Assessment of teak production characteristics using 1 m spacing in a plantation in Nicaragua

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Photo 1.
A view into Teak plantage.
Photo L. Uradnicek.

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RÉSUMÉ

ÉVALUATION DES CARACTÉRISTIQUES DE PRODUCTION DE TECK AVEC ESPACEMENT DE 1 M X 1 M DANS UNE PLANTATION AU NICARAGUA

Cette étude s'est déroulée dans une plantation forestière en Amérique centrale, proche de la ville de Diriamba au Nicaragua, où des plantations de teck sur 48,9 ha, dans une zone de reboisement de 76,5 ha, sont renouvelées depuis 2006 (2006 : 7,90 ha ; 2007 : 13,63 ha ; 2008 : 11,93 ha ; 2009 : 12,87 ha ; 2010 : 21,70 ha). Cette plantation sort de l'ordinaire du fait de l'espacement de 1 x 1 m des arbres et des facteurs écologiques limitants de cette zone tropicale aride. L'espacement de 1 x 1 m a été choisi pour favoriser la croissance en hauteur et obtenir ainsi des tiges de haute taille, et pour limiter les ramifications afin d'éviter la formation de houppiers importants. Cela permet de démarrer une production de poteaux de teck, adaptés à certaines constructions, dès la première coupe d'éclaircissement. Les paramètres de croissance des tecks (hauteur, circonférence) ont été mesurés dans les placettes expérimentales mises en place en 2011. Des données complémentaires (mortalité, arbres cassés ou tordus) ont également été relevées. Une méthodologie de terrain a été développée et les résultats restitués sous forme de tableaux et graphiques. Une évaluation statistique des paramètres de croissance a été menée à partir des mesures prises sur les placettes expérimentales délimitées dans la plantation. Les jeunes arbres plantés la même année ont été comparés selon leur provenance en termes de hauteur, de circonférence, de productivité et de mortalité. Au total, 10 955 arbres sur 143 placettes ont été mesurés. Sur ces peuplements de 1 à 5 ans d'âge, le bois sur pied total est estimé à 1 287,89 m^3, la masse moyenne de bois à l'hectare à 17,89 m^3, la hauteur moyenne des peuplements à 3,03 m et la circonférence moyenne à hauteur de poitrine à 2,74 cm. Les arbres cassés représentent 5,64 %, les arbres tordus 5,66 % et la mortalité moyenne s'établit à 21,48 %.

Mots-clés : *Tectona*, teck, plantation, Nicaragua.

ABSTRACT

ASSESSMENT OF TEAK PRODUCTION CHARACTERISTICS USING 1 M SPACING IN A PLANTATION IN NICARAGUA

This investigation was carried out in a forestry plantation in Central America, near the city of Diriamba in Nicaragua, where 48.9 ha of a 76.5 ha afforested area has been repeatedly planted with teak since 2006 (2006: 7.90 ha; 2007: 13.63 ha; 2008: 11.93 ha; 2009: 12.87 ha; 2010: 21.70 ha). This plantation is unusual because of the unique 1x1 m spacing of the teak trees and the limiting ecological factors of this arid tropical zone. The aim of the 1x1m spacing was to promote the growth of tall teak stems, inhibit branching to prevent the formation of a wide crown and begin production from the first thinning with teak poles, which are suitable for some types of construction. In 2011, experimental plots were established and the growth parameters (height and circumference) of teaks in the plantation were measured. Additional data were recorded, such as mortality, or twisted and snapped trees. A field methodology was designed and the growth results recorded were formatted into tables and charts. Based on the measurements made in the experimental plots marked out in the plantation, a statistical assessment of the growth parameters was conducted. Teak seedlings planted in the same years were compared according to provenance in terms of height, circumference, yields and mortality. Altogether, 10,955 trees in 143 experimental plots were measured. The stands were 1 to 5 years of age, the total calculated growing stock was 1,287.89 m^3, the mean wood mass per hectare was 17.89 m^3, with a mean stand height of 3.03 m and mean DBH of 2.74 cm. Snapped trees amounted to 5.64%, twisted trees to 5.66% and mean mortality was 21.48%.

Keywords: *Tectona*, teak, plantation, Nicaragua.

