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Studies on the productivity of *Brosimum alicastrum* a tropical tree used for animal feed in the Yucatan Peninsula

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Abstract

Results on the productivity of *Brosimum alicastrum* grown in Yucatán are reported. Forage production from the pruning of trees with stem perimeters between 80 and 205 cm and an estimated height of 14.4 m was an average of 163.3 kg per tree per year. Seed production of 30 year-old trees was 95.5 kg per tree per year. This specie presents two fruiting seasons a year when there is no water restriction; the first from March to April and the second from August to September. If sufficient water is not available in the dry season, the tree will only flower during the summer. One kilogram contains an average of 323 seeds. Seed weight ranged from 2.0 to 5.0 g, with 37.15 % weighing between 2.6 and 3.1 g. The trees studied herein showed an average of 29 fruits per branch. Aborted inflorescences and fruits were quantified. It was found that the number of aborted inflorescences during the months of August-September averaged 9384 in 12 year-old trees. Data are discussed in relation to its importance for food production in the tropics.

Keywords: Bioproductivity, *Brosimum alicastrum*, growth, seed production.

Introduction

Brosimum alicastrum has been described as an underexploited species with significant potential (National Academy of Sciences, 1975). This tree is native to the Mesoamerican region and the Caribbean, inhabiting warm, semi warm, tropical and mild climates, from 10 to 1600 meters above sea level and grows in the wild in association with a variety of vegetation (Conabio-Conafor, 2013; Pardo-Tejeda et al. 1976). In the Yucatan Peninsula, it can reach heights of 15-22 m Durán et al. (2000)**.** The common name for *Brosimum alicastrum* in Yucatan is *Ramón*, (Ramón or breadnut tree in English) deriving from the Spanish word *ramonear* (to forage or browse) in reference to its consumption by cattle, which find it particularly palatable. Other environmental services mentioned for this species, besides its nutritional potential, include protection of soil and water bodies, conservation of biodiversity and the fact that it shows promise for restoration purposes. In the northern part of Yucatan, where there is practically no soil, *Brosimum* is one of the few forest species that actually thrive.

Studies focused on the pattern of carbon dioxide fixation and transpiration in this tree and have defined it as a C_3 type plant, with a maximum fixation of 5 µmol m^2s^1 at 500 µmol m^2s^1 of light, and that its water use efficiency ranges between 0.55 and 1.55 µmol/mmol^{-1} depending on the time of day (Hernández-González et al. unpublished). Results have, demonstrated that this plant species thrives for the first seven years with a high growth rate of 65 cm during the first year, reaching 75 cm over the subsequent five years, when established in commercial plantations totally exposed to existing high radiation. The juvenile stage of these trees ends at seven years, the age at which they begin to flower Hernández-González, et al.; In press)

One important environmental service provided by this tree in the Yucatán peninsula, as mentioned above, is the use of its foliage as forage for cattle, goats and horses, during the summer. The aim of the present study was to obtain information of its productivity.

Materials and Methods

2.1. Study areas. Plant studies were conducted on three sites in northern Yucatan: 1.- Xoccheila Hacienda in the municipality of Sacalum, Yucatán (20° 33' N; 89° 34' W). 2.- The town of Sacalum, Yucatan (20° 25' N; 89° 33' W). 3.- The Center of Scientific Research of Yucatan in the city of Merida, Yucatán (21º 1' N; -89º 38' W), in México.

2.2. Biomass production. Annual biomass formation (branches and leaves) was estimated in trees located at Sacalum, Yucatan with heights between 13 and 15 meters and aged 30 years or over. These trees are continually pruned year after year to provide forage for cattle.

The trees had been pruned 12-13 months prior to their selection and for the purposes of this study they were pruned manually using a machete or *coa* (long-handled sickle). All the branches and leaves were weighed using a regular weighing machine (fresh weight). Trunk perimeter at chest height and tree height were measured with a measuring tape.

2.3. Seed production per tree. Seed production for an annual cycle was evaluated in two female trees of *B. alicastrum* of approximately 30 years growing in the city of Mérida. Plastic mesh neeting was placed around the trees to collect fruits and seeds. The pericarp of the fruits is regularly consumed by bats, birds, etc., while the seed is left intact and can be collected. In this study, the pericarp of the small number of fruits collected was removed and the remaining seeds were weighed (fresh weight) on a weighing scale (Sartorius, BL3100, USA). The number of seeds in one kilogram was counted and the unitary weight was estimated in order to chart weight distribution.

