Long fallow	Fibers	Kass & Somarriba 1999
A. fourcroydes	henequén	Homegarden	Maya		Yucatán			Mariaca-Méndez 2012
A. fourcroydes	Henequén	Homegarden	Maya		Quintana Roo			Mariaca-Méndez 2012
A. fourcroydes	henequén	Homegarden	Maya		Campeche			Mariaca-Méndez 2012
A. fourcroydes	henequén	Homegarden	Maya		Campeche		Ornamental, medicinal	Mariaca-Méndez 2012
A. fourcroydes	henequén	Homegarden	Maya	Pomuch, Mpio Hecelchakán	Campeche		Medicinal	Poot-Pool 2008
A. fourcroydes	henequén	Arid zones	Huastec		SLP, Veracruz		Fibers	Puig 1994
A. fourcroydes		Homegarden	Maya	Tixcacaltuyub y Tixpeual	Yucatán		Medicinal, apiculture, fibers and live fence	Rico-Gray *et al.* 1991

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. fourcroydes					Tamaulipas, Nuevo León and Coahuila			Stienen 1990
A. fourcroydes	henequén	Homegardens	Mestizo	ejido de Tziscao, La Trinitaria	Chiapas		Ornamental	Torres-Díaz 2011
A. inaequidens	maguey alto, bruto	Managed forests, agroforests	Mestizo	Queréndaro, Indaparapeo	Michoacán	greenhouses and reforestations in wild sites where agave populations already existed	Distilled beverages, edible, medicinal, construction, medicinal, veterinary, forage, *aguamiel*, *pulque*, ornamental, fiber, hunting, bird nests, soil retention	Torres-García *et al.* 2015a
A. karwinskii	cachitún	Arid zones	Mestizo	Zapotitlán Salinas	Puebla	hedges and limits	To limit plots	Moreno-Calles *et al.* 2013
A. karwinskii		Arid zones		Valles Centrales	Oaxaca	hedges and live fences	Mezcal, live fences, food	This study
A. lechuguilla	lechuguilla	Homegarden		Noroeste de México		homegarden	Fibers	Ffolliott 1998
A. lechuguilla	lechuguilla		Otomí (Hñähñú)	El Botho, located in the Alto Mezquital region	Hidalgo		Fibers	Pérez-Botho *et al.* 2015
A. lechuguilla	lechuguilla	Silvopastoril	Mestizo	Peñón Blanco	Durango		Fibers, forage (flores)	Russo 1990
A. lechuguilla	lechuguilla	Arid zones		Chihuahuan desert	Chihuahua	hedges	Live fences, crop protection	López-Yáñez 1990
A. macroacantha	cacaya or rabo de león	Homegarden	Mestizo/Nahua	Coxcatlán	Puebla	homegarden	Edible flowers	Hernández-Soto 2009
A. mapisaga	maguey pulquero	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	lines to prevent erosion, live fences, terraces	Soil control, *aguamiel* and *pulque*	Moreno-Calles *et al.* 2013
A. mapisaga	maguey, xayametl	Metepantle		La Malinche	Tlaxcala	terraces	Edible, *aguamiel*, *pulque*, distilled spirits, extraction of edible insects, medicinal, construction, fuel, live fences, as a perch, ceremonial, religious	Patrick 1977
A. mapisaga	maguey	Arid zones		Chihuahuan desert	Chihuahua	live fence	Live fence, *aguamiel* and *pulque*, forage, medicinal, pest control, aesthetic value	López-Yáñez 1990

