DOI: https://doi.org/10.29298/rmcf.v10i52.398

Article

Propiedades del suelo y nitrógeno como indicadores del crecimiento en plantaciones comerciales de teca

Soil properties and nitrogen as indicators of growth in teak commercial stands

Eduardo Salcedo-Pérez[1], Bayron Alexander Ruiz Blandon[1,3], Efrén Hernández Álvarez[2*], Ricardo González Cruz[3], Antonio Bernabé-Antonio[3], Eulogio Orozco-Guareño[4], César Bonifacio Ramírez-López[3], José Anzaldo Hernández[3] y Ezequiel Delgado-Fornué[3]

Resumen:

La teca es una especie importante en los mercados forestales, debido al valor de su madera, lo cual en México ha incrementado el interés de establecer plantaciones. Sin embargo, la influencia de las propiedades del suelo y nitrógeno bajo esas condiciones han sido poco evaluadas. El objetivo del presente estudio fue medir la calidad del suelo en plantaciones comerciales de teca en Nayarit, México. Antes de plantar (30 días), se aplicaron fertilizantes 50 – 120 - 75 (NPK), 3 t ha^{-1} de hidróxido de Ca, 250 kg ha^{-1} de fosfato diamónico, 63 kg ha^{-1} de cloruro de potasio y 75 kg ha^{-1} de sulfato de potasio. A la edad de 6 años, se midieron el diámetro, altura, área basal y se calculó el volumen, con el propósito de contrastar el crecimiento y productividad entre plantaciones. En muestras de suelo, se determinó la textura, densidad aparente (Da), capacidad de intercambio catiónico (CIC), pH, conductividad eléctrica (CE), materia orgánica (MO) y relación C/N para conocer la mineralización de la MO, así como el nitrógeno en la biomasa. El ANOVA y prueba de *Tukey* demostraron que los suelos con pH > 6 < 7, CIC > 30 $cmol^{(+)}$ kg^{-1}, MO > 2.5 % y relación C/N > 15 de 0 – 10 cm, se asociaron a la plantación de mejor productividad, así como la mayor concentración de nitrógeno en hojas. Se concluye que en México, el éxito en la productividad de plantaciones con especies exóticas dependerá, esencialmente, de las propiedades del suelo.

Palabras clave: Crecimiento, incremento medio anual, nitrógeno, propiedades del suelo, *Tectona grandis* L.f., volumen.

Abstract:

Teak is an important species in the forest markets, due to the value of the timber which, it has increased the interest to establish stands in Mexico. However, the influence of properties soil and nitrogen on plantations have been poorly evaluated. The aim of the study was to measure quality soil in 6-yrs-old commercial teak plantations in Nayarit, Mexico. 30 days before planting, were applied to fertilizers soils 50- 120 - 75 (NPP), 3 t ha^{-1} Ca hydroxide, 250 kg ha^{-1} of diammonium phosphate, 63 kg ha^{-1} of potassium chloride and 75 kg ha^{-1} Potassium sulfate to improve your fertility. After 6 yrs-old, the diameter, height, basal area and volume were measured in order to contrast the growth and productivity between stands. Soil samples, the texture, bulk density (BD), cation exchange capacity (CEC), pH, electrical conductivity (EC), organic matter (OM) and C:N ratio were determined to know the OM mineralization, as well as nitrogen in biomass. The ANOVA and Tukey test showed that soils with pH > 6 < 7, CEC > 30 $cmol^{(+)}$ kg^{-1}, OM > 2.5 % and C:N ratio > 15 of 0 - 10 cm, were associated with the best stand productivity, as well as the highest nitrogen concentration in leaves. It is concluded that the success in the stand's productivity with exotic species in Mexico, will depend essentially on the health of the soil.

Keywords: Growth, average annual increase, nitrogen, soil properties, *Tectona grandis* L.f., volume.

Fecha de recepción/Reception date: 25 de julio de 2018
Fecha de aceptación/Acceptance date: 06 de noviembre de 2018

[1] Centro Universitario de Ciencias Biológicas y Agropecuarias, Departamento de Botánica y Zoología, Universidad de Guadalajara. México.
[2] Centro Universitario de Ciencias Biológicas y Agropecuarias, Departamento de Producción Forestal, Universidad de Guadalajara. México. Correo-e: efren.hernandez@academicos.udg.mx
[3] Centro Universitario de Ciencias Exactas e Ingenierías, Departamento de Madera, Celulosa y Papel, Universidad de Guadalajara. México.
[4] Centro Universitario de Ciencias Exactas e Ingenierías, Departamento de Química, Universidad de Guadalajara. México.

Introduction

Due to the high quality of its timber, *Tectona grandis* L.f. (teak) is attached a major importance in forest markets. It is planted in approximately 70 countries, and its main producers are India, Indonesia, Myanmar, and Thailand (Bohre *et al.,* 2013; Sreejesh *et al.,* 2013). Teak is a rapidly growing species that belongs to the Lamiaceae family; in its location of origin, it can reach a height of over 50 m, and a diameter of 2 m. It is one of the best known timber species in the world, and its stands occupy the largest planting area (Fonseca, 2004; Espitia *et al.,* 2011; Zhou *et al.,* 2012; Ruiz, 2016; GRIN, 2017).

According to a 2005 estimate, 74 % of the stands with hardwood species in tropical areas corresponded to *T. grandis* (FAO, 2009), the commercial value of whose unsawn timber is 717 USD m^3 (De Camino and Morales, 2013). Not only its economic potential but also the edaphoclimatic conditions in Mexico have favored a growing interest in its culture, primarily in the south and east of the country (Jayaraman, 2011; Conafor, 2013a; Hernández *et al.,* 2017).