RESUMEN

EVALUACIÓN DE LAS CARACTERÍSTICAS DE PRODUCCIÓN DE TECA CON ESPACIAMIENTO DE 1X1 M EN UNA PLANTACIÓN DE NICARAGUA

Este estudio se desarrolló en una plantación forestal de América Central, cerca de la ciudad de Diriamba en Nicaragua, donde 48,9 ha de un área de forestación de 76,5 ha se vienen sembrando con teca desde 2006 (2006: 7,90 ha; 2007: 13,63 ha; 2008: 11,93 ha; 2009: 12,87 ha; 2010: 21,70 ha). Esta plantación es inusual por el espaciamiento de los árboles de 1x1 m y los factores ecológicos limitantes de esta zona tropical árida. Se eligió el espaciamiento de 1x1m para favorecer el crecimiento de tallos altos de teca y limitar la ramificación, evitando así la formación de copas anchas. Esto permite iniciar la producción de postes de teca, apropiados para ciertas construcciones, desde el primer raleo. Se midieron los parámetros de crecimiento de las tecas (altura y circunferencia) en las parcelas experimentales establecidas en 2011. También se registraron datos complementarios (mortalidad, árboles quebrados o torcidos). Se desarrolló una metodología de campo y los resultados registrados se plasmaron en tablas y gráficos. Se realizó una evaluación estadística de los parámetros de crecimiento basándose en las mediciones efectuadas en las parcelas experimentales delimitadas en la plantación. Se compararon los árboles jóvenes sembrados el mismo año según su procedencia en cuanto a altura, circunferencia, productividad y mortalidad. En total, se midieron 10 955 árboles en 143 parcelas experimentales. En estos rodales de 1 a 5 años de edad, se calcularon unas existencias de 1 287,89 m^3, un volumen promedio por hectárea de 17,89 m^3, una altura promedio de los rodales de 3,03 m y un diámetro promedio a la altura del pecho de 2,74 cm. Los árboles quebrados suponen el 5,64%, los árboles torcidos el 5,66% y el promedio de mortalidad es de 21,48%.

Palabras clave: *Tectona*, teca, plantación, Nicaragua.

Introduction

The natural range of the teak (*Tectona grandis* L. f.) is in India, Laos, Myanmar and Thailand. The teak wood is used in one of the oldest commercial goods in the world. Teak was firstly planted in Central America in 1926 at the Summit Botanical Garden in the former Channel Zone of the Panama Canal (De Camino *et al*., 2002). Since then it has been planted in nearly all tropical American countries (Ladrach, 2009). The teak grows to slightly lower heights in Central America than in its natural range (Francis and Lowe, 2000; Keogh, 1990).

A study by Kollert and Cherubini (2012) presented that the total afforested area of grown teak forests is 4,346,370 ha in the world. Asia has 3,598,040 ha (without natural teak forests). There are 469,800 ha of planted teak stands in Africa. In Oceania there are 8,530 ha of areas afforested by teak. Tropical America has 270,000 ha of teak, mainly in Brazil, Ecuador, Panama, Costa Rica, Guatemala and recently also Nicaragua.

Generally, we can distinguish three basic characteristics significant for the growth of teak. They are geomorphology, the climate and the soil. Vaides (2004) presented extended list of the main characteristics explored when establishing a teak plantation that have a significant relation to growth and yield of this species. They are usually the slope inclination, precipitation and temperature, soil depth, content of calcium, magnesium, ferrum, humus and the pH. Montero *et al.* (2001) presented for teak a positive correlation with the topographic position, indicating that the species grows best in flat lands and on medium slopes.

The aim of this study was to analyze the growth of teak in the plantation of the HFC company in Nicaragua. The plantation is extraordinary for two reasons. First, the applied spacing of 1x1 m is unusual for the teak; second, there are the limiting ecological factors of the zone of arid tropics, for which only scarce data on teak production is available in literature (Buvaneswaran *et al*., 2006). Moreover, the available literature provides no information on growing teak in Nicaragua, although plantations have been established there (NORTEAK, 2012).

Material and methods

Site description

The studied plantation has been established in historically two adjacent agricultural farms - La Reserva and La Reina (11° 49’ 0” N, 86° 13’ 10” W). These two together have an area of 211 ha. According to the Climate Atlas of Nicaragua (INETER, 2004), the farm lies within the arid tropical climate zone, climate subregion AW2, hot, dry, with annual mean precipitation between 1,400 and 1,800 mm during summer.

Entire area is classified as the life zone of tropical dry forest and forest formations as low and medium deciduous forests of warm and dry zone (MARENA/INAFOR, 2002).

From the physiogeographic point of view, the farm lies in the Province of Pacific Volcanoes, Diriamba Slopes group. The group of Diriamba soils contains deep to moderately shallow soils, well drained, of reddish colour, with discontinuous fragmented hardened horizon in a depth of 30 to 60 cm, which represents some limitations to the growth of roots (MARENA/INAFOR, 2002). The origin of the soil is volcanic ash, which covered the old soils or conglomerates of igneous rocks. Slopes are gently to moderately steep. These soils are heavily eroded. They are located to the south of Diriamba.

According to the Climate Atlas of Nicaragua (INETER, 2004), we can assume that there are two basic soil types on the farm: Altisols and Ultisols. Properties of Altisols (fertility and physical properties) are better than those of Ultisols.

