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Tezcalera, a traditional agricultural system that promotes native wild and agrestal germplasm conservation

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Abstract

Background: Traditional agricultural systems in Mesoamerica are adaptations of ancient farmers to the complex and varied environments. Tezcalera represents one of them.

Questions: How is the environmental context under which the tezcalera develop? Which management practices are followed in tezcalera? How do these management practices affect weeds' richness, composition, and abundance? How do these management practices contribute to the resilience of the agricultural system, the tropical dry forests, and to the maintenance of subsistence resources?

Studied species: Weeds growing in tezcaleras with different management.

Study site and dates: Zumpahuacán, Estado de México, 2020-2021.

Methods: Twenty-four collaborators were interviewed about the environmental, technological, and cultural aspects of tezcalera. We recorded weeds' richness, composition, and abundance in seven plots with different management histories.

Results: Tezcaleras originate from the slash-burn process and follow different paths: tlacolol-milsol-shallow plot, potrero, and recently, *Agave* crop. We recorded 161 morphospecies from 45 botanical families; 95 % were native to tropical dry forests. Twenty-five species are endemic to the Balsas region, and thirty-four are at risk. Richness and abundance varied between tezcaleras, where tlacolol plots exhibited the highest values. Plant composition was similar; 65 % had intangible or tangible values.

Conclusions: Tezcalera is a biocultural unit and a resilient agroecosystem. Traditional practices remain and positively impact the richness and composition of native weeds. The uncontrolled use of herbicides and the introduction of *Agave* crop are displacing traditional crops and modifying traditional practices, risking local agrobiodiversity.

Keywords: human labor, Mesoamerica, milpa, polyculture, resilience, shifting cultivation.

Resumen

Antecedentes: Los sistemas agrícolas tradicionales en Mesoamérica son adaptaciones ancestrales a los diversos y complejos ambientes. La tezcalera representa uno de ellos.

Preguntas: ¿En qué contexto ambiental se desarrolla la tezcalera? ¿Cuáles son las prácticas de manejo que se llevan a cabo en la tezcalera?¿Cómo afectan a la riqueza, composición y abundancia de las arvenses? ¿Cómo influyen en la resiliencia del sistema agrícola, de los bosques tropicales secos y al mantenimiento de los recursos para la subsitencia?

Especies de estudio: Arvenses en tezcaleras con diferente manejo.

Sitio y años de estudio: Zumpahuacán, Estado de México, 2020-2021.

Métodos: Entrevistas sobre prácticas de manejo de la tezcalera. Registro de la riqueza, composición y abundancia de malezas en parcelas con diferente historia de manejo.

Resultados: Las tezcaleras se originan de la roza-tumba-quema y siguen diferentes rutas: el tlacolol-milsol-regeneración o potrero, y recientemente, cultivo de *Agave*. Registramos 161 morfoespecies y 45 familias botánicas; 95 % nativas de la selva baja caducifolia. Veinticinco son endémicas de la región del Balsas y 34 están en alguna categoría de riesgo. La riqueza y abundancia de las arvenses varió entre tezcaleras. La composición florística fue similar; 65 % tuvieron valor tangible o intangible.

Conclusiones: La tezcalera es una unidad biocultural y un agroecosistema resiliente. Las prácticas tradicionales favorecen la riqueza y composición de las especies nativas. Los herbicidas y la introducción del cultivo de *Agave* desplazan a los cultivos tradicionales, poniendo en riesgo la agrobiodiversidad local.

Palabras clave: agricultura trashumante, humano, Mesoamérica, milpa, policultivo, resiliencia, trabajo.

Adaptations created by ancient farmers to the complex and varied environments characterize Mexican agriculture systems. Water availability and soil fertility have been the primary environmental drivers in the development of Mesoamerica's many agricultural systems, often known as agroecosystems or traditional agricultural systems (TAE) (Martínez-Alfaro 2001, Cruz-León 2003). These TAE are distinguished by an accumulation of practices, technologies, and cultural aspects developed in response to socioecological conditions. All these elements have been passed down through many generations and are still used today. TAE has emerged without scientific knowledge, external inputs, capital, credit, or developed markets (Altieri & Merrick 1987). They usually consist of tiny areas (plots) where various native crops coexist with wild or weedy relatives of agricultural plants (Altieri & Merrick 1987, Oldfield & Alcorn 1987, Velasco-Murguía *et al.* 2021).

Traditional agricultural systems have been studied in Mexico since the early twentieth century (Cook 1919, Diehl 1969). Still, systematic studies began in the 1970s with milpa studies in various regions of Mexico, most notably in Yucatán and Puebla (Hernández-X & Ramos 1977, Hernández-X 1988, Cruz-León 2003). Most studies on traditional agricultural systems in Mexico have concentrated on various aspects such as irrigation system control, soil erosion control, plant uses and management, traditional ecological knowledge, or socioeconomic and marketing aspects (Pérez-Sánchez *et al*. 2014). Puig (1994) and more recently (Moreno-Calles *et al.* 2013), synthesized roughly 20 agroforestry systems, categorizing them according to the type of landscape managed, the intensity of landscape management, and the ecological and biocultural settings.

Previous research in tropical and subtropical TAE has documented floristic diversity, composition, and richness in slash-and-burn milpas or adjacent secondary vegetation at various abandonment ages or management (post-milpa fallows). Quintana-Ascencio *et al*. (1996) studied seed bank components from milpa to post-milpa fallow plots; Van Breugel *et al*. (2007) studied species richness and composition in secondary forest plots. Velasco-Murguía *et al.* (2021) analyzed the diversity, abundance, and similarity of the woody species growing in post-*milpa* fallows. More recently, Guillen-Pasillas *et al*. (2023), recorded weed composition in Tseltal maya milpa based on interviews and frequent visits to different *milpas*. However, no-weed composition, richness, and abundance studies in active *milpa* plots originating from slash-and-burn and their relationship with tropical dry forest has been conducted. According to Velasco-Murguía *et al.* (2021), the slash-and-burn agricultural system has been used for centuries, generating a mosaic of successional stages in the landscape, likely increasing landscape diversity and resilience, and helping to explain the cultivation system's millennial persistence. However, they concluded that research on the revegetation processes in milpa fallow is limited.

Different agricultural systems coexist in Estado de Mexico, ranging from traditional to the most technological, including the rising use of greenhouses for floral production (Cruzalta-Casas 2018, Pérez-Fuentes 2019). Previous research on agricultural systems such as milpas and terraces has been conducted in various municipalities of the northern and central portions of the State of Mexico (Pérez-Sánchez & Juan-Pérez 2013, Vásquez-González *et al*. 2016).

Tezcaleras have not been described previously. In some historical sources, agriculture developed in rocky landscape was mentioned "[Ni] en todo este pueblo, ni [en] sus sujetos, hay río ninguno, sino algunos arroyuelos pequeños, y no tienen regadío ninguno; y los maizales los siembran entre las piedras, en las cañadas, q[ue] sedan muy bien." (Acuña 1986: México Tomo I). However, the rocky topography is typical of several communities of the State of Mexico, as well as Guerrero and Morelos, as their toponymic names suggest (Texcaltzingo, Texcaltitlán, and Tetzontepec), and agriculture is developed inside. Tezcalera means "rocky land". This landscape is commonly recognized and, as an agricultural system, is the most important in many communities of the municipality of Zumpahuacán, considerably distinct from previously recorded agricultural systems that imply substantial local adjustments for its operation. In this study, we followed the three axes proposed by Hernández-X. (1988) to describe the environmental conditions under which this TAE develops, the management strategies used by campesinos, and the impact of these management practices on the richness, composition, and abundance of native wild and agrestal germplasm growing in this ancestral TAE. We answered the following questions: How is the environmental context under which the tezcalera develop? Which management practices are followed in tezcalera? How do these management practices affect weeds' richness, composition, and abundance? How do these management practices contribute to the resilience of the agricultural system, the tropical dry forests, and the maintenance of subsistence resources?