2.4. Seed production per branch. To estimate seed production per branch, ten adjacent branches were selected from the trees mentioned above with a length of 2.0 to 2.5 m at a height of 2 meters from ground level or above. The branches were marked and the fruits counted before they reached physiological maturity.

2.5. Aborted inflorescences and immature fruits. Two adjacent trees, approximately 10 years of age, were selected to harvest aborted inflorescences and immature fruits. Plastic mesh netting was placed around the trees and left throughout the flowering period and initiation of fruiting. Harvesting and counting of inflorescences and immature fruits were carried out manually.

2.6. Statistical analyses. A correlation analysis was performed between biomass production and diameter of *B. alicastrum*. A principal components analysis was carried out to establish a pattern between height, biomass production and diameter of *B. alicastrum*. A *t* test was also conducted to compare seed production in autumn and spring. The data were analyzed using the Statistica 7 (Statsoft, Tulsa, Oklahoma, USA).

Results

Climatic data were collected and as resume it can be pointed out that average annual precipitation for the period 2010-2012 was 869.4 mm, with significant variations from one year to another; highest precipitation was from June to September of 2011. The mean temperature for the three years was 23°C, with the highest values up to 37°C in April and May of 2011, while the average annual relative humidity for the same period was 80%. Thus, the region can be classified as warm sub-humid with summer rains. The trees used during the present study grew up in soils that belong to the group of Leptosols very rocky with underlying stones.

3.1. Biomass productivity. Biomass production in Ramón trees of Sacalum varied depending on the height and diameter of each individual shows. The average production of the ten trees under study was 163.3 kg per tree (Table 1). The interval of production was from 117 kg for a 13-meter high tree with a perimeter of 78 cm to 227 kg for a 15-meter tree with a perimeter of 204 cm. This biomass productivity is a reflection of the fact that *Brosimum* trees without management can produce an average of 13.60 kg up to 18.9 kg per month in larger trees. A high correlation was found between diameter and biomass production (Fig. 1). In one year, a tree produces a total of 163.3 kg, which could represent a forage productivity of 48.9 ton per year on a commercial plantation of 300 trees per hectare, or 36.6 ton with 200 trees to the hectare, a significant quantity if compared with pasture production.

Table 1. Characteristics of the *Brosimum alicastrum* trees sampled in Sacalum, Yucatán, for shoot biomass (branches and leaves) annual acumulation.

Height (m)	Estimated Age (years)	Perimeter (cm)	Biomass (fresh weight). (kg)
13	30	80	128
15	30	122	169
15	30	205	183.5
15	30	104	158.5
15	30	204	227
15	30	176	178.5
13	30	80	134
15	30	168	180
13	30	78	117
15	30	85	158