In Mexico, teak occupies the fifth place in economic importance among the broadleaves, with approximately 18 000 ha of plantations established in the states of *Chiapas*, *Veracruz*, *Tabasco*, *Campeche*, and *Quintana Roo* (López and González, 2005; Conafor, 2011, 2013a). It is an exotic species; therefore, the parameters affecting its growth and productivity when planted in areas with similar hydroclimatological conditions are unknown. Seven year-old commercial teak stands in Ecuador produced 153.10 m^3 ha^{-1}, while those in Mexico produced 89.2 m^3 ha^{-1} (SAF, 2009; Conafor, 2013a); this variability is highly significant. Zhou *et al.* (2012) proved that its growth is reduced by severely acidic soils that are low in nutrients. On the other hand, certain abiotic factors such as high precipitations, low temperatures, soil slopes of more than 50 %, the altitude of the stands, and poor drainage also limit its growth (Pérez and Kanninen, 2005; Upadhyay *et al.,* 2005; Watanabe, 2009; Salcedo *et al.,* 2014).

The present study poses the hypothesis that teak tree growth is favored by ideal hydroclimatological conditions and soils with a near-neutral pH, concentration of organic matter (OM) of more than 1 %, and a high leaf nitrogen (N) concentration.

Updated information on the behavior of *T. grandis* generated by this research confirms that significant changes in the soil properties and in the availability of N conditioned its growth in the study area. The purpose of the study was to assess the quality of the soil in terms of its basic properties and of N concentration as indicators of growth in 6 year-old commercial teak stands in *Nayarit*, Mexico.

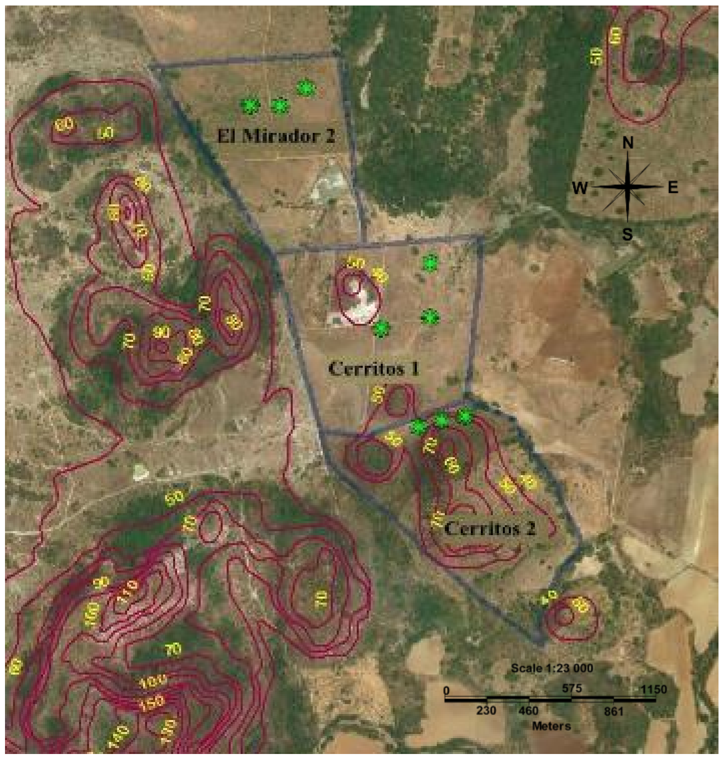
Materials and Methods

Study area

The study was carried out at three commercial teak stands (CTS) established in the municipality of *Ruiz*, *Nayarit*, Mexico, in July, 2008: *Cerritos 1*, *Cerritos 2* and *El Mirador 2* (Figure 1). The CTSs owned by the company *Agroforestal Nayarita*, S. A. were managed in keeping with the guidelines of Conafor (Figure 2). The area of influence of the CTSs is characterized by a warm subhumid climate with summer rains, an altitude of 25 m, an annual precipitation of 1 496.7 mm (historical average from 1946 to 216), and a mean annual temperature of 23.5 °C (historical average from 19789 to 2016) (Figure 1) (Inegi, 2017).

Before establishing the CTSs, the pH of the soils had been determined to be moderately acidic (5.3), with < 0.5 % OM, low N concentrations (< 0.02 %), available phosphorus (P) (0.001 %), potassium (K) (< 3 %), manganese (Mn) (0.0003 %), magnesium (Mg) (0.017 %), and copper (Cu) (0.00004 %); moderately high exchangeable calcium (Ca) concentrations (67 %), and high iron (Fe) concentrations (> 0.06 %). Based on this, thirty days before planting, the fertilizer N-P-K at a 50 – 120 - 75 kg ha^{-1} rate, 3 t ha^{-1} of Ca hydroxide, 250 kg ha^{-1} of diammonium phosphate, 63 kg ha^{-1} of potassium chloride, and 75 kg ha^{-1} of potassium sulphate were applied to the soils as a corrective. When the seedlings reached an age of 8 months in the nursery (a height of ~ 20 cm and a diameter of 8 mm), they were transplanted to the final sites under a real framework system at a 3.5 × 3.5 m spatial arrangement (918 plants ha^{-1}).

Their position within the growth plots were considered as treatments.



Upper area = *El Mirador 2* (21°54'28.4" N, 105°03'43.3" O, 41 msnm); Center = *Cerritos 1* (21°54'10.8" N, 105°03'29.2" O, 39 msnm); Lower area = *Cerritos 2* (21°54'00.0" N, 105°03'27.7" O, 39 msnm) (INEGI, 2016).

Figure 1. Geolocation of teak commercial stands (CTSs).

a) *Cerritos 1* (10.66 ha); b) *Cerritos 2* (23.34 ha), and c) *El Mirador 2* (19.95 ha).