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. marmorata	pitzometl	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges, vegetation islands, terraces	Mezcal, food, live fence, fuel	Moreno-Calles *et al.* 2011
A. marmorata	pichomel	Homegardens	Mestizo, Nahuatl	San Rafael Coxcatlán	Puebla		Edible, medicinal	Blanckaert *et al.* 2004
A. marmorata		Homegardens	Mestizo/Nahuatl	Coxcatlán	Puebla	homegarden	Ornamental	Hernández-Soto 2009
A. marmorata	pitzometl, pichomel	Arid zones	Mestizo	Zapotitlán Salinas	Puebla	hedges and lines	To limit plots, medicinal, ceremonial, construction, utensils, soil retention, live fence, *aguamiel* and *pulque*	Moreno-Calles *et al.* 2013
A. marmorata		Arid zones	Mestizo, Nahuatl	Zapotitlán Salinas, Quiotepec	Puebla y Oaxaca	metepantles, apantles		Vallejo *et al.* 2015
A. marmorata	tepeztate	Managed forests, agroforests	Zapotec	San Dionisio Ocotepec	Oaxaca	forest management	Mezcal	This study
A. maximiliana	lechuguilla	Managed forests, agroforests	Mestizo	Mascota	Jalisco	greenhouses and reforestation in wild forest sites where there existed agave populations	Distilled spirits (*raicilla*), edible, medicinal, forage, *barbacoa*, sale and barter, ornamental, fermented drink, soil retention, bait, fertilizer	Huerta-Galván 2018
A. mitis	magueyito	Homegarden		Coyomeapan	Puebla	crop	Ornamental	Larios *et al.* 2013
A. murpheyi	maguey	Arid zones	Papago	Quitovac	Sonora		Edible, fiber	Nabhan *et al.* 1982
A. peacockii	maguey ixtlero	Arid zones	indigenous and Mestizo	several	Puebla, Oaxaca	diverse		Casas *et al.* 2001
A. potatorum	papalometl	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges, vegetation isles	Mezcal, food	Moreno-Calles *et al.* 2011
A. potatorum	papalometl	Arid zones	Indigenous and Mestizo	various	Puebla, Oaxaca	diverse		Casas *et al.* 2001
A. potatorum	tobalá	Managed forests, agroforests	Zapotec	San Dionisio Ocotepec	Oaxaca			This study
A. promontorii		Arid zones		San Bartolo, Punta San Pedro, Boca de la Sierra	Baja California			Arriaga & Rodríguez-Estrella 1997

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. rhodacantha	ixtero, amarillo and verde	Agrosilvopastoral	Mestizo	Zapotitlán de Vadillo	Jalisco	mixed agricultura, milpa-agave pitayas-mezquite	Distilled spirits (mezcal), food, live fences, Construction, forage, medicinal ornate, ritual (mezcal), fibers	Vargas-Ponce *et al.* 2007
A. salmiana	pulquero	Arid zones				hedges, vegetation lines	*Pulque*, live fence	Campos-Salas *et al.* 2016
A. salmiana		Homegarden	Mestizos/ Nahuatl	Coxcatlán	Puebla	homegardens	Ornamental	Hernández-Soto 2009
A. salmiana	maguey	Homegarden	Maya		Campeche		Ornamental	Mariaca-Méndez 2012
A. salmiana	maguey	Metepantle	Mestizo	Vicente Guerrero	Tlaxcala	hedges and lines	*Pulque*	Magdaleno-Miranda *et al.* 2005
A. salmiana		Metepantle	Tlaxcaltecas (Nahuatl)		Tlaxcala			Martínez-Saldaña & Romero-Contreras 1993
A. salmiana	ametl	Metepantle		La Malinche	Tlaxcala	terraces	Edible, *aguamiel, pulque*, distilled spirits, edible insect extraction, medicinal, construction, fuel, live fence, perch, ceremonial religious uses	Patrick 1977
A. salmiana		Metepantle		Vicente Guerrero	Tlaxcala			Magdaleno-Miranda *et al.* 2005
A. salmiana		Metepantle	Mestizo, Nahuatl	Zapotitlán Salinas, Quiotepec	Puebla and Oaxaca	metepantles, apantles		Vallejo *et al.* 2015
A. salmiana	mexcali, pulquero	Homegarden		Coyomeapan	Puebla	crop	Edible, *pulque*	Larios *et al.* 2013
A. salmiana	maguey	Arid zones		Chihuahuan desert	Chihuahua	live fence	Live fences, *aguamiel* and *pulque*, forage, medicinal, pest control, aesthetic value	López-Yáñez 1990
A. salmiana	maguey	Metepantle	Mexica (Nahuatl)	Ixtapalapa	México	terraces	*Pulque*, edible, soil retention, fibers	Blanton 1972
A. salmiana	pulquero	Arid zones				hedges, vegetation lines	*Pulque*, live fence	Campos-Salas *et al.* 2016
A. salmiana	maguey	Homegarden	Mestizo, Nahuatl	San Rafael Coxcatlán	Puebla		Edible	Blanckaert *et al.* 2004
A. salmiana var. *crassispina*	maguey	Arid zones		Chihuahuan desert	Chihuahua	live fence	Live fence, forage, medicinal, pest control, aesthetic value	López-Yáñez 1990

