ACTA AMAZONICA
http://dx.doi.org/10.1590/1809-4392202402622

GEOSCIENCES - ORIGINAL ARTICLE

Analysis of the *Guazuma crinita* site index as a predictor of forest plantation quality in the Aguaytía River basin, Ucayali, Peru

Edinson E. LÓPEZ-GALÁN[1], Jorge M. REVILLA-CHÁVEZ[2,4]*, Gilberto DOMÍNGUEZ-TORREJON[1], Héctor E. VIDAURRE-ARÉVALO[7], Leoncio J. UGARTE-GUERRA[8], Jorge BENDEZÚ[3], Jorge J. REVILLA-MACEDO[6], Alexandre M. SEBBENN[4,5]

[1] Programa de Maestríía de Bosques y Gestióón de Recursos Forestales, Escuela de Posgrado, Universidad Nacional Agraria La Molina, Av. La Molina, Distrito de La Molina, Lima 25012, Perú

[2] Instituto de Investigaciones de la Amazonía Peruana, Yarinacocha, Coronel Portillo, Ucayali 25004, Perú

[3] Universidad Privada del Norte (UPN), Lima 15083, Perú

[4] Postgraduate Program in Agronomy, Universidade Estadual Paulista/UNESP, CEP 15385-000, Ilha Solteira - SP, Brazil

[5] São Paulo Forestry Institute, CEP 01059-970, São Paulo - SP, Brazil

[6] Universidad Nacional de Ucayali, Facultad de Ciencias Forestales y Ambientales, Escuela Profesional de Ingeniería Forestal, Pucallpa, Ucayali 250101, Perú

[7] Ministerio de Agricultura, Servicio Forestal SERFOR, Dirección General de Gestión del Conocimiento Forestal y de la Fauna Silvestre, Lima 15065, Perú

[8] Ministerio de Agricultura, Servicio Forestal SERFOR, Programa BPS, Lima 15065, Perú

* Corresponding author: jrevilla@iiap.gob.pe

ABSTRACT

The site index (SI) was evaluated in *Guazuma crinita* plantations for the Aguaytía River region, Ucayali, Peru, with seedlings from 200 open-pollinated families from 14 sites using a randomized block design in three sectors of the basin. At 48 months, the height (H), diameter at breast height (DBH), and the number of branches with leaves (C/Leaf) and without leaves (S/Leaf) of the trees in 11 plantations were measured. The population means were 9.8 cm (DAP), 1139.6 cm (H), 12.4 branches (C/Leaf) and 2.4 branches (S/Leaf), distributed in four phenotypic groups (G1, G2, G3, G4). Groups G1 and G3 presented greater growth in DAP and H. The correlations between SI and edaphic variables show a significantly positive association with calcium (Ca^{+2}: 0.62), cation exchange capacity (CEC: 0.67), magnesium (Mg^{+2}: 0.61), and pH (059), and non-significant negative association with texture (-0.38), sand (-0.38), potassium (K^{+}: -0.15) and aluminum (Al^{+3}: -0.39). Physiographic and climatic correlations indicate a significantly strong association between SI and elevation (0.85) and precipitation (0.97), while correlations between SI and DBH, H, basal area (BA) and volume (V) They have a high significance of 0.8, 0.7, 0.7 and 0.8, respectively. The middle and upper sectors of the basin present more favorable conditions for the development of commercial plantations that improve with the selection of the best phenotypic groups from the Río Aguaytía, San Alejandro, Río Curimana and Von Humboldt collection sites.