Figure 2. Commercial teak stands (CTSs) under forest management.

Dendrometry and stereometry

Three 7 × 25.4 m experimental plots were built in each CTS and distributed at random (533.6 m^2 sampled per stand). The dendrometric and dasometric variables were: a) tree diameter at breast height (DBH), measured at 1.30 m above the stem base, with diametric measuring tape; and b) total height (h), measured at a distance of approximately 15 m from the tree using a Haga hypsometer 25 trees were considered in each sampling unit; the measurements were taken in July, 2014, using to the techniques recommended by Arteaga and Castelán (2008).

The basis for estimating the volume of the standing trees was the basal area (BA), according to the following equation (1):

$$BA = \left(\frac{\pi}{4}\right) D^2 \qquad (1)$$

Where:

BA = Basal area (m^2)

D = Diameter of both ends of each cylinder (m)

The volume of the standing trees was estimated using the following expression (2):

$$V = (BA)(h)(MC) \tag{2}$$

Where:

V = Stem volume (m^3)

BA = Basal area (m^2)

h = Height (m)

MC = Morphic coefficient of 0.5 (Arteaga and Castelán, 2008)

Three trees of different sizes were felled in each plot; the stem volume was estimated, and the total volume of all felled trees was calculated according to Smaliam's formula (Cancino, 2006):

$$V = \frac{A_b + A_s}{2L} \tag{3}$$

Where:

V = Log volume (m^3)

A_b = Basal (largest) diameter of the log (m)

A_s = Diameter of the smaller end of the log m)

L = Length of the solid stem $L = L_2 - L_1$ (m)

The mean annual increments (MAI) in height and diameter were also estimated, by dividing the average of the variables mentioned above by the age of the stand:

$$MAI = \frac{\mathrm{DSV}}{Age}$$

(4)

Where:

MAI = Mean annual increment

DSV = Dendrometric and stereometric values (cm, m, m^3)

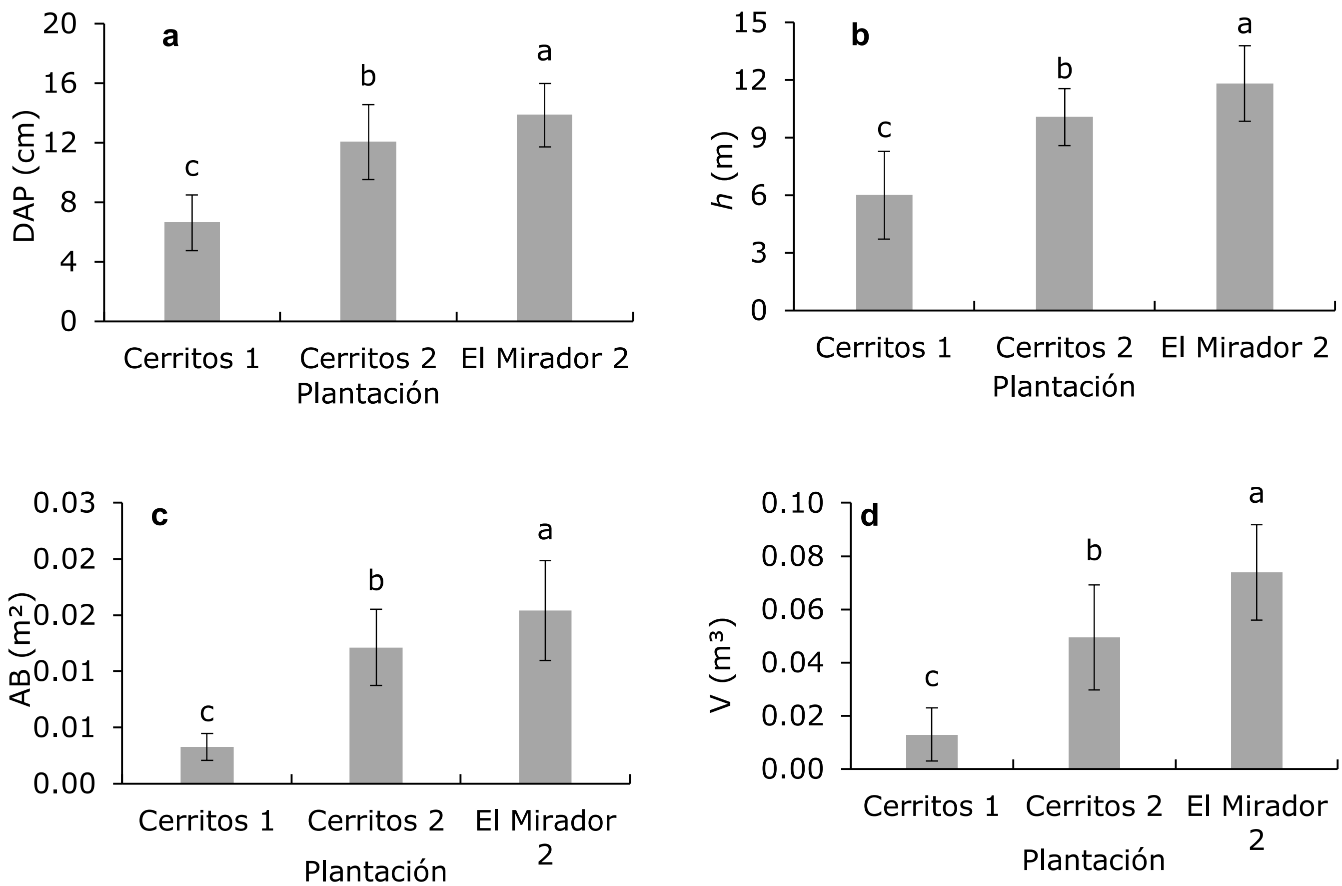
Soil samples were collected in zig-zag manner at 0-10 and 10- 30 cm at each sampling plot. The sampling was carried out in July, 2014. The properties of the soils were determined based on the norm NOM-021-RECNAT-2000 (Semarnat, 2002): texture (Bouyoucos hydrometer), apparent density (AD) (clod method), pH in water (1:2), cation exchange capacity (CEC) (Ammonium Acetate), electric conductivity (EC) (electric conductometry), and organic carbon (C %) (Shimadzu TOC 5050-A), which was converted into OM by multiplying the average percentage of C in the OM (58 %), respectively. The total N concentration was estimated by means of an elemental analysis (using a LECO TruSpec® Micro analyzer), based on 2 mg of samples of both biomass and soil, and on the soil C/N ratio as indicated by its expression.