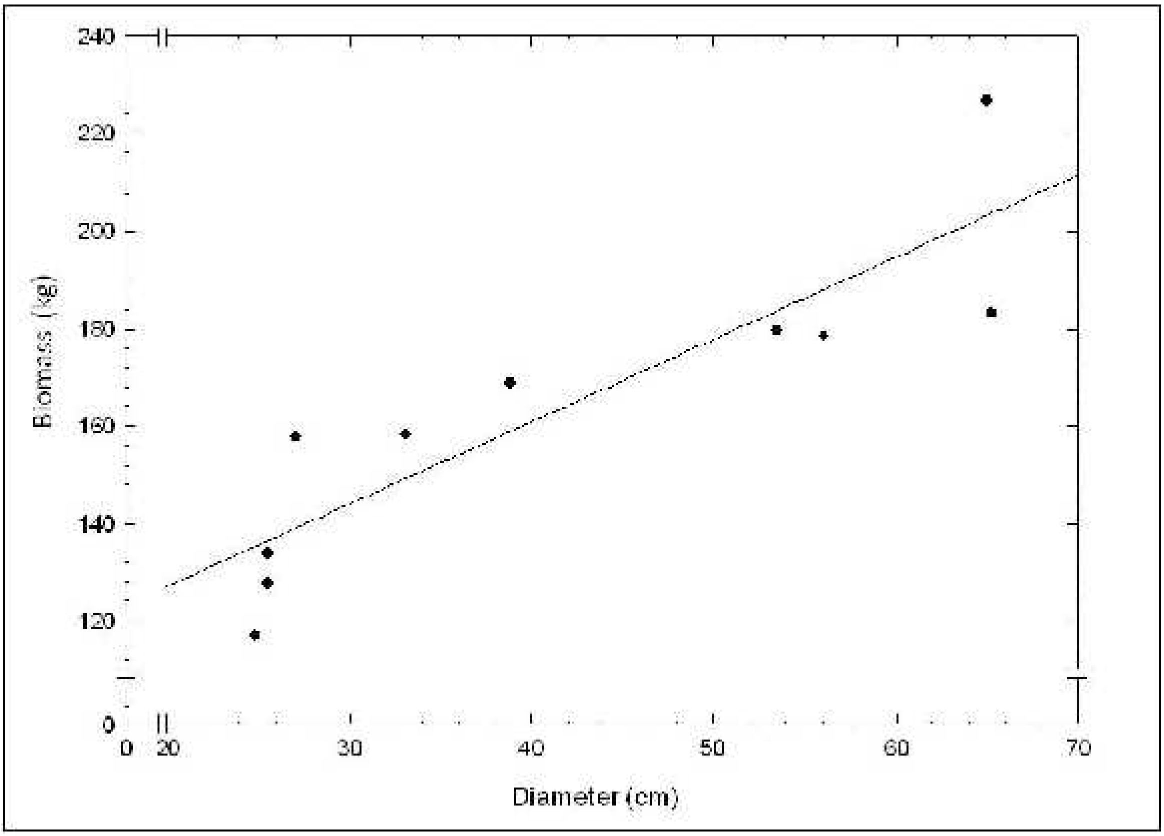

Figure 1. Correlation between diameter and biomass production of *Brosimum alicastrum* growing in their natural environment. Data were collected from 30-year-old trees. $r^2 = 0.78$. ($N = 10$).

Using a principal components analysis (PC) of the data it can be observed that there is a strong correlation between heights, diameter and biomass production (Fig. 2). A 100% of the variance is explained with only two components and 83.21% of data variability is explained with the PC1. It can be appreciated that the trees with lower biomass production, smaller diameter and less height grouped to the left, while the trees with higher biomass production and greater diameter grouped to the right; in other words, the trees with greater diameter will produce more biomass (regardless of their age).