Materials and methods

Study site. Zumpahuacán is in the southern portion of Mexico, between 18° 50' 11'' N and 99° 34' 43'' W, ranging from 1,000 to 2,600 m asl (Estado de México 2023). It is bounded on the south by the states of Morelos and Guerrero, on the north by the municipality of Tenancingo, on the east by Malinalco, and the west by Guerrero. From a biographic and floristic perspective, it is an interesting zone since it is located at the intersection between the Holarctic and Neotropical regions, and it is part of the biogeographic province known as Sierras y Valles Guerrerenses de la Cuenca del Balsas (INEGI 2023) (Figure 1). It has been designated as a Natural Protected Area, along with Malinalco and Tenancingo (Parque Ecológico y Recreativo de Tenancingo-Malinalco-Zumpahuacán) by the Mexican government since 1981 (Gobierno del Estado de México 2023).

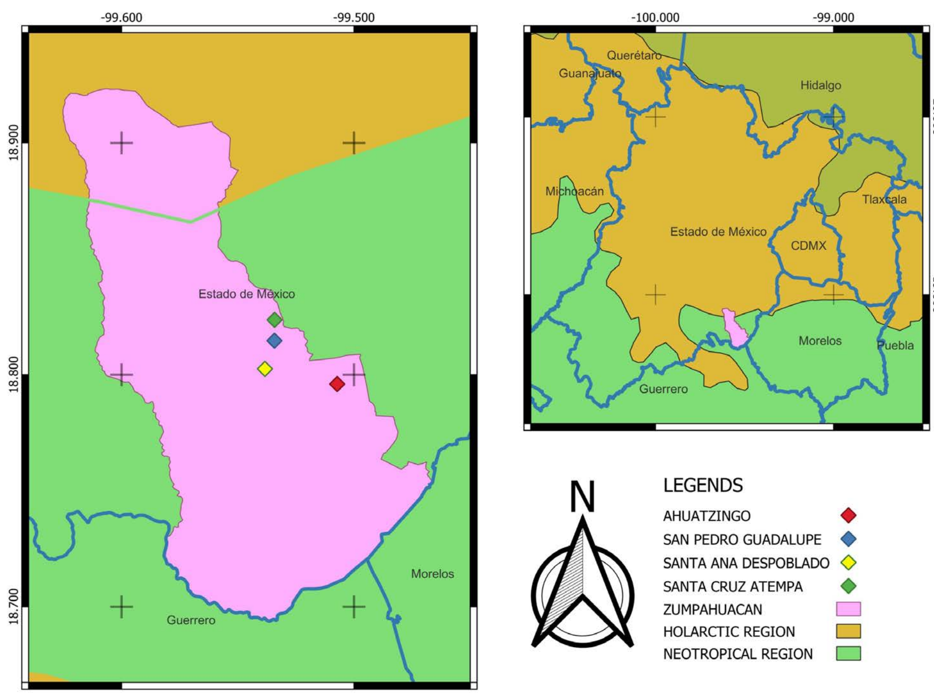

Figure 1. Study site.

This municipality is dominated by tropical and subtropical vegetation, including pine forest, oak forest, tropical semi-evergreen forest, gallery forest, and tropical deciduous forest (López-Patiño *et al.* 2012), which cover most of the municipality's land area (Casanova 1999). The typical climate is template, subhumid, with less than 5 % winter precipitation. The average annual temperature is 14 °C, and the average annual rainfall is 651.1 mm (López-Patiño *et al*. 2012). Zumpahuacán's dominant topography is Karstic, with smooth hills of Cretacic-Jurassic sedimentary rocks (INEGI 2010, Cretaceous Formations of Central America and Mexico) (Figure 2). Zumpahuacán has one of the most extensive areas of Leptosols, which are exploited to extract quarry and other minerals (Sotelo-Ruíz *et al.* 2020).

Zumpahuacán is home to 18,833 people, most of them mestizos, who live in 15 small communities known as delegaciones (Gobierno del Estado de México 2004), and it is classified as one of the twelve poorest municipalities in Mexico (Gobierno de México 2022). Agricultural and cattle activities are developed in this Karstic landscape (Figure 2A -C). They cultivate maize, beans, squash, and watermelon for subsistence. However, many plant products are gathered from wild like *Aristolochia orbicularis* Duch., tlacopa; *Asclepias linaria* Cav., soldadillo/siete negritos; *Cosmos sulphureus* Cav., chuchupal/mozote; *Dalea foliolosa* (Aiton) Barneby, escoba; *Dalea leporina* (Aiton) Bullock, escoba; *Erigeron karvinskianus* DC., escoba; *Schkuhria pinnata* (Lam.) Kuntze, escoba anis; *Tagetes micrantha* Cav., escoba. Others are tolerated like *Porophyllum calcicola* B.L. Rob. & Greenm., pápalo de monte; *Porophyllum ruderale* var. *macrocephalum* (DC.) Cronquist, pápalo, and many are protected species, like *Leucaena leucocephala* (Lam.) de Wit, guaje; *Spondias purpurea* L., ciruelo. All these mentioned species are part of the hundreds of species from the tropical dry forest and semideciduous forests that satisfy families' necessities, and they are also sold in regional markets of the Estado de Mexico (Chalma, Malinalco, Tenancingo, Tenango) or some municipalities of the state of Morelos.

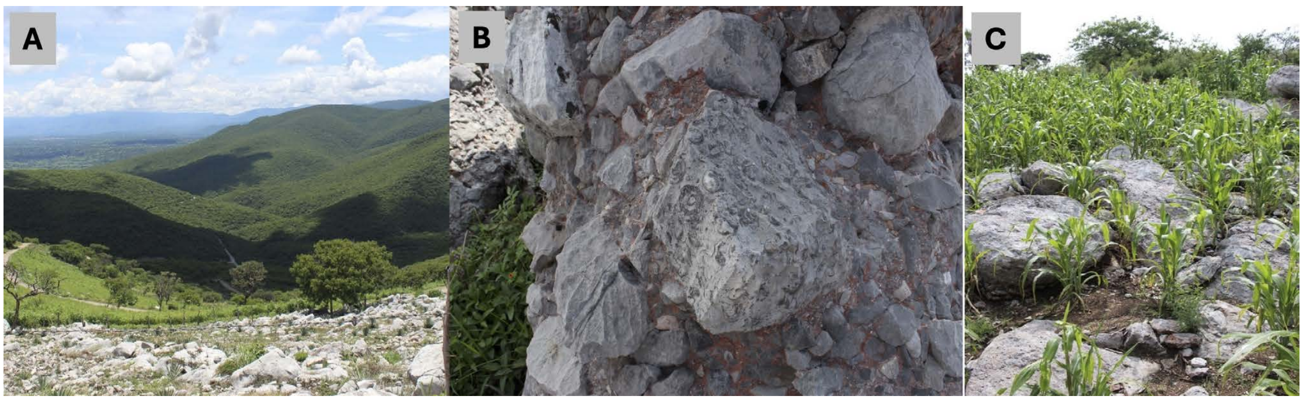

Figure 2. Typical karstic landscape of Zumpahuacán, Estado de Mexico: a) Smooth hills with tropical dry forest; b) Cretacic-Jurassic sedimentary rocks; c) milpa growing between sedimentary rocks.

This town was part of the Matlatzinca culture's nuclear zone until the Aztec Empire in 1428 (Velasco-Godoy 2003, Garza-Merodio & Fernandez-Christlieb 2016) and played a major role in trade operations between the shore and the Aztec-dominated central region. However, acculturation processes eradicated both languages, and now no one speaks or understands Náhuatl or Matlatzinca. Despite this, Náhuatl words can be found in the names of flora, animals, and local landmarks (parajes). Its name is a toponym derived from zompantli, meaning "place with skull hangers" (Velasco-Godoy 2003).

Collaborator selection and interviews. To comprehend tezcalera management, we used Hernández-X.'s (1988) three axes for studying TAE: ecological, technological, and socioeconomic.

