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-Pérez¹, Bayron Alexander Ruiz Blandon¹-³, Efrén Hernández Álvarez²*, Ricardo González Cruz³, Antonio Bernabé-Antonio³, Eulogio Orozco-Guareño⁴, César Bonifacio Ramírez-López³, José Anzaldo Hernández³ y Ezequiel Delgado-Fornué³

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.
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).
Dendrometry and stereometry

Three 7 × 25.4 m experimental plots were built in each CTS and distributed at random (533.6 m² 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):

\[
BA = \left( \frac{n}{4} \right) D^2
\]
Where:

\( BA = \) Basal area (m²)

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

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

\[
V = (BA)(h)(MC)
\]  

Where:

\( V = \) Stem volume (m³)

\( BA = \) Basal area (m²)

\( h = \) 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 Smalian’s formula (Cancino, 2006):

\[
V = \frac{A_b + A_s}{2L}
\]  

Where:

\( V = \) Log volume (m³)

\( A_b = \) 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:

\[
MAI = \frac{DSV}{Age}
\]

(4)

Where:

\( MAI \) = Mean annual increment

\( DSV \) = Dendrometric and stereometric values (cm, m, m³)

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).
$\text{IMAD} = \text{Mean Annual Diameter Increment (MADI)}$; $\text{IMA}_h = \text{Mean Annual Height Increment (MAHI)}$. 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.

<table>
<thead>
<tr>
<th></th>
<th>Cerritos 1 Stand</th>
<th>Cerritos 2 Stand</th>
<th>El Mirador 2 Stand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (cm)</td>
<td>0-10</td>
<td>10-30</td>
<td>0-10</td>
</tr>
<tr>
<td>Texture</td>
<td>Ls</td>
<td>Lc</td>
<td>Lc</td>
</tr>
<tr>
<td>AD (g cm³)</td>
<td>0.87 ± 0.02</td>
<td>1.14 ± 0.01</td>
<td>0.95 ± 0.03</td>
</tr>
<tr>
<td>CEC (cmol(+)/kg)</td>
<td>28.70 ± 0.004</td>
<td>28.13 ± 0.02</td>
<td>38.85 ± 0.01</td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>0.06 ± 0.002</td>
<td>0.05 ± 0.01</td>
<td>0.04 ± 0.003</td>
</tr>
<tr>
<td>pH</td>
<td>6.22 ± 0.003</td>
<td>5.37 ± 0.002</td>
<td>5.58 ± 0.004</td>
</tr>
<tr>
<td>OM (%)</td>
<td>2.24 ± 0.01</td>
<td>0.62 ± 0.01</td>
<td>1.48 ± 0.002</td>
</tr>
<tr>
<td>C (%)</td>
<td>1.29 ± 0.002</td>
<td>0.35 ± 0.18</td>
<td>0.86 ± 0.30</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.07 ± 0.01</td>
<td>0.06 ± 0.001</td>
<td>0.06 ± 0.01</td>
</tr>
<tr>
<td>C/N</td>
<td>18.53 ± 0.09</td>
<td>5.87 ± 0.08</td>
<td>14.32 ± 1.04</td>
</tr>
</tbody>
</table>

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,
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.

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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.

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