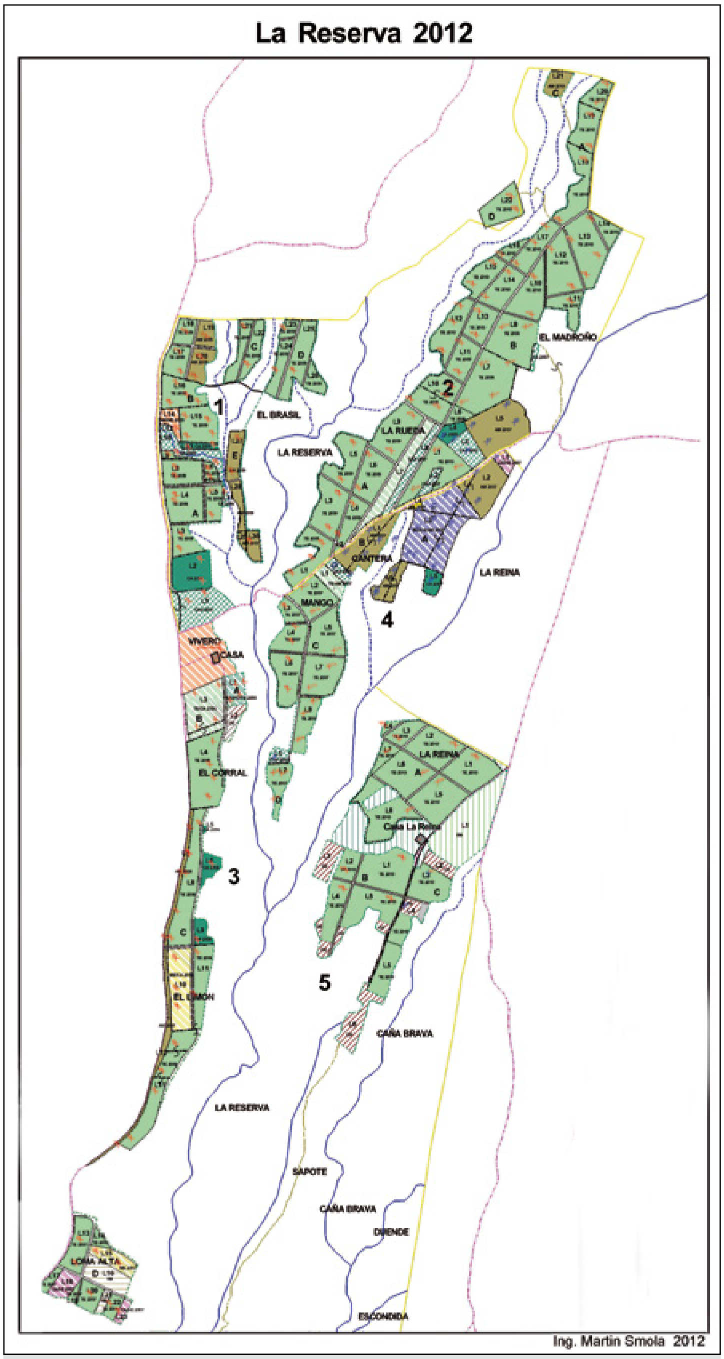

Figure 1.
Map of the parcel location.

Established plantation

In 2005, before the plantation was established, an inventory of the total area of the farm had been carried out with the aim to classify the current condition of the vegetation cover. Plots with secondary forests, high shrubs (rastrojo alto), low shrubs (rastrojo bajo), plots with abandoned pastures and fields for growing crop plants were distinguished. At the same time, the entire area was divided into logical spatial units and dividing cleared boundary lines and roads were designed to facilitate access to all plots. 88 ha of the lands were selected to establish the plantation, out of which 2.60 ha were established for underplanting below the original stand (figure 1).

The plantation is divided into 5 departments with numerical marks 1-5; these are further divided into stands marked by capital letters. The stands are again divided into stand groups (lote) marked by ordinal numbers. A stand map was created for the plantation using GPS and satellite photos.

The plantations were established as monocultures of the teak and acacia (*Acacia mangium* Willd). Some of the stands were established as mixtures of two or even three species. Autochthonous specie mahogany (*Swietenia humilis* Zucc.) was used for underplanting. Area of plantation had following evolution (year/established area): 2006/7.90 ha; 2007/13.63 ha; 2008/11.93 ha; 2009/12.87 ha; 2010/21.70 ha. The teak was planted in a spacing of 1x1 m, acacias, mahoganies and mixtures in spacing of 2x2 m. The aim of the 1x1m spacing was to support the height growth of the teak and thus gain sufficiently tall stems, reduce a formation of a wide crown by self-branching, and gain product novel for the teak as early as by the first thinning – pole timber, suitable for some constructions. Reproduction material *Tectona grandis* was grown in the farm's own forest nursery from seeds gained from various available sources: *Tectona grandis* CATIE Costa Rica, CETROPIC Nikaragua, Don Victor Nicaragua, CACH Hojancha Costa Rica, Lote 0-2008162TEC01, Lote 0-2008162TEA01 Santa Cruz, Semilla Certificada, Autorizada B.

Data collection

Data collection was performed since November 2011. Usually two (max. 5 based on the stand size) permanent research plots were established in each lote. Their dimensions were 10x10 m and they contained 100 trees. The plots were surveyed by GPS, the corners in the terrain were marked by iron rods and corner trees were marked by colour stripes. Trees were measured in rows. Their height was measured using a tree-height measuring stick with 10 cm accuracy and the stem girth at breast height (GBH) using a measuring tape with 0.5 cm accuracy. Missing trees, bent trees and trees with dried leading shoots were documented. In total, we recorded 10,955 trees at 143 research plots and 70 lotes.

To establish form factors for trees of various height classes (11 height classes with a difference of 1 m), 230 trees were sampled – steam girth was measured at 50 cm increments and at breast height.

Data processing

All data were stored and processed initially by Microsoft Excel (Microsoft Office 2010, Microsoft Corporation, Redmont, WA) and finally by STATISTICA software (STATISTICA Cz 12Copyright©StatSoft, Inc., Tulsa, Oklahoma).

