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Research article

# Silvopastoral systems of the Chol Mayan ethnic group in southern Mexico: Strategies with a traditional basis

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ABSTRACT

Silvopastoral systems combine trees and/or shrubs with grazing cattle. In the municipality of Salto de Agua, Chiapas, Mexico, some indigenous communities have developed silvopastoral systems based on their traditional knowledge regarding use of local natural resources. Through analysis of classification based on the composition of tree vegetation, two groups of grazing units were identified in the study area. Different attributes of tree and herbaceous vegetation, as well as of agricultural management and production, were compared between the two groups. Results indicate that at least two strategies of silvopastoral management exist. The first - LTD - is characterized by an average density of 22 adult trees $ha^{-1}$ in grazing units with an average surface area of 22.4 ha. The second - HTD - has an average of 54.4 trees $ha^{-1}$ in grazing units with an average surface area of 12.2 ha. Average richness per grazing unit for the LTD strategy was 7.2 species, and for HTD strategy it was 12.7 species. Average basal area for LTD was 1.7 m2 $ha^{-1}$, and for HTD 3.8 m2 $ha^{-1}$. Finally, the average level of fixed carbon for LTD was 2.12 mg $ha^{-1}$, and for HTD 4.89 mg $ha^{-1}$. For all variables, there was a significant difference between the two strategies. In addition, both strategies differ in prairie management. In the HTD strategy, growers spare their preferred spontaneously growing tree species by clearing around them. Many of these species, particularly those harvested for timber, belong to the original vegetation. In these prairies, average coverage of native grasses ($60.8 \pm 7.85$) was significantly greater than in the LTD strategy ($38.4 \pm 11.32$), and neither fertilizers nor fire are used to maintain or improve the pastures; by contrast, in HTD prairies, introduced grasses, principally *Cynodon plectostachyus*, have a higher average coverage ($43.4 \pm 13.75$) than in the LTD prairies ($17.08 \pm 9.02$). Regardless of the differences in composition of tree and herbaceous vegetation, in both types of grazing units a similar animal load is maintained.

Many attributes of these silvopastoral strategies - based on traditional technology of the Chol farmers of the Tulija River Valley - concord with sustainable agriculture and provide a wide variety of services to the farmer and the environment. Diffusion of this technology in areas similar to that of this region could have a positive impact on the economy of conventional cattle raisers while generating environmental services.



## 1. Introduction

Silvopastoral systems combine cattle raising in pastures with use of woody plants (Nair, 1997; Pezo and Ibrahim, 1999). There are many variants of such systems, adapted to a broad range of environmental conditions and that incorporate growers' wisdom and interests. Presence of trees in areas where cattle are raised, especially in warm humid climates, enhances the ecosystem's persistence, particularly by improving and maintaining soil conditions. Studies in Mexico and Central America have shown that the presence of trees in prairies increases the soil's organic carbon content as well as its potassium, total nitrogen, phosphorus, calcium, and magnesium contents (Rhoades et al., 1998; Giraldo et al., 2006; Crespo, 2008; Morales Coutiño, 2010; Romero Murcia, 2010). Furthermore, reduced variations in humidity and temperature due

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to the presence of the trees, as well as the leaf litter they produce, promotes a stable diversity of macrofauna, which facilitates decomposition and nutrient recycling processes (Sánchez et al., 2010). Therefore, trees maintain soil conditions and enhance the system's productivity. The tree canopy reduces overall temperature and minimizes temperature fluctuations beneath the trees, contributing to improved animal production and reproduction (Nair, 1997). Further benefits include mitigation of effects of climate change through carbon capture and storage in tree biomass and necromass, moderation of runoff and lixiviation, watershed protection, biodiversity conservation, and landscape connectivity. These environmental services allow for persistence of some of the original system's ecological processes while improving agroecosystem productivity (Ibrahim et al., 2000, 2007; Jose, 2009; Nair, 1997; Murgueitio et al., 2006) as well as the system's capacity to absorb disturbances and reorganize itself, while maintaining essentially the same function, structure, and identity (Walker et al., 2004). This resilience is especially important for vulnerable socioeconomic systems, such as those of the indigenous communities of southern Mexico which have undergone great changes in recent decades, some of which have been due to the spread of cattle raising.

The introduction of cattle raising to warm humid zones of Mexico and Central America has led to a loss of forest resources, reduction in biological diversity, soil degradation, low animal productivity in pastures, and socioeconomic polarization (Nahed et al., 2010). Cattle raising has greatly increased in southeast Mexico in recent decades (Alemán et al., 2007). In 1970, Chiapas had 1,249,300 head of cattle, and in 2007 there were 2,500,000 cattle - a 100% increase in 37 years, at the expense of forest areas (Jiménez-Ferrer et al., 2010). In some areas, such as the buffer zone of the Montes Azules Biosphere Reserve in Chiapas, in recent decades pastures reached such severe states of degradation that cattle ranchers abandoned them, but these pastures were unable to later achieve a successional state similar to the original (Levy et al., 2010). Traditional farming methods may include more efficient techniques for using natural resources while helping to resolve this problematic situation. Studies of the indigenous areas of Chiapas indicate that the Lacandon, Tseltal, Tsotsil, and Chol Mayan populations possess extensive knowledge regarding use of woody species, as well as of the relationship of these species to crop production and - more recently - animal production (Jiménez-Ferrer and Hernández, 2007). Thus, traditional agricultural technology (Hernández, 1977) has proved essential to developing processes for rehabilitating and restoring degraded areas in the Lacandon region of Chiapas, Mexico - in particular for restoring pastures (Levy et al., 2014).

In the Tulija River Valley, in the municipality of Salto de Agua in Chiapas, Mexico, cattle raising began to be practiced in 1970; in the following years, the surface area covered by grazing units grew at an average annual rate of 12.25% (Fernández Ortiz and García, 1983) at the cost of mature vegetation. Currently, these grazing units contain a large quantity and variety of dispersed trees and/or trees in living fences, unlike the grazing units of agribusiness ranches. Although cattle raising practices appear to vary from farmer to farmer in the study area, the presence of trees is notable throughout the landscape, indicating shared management tendencies. This type of silvopastoral system, based on traditional knowledge, may be a viable option for developing diversified systems of resource use which enhance the economy of small-scale farm families, protect natural resources (Murgueitio et al., 2006), and allow for adapting to climate change on local, regional, and global levels (Nahed et al., 2013).

The objectives of this study were to characterize the Chol Mayan silvopastoral system in the Tulija River valley and to define its variants with respect to ecological and technological characteristics. We pose the hypothesis that Chol Mayan peasant farmers in the study area have applied and developed a variety of traditional techniques to establish and maintain their silvopastoral systems.

