Plant Management in Agroforestry Systems of Rosetophyllous Forests in the Tehuacán Valley, Mexico

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Plant management in agroforestry systems of rosetophyllous forests in the Tehuacán Valley, Mexico. With a human cultural history of nearly 12,000 years, the Tehuacan Valley is one of the main reservoirs of biocultural richness of Mexico, harboring archaeological remains with early signs of agriculture associated with forest management. Current peoples' subsistence is based on agriculture, livestock, and use of forest products, practicing productive systems with reminiscences of ancient practices. The Tehuacan Valley is a Biosphere Reserve, but some areas are affected by deforestation and overexploitation of natural resources. Identifying proposals for maintaining human culture and biodiversity are central issues of research and policies in the region, and we consider that agroforestry systems (AFS) may play important roles in such purposes. This study documented the conservation capacities of AFS and problems affecting them, analyzing plant species diversity in forests and AFS of rosetophyllous Izotal and Mexical forests, plant management influencing AFS composition, and factors influencing people's decisions about keeping plants inside their AFS. We recorded 113 plant species in the Izotal forest and 89 in the associated AFS, while 96 species in the Mexical forest and 64 in AFS. AFS maintain 76 and 88 % of the native species recorded in the Izotal and Mexical forests, respectively. Shannon diversity index in both forest types averaged 3.99 ± 1.01, while average diversity in AFS was 3.36 ± 0.99. AFS sampled in the Mexical have more vegetation cover because of the cultivation of *Agave salmiana*. The main agroforestry practices are fringes against soil erosion and the borders surrounding plots, where people leave plants standing, sow seeds and vegetative propagules of different species, transplant entire individuals, or cultivate others with special care. The reasons people decide to conduct these practices are mainly for shade, fodder, food, beverages allowing monetary incomes, fuelwood, material for construction, and aesthetic value. AFS maintain a high richness and diversity of plant species, but significantly, lower than forests. It is possible to enrich AFS composition and improve their contribution to regional strategies of biodiversity conservation and people's wealth.

Manejo de plantas en sistemas agroforestales de bosques rosetófilos en el Valle de Tehuacán, Mexico. Con una historia cultural de cerca de 12,000 años, el Valle de Tehuacán es uno de los principales reservorios de riqueza biocultural de Mexico, el cual además resguarda elementos arqueológicos con signos tempranos de agricultura asociada al manejo forestal. La subsistencia de la gente actual se basa en la agricultura, la ganadería y el uso de recursos forestales. Y en los sistemas productivos actuales es posible apreciar antiguas prácticas de manejo. El Valle de Tehuacán es una Reserva de la Biosfera, sin embargo algunas áreas son afectadas por la deforestación y sobreexplotación de recursos naturales. La búsqueda de propuestas para

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mantener la armonía entre los requerimientos humanos y la biodiversidad es uno de los principales retos de la investigación y diseño de políticas públicas en la región. Los sistemas agroforestales (SAF) pueden contribuir significativamente a estos propósitos. Este estudio documenta las capacidades de conservación de los SAF y los problemas que los afectan, analizando el manejo de especies vegetales y la diversidad de plantas en bosques rosetófilos denominados izotal y mexical, y en los SAF que se construyen con base en su transformación, las prácticas de manejo para mantener plantas dentro de los SAF, así como los factores que influencian las decisiones de la gente. Se registraron 113 especies de plantas en el izotal y 89 en el SAF asociado, mientras que se encontraron 96 especies en el mexical y 64 en el SAF asociado. Los SAF mantienen entre 76 y 88 % de las especies nativas registradas en los bosques de izotal y mexical, respectivamente. El índice de diversidad de Shannon en ambos tipos de bosques fue en promedio 3.99 ± 1.01, mientras que en los SAF el promedio fue 3.36 ± 0.99. Los SAF muestreados en el mexical tienen mayor cubierta vegetal debido al cultivo del maguey pulquero *Agave salmiana*. Las principales prácticas agroforestales son las franjas contra la erosión de suelo, así como los bordes de vegetación que rodean las parcelas. En estas áreas la gente deja en pie plantas del bosque, siembra semillas o propágulos vegetativos de otras, trasplanta individuos completos de algunas y cultiva otras con cuidados especiales. Las principales razones por las que la gente mantiene estas plantas son la procuración de sombra, forraje, alimentos, producción de pulque que asegura ingresos monetarios, material de construcción, leña, y valores estéticos. Los SAF mantienen una alta riqueza y diversidad de especies de plantas nativas, aunque significativamente menor que la que existe en los bosques. Sin embargo, es posible enriquecer la composición de los SAF y mejorar su contribución a la conservación de la biodiversidad regional y al mejoramiento de la calidad de vida de la gente.

Key Words: Arid zones, biocultural diversity, biodiversity conservation, plant management, rosetophyllous forest, Tehuacán-Cuicatlán Valley, ethnobotany..

Introduction

Mexico is one of the countries with the highest biocultural diversity in the world (Toledo 2008). In approximately two million km^2, this country maintains nearly 10 % of the biological diversity of the planet (Mittermeier 1988; Mittermeier et al. 1997). In this territory, there is also high human cultural diversity currently expressed in nearly 283 languages recorded by Ethnologue (Lewis et al. 2015). Biological, ecological, and cultural diversities have interacted in this setting for more than 12,000 years (MacNeish 1967, 1992), conforming an extraordinary biocultural heritage represented by a high ethnobiological knowledge, and techniques for managing biodiversity; nearly 7000 plant species are currently utilized by peoples of Mexico, and more than 1000 species are managed in different forms (Casas et al. 2014). An additional important biocultural expression is domestication and diversification of genetic resources of more than 200 native plant species and numerous others (hundreds) introduced from other parts of the world, as well as the incipient domestication associated with silvicultural management of at least 800 plant species (Blancas et al. 2010; Casas et al. 2014). In addition, Mexico has been the setting of a high diversification of agricultural and agroforestry systems, silvicultural and silvo-pastoral systems (Boege 2008; Moreno-Calles et al 2013). Such biocultural richness represents valuable opportunities for developing innovations and strategies for sustainable management of natural resources and ecosystems, an indispensable task for conservation of ecosystems and the wellbeing of people.

The Tehuacán-Cuicatlán Valley is one of the regions with the highest biocultural diversity of Mexico (Casas et al. 2014). In a relatively small territory of nearly 10,000 km^2, researchers have recorded more than 3000 vascular plant species distributed in 37 types of plant associations (Dávila et al. 2002; Valiente-Banuet et al. 2009). Also, the region sustains a high richness of landscapes conformed by diverse agroforestry and forestry systems managed over thousands of years (Moreno-Calles et al. 2010; Blancas et al. 2010, 2013; Larios et al. 2013; Vallejo et al. 2014, 2015). The Tehuacan Valley is in addition one of the zones where the earliest practices of agriculture (agroforestry systems) were practiced by humans in the New World (MacNeish 1967, 1992; Smith 1965). Peoples practicing such early agriculture, nearly 9000 years ago, domesticated some of the main current crops of the world, among them maize, beans, squashes, chili peppers, amaranth, avocado, and cotton (Smith 1965; MacNeish 1967).