Stem volume of the trees sampled was calculated using Huber's formula (Šmelko, 2007). Hubers formula is defined as:

$$v = g^{1/2} \times l$$

Where:
v is the volume of stem,
g is the basal area is in half of stem,
l is the length.

Form factors were calculated as a quotient of the real stem volume and the volume of cylinder with a base corresponding to the area of stem section at breast height and with a height corresponding to the height of the stem. Form factors of all sample trees in the particular height class were averaged out.

All trees at research plots within one lote were classified into height classes. The mean diameter at breast height (DBH) and the mean height were calculated for each lote. The growing stock (stem volume) at research plots was calculated as a sum of stem volumes of individual trees. This value was converted to the area of the entire lote and to a hectare. The stem volume of individual trees was calculated as a product of their basal area, height and form factor of the appropriate height class.

The gained mean growth quantities for particular lotes were statistically assessed based on age and provenience in the ANOVA application.

Photo 2.
A view of the work – measuring.
Photo P. Haninec.

Results

Description of teak plantation

In 2011, 76.5 ha in total were afforested; teak stands were planted on an area of 48.9 ha. Age of stands was between 1 and 5 years, not counting in the year of planting due to the fact that it took place in the second half of the year. The calculated total growing stock was 1287.89 m^3, the mean wood mass per hectare was 17.89 m^3, with a mean stand height of 3.03 m and DBH of 2.74 cm. There were recorded 5.64% of broken trees, 5.66% of bent trees and the mean mortality was 21.48%.

Evaluation of growth quantities based on the year of planting, or age

Growth dynamics in time was assessed based on the year of establishment of particular lotes. The mean annual height increment in the following years is about 80 cm (table I); the low value of increment in the oldest stands can be caused by a small number of measurements (only few stands were established in 2006), the used local provenience or differences in the quality of sites afforested in individual years.

The proportion of trees in height classes based on age is presented in table II. There is an obvious shift of tree proportions into higher height classes with the age of the stand. This tendency slows down starting from the age of four – the height class with the highest proportion remains class 7 (600-699 cm) from 2008, class 8 (700-799 cm) increases by a few percent only. By contrast, with an increasing age, the proportion of trees in classes 1-3 (0-299 cm) decreases continually.

Comparison of the used provenances of material for planting

Mortality of the particular proveniences (table III) ranges between 11.7 and 26.9%. Mortality is caused by typical losses before one year after afforestation dependent on the quality of plants and the conducted planting as well as interspecies competition of individuals, which could be expected for the teak considering the spacing of 1x1 m and the limiting conditions of arid tropics.

As regards growth quantities, we attempted to compare the particular proveniences. Unfortunately, as the plantation was not established as a scientific experiment, there is no research design. There is not a sufficient amount of repetitions for all proveniences and all years of establishment.

Table I.
Mean values of monitored quantities by individual years of planting without difference of origin.

Parameter	Years 2006	2007	2008	2009	2010
Mean height (cm)[a]	462.5 ± 202.6	508.2 ± 174.2	502.1 ± 194.9	360.2 ± 146.5	146.2 ± 98.2
Mean girth (cm)[a]	13.0 ± 5.8	12.7 ± 6.5	13.0 ± 4.9	10.1 ± 4.6	4.6 ± 4
Mean growing stock (m^3/ha)	47.21	52.01	40.74	31.72	3.77
Mean annual increment (m^3/ha/year)	9.40	13.00	13.57	15.86	3.77
Mean mortality (%)	23.14	18.50	28.47	11.84	26.90
Broken trees (%)	7.74	5.92	9.34	7.50	3.42
Bent trees (%)	3.65	12.40	7.28	5.18	3.18
Mean height of 25% of the tallest trees (cm)[a]	674.9 ± 70.5	692.3 ± 74.4	702.9 ± 74.4	531.3 ± 63.6	262.5 ± 62.8
Mean girth 25% of the tallest trees (cm)[a]	18.9 ± 2.6	17.7 ± 8.2	17.0 ± 2.0	17.8 ± 7.3	9.0 ± 3.4
Mean height 5% of the tallest trees (cm)[a]	786.8 ± 47.6	808.0 ± 55.6	821.3 ± 30.9	631.4 ± 34.7	359.2 ± 63.7
Mean girth 5% of the tallest trees (cm)[a]	23.0 ± 2.8	22.8 ± 17.4	21.1 ± 1.5	17.8 ± 7.3	12.3 ± 6.3

[a] Mean ± SE.

Table II.
The proportion of trees in height classes based on years of planting.

Year	Height classes (cm)										
	100	200	300	400	500	600	700	800	900	1000	1100
2006	95	106	130	171	252	267	269	122	21	2	0
2007	32	75	93	230	332	355	292	159	32	7	1
2008	34	95	115	128	182	186	248	111	53	0	0
2009	157	408	529	851	777	365	133	5	0	0	0
2010	1,455	1,081	802	155	32	7	2	0	0	0	0

Table III.
Mortality in the particular proveniences within the entire plantation.