## 2. Materials and methods

### 2.1. Study site

The study area is located in the alluvial plain of the Tulija River in the rural communities Suclumpa and El Toro, in the municipality Salto de Agua, in the Mexican state of Chiapas. Located between 17° 23′ and 17° 25′ north latitude and 92°07′ and 92° 11′ west longitude, it is delimited by the Tulija River and two highland mountain chains; altitude ranges from 0 to 100 masl.

The main economic activity of this area is cattle raising. Therefore, the principal plant cover is induced prairies, bordered by secondary vegetation and vestiges of evergreen forest. Predominant soils are gleysols and luvisols near the river, and lithosols on the nearby slopes. Climate is warm humid with an average annual precipitation of 3369.5 mm, and average annual temperature is 26.7° C (PEOT Chiapas, 2005).

In the communities Suclumpa and El Toro, we selected 35 grazing units, each used by a different Chol farmer. The study was carried out from October 2011 to October 2012. Prairies selected were those with grazing units of the average size of those of the region - from 10 to 25 ha - for which those who use them authorized that they be included in the study. In these plots, the following were evaluated: i) tree vegetation, ii) herbaceous vegetation, iii) management practices, and iv) socioeconomic aspects of cattle production.

### 2.2. Evaluation of tree and herbaceous vegetation

In each grazing unit, four 1000 $m^2$ sampling plots were randomly selected (radius: 17.87 m). In each one, the quantity and species of all trees of the following class sizes were recorded: adults (diameter at breast height (DBH) greater than 10 cm); juveniles (DBH less than 10 cm, but height greater than1 m); seedlings (less than 1 m in height); and stumps (cut adults). For adults, we recorded DBH, estimated total height (at the apical meristem), and canopy cover (measuring two radii from the trunk to the canopy edge).

With this information, the following variables were estimated for each prairie:

i) Total tree density: total number of individuals per hectare, without distinguishing class size
ii) Prairie richness: number of tree species per hectare, without distinguishing class size
iii) Basal area of adult trees: calculated using the equation where *ab* is the basal area and *c* is the circumference of the trunk at breast height. Then the basal areas of all trees in the prairie sampled were summed.
iv) Cover: area of the ellipse defined by the greatest and smallest radius of the perimeter of the trunk to the projection of the canopy of each tree. The equation was used, where *ae* is the area of the ellipse, and $r_1$ and $r_2$ are the radii (Mueller-Dombois and Ellenberg, 1974). The areas of cover of all trees sampled in each prairie were later summed.
v) Tree density per class size: number of individuals per hectare, grouped by class size
vi) Carbon stored by tree vegetation: The allometric equation proposed by Chave et al. (2005) was used to calculate kilograms of carbon stored in each adult tree (DBH > 10 cm):

$$Y = \exp\left(-2.977 + nl\left(\rho D^2 h\right)\right)$$

where:

$Y$ = biomass (kg/tree)
exp (n) = 2.718 $^{n}$ (raise the base e = 2.718 to the nth power)
$nl$ = natural logarithm (base e)
$\rho$ = density per tropical species (g/cm$^3$)
$D$ = diameter at breast height (cm)
$h$ = height (m)

We then summed the values for all trees and obtained a value for carbon stored per hectare.

Furthermore, in each sample plot, the botanical composition and its proportion with respect to the total herbaceous and shrub component were evaluated with the line interception method (Mueller-Dombois and Ellenberg, 1974). This method consists of measuring the longitude of the intercepted line, directly or by projection of the aerial cover of each herbaceous and shrub species identified or life form. In exposed areas without the presence of trees, two 5 m lines were randomly drawn in each of the four samples (eight lines per grazing unit).

With this information, average cover of herbaceous vegetation was obtained. For this, a single percentage value of cover was calculated for each grazing unit from the following groups of species and life forms:

i) introduced grasses, ii) spontaneous vegetation (including native grasses, herbaceous plants, and other vegetation excluding legumes), iii) legumes, and iv) bare soil, leaf litter, and cattle excrement.

### *2.3. Characterization of management approaches to cattle production*

Through questionnaires applied to farmers using the semi-structured informal interview technique (Gillham, 2005), different practices and technological and social aspects of cattle production were recorded. With this information, the following variables were obtained in order to characterize uses of each prairie, as well as technological and social indicators previously defined by Mena et al. (2004) and Nahed et al. (2000).

i) Use variables: number and type of activities in the selected grazing units (maize field, prairie, areas with fruit trees, fallow plot used to harvest wood, etc.); history of use of the grazing units; fomenting and cultivation of trees; method of establishing the prairie including grass species used and use of fire and fertilizers; rest period of the prairie from grazing; type of clearing (manual/herbicide/mixed) used to maintain the prairie; number of trees cut for firewood each year; and farmers' uses of tree species.
ii) Technological and social indicators: surface area devoted to cattle raising, surface area under communal use, surface area devoted to crop production, herd size, animal load, birth rate, age at weaning, adult mortality rate, prairie surface area owned, prairie surface area rented, farmer age, years of experience in cattle raising, number of beneficiaries in the family, type of land tenancy, and level of formal education.

### *2.4. Analysis of information*

#### *2.4.1. Classification of grazing units based on tree vegetation*

With the data for abundance for each tree species per each grazing unit (data from the four sampling units were summed), without discriminating by community of origin or size class, a hierarchical classification of the grazing units was carried out using the Ward method (Greig-Smith, 1983), with the software PC-ORD Multivariate Analysis of Ecological Data (McCune and Mefford, 2011).

Later, for each tree species, the importance value index (IVI) was calculated as the sum of the number of individuals and the frequency of the species in each group of grazing units as a result of the classification mentioned above, with the aim of identifying the most abundant species in these groups and the species that were unique to each group.

#### *2.4.2. Comparison of variables of interest among groups of grazing units*

For each of the variables previously listed, average values and 95% confidence intervals were calculated for each group of grazing units. Confidence intervals were compared among groups of grazing units to determine whether significant differences existed among average values for each variable. For qualitative data, contingency tables were analyzed (Legendre and Legendre, 1998).

## 3. Results

### *3.1. Classification of prairies based on tree vegetation*

Analysis of classification based on composition of tree vegetation resulted in two groups of grazing units (Fig. 1). Group 1 consisted of 18 prairies - 14 from the community Suclumpa and four from El Toro, and group 1 consisted of 17 prairies - 10 from Suclumpa and four from El Toro.

Sixty one different tree species were found among all size classes, of which 12 could not be identified. Of all species, only 45 included adult individuals. Of all species identified, 51% were typical of mature vegetation, 34.7% belonged to secondary vegetation, and 14.3% were fruit trees, most of them introduced species.