Agave species	Common name	Type of AFS	Cultural Group	Locality	State	Agroforestry practices	Uses	Author/year
A. salmiana var. *crassispina*	maguey criollo	Managed forests, agroforests	Mestizo	Pinos	Zacatecas		Mezcal, insects (gusano blanco, gusano rojo, escamoles)	De Luna-Valadez *et al.* 2013
A. salmiana var. *crassispina*	maguey verde	Arid zones	Mestizo	Pinos	Zacatecas		Mezcal, forage and collection of edible insects, (gusano blanco, gusano rojo and escamoles)	Esparza-Frausto *et al.* 2008
A. salmiana var. *crassispina*		Arid zones	Mestizo	"El Milagro" Municipio Villa González Ortega	Zacatecas		Collection of edible insects, escamoles	Hernández-Roldán *et al.* 2017
A. salmiana var. *ferox*	xilometl, tlilmetl, prieto corriente or criollo	Metepantle		La Malinche	Tlaxcala	terraces	Edible, *aguamiel*, *pulque*, distilled spirits, collection of edible insects, medicinal, construction, fuel, live fence, perch, ceremonial, religious	Patrick 1977
A. salmiana var. *ferox*	de puya	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges, vegetation islands, terraces	Forage, fuel, live fence, construction	Moreno-Calles *et al.* 2011
A. salmiana var. *ferox*	de puya	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges, vegetation islands	Forage, fuel, live fence, construction	Blancas *et al.* 2009
A. salmiana var. *ferox*	maguey de puya	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	lines to prevent erosion, live fences, terraces	Construction, fuel, forage, to limit plots, live fence	Moreno-Calles *et al.* 2013
A. scaposa	de potrero	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges, vegetation islands	Construction, Edible insects, fuel, forage, to limit plots, live fence	Moreno-Calles *et al.* 2011
A. scaposa	maguey de potrero	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	hedges and lines	To limit plots, collection of edible insects	Moreno-Calles *et al.* 2011
A. scaposa	maguey de potrero	Arid zones	Mestizo	San Luis Atolotitlán, Caltepec	Puebla	lines to prevent erosion, live fence, terraces	Construction, *condachos* habitat, fuel, forage, to limit plots, live fence, edible flowers	Moreno-Calles *et al.* 2011
A. sisalana	maguey de ixtle	Homegarden	Mestizo/Tsotsil	Gabriel Esquinca Municipio de San Fernando	Chiapas	homegarden	Ornamental, fibers	Gutiérrez-Miranda 2003
A. sisalana	henequén	Homegarden	Chontal		Tabasco		Ornamental	Mariaca-Méndez 2012
A. sisalana	agave	Homegarden	Maya		Yucatán			Mariaca-Méndez 2012

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A. sisalana	henequén pequeño	Homegarden	Maya		Campeche		Ornamental, fibers	Mariaca-Méndez 2012
A. sisalana	henequén	Homegarden	Maya Chontal	Comalcalco	Tabasco			Tamayo-Ortega 1995
A. sp.	flor de maguey	Homegarden		Coyomeapan	Puebla	crop	Ornamental, edible	Larios *et al.* 2013
A. sp.	maguey	Homegarden		Balzapote	Veracruz		Ornamental	Chavero & Roces 1988
A. sp.	maguey	Metepantle			México	crop	Surface runoff control, humidity retention	Loredo *et al.* 2001
A. sp.		Homegarden	Mestizos/ Nahuatl	Coxcatlán	Puebla	homegardens	Ornamental	Hernández-Soto 2009
A. sp.	maguey	Metepantle	precolombine/ actual	Valle del Mezquital	Hidalgo	terraces		Hunter 2009
A. sp.	maguey	Long fallow	Mestizo	Not specified, it mentions the North of Mexico region	North México	long fallow	Food	Kass & Somarriba 1999
A. sp.	henequén	Homegarden	Maya		Yucatán		Fibers	Mariaca-Méndez 2012
A. sp.	maguey verde	Homegarden	Chontal		Tabasco		Condiment, ornamental, medicinal	Mariaca-Méndez 2012
A. sp.	maguey	Metepantle		Parras de la Fuente	Coahuila			Martínez-Saldaña 2007
A. sp.	maguey	Homegarden	Tzeltal	Aguacatenango	Chiapas		Ornamental	Perez-Grovas 2011
A. sp.		Homegarden	Maya	Tixcacaltuyub y Tixpeual	Yucatán		Medicinal, apiculture, fibers	Rico-Gray *et al.* 1991
A. sp.	mesagoli	Temperate zones	Rarámuri	Basíhuare, Municipio de Guachochi	Chihuahua		Edible (heart and quiote), the juice is added to tesgüino	LaRochelle 2003
A. sp.	chawí		Rarámuri	Basíhuare, Municipio de Guachochi	Chihuahua		Edible (heart), juice is added to tesgüino	LaRochelle 2003
A. sp.		Homegarden			Tamaulipas, Nuevo León and Coahuila		Live fence, fuel	Stienen 1990
A. sp.		Metepantle	Mestizo, Nahuatl	Zapotitlán Salinas, Quiotepec	Puebla y Oaxaca	metepantles, apantles		Vallejo *et al.* 2015
A. sp.	maguey	Temperate zones			Tlaxcala		Live fence	Xochitiotzin-Hernández 2005
A. sp.		Arid zones		El Bajío	central México	hedges	Live fence	Zuria & Gates 2006
A. sp.		Homegarden	Zapotec	Loxicha, Oaxaca	Oaxaca		Edible, ornamental	Aguilar-Støen *et al.* 2009