Provenience	Local	Cetropic	don Victor	Catie	Hoj8	Hoj10
Mortality (%)	25.5	14.9	22.5	13.1	11.7	26.9

Therefore, we compare only proveniences used for planting in the same year. We can compare only years 2007, 2008 and 2009. In these years we used more than one reproduction material in the same year. In 2007 seeds of Cetropic provenience and of local origin were used. In 2008, proveniences Cetropic, don Victor and Catie were used for afforestation and proveniences don Victor, Hojancha C2008 and Catie were used in 2009 (table IV).

Mean height, mean girth and mean growing stock were evaluated using Tukey's HSD test. In 2007 statistically significant differences were found in the mean height and the mean girth. The mean height of Cetropic trees was about 9 % lower than that of Local trees (p=0.0001), while the mean girth of Cetropic trees was about 12 % lower than the mean girth of Local trees (p=0.0002). The difference in the growing stock was not significant (p=0.87).

In 2008, statistically significant differences were found between each provenience in the mean height, mean girth and mean growing stock. The lowest values had trees from provenience Cetropic. The mean height of Cetropic trees was 396.6 cm. It was about 35 % lower than don Victor trees (p=0.0002) and about 45 % lower than Catie trees (p=0.0001), respectively. The mean girth of Cetropic trees was 9.0 cm, which was about 33 % lower than don Victor trees (p=0.0003) and about 41 % than Catie trees (p=0.0001), respectively. The highest difference was found in the stem volume. The mean stem volume of Cetropic trees was only 2,655.2 cm^3, while it was 6,823.8 cm^3 for don Victor trees and 9,681.6 cm^3 for Catie trees. Statistical difference among these values was p=0.00001 when comparing the don Victor reproduction material with the Cetropic and also when comparing the Catie's with the Cetropic's.

In 2009, the mean height significantly differed between the don Victor trees and the Hojancha C2008 trees (p=0.00002) and the Catie trees (p=0.00002), respectively. The difference of mean height between Hojancha C2008 trees and Catie trees was not found (p=0.725). There was no statistically significant difference in the mean tree girth. However, the difference in the stem volume was found between don Victor's mean tree and Catie's mean tree (p=0.0082) and between don Victor's mean tree and Hojancha C2008 (p=0.00075). Don Victor's mean tree stem volume was 21 % higher stem than Catie's and 25 % higher than Hojancha C2008's, respectively. The difference of stem volume between Hojancha C2008's and Catie's was not significant.

Discussion

Growth parameters

Production of young stands has only been studied by a few authors, e.g. in Brazil Cruz *et al.* (2008) studied stands younger than 6 years of age, Vaides *et al.* (2005/2006) studied 7-year-old stands in Guatemala. Kanninen *et al.* (2004) described teak's growth parameters of 8 years-old stand. In this stand, the average DBH was between 15.2-20.1 cm, the total height was between 17.7-19.5 m and total volume varied from 90 to 200 m^3/ha respectively. Eight to ten (8-10) years-old teak stand had DBH in the range of 17-26 cm, height of 15-24 m and it was cultivated in Costa Rica (Pérez and Kanninen, 2005). Other 8 years-old teak stand had DBH 9.4 cm and total height around 12.4 m in Costa Rica (Perez, 2008). The maximum value of the mean annual increment (MAI) occurs at a relatively young age, between 7 and 12 years, and reaches 10-25 m^3/ha/year depending on the site class (Miller, 1969; Fonseca, 2004). Our oldest teak's stands were 5 years-old. The mean height of these stands was 4.6 m, mean DBH was 4.1 cm, average stand volume was 47.21 m^3/ha and average MAI was 9.4 m^3/ha/year.

Table IV.
Mean values of monitored quantities of proveniences planted 2007 – 2009.

Year 2007 Parameter / Provenience	Local	Cetropic	
Mean height (cm)[a]	545.6 ± 8.8	500.9 ± 4.9	
Mean girth (cm)[a]	14.0 ± 0.2	12.4 ± 0.2	
Mean growing stock (cm^3/tree)[a]	7,050.8 ± 271.9	6,687.4 ± 997.3	
Mortality (%)	33.5	13.5	
Broken trees (%)	0.3	7.7	
Bent trees (%)	6.3	14.4	
Year 2008 **Provenience**	**Cetropic**	**don Victor**	**Catie**
Mean height (cm)[a]	340.3 ± 11.3	520.6 ± 6.5	611.4 ± 17.2
Mean girth (cm)[a]	9.0 ± 0.2	13.4 ± 0.2	15.2 ± 0.4
Mean growing stock (cm^3/tree)[a]	2,655.2 ± 212.5	6,823.8 ± 187.5	9,681.6 ± 554.1
Mortality (%)	21.5	31.1	29.0
Broken trees (%)	6.7	11.2	5.0
Bent trees (%)	4.5	8.0	9.0
Year 2009 **Provenience**	**don Victor**	**Hojancha C2008**	**Catie**
Mean height (cm)[a]	396.6 ± 5.5	349.5 ± 3.1	355.4 ± 6.6
Mean girth (cm)[a]	10.4 ± 0.1	10.0 ± 0.1	10.2 ± 0.2
Mean growing stock (cm^3/tree)[a]	3,654.8 ± 105.9	2,760.2 ± 191.4	2,910.1 ± 108.6
Mortality (%)	13.9	11.7	10.0
Broken trees (%)	6.3	7.0	9.4
Bent trees (%)	6.4	3.7	6.2

[a] Mean ± SE.

