Article

Site quality for *Agave durangensis* Gentry in the Mountain range of Registrillo, Durango

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Abstract

The *Agave durangensis* Gentry, is a natural resource that has been empirically exploited by the inhabitants of the semi-desert zone of the state of Durango. There are no scientific and regulatory elements that regulate or optimize the harvest of this product; therefore, having the present, provides the necessary tools for the correct use of agave. In the present investigation, the feasibility of five mathematical models was tested to determine the site quality of *A. durangensis* in the semi-desert zone of the Mountain range of Registrillo, Municipality of Durango, Mexico. The database used consisted of 204 pairs of dominant agaves in height-age, selected from 180 sampling sites in 1 000 m^2 each, taken in the study area through systematic sampling. The adjustment of the mathematical models was performed by weighted non-linear regression methods to correct the problem of heterocedasticity of variance observed in the dominant-age height relationship. The results of the adjustment of the equations indicate that the Chapman-Richards model was the one that best determines site quality. Based on the analysis carried out, it is concluded that the use of site index models is feasible to classify the productivity of *A. durangensis* sites in the study area. The developed model provides compatible equations of site index and growth in dominant height.

Keywords: agave ash, site index models, weighted non-linear regression.

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Introduction

The intensive use of agave ash (*Agave durangensis* Gentry and *A. salmiana*) to obtain ethyl alcohol in the Durango region dates back more than 50 years. Previously, the use of this plant was done domestically, since there were no vinases that used considerable quantities for commercial exploitation. It is at the end of the seventies when some mezcal-producing plants were established in the region of the Mountain range of Registrillo, which consumed and hoarded the agave ash, for the production of beverages such as mezcal (Díaz, 2002).

The Official Mexican Standard 007, version 1997 of the Ministry of Environment and Natural Resources (NOM-007-SEMARNAT-1997), states that this species must be exploited under techniques that ensure its development and sustainability. However, this is rare, since management programs lack technical information to quantitatively and qualitatively measure its potential (Díaz, 2002). On the other hand, Velasco and Marquez (2003) point out that with the increase in demand for mezcalero agave to satisfy the regional, national and international market, the resource has been under pressure.

Currently, it has become a rule to implement methods based on the productive potential that classify forest areas that make estimates for the future growth of the resource to be harvested. 'The site index is the unit of measurement with which the productivity of the forest areas is determined, this is defined as the maximum height reached by the dominant or codominant trees at a base age under the current conditions presented by the site' (Pritchett, 1991). This parameter of productivity can be applied and estimated in other non-timber plants, such as agaves, since it is also possible to classify these plants by their dominance, proposed by Kraft (1884).

The knowledge of this factor contributes in the decision making for the elaboration of an adequate management program, when determining a cutting intensity that does not put at risk the sustained yield and at the same time, avoid the deterioration of a forest area underutilization (Corral- Rivas *et al*., 2014). The objective of the present work was to evaluate the feasibility of mathematical models to determine the site quality for *A. durangensis* in the Mountain range of Registrillo region, municipality of Durango, Mexico, by using the dominant-age height relationship.

Materials and methods

Location of the study area

This investigation was carried out in the Mountain range of Registrillo in the municipality of Durango, Mexico, located within the geographic coordinates 23º 55' and 23º 41' north latitude and 104º 25' and 104º 33' west longitude with respect to the Greenwich meridian; specifically, in lands of the commons San Francisco of Manzanal, Tomas Urbina, Jose María Pino Suarez, Nicolás Romero, Valle Florido, Antonio Gaxiola, Primero of Mayo and Colonia Minerva. The access to the land is through the Durango-Mezquital road or the Durango-Mexico highway (Figure 1) at a distance of 25 km from the city of Durango, Durango.