KEYWORDS: Amazon Forest, forest plantation, white bolaina, site index, provenance

Análisis del índice de sitio de *Guazuma crinita* como predictor de la calidad de las plantaciones forestales en la cuenca del río Aguaytía, Ucayali, Perú

RESUMEN

Se evaluó el índice de sitio (SI) en plantaciones de *Guazuma crinita* para la región del río Aguaytía, Ucayali, Perú, con plántulas de 200 familias de polinización abierta de 14 sitios mediante un diseño de bloques al azar en tres sectores de la cuenca. A los 48 meses, se midió la altura (H), el diámetro a la altura del pecho (DAP), el número de ramas con hojas (C/Hoja) y sin hojas (S/Hoja) de los árboles en 11 plantaciones. Las medias poblacionales fueron 9.8 cm (DAP), 1139.6 cm (H), 12.4 ramas (C/Hoja) y 2.4 ramas (S/Hoja), distribuidos en cuatro grupos fenotípicos (G1, G2, G3, G4). Los grupos G1 y G3 presentaron mayores crecimientos en DAP y H. Las correlaciones entre SI y variables edáficas muestran una asociación significativamente positiva con calcio (Ca^{+2}: 0,62), capacidad de intercambio catiónico (CEC: 0,67), magnesio (Mg^{+2}: 0,61), y pH (059), y asociación negativa no significativa con textura (-0,38), arena (-0,38), potasio (K^{+}: -0,15) y aluminio (Al^{+3}: -0,39). Las correlaciones fisiográficas y climáticas indican una asociación significativamente fuerte entre SI y la elevación (0,85) y la precipitación (0,97), mientras que las correlaciones entre SI y DAP, H, área basal (BA) y volumen (V) tienen una alta significancia de 0,8; 0,7; 0,7 y 0,8 respectivamente. Los sectores medio y alto de la cuenca presentan condiciones más favorables para el desarrollo de plantaciones comerciales que mejoran con la selección de los mejores grupos fenotípicos de los sitios de recolección Río Aguaytía, San Alejandro, Río Curimana y Von Humboldt.

PALABRAS CLAVE: Selva Amazónica, plantación forestal, bolaina blanca, procedencia, índice de sitio

CITE AS: López-Galán, E.E.; Revilla-Chávez, J.M.; Domínguez-Torrejon, G.; Vidaurre-Arévalo, H.E.; Ugarte-Guerra, L.J.; Bendezú, J.; *et al.* 2026. Analysis of the *Guazuma crinita* site index as a predictor of forest plantation quality in the Aguaytía River basin, Ucayali, Peru. *Acta Amazonica* 56: e55gs24262.

INTRODUCTION

The popularity of bolaina blanca, or *Guzuma crinita*, timber has led to producers cutting down younger and younger trees (Rochon *et al.*, 2007). This wood is then processed at sawmills located in the Curimaná and Nueva Requena areas, within the Coronel Portillo and Padre Abad provinces of Ucayali, Peru. Most of this wood comes from naturally regrowing forests along the Aguaytía River and its connected streams. Yet, this supply struggles to keep pace with the timber industry's increasing needs (Revilla-Chávez *et al.* 2022b). As a result, the region of Huánuco has seen the creation of commercial tree farms to meet the strong demand, presenting a key financial chance for those replanting forests in Amazonian areas (Ramos-Huapaya and Domínguez 2016). This could become a good replacement for only cutting down certain trees in natural forests if the right support plans are put into place (Martínez-Zurimendi *et al.* 2015).

The places where trees grow best depend on environmental conditions. Therefore, it's key to know how well tree species chosen for tropical forest planting can adjust, grow, and live. In these regions, temperature, rainfall amounts, and elevation create the basic environmental conditions, and also affect other environmental aspects, either straight away or in less obvious ways (Revilla-Chávez *et al.* 2022b). Therefore, a plantation site is established as a uniform area that can promote growth, where ecological characteristics (such as forest, fauna, climate, topography, soil) are also important to consider. Site evaluations can contribute to identifying the productive potential of present and future forest stocks (Murillo-Brito 2017; Hernández-Ramos *et al.* 2023; García-Cuevas *et al.* 2021; Carvajal-Arroyo 2022).