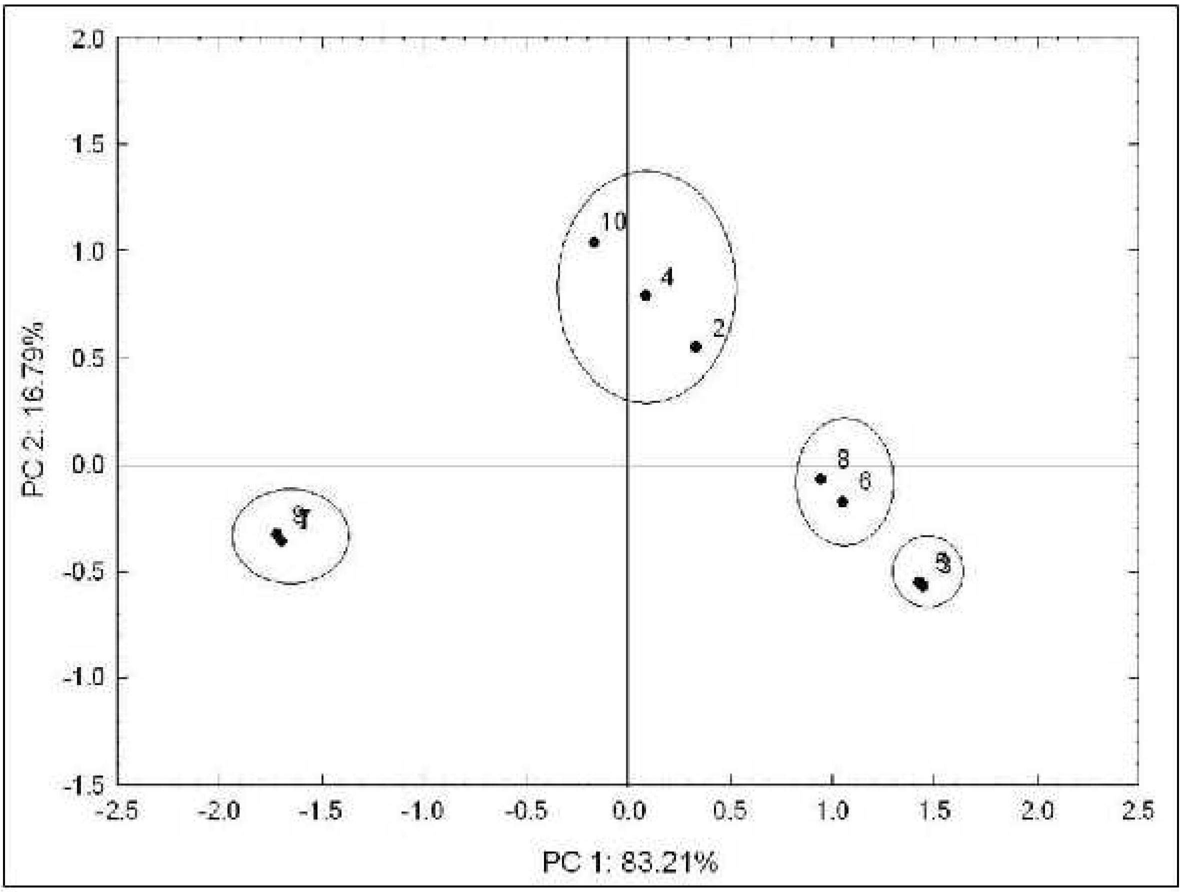

Figure 2. Principal components analysis of biomass production, height and diameter of *Brosimum alicastrum* growing in its natural environment. Data were collected from 30-year-old trees. (N = 10).

3.2. Seed production per tree. Brosimum trees chosen for their similar appearance, both in height and age showed two peaks of seed production throughout the year. The first was registered in the period from the end of July to September (autumn) of 2011 and the second from the end of March to May (spring) of 2012. The seeds were collected from, and the data are presented in histograms (Fig. 3). Highest seed production occurs in the spring period, in the months of March to May, while in the summer, from July to September, production is only a third of that collected in the spring. The average fresh weight of seed production per year per tree was 95.5 kg. No significant difference was found in total seed production between the two trees: t = -2.69; P = 0.11. One of the trees accumulated a total of 93.6 kg (fresh weight) and the second 97.5 kg. This could represent an annual seed productivity of 28.6 ton in a commercial plantation of 300 trees per hectare or 19.1 ton with 200 trees to the hectare.

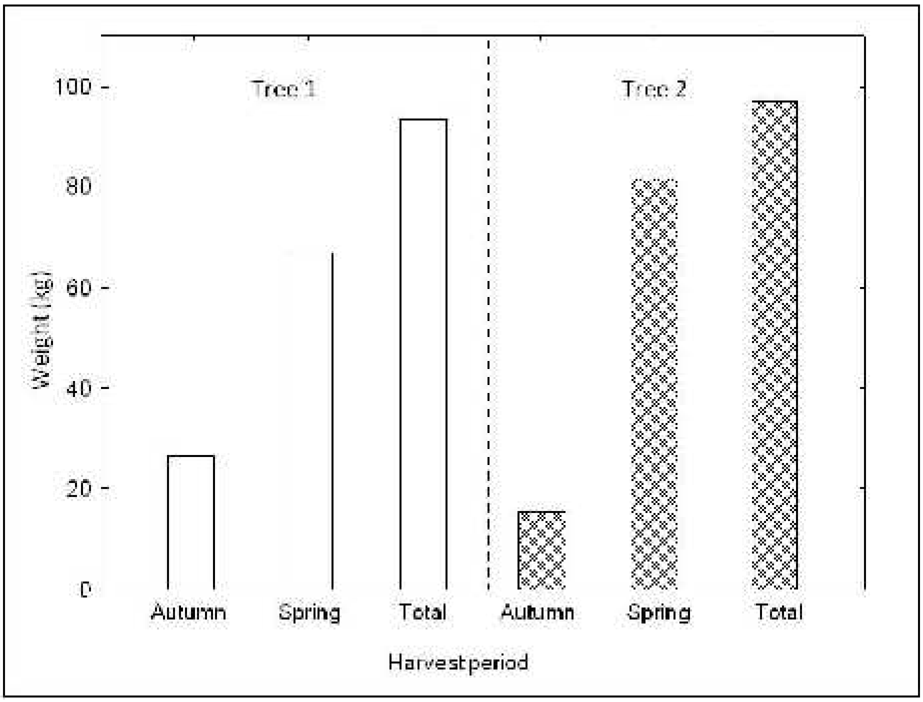

Figure 3. Weight of seeds of *Brosimum alicastrum* harvested in two periods. Autumn 2011 and Spring 2012. No significant difference was found (t = 2.69; P = 0.11)

Seed production of *B. alicastrum* for both trees evaluated was lower in the autumn period, but was triplicated in the spring. It is important to note that these trees flower twice a year, but only if they receive enough water during the year, otherwise there will be only one harvest during the rainy season.