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A. sp.					México	Terraces		Aguilar *et al.* 2003
A. sp.		Homegarden		Balzapote	Veracruz	homegardens	Medicinal, veterinary medicine	Álvarez-Lugo 1997
A. sp.	maguey and pulquero	Homegarden	Mazahua	La Purísima Concepción Mayorazgo, San Felipe del Progreso	Estado de México	solar	Fuel, live fence, *pulque* extraction for family consumption or for sale	Guerrero-Peñuelas 2007
A. sp.	maguey aviludo	Metepantle		Ixtacuixtla	Tlaxcala	terraces, hedges	To gather gusano blanco and chinicuil, soil retention, *aguamiel*, *pulque*, fibers construction (iscapul)	Pérez-Sánchez 2012
A. sp.		Metepantle	Colonial origin	la Laguna	Tlaxcala	terraces	Pulque, soil retention	Borejsza *et al.* 2008
A. sp.		Metepantle	prehistoric	Cerro Juanaqueña	Chihuahua	terraces		Hard *et al.* 1999
A. spp.	maguey/mezcal	Arid zones	Mestizo		Baja California			Nabhan *et al.* 2010
A. spp.		Agrosilvopastoral	Mestizo	Peñón Blanco	Durango		Live fence	Russo 1990
A. spp.		Metepantle		La Quemada	Zacatecas	terraces	Food, *aguamiel*	Trombold & Israde-Alcantara 2005
A. spp.		Arid zones	Nahuatl and Mestizo	Chilapa-Centro Montaña de Guerrero	Guerrero	cropping and application of organic fertilizer, reforestation and fencing of the spring with *maguey*	Mezcal, soil retention, infiltration	Aguilar *et al.* 2003
A. spp.		Metepantle			Tlaxcala	hedge plantation, terraces	Terraces, to limit plots	Altieri &Trujillo 1987
A. striata		Homegarden			Tamaulipas, Nuevo León and Coahuila		Live fence, fibers	Stienen 1990
A. striata subsb. *falcata*	maguey	Arid zones		Chihuahuan desert	Chihuahua	live fence	Live fence, forage, medicinal, pest control, aesthetic value	López-Yáñez 1990
A. tequilana	agave azul tequilero	Homegarden	Maya		Campeche		Ornamental	Mariaca-Mendéz 2012
A. tequilana	agave azul	Agrosilvopastoral			Jalisco		Tequila	Rosales *et al.* 2008
A. tequilana	agave azul	Homegarden			Jalisco		Tequila	Rosales *et al.* 2008

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A. tequilana	tequila	Homegarden	Maya		Yucatán			Mariaca-Méndez 2012
A. tequilana	tequila	Homegarden	Maya		Quintana Roo			Mariaca-Méndez 2012
A. tequilana	tequila	Homegarden	Maya		Campeche			Mariaca-Méndez 2012
A. tequilana var. *azul*	azul	Agrosilvopastoral	Mestizo	Tequila	Jalisco		Tequila, sale of maguey plants	Herrera-Pérez *et al.* 2017
A. triangularis	tunecho	Arid zones	Indigenous and mestizos	various	Puebla, Oaxaca	diverse	Live fence	Casas *et al.* 2001
A. weberi	maguey manso	Arid zones		Xichu, sierra gorda	Guanajuato	slash and burn	*Aguamiel*, fibers	van Dijk *et al.* 2017