The effect of Maya traditional harvesting on the leaf production, and demographic parameters of *Sabal* palm in the Yucatán Peninsula, Mexico

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**A B S T R A C T**

Palm leaves are an important resource for family households. The effect of harvest on leaf production, growth and fecundity of wild individual palm trees has been studied, but little is known about palm harvest in agro-forestry systems. In the Maya area of the Yucatán Peninsula, Mexico, leaves of the xa’an palm (*Sabal yapa*, and *Sabal mexicana*) have been used since pre-Hispanic days for thatching the roofs of traditional Maya houses. The Maya have introduced xa’an palms in homegardens and the care they provide them improves their growth. Maya householders agree on what they consider to be the best harvest intensity for xa’an, recommending one or two harvest events per year, and leaving one or two leaves in each event; however, there is not ecological information documenting whether the traditional harvesting practices are the most adequate to maintain or increase leaf production, and their effect on the growth and fecundity of the palm trees. In Maxcanú, Yucatán, we studied eight family homegardens with *S. yapa* and *S. mexicana*. The selected individuals from each homegarden (*n* = 252) underwent six harvest treatments for 2 years: C: control, no harvest; A1: annual harvest, leaving three leaves on the palm; A: annual harvest leaving two leaves, Ah: annual harvest leaving one leaf, Sl: two harvests per year leaving three leaves, Sm: two harvests per year leaving two leaves. Treatments Ah and Sm simulated the traditional harvest method, and the remaining treatments simulated higher or lower harvest intensities and frequencies. Leaf production was higher in individual palms under higher harvest intensities and frequencies (Ah, Sl and Sm), but palm growth and leaf size were not affected by harvest. Number of inflorescences per palm differed between treatments and between homegardens during the first year only, but we could not find a clear pattern of variation. Production of new leaves was affected by initial palm size and initial leaf number. Removing mature leaves while leaving the young ones, as well as the intensity and frequency, with which traditional harvest is practiced, stimulate palms to compensate the defoliation effects by producing new leaves. This practice is based on empirical Maya knowledge that enables the manipulation of micro-environmental conditions and the development of sustainable harvesting strategies for the xa’an palm in traditional agro-forestry systems.

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1. Introduction

Palms are important non-timber forest products (NTFP) in most tropical regions of the world (Balick and Beck, 1990; Khan and De Granville, 1992; Pedersen and Balslev, 1992). Arecaceae is among the plant families with the largest number of useful species, providing food, medicine, household utensils, and handicrafts (Balick, 1988; Balick and Beck, 1990; Khan and De Granville, 1992; Pedersen and Balslev, 1992), and also constitute an important part of incomes for rural households (Hodel, 1992).

Palm leaves are frequently used in the construction of house roofs (Caballero, 1994; Ratsirarson et al., 1996; Zuidema and Werger, 2000a). In the Yucatán Peninsula, leaves of the xa’an palm (*Sabal yapa* Wright ex Becc., and *Sabal mexicana* Mart., Arecaceae) are used for this purpose by the Maya people (Caballero, 1994). In some regions, palm leaves are extracted from the natural vegetation (Pulido and Caballero, 2006), but reduction in size of natural areas has led to introduce *Sabal* palms in managed systems such as homegardens (Caballero, 1994).

There is a consensus among farmers throughout the Maya area of Yucatán regarding the harvesting regime of *xa’an* palm leaves (Gama, 2001). Traditionally, only mature leaves are cut from...

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individuals with stems 5 m height or less, and at least one, or preferably two, mature leaves are left remaining on the palm along with the new unfolding leaf (cogollo). Harvest takes place once or twice per year, never more, depending on household demands. Individual palm trees are never felled to make the harvest easier. Some studies document cases of over-exploitation of palm leaves (O’Brien and Kinnaird, 1996) or the felling of complete individuals to ease leaf harvest (Peters et al., 1989; Vásquez and Gentry, 1989; Pedersen and Balslev, 1992), but in general, leaf extraction experiments in natural vegetation show positive effects on the palm plant (Mendoza et al., 1987; Oyama and Mendoza, 1990; O’Brien and Kinnaird, 1996; Zuidema and Weger, 2000b). The extraction of palm leaves, therefore, has been documented to be a sustainable activity throughout time (Nations, 1992; Reining and Heinzman, 1992; Pulido and Caballero, 2006).