Such a long human cultural history allowed the development of agricultural and silvicultural systems that included the in situ management and domestication of wild plant populations, a process that is still ongoing and can be documented (Casas et al. 1997, 2001, 2007; Lira et al. 2009). According to Smith (1965), one of the earliest types of agriculture developed in the Tehuacán Valley could have been the silvicultural management of dry lands through which people favored growing useful plants like prickle pears, columnar cacti, fruit trees, and legumes in dry lands (Casas and Caballero 1995). According to MacNeish (1967), there could have been two types of early agriculture: hydro-horticulture in oases spread throughout the valley associated to springs, as well as stream horticulture, using the humid areas close to gullies. All these systems are hypothetical, but it is possible to observe their current existence in the area. And all of them are agroforestry systems combining wild and domesticated elements managed by people.

Agroforestry systems integrate crops and wild species from forests, and interactions among their components have remarkable benefits in terms of resources provision and functional ecosystem services (Altieri and C. Nicholls 2000, Toledo 2008), which in turn influence better conditions for resilience and sustainability of the systems (Nair 1998). Management of biological diversity in AFS includes managing the diversity of landscapes, wild and domesticated species, and genetic diversity of species composing the system (Jackson et al. 2007). All this technical experience is currently of high relevance for designing actions for biodiversity conservation.

In the Tehuacan Valley, people practice a broad spectrum of management techniques that have been documented by several authors (Casas et al. 2001, 2014; Blancas et al. 2010, 2013). Cultivated plants receive a more intense management than others, and nearly 57 % of the cultivated plants species recorded are native, coexisting with their wild relatives that are part of the local forests. In addition, wild plant species may have other management forms within agroforestry systems, which become reservoirs of a significant fraction of native biodiversity (Blancas et al. 2010; Casas et al. 2014). Some species that are part of the original forest are in situ managed, but some others are carried to agroforestry systems from neighboring and even distant (ex situ management) forests. Local people bring to AFS and tend numerous living specimens of wild plants.

In the Tehuacán Valley, a broad variety of agroforestry systems have been described, including fields with seasonal cultivation of maize, as well as those with irrigation, and homegardens which involve intense interactions between people and plants (Blancas et al. 2010). Among the most relevant studies of AFS in the region are those conducted by Moreno-Calles et al. (2010, 2012) in the arid slopes of the region. These authors studied AFS associated to the jiotillal forest (dominated by *Escontria chiotilla* (A.A.Weber ex K.Schum.) Rose), which maintain on average 56 % of the native plant species recorded in the forest. These authors found that SAF associated to the chichipera forest (dominated by *Polaskia chichipe* (Gosselin) Backeb.) maintain on average 74 % native species and that AFS plots associated to garambullal forest (dominated by the garambullo *Myrtillocactus schenckii* (J.A. Purpus) Britton & Rose) maintain up to 97 % of the plant species composing the forest. Other studies found that the AFS mentioned maintain nearly 94 % of the genetic variation of populations of the dominant arboreal species of the forests (Otero-Arnaiz et al. 2005; Casas et al. 2006; Parra et al. 2010; Cruse-Sanders et al. 2013). Studies in the temperate areas of the Tehuacán Valley recorded that AFS keep on average nearly 43 % of the perennial species from the associated natural forests (Vallejo et al. 2014, 2015). Processes carried out in AFS occur at the landscape level where people leave or remove individuals of different species, adjust hydrological and erosive processes, as part of landscape management, similarly as conceptualized by Terrell et al. (2003) (Table 1).

In homegardens of the Tehuacán Valley, Larios et al. (2013) found that the systems maintain more than 350 plant species, 34 % of them being native of the region and 16 % of them being part of the surrounding forests. In general, the systems generated by the local peasants are important for maintaining the genetic diversity of wild, silvicultural, and cultivated plant populations. These artificial systems are reservoirs of resources, areas of domestication, and areas of interaction among the components of the wild and domesticated systems.

This study was conducted in the western Tehuacán Valley, focusing attention on AFS associated with rosetophyllous forests, particularly those called Izotal, dominated by *Yucca periculosa* Baker and the Mediterranean-like vegetation described as Mexical by Valiente-Banuet et al. (2000, 2009). Mexical is dominated by sclerophyllous species but becomes dominated by palms *Brahea nitida* André and *B. dulcis* (Kunth) Mart. and rosetophyllous components in medium disturbed areas. No information about AFS associated with these forests was available before our study, and we consider that

TABLE 1. TOTAL NUMBER OF PLANT SPECIES OCCURRING IN AFS AND THE IZOTAL AND MEXICAL FORESTS TO WHICH THEY ARE ASSOCIATED. PERCENTAGE OF NATIVE SPECIES IN EACH FOREST TYPE, RESPECTIVELY.

Forest/agroforestry systems	No. of species in forest	No. of species in AFS	% of native species in AFS	No. of shared species
Izotal	113	89	78.76 %	27
Mexical	96	64	66.6 %	47

understanding these forests and AFS are important for designing regional strategies of biodiversity and biocultural conservation since these occupy a considerable extent in the Tehuacan Valley. We particularly explored the capacity that local AFS have for maintaining plant species composition of the natural forests and how and why people manage plants maintained in these AFS.

Methods

STUDY AREA

The Tehuacán Valley is a phytogeographic province belonging to the Xerophytic Mexican Region (Rzedowski 1978). It comprises an area of 10,000 km^2 located in the southeast of the state of Puebla and the north of the neighboring state of Oaxaca. Our study was conducted in the western Tehuacán Valley (Fig. 1) in an arid zone with vegetation including the Izotal dominated by *Yucca periculosa* and the Mexical. We particularly studied forests and AFS associated with these vegetation types in the villages of Tepoxtitlán and Las Cumbres de Chicometepec, in the municipality of Atexcal, Puebla. Local people are Mestizo, originally Náhuatl speakers. The climate of the area is semi-warm, sub-humid with annual mean temperatures of nearly 18 °C. However, in Las Cumbres de Chicometepec, no more than 5 km away from Tepoxtitlán, the Mexical dominates in an environment cooler, with recurrent frosts and is markedly windier than the territory of Tepoxtitlán. The rainy season is in summer with annual precipitation of 546.6 mm. Soils in both villages are derived from limestones. Land tenure is partly private and collective under the regimes of ejido and communal land. The total area with AFS is nearly 179 ha.