An average of 323 seeds per kilogram was found. Figure 4 shows seed distribution frequency by weight. One can appreciate that 37.15% of seed weight ranges between 2.6 and 3.1 g, followed by 25.69% of seeds weighing between 3.2 and 3.7 g and a third level of 19.81% of seeds weighing between 2.0 and 2.6 g, 10.21% weigh between 3.8 and 4.3 g and 4.33% between 4.4 and 5.0 g. This wide distribution of seed weight, ranging from 2 to 5 g, is most likely due to the seeds' degree of precedence on the branch and at which level of the tree they are growing. One observation that requires further quantification is that the larger fruits are mainly found in the lower third of the tree, while the smaller ones are located in the upper third or apex.

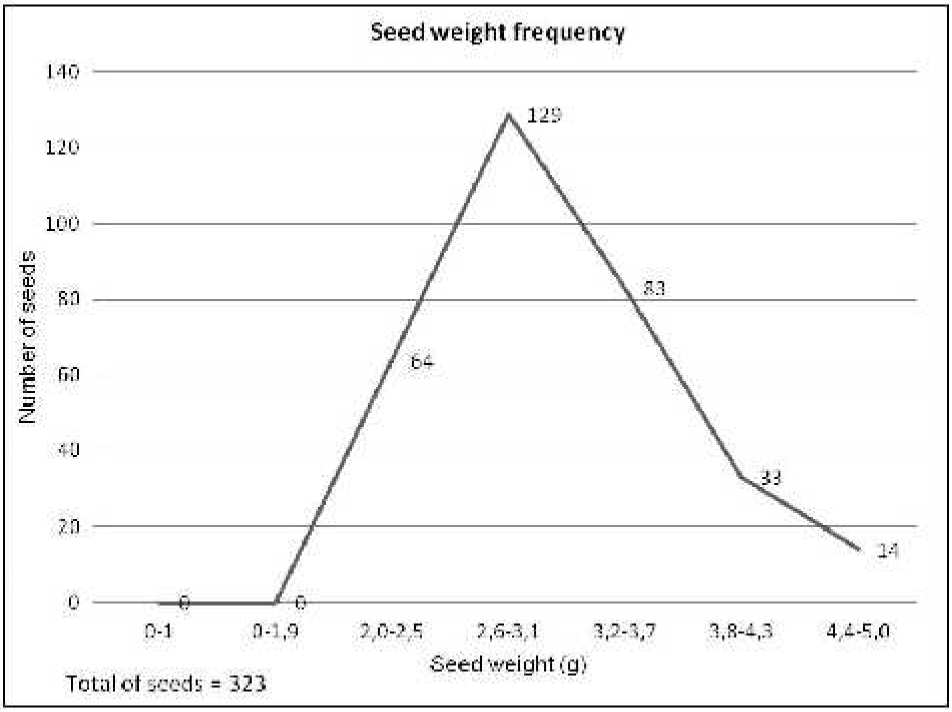

Figure 4. Frequency distribution of seed per weight from *Brosimum alicastrum.*

3.3. Seed production per branch. The results of seed production for ten branches from the two trees under study were counted (Fig. 5). One of the trees produced an average of 29 fruits per branch, while the other produced 26.4 per branch. Fruit setting was variable however; in the first tree some branches retained only 3 fruits while others retained 63. In the second tree there were branches that retained 6 fruits and others 123. Fruit dispersion is affected by the aborted inflorescences or immature fruits, which were observed to be quite numerous.