For this reason, the World Center for Agroforestry (ICRAF) has conducted domestication trials of *G. crinita* to evaluate the response of F1 progeny collected between 1999 and 2005 and installed in 15 plantations as seed orchards. In production plots in the Aguaytía River basin, preliminary results indicate that there are significant differences in the growth of *G. crinita* due to genetic, climatic, and edaphic factors (Revilla-Chávez *et al.* 2022a, 2022b). Thus, it is important to measure the productivity indicators in the plantations in which the research was conducted and their interaction with the site index (SI; Vaca *et al.* 2020). In a previous study on stability, adaptability, and productivity at 36 months of age in the same river basin, both site and progeny showed significant differences; however, no significant differences were found for the genotype-environment interaction (Revilla-Chávez *et al.* 2022b). Therefore, this study contributes new information on site indices for diameter, height, and leaf traits of *G. crinita* at 48 months of age, based on observations of the upper quintile of trees. The evaluation of the site index in forest plantations of the Aguaytía River basin is particularly relevant as it links growth performance with soil, climate, and provenance through phenotypic grouping, providing a robust indicator of the species' potential for commercial plantations in the Peruvian Amazon.

MATERIAL AND METHODS

Study Species

Guazuma crinita (bolaina blanca) is a durable, fast-growing heliophyte tree species that can reach usable dimensions between 6 and 9 years (Revilla *et al.* 2021). The species is widely distributed throughout the Neotropics, from Central America to the Amazon, southern Brazil and Bolivia, and mostly occurs at up to 1,500 m above sea level (Reynel *et al.*, 2003). The species is abundant in the Peruvian Amazon, occurring in areas with both constant high rainfall and a marked dry season, where it develops mainly in early secondary vegetation, along roads, and in disturbed sites, growing on silty to sandy soils of low fertility or stony substrates. Although it does not tolerate waterlogging during the seedling stage, it thrives in nutrient-rich soils along riverbanks and streams, forming nearly homogeneous "bolainales" or isolated individuals. It is often associated with pioneer species such as *Schizolobium amazonicum*, *Croton matourensis*, *Cecropia* spp., *Calycophyllum spruceanum*, *Cordia alliodora* and *Inga* spp., among others (Flores 2018).

Study sites

The research was conducted in the Aguaytía River basin, a tributary of the Ucayali River, Coronel Portillo province, Ucayali, Peru (9°24'12.3" S and 8°08'25.9" S and 75°54'38.9" W and 74°04'25.2"W), covering an area of 1,762,086 ha. The Aguaytía River basin extends southwest of the city of Pucallpa and presents a mountainous landscape on the western side and a predominantly flat and flood prone relief to the east (Revilla-Chávez *et al.* 2021).

Experimental design

In 1998, the Agroforestry Tree Domestication Program of the World Center for Agroforestry (ICRAF) carried out a collection of *G. crinita* open-pollinated seeds from 200 trees from 14 sites (provenances) in the Aguaytia River basin (Figure 1a). Selection was based on commercial quality criteria, i.e., stem form and crown. With the germplasm of the 14 provenances, 15 plantations or plots of 2,500 m^2 each were installed in 2001 in the non-flooding zone of the Aguaytia River basin. Seedlings were planted at a spacing of 2.5 x 2.5 m, using a randomized block design, 15 plots with 200 subplots each, each subplot corresponds to one progeny (200 progenies) two plants per progeny in each subplot, for a total of 400 plants per plot, plus two non-evaluable border lines with a five-meter-wide "fire break" around the plot. The plots were distributed in three geographic sectors (block), corresponding to the lower, middle, and upper parts of the basin.