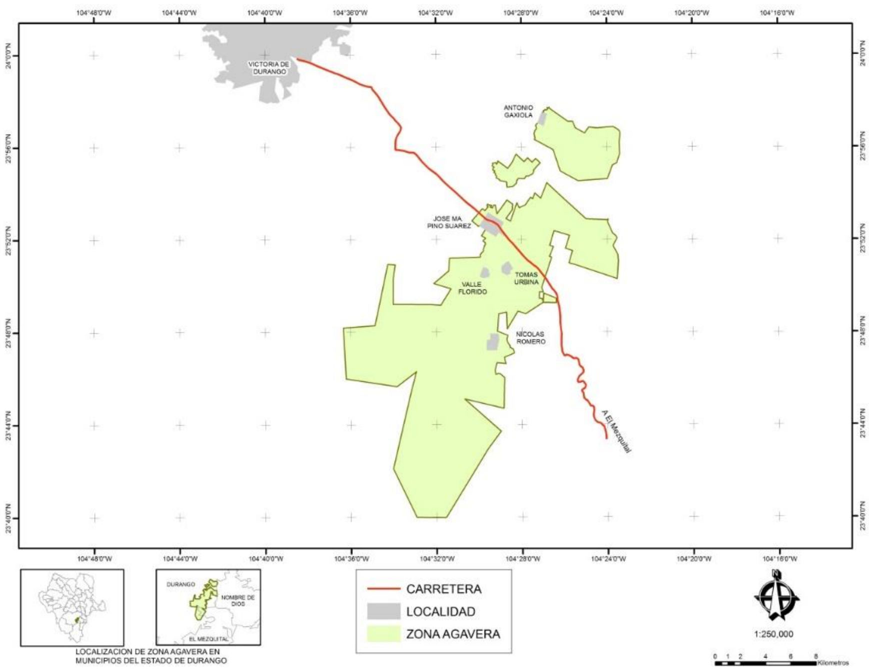

Figure 1. Location of the study area.

Sampling methods

A directed sampling with circular sites of 1 000 m^2 was used, with the purpose of covering all ranges of station quality, age, altitude, exposure and slope, considering also the biometric characteristics of *A. durangensis* and its spatial distribution within of the study area for the elaboration of the site index curves. This type of sampling is common in the development of works related to the estimation of quality curves (Corral-Rivas *et al*., 2014). The agaves used to carry out this work corresponded to those whose phenotypic characteristics (height and vigor) have the appearance of being dominant within the different sampling sites and growing free of suppression (Figure 2).

Figure 2. Field-directed sampling method.

Statistics used

The data used for the development of the site index curves included 204 pairs of dominant height and age. These observations were adjusted non-linear models: Weibull I, Chapman-Richards, Korf, Sloboda and McDill and Amateis, under the consideration that the dominant-age relationship corresponds to the sigmoid growth curve, which is not of the type linear (Rodríguez and Leihner, 2006). The mathematical expressions of the tested models are presented in Table 1, in all the equations the dominant height growth of the agaves was expressed as a function of age.

Table 1. Mathematical models used to determine the site quality of *A. durangensis*.

Núm.	Model	Source
1	$H = b_0\left(1 - \exp^{-b_1}\left(t - b_2\right)^{b_3}\right)$	Weibull I
2	$H = b_0\left(1 - \exp\left(-b_1 t\right)\right)^{b_2}$	Chapman-Richards
3	$H = b_0 \exp\left(-b_1 t^{-b_2}\right)$	Korf
4	$H = b_0 \exp\left(-b_1 \exp\left(\frac{b_2}{\left(b_3 - 1\right)\cdot t^{\left(b_3 - 1\right)}}\right)\right)$	Sloboda
5	$H = \frac{b_0}{1 + b_2 / t^{b_1}}$	McDill and Amateis

H= dominant height (in cm); *t*= age (in years); exp= base of natural logarithms; b_0, b_1, b_2, b_3= parameters to be estimated.

The proposed models for the estimation of the site index of *A. durangensis* were selected according to other investigations carried out on timber species, specifically of the *Pinus* genus (Corral-Rivas *et al*., 2004; Vargas, 2010) and because they have particularly showed the most satisfactory results. The adjustment of the models was performed by ordinary least squares using the NLIN procedure of the statistical program SAS/STAT® (SAS Institute Inc., 2004). To correct the heterocedasticity problem of variance observed in dominant-age height relationships, the weighted regression methods proposed by Furnival (1961) and Cailliez (1980) were used.

The criteria used to calibrate and determine the sensitivity of the models were based on a numerical and graphical analysis of the residues. The numerical analysis consisted in the comparison of four statistics frequently used in forest modeling: the bias, the root of the mean square error, the adjusted coefficient of determination and the Akaike information criterion in differences. The root mean squared error (REMC) analyzes the accuracy of the estimates, the adjusted coefficient of determination (R2adj) represents the variance that is explained by the model, and the Akaike Information Criteria in differences (AICd) is used to select the variance. Better model and is based on minimizing the distance of Kullback-Liebler (Burnham and Anderson, 1998). The mathematical expressions of said statistics are presented in Table 2.