SAMPLING OF FORESTS AND AFS

Vegetation types studied are (1) Izotal, dominated by the izote *Yucca periculosa* at high densities (500 to 1000 individuals/ha) with individuals up to 4 m in height, in zones with calcareous soils, in elevations around 1700 m (Valiente-Banuet et al. 2009). (2) Matorral of sclerophyllous and rosetophyllous shrubs up to 2 m in height without spines or Mexical. In some patches, vegetation is dominated by the palm *Brahea nitida* which appears to be secondary Mexical previously cleared for agriculture and then left to recover; local people

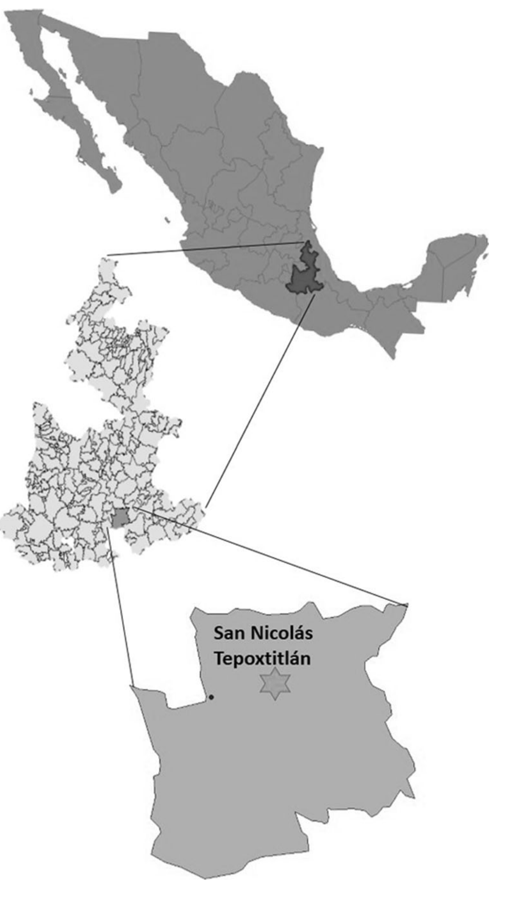

Fig. 1. Location of San Nicolás Tepoxtitlán and La Cumbre of Chicomoetepec, Puebla in the Biosphere Reserve of Tehuacán-Cuicatlán, central Mexico.

used to favor palms since they use their leaves for weaving hats and baskets, and the mats called "petates;" in addition, they use their trunks for constructing houses and fences.

In each vegetation type, we evaluated the capacity of AFS for conserving plant diversity. We sampled vegetation in forests and in AFS and then compared their richness, composition, and diversity. In forests, we sampled the vegetation through square plots 50 m × 10 m (500 m^2) subdivided into five square plots 100 m^2 each. In each sampling unit, we recorded all individuals of perennial plant species (trees, shrubs, agaves, and cacti) measuring the height and diameters of the canopy of each. For trees, we also measured the breast height diameter (BHD). We also recorded herbaceous species in five square plots 1 × 1 m^2 randomly placed per sampling unit in which we recorded the species richness.

We sampled vegetation of three plots of AFS associated with each vegetation type. We measured and mapped in detail the whole plot and all agroforestry practices they had, in order to estimate the percentage of vegetation cover. For each patch of vegetation maintained in agroforestry practices, we sampled vegetation through 20 × 5 m square plots (100 m^2), recording species richness, and density of each perennial plant species. Herbaceous plants were sampled through two 1 × 1 m square plots per sampling unit. The species collected were identified using the nomenclature of the database TROPICOS and MOBOT.

Ecological Parameters Analyzed

The density of each species per sampled unit was determined as the number of individual plants of that species per area unit in forests and AFS. Vegetation sampling allowed estimated species richness, diversity, and the ecological importance values of every species. The latter parameter was estimated as the product of density, frequency and biomass (Osorio et al. 1996; Valiente-Banuet et al. 2009). We estimated the biomass through formulas of volume of geometric bodies generally resembling the plants we sampled, using the data on height, BHD, and the two diameters of the canopies following the method used by Pérez-Negrón and Casas (2007) and other authors. For trees, we used the formula of a trunked cone ($V = \pi/12$ h (D2 + Dd + d2), for shrubs ellipsoids ($V = 2$ ($2\ \pi\ r^2$/h/3), for columnar cacti cylinder ($V = \pi\ r^2$ h), and for spherical cacti spheres ($V = \pi\ r^2$), we sampled, using the data on height (h), BHD, and the two diameters (D, large diameters, and d, smaller diameters) of the canopies. For *Opuntia* species, the rectangular cuboid ($V = l_1 \times l_w \times l_h$) long per wide per height longitude.

The species composition was estimated according to the number of plant families, genera, and species. Diversity was calculated with the program EstimateS (Version 9.1.0) using the Simpson (Magurran, 1988) and Shannon (Shannon and Weaver, 1949) indexes, in order to analyze the homogeneity and heterogeneity of plant communities.

In addition, we estimated the β diversity among forest types and among forests, among AFS plots, and among forests and AFS plots. We compared matrices of species similarity by using the Jaccard index. We compared the 12 sampling sites (six AFS and six of different forests) through cluster analysis based on the method of average among groups (McCune and Grace 2002); the resulting dendrogram was calculated through the program PC-ORD (McCune and Mefford 1999).

Interviews

We conducted semi-structured interviews with people managing the six AFS plots studied. We followed methods developed by Blancas et al. (2010, 2013); Moreno-Calles et al. (2010, 2012), and Vallejo et al. (2014) to document (1) general information about the households' economy and the role of the AFS plots in their lives, (2) agricultural and agroforestry management techniques, and (3) pastoral management associated with the system. In addition, we documented the details about the plant species maintained in the areas of agroforestry practices sampled. Our first contact with the community was through asking permission from the local authorities (Communal land and Ejidal land authorities), as well as the Municipal authorities. Then they prepared a General Assembly in which men and women participated. We presented the project and asked their authorization. In the meeting, we asked to make explicit who would be in the disposition of collaborating with us among the "comuneros" and "ejidatarios" and even those with private land within the ecosystems with the vegetation types we were particularly interested in. Among the managers, we included two men and a woman (single woman, head of the family) in the Mexical zone and two men and a woman in the Izotal zone. The criterion was the disposition of participating and to be the household's head. Each manager of an agroforestry system was interviewed and we included questions about the history of the plot (when the family started using the plot, which crops are cultivated, how are they cultivated, yields, inter-annual variations in environmental conditions and yields, and main problems associated with agricultural production). Particularly important were questions in relation to details about decisions to let standing vegetation in the different agroforestry practices, the reasons, the advantages and roles, their view about the importance of those species and practices, plant uses, and management and function of agroforestry practices. Other details about use or not of agrochemicals were included in the interviews, as well as the main problems they considered to have in relation to agricultural production and maintenance of agroforestry systems.