The differences in growth, productivity, and soil properties between the CTSs were analyzed using ANOVA. The means of each variable were analyzed using P-P Plot graphs and therefore had a normal distribution. Tukey mean comparison tests were utilized to examine the differences between the means of the studied variables of the CTSs (P <0.05). The statistical software utilized for all the analyses was SAS version 9.0 (SAS Institute, 2009).

Results and Discussion

Teak growth

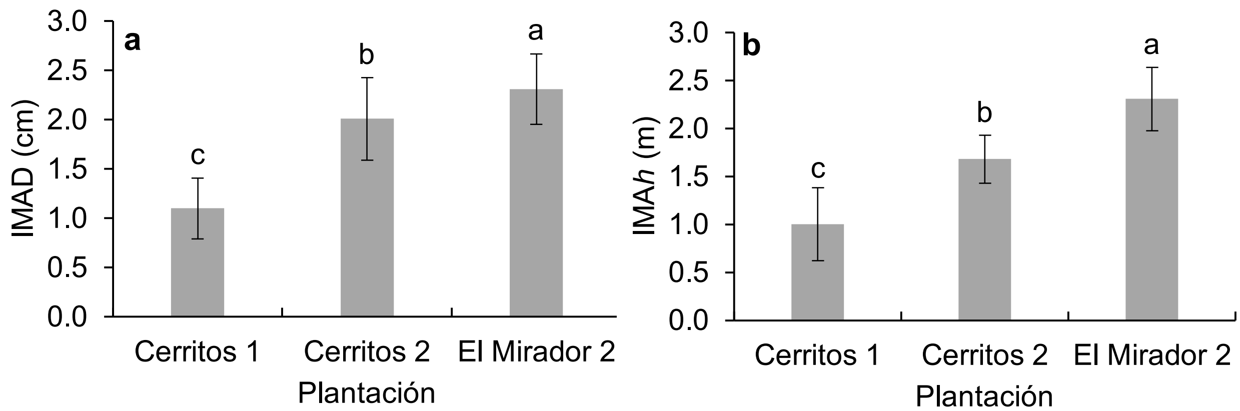
Assuming that all CTSs were managed in the same manner, Figure 3 shows the dendrometric and stereometric behavior of *El Mirador 2*, *Cerritos 1* and *Cerritos 2*.

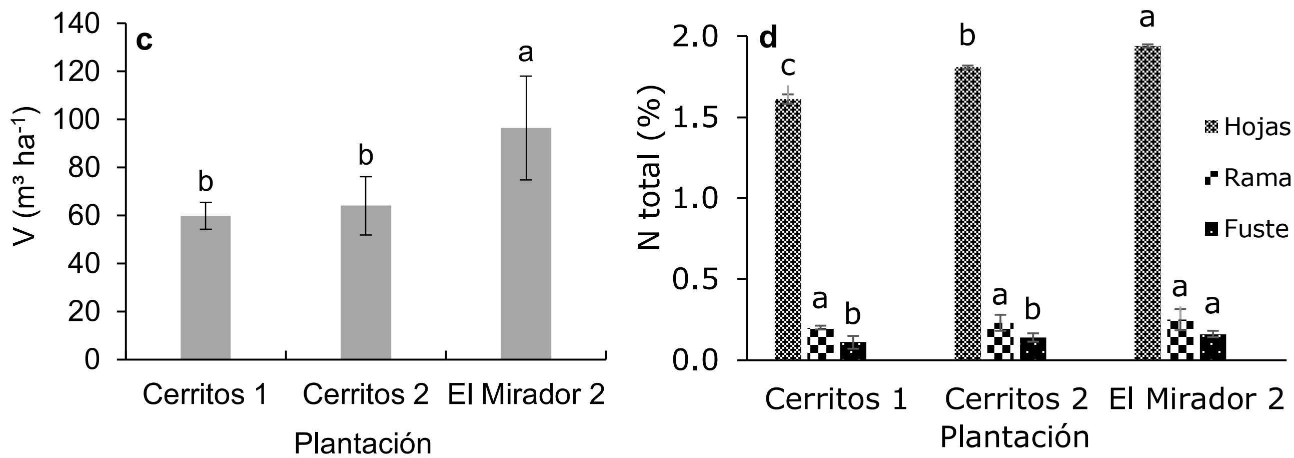


The data are means of 75 repetitions. Means with different letters on each bar (standard deviation) are statistically different (Tukey, $P < 0.05$).

Figure 3. Dendrometric and stereometric behavior of commercial teak stands (CTS) at 6 years in *Nayarit*, Mexico.