Pals from natural vegetation are highly tolerant to defoliation (Zuidema and Weger, 2000b) although the effect of the intensity and frequency of defoliation on leaf production varies between palm species. Common understory species such as Geonoma deversa and Astrocarum mexicanum do not appear to completely compensate the effect of defoliation, the production of new leaves diminishes when 100% of the leaves are frequently removed (Mendoza et al., 1987; Zuidema and Weger, 2000b). Other species such as Chamaedorea radicans and Livingstonia rotundifolia increase leaf production proportionally to the extraction rate, although leaf size decreases (O’Brien and Kinnaird, 1996; Endress et al., 2004). Growth, survival, and flower and fruit production are affected by harvesting in Chamaedorea tepejilote, C. radic. ius and Sabal uresana (Oyama and Mendoza, 1990; Joyal, 1996; Endress et al., 2004). In general, low light availability below the forest canopy and intense leaf extraction seem to negatively affect the production of new leaves and the palm’s vital rates (O’Brien and Kinnaird, 1996; Svenning and Macías, 2002; Endress et al., 2004).

Several authors have suggested that species managed in natural vegetation may be introduced into agro-forestry systems to increase leaf production, encouraging their sustainable use (Svenning and Macías, 2002). Nevertheless, the harvest of cultivated palm leaves has been overlooked. In these systems, palms occur under different conditions than those thriving in the forest understory, so their response to defoliation could be different from the one observed in the wild populations. Xa’an palms in the Yucatán peninsula have been exploited since pre-Hispanic times and their introduction to family homegardens during the Spanish colonial period has enabled peasants to manipulate their populations (Caballero, 1994) and sustain their population growth (Martínez-Ballesté et al., 2005). Traditional harvest practices have been the result of empirical learning socially shared and transmitted from one generation to the next.

Previous results show that various management practices used in homegardens (such as seedling protection, occasional seeding and watering) favor the sustainability of Sabal populations and increase the numbers of palms with stem-sizes appropriate for harvesting leaves (Martínez-Ballesté et al., 2005). However, it had not evaluated whether the harvest intensity recommended by Maya farmers is the most appropriate one to increase or maintain leaf yield or if other defoliation intensities would be better. In this study we conducted such evaluation, which was considered to be important because, in addition to the local traditional use, xa’an leaves are commercialized in other regions of Yucatán Peninsula to roof buildings of tourist resorts along México’s Caribbean coasts.

Despite the commercial demand of leaves has markedly increased (Caballero et al., 2004), the harvest strategies remain the same in the entire Peninsula. Thus, our results could contribute to design an appropriate strategy to face the new pressures that have been set on leaf extraction. Our specific questions were: (1) are traditional Maya harvest practices the most appropriate for sustainable leaf production in homegardens? and (2) what is the impact of different defoliation intensities on growth, fecundity, and new leaf production in the palms growing in homegardens?

2. Methods

2.1. Study site and species description

A defoliation experiment was carried out in the town of Maxcanú, Yucatán, Mexico, in homegardens where S. mexicana and S. yapa were managed. In these agro-forestry systems, palms are combined with a great variety of wild and cultivated trees and bushes (Caballero, 1992). Various management practices, such as watering and weeding, are carried out by local people to foster the growth of promoted species.

After having obtained permission from the Maya farmers, a defoliation experiment was conducted in eight homegardens. Six of them had both species and two had only S. mexicana. The eight homegardens had at least one building with palm roof, which indicates that Sabal leaves were still in use. All selected individuals of both Sabal species in the homegardens showed evidence to have been harvested. Some of the households had a higher palm tree species density than others, and therefore a great variation in the intensity of solar radiation was found. We observed irrigation practices in only one garden and a very high weed density in two others. Soil, according to Maya classification (Aguíl. era, 1958), was black (lithosol) in seven homegardens and one had red soil (rendzina).