Results

Characterization of Agroforestry Management

There are 177 people living in Tepoxtitlán and Las Cumbres de Chicometepec. The main economic activity is agriculture under a rainfed regime, followed by raising of goats, mining (extraction of onyx), and informal jobs. Households have five to seven plots of one hectare each on average, usually practicing agriculture in part of them after 3 to 5 years of cultivation and 1 to 2 years left as fallow land.

In Tepoxtitlán land tenure is mainly of the collective property called ejido, and their AFS are associated with Izotal forest. In agricultural plots, the main crops are maize, beans, and squash. The main variety of maize cultivated in the zone is that called "criollo" (local or native varieties), which has been adapted to the technical and environmental conditions of the area for a long time. The local varieties of beans are called "flor de mayo," "peruano," "bayo," "mantequilla," and "negro." For both crops, people practice selection of seeds choosing the most vigorous ones for the following cultivation year. In Las Cumbres, agricultural land tenure is communal and AFS are associated with the Mexical forest. In this zone, the main crops are maize, fava beans, wheat, and agave (*Agave salmiana* Otto ex Salm Dyck).

Agricultural management in both zones starts with clearance of land between February and April, whereas sowing is carried out in June (some years at the beginning, some years at the end of this month). Labors and techniques of land clearing depend on the characteristic of the terrain. In Tepoxtitlán, it is viable using tractor and most people make use of it, but in Las Cumbres, people make use of ploughs because the terrain has more pronounced slopes. Most people use organic fertilizers from their animals' dung and remains of the plants removed after clearing the land.

Households destine all maize harvested for direct consumption; during "good years," people may even commercialize beans, wheat, and fava beans. The fermented sap called "pulque" of *Agave salmiana*, cultivated and promoted in AFS, is partly destined for direct consumption but mainly to commercialization. For propagating this, agave people obtain vegetative propagules and plant them in fringes and around the plot. There are some wild agaves obtained from forests, mixed with the predominant domesticated agaves of the same species.

According to the interviews, most perennial native plants occurring in AFS are left standing. The main reasons for leaving trees in AFS associated with Izotal forest are to provide shade, living fences, food, fodder, fuelwood, and ornamental elements. Trees and other plants left standing may also be promoted, deliberately planting propagules or entire plants, mainly those occurring in the surrounding area of the plot and fringes directed to protect the plot against soil erosion. The main species left standing in these AFS are *guaje* (*Leucaena esculenta* Benth.), *palo blanco* (*Leucaena leucocephala* (Lam.) de Wit), *mezquite* (*Prosopis laevigata* (Humb.& Bonpl. ex Willd.) M.C.Johnst.), which provide shade, food, fodder, and living fences. Seeds of these trees may be sown in seedbeds and the young plants then transplanted to the plots. In AFS derived from the Mexical, the main reasons for leaving plants standing are their direct use by households and some of them for their economic value for commercialization. In addition, plants are left standing because of their provision of shade, material for construction, fuelwood, fodder, and living fences ornamental purposes. The main species left standing are *sosocoche* (*Dasylirion serratifolium* Baker), which provides food (their flowers) and fibers for handcrafts; the *sotolín* (*Nolina parviflora* Hemsl.) is particularly appreciated as an ornamental plant (ornament for the plot), and it is left standing as living fence. Undoubtedly, the most important species in all agroforestry practices is the *maguey pulquero* (*Agave salmiana*), which retains soil, is good for living fences, and provides the sweet sap used for producing the fermented beverage *pulque* which is nutritious. It is partly dedicated to direct consumption but also for commercialization. Also important is *Brahea nitida* which provides material for construction, stems for constructing fences and house walls, and leaves for thatching houses.

The main agroforestry practices in AFS associated with the Izotal are (1) living fences, for delimiting the plots and retaining soil and water, (2) fringes against soil erosion and for retaining water, (3) relicts of vegetation for dividing the plot into different sections, and (4) isolated individuals, mainly trees for providing shade. In AFS derived from the Mexical, agroforestry practices are (1) living fences with similar purposes as referred to above and (2) fringes of vegetation, where people maintain species of agave and retain soil and water. Numerous legume trees like *Acacia* spp., *Senna* spp., *Mimosa* spp. and numerous other trees and shrubs are left standing for shade, fodder, and fuelwood. Other species like *Leucaena esculenta* and *L. leucocephala* are not only left standing but are also cultivated for food and fodder. Izotes (*Yucca periculosa*) is an important plant left standing because it provides stems for construction and fiber for manufacturing the tlacopaxtles, a kind of harness.

Among important regulations existing in the area, the authorities of the Biosphere Reserve Tehuacán-Cuicatlán prohibit clearing forest. Two persons interviewed mentioned that they would like to remove the whole vegetation cover in order to have more land for cultivation, particularly because they have noticed decreases in their production. The remaining people interviewed mentioned that they would not clear the remaining vegetation since it helps to retain water, soil, and delimiting the plots. However, some governmental programs such as PROCAMPO provide monetary incomes to people for renting tractors, paying hand labor, and buying chemical inputs and seeds. Other programs from SEMARNAT enhance maintaining agaves in agricultural plots.

The communities have constructed regulations for maintaining livestock in particular areas during the agricultural cycle. Then, after harvesting, people bring animals to their fields for consuming the beddings and harvest the stubble to store it.

Agriculture in the zone is progressively the responsibility of older people since most young people migrate to cities (Tehuacán, Puebla, Mexico City, and several cities in the USA). The result is that agriculture is not totally a household activity, and they need to employ hand labor (the cost is nearly 10 U.S. dollars per day per person).

Species Richness and Diversity

Figure 2 shows the arrangement of the different agroforestry practices recorded in the AFS associated with the Izotal forest, where vegetation cover is on average 50 % ± 34 (X ± SD) and agroforestry practices include living fences, fringes against erosion, relicts of vegetation, vegetation isles, and isolated individuals (Table 2). This figure also shows the arrangement of AFS associated with Mexical, where vegetation cover is also close to 50 % ± 42 (X ± SD), where the agroforestry practices include living fences, and fringes against erosion with agave (Table 2).

We recorded 204 plant species (Appendix 1—Electronic Supplementary Material) belonging to 114 genera of 46 families in both forests and AFS. The more representative families are Asteraceae, Fabaceae, Poaceae, and Cactaceae. Out of all species recorded, 114 (56 %) were registered in AFS and 144 (70.6 %) in forests.