The ANOVA exhibited significant differences in the average DBH (P = 0.0061; Figure 3a), *h* (*P* = 0.0080; Figure 3b), BA (*P* = 0.0027; Figure 3c), and *V* (*P* = 0.0008; Figure 3d) per tree between the sampled CTSs. The Tukey's test confirmed that *El Mirador 2* was the stand with the highest average DBH (50 %), *h* (45 %), BA (78 %) and *V* (80 %) per tree, compared to *Cerritos 1*, the stand with the lowest growth. Likewise, the CTS *El Mirador 2* registered the highest dendrometric MAI (Figure 4ab), productivity (Figure 4c), and biomass N concentration (Figure 4d), compared to *Cerritos 1* and *Cerritos 2*, respectively. The productivity of *El Mirador* was 36.73 m^3 ha^{-1} higher than that of *Cerritos 1* (*P* <0.0001; Figure 4c). The highest N concentration occurred in the leaves (nearly 80 % of the aerial tree biomass; *P* <0.0001); of all three CTSs, *El Mirador* obtained the highest values, by 10 %, for each of the tree components (Figure 4d).





IMAD = Mean Annual Diameter Increment (MADI); *IMAh* = Mean Annual Height Increment (MAHI). The data are means of 75 repetitions. Means with different letters on each bar (standard deviation) are statistically different (Tukey, $P < 0.05$).

Figure 4. Mean annual increment (MAI), productivity and N concentration in 6 year-old commercial teak stands (CTSs) in *Nayarit*, Mexico.

In relation to the dasometric behavior and increments of the CTSs, Mollinedo *et al.* (2005) documented that the quality of the sites conditions the growth of *T. grandis*, as 3.6 year-old stands established in Panama registered an average height of 13.43 m (*h*), a MAHI of 1.81 m year^{-1} and a MADI of 1.99 cm year^{-1} per tree in low quality sites; a height of 15.38 m, a MAHI of 2.77 m year^{-1}, and a MADI of 2.77 cm year^{-1} in sites of medium quality, and a height of 17.14 m, a MAHI of 3.72 m year^{-1}, and a MADI of 3.67 cm year^{-1} in sites with a high quality. These values are comparable to those of *El Mirador 2* and *Cerritos 2*. As for the productivity of the CTSs, yields of 153.10 m^3 ha^{-1} at 7 years were cited by *SAF* (2009), and of 73.3 m^3 ha^{-1} at 6 years, by Conafor (2013ab) in Mexico; the latter yield was 14 % lower than that obtained at *El Mirador 2*. The productivity of *Cerritos 2* and *El Mirador 2* was similar to that registered at 10 year old CTSs assessed by Derwisch *et al.* (2009) in Panama.

According to Musálem (2007), Arteaga and Castelán (2008), and De Camino and Morales (2013), the forest management of the stands, the (tree-to-tree) spacing, plantation systems, and age can accelerate or decelerate teak growth and productivity. Between the third and fifth years, the progression of growth in terms of height is accelerated (an average of 3 to 15 m per tree); this favors rapid increments in BA and V. However, at ages above 15 years, this progression decelerates.

Nitrogen has been documented to concentrate mainly in the leaves of certain plants, and the availability of this element favors the formation of biomass, as there is a positive correlation between this nutrient and the growth of vegetal species (Salisbury and Ross 1994; Alcántar and Trejo, 2007; Shrawat *et al.,* 2008; Salcedo *et al.*, 2014; Balám-Che *et al.,* 2015; Zhou *et al.,* 2017). The leaf N concentration estimated in the present study is comparable to that reported by Ypushima-Pinedo *et al.* (2014) at 9 year-old CTSs in *Veracruz* and *Nayarit*, Mexico, as well as to the values registered by Murillo *et al.* (2015) at 3 to 18 year-old CTSs in Panama.

Physical and chemical soil properties

The present study showed that the soils on which the CTSs attained the best development were those with a loamy-clayey texture, an AD of 0.9 to 1 g cm^3 (*P* <0.0001), a CEC above 37 $cmol^{(+)}$ kg^{-1} (*P* <0.0001), a pH close to neutral (> 6 < 7; *P* <0.0001), OM > 1 % (*P* <0.0001), and a C/N ratio between 15 and 30 of 0 – 10 and 10 – 30 cm (*P* <.0001), as evidenced at *El Mirador 2*. The EC was statistically similar at all three stands (*P* = 0.0994) (Table 1).

Table 1. Characteristics of the mineral soil of three commercial teak stands (CTSs) in *Nayarit*, Mexico.

	***Cerritos 1* Stand**		***Cerritos 2* Stand**		***El Mirador 2* Stand**	
Depth (cm)	**0-10**	**10-30**	**0-10**	**10-30**	**0-10**	**10-30**
Texture	Ls		Lc		Lc	
AD (g cm³)	0.87 c ± 0.02	1.14 a ± 0.01	0.95 b ± 0.03	1.12 a ± 0.01	0.99 b ± 0.05	1.13 a ± 0.01
CEC (cmol $^{(+)}$ kg^{-1})	28.70 e ± 0.004	28.13 f ± 0.02	38.85 a ± 0.01	38.07 b ± 0.03	37.80 c ± 0.02	37.06 d ± 0.004
EC (dS m^{-1})	0.06 a ± 0.002	0.05 a ± 0.01	0.04 a ± 0.003	0.04 a ± 0.01	0.05 a ± 0.004	0.05 a ± 0.01
pH	6.22 b ± 0.003	5.37 f ± 0.002	5.58 e ± 0.004	5.72 d ± 0.01	6.31 a ± 0.01	6.06 c ± 0.003
OM (%)	2.24 b ± 0.01	0.62 f ± 0.01	1.48 c ± 0.002	0.92 e ± 0.003	2.64 a ± 0.01	1.30 d ± 0.004
C (%)	1.29 b ± 0.002	0.35 e ± 0.18	0.86 c ± 0.30	0.53 d ± 0.003	1.53 a ± 0.03	1.12 b ± 0.11
N (%)	0.07 a ± 0.01	0.06 a ±0.001	0.06 a ± 0.01	0.05 a ± 0.004	0.05 a ± 0.003	0.07 a ± 0.01
C/N	18.53 b ± 0.09	5.87 f ± 0.08	14.32 d ± 1.04	10.68 e ± 2.01	30.65 a ± 0.11	15.98 c ± 1.13

Ls = Loamy-sandy; Lc = Loamy-clayey. The means are the result of three repeats. Means (± standard deviation) with different letters on each column are statistically different (Tukey, $P < 0.05$).