All plantations were established by the ICRAF program, based on the principles of participatory research with farmers and on farms (Cornelius and Ugarte 2010). The areas in which the plantations were installed correspond to areas with previous land use for annual crops, pastures, and areas

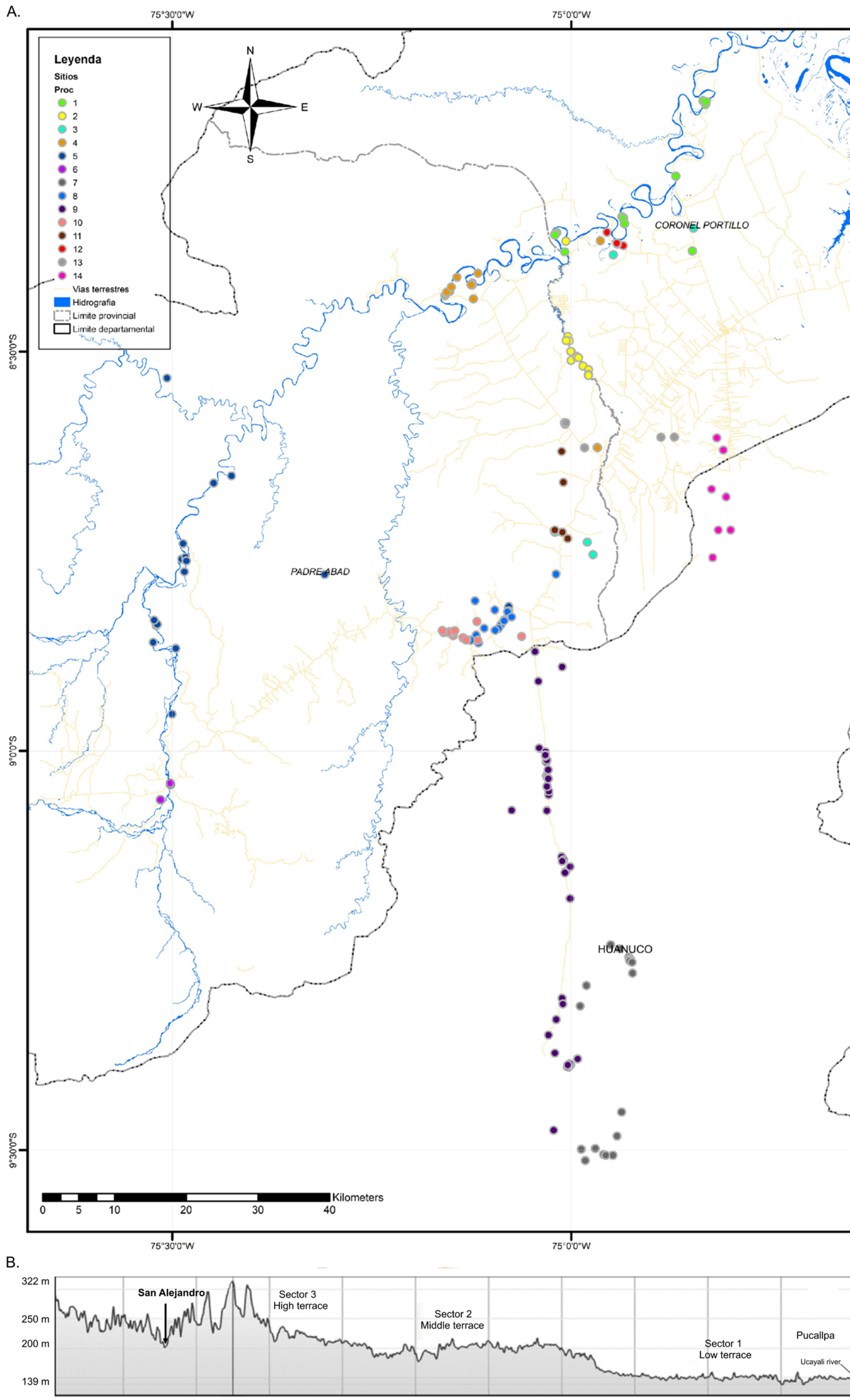

Figure 1. Location of progeny collection and groups of *Guazuma crinita* plots in the Aguaytia river basin. A. Seed collection locations from 209 trees for *Guazuma crinita* progeny testing: 1= New Requena – River (17 trees); 2= Neshuya Stream (13 trees); 3= Tahuayo Stream (11 trees); 4= Curimana – River (20 trees); 5= Aguaytia River (19 trees); 6= Yurac Stream (3 trees); 7= Inca Port (18 trees); 8= Von Humboldt (17 trees); 9= Macuya (49 trees); 10= Santo Alexandre (17 trees); 11= CFB up to Km 72 (7 trees); 12= Road to Nueva Requena (4 trees); 13= Road to Curimaná (7 trees); 14= Road to Tournavista (7 trees) (Source: Revilla-Chávez ***et al.***, 2021). The collection coordinates can be found in the Table A1. B. altitude of the sectors in the Aguaytia River basin.

in recovery. At 36 months of age, phenotypic thinning, consisting of the elimination of the shortest individual, with a forked and/or inclined stem for each progeny, according to the Revilla-Chávez *et al.* (2024b) classification. For the present study, 11 of the 15 plantations or plot, distributed across three elevation sectors or block were included in the analysis, where: block 1 corresponds to Campo Verde - Nueva Requena lower basin; block 2 to Neshuya - Curimaná highway, middle basin; and block 3 includes plants, from 14 collection sites and 193 identified progenies.

Study variables

At 48 months after planting, height (H, m), diameter at breast height (DBH, cm), basal area (m^2 ha^{-1}) and volume (m^3 ha^{-1}), and the number of top branches with leaves (BTWL) and without leaves (BTWOL) were used to determine the site index (SI) and the productivity of commercial forest plantations. Considering the different number of progenies per provenance (Figure 2), the observations were classified into four phenotypic groups (G1, G2, G3, and G4) based on the values of the measured variables, in order to evaluate their influence on the site index and productivity.