In AFS associated with the Izotal forest, we recorded 89 species, while 113 species are in the forest (Table 1). Forest and AFS share 27 species (23 %): *Mammillaria zephyrantoides*, *Bursera aff. arida*, *Bursera schlechtendallii*, *Brickellia* sp., *Lasiocarpus* sp., *Galphimia glauca*, *Celtis pallida*, *Aeschynomene compacta*, *Brickellia veronicifolia*, *Pterostemon rotundifolius*, *Pseudosmodingium multifolium*, *Senna pallida*, *Senna unijuga*, *Turnera diffusa*, *Cnidoscolus tehuacaensis*, *Gochnatia hypoleuca*, *Lippia alba*, *Baccharis serrifolia*, *Bursera galeottiana*, *Cordia curassavica*, *Wimmeria microphylla*, *Salvia aspera*, *Neobuxbaumia macrocephala*, *Fouquieria formosa*, *Opuntia pilifera*, *Ferocactus latispinus*, *Dasylirion serratifolium*, and *Caesalpina pringlei*. All these species are mainly left standing in AFS, but *M. zephyrantoides* and *F. latispinus* are transplanted from the center of the plot to fringes or the fences surrounding the plot, and some are transplanted from other areas of the forest. The main reason is their ornamental function.

Species of the Izotal forest occurring in the associated AFS are *Casimiroa calderoniae*, *Eysenhardtia* sp., *Acacia clochiacantha*, *Mimosa aculeaticarpa*, *Dalea tomentosa*, *Salvia lasiantha*, *Viguiera pinnatilobadam*, *Caesalpina pringlei*, *Acourtia glomerata*, *Malpighia galeottiana*, *Byrsonima* sp., *Eysenhardtia polystachia*, *Zaluzania montagnifolia*,

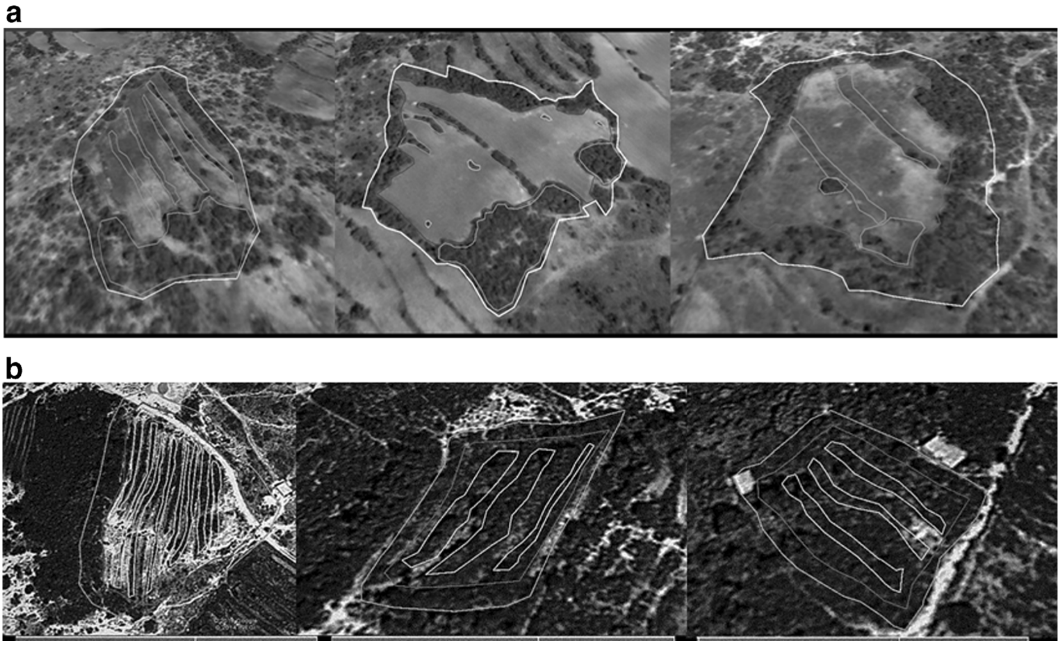

Fig. 2. **a** Plots of agroforestry systems associated with Izotal and the main agroforestry practices. **b** Plots of agroforestry systems associated with Mexical and the main agroforestry practices.

Prosopis laevigata, *Leucaena esculenta*, *Mimosa* sp., *Lantana camara*, *Tithonia tubiformis*, *Desmodium* sp., *Marginatocereus marginatus*, *Tecoma stans*, *Tagetes* sp., *Montanoa tomentosa*, and *Gaudichaudia galeottiana*. All these species are mainly left standing, but seeds of *L. esculenta* are

TABLE 2. VEGETATION COVER IN THE DIFFERENT AGROFORESTRY PRACTICES RECORDED IN AGROFORESTRY PLOTS ASSOCIATED TO IZOTAL (IAFS) AND MEXICAL (MAFS).

Forest	Agroforestry system	Total cover	Agroforestry practices	Area (m^2)
Izotal	IAFS 1	8312 m^2 (57 %)	Living fence	4526 m^2
			Vegetation fringe	1600 m^2
			Vegetation relict	2186 m^2
	IAFS 2	8541.7 m^2	Living fence	4937 m^2
		(48.68 %)	Vegetation fringe	884 m^2
			Vegetation relict	2655 m^2
			Isolated individual	65.7 m^2
	IAFS 3	9767.5 m^2	Living fence	8016.3 m^2
		(54.53 %)	Vegetation fringe	1138 m^2
			Vegetation relict	408 m^2
			Isolated individual	163.5 m^2
			Vegetation patch	41.7 m^2
Mexical	MAFS 1	8017 m^2	Living fence	5397 m^2
		(51.7 %)	Vegetation fringe	2620 m^2
	MAFS 2	1665.3 m^2	Living fence	978 m^2
		(59.5 %)	Vegetation fringe	687.3 m^2
	MAFS 3	950.5 m^2	Living fence	625 m^2
		(51.2 %)	Vegetation fringe	325.5 m^2

sown in seedbeds and then transplanted and stems of *M. marginatus* are transplanted to the fences and fringes.

In AFS associated with Mexical, we recorded 83 species, while in the forest, we recorded 96 species, both environments sharing 41 species (42 %). Species of the Mexical forest absent in AFS are *Acacia subangulata*, *Agave peackoki*, *Agave potatorum*, *Ageratina tomentella*, *Arbutus jalapensis*, *Baccharis serrifolia*, *Brahea dulcis*, *Brickellia* sp., *Buddleja cordata*, *Bursera schlechtendalii*, *Bursera galeottiana*, *Calliandropsis* sp., *Calliandria grandiflora*, *Celtis caudata*, *Opuntia pubescens*, *Gochnatia hypoleuca*, *Cordia curassavica*, *Dichondra argentea*, *Hintonia standleyana*, *Mammillaria pyramidalis*, *Mimosa aculeaticarpa*, *Parthenium hysterophorus*, *Pseudosmodingium multifolium*, *Quercus cubila*, *Salvia aspera*, *Salvia fruticosa*, *Salvia oaxacana*, *Salvia lasiantha*, *Senna pallida*, *Senna galeottiana*, *Tradescantia crassifolia*, and *Viguiera pinnatilobada*. Some of these species are culturally appreciated but do not tolerate the disturbed areas. This is the case with agaves and cacti. Others are abundant in the forest and the landscape matrix and not specially cared in the fields sampled, although observed in other plots.