Soils with a loamy-clayey texture benefit the growth and productivity of teak, since they favor water infiltration and retention during the dry season, as suggested by various authors (Fonseca, 2004; De Camino and Morales, 2013; Salcedo *et al.*, 2014; Ypushima-Pinedo *et al.*, 2014; Chaturvedi and Raghubanshi 2015), and as shown by the productivity of *El Mirador 2*. Soils with an AD > 1 g cm^3 interfere with the nutrition of teak trees (whose roots are scarcely extended in the soil), due to the increase in macropores. Changes in soil use generally modify the AD and benefit the retention of OM and of certain nutrients, such as N, P and S (Balagopalan and Jose, 1997; Rodas, 2006). Teak trees can adapt to a large variety of soils. A highly acidic pH decelerates their growth and productivity (Fonseca, 2004; Zhou *et al.,* 2012; De Camino and Morales, 2013). Thus, a larger timber volume was obtained by Mollinedo *et al.* (2005) on soils with a pH > 5.5 in teak stands established in Panama; by Watanabe *et al.* (2009), on soils with a pH of 6.5 to 7.5 in Africa, and Chaturvedi and Raghubanshi (2015), on soils with a pH > 7; these figures are comparable to those registered for the CTS *El Mirador 2*.

The results obtained by Balám-che *et al.* (2015) for CEC in stands in Mexico were lower than those registered on the soils of *El Mirador 2*; therefore, a loamy-clayey texture was a determining factor for cations retention, which increased the chemical fertility of the soil and contributed to the development of the CTSs (Mollinedo *et al.*, 2005, Salcedo-Pérez *et al.,* 2005). The application of correctives and fertilizers favors the increase in height and volume of teak trees by over 50 %, although their demand of nutrients is low during the first months of growth. However, the activity of the plants decreases as their crown size increases with age; this causes an increment in the deposits of OM in the soils (Fonseca, 2004; Suzuki *et al.,* 2007; Ugalde, 2013; Balám-Che *et al.,* 2015).

The N concentration in the soils analyzed in the present study was lower than that documented by Chaturvedi and Raghubanshi (2015) in India. The presence of this nutrient is necessary for microbial growth, as microbes degrade the OM; low N concentrations result in a slow decay of the OM. In this case, the mineralization of organic C will depend on the addition of alternative sources of N (Ferrara and Alarcón, 2001; FAO, 2017). The values obtained for the C/N ratio at *El Mirador 2* were very high (approximately twice those of *Cerritos 1* and *Cerritos 2*), which indicates a low concentration of OM in the analyzed soils. When the C/N ratio is above 14, the decay of OM is slow, since microorganisms immobilize N, hindering its utilization by the plants (Maycotte *et al*. 2011; Porta *et al*., 2014; Gamarra *et al.,* 2018).

Conclusions

Although the three stands were established under the same hydroclimatic and forest management conditions, the differences in tree growth are directly proportional to the quality of the soils and to the N concentration in the leaf biomass. The highest increments and productivity of teak occur on soils with the closest to neutral pH (> 6 < 7), a CEC of > 30 cmol $^{(+)}$ kg^{-1}, > 2.5 % OM at 0 – 10 cm, and a C/N ratio > 15. Also outstanding are the high leaf N concentrations, which amount to 83 % of the tree aerial biomass. The successful establishment of CTSs in exotic tropical areas requires, among other things, prioritizing soil health and the availability of N; otherwise, the productivity will be significantly affected.

Acknowledgements

We wish to express our gratitude to Álvaro Navarro Esquivel, BS, and his co-workers for approving the implementation of the project at the commercial teak stands under their charge; to the Department of Forest Production for partially funding of the project through P3E:224301-2327924; to the Department of Wood, Pulp and Paper (*DMCyP*), to Lovren R. G. H., for his indirect participation, and to the National Council for Science and Technology (*Consejo Nacional de Ciencia y Tecnología*, Conacyt) for financing the studies of Bayron Alexander Ruiz Blandon, MS, at the University of Guadalajara (*UdeG*).

Conflict of interests

The authors declare that they have no conflict of interests.

Contribution by author

Eduardo Salcedo-Pérez, Bayron Alexander Ruiz Blandon, and Efrén Hernández Álvarez: financial contribution, field work, laboratory work on the vegetal component and physical properties of the soils, analysis and interpretation of the results, and drafting of the manuscript; Ricardo González Cruz, Eulogio Orozco-Guareño, José Anzaldo Hernández and Ezequiel Delgado-Fornué: analysis and interpretation of results regarding the chemical properties of the soil, laboratory work, and editing of the manuscript; Antonio Bernabé-Antonio and César Bonifacio Ramírez-López: revision of the manuscript, and drafting and statistical interpretation of the results.

References

Alcántar, G. y L. Trejo. 2007. Nutrición de cultivos. Mundi Prensa. México, D.F., México. 451 p.