Group 1 had a total of 32 species, of which seven were exclusive to this group, although most of these were not very abundant; *Eugenia axillaris* (Sw.) Wild, *Posoqueria latifolia* (Rudge) Schult, and *Calophyllum brasiliense* Cambess. were species belonging to advanced successional stages (Pennington and Sarukhán, 2005). *Pterocarpus rohrii* Vahl, present in both groups, was more abundant in group 1. Group 2 had 54 species, 24 of which were unique to this group, the majority with low abundance; exceptions – those with relatively high abundance - were *Brosimum alicastrum* Sw., *Sabal mexicana* Mart., and *Miconia argentea* (Sw.) DC. - species belonging to advanced successional stages (Pennington and Sarukhán, 2005). Some species which were shared, but which were more characteristic of group 2 given their higher abundance in this group, were *Tabebuia rosea* (Bertol.) DC., *Parmentiera aculeata* (Kunth.) Seem., *Citrus sinensis* (L.) Osbeck, *Enterolobium cyclocarpum* (Jacq.) Griseb., and *Spondias mombin* L., all of which were secondary vegetation or cultivated fruit trees (Table 1).

### *3.2. Uses of species*

We recorded four types of uses by Chol Mayan farmers for tree species in their grazing units. No significant differences were found between groups of grazing units for percentages of species used for each purpose. In general, 40.8% are used for timber, principally for building houses, furniture, and corrals for cattle. Fruit is consumed from 26.5% of the species, 12.2% are exclusively used for firewood, and 10.2% are used for fence posts as well as firewood. We were unable to identify possible uses of the remaining 10.2%. The most abundant species used for timber are *Cedrela odorata*, *Blepharidium*

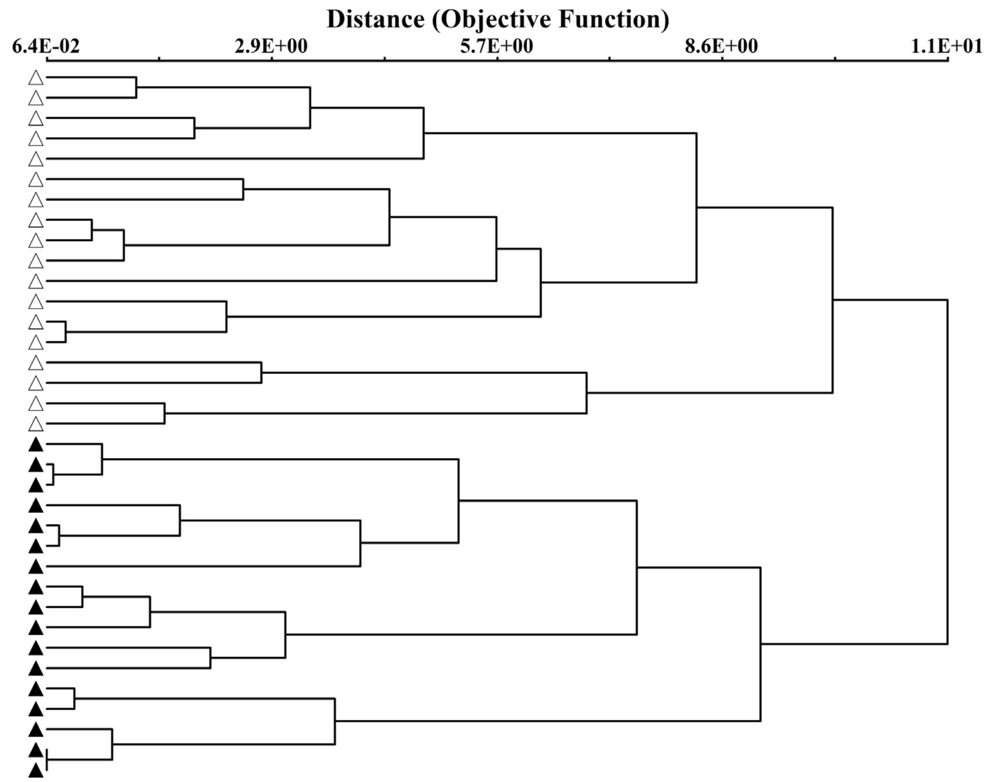


**Fig. 1.** Hierarchical classification of grazing units in the Tulija River Valley based on composition of tree vegetation. Grazing units symbolized by white triangles belong to group 1 and those symbolized by black triangles to group 2.

*mexicanun*, *Zanthoxylum riedelianum*, *Pterocarpus rohrii,* and *Tabebuia rosea*. The most abundant fruit producing species are *Psidium guajava*, *Byrsonima crassifolia*, *Parmentiera aculeata*, and *Citrus aurantiifolia*. Finally, the most abundant species used exclusively for firewood are *Guazuma ulmifolia, Cupania dentata,* and *Inga vera* (Table 1).

### 3.3. Comparison of structural variables between the two groups of grazing units

#### 3.3.1. Tree vegetation

Average values per hectare of the variables total tree density, total tree species richness, basal area, and canopy area proved to be significantly greater in group 2 (Fig. 2). On average, group 1 had 22 adult trees per hectare, 13.4 juveniles, 43.7 seedlings, 4.7 stumps, and a total density of 83.9 individuals $ha^{-1}$, while grazing units of group 2 had an average of 54.4 adult trees, 106.6 juveniles, 204.3 seedlings, 11.7 stumps, and a total density of 376.9 individuals $ha^{-1}$. Average density for adult and juvenile trees also varied significantly between groups (Fig. 3).

Values for tree species richness, tree basal area, canopy cover area, and average carbon proved to be significantly less in group 1 than in group 2. Average richness per grazing unit for group 1 was 7.2 species, while for group 2 it was 12.7 species. Average basal area for group 1 was 1.7 $m^2$ $ha^{-1}$ and for group 2 it was 3.8 $m^2$ $ha^{-1}$. Average canopy cover of group 1 was 627.5 $m^2$ $ha^{-1}$, while for group 2 it was 1509.7 $m^2$ $ha^{-1}$. Finally, the average level of fixed carbon for group 1 was 2.12 ± 1.02 mg $ha^{-1}$, and for group 2 it was 4.89 ± 1.2 mg $ha^{-1}$ (Fig. 4).

The contingency table test for percentages of size classes per group of grazing units indicates that the size class distributions are different ($\chi^2 = 72.95, p < 0.0001$). In the distribution of size classes for group 1, the percentage of juveniles was less than the percentage of adult trees, while in group 2 the percentage of juveniles was greater than that of adults (Fig. 5).

#### 3.3.2. Herbaceous vegetation

During sampling, the following introduced grasses were recorded: *Cynodon plectostacyius* (K.Schum) Pilg. (star grass), *Brachiaria brizantha* (A.Rich.) Stapf (brizanta), *B. humidicola* (Rendle) Schweick. (humidicola), and *Hyparrhenia rufa* (Nees) Stapf (jaragua). Induced vegetation included native grasses, herbaceous dicotyledons, shrubs, ferns, rushes (*Juncus* spp.), and sedges. Induced vegetation (mainly native grasses) on average was the most abundant (49.3%), followed by introduced grasses (30.6%) - of which *C. plectostachyus* was the most abundant, native legumes (16.6%) and a low percentage of bare soil, dead matter, and excrement (3.5%).