The species occurring in AFS and in the Mexical forest are *Ageratina achyranthifolia*, *Anagalis arvensis*, *Anoda cristata*, *Berberis qinquefolia*, *Bouteloua* sp., *Bursera copallifera*, *Casimiroa calderoniae*, *Casimiroa edulis*, *Castilleja scorzonerifolia*, *Dalhea apiculata*, *Dalia coccinea*, *Dalium* sp., *Erodium cicuitarium*, *Krameria cytisoides*, *Lantana achyranthifolia*, *Lantana camara*, *Malva parviflora*, *Mammillaria zephyrantoides*, *Medicago* sp., *Melampodium* sp., *Montanoa* sp., *Oenothera rosea*, *Phaseolus* sp., *Phytolacca icosandra*, *Piqueria trinervia*, *Rhus chondroloma*, *Ricinus communis*, *Salvia candicans*, *Salvia tillifolia*, *Schinus molle*, *Solanum* sp., *Tagetes lunulata*, and *Tagetes micrantha*. Most of these are useful species, appreciated and left standing or promoted in plots, particularly the quelites (edible wild herbs) *Anoda critata*, *Malva parviflora*, and *Phytolacca icosadra*.

From the 204 plant species recorded in the study, 118 are perennial and 86 are annual. Perennial species are richer in forests (96 species) than in AFS (56 species) (Fig. 3). AFS maintain on average 58 % of perennial plant species of the associated forests. According to Fig. 3, the ecologically more important species in the Izotal forest are *Baccharis serrifolia*, *Salvia thymoides*, and *Yucca periculosa*, while in the Mexical, these are *Brahea nitida*, *Agave peackoki*, and *Baccharis serrifolia*. The species with higher density in AFS associated to the Izotal are *Perymenium discolor*, *Lantana achyranthifolia*, and *Yucca periculosa*, whereas in AFS associated with the Mexical, the most important species is in all cases *Agave salmiana*.

According to the NOM-059-SEMARNAT-2010 (NOM meaning Norma Oficial Mexicana or Mexican Official Rules for protection of species, SEMARNAT meaning Secretaría del Medio Ambiente y Recursos Natuales, Ministry of Environment and Natural Resources of Mexico), the species recorded in a risk category are (1) requiring special protection, *Brahea nitida* and *Agave peacockii*, (2) threatened, *Mammillaria haageana* and *Bouvardia erecta*, and (3) in danger of extinction: *Mammillaria pyramidalis* and *Litsea glaucesens*. From all these species, only *Brahea nitida* and *Bouvardia erecta* are clearly protected in AFS.

Figure 4 shows the Shannon and Simpson indexes calculated for AFS and forests. No significant differences were identified among forests and AFS. However, Fig. 5 indicates that AFS associated with the Izotal forest are only 35 % similar to this type of forest, but those AFS associated to the Mexical are even less similar to the forest.

Discussion

Agroforestry Management

AFS associated with Izotal are mainly directed to produce maize and beans through milpa whereas those associated with Mexical include in addition wheat, fava beans, and *Agave salmiana*. Agroforestry practices favor the heterogeneity of components inside the plots since people select species that are left standing, as well as other species that colonize these managed environments. Clearing of vegetation for establishing agricultural plots favor the abundance of some species that are scarcer in the forests, particularly herbaceous plants (Blanckaert et al. 2007), which are benefitted by the disturbance. Disturbance is lower in AFS plots associated with the Mexical than in those associated with the Izotal, where tractors are more commonly used. However, even though these strong differences exist, it is relevant that vegetation cover in both types of AFS is approximately 50 %.

AFS maintain species richness similar to those recorded in forests to which these AFS are associated, but the richness is generally lower in AFS

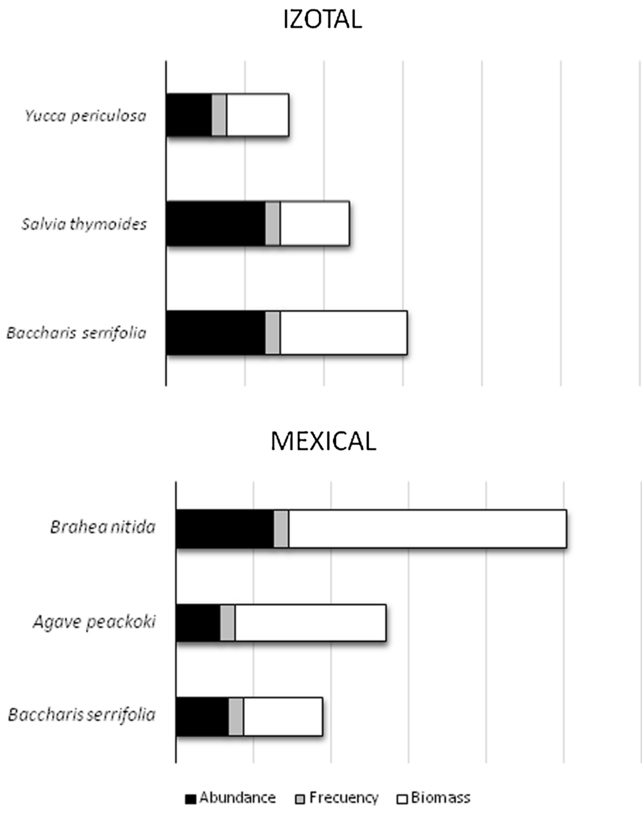

Fig. 3. Ecological importance value (EIV) of the more representative species in the Mexical and Izotal rosetophyllous forests in the Tehuacán Valley. EIV was calculated based on vegetation sampling in the study sites and as a relation of the density, biomass, and frequency of the species occurring in the sampled sites.

because of vegetation clearing. This is also because of the promotion of some particular species that are deliberately left standing or enhanced by people, which is a pattern common in the silvicultural management patterns associated with AFS of the region (Casas et al. 1997, 2007). The reasons for maintaining tree species are shade, food, fuelwood, and fodder, similarly to the reasons reported by Moreno-Calles (2010, 2012), and Vallejo et al. (2015). The AFS studied are similar to the forests to which these are associated but may differ according to social and cultural aspects, influencing their management and, therefore, their composition, richness, and diversity. In Las Cumbres, where the more pronounced slopes limit the possibility of using machines, AFS are delimited by living fences and have fringes abundant in *Agave salmiana* for production of pulque. In Tepoxtitlán, land tenure is ejidal and communal, plots are plain and larger, allowing the use of a tractor. Although agroforestry practices are organized to allow the use of tractors, the plots still maintain 50 % of vegetation cover in fringes and vegetation patches particularly large among modules composing the plots. Agroforestry management is influenced undoubtedly by land tenure, extent, topography, soil types, forest resources available in the surrounding areas, precipitation, and availability of irrigation.