Arteaga, M. B. y M. L. Castelán. 2008. Evaluación dasométrica temprana de una plantación agroforestal de tres especies introducidas, en el municipio de Huehuetla, Hidalgo. Revista Chapingo: Serie Ciencias Forestales y del Ambiente 14 (2): 105-111.

Balagopalan, M. and A. I. Jose. 1997. Effect of tree species on soil properties along a transect through teak, eucalypt and rubber in Kerala. *In:* Chand, S., C. Mohanan and S. Sankar. Proceedings of the international teak symposium. Thiruvananthapuram, Kerala, India. pp 236-241.

Balám-Che, M., A. Gómez-Guerrero, J. J. Vargas-Hernández, A. Aldrete y J. J. Obrador-Olán. 2015. Fertilización inicial de plantaciones comerciales de teca (*Tectona grandis* Linn F.) en el sureste de México. Revista Fitotecnia Mexicana 38 (2): 205-212.

Bohre, P., O. Chaubey and P. Singhal. 2013. Biomass accumulation and carbon sequestration in *Tectona grandis* Linn. f. and *Gmelina arborea* Roxb. Journal of BioScience and Biotechnology 5 (3): 153-174.

Cancino, J. 2006. Dendrometría básica. Universidad de Concepción, Chile. 163 p.

Comisión Nacional Forestal (Conafor). 2011. Situación actual y perspectivas de las plantaciones forestales comerciales en México. Comisión Nacional Forestal-Colegio de Posgraduados. México, D. F. México. 472 p.

Comisión Nacional Forestal (Conafor). 2013a. Programa de Desarrollo de Plantaciones Forestales Comerciales, a 15 Años de su Creación. Comisión Nacional Forestal-Colegio de Posgraduados. México, D. F., México. 472 p.

Comisión Nacional Forestal (Conafor). 2013b. Evaluación de la situación actual de proyectos de Plantaciones Forestales Comerciales finiquitados. México, D. F., México. 74 p.

Chaturvedi, R. K. and A.S. Raghubanshi. 2015. Assessment of carbon density and accumulation in mono-and multi-specific stands in Teak and Sal forests of a tropical dry region in India. Forest Ecology and Management 339: 11-21.

De Camino, R. V. y J. P. Morales. 2013. Las plantaciones de teca en América Latina: Mitos y realidades. Serie Técnica. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). División de Investigación y Desarrollo. Turrialba, Costa Rica. 392 p.

Derwisch, S., L. Schwendenmann, R. Olschewski and D. Hölscher. 2009. Estimation and economic evaluation of aboveground carbon storage of *Tectona grandis* plantations in Western Panama. New Forests 37 (3): 227-240.

Espitia, C., G. Murillo y P. Castillo. 2011. Ganancia genética esperada en teca (*Tectona grandis* L.f.) en Córdoba (Colombia). Colombia forestal 14 (1): 81-93.

Ferrera C., R y A. Alarcón. 2001. La microbiología del suelo en la agricultura sostenible. CIENCIA Ergo-Sum 8 (2): 175-183.

Fonseca G., W. 2004. Manual para productores de teca (*Tectona grandis* L. f) en Costa Rica. Heredia, Costa Rica. 115 p.

Food and Agriculture Organization of the United Nations (FAO). 2009. The Future of Teak and the High-Grade Tropical Hardwood Sector: Planted Forests and Trees Working Paper FP/44E. Roma, Italia. http://www.fao.org. (15 de noviembre de 2016).

Food and Agriculture Organization of the United Nations (FAO). 2017. Soil Organic Carbon: the hidden potential. Food and Agriculture Organization of the United Nations. Rome, Italy. 76 p.

Gamarra L, C. C., M. I. Lezcano D., M. V. de Ortíz, M. D. P. Galeano y A. J. N. Cardús C. 2018. Relación carbono-nitrógeno en suelos de sistemas silvopastoriles del Chaco paraguayo. Revista Mexicana de Ciencias Forestales 9 (46): 4-26.

Germplasm Resources Information Network (GRIN). 2017. National Plant Germplasm System: Taxonomy for plants resources. Information network. https://npgsweb.ars-grin.gov/gringlobal/taxonomydetail.aspx?id=80123. (11 de mayo de 2017).

Hernández A., E., B. A. Ruiz, A. Gallegos y E. Salcedo. 2017. Estimación volumétrica en una plantación. Revista e-Cucba 5: 23-30.

Instituto Nacional de Estadística y Geografía (INEGI). 2017. Anuario estadístico y geográfico de Nayarit 2017. México. 469 p.

Instituto Nacional de Estadística y Geografía (INEGI). 2016. Mapa Digital de México (versión 6.1.0), México. http://gaia.inegi.org.mx/mdm6/. (12 febrero 2016).

Jayaraman, K. 2011. Report on the International Training Programme on teak Innovations in the Management of Planted Teak, Forests. 31 August - 3 September Kerala Forest Research Institute. Peechi, Kerala, India. 9 p

López, L. C. y A. González. 2005. Cultivo de la especie forestal comercial teca en el Sureste de México. Plan de negocios. Fundación mexicana para la Investigación Agropecuaria y Forestal. México, D.F., México. 55 p.

Maycotte, C. C., C. A. Pereira, B. E. Restrepo, F. Mauro, A. Calle, M. J. Velarde. 2011. Edafología 1. Universidad Autónoma del Estado de Hidalgo. Pachuca De Soto, Hidalgo, México. 170 p.

Mollinedo, M., L. Ugalde, A. Alvarado, J. Verjans y L. Rudy. 2005. Relación suelo-árbol y factores de sitio, en plantaciones jóvenes de teca (*Tectona grandis* L. f.), en la zona oeste de la cuenca del canal de Panamá. Agronomía Costarricense 29 (1): 67-75.