Groups of grazing units showed differences in composition of herbaceous vegetation. Group 1 had a significantly greater average cover of introduced grasses (43.4 ± 13.75) than group 2 (17.08 ± 9.02) (Fig. 6A). Among introduced grasses recorded for group 1, *Cynodon plectostachyus* was the most abundant. Group 2 had a statistically greater average cover of induced vegetation (60.8 ± 7.85) than group 1 (38.4 ± 11.32) (Fig. 6B). Average cover of spontaneous legumes, as well as that of bare soil and leaf litter, was similar in both groups (Fig. 6C–D).

#### 3.3.3. Agricultural production

Of all farmers, 71% carry out at least one additional economic activity besides cattle raising within their grazing unit: 13% cultivate maize (*milpa*), 33% raise foul, and 8% have areas with fruit trees and medicinal plants, while 17% leave certain areas under fallow with secondary vegetation which may later provide products such

**Table 1**
Tree species present in the induced prairies of the Tulija River Valley, their uses, and type of original vegetation to which they belong.

| Category | Species | Family | Uses | Type of vegetation |
|---|---|---|---|---|
| Shared abundant | *Psidium guajava* L. | Myrtaceae | Fruit | Secondary |
| | *Cedrela odorata* L. | Meliaceae | Lumber | Secondary |
| | *Byrsonima crassifolia* (L.) Kunth | Malpighiaceae | Fruit | Mature |
| | *Blepharidium mexicanun* Standl. | Rubiaceae | Lumber | Secondary |
| | *Guazuma ulmifolia* Lam. | Malvaceae | Firewood | Secondary |
| | *Acosmium panamense* (Benth.) Yakovlev | Leguminosae | Posts/Firewood | Mature |
| | *Cupania dentata* Mociño. & Sessé ex DC. | Sapindaceae | Firewood | Mature |
| | *Zanthoxylum riedelianum* Engl. | Rutaceae | Lumber | Mature |
| | *Cojoba arborea* (L.) Britton & Rose | Leguminosae | Lumber | Mature |
| | *Inga vera* Willd. | Leguminosae | Firewood | Mature |
| Shared not very abundant | *Genipa americana* L. | Rubiaceae | Lumber | Mature |
| | *Gliricidia sepium* (Jacq.) Walp. | Leguminoseae | Posts | Mature |
| | *Lonchocarpus* sp. | Leguminoseae | Lumber | Mature |
| | *Zuelania guidonia* (Sw.) Britton & Millsp. | Salicaceae | Lumber | Mature |
| | *Ormosia macrocalyx* Ducke | Leguminosae | Lumber | Secondary |
| | *Simarouba glauca* DC. | Simaroubaceae | Lumber | Mature |
| | *Lysiloma acapulcense* (Kunth) Benth | Leguminosae | Fruit | Mature |
| | *Inga* sp. | Leguminosae | Firewood | Mature |
| Abundant Group 1 | *Pterocarpus rohrii* Vahl | Leguminosae | Lumber | Secondary |
| Abundant Group 2 | *Tabebuia rosea* (Bertol.) Bertero ex A.DC. | Bignoniaceae | Posts/Firewood | Secondary |
| | *Parmentiera aculeata* (Kunth) Seemann | Bignoniaceae | Fruit | Secondary |
| | *Cochlospermum vitifolium* (Willd.) Spreng. | Bixaceae | Firewood | Secondary |
| | *Citrus aurantiifolia* (Christm.) Swingle | Rutaceae | Fruit | Cultivated |
| | *Citrus sinensis* (L.) Osbeck | Rutaceae | Fruit | Cultivated |
| | *Enterolobium cyclocarpum* (Jacq.) Griseb. | Leguminosae | Lumber | Secondary |
| | *Senna multijuga* (Rich.) H.S.Irwin &Barneby | Leguminosae | – | Secondary |
| | *Spondias mombin* L. | Anacardiaceae | Fruit | Secondary |
| Unique to Group 1 | *Eugenia axillaris* (Sw.) Wild | Myrtaceae | – | Mature |
| | *Posoqueria latifolia* (Rudge) Schult. | Rubiaceae | – | Mature |
| | *Calophyllum brasiliense* Cambess. | Gutiferaceae | Lumber | Mature |
| | *Coccolova barbadensis* Jacq. | Polygonaceae | Firewood | Secondary |
| | *Sapindus saponaria* L. | Sapindaceae | Fruit | Secondary |
| Unique to Group 2 | *Brosimum alicastrum* Sw. | Moraceae | Lumber | Mature |
| | *Sabal mexicana* Mart. | Arecaceae | Roof | Mature |
| | *Miconia argentea* (Sw.) DC. | Melastomataceae | Posts | Mature |
| | *Citrus reticulata* Blanco | Rutaceae | Fruit | Cultivated |
| | *Zanthoxylum fagara* (L.) Sarg. | Rutaceae | – | Mature |
| | *Astronium graveolens* Jacq. | Anacardiaceae | Lumber | Mature |
| | *Pachira aquatica* Aubl. | Malvaceae | Fruit | Mature |
| | *Citrus limetta* Risso | Rutaceae | Fruit | Cultivated |
| | *Persea americana* Mill. | Lauraceae | Fruit | Cultivated |
| | *Simira salvadorensis* (Standl.) Steyerm. | Rubiaceae | Lumber | Mature |
| | *Dialium guianense* (Aubl.) Sandwith | Leguminosae | Posts | Mature |
| | *Swietenia macrophylla* King | Meliaceae | Lumber | Mature |
| | *Luehea speciosa* Willd. | Malvaceae | Lumber | Secondary |
| | *Cordia alliodora* (Ruiz & Pavón) Oken | Boraginaceae | Lumber | Secondary |
| | *Cecropia obtusifolia* Bertol. | Urticaceae | – | Secondary |
| | *Annona reticulata* L. | Annonaceae | Fruit | Cultivated |
| | *Citrus maxima* (Burm.) Merr. | Rutaceae | Fruit | Cultivated |

as firewood and lumber. The remaining 29% of the prairies were exclusively devoted to cattle raising. Furthermore, all farmers interviewed carried out other economic activities outside their grazing units, such as raising pigs, beekeeping, or coffee and fruit production for self-consumption and sale.

All farmers plant *milpa* immediately after initially clearing areas which will later be used as induced prairies; these *milpas* are planted for an average of 2.75 years. The prairies (grazing units) are then used from 20 to 50 years consecutively, with an average of 27 years.