Species Richness and Diversity

Management of AFS by local people allows conservation of native biodiversity as well as the introduction of new species and varieties either wild or cultivated (Casas et al. 2006). These processes have occurred throughout time and have determined that AFS are heterogeneous not only in composition but also in techniques and criteria for favoring one or another species, one or another variety. The important point is that the result of such a process is the

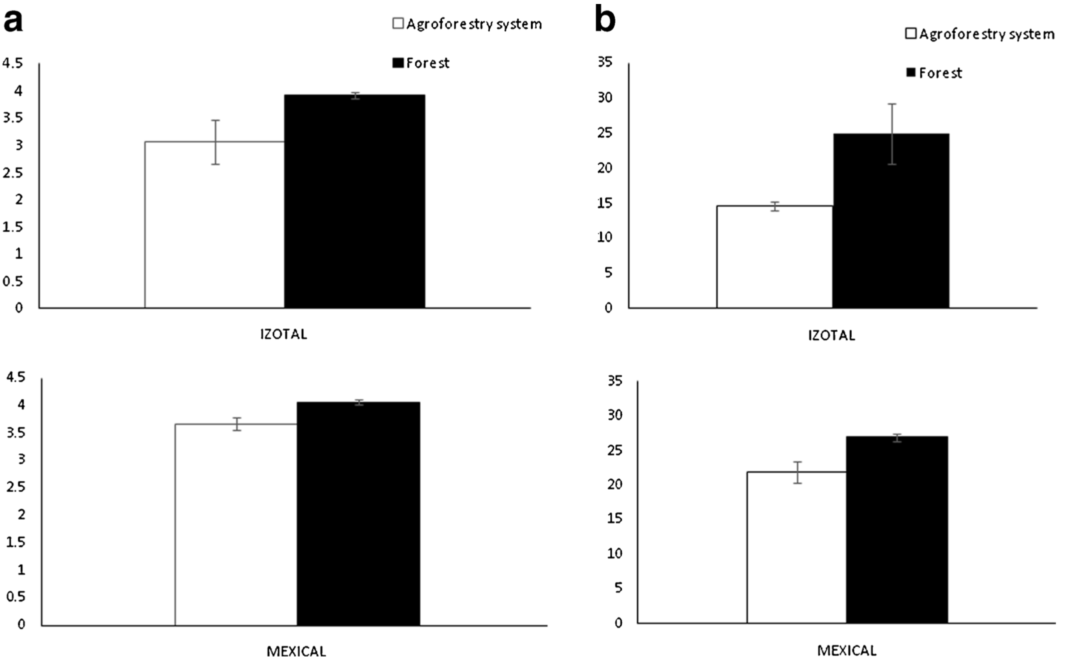

Fig. 4. Analysis of diversity based on the **a** Shannon and **b** Simpson indexes, respectively, among the Izotal (IF) and the Mexical (MF) forests and their agroforestry systems (IAF and MAF, respectively) associated.

configuration of species richness and diversity, which is influenced by what is deliberately promoted or depleted according to human decision making. And also, that richness and diversity make

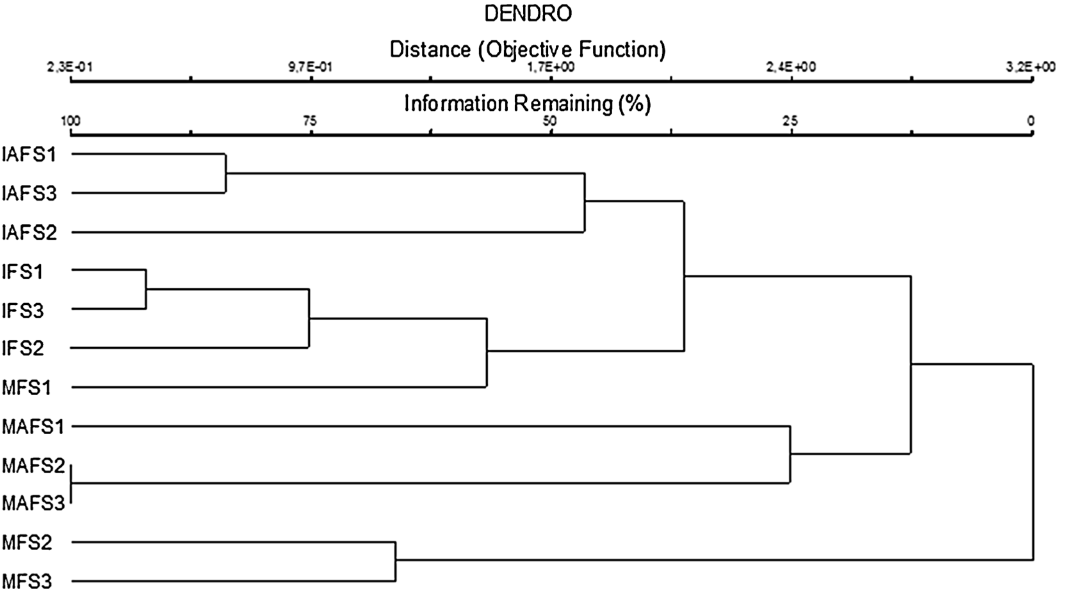

Fig. 5. UPGMA dendrogram comparing the similarity in composition of Izotal and Mexical forests (IF and MF, respectively) and their associated agroforestry systems (IAF and MAF, respectively).

AFS significantly important options for providing products for satisfying human needs but also for providing high potential to maintain crucial ecosystem functions that may increase the resilience of the system.

Our research shows that the AFS studied have the capacity of conserving nearly 79 % of the perennial species richness occurring in the forest associated and nearly 55 % of the total plant species richness recorded. These ciphers are close to what Noble and Dirzo (1997) estimated in their study; these authors calculated that traditional AFS might maintain 50 to 80 % of the regional richness of plant species. In addition, the result is similar to the general estimation reported by several studies that suggest that AFS may maintain nearly 60 % of plant species richness occurring in the associated forests (Wilken 1977; Leakey 1999; Altieri and C. Nicholls 2000; Backes 2001; Bhagwat et al. 2008; Moreno-Calles et al. 2010). Our data are within the range of richness of associated forests maintained in AFS associated with columnar cacti forests, forests of alluvial valleys, and temperate zones (Moreno-Calles et al. 2010; Vallejo et al. 2014, 2015) of the Tehuacán Valley, which may be from 45 to 97 % of natural vegetation.