Our data showed lower values than other authors. According to authors opinion it was mainly due to three facts. Firstly, our stand was younger than stands described by other authors. At the age of 5 years, growth parameters of the teak in the studied plantation do not reach the above mentioned values of older stands. Secondly, the stands differed in environmental/ecological conditions – mainly in geomorphology, climate and soil. Studied plantation is located in hot and dry subregion of arid tropical climate zone (INETER, 2004; MARENA/INAFOR, 2002). Rugmini and Balagopalan (2000) discovered the decrease in tree height and DBH from plain lands to hilly terrain in plantations of the same age and stocking indicating a loss of tree vigour with elevation increase. Thulasidas and Bhat (2009) compared moist and dry sites and acquired 40% lower values of the mean DBH at the age of 35 years. Our plantation lies in tropical zone with lower sum of precipitation, longer dry season and hilly terrain. These conditions can influence teak growth negatively. At last, the compared stands differed in the spacing density. Tropical plantations for growing sawtimber are usually established at densities similar to those for growing pulpwood, with 1,000 or 1,100 trees/ha being typical (Ladrach, 2004). Rondon (2006) evaluated the influence of spacings 3x2 m, 3x3 m, 4x3 m, 4x4 m, 5x3 m, 5x4 m and 5x5 m with the population density varying from 400 to 1,666 plants/ha on the teak growth. Our plantation was established with spacing of 1x1 m and initial density of 10,000 plants/ha. Ola-Adams (1990) found that at different plantation spacings varying from 1.37 m x 1.37 m to 3.96 x 3.96 m, the percentage of survival and the DBH increased with increasing spacing, while merchantable height, stem volume, and basal area decreased with increasing spacing. Rondon (2006) found similar results and trends as have been ascertained in the studied plantation with 1x1 m spacing. Also Adegbeihn (1982) reports the effect of spacing on different tree and stand variables. The results show that while mean DBH, mean DBH of dominant

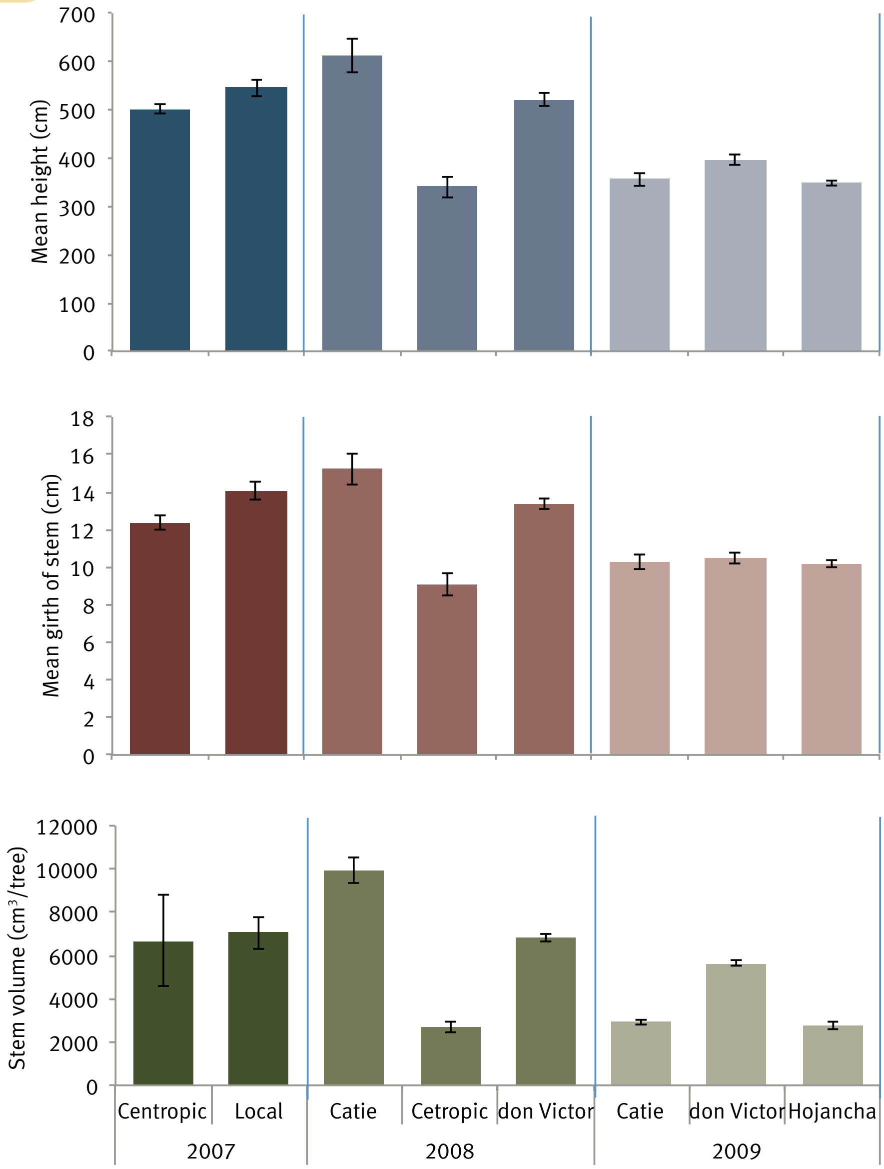

Figure 2.
Comparison of the used proveniences of material for planting. Reproduction material planted in 2007-2009. Mean values – height in cm; girth in cm; stem volume in cm³/tree with SE.