Of all farmers, 86% used fire to establish their prairies, and none used fertilizers; 99% planted *Cynodon plectostachyus*. According to interviewees, *C. plectostachyus* better withstands the dry period, resprouts even under high levels of cattle grazing, is effective in fattening cattle, and may be used in flood-prone areas; 13% of farmers also said they prefer the grasses *Brachiaria brizantha* and *B. humidicola* over *C. plectostachyus*.

With respect to tree management, 91% of farmers stated that trees spontaneously grow in the prairies, and for both groups of grazing units, they said they cut from two to four adult trees per year for firewood, with an average of three per year.

Some farmers promote growth of desired tree species which grow spontaneously by manually clearing weeds around the preferred seedling and juvenile trees. This manual clearing is is carried out by a significantly greater percentage of farmers from group 2 than group 1 ($\chi^2 = 8.96, p = 0.0028$); 92% of farmers from group 2 manually clear around juvenile trees and seedlings on their prairies while only 30% of group 1 do so.

Prairies are maintained using three types of weeding: manual, with herbicide, or mixed (manual reinforced with herbicide). Percentages of farmers that practice each type of weeding differ between groups of grazing units ($\chi^2 = 7.26, p = 0.026$). In grazing units of group 1, 32% of farmers use herbicide or mixed methods, while only 13% weed manually. Meanwhile, in grazing units of group 2, 41% of farmers weed manually and the remaining 14% use mixed methods. Most farmers clear their prairies twice a year; no significant differences were found between groups of grazing units. Furthermore, none of the farmers use fertilizer nor fire - a common

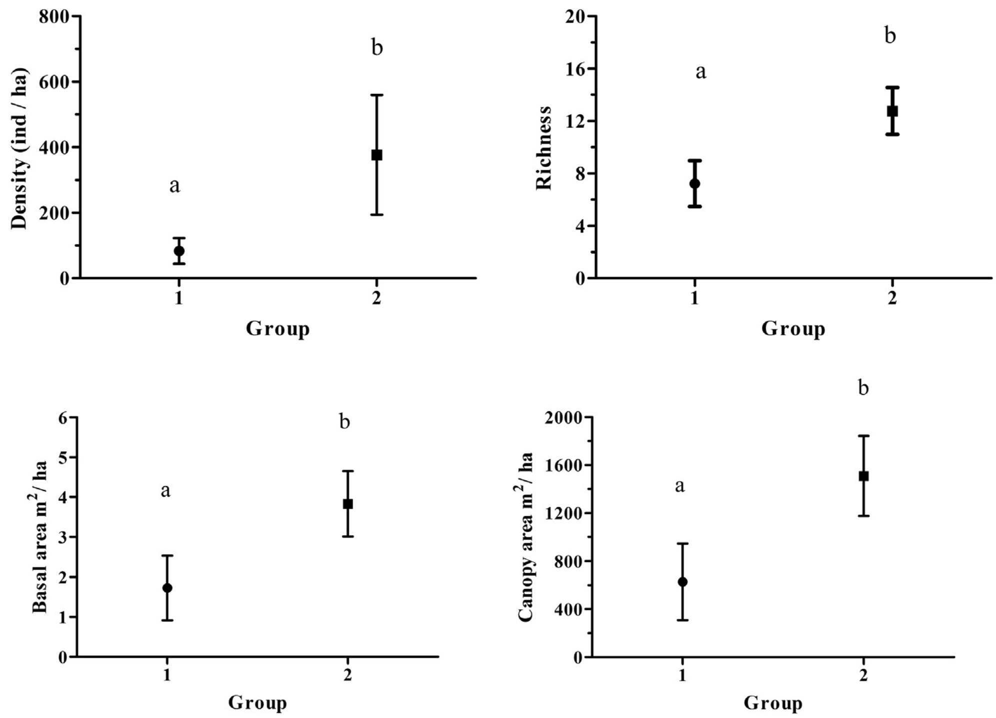


**Fig. 2.** Average values and 95% confidence intervals for the variables total density, total species richness, basal area, and area of canopy cover for two groups of grazing units in the Tulija River Valley. All variables show confidence intervals which are not superimposed between groups. Different letters indicate that the groups differ significantly.

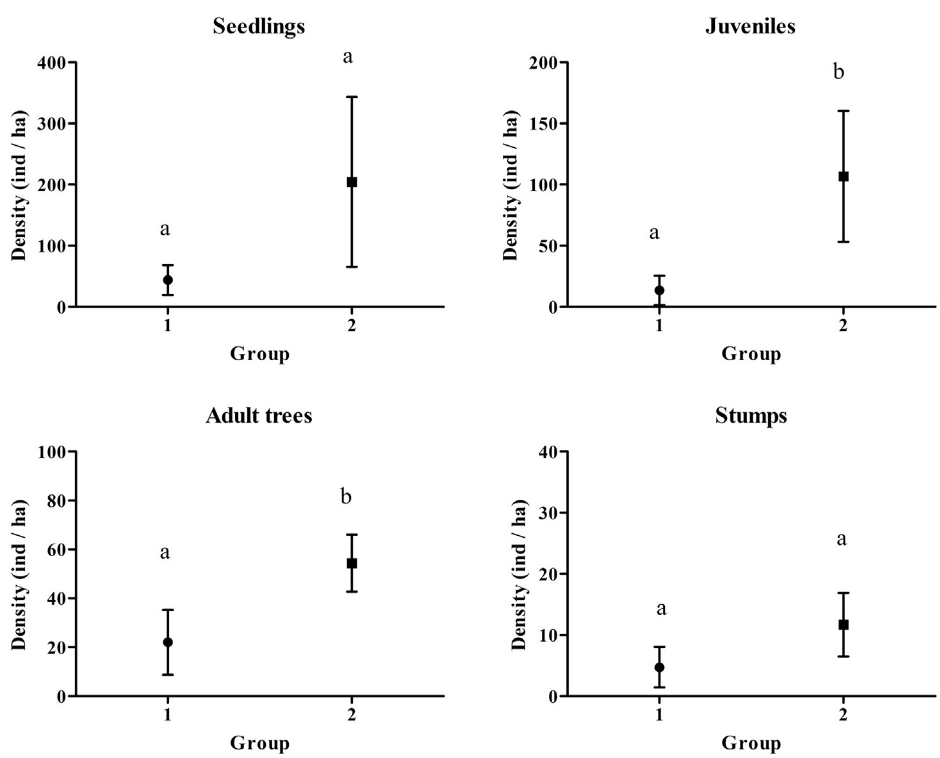


**Fig. 3.** Average values and 95% confidence intervals for tree density for four size classes in each of two groups of grazing units in the Tulija River Valley. Different letters indicate that the groups differ significantly.

agriculture practice in southern Mexico to stimulate regrowth of grasses. Interviewees argue that use of fire deteriorates the prairies, promotes undesirable species, and reduces availability of animal feed.