In 2020, we started ethnobotanical studies with students of the Universidad Autónoma Metropolitana in seven communities of this municipality, including the municipal seat. During these studies, we became interested in tezcaleras. Derived from our field experience, in 2021, we decided to work in four to study tezcaleras: Ahuatzingo, San Pedro Guadalupe, Santa Ana Despoblado, and Santa Cruz Atempa (Figure 1). All of them are small communities with a population of less than 400 people, whose principal activity is agriculture.

Before the fieldwork, we contacted the Delegados, the local authorities in these communities, and told them about our interest in studying tezcaleras (Albuquerque 2014a). Following that, we carried out tours inside the communities and spoke with the residents to see if they were interested in joining our project. It is important to mention that this study was developed during the COVID-19 pandemic, and people feared infections. We followed local restrictions throughout the project and were careful to obtain permission before visiting locations or fields to collect and photograph landscapes, plants, and people. The participants were picked according to their availability.

Semi-structured interviews were conducted with six campesinos from each community (total N = 24) to learn about agricultural practices and tools used in tezcalera management, as well as their knowledge of floristic aspects related to wild and agrestal plants growing inside the plots (Alexiades 1996, Albuquerque 2014b). Following the guided tour method, we also visited the plots to observe and document agricultural practices, take photographs, and interact with the laborers whom the landowner hires to do some work (Albuquerque 2014b).

Campesinos stated several terms during the interviews: roze and quema, tlacolol, milsol, and barbecho. We learned from campesinos' descriptions and field trips that these terms were linked to temporal/spatial changes of the tezcalera, and we observed variations in floristic composition. Based on this information, we chose seven tezcaleras with different management histories to describe these possible changes in floristic composition based on the kind of crop, fallow period, time with this management, and times of agrochemicals application during one year (Table 1): one tezcalera in the fallow process for six years (tezfa); two tlacololes coming from fallows of dry deciduous forest with different fallow times, and opened the year of the study to cultivate them with milpa (maize) and other crop species (tla15 y tla40); one milsol, which is a tezcalera cultivated with maize for eight consecutive years (milma); two tezcaleras cultivated with *Agave angustifolia*, also with different years of cultivation (milaga4, milaga2); one tezcalera

Table 1. Quantifying the intensity of management and technology in plots with different management practices. Positive values above cero indicate higher intensity and technology; for perennial crops, we assigned a higher value; fallow- higher value indicates no fallow time; time of use- higher value indicates continuous use each season. The cases of d, e, and f indicate the total times campesinos follow these practices. Kind of tezcaleras: one tezcalera in the fallow process for six years (tezfa); two tlacololes coming from fallows of dry deciduous forest with different fallow times, and opened the year of the study to cultivate them with milpa (maize) and other crop species (tla15 y tla40); one milsol, which is a tezcalera cultivated with maize for eight consecutive years (milma); two tezcaleras cultivated with *Agave angustifolia*, also with different years of cultivation (milaga4, milaga2); one tezcalera used for foraging (potrero).

	TEZFA	TLA15	TLA40	MILMA	MILAGA4	MILAGA2	POTRERO
a) Crop	-	Maize, squash, pumpkin	Maize, squash, pumpkin, beans, pápalo	Maize (*milpa*)	*A. angustifolia* variety Penca china	*A. angustifolia* variety Penca china	-
1) Crop value	**0**	**0.25**	**0.25**	**0.25**	**1**	**1**	**0**
b) Fallow period	6	10-15	30-40	0	0	0	0
2. Fallow period value	**0.25**	**-1**	**-1**	**1**	**1**	**1**	**1**
c) Time with this management (years)	-	months	months	8	3-4	2	10
3. Time with this management value	**0**	**0.5**	**0.5**	**1**	**1**	**1**	**1**
4) Land management value (1+2+3)	***0.25***	***-0.25***	***-0.25***	***2.5***	***3***	***3***	***2***
d) Number of applications of chemical fertilizer	-	2	2	2	2	1	-
e) Number of applications of herbicides	-	1	2	2-3, or even more	2	1	-
f) Number of applications of pesticides	-	2	2	3 or even more	2-3	1-2	-
5) Level of technology value (d+e+f)	***0***	***5***	***6***	***7-8***	***6-7***	***3-4***	***0***
INTENSITY OF MANAGEMENT VALUE (4+5)	***0.25***	***4.75***	***5.75***	***9.5-10.5***	***9-10***	***6-7***	***2***

used for foraging (potrero) (Figure 3); in this case, potreros correspond to milsoles that are destinated to foraging for some years, and then they go into fallow, thus beginning a regeneration process of the tropical dry forest.

To analyze the possible relationship between agricultural practices and the richness, composition, and abundance of native wild and agrestal germplasm growing in this ancestral TAE, a structured interview was applied to the plots' owners to get specific information about the crops grown, the agricultural practices employed, the tools used, and the dates, names, and amounts of inputs used.

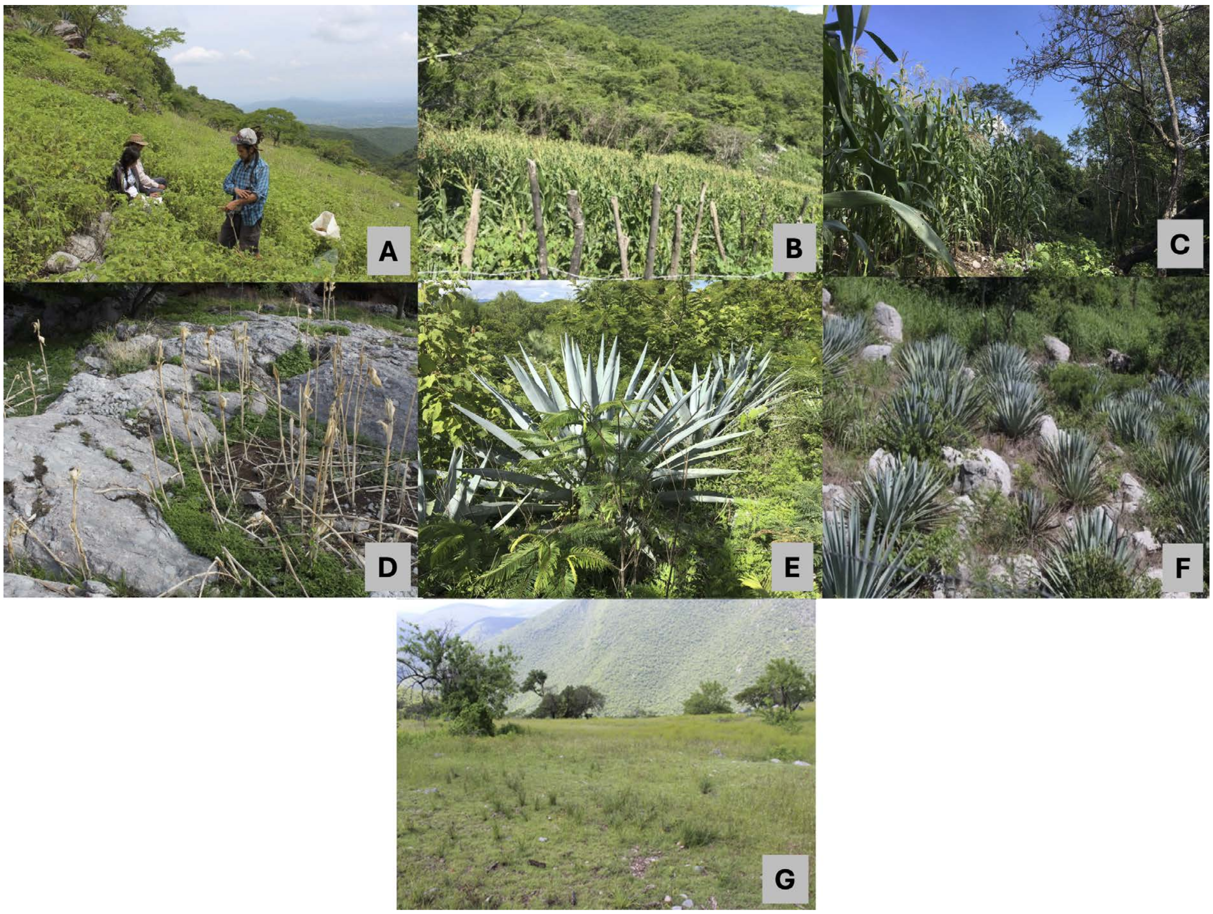

Figure 3. Tezcalera plots with different management history: a) tezcalera in the fallow process for six years (tezfa); b) tlacolol coming from fallow period of 15 years (tla15) and cultivate with milpa (maize) and other crop species; c) tlacolol coming from fallow period of 40 years (tla40) and cultivate with milpa (maize) and other crop species; d) milsol cultivated with maize for eight consecutive years (milma); e) tezcalera with *Agave angustifolia* cultivation for four years (milaga4); f) tezcalera with *Agave angustifolia* cultivation for two years (milaga2); g) tezcalera used for foraging (potrero).