trees, and basal area production are significantly affected by spacing, mean height, top height, and total volume production remain independent to the effect of this factor. And Sibomana *et al.* (1997) assessed the performance of teak (*Tectona grandis*) planted at four square-shaped spacings (1.5, 2.0, 2.5 and 3.0 m). The variables studied were DBH, total height and height to the first live branch, survival, number of branches, basal area and volume production at ages 1, 3, 7 and 9 yrs. Results showed that DBH, number of branches, total height, basal area, basic density and some strength properties were significantly affected by spacing. The DBH and the number of branches increased with increasing spacing, while basal area decreased. Generally, an increase in population density caused a decrease in teak tree girth, whereas the height was relatively constant. But Nayak and Senapati (1998) presented an opposite trend of height: tree height was highest with a close spacing of 1x1 m, while the GBH was the highest with a wide spacing of 4x2 m.

Therefore, rapid growth of young stands should be encouraged by reducing stand density. Density is important for the crown to develop an optimal tree growth on the one hand and maximum production of desire usable volume on the other (Suri, 1975; Krajicek *et al.*, 1961; Adegbehi, 2002; Prodan *et al.*, 1997). Lowe (1976) described that *Tectona grandis* appears to be a strongly site sensitive species and with strong discriminative growth (i.e. a quarter of the trees can account for more than half of the basal area increment as vertical dominance appears due to competition). According to Kokutse *et al.* (2010), very high stand density affected radial growth, particularly of suppressed trees, which responded little to thinning operations. Our results showed that spacing 1x1m created trees with lower growth parameters. But 25 % tallest trees had total height of 6.8 m and DBH of 6.0 cm, respectively. And 5 % tallest trees had total height of 7.9 m and DBH of 7.3 cm, respectively. We can say that mean height of 8 years-old stands should be similar as other sites in the world where the teak is grown, because mean annual height increment of our stands is about 80 cm. As several authors demonstrated that highest difference in growth parameters depend on spacing is in DBH. It was the same in our teak stands. The mean DBH of the widest trees was only 7.3 cm. Mean annual diameter increment was 0.7 cm. These are lower values comparing with other teak stands. On the other hand it is a sign that we need to make a thinning in these stands.

Provenience

A several authors describe difference growth parameters, wood quality, ecology condition or plant clones of the used proveniences (Pedersen *et al.*, 2007; Narayanan *et al.*, 2009; Husen, 2010; Isotupa and Tyynela, 2010). Comparison of wood quality was impossible. Our teak's stands were not contained wood core for commercial used. But we find significant differences on the studied plantation among most of growth parameters of the used proveniences – mainly mean total height, mean DBH, mean growing stock and mortality. Pedersen *et al.* (2007) found that the differences in the specific explored proveniences deviated from the mean by up to 40% in volume and 10% in height at the age of thirty years in Tanzania. We found height difference between 9-95 %, difference by girth was between 2-40 % and growing stock was between 5-73 %.

But the lowest difference in proveniences was 2 years-old teak and the highest difference was by 3 years-old teak. Result showed that the best origin of reproduction material is don Victor and Catie in environmental conditions our studied plantation. In 2008, mean total height, mean DBH, mean growing stock are the highest by Catie reproduction material, but in 2009 same growing parameters are the highest by don Victor material. However in 2008 and 2009 difference between Catie and don Victor materials is not too large. On the second hand, Cetropic and Hojancha C2008 reproduction materials show the lowest mean total height, mean DBH and mean growing stock when comparing all of reproduction materials. These results confirm Narayanan *et al.* (2009) which prove a significant dependence of growth characteristics and timber quality on heredity.

Natural conditions

Generally, we can distinguish three basic characteristics significant for the growth of teak. Those are geomorphology, the climate and the soil. Vaides (2004) presented a list of the main characteristics explored when establishing a teak plantation that have a significant relation to growth and yield of this species. Those are usually the slope inclination, precipitation and temperature, soil depth, content of calcium, magnesium, iron, humus and the pH. Montero *et al.* (2001) presented for teak a positive correlation with the topographic position, indicating that the species grows best in flat lands and on medium slopes. Rugmini and Balagopalan (2000) described the decrease in tree height and DBH from plain lands to hilly terrain for plantations of the same age and stocking indicating a loss of tree vigour with sloping terrains.

With regard to potassium, a concentration of 1% was adequate for good growth (Montero *et al.*, 2001). The teak grows best in deep, porous, fertile and drained alluvial soils with neutral or acid pH (Kadambi, 1972). The content of humus in the soil supports its growth (Fagberno and Agboola, 1993). Soil moisture is an important factor for teak growth as soil organic matter contributes to increasing the water holding capacity and water content in the soil. Also, nitrogen and exchangeable Ca and Mg are important factors of teak growth (Watanabe *et al.*, 2010). However, the amount of precipitation and the length of the dry season are considered the most significant ecological factors. Santosh *et al.* (2007) found a correlation between tree ring width of teak and precipitation in June – September, while Somaru *et al.* (2010) found its correlation with the moisture index from the period April – September. April - September moisture index might be one of the parameters limiting the growth of teak trees over a large spatial scale. Good growth rates for *T. grandis* were observed in sites with mean annual precipitation of ≥1,500 mm (Montero *et al.*, 2001). The tree ring width depended strongly on mean monthly temperature during the rainy season and the most significant relationships were found corresponding to the months of June and July (Kokutse *et al.*, 2010).