Edaphoclimatic characterization

For site characterization, plantations were mapped in relation to the digital coverage of the Ecological Economic Zoning of the Aguaytia River basin (GRU 2017) using ArcGIS 10.5 with the ArcMap 10.5 tool and ArcCatalog 10.5 (Table A1). The temperature (°C), precipitation (mm ha^{-1} $year^{-1}$), and elevation (m a.s.l.) were obtained from Fick and Hijmans (2017), and the classification of climatic zones was from on the Climate Classification map of Peru (SENAMHI 2018) (Table A2). Soil characteristics were assessed based on samples taken using the Bazan (2017) methodology and analyzed in the National Institute of Agrarian Innovation (INIA) soil laboratory (Table A3).

DATA ANALYSIS

Descriptive statistics for the set of plots were developed for tree height (H, m), diameter at breast height (DBH, cm), and the number of upper stem branches with and without leaves (Table 1). In addition, the basal area (AB, m^2) was derived as AB = π $DBH^2 . 400^{-1}$, and the tree volume (V, m^3) was estimated using the species-specific allometric equation $Ln(V)= 0.79 + 6.07 Ln (DBH^2) + 10.85 Ln (DBH*H) – 10.49 Ln (DBH^2*H)$ (Revilla *et al.*, 2021).

Provenance, defined as the seed collection area comprising more than one progeny, and progeny, defined as plants derived from open-pollinated seeds of a selected tree, were explicitly considered as grouping factors to assess differences between genetic sources, while edaphic, physiographic and climatic variables of the study sites (soil texture, clay, sand, Ca^{+2}, Mg^{+2}, K^+, CEC, pH, organic carbon, P; altitude, precipitation and temperature) were used in the site index and productivity analyses.

Table 1. Descriptive statistics of diameter at breast height (DBH, cm), total height (H, m), number of top branches with leaves (BTWL), and number of top branches without leaves (BTWOL) of *Guazuma crinita* at 48 months of age across all evaluated trees and plots in the Aguaytía River basin, Ucayali, Peru.