Pals of the genus Sabal are hermaphrodite, 15–20 m tall, with single trunks, fan-shaped leaves, and inflorescences approximately 3 m long produced between January and March. S. mexicana is more robust than S. yapa, even though the reproductive structures are similar (Quero, 1992). S. yapa is the most widely distributed species in the Yucatán Peninsula, a common element in primary forests and secondary vegetation in the central and northern part of the Peninsula. It is found in agro-forestry systems such as pasturelands, corn fields (milpas) and homegardens (Zona, 1990; Caballero, 1994). S. mexicana is also widely distributed in Mexico, although in the central and northern parts of the Yucatán Peninsula it is only found cultivated in homegardens.

2.2. Experimental defoliation

The defoliation experiment lasted from July 2000 to July 2002. Taking into account traditional harvest strategies, we considered three factors in the experimental design.

(a) Plant size: We included only harvestable-sized individuals in the experiment. Since annual leaf production depends on plant height (Martínez-Ballesté, 2006) we stratified the sampling procedure, selecting six individuals from each of three categories: 1–100 cm, 101–200 cm, and 201–500 cm.

(b) Harvest intensity: We applied three harvest intensities: h: high, with only one leaf remaining after harvest, m: medium, with two leaves remaining and l: low, with three leaves remaining. In every case the unfolding leaf bud called “cogollo” was left intact.

(c) Harvest frequency: A: annual, and S: semestral.

We also included a control (C) that was not harvested (Table 1). Treatments Ah and Sm corresponded to the traditional harvest method and the remaining treatments simulated higher or lower harvest intensities and frequencies. A treatment consisting of two annual harvests with only one leaf remaining on the palm (Sh) was
not included since the farmers did not allow this level of extraction considering that their palms would die.

Palm height was annually measured at the base of the apical meristem for 2 years, and the number of inflorescences produced by reproductive individuals was counted. In both species of Sabal, palms produce flowers after they have reached 3 m in height, so we only counted the inflorescences in palms surpassing this height. We found a high correlation in the initial leaf sample, between the length of the leaf and the width of the hastula ($r = 0.81$ for S. mexicana and $r = 0.71$ for S. yapa). Since it was extremely difficult to measure leaf length in standing leaves of large palms, in order to estimate their size in the last census we only measured the width of the hastula in the leaves of each marked individual.

We used an experimental design of random blocks with each homegarden conforming a block; this allowed us to control the variation between sites and diminish the experimental error. An individual of each size category was randomly assigned to each of the six treatments per homegarden. This was done with each species separately. The landowners were paid the value of the leaves of those palms so that, during the 2 years the study lasted, we were the only ones harvesting them.

In order to evaluate the effect of the different treatments on leaf production, individual growth, inflorescence production, and leaf length, we used generalized linear models (GLM). GLMs recognize that different probabilistic distributions of the exponential family appropriately represent data of different nature. The linearization of the model is achieved by using different transformations known as link functions. Because new leaf and inflorescence production are counting data, a log-linear model is appropriate because it assumes a Poisson error type and uses a log link function. Palm growth, measured as a yearly increase in height, was analyzed using a reciprocal transformation and a gamma error distribution. This model is appropriate because there was no homoscedasticity but the coefficient of variation was approximately constant. Finally, data on leaf length were analyzed through an ANOVA (normal error and identity link function; Crawley, 1993). Except for the log-linear model used to evaluate inflorescence production, the homegarden (block) was not a significant variable and was therefore excluded from the analyses.

We initially fitted a model that included species, treatment, homegarden (considered as categorical variables), initial stature and initial number of leaves (considered as continuous variables), and their interactions as explanatory variables. We then simplified the model by eliminating non-significant terms in order to obtain the minimal appropriate model. When a categorical variable becomes significant, the data in different pairs of levels of that variable were pooled in order to assess if there were significant differences between them (Crawley, 1993). All the analyses were conducted by using GLIM 4.0. Because all reproductive individuals had similar size, we did not include initial height as an explanatory variable when analyzing inflorescence production.