Table 2. Calibration and sensitivity of the models used to determine the site index for *A. durangensis*.

Nombre	Ecuación	Número
Slant	$\overline{E}=\sum_{i=1}^{n}(y_i-\hat{y}_i)/n$	1)
Root of the mean square error	$RMSE=\sqrt{\sum_{i=1}^{n}(y_i-\hat{y}_i)^2/(n-p)}$	2)
Coefficient of determination adjusted	$R_{\text{adj}}^2=1-(n-1)\cdot\sum_{i=1}^{n}(y_i-\hat{y}_i)^2/(n-p)\cdot\sum_{i=1}^{n}(y_i-y_i)^2$	3)
Akaike information criterion in differences (AICd)	$AICd=n\cdot\ln\hat{\sigma}^2+2\cdot l-\min(n\cdot\ln\hat{\sigma}^2+2\cdot l)$	4)

y_i, $\hat{y}_i$, $\bar{y}$ = observed, predicted and mean value of the dependent variable; n= total number of observations used to adjust the model; l= number of parameters of the model calculated as ($p+1$); $\hat{\sigma}^2$= variance estimator; p= number of parameters of the model.

For the graphical analysis, different representations of the experimental data and the residues after the adjustment of the models were examined. These graphs represent a very important tool in the selection of a model, since they allow to detect errors or abnormal behaviors (Rawlings, 1988).

The site quality curves were generated through the parameter substitution method, this method makes a parameter or group of parameters dependent on site quality. The derived curves are anamorphic, due to the nature of the experimental data (only one measure of dominant height and age was counted).

Results and discussion

The estimation of the parameters, in all cases, was significant or different from zero. The results indicate that all models predict similarly the dominant height of *A. durangensis*. However, models 1 and 2 (Weibull and Chapman-Richards) presented better adjustments, since the values of the Akaike information criterion were the lowest (Table 3).

Table 3. Estimated statistics of the selected models.

Model	β_O	β_1	β_2	β_3	Sesgo	RMSE	R^2	AICd
1	190.4488	0.0192	0.1863	1.5384	0.099424	30.16418	0.635957	0.949
2	191.3502	0.126277	2.209669		0.188395	30.16671	0.634076	0
3	193.6255	22.66431	1.516611		0.215478	30.84025	0.617553	9.009
4	190.6384	4.324558	0.207562	0.132335	0.154737	30.21396	0.634755	1.621
5	191.163 5	2.199 848	164.553 8		0.154034	30.361 88	0.629325	2.631

Also, these two models had slightly higher coefficients of determination and their errors were low. The bias values (0.099424 and 0.188395 cm for model 1 and 2, respectively) indicate only a minor underestimation. Based on the principle of selecting the simplest model, Model 2 or Chapman-Richards is recommended for determining the site index of the species *A. durangensis* in the studied area. The expression to be used is determined by the following equation:

$$H = 191.3502(1 - \exp(-0.126277t))^{2.209669}$$

Where: H= dominant height (in cm); t= age (in years).

The graphic analysis of the residuals for this model showed an adequate distribution, by adequately correcting the heterocedasticity problem of variance present in the dominant-age height relationship of the data analyzed (Figures 3 and 4). The Figure 3 is the result of the residuals obtained from the adjustment of the model without weighted regression, where a problem of inequality of variance is clearly shown. The correction of this problem is observed in Figure 4, which was derived from the studentized residuals obtained from the weighted adjustment.