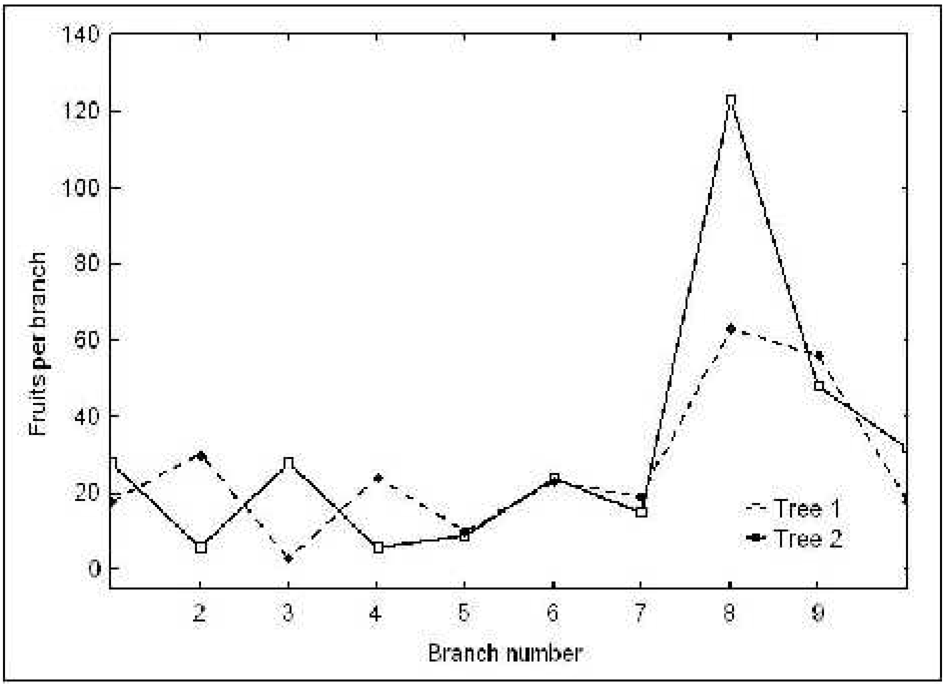

Figure 5. Fruit number per branch on two 30 years old trees of *Brosimum alicastrum*.

3.4. Aborted inflorescences and immature fruits. Trees with an age of 12 years were selected to carry out the quantification of aborted inflorescences and immature fruit. Table 2 shows the total number of inflorescences and immature fruits aborted by the trees under study. The twelve-year-old trees aborted an average of 9384 of these structures. If all the inflorescences were able to reach complete fruition with seed, assuming an average weight of 3.2 g per seed, it would be possible to obtain a potential average increase of 29.05 ton of seeds per 10-year-old tree. These data, in conjunction with those quantified and referred to in previous paragraphs, would provide a most significant productivity. Theoretically speaking, a 10-year-old tree has the potential of producing approximately 123.6 kg per year; equivalent to 24.7 ton/hectare on a plantation of 200 trees or 37.0 ton/hectare on a plantation of 300 trees per hectare. These results must be collated in future studies with a greater number of repetitions and in different localities, since abortion of inflorescences and immature fruits is known to be caused by different environmental agents such as drought, air, flooding and soil fertility.

Table 2. Inflorescences and immature fruits aborted by *Brosimum alicastrum* trees. The evaluation was carried out during the months of July-August 2012.

Tree Number	Estimated Age	Aborted Inflorescences and immature Fruits	Estimated seed Production Potential (Kg)
1	12 years	8830	28.768
2	12 years	9939	29.350

Discussion

It is widely recognized and well documented that the most common environmental service of *Brosimum alicastrum* in Yucatan is its use as cattle forage. This high service value explains why 1 to 6 of these trees can be found in the backyards of houses in most of the small towns of Yucatan. This study showed that the forage production of this tree is about 163.4 kg/tree per year, which could result in a harvest of almost 48.9 ton of forage per year per hectare. It is important to note that the trees harvested are normally located in family orchards and are not specifically fertilized, nor do they receive programmed irrigation. On average, pasture forage is reported to produce approximately 60 ton per hectare per year. These fields however, require agricultural management such as fertilization, pesticides and irrigation during the dry season. The *B. alicastrum* does not needs agricultural management; however, it does require manpower to carry out pruning and transportation to the corrals.

The formation of new biomass in 12 months is an example of high productivity in a tree. Furthermore, as tree owners have pointed out, these trees continue to produce equivalent forage values after the pruning process over a period of 50 years or more. Thus, we can appreciate the significant importance of this tree for the farmers' economy.