Rather than recording the surrounding vegetation, we recorded the wild and agrestal weed species that thrive within each plot. We followed the "W" method (Caamal & Castillo 2011), which entailed drawing an imaginary diagonal line within each plot and collocating 50 × 50 cm squares every 20 meters, following the silhouette of an imaginary letter W. In each square, the abundance of each morphospecies was registered. To compare with the floristic components of tropical dry forest, we collected voucher specimens from different areas of post-milpa fallows, many surrounding active milpas (Figure 4).

Two or three voucher specimens of each morphospecies were collected, pressed, and dried according to standard methods (Lot & Chiang 1986). Specimens were identified, and scientific names were adjusted to the International Plant Names Index (INPI 2024).

Figure 4. Sampling stages in the different tezcaleras: a) inside each plot, several 50 × 50 cm squares were collocated; b) inside each square, the different weeds were recorded, with their respective abundance; c) voucher specimens were obtained from each plot.

Data analysis. Interview responses about agricultural practices were analyzed with descriptive statistics. Their descriptions were used to visually represent the management of tezcalera, including dates and tools.

To compare possible differences in agricultural practices between plots with different management histories, information from the plots' owners was also transformed in numbers to elaborate two values:

i) a land management value (annual polyculture, milpa + squash + beans = 0.25; annual monoculture only with milpa = 0.5; *Agave* = 1.0); fallow period (without fallow = 1; short fallow period = 0.25; medium fallow period = -0.5; long fallow period = -1.0); time with this management value (two or more years = 1.0; months = 0.5; fallow = 0).

ii) a technology-level value, which includes the use of agrochemicals (herbicides, pesticides, and chemical fertilizers) and the timing of their application.

The intensity of management value was calculated as the sum of land management and technology level values. Values near zero suggest low-intensity management; high values imply high-intensity management (Table 1). These values were correlated with floristic information.

We constructed an Excel database based on floristic sampling to calculate the relative abundance (RA) and relative frequency (RF) of morphospecies using the following formulas:

$$RA = \text{abundance of species x} / \text{total abundance}$$
$$RF = \text{number of squares with the presence of species x} / \text{total number of squares}$$

With these data, the importance value (IV) of each weed was obtained as follows:

$$IV \text{ species} = RA + RF$$

Because the basal area or plant cover was not included, this IV differed from that provided for studies on the relative ecological importance of different species in plant communities (Mueller-Dombois & Ellenberg 1974). Each species may have a maximum value of 2. Values close to 2 suggest that certain species have become dominant. According to Moreno (2001) and Baselga & Gómez-Rodríguez (2019), we evaluated specific richness using richness and abundance data. We also counted the number of herbs, shrubs, and trees (POWO 2024) in each plot, as well as the number of native/exotic species (POWO 2024) and their risk status (POWO 2024).

To evaluate possible relationships between tezcaleras according to their plant composition, we elaborated a database with the absence-presence of species, and we applied a PCoA analysis using PAST 4.

Results

Ecological, technological, and socioeconomic characteristics of tezcaleras. Tezcaleras are TAE found in cretaceous rocks, some more than one meter tall, with rough, often angled surfaces. A thin, sometimes deep, soil layer, as well as humidity, captures between. Campesinos sow seeds of crop species such as maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), squashes and pumpkins (*Cucurbita moschata* Duchesne, *C. pepo* L.), chilacayote (*C. ficifolia* Bouché), watermelon (*Citrullus lanatus* (Thunb.) Mansf.), bule (*Lagenaria siceraria* (Molina) Standl.); maguey (*Agave angustifolia* Haw.) production has recently displaced conventional crops. Some campesinos promote edible weeds known as "quelites" in some instances. Tezcaleras, according to campesinos, have a cyclic process with multiple stages that begin in tropical dry forests or tiny patches of oak forest (Figure 5). The following are the names and processes involved:

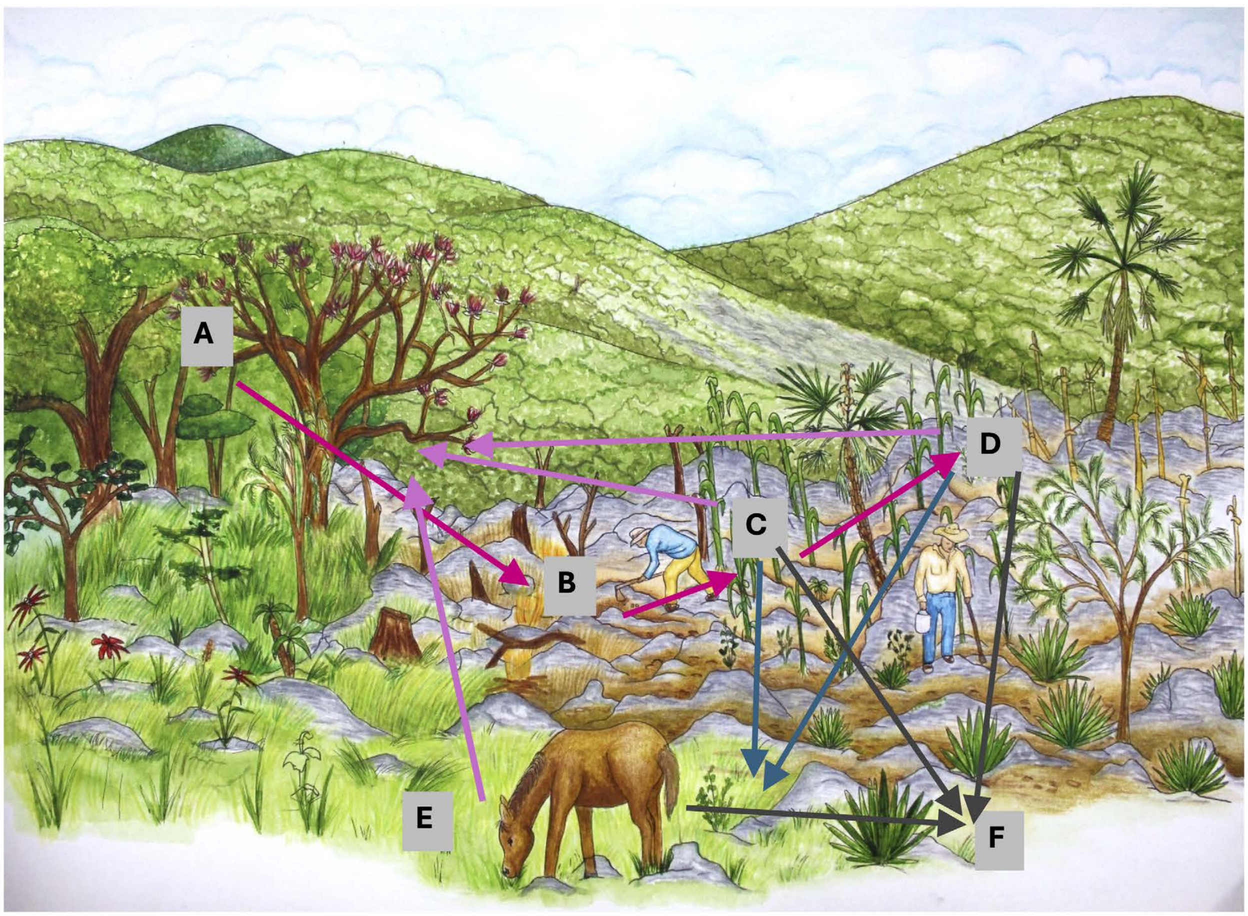

Figure 5. Tezcalera cycle: a) primary vegetation, tropical dry forest; b) roze-quema (slash and burn) where a small plot is cleaned; c) tlacolol: first year of sowing; d) milsol, from the second or more years of continuos cultivation; e) potrero, destinated for foraging. It comes from tlacolol or milsol. New crop, *Agave angustifolia*. It comes from tlacolol, milsol, or even potrero. The destiny of this kind of tezcalera management is unknown. Pink lines indicate the forward process from tropical dry forest to the traditional milpa system (monoculture or polyculture); blue lines indicate foraging use (potrero) of tlacolol or milsol. It can last only a few months or years; lilac lines indicate the reverse to the fallow process; black lines indicate changes to an intensive permanent crop, *Agave angustifolia*.

Roze-quema.- To clean a plot of forest, mature trees are cut with an ax, cutlass, or electric saw, leaving the base of the trees of different perennial species such as palma (*Brahea dulcis* (Kunth) Mart.), different species of copales or cuajiotes (*Bursera* spp.), guaje (*Leucaena macrophylla* Benth), and cacaloxochitl (*Plumeria rubra* L.), among others, to allow for further regeneration. The shrubs and herbs are then cut down using a cutlass (Figure 6A, B). All the material is gathered and burned in heaps (rejuntar) throughout the plot (Figure 6C, D). To contain the fire, campesinos clean a 1 m wide line around the plot (guardarraya). The hash is collected and distributed throughout the plot. Campesinos believe that hash fertilizes the soil and kills nixcuitl (bug larvae). This must be done before planting during the dry season.

Tlacolol.- After cleaning the plot, campesinos begin cultivating it at the start of the wet season, between May and July. Tlacolol involves two types of management: a) traditional management, which is manual labor, and occurs when campesinos have time for agricultural labor or when *milpa* (maize) is growing together with other crops like beans (*Phaseolus*), chilacayote (*Cucurbita ficifolia*), pipián (*C. argyrosperma* C. Huber), squash (*C. pepo*), pumpkin (*C. moschata)*. Campesinos also gather some *quelites* like different kind of pápalos (*Porophyllum ruderal*e

Figure 6. Agricultural activities followed in tezcalera: a) a fallow plot of tropical dry forest, before slash and burn; b) big trees are cut and left in the plot; shrubs and herbs are then cut down using a cutlass; c) All the material is gathered and burned in heaps (*rejuntar*); d) weeding with herbicides before sowing; e) Seeds are ready for sowing. Campesinos use bules, morrales, nylon, or buckets. f) Sowing with azadón; g) tools used during sowing: azadón, palo de siembra, barreta or chuzo; g) tools used during harvest: pizcalón, and ayate; h) the maize stems (*aguasol*) are gathered and burned in milsoles, after harvest. In many cases, campesinos use aguasol to elaborate fences.

(Jacq.) Cass., *P. warnockii* R.R. Jhonson), chichihuanche (*Euphorbia eglandulosa* V.W. Steinm.). To store the seeds and transport them while sowing, they use bules (natural containers elaborated from *Lagenaria siceraria* fruits), or morrales elaborated with palm leaves (*Brahea dulcis*), or nylon. During sowing (Figure 6E, F), they sow 4 or 5 seeds in those areas where they consider there is enough soil. To do this, they use palo de siembra (a thin piece of trunk or branch whose point is sharpened with the cutlass), barreta, azadón or chuzo (a thin piece of trunk; in one side, a relatively sharpened piece of iron blade is inserted) (Figure 6G), to make a small hole and incorporate the seeds, then cover them with a small amount of soil that is pushed with the feet. They mention that soil fertility is adequate in this kind of plots, so they do not apply fertilizers or agrochemicals. Two or three weddings are done with cutlass and azadón, depending on the rainy season; they are necessary before ears are ready for eating as elotes, and before the harvest of mature ears (mazorca), at the end of the season. For ear harvest, they use pizcalón, a thin metal rod introduced in the basal area of the leaves that involve the ear; they cut the external leaves and pull the ears. Elotes or mazorcas are kept in ayates (Figure 6H). b) technician management occurs when campesinos apply agrochemicals such as fertilizers, pesticides, and herbicides. This management occurs when campesinos cultivate *milpa* and wish to "ensure" their yield. Even though the tlacolol soil includes many natural nutrients and some biological interactions, they opt to use them. Herbicides used for weeding include Amina 4, Diablo, Secafin, red-capped Faena, green-capped Faena, and Paraquat. Campesinos dilute 30 ml/ 10 lt of water and sprinkle it with a spray pump before sowing, between May and June, at the start of the rainy season. Because perennial weeds, such as climbs, develop quicker than crops, some apply a second spray one month after sowing. Chemical fertilizer is also used, most typically urea, sulfate, or a combination of both. They are added only once, after the rainy season has begun, to aid in the assimilation of fertilizer into the soil and its absorption by the plants (Figure 7A, B).

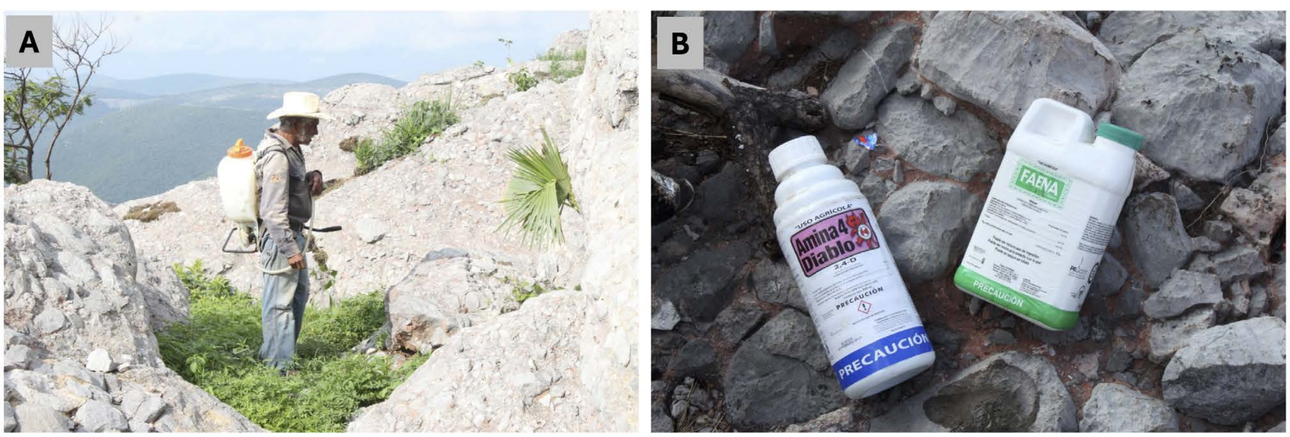

Figure 7. Weeding practice within tezcaleras: a) pump to spray herbicides; b) some of the commercial herbicides.

Milsol.- From the second year until the areas fallow again after several years of continuous cultivation, plots are known as milsol. As a result, milsoles of varying ages exist: two years, or ten years. According to the campesinos, the oldest is roughly 20 years old. Milsol plots are cultivated with conventional annual crops, although campesinos have lately added *Agave angustifolia*, which is changing traditional methods, particularly the time set aside for fallow.