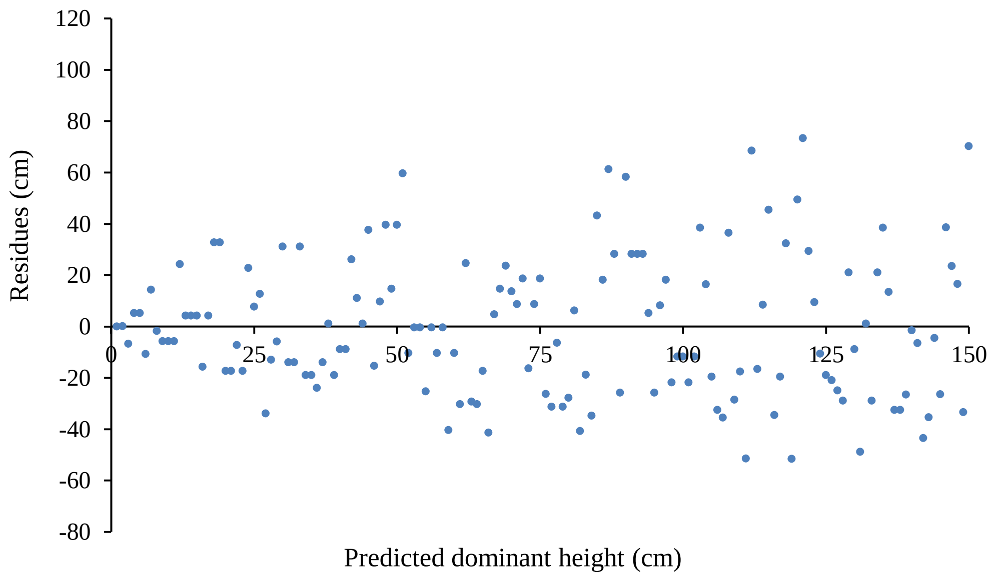

Figure 3. Residues against the predicted dominant height without correcting the variance heterocedasticity for *A. durangensis*.

The value of k obtained from the residuals generated by this equation was 1.17. This value was then included within the weighting factor $w_i = {}^{1}/_{d_{sti}^{k}}$ to obtain the homocedastic residuals of Figure 4.

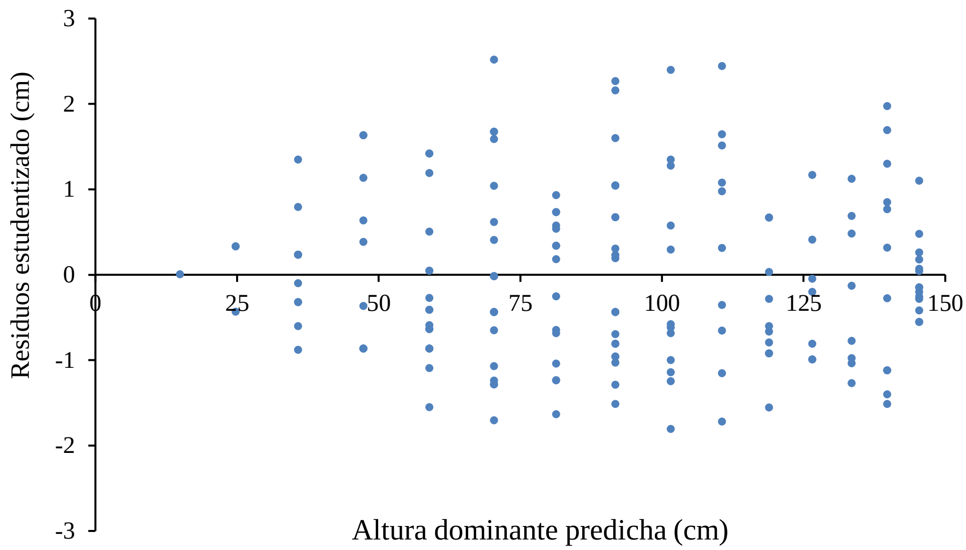

Figure 4. Studied residuals against the predicted dominant height with corrected heteroskedasticity for *A. durangensis*.

Finally, the qualities of the site index were determined in relation to a base age of 10 years, leaving 45 cm, 70 cm, 95 cm, 120 cm and 145 cm for the site qualities (CS) 1, 2, 3, 4 and 5 respectively (Figure 5). The CS 3 corresponds to the guide curve superimposed on the dominant-age height data pairs. It was decided to use a base age of 10 years, because it is estimated that this value corresponds to the physiological turn of the species. In the graphic representation of the anamorphic curves, it can be observed how they fit very well to the data cloud of dominant height and age for *A. durangensis* (Figure 6).