De Camino *et al.* (2002) summarized that teak can withstand dry seasons lasting 5 months, but grows best when the dry season is short. For sawtimber production, it is best to select sites where the dry season is less than 3 months long, with well drained clay loam to sandy loam soils that have an effective rooting depth of more than 80 cm and a soil pH ranging from 6.0 to 7.5. Teak grows best with an annual precipitation between 1,500 mm and 2,500 mm per year and where calcium levels are greater than 10 meq/100 ml of soil, i.e. alkaline soils.

The main factors defined for Central America that have to be taken into account when selecting a site for the teak are (Ugalde, 1997):

- temperature: within the range of 25-27°C, inappropriate growth is observed outside this range;
- precipitation: teak grows well within 1,250-2,500 mm range of precipitation, with the dry season lasting 3-5 months;
- position: best yields are reached in teak stands at altitudes up to 600 m a.s.l.;
- soil: good growth is achieved in sandy to medium clay soils, rich, deep, well drained, with neutral to medium acid pH.

From the perspective of the above mentioned site characteristics, teak plantations on the La Reserva and La Reina farm can be described as follows:

- temperature: according to the Climate Atlas of Nicaragua (INETER, 2004), the mean temperature is around 26°C, with the maximum of 27.9°C in April and the minimum of 24.0°C in December;
- precipitation: according to the Climate Atlas of Nicaragua (INETER, 2004), the teak plantation is located at the lower edge of the warm zone with the mean annual precipitation around 1,400 mm. According to information from NASA Langley Research Center Atmospheric Science Data Center (2002)[1], annual precipitation in the Diriamba area reaches 1,548 mm. The dry season lasts 5 - 6 months;
- topographic position: the lowest point (82 m a.s.l.) on the La Reserva and La Reina farm is located in the valley of the El Tular River at the western edge of the lands; the highest point (480 m a.s.l.) is Loma Alta hill at the north-eastern edge; the mean altitude is about 220 m a.s.l. The plantation has been established on gently undulating plateaus bordered by the La Graneza and the El limon rivers. The slopes of the teak plantation do not exceed 25°;
- soil: there are two basic soil types - Altisols and Ultisols; the conducted analyses show that clay to sandy clay soils prevail, relatively deep, locally waterlogged by stagnating water, the pH in the upper layer to 20 cm is medium acid (6.03), slightly acid (6.40) and very slightly acid (6.75), in deeper layers, 40-100 cm, neutral values (6.85) are added;
- limiting factors: the main limiting factor on the La Reserva and La Reina farm is probably the presence of the compacted horizon (Talpetate), which is located in various depths under the surface, most often in horizon A 0-1 m, or in deeper overlaid horizons several meters under the surface. This impenetrable horizon, which originated in consequence of volcanic activity of Masaya Volcano about 2,000 years ago (Prat and Quantin, 1991), is present in the area of both farms (La Reserva and La Reina) in several forms.

[1] https://earthdata.nasa.gov/about/daacs/daac-asdc

- Another external limiting factor characterizing the natural site conditions of teak plantations of La Reserva and La Reina is the relatively frequent strong wind and the location of plantings on unsheltered plateaus. Properties such as the strength, frequency and the prevailing direction of the wind have not been measured yet. In spite of this, a negative effect of this factor in some parts of the plantations can be proved by the high amount of bent and broken trees.

We can conclude that the qualitative characteristics of teak plantation sites on the La Reserva and La Reina farm correspond to the characteristics stated as the optimum for teak growing in Central America (Ugalde, 1997) regarding most of the mentioned factors. Worse characteristics (at the bottom limit) are the lower sum of precipitation and the longer dry season. A significant limiting factor for teak growing in the plantation (especially La Reserva) can be the presence of the impenetrable Talpetate horizon.

Conclusion

The study provides an overview of production characteristics of a teak plantation established near Diriamba in Nicaragua in an area with precipitation and the length of dry season at the bottom limit of the species tolerance. Another special feature of the plantation is the spacing used – 1x1 m – which allows a production of a large amount of pole timber by thinning. This might bring an early return on investments; on the other hand, it slows down the diameter growth and thus postpones the time of logging of the target product.

Based on the obtained results the further management of plantation should be concerned with the change of the plant spacing, i.e. by using selection cutting or to set new experimental plots which would be tested for several types of interventions such as the negative selection, positive selection or its combination. According to the stands response we should reconsider and define further operations. We can conclude that the growing characteristics of teak plantation sites on the La Reserva and La Reina farm correspond to the characteristics stated as the optimum for teak growing in Central America (Ugalde, 1997) regarding most of the mentioned factors. Worse characteristics (at the bottom limit) are the lower sum of precipitation and the longer dry season.

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