The milsol stage is extremely vulnerable to fertilizers and agrochemicals. Campesinos believe that because soil becomes exhausted and production decreases year after year, they must add chemical fertilizer, which is applied twice or three times during crop growth. Herbicides are also applied twice, three times, or more times. Weeds have no cultural significance in this scenario; they are just named jehuite and eradicated.

Pests such as gusano cogollero (*Spodoptera frugiperda* (J.E. Smith), Noctuidae), picudo (Curculionidae), and isticuil (Scarabaeidae) are common in these plots. Campesinos use a spray pump to apply Monitor, Malation, or

Foley when pests appear. Campesinos stated that they began using these products about 30 years ago. Before it, all practices were carried out completely using human labor and traditional tools. Campesinos mentioned that pests were uncommon. The only problem was gusano cogollero, which used to be controlled with ash.

Barbecho is another farming technique in Zumpahuacán. Because barbecho is performed in even plots with a deeper layer of soil, fallow is relatively brief, lasting just a few months, and maybe plowed with a yunta or tractor (Figure 8A, B), Zumpahuacán campesinos clearly distinguished it from Tezcaleras. All of them stated that the barbechos that are currently being worked on have always existed, and it is likely that they were also opened from the forest, but they did not see this activity. Occasionally, campesinos move small and loose rocks on one of the borders of the tezcalera to facilitate labor inside the plot. These rocks are collocated on one of the borders like a fence, whose local name is retajo (Figure 8B).

Agricultural activities, in general, rest on traditional socioeconomic and cultural elements that reinforce the characterization of tezcaleras as a traditional agriculture system. As it can be perceived, almost all these activities, except for pesticide application, rely on human labor, which is carried out with familiar labor because hiring laborers is expensive. It is increasingly difficult to find people. They hire laborers for most of the practices, whose numbers vary depending on the type of labor (Table 2).

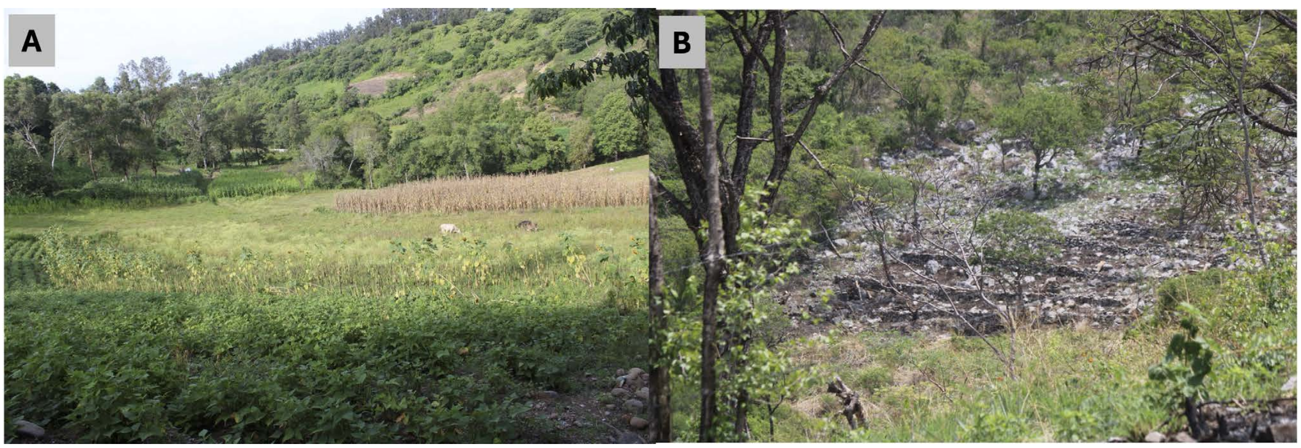

Figure 8. Variations in landscape management: a) Barbecho, which is used for intensive agriculture; b) Retajo, which is a small fence constructed with small, loose rocks.

They also follow some traditional ceremonies completely related to agriculture. *Campesinos* and their families perform a misa (Catholic ceremony in the temple) on May 15th, corresponding to San Isidro Labrador. The priest blesses the seeds that will be sown and the tools and beasts they will use for agricultural tasks.

The 28th of September corresponds to San Lorenzo. Winds are particularly frequent throughout this month, and it is normal for them to blow down the milpas. Campesinos place pericón crosses (*Tagetes lucida* Cav.) in the four corners to ward off envy or the devil, who is responsible for throwing them away.

Starting in November, when harvesting season begins, *campesinos* who are harvesting shoot off fireworks to warn others (Table 2).

Changes in wild and agrestal richness and composition in tezcaleras with different management histories. The results of floristic sampling of tezcaleras with different management provide vital information regarding the effect of cyclic management on wild and agrestal weed richness and composition, as well as their conservation. We collected 161 morphospecies from 45 botanical families, of which 118 were identified to species level, 16 to genera, and seven to family; 27 were still unidentified. Related to their biological form, 51 are woody species (more than 30 %), from which 21 species are trees, 18 are vines, and 12 are shrubs; 82 are annual, perennial, or arborescent herbs, and one

Table 2. Agricultural practices followed in tezcaleras.

AGRICULTURAL PRACTICE	COLABORATORS (%)	PERIOD	TOOLS/INPUTS, % OF COLABORATORS	KIND OF WORK	
				Family	Laborers
ROZE	100	Sept-Oct	TOOLS: Cutlass, 83.3; Ax, 79.2; Electric saw, 70.8	54.2	50 1-3 Laborers
REJUNTAR	100	May-Jun	TOOLS: Cutlass, 75; Azadón (Hoe), 29.2; Garra/Gata (Rake), 29.2	87.6	29.2 1 Laborer
BURNING	83.3	May-Jun	TOOLS: *Azadón* (Hoe), 15; *Garra*/*Gata* (Rake), 35	60	40 1 Laborer
SOWING	100	Middle June-middle July	TOOLS: Azadón (Hoe), 87.5; Bucket, 12.5, Chuzo, 29.2	70.9	37.5 1-3 Laborers
WEEDINGS	100	First, May-Jun Second, Ago-Sep	TOOLS: Azadón (Hoe), 29.2; Cutlass, 70.1; Pump, 100 INPUTS: Gramoson, 29.2; Faena, 25; Paraquat, 20.8; Diablo, 12.5; Sellador 4.2; Hierbamina, 4.2	100	33.3 1-3 Laborers
FERTILIZATION (CHEMICAL OR NATURAL)	95.8	Jul-Ago	TOOLS: Bucket, 100 INPUTS: Sulfato, 78,3; soil, 43.5; Urea, 26.1; Manure, 4.3	X 73.9	30.4 1 Laborer
HARVESTING	100	Nov-Dic	TOOLS: Pizcalón, 87.5; Ayate, 66.7; Sacks, 16.7; Wheelbarrow, 4.2; Beasts (donkeys, horses, mules), 16.7	X 43.5	73.9 5-8 Laborers
PEST CONTROL	95.8	Agos-Sep	TOOLS: Pump, 100 INPUTS: Foley, 43.5; Arribo, 4.3; Monitor, 30.43; Malation, 17.4; Tamaron, 8.7	X 86.9	13 1 Laborer
CEREMONIES-RITUALS	66.7	May 15	A Catholic ceremony is held for the day of San Isidro, the seeds, tools, and animals are blessed.		
		September 28th	A Catholic ceremony is held and the *milpas* are flowered, for which pericón (*Tagetes lucida*) crosses are made, and they are placed in the four edges of the plots, to protect the harvest from evils and envy.		
		From end of November	Harvest. The combat is carried out, which means to burn rockets that thunder to warn who is picking. The owners also make a meal for the laborers.		

parasitic (Table S1). The most common families were Asteraceae, Fabaceae, Poaceae, Euphorbiaceae, and Malvaceae. The rest of the families were represented by five (Solanaceae), or fewer species.