Other publications have reported obtaining a forage production of 400 to 800 kg per adult tree in natural conditions (Ayala and Sandoval, 1995**;** Pardo-Tejeda and Sánchez, 1980), which is almost double the production reported in this study. Most likely, because trees in those studies were growing in conditions with greater soil availability and sufficient water. If this is the case, it would be possible to obtain 80 ton per hectare per year, values which greatly surpass the productivity of pasture systems. Another study carried out under experimental conditions reported that one 10-year-old tree produced from 35 to 70 kg per year (López et al. 1994), one can assume, therefore, that the age at which the pruning is carried out affects biomass production.

Ayala and Sandoval (1995) have indicated that the age of the trees at the first pruning has a positive relationship to yield in subsequent harvests, while old trees manifest a greater response to pruning due to a higher accumulation of reserves in the stem and radical system (Stür et al. 1994**;** Montgomery and Chazdon, 2002). According to our results biomass production does not depend on age alone, as all the trees evaluated were approximately 30 years old and their production was very variable, from 117 to 227 kg per adult tree per year (Table 2). These trees also presented variations in height and diameter, possibly due to differences in soil fertility and water availability. From the regression analysis, carried out with data from this study, we can observe a strong correlation between diameter and biomass production, while the principal components analysis shows that data variability is explained in 83.21% with PC1, where we can observe an increase in biomass production in response to increased diameter and height.

From experiments carried out on *Leucaena leucocephala*, another species used for forage in the tropics, Becerra (1984) affirms that longer defoliation intervals allow the plant to increase foliar surface which will facilitate greater photosynthetic capacity and thus a higher production of biomass.

This could also be the case in *B. alicastrum,* as (Mendoza-Castillo et al. 2000) have reported that the yield and production of biomass increased when the number of months between pruning was also increased. If we take into consideration that, before the pruning that was done for this study, the *B. alicastrum* had been subjected to a traditional pruning, leaving the trunk practically without branches or leaves, we can appreciate the high capacity of these trees for biomass formation. What is more, the vigorous development of new shoots after such a drastic pruning during the dry season is a reflection of a very efficient radical system for the absorption of water and nutrients (Querejeta et al. 2006) and also indicates a large quantity of reserves in the stem and roots (Montgomery and Chazdon, 2002**;** Mendoza-Castillo et al. 2000) given that, in only one year, these trees showed a significant recovery by forming a new canopy, similar to the one present a year before. Annual pruning also controls the advancement of plagues and diseases, which can also contribute to maintaining constant growth and to the recovery of leaf development without being affected by pathogens.

The phenology of this species is quite variable due to its wide distribution. Fruiting varies from February to October in Central America and in certain areas there can be two production peaks (Cordero and Boshier, 2003)**.** In Veracruz, Mexico the flowering peak is between February and March and fruiting is in May and June (Peters, 1989). The *B. alicastrum* trees analyzed in this study presented two fruiting peaks; the first harvest was carried out in the autumn of 2011 (August-September) and the second in the spring of 2012 (March-May). Peters (1989) has pointed out that the phenology could be related to the periodicity of rainfall, producing flowers in the dry season and producing fruit in the rainy season; however, we were able to determine that the first harvest presented flowering during the rainy season and the second harvest was carried out when environmental conditions were more extreme with high temperatures (an average of 33°C) during the period of low water availability. Seed production was greater in this last period; more than double that of the autumn period, with a total production of almost 100 kg per tree per year.

The establishment of *B. alicastrum* plantations for the production of cattle forage would be of great benefit to the cattle farmers of the area. This tree would be an alternative source of forage at a low cost, as it offers not only a large quantity of biomass during the dry season, but also a very high fruit and seed production. In addition, according to some authors, the nutritional quality of the seeds is an extra benefit to maintain a balanced, low cost diet for cattle. In this context, it would be convenient to consider the report by Duryea and McClain, (1984) who have written that the success of a plantation depends on the quality of the plants, which is defined by their final behavior in the ground and is regulated by their morphological and physiological attributes, as well as their interaction with the environment of the plantation.

Conclusions

The results obtained in this study indicate that *Brosimum alicastrum* productivity is high in the environmental conditions prevailing in Yucatan. Based on this study therefore, the proposal is to establish commercial plantations of this species for the optimal exploitation of their environmental services such as the production of forage and seeds as a food source at low cost and this could be considered as a component for sustainability for the Mexican tropics.

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