According to Vallejo et al. (2014), the Tehuacán Valley has three main agricultural zones (the lowlands of the great alluvial valley, slopes with columnar cacti, mainly in volcanic soils, and temperate areas with coniferous and oak forests). This study includes a fourth important zone of slopes with soils derived from calcareous rocks. The studies by Moreno-Calles et al. (2010) reported that AFS on dry slopes with volcanic soils and columnar cacti forests maintain 134 plant species representing 59 % of all species of the associated forests, while AFS associated to Izotal and Mexical harbor 208 plant species. For the temperate zones, Vallejo et al. (2014) reported 79 species of trees and shrubs and for the alluvial valleys 66 species of perennial plant species; in this study, we recorded 59 species of perennial plants—in other words, higher plant species richness, mainly including herbaceous plants.

It is important to note that the studied areas are dryer than the others. The annual mean precipitation in the study area is 500 mm and the soils are calcareous. AFS associated with columnar cacti forests receive annual precipitation from 300 to 600 mm and some others 700 to 800 mm in volcanic or alluvial soils (Moreno-Calles et al., 2010).

Moreno-Calles et al. (2010) consider that the high diversity maintained in AFS may in part be due to the species richness existing in the forests associated with the AFS. This could be a factor but not the only one. In this study, we recorded 113 species in the Izotal and 64 species in the Mexical forests, respectively. The similarity between Izotal and SAFs in that area is 23 % and between Mexical and SAFs is nearly 42 %. A review by Bhagwat et al. (2008) shows that similarity between AFS and forests associated are on average 25 % of herbaceous plants and 39 % of trees. This indicates that management patterns, not only the original diversity, are drivers of the diversity maintained in AFS.

Sociocultural Processes

Composition and abundance of species occurring in AFS reflect social and cultural values and may be indicators of economic, social, and ecological patterns of a community (Albuquerque et al. 2005). These systems have experimented a long history of interactions between people and ecosystems (Casas et al. 2008, 2014), which are highly heterogeneous among environmental units, providing different and complementary resources for multiple purposes (Casas et al. 2008). Such diversity and complementarity is also related to the variety of management forms documented for plant species (Blancas et al. 2010, 2013), forests (Casas et al. 2007, 2014), and agroforestry systems (Altieri and Nicholls 2006; Casas et al. 2008; Blancas et al. 2010; Moreno-Calles 2010, 2012, 2013; Vallejo et al 2013, 2014; Larios et al 2014).

However, the high conservation capacity of AFS, the flora of arid zones like the Tehuacán Valley, is particularly vulnerable to disturbance. Plant species in categories of risk, requirements of special protection, threatened or in danger of extinction, all deserve special attention. AFS may be important reservoirs of biodiversity conservation but some indications, policies, and special protection should be part of regional strategies of biodiversity conservation and ecosystem services maintenance compatible with land use.

Some people from Tepoxtitlán have a sense of identity with their land, which is seen as a source provider of goods and services, and which may establish the bases for positive interactions between local societies and natural resources and ecosystems (Berkes 2001). Unfortunately, other people are living a process of rootlessness, without a view about the importance of conserving land, biodiversity and ecosystems, and the interaction is in risk of becoming deleterious. The latter fact is strongly related to migration to urban areas or to the USA and the consequent loss of identity.

Problems that are currently facing the AFS in this study are similar to those identified in other areas of the Tehuacan Valley and other regions of Mexico. For instance, the study by Moreno-Calles et al. (2010, 2012, 2013), Romo-Lozano et al. (2010), and Vallejo et al. (2013, 2014) indicate that the promotion of intensive agricultural packages are a primary cause of losing the traditional methods of agriculture. Machinery, agrochemical inputs commonly designed for a kind of environments and that are promoted by companies, governmental agencies and banks, are more interested in their own businesses than in agriculture production, ecosystem conservation, or people's lives. Another source of problems is the fragmentation of land managed by households. Private or collective regimes of land tenure have similar challenges. A piece of land that in the past was cultivated by one household head after few decades should be fragmented in order to inherit a piece of land to the members of the family. Such fragmentation enhances the need to remove vegetation cover in order to cultivate a larger area of land. Although some governmental programs promote maintenance of vegetation, others promote its removal. The institutions in favor and against of conservation of vegetation cover should resolve such a contradiction.

We consider that AFS should be part of the strategies for conservation of biodiversity and ecosystem services. These systems are biodiversity conservation reservoirs and should be improved in order to strength their capacities: These systems could be designed for (1) maintaining the diversity of remnant habitats at landscape level, (2) establishing and maintaining connections favoring gene flow among patches of more and less conserved areas, (3) decreasing pressure on natural ecosystems for obtaining resources, (4) buffering the clearing of natural areas for establishing new agricultural plots, and (5) preventing the conversion of land to intensive agricultural areas which have proved to be particularly destructive (Noble and Dirzo 1997; Bhagwat et al. 2008; Casas et al. 2014).

AFS have an important function in maintaining biodiversity and are a good technical alternative for the sustainable management of natural resources and ecosystems. A key issue for improving these systems is the development of strategies to improve their capacity for maintaining soil and water, soil nutrients, and systematic management of genetic resources capable of increasing production. All these purposes are viable without the conventional intensive methods of agrochemicals and improved seeds. Numerous techniques are emerging for soil management, efficient use of water, and participatory breeding programs. In addition, the permanence of certain species, particularly those that may provide more and better resources, is possible and desirable, compatible with native biodiversity conservation. Higher production, broader spectrum of products, permanence, stability, and resilience of the system are among benefits that would help enhance the expansion of AFS. Conservation, recovering, and enhancement of AFS may be a powerful strategy for stopping and reversing processes of desertification, eutrophication, and other global environmental problems associated with the intensive model of agriculture.

Our study aspires to document the technical and cultural experiences of AFS in a zone of the Tehuacan Valley, but the techniques and results documented may be useful for supporting the arguments that these systems exist, that are viable for long-term preservation of biodiversity and ecosystem services, and that can be improved for constructing technical alternatives to solve important problems contributing to global change.

The strategies should consider the whole landscape, including natural vegetation, AFS, homegardens, and fallow lands as a totality. Local people are the main protagonists of this process; they know their land better than anybody else does. However, the economic, cultural, and social processes that affect them and their decisions about managing or not AFS should be studied to construct regulations and policies. Similarly, ecology and agroecology should be very active not only in identifying the causes of failures of the traditional systems but also ways to solve them and make the systems stronger according to the current needs of society at local and global levels.

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