There were just three exotic species: *Chenopodium* aff. *album* L, *Cyclanthera dissecta* (Torr. & A. Gray) Arn., and *Sida abutilifolia* Mill. Some have restricted distribution and are endemic to the Balsas region, like *Bursera hintonii* Bullock, *Cordia morelosana* Standl., *Lippia bicolor* Kunth & C.D. Bouché, *Marina greenmaniana* (Rose) Barneby, *Porophyllum calcicola*. Thirty-four species were classified as endangered or vulnerable: 29 as least concern, three as vulnerable, and one as nearly endangered (Table S1). A comparison of floristic composition in tezcalera plots with different management history, fallow periods, and agricultural practices reveals significant differences:

The tezcalera under fallow for 5-6 years (tezfa) presented a floristic composition mostly of annual species, as well as some representative shrub and tree species of tropical dry forest: *Brahea dulcis*, *Croton ciliatoglandulifer* Ortega, *Vachellia pennatula* (Schltdl. & Cham.) Seigler & Ebinger., *Lysiloma acapulcense* (Kunth) Benth., and *Acacia cochliacantha* Humb. & Bonpl. ex Willd., which suggests that they are some of the pioneer species that begin the succession process (Table 3).

Both tlacolol plots (*tla15* y *tla40*) were destined for *milpa* cultivation, mixed with other annual crops like squash and beans. Both plots had similar Levels of Technification and Management Intensity values. Both exhibited h the lowest abundance and the highest specific richness values. They also have common woody and vine species, all of them because of regrowth after *slash*.

In the case of milsoles (milma, milaga4, milaga2), Land Management and Level of Technification values are higher than those of tlacololes. They tend to exhibit lower species, family richness, and specific richness but higher abundance values, and they contain smaller vine species than tlacololes.

The plot destined for foraging (potrero) had the lowest floristic richness scores. Even though the owner considered it an abandoned plot and exhibited the lowest intensity of management values, it has been utilized as pasture for ten years. Thus, the floristic composition has diminished; most species are annual weeds. Despite these differences in richness and abundance, the PCoA based on presence-absence did not exhibit groups between tezcaleras, suggesting that plant composition is similar (Figure 9).

From the 164 morphospecies, 114 had an intangible or tangible value for Campesinos: 28 are recognized by morpho-physiological attributes (flower color, leaves, and texture) and include regrowth of trees and shrubs, as well as annual weeds; 44 are recognized by their medicinal benefits; 37 species are food plants, including leaves, fruits, or seeds; and ten species are used to elaborate different handcrafts (Table S1). Comparisons between tezcaleras with different management indicated that there were recognizable or useful species; however, in *potrero* and *Agave1* the number of edible plants was lower.

Discussion

Tezcalera is a traditional agroecosystem (TAS), as defined by Dell (1953), Cruz-León (2003), and Pérez-Sánchez *et al.* (2014): it develops in response to environmental factors such as physiography, soil, and water availability, technological level, and function based on human labor. It is also a relic of one of Mesoamerica's most ancient agricultural systems, based on slash-and-burn (Cook 1919, Flannery *et al*. 1967). According to local *campesinos*, in the tezcalera, there are various stages of the same agricultural system, beginning with the cleaning of tropical dry forest plots, where tlacolol corresponds to the first-year cultivation. From the second to subsequent years, tlacololes are named milsol, traditionally cultivated for various years and then abandoned to fallow for other years. This notion of a cyclic process in tezcalera has been fundamental to preserving the entire ecosystem, including many floristic elements that are representative of the Balsas floristic region. Campesinos understand that the fallow process will ensure soil recovery and the possibility of sown in this place someday, some years later. These findings are analogous to those reported by Pérez-García & del Castillo (2017) in Oaxaca. As we mentioned before, barbecho is an intensive agricultural system that differs in management. Thus, floristic composition and structure have become very simplistic. In the case of *Agave* monoculture, this is also happening.

In this cycle process, maize or milpa is the essential component, which can be cultivated alone or accompanied by other crops. This process is very similar to those descriptions made a century ago. Cook (1919) and Diehl (1969) described milpa as "the raising of corn on clearings in tropical forest areas, and these plots are abandoned after two or three crops, or possibly more, depending on the characteristics of the specific plot, the amount of time it has rested since last used, and the work habits of the individual farmer."

During literature revision, we found variations in the terms used in Zumpahuacán. For example, Dell (1953) referred to milpa and tlacolol as distinct systems closely linked in the processes involved. Many scholars have regarded milpa as an obliged polyculture system based on maize, beans, and squash since the 1960s. This concept was supported by Grigg (1974). For the inhabitants of Zumpahuacán, milpa is just maize, growing alone or accompanied by other crop species.

Table 3. Comparison between tezcaleras of different management histories. Kind of Tezcalera: tezcalera under fallow process for 5-6 years (**tezfa**); tlacolol plots (**tla15** y **tla40**); milsoles (**milma**, **milaga4**, **milaga2**); plot destinated for foraging (**potrero**).

	TEZFA	TLA15	TLA40	MILMA	MILAGA4	MILAGA2	POTRERO
Land management (1+2+3)	0.25	0.25	-0.25	2.5	3	3	2
Level of technification	0	3 5	3 6	3 7-8	3 6-7	3 3-4	0 0
Intensity of management	0.25	5.25	5.75	9-13	9-10	6-7	2
Family richness	20	29	22	18	16	27	15
Species richness	4 morfospecies 45 species	64 morfo-species /53 species/ 1 unidentified	51 morfo-species / 44 species/ 1 unidentified	34 morfo-species / 33 species	35 morfo-species / 34 species	55 morfospe-cies / 45 species	30 morfo-species / 28 species
Abundance	923	75	103	190	351	668	923
Specific richness	6.59	14.592	10.788	6.289	5.972	8.302	6.59
Native/Introduced	43 native /1 introduced /1 no information	52 native / 1 introduced	41 native/ 3 introduced	32 native /1 introduced	33 native, 1 no informa-tion	43 native / 2 introduced	43 native /1 introduced /1 no informa-tion
Risk category	4 less concern	8 less con-cern /1 vul-nerable	10 less con-cern /2 vul-nerable	8 less con-cern / 1 almost endangered	9 less con-cern	11less concern / 1 vulnerable	4 less concern
Trees/shrubs/herbs/vines	4 trees/ 1 arborescent/ 2 shrubs/ 2 vines/ 36 herbs	3 trees/ 2 shrubs/ 11 vines/ 1 parasitic/ 37 herbs	7 trees/ 2 shrubs/ 10 vines/ 1 arrosetado/ 25 herbs	3 trees/ 1 arbores-cent/ 3 shrubs/ 5 vines/ 1 arrose-tado/ 21 herbs	7 trees/ 1 arbores-cent/ 2 shrubs/ 1 vine/ 2 arrosetado/ 22 herbs	3 trees/ 1 arborescent/ 4 shrubs/ 3 vines/ 2 arrosetado/ 33 herbs	4 trees/ 1 arborescent/ 2 shrubs/ 2 vines/ 36 herbs
Number of species with intangible and tangible values Edible/medicinal plants	40 10/15	44 12/15	39 10/14	30 6/12	36 12/13	30 6/12	40 10/15

Some authors considered the concepts tlacolol and barbecho to be synonyms Flannery *et al.* (1967) Moreno-Calles *et al*. (2013); others, such as Lees (1971), consider the whole cycle process (from slash and burn to fallow) and barbecho to be synonyms: "a system of 'barbecho' is practiced: the natural vegetation is cut down with cutlass´s, horned on the field, the field is plowed and planted for perhaps three to five years, then left fallow for about the same amount of time, and the cycle is repeated again."