*3.3.4. Technological and social indicators*

Most cattle raisers in the study area breed and fatten calves or breed calves for sale and posterior fattening in other regions of the country; 73% of farmers combine breeding and fattening of calves,

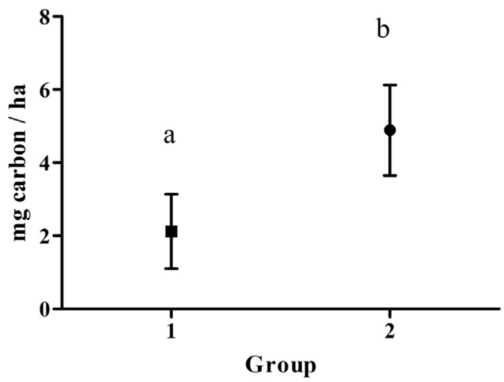


**Fig. 4.** Average values and 95% confidence intervals for fixed carbon (mg/ha) for trees for two groups of grazing units in the Tulija River Valley. Confidence intervals of the two groups are not superimposed. Different letters indicate that the groups differ significantly.

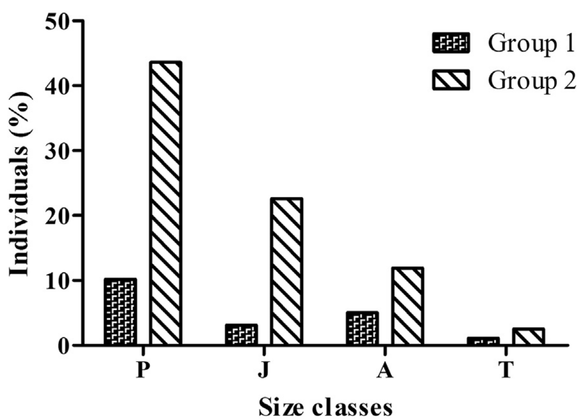


**Fig. 5.** Relative distribution of size classes for naturally regenerated trees for two groups of grazing units in the Tulija River Valley. SD: seedlings; J: juveniles; A: adults; ST: stumps. The distribution of percentages of size classes was significantly different between groups of grazing units ($\chi^2 = 72.95, p < 0.0001$).

and the remaining 27% purchase weaned calves to fatten them in their prairies. Calves are sold at an average weight of 380 kg. Discarded cows and breeding bulls are also sold. Rotation of cattle among pastures did not show significant differences between groups of prairies. On average, farmers rotate the cattle every 33 days; 80% have at least one fence in their cattle raising plot.

On average, farmers of group 1 grazing units have almost twice the prairie surface area as those of group 2 and tend to farm a greater amount of agricultural land (Table 2); 50% of these farmers have purchased land (private property), while the other 50% possess exclusively that land which was assigned to them when the community was settled (*ejido*[1] property). Furthermore, farmers of group 1 tend to produce calves of an older weaning age and greater weight than those of group 2. Group 2 grazing units are used by individual *ejido* members, except one grazing unit which is collectively used ("common used" property). Group 2 farmers have a higher formal educational level, while group 1 farmers' formal education is limited to secondary school (Table 3). All farmers have electricity and running water in their homes; none have automobiles. All farmers belong to a municipal cattle raising association. These organizations gather up cattle from their members and seek out purchasers from other states who pay higher sale prices, and also coordinate sanitary control; however many farmers interviewed feel that the organization to which they belong does not provide them with significant benefits. The principal expenses for animal production are for purchase of calves, vaccines, antibiotics, vitamins, internal and external anti-parasite medicines, feed supplements and paying wage laborers. Sale of cattle provides the principal income for these farm families, who do not receive economic support from government institutions.

## 4. Discussion

### 4.1. Tree vegetation

Chol farmers of the Tulija River Valley in Chiapas, Mexico use at least two different silvopastoral management strategies in their prairies: one with a low density of dispersed trees (LTD strategy) - corresponding to the grazing units of group 1, and the other with a high density of dispersed trees (HTD strategy) corresponding to group 2 grazing units. Average densities of adult trees in grazing units of both strategies identified in this study proved to be greater than those found in studies in the Mexican state of Tabasco by Nahed et al. (2013), who found 12 trees $ha^{-1}$ and in the state of Veracruz where Guevara et al. (1994) found 8.6 trees $ha^{-1}$. However, in both these studies total species richness for trees proved to be greater than the 32 species recorded in the LTD grazing units in the present study. Meanwhile, values for average adult tree density in the HTD grazing units of the current study (54.4 individuals $ha^{-1}$, with 54 species) proved to be greater than those recorded in the nearby region of the Tabasco Sierra, in which 38 trees $ha^{-1}$ belonging to 24 species were found (Grande et al., 2010); they were also greater than those in Costa Rica and Nicaragua, where 10.3 and 32.3 trees $ha^{-1}$ belonging to 72 and 107 species respectively were found (Ibrahim et al., 2006), although in this last study species richness was greater than in the HTD grazing units of the current study. Finally, values for tree density of both strategies were lower than those observed in other studies in the state of Chiapas. For example, Ramirez-Marcial et al. (2012) found grazing units with an average of 71 trees $ha^{-1}$ belonging to 28 species in the Central Depression of Chiapas, and Gómez Castro et al. (2011) found an average of 93 trees $ha^{-1}$ on the coast of Chiapas in young grazing units with remnant vegetation in the process of degradation. Thus, the values for density of adult trees found in the grazing units of the Tulija River Valley fall in the middle of the range of those of other silvopastoral systems in southern Mexico and Central America. Values for species richness of isolated trees in grazing units with the HTD strategy are higher than those of other grazing units in Mexico, but lower than in Central America. Nevertheless, the current study excluded trees in living fences, gardens, forest remnants, and stands of secondary vegetation present in many of the grazing units which provide goods and services to the farmer such as shade for cattle, firewood, lumber, fruit, and fertile land for crop production. Thus, the inclusion of these trees would increase values for density and richness of tree species throughout the system.

Besides the services to farmers already mentioned, trees contribute to cleaner agricultural production and provide services to the ecosystem, such as biodiversity conservation and climate change mitigation through carbon capture and storage in tree biomass (Ibrahim et al., 2000; Murgueitio et al., 2006; Jose, 2009). In the current study, the average level of carbon stored by HTD grazing units (4.89 mg C $ha^{-1}$) was greater than that recorded in silvopastoral systems in Tabasco (3 mg C $ha^{-1}$) (Nahed et al., 2013), and similar to values found for grazing units in the Lacandon region: 5 mg C $ha^{-1}$ (Morales Coutiño, 2010) and 4.23 mg C $ha^{-1}$ (Jiménez Ferrer et al., 2011), but less than that observed in Costa

[1] An *ejido* is a communal landholding within which community members individually possess a specific plot.