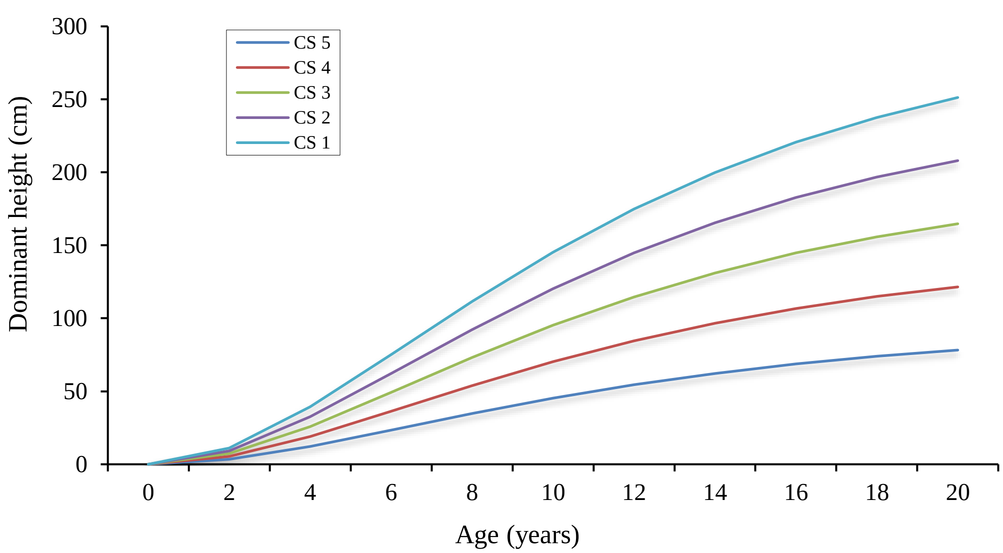

Figure 5. Site index curves obtained after solving the model by the parameter β_0.

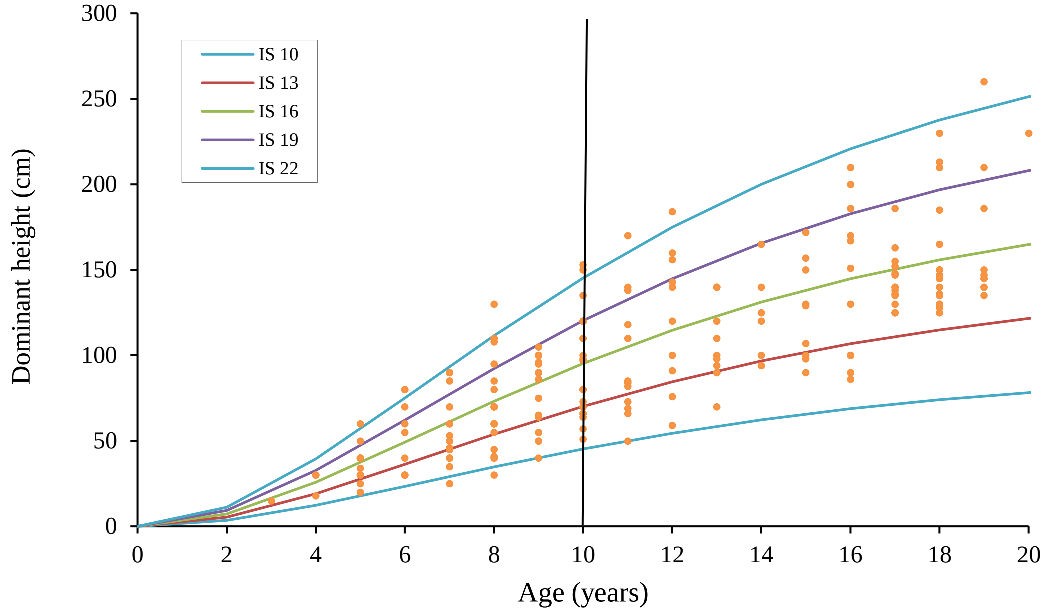

Figure 6. Anamorphic curves of site index for *A. durangensis* obtained with the Chapman-Richards model at a base age of 10 years.

Also, the Chapman-Richards model showed good flexibility for the estimation of the site index of *A. durangensis* explaining more than 62% of variance observed in the dominant height. This result indicates that the Chapman-Richards model also shows good flexibility for modeling the site index of non-timber species such as maguey, as well as timber species (Corral-Rivas *et al*., 2004). Until the writing date of this work, the mathematical tools developed for the management of maguey in the study region were very few. The work of Díaz *et al*. (2007); Ortiz (2007), who propose some mathematical models to elaborate production tables of *A. durangensis*; however, they have the disadvantage of not considering site quality as an input variable and therefore assume the same productivity levels for all stands.

Loera *et al*. (2012) conducted a study on the ecological factors of an agave community in the same region, and found a significant relationship between age and height of the agaves, a result that is consistent with the present in the use of the variable age as a variable of predictive importance in the modeling of the growth of this species; on the other hand, Aguirre *et al*. (2001) report relationships between mezcalero agave dimensions in San Luis Potosí, Mexico and site conditions. The use of season quality curves developed in this work will allow forest managers to make technical decisions that do not compromise *A. durangensis* persistence, so that in the quality of site 5 (poor) the possibility of harvesting should be lower than in those areas that enjoy a quality of site 1 (good).