According to Barrett (1970), slash and burn vary from barbecho due to the length of the fallow: "The methods used to raise these crops were several. Palerm describes three general systems as being widespread in Mesoamerica: slash and burn (roza), fallow (barbecho), and irrigation (regadío), The roza system, with its long-term forest fallow, was largely restricted to humid tropical areas, but a combination of irrigation and short-term fallow, or barbecho, was undoubtedly practiced in the Tepalcatepec lowland." Zumpahuacán collaborators distinguished slash and burn from barbecho; thus, their conception is more like Grigg (1974) description: "In the uplands of the Mesa Central, and particularly on the steeper slopes, is found the barbecho system. There is some soil preparation after burning, and the fallow period rarely exceeds the period under crops, so the natural vegetation is not allowed to regenerate."

The socioeconomic dynamics involved in tezcalera management add elements that characterize it as a TAS: most of the activities and the tools employed during them are sustained by human energy. Cook (1919) stated in the instance of milpa: "...since only a minimum of labor and equipment is required. The ax, or the cutlass, is the only necessary tool. Tribes who did not have effective cutting implements felled or girdled the trees by building fires around them." He also described different aspects of milpa agriculture based on the family's labor. As we described in the results, this pattern was found again 100 years later in tezcaleras. The prevalence of this TAS exhibits a real adaptation to socio-environmental conditions.

Cultural practices are the third component to characterize this TAS: those ceremonies followed at different moments of the agricultural cycle of milpa have been documented very early in colonial literature (Acuña 1986, Sierra-Carrillo 2007). They are clearly part of the Mesoamerican cosmovision, adapted during the colonial epoque, and at present generate links between different communities, enhancing the identity of their inhabitants. Because they are related to seed and land "protection" through religious practices, Campesinos ensure not only useful products (corn, beans, quelites), but also the maintenance of the ecosystem.

Floristic composition in tezcaleras with a different management history. Tezcaleras in Zumpahuacán are important habitats for native and endemic tropical species. As previously stated, a relevant characteristic of this TAS is that practically all the wild and agrestal species that are growing in the tezcaleras are native, which is a remarkable find-

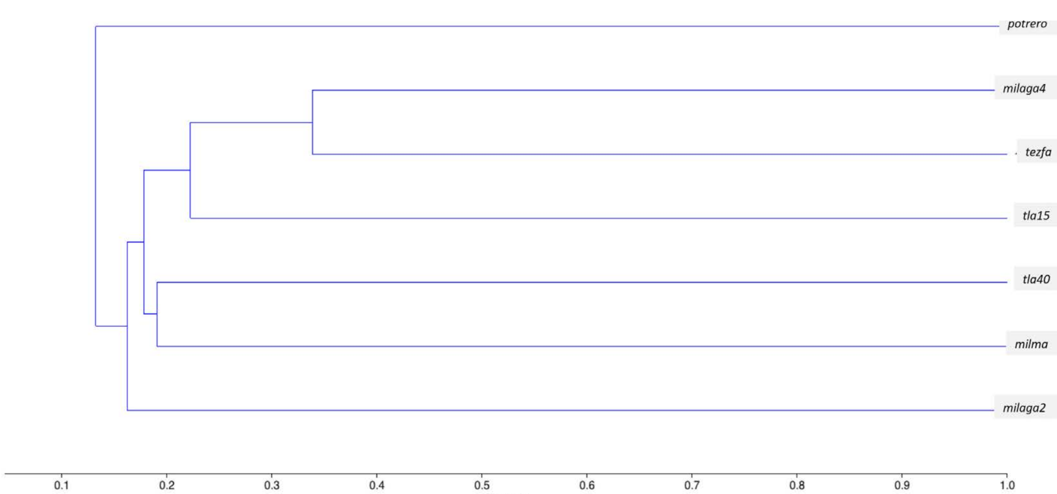

Figure 9. Cluster Analysis based on absence-presence of wild and agrestal species in seven tezcalera plots: tezcalera under fallow process for 5-6 years (tezfa); tlacolol plots (tla15 y tla40); milsoles (milma, milaga4, milaga2); plot destinated for foraging (potrero).

ing given that at least 40% of the species in previous research in other agroecosystems were exotic (Vieyra-Odilón & Vibrans 2001, Rendón-Aguilar *et al.* 2021, Rivera-Ramírez *et al*. 2021). These findings support the notion that many native weeds are adapted to milpa traditional management due to life-history characteristics that allow them to resist the presence and displacement of exotic weeds (Molina-Freaner *et al*. 2008). In this case, the very rocky topography and significant seasonality could favor the presence of native species despite the extensive use of herbicides.

Another feature of this TAS is the presence of 35 species classified in one of the risk categories, which is a high value compared to previous publications. We found twelve species endemics to the Balsas region or southern Mexico, without information on their risk status. This study provides a window into these species' ecological and biogeographical characteristics, which are much more interesting when they are part of the dynamic of agricultural management. A comparison of plots with different management histories gives evidence of the ecological influence of management intensity on floristic composition and native germplasm conservation. Tlacolol had more species and families and a greater specific richness. A similar pattern was found in one of the *Agave* plots (milaga 2), which had a comparable Intensity of Management value. Because intense *Agave* cultivation is new (less than seven years), it will be interesting to see how it affects floristic richness and composition. Potrero represents another management history, where intense management may drastically diminish the floristic richness and affect the composition. Intensity of Management is the sum of different components. However, previous studies have suggested that herbicides seem to influence the species richness, as well as the relative abundance of some species (Rivera-Ramírez *et al*. 2021, Rendón-Aguilar *et al.* 2021). This pattern was observed in milsoles, where weeding control with herbicides is frequent. These issues have been discussed with campesinos, who are clear that weed richness and abundance have changed and decreased. However, they argue that weed management is faster, and they don't have time to manually clean their plots. It is necessary to evaluate more plots to have comparably more data and to understand the dynamic of this kind of management, including herbicides and chemical fertilizers on floristic richness and composition, as Velasco-Murguía *et al.* (2021) suggested.

Floristic composition is primarily composed of native species. An important proportion corresponds to woody species and vines, which are representative of the tropical dry forest. The presence of tocones is important to the faster recovery of vegetation during fallow periods (Pérez-García & del Castillo 2016, 2017). The presence of surrounding areas with different fallow times is necessary to allow rapid recovery of milsoles and potreros, to maintain carbon reservoirs, to maintain wild and weed native germplasm, and the to resilience of this important area of tropical dry forest within the biographic province of Cuenca del Balsas (Velasco-Murguía *et al.* (2021).

We conclude that tezcalera is a biocultural unit, clearly differentiated from others, based on ecological, technological, and cultural elements that characterize it. Because of the intrinsic nature of tezcalera, most ancient traditional practices have survived and have had a positive impact, not only on the floristic richness and composition of native weeds but also on the entire ecosystem. This TAE has allowed the coexistence of domesticated, tolerated, and wild elements, many of them with tangible and intangible values, thus favoring the local necessities. Also, has allowed the prevalence of some ancestral rituals that maintain the bond and respect between local campesinos with nature.

The persistence of slash -and-burn practices followed by fallow seasons has allowed tropical dry forest to regrow while avoiding the intrusion of exotic species. Tezcaleras, like other TAS, have been regarded as low-yielding and damaging due to slash and burn. However, our results indicated the opposite: tezcaleras has proven to be a sanctuary for agrobiodiversity, including numerous endemic species, and/or in one of the risk categories.

Regarding crop productivity, they produce enough for families 'subsistence and occasionally for sale. The most serious issues are the uncontrolled use of herbicides and the introduction of perennial crops, such as the *Agave* crop, which are displacing annual and native crops and potentially affect native wild and agrestal agrobiodiversity. The introduction of technology has also altered social organization. Campesinos used to band together to aid one another in sowing, weeding, and harvesting. In recent years, most of them have found work outside of the town, so they do not have time to participate in this community organization. It is also difficult to find peones (laborers) from the local communities.

Efforts must be made to protect tezcaleras, promote their products for local and regional consumption, and support local farmers in continuing their traditional crops and management practices. Thus, tezcaleras can exemplify a sustainable traditional agriculture system and a biocultural unit in the Balsas region.

Supplementary material

Supplemental data for this article can be accessed here: https://doi.org/10.17129/botsci.3422

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