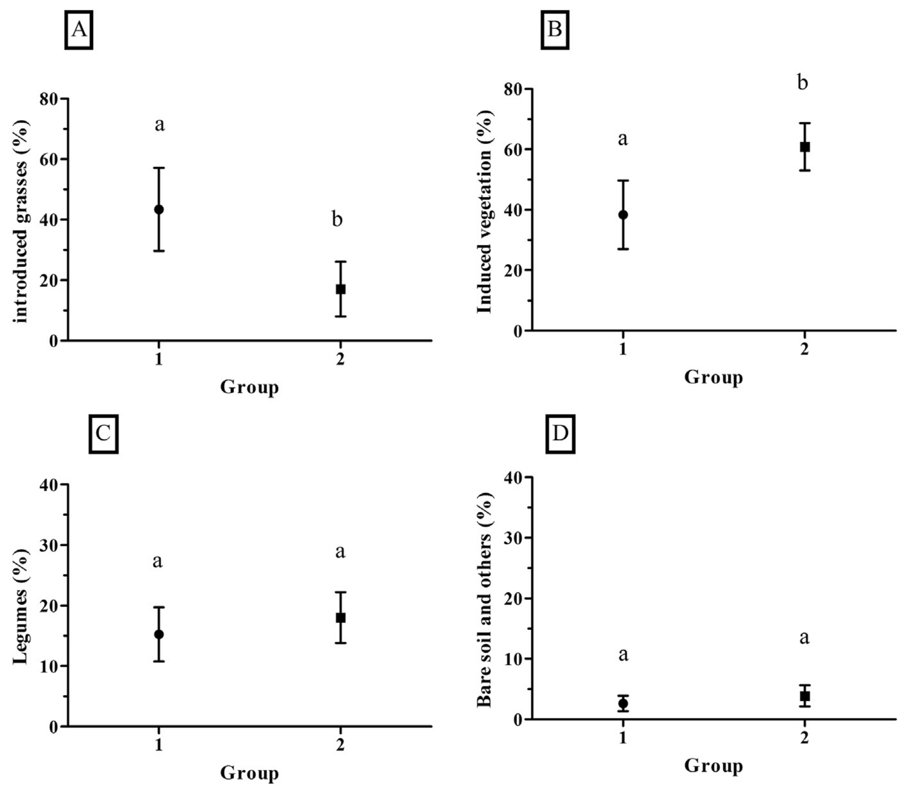


**Fig. 6.** Average cover and 95% confidence intervals for: A) introduced grasses, B) induced vegetation, C) legumes, D) bare soil and others for each of two groups of grazing units in the Tulija River Valley. Different letters indicate that the groups differ significantly.

**Table 2**
Technological indicators for raising cattle in the Tulija River Valley.

| Indicator | Production system | |
|---|---|---|
| | Group 1 | Group 2 |
| N = 22 | 10 | 12 |
| Surface area devoted to cattle raising, ha | 22.4 (±8.9)[a] | 12.2 (±1.3)[a] |
| Surface area devoted to crop agriculture, ha | 3.6 (±3.2) | 2 (±0.47) |
| Herd size, AU | 42.2 (±16.3) | 34.8 (±0.5) |
| Animal load, AU/ha | 2.13 (±0.8) | 2.63 (±0.67) |
| Adult mortality rate | 1.72 (±1.75) | 1.72 (±2) |
| Age at weaning, months | 7.9 (±1.3) | 6.46 (±0.4) |
| Weight at weaning, kg | 207 (±25.5) | 187.3 (±11.3) |
| Length of fattening, months | 12.1 (±3.2) | 11.5 (±0.5) |
| Age of calf at sale, months | 15 (±3.7) | 13.3 (±2.6) |

[a] Different confidence intervals.

**Table 3**
Social indicators of Chol Mayan *ejido* members in the Tulija River Valley. For all variables, differences between groups of prairies were not significant.

| Indicator | Production system | |
|---|---|---|
| | Group 1 | Group 2 |
| N = 22 | 10 | 12 |
| Farmer age, years | 53.2 (±8.9) | 50 (±6.95) |
| Family members, n°. | 5.1 (±1.4) | 4.4 (±1.25) |
| Type of land tenancy, (%) | | |
| - Private property | 50 | 0 |
| - *ejido* property | 50 | 92 |
| - “Common use” property | 0 | 8 |
| Formal educational level, (%) | | |
| - None or primary incomplete | 40 | 25 |
| - Primary | 20 | 42 |
| - Secondary | 40 | 8 |
| - High school | 0 | 17 |
| - University | 0 | 8 |

Rica (11.8 mg C $ha^{-1}$) and Nicaragua (7.5 mg C $ha^{-1}$) (Ibrahim et al., 2006). Carbon values for LTD grazing units (2.12 mg C $ha^{-1}$) were less than those of all the other cases mentioned. With respect to biodiversity conservation, native vegetation species are notably abundant in the grazing units of the current study, particularly species of trees characteristic of mature forest. These components of the conserved ecosystem and the processes associated with them make up part of the “system memory”, which provides it with greater resilience (Gunderson, 2000; Walker et al., 2004). Some of the grazing units studied were established 50 years ago and their cover is in good condition, without signs of degradation and with a notable presence of seedlings of these late tree species. Given the presence of these seedlings, this traditional technology allows for succession and continual replacement of adult trees which are annually harvested, unlike that which occurs in the degraded pastures of the Lacandon region (Levy et al., unpublished results; Román et al., 2011); thus, these farmers avoid fire in their prairies and continually manually weed in order to maintain the desired tree density in their pasture. A majority of species recorded in this study belong to mature as well as secondary native vegetation, and probably their reproductive structures continue to be reproduced in stands of secondary vegetation (fallow areas, coastal vegetation) and remains of mature forest which coexist with the prairies in the grazing units. In in the Lacandon region, in comparison with treeless prairies, a greater availability of reproductive structures of native species have been found in pastures with remains of mature vegetation and isolated trees (García-Orth, 2008), which in turn attract dispersers (Esquivel et al., 2009). Other silvopastoral systems in southern Mexico contain some of the species recorded in this study, such as *Spondias mombin, Tabebuia rosea, Guazuma* *ulmifolia, Blepharidium mexicanun,* and *Enterolobium cyclocarpum*, which belong to secondary vegetation, and *Acosmium panamense* and *Swietenia macrophylla* which belong to mature vegetation, but also species which may belong to either of these vegetation types, such as *Byrsonima crassifolia, Gliricidia sepium, Genipa americana*, and *Zuelania guidonia* (Grande et al., 2010; Nahed et al., 2013; Ramirez-Marcial et al., 2012).