Conclusions

The dominant height-age relationship of the species *A. durangensis* was found to be a valid parameter to determine the quality of the site in the study area. Of the models analyzed, the Champman-Richards model was the most adequate to construct the system of anamorphic curves for *A. durangensis* in the studied area, providing adequate estimates of the site index and the height growth dominant for said species.

The results of this work represent a very useful tool for forest managers in the field of non-timber forest resources, since there is almost no research in this regard. By now having a measure of the quality of the site, the dasocratic division of the productive potential of each of the stands and subroads can be made; through, its incorporation into the management programs of the area.

Cited literature

Aguirre, J. R.; Charcas, H. y Flores, J. L. 2001. El maguey potosino. Consejo Potosino de Ciencias y tecnología, Gobierno del Estado de San Luis Potosí; Instituto de Investigación de Zonas Desérticas, Universidad Autónoma de San Luis Potosí, México. 47-56 pp.

Cailliez, F. 1980. Estimación del volumen forestal y proyección del rendimiento con referencia a los trópicos. Vol 1. Estimación del volumen. FAO. Roma, Italia. 92. p.

Corral, R. J. J.; Álvarez, J. G.; Ruíz, A. D. and Gadow, K. V. 2004. Compatible height and site index models for five pine species in El Salto, Durango (México). Forest Ecol. Management. 201(2-3):145-160.

Díaz, M. 2002. Permiso de aprovechamiento de agave cenizo, para el ejido San Francisco del Manzanal, municipio de Durango. UJED. Escuela de Ciencias Forestales. Durango, Durango. 92 pp.

Díaz, M., Bretado, J. y Montiel, E. 2007. Elaboración de tablas de producción para el agave en el municipio de Durango, Durango. *In*: memorias del VIII Congreso Mexicano de Recursos Forestales. Sociedad Mexicana de Recursos Forestales. Facultad de Ingeniería en Tecnología de la Madera-UMSNH. Morelia, Michoacán, México. 1-7 pp.

Furnival, G. M. 1961. An index for comparing equations used on constructing volume tables. Forestrie Science. 7(4):337-341.

Kraft, G. 1884. Beiträge zur Lehre von den Durchforstungen, Schlagstellungen and Lichtungshieben. Klindworth’s Verlag, Hannover. 147 pp.

Loera, H.; Rodríguez, E.; Montiel, E.; Díaz, M.; Orona, I.; Ojeda, G.; López, J. C. y Iliana, S. I. 2012. Factores ecológicos de una comunidad de *Agave durangensis* en la Sierra de Registrillo, Durango. México. UJED. Agrofaz. 12(1):81-88.

Norma Oficial Mexicana. (NOM-007-SEMARNAT- 1997). Diario Oficial de la Federación. México. 23 de octubre de 1995. 8 p.

Ortiz, R. 2007. Evaluación de los modelos matemáticos para elaborar tablas de producción, para *Agave durangensis Gentry* en el municipio de Durango, Durango. Tesis de maestría. Facultad de Ciencias Forestales, UJED Durango, México. 46 p.

Pritchett, W. L. 1991. Suelos forestales: propiedades, conservación y mejoramiento. (Ed.). Limusa. México, DF. 634 p.

Rawlings, J., Pantula, S. and Dickey, D. (1988). Applied regression analysis: a reseach tool. 2nd ed. Raleigh, NC. USA: Springer.

Rodríguez W. and Leihner, D. 2006. Análisis del crecimiento vegetal. Volumen 7 de la Serie: fisiología de la producción de los cultivos tropicales. Primera edición. Editorial Universidad de Costa Rica. San José, Costa Rica. 37 p.

Statistical Analysis System (SAS). 2004. User's guide. SAS/ETS® 9.1. SAS Institute Inc. Cary, NC. USA. s/p.

Velasco, G. O. H y Márquez, L. M. A. 2003. Desarrollo sustentable del maguey mezcalero en Durango. IPN. CIIDIR Durango, Durango. 174 p.

Vargas. B.; Álvarez, J.; Corral, R. J. y Aguirre, O. 2010. Construcción de curvas dinámicas de índice de sitio para *Pinus cooperi* Blanco. Fitotec. Mex. 33(4):343-351.