Murillo, R., A. Alvarado y J. Mark V. 2015. Concentración y acumulación de nutrimentos en la biomasa aérea de plantaciones de teca de 3 a 18 años en la cuenca del Canal de Panamá. Agronomía Costarricense 39 (3): 117-136.

Musálem S, M. A. 2007. Guía silvicultural de teca (*Tectona grandis* L.). *In:* Musálem, M. A. Memorias del Curso Silvicultura de Plantaciones Forestales Comerciales. Universidad Autónoma Chapingo. División de Ciencias Forestales. Programa de Postgrado. Chapingo, Estado de México, México. 50 p.

Pérez, D. and M. Kanninen. 2005. Stand growth scenarios for *Tectona grandis* plantations in Costa Rica. Forest Ecology and Management 210: 425-441.

Porta C., J., M. López–Acevedo R. y R. M. Poch C. 2014. Edafología: Uso y protección de suelos. 3a edición. Mundi-Prensa. Madrid, España. 607 p.

Rodas, C. 2006. Efecto del establecimiento de plantaciones forestales de teca (*Tectona grandis*) en áreas de potreros sobre características del suelo en Petén, Guatemala. Tesis de Maestría. Centro Agronómico Tropical de Investigación y Enseñanza (Catie). Turrialba, Costa Rica. 105 p.

Ruiz B, B. A. 2016. Valoración del carbono almacenado en una plantación forestal comercial de teca (*Tectona grandis*) bajo tres condiciones edáficas en Nayarit, México. Tesis de maestría. Centro Universitario de Ciencias Exactas e Ingenierías. Departamento de Madera, Celulosa y Papel Ing. Karl Augustin Grellmann. Zapopan, Jal., México. 84 p.

Salcedo-Pérez, E., A. Galvis, T. M. Hernández, R. Rodríguez, F. Zamora, R. Bugarin, R. Carrillo. 2005. La humedad aprovechable y su relación con la materia orgánica y superficie específica del suelo. Terra Latinoamericana 25: 419-425.

Salcedo P., E., A. L. Ypushima, R. González, J. F. Zamora, R. Rodríguez y R. Sánchez. 2014. Efecto de las propiedades edáficas y el contenido nutrimental foliar sobre el crecimiento de teca. Revista Mexicana de Ciencias Forestales 5 (24): 80-91.

Salisbury, F. B. y C. W. Ross. 1994. Fisiología Vegetal. Ed. Grupo Editorial Iberoamericano. México, D.F., México. 759 p.

Secretaría del Medio Ambiente y Recursos Naturales (Semarnat). 2002. Norma Oficial Mexicana NOM-021-RECNAT-2000, que establece las especificaciones de fertilidad, salinidad y clasificación de suelos. Estudios, muestreo y análisis. Diario oficial de la Federación. México, D. F., México. 85 p.

Shrawat, K. A., R. T. Carroll, M. DePauw, G. J. Taylor and A. Good. 2008. Genetic engineering of improved nitrogen use efficiency in rice by the tissue-specific expression of alanine aminotransferase. Plant Biotechnology Journal 6 (7): 722-732.

Society of American Foresters (SAF). 2009. Manejo de las plantaciones de teca para productos sólidos. STF Noticias. ISTF. *In:* Actas, Convención Nacional de la SAF, Sección International Trade and Markets. Sociedad Internacional de Forestales Tropicales. Orlando, FL USA. 27 p.

Sreejesh, K. K., T. P. Thomas, P. Rugmini, K. M. Prasanth and P. K. Kripa. 2013. Carbon sequestration Potential of Teak (*Tectona grandis*) plantations in Kerala. Research Journal of Recent Sciences 2: 167-170.

Statistical Analysis System (SAS). 2009. (Version 9.0) Raleigh, NC USA. s/p.

Suzuki, R., S. Takeda y H. M. Thein. 2007. Chronosequence changes in soil properties of teak (*Tectona grandis*) plantations in the Bago mountains, Myanmar. Journal of Tropical Forest Science 5 (24): 207-217.

Ugalde, A. L. 2013. Teak: New Trends in Silviculture, Commercialization and Wood Utilization. International Forestry and AgroForestry and Fao. San José, Costa Rica. 552 p.

Upadhyay, A., T. Eid, P. L. Sankhayan. 2005. Construction of site index equations for even aged stands of *Tectona grandis* (teak) from permanent plot data in India. Forest Ecology and Management 212: 14-22.

Watanabe, Y., T. Masunaga, E. Owusu-Sekyere, M. Buri, O. I. Oladele and T. Wakatsuki. 2009. Evaluation of growth and carbon storage as influenced by soil chemical properties and moisture on teak (*Tectona grandis*) in Ashanti region, Ghana. J. Journal of Food Agriculture and Environment 7 (2): 640-650.

Ypushima-Pinedo, A. L., E. Salcedo, R. Manríquez, J. A. Silva, J. F. Zamora y E. Hernández. 2014. Propiedades de la madera y relación del estado nutrimental con el crecimiento en teca. Revista Mexicana de Ciencias Forestales 5 (24): 26-39.

Zhou, Z., K. Liang, D. Xu, Y. Zhang, G. Huang and H. Ma. 2012. Effects of calcium, boron and nitrogen fertilization on the growth of teak (*Tectona grandis*) seedlings and chemical property of acidic soil substrate. New Forests 43: 231–243.

Zhou, Z., S. Liu, K. Liang, H. Ma and G. Huang. 2017. Growth and mineral nutrient analysis of teak (*Tectona grandis*) grown on acidic soils in south China. Journal of Forestry Research 28: 503–511.