#### 4.1.1. Uses of the tree species

Chol Mayan farmers who use either of the grazing unit management strategies described above are familiar with and utilize the tree species in a similar manner. Types of use identified are similar to those of other silvopastoral systems in Mexico, but unlike in those systems, Tulija farmers do not directly use foliage of fodder tree species present in their grazing units to supplement cattle feed (Gomez-Castro et al., 2011; Palma, 2011; Ramirez-Marcial et al., 2012). This use could be unnecessary due to favorable conditions of the prairie even during the dry season, but it also may be undesirable to retard tree development given the importance of their other uses for the farmers. The variety of products obtained from the prairies, added to those from the gardens, maize fields, coffee fields, raising of small animal species, etc., covers a large part of the farm families' needs, whether for self-consumption, sale, or exchange with other families (Lerner-Martínez, 2008).

### 4.2. Herbaceous vegetation

The difference in herbaceous vegetation observed between the grazing units of each strategy appears to be inconsistent with the fact that the majority of interviewees assured that they have planted *C. plectostachyus* and/or other grasses introduced upon establishing the prairies. However, unlike the LTD grazing units, in the HTD units native grasses ended up being the dominant ones. In the LTD units, the low tree density allowed introduced grasses to better prosper, especially *C. plectostachyus* which is not very shade tolerant (Nahed et al., 2013). A similar phenomena was observed in grazing units in Tabasco, in which the presence of a majority of native grasses (*Paspalum* spp., *Axonopus* spp.) was attributed to their greater capacity to tolerate the shade of trees, unlike that which occurs with introduced grasses (Nahed et al., 2013). Frequent burning of the prairies impedes natural repopulation of tree species of mature successional stages, but also destroys native grasses which lack adaptations to fire, as they are species which colonize forest patches which are constantly disturbed, such as paths.

### 4.3. Strategies for maintaining grazing units

Farmers using the LTD strategy eliminate undesirable trees during their early stages of growth by using chemicals, as the low percentage of juveniles observed in these grazing units indicates. Furthermore, it is possible that seedlings of tree species do not reach the juvenile stage due to strong direct competition exercised by exotic grasses which are predominant in these prairies (Benítez-Malvido et al., 2001). Farmers using the HTD strategy foster spontaneous repopulation of desirable tree species in their prairies according to their needs and knowledge; for this reason they avoid fire, rather clearing manually around selected tree seedlings. This practice has been observed in traditional silvopastoral systems in the neighboring state of Tabasco (Grande and Maldonado, 2011; Nahed et al., 2013) and results in the presence of a large quantity of seedlings and juveniles, generating a size class structure similar to that of naturally growing populations (Silvertown, 1987). This type of population structure was also recorded in silvopastoral systems in the Central Depression of Chiapas (Ramirez-Marcial et al., 2012) and in Nicaragua (Esquivel et al., 2008).

With respect to technological and social indicators of the system, prairies of both groups support the same animal load (animal units/ha), but animals in the LTD grazing units feed to a greater extent on introduced grasses; therefore, we would expect to observe a greater weight and/or lesser age at weaning of the calves, a lesser duration of fattening, and a lower of the age of sale of the calves. This was observed as a tendency, but no significant differences were found for the values for these attributes between the two groups, which could indicate that the LTD prairies are being underutilized, that the HTD prairies are more productive due to the nitrogen contribution of tree and herbaceous legumes and that their production is more homogenous throughout the year, or that we were not able to detect differences due to the wide variability of the data and low number of interviewees. Values for animal load, along with other technological indicators evaluated in this study, are similar to those found in silvopastoral systems in the region of the Lacandon Jungle in Chiapas (2.7 AU 7 $ha^{-1}$) (Jiménez Ferrer et al., 2011), and in Huitiupan, Chiapas (2.2 AU $ha^{-1}$) (Nahed et al., 2013).

The HTD strategy includes more traditional aspects of prairie management, such as selective fomenting and use of native trees, despite the greater formal educational level of the farmers using this strategy, most of whom have a high school or university education, while those using the LTD strategy have only a secondary education. All farmers recognized the need to acquire further knowledge regarding cattle production in order to confront a variety of difficulties, as they have received very little technical training from government agencies or academic institutions.

It is worth mentioning that intensive agricultural systems commonly use irrigation in order to sustain high productivity. However, inadequate irrigation management often results in waterlogging, salinity, and inequitable distribution of groundwater among inhabitants due to use of electric pumps, which are increasingly more frequent worldwide (Valipour, 2014a, 2014b; Yannopoulos et al., 2015). In the system studied, and in general in this region of Chiapas, irrigation is not used, as only rain water is needed for the prairies, and thus energy use is greatly reduced and associated problems are avoided. In a global context which foresees a strong increase in pressure on water resources due to irrigation, this type of agricultural water management is critical (Valipour, 2014c; Valipour et al., 2014).

The Chol Mayan silvopastoral system of the Tulija River Valley - in particular the HTD strategy developed by a group of these farmers - has many attributes which concord with sustainable agriculture, and thus reduces the vulnerability of their communities in the face of economic, social, and ecological changes as compared to local conventional cattle raising systems. For example, there is no contamination by fertilizers; and the high number of trees contributes to mitigation of greenhouse gases. Although the farmers have lacked external advisory, they have developed their own strategies. In order to complement the results, future studies should incorporate information regarding trees in living fences, gardens, forest remnants, and stands of secondary vegetation, with the purpose to obtain a more precise tree density and estimate landscape connectivity. Furthermore it is relevant to study and compare soil characteristics in the grazing units of the two strategies. However, we believe there is a need for outreach regarding the technologies presented here as these simple diversified livestock management practices allow for maintaining trees in farm plots without hindering agricultural production. These finding applies to many states of Mexico and other tropical nations. Diffusion of these practices in other regions of Chiapas, such as the Lacandon region, could positively impact the economy of conventional cattle raisers while at the same time generating environmental services.

## 5. Conclusions

The Chol Mayans of two communities of the Tulija River Valley in the municipality of Salto de Agua practice at least two strategies of silvopastoral cattle management. These strategies differ with respect to density, basal area, canopy area, and floristic composition of the dispersed trees in the prairies, composition of herbaceous vegetation, and farmers' techniques of clearing and promoting trees in the grazing units.

Management of prairies with high tree densities is based on traditional Chol Mayan agricultural technology - particularly inducing a predominance of native grasses along with manual clearing, fire suppression, and fomenting seedlings and juveniles of useful tree species, all of which promote repopulation and replacement of harvested trees. The resulting high tree density does not negatively affect cattle production.

The tree vegetation is abundant, not only as isolated trees in their grazing units but also in other agricultural plots, fallow areas, and river or remnant vegetation – as well as in living fences. This results in greater benefits for the farmer - such as lumber for construction, fenceposts, firewood, and shade, as well as for the ecosystem - such as carbon storage and conservation of species characteristic of the original vegetation.

For these reasons, the HTD management strategy by a group of small-scale Chol Mayan farmers has many attributes which concord with sustainable agriculture.

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