### 3. Results

We found no differences in leaf production between treatments during the first year of the study ($\chi^2 = 6.78$, $p = 0.2375$), but there were significant differences during the second year ($\chi^2 = 27.86$, $p < 0.0001$; Fig. 1). There were no differences in leaf production in treatments Ah, Sl and Sm of the two species studied, treatments in which most of the leaves were produced. However, treatments Al and Am were significantly different from the rest, showing the least leaf production. The control treatment was significantly different to all experimental treatments, showing an intermediate level of leaf production (Fig. 1). Individual plants of S. mexicana produced significantly more leaves than those of S. yapa ($\chi^2 = 3.86$, $p = 0.0494$; Fig. 1).

The individual palms that had more leaves when the experiment started produced more leaves per year than those that had a smaller initial leaf number ($\chi^2 = 40.76$, $p < 0.0001$). Also, taller individuals produced more leaves ($\chi^2 = 39.61$, $p < 0.0001$). The interaction of these two variables was also significant ($\chi^2 = 13.60$, $p = 0.0002$). The initial number of leaves had a larger effect on smaller palms than on the taller ones (Fig. 2). There were no

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**Table 1**

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<td>Sm</td>
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**Fig. 1.** Leaf production per individual under each treatment (mean ± S.E.) for S. mexicana (grey) and S. yapa (white), during the second year of study. Treatments were: C: control plants, Al: annual harvest with three leaves left on the palm, Am: annual harvest with two leaves left on the palm, Ah: annual harvest with one leaf left on the palm, Sl: two harvests per year with three leaves left on the palm, Sm: two harvests per year with two leaves left on the palm.

**Fig. 2.** Annual leaf production in individuals of (a) S. mexicana and (b) S. yapa, considering palm height and leaf number at the beginning of the experiment.
significant interactions between initial height, leaf number and defoliation treatments.

The inflorescence production per reproductive individual was significantly different between treatments ($\chi^2 = 4.45, p = 0.0347$) and between homegardens ($\chi^2 = 22.05, p < 0.0001$) only during the first year. In treatments C, Am and SI, there were no differences between palms, and they produced more inflorescences than the palms under treatments Al, Ah and Sm. These last treatments did not differ in fecundity. There were no differences in inflorescence production between species. None of the harvest treatments have significant effects on palm growth or leaf size.

4. Discussion

Traditional harvest practices used by Maya farmers (Ah and Sm treatments) were found to be the most appropriate ones in terms of leaf production. These treatments, frequently recommended by local people for harvesting leaves of the two Sabal species studied, produced a higher number of leaves than treatments with lower levels of extraction. After 2 years under the same harvest regime, the most frequently and intensely harvested palms produced more leaves. One of the compensation mechanisms with which plants reduce the impact of defoliation is the activation of leaf meristems and increased leaf production (Oesterheld and McNaughton, 1991; Trumble et al., 1995), which seems to occur in the palm species studied. This compensation mechanism may be possible because defoliation decreases self-shading, allowing for a larger production of photosynthates that may then be allocated to leaf production (Gold and Caldwell, 1990; Anten and Ackery, 2001).

Adequate carbon balance in plants not only depends on the available leaf area, but also on leaf replacement (Chabot and Hicks, 1982). Maya farmers harvest first the old leaves of Sabal palms, leaving the youngest ones on the palm. Young leaves have a greater photosynthetic capacity than the old ones (Bazzaz, 1996), so the removal of old leaves could be a good harvest strategy if the youngest ones can maintain the new leaf production. This could be related with Sabal’s high tolerance to defoliation. If we assume that variations in soil, plant cover, or irrigation within parcels, were not factors determining the initial differences in the number of leaves per palm (which seems reasonable since homegardens did not have a significant effect on leaf production), then these differences should be the consequence of previous harvest events. Palms with fewer leaves were those that had been exposed to more intense defoliation. The observed pattern of a greater leaf production in individuals with more leaves before the beginning the experiment (Fig. 2), may be explained if the palm’s capacity to produce new leaves is diminished when its leaf tissue has been reduced by previous harvest events (Fig. 2). Reports of other palm species indicate that the compensation capacity is reduced by intense or recurrent defoliation when energy and nutrient reserves are depleted (Joyal, 1996; Flores and Ashton, 2000). It is known that an important proportion of products of photosynthesis are stored in leaves (Chabot and Hicks, 1982), which means that defoliation directly diminishes the plant reserves and, consequently, its compensation capacity. The fact that this effect was more evident in small palms than in the large ones (Fig. 2) suggests that the reserves the small individuals depend on are particularly scarce (Joyal, 1996).

It was not possible to test more intense defoliation treatments, such as the removal of all leaves, or leaving only one leaf in a semestral harvest (Sh). Nevertheless, Maya farmers mentioned that the palm produces less leaves or can die when only the cogollo is left and all leaves are removed. Results of a demographic study with S. yapa (Martinez-Ballesté et al., 2005) indicate a decrease in population growth rates due to excessive harvest (removal of all the leaves or even the cogollo) in a homegarden. This information suggests that, as in other palm species (Mendoza et al., 1987; Oyama and Mendoza, 1990; Joyal, 1996; Flores and Ashton, 2000; Zuidema and Werger, 2000b), production in Sabal could decrease if all leaves are harvested.

Even though palm growth rate is frequently correlated with leaf replacement rates (Ackery, 1997; Reich et al., 1992; O’Brien and Kannirad, 1996; Joyal, 1996; Flores and Ashton, 2000; Zuidema and Werger, 2000b), in the species of Sabal palms studied, an increase in leaf production as a result of intensified harvesting was not related to a height increase. Maya householders mentioned that continuous harvest reduces palm growth, and in this way the palms remain at a size that makes easier the leaf harvest. It is known that in species like Chamaedorea elegans, growth associated to defoliation diminishes when there is low light availability (Anten et al., 2003). This could be the situation in some of the homegardens in which the canopy was denser. However, it is still unclear why in Sabal, increased leaf production did not cause increasing growth, as we did not observe any differences in leaf size that could reflect reduced internode lengths.

Various studies have shown a negative correlation between defoliation levels and production of reproductive structures (Lee and Bazzaz, 1980; Clark and Clark, 1988; Ataroff and Schwarzkopf, 1992; Ackery et al., 2000; Flores and Ashton, 2000; Endress et al., 2004). Species like Chamaedorea elegans compensate the effect of defoliation assigning greater biomass to leaf blades than to reproductive structures (Anten et al., 2003). The harvest treatments during the first year of our experiment had a significant effect on the production of inflorescences in Sabal, but not during the second year. Treatments with the highest defoliation intensity (Ah and Sm) produced less inflorescences but not significantly different to those treatments under the least defoliation (Al); therefore, the relation between defoliation and production of reproductive structures was not clear. Our statistical analysis showed that homegardens had a much more important effect on inflorescence production during the first year. The specific conditions of each garden and the availability of resources such as light, water and nutrients within these spaces could have a greater effect than defoliation on inflorescence production. In future research, it would be important to obtain information about these parameters to evaluate their impact on the reproduction of these palms.

The results of this study show that harvest strategies used by Maya farmers can maintain the largest leaf production rate without affecting growth, leaf size, and possibly, individual reproduction. Other species of palms harvested in tropical areas not always maintain a sustainable leaf production (Zuidema and Werger, 2000a; Svenning and Macías, 2002; Endress et al., 2004). Shaded conditions under the forest canopy (O’Brien and Kannirad, 1996), immature palm harvest, or very intensive or destructive harvest of the entire individual to obtain leaves (Svenning and Macías, 2002) are seemingly the causes. In the cases of Sabal studied, their introduction into homegardens has assured the availability of the resource as a result of closer control of environmental conditions (Caballero, 1994; Martinez-Ballesté et al., 2005). On the other hand, the cultural and economic importance this resource has had in the Maya culture since pre-Hispanic days (Martinez-Ballesté et al., 2006) has favored the empirical development of harvest practices which, according to the experiments of this study, not only do not have a negative effect on palm growth and reproduction but encourage leaf production. The development of management strategies in agro-forestry systems such as homegardens, and the associated traditional ecological knowledge – at least with these two species – have been the basis of regimes of sustainable harvest of the palm species studied.
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References


Quero, H., 1992. Las Palmas Silvestres de la Peninsula de Yucatan, Instituto de Biología, Universidad Nacional Autonoma de Mexico, Mexico, 63 pp.