Statistics	DBH (cm)	H (m)	BTWL (# branches)	BTWOL (# branches)
Number of observations	3181	3181	3181	3181
Median	9.3	10.6	10	2
Mean	9.8	11.4	12.4	2.4
Standard deviation (n)	3.8	4.5	7.7	2
Coefficient of variation (%)	0.4	0.39	0.6	0.9
Lower limit of the mean (95%)	9.7	11.2	12.2	2.2
Upper limit of the mean (95%)	9.9	11.6	12.7	2.3

To classify tree performance across provenances, phenotypic groups were established (Table 2). These groups were defined using k-means clustering (k = 4) in the RStudio Integrated Development Environment (IDE) (version 1.1.463) and the Graphpad Prism 6 program (Romero *et al.*, 2020), applied to standardized tree-level characteristics (height, diameter at breast height, number of branches). The objective of this step was to identify distinct yield classes that integrate multiple traits and guide subsequent analyses of site index and productivity. The clustering procedure was performed after an exploratory inspection (elbow method) and validated using nonparametric comparisons (Dunn's test) to ensure significant separation between groups.

The site index (SI) was subsequently calculated at the plot level (Table 3). For each plot, dominant height was defined as the mean height of trees at or above the 80th percentile (upper quintile) of the height distribution within that plot, calculated using the Excel function PERCENTILE.INC. This dominant height at the reference age of 48 months was used as the SI. By definition, the SI was obtained per plot, not per tree, to capture productivity at the site level. The normality of the variables was checked using the Kolmogorov-Smirnov test, and since several distributions were abnormal, Spearman's rank correlations were used to evaluate the associations between IS and edaphic, physiographic, and climatic variables. Differences in IS between groups and phenotypic sectors (lower, middle, and upper catchment) were checked using Kruskal-Wallis tests with Dunn's post-hoc comparisons. All analyses were performed in R (v4.2.2) / RStudio (v1.1.463).

Correlation of the site index with edaphic, physiographic, climatic, and phenotypic variables

The normality of the variables was checked using the Kolmogorov-Smirnov test in R (v4.2.2, Rcmdr package). Since most variables and the site index (SI) did not meet the normality assumptions, correlations were assessed using Spearman's rank coefficient in RStudio (v1.1.463). The analysis considered three groups of variables:

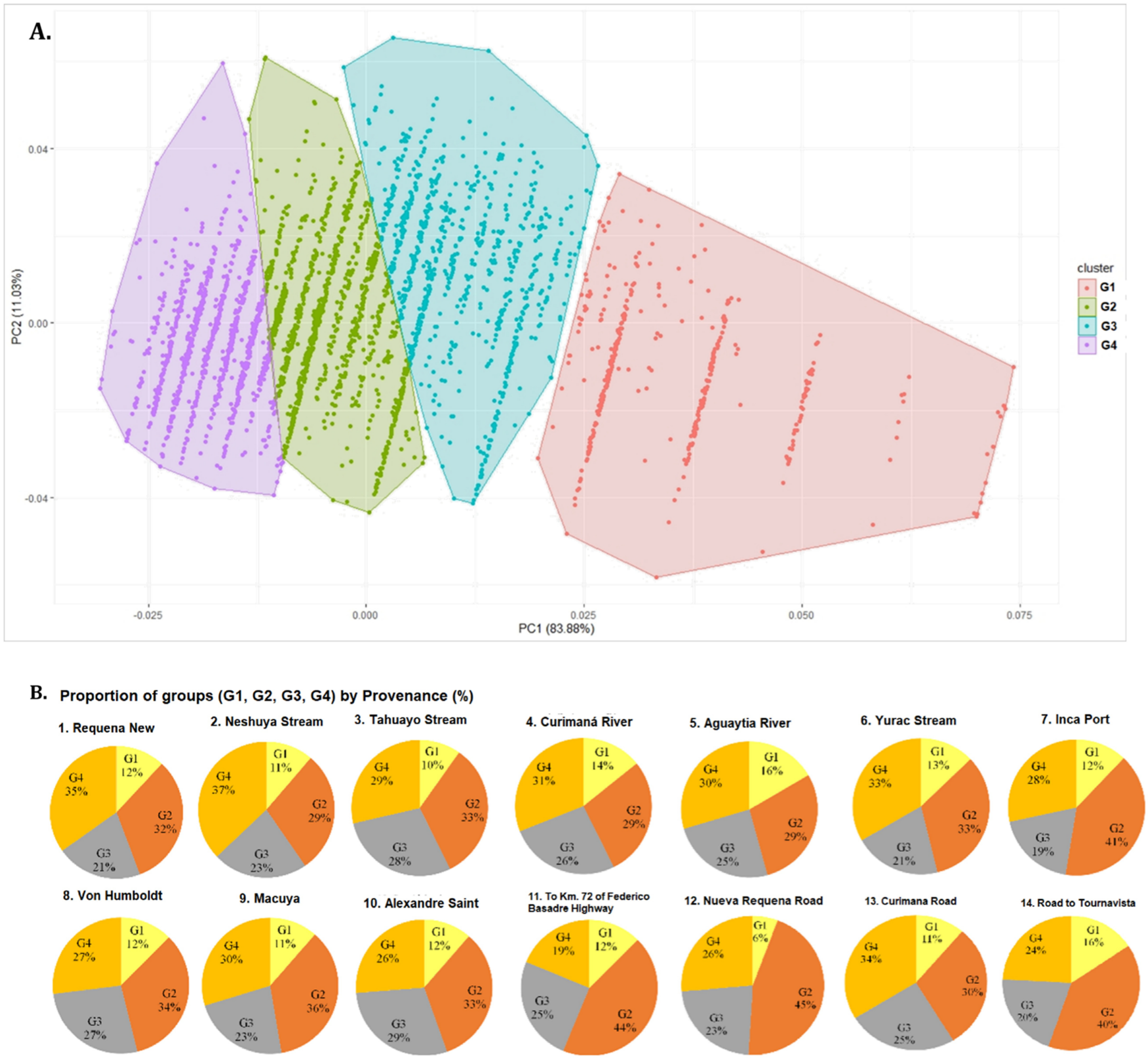

Figure 2. Phenotypic grouping by provenance of *G. crinita*. A. Clustering by phenotypic mean by origin at 48 months of age using the K-means algorithm, where: G1=H (15.33 m), DBH (13.56 cm), BTWL (28.52), BTWOL (1.763); G2=H (10.21 m), DBH (9.06 cm), BTWL (10,554), BTWOL (2.313); G3=H (14.93 m), DBH (13.36 cm), BTWL (16.289), BTWOL (2.846); G4=H (6.91m), DBH (6.29 cm), BTWL (5.109), and BTWOL (1.935). B. Map of phenotypic group proportions by provenance identified in plantations at 48 months of age (%).

Soil properties (Table 4a): texture (sand, silt, clay), pH, organic carbon, available phosphorus, cation exchange capacity (CEC), and exchangeable cations (Ca^{+2}, Mg^{+2}, K^{+}, Al^{+3}), measured at two depths (0–15 cm and 15–30 cm).

Physiographic and climatic variables (Table 4b): altitude (m a.s.l.), mean annual precipitation (mm), and mean annual temperature (°C).

Phenotypic variables (Table 4c): total height (A, m), diameter at breast height (DBH, cm), basal area (BA, m^2), and volume (V, m^3), all measured at 48 months. Provenance and progeny were also included as categorical factors.

In all cases, the site index was calculated per experimental plot as the dominant mean height of trees in the upper quintile of the height distribution at 48 months of age.

RESULTS

Descriptive statistics for the *Guazuma crinita* data at 48 months of age

Across all plots, trees showed an average DBH of 9.8 ± 0.4 cm and a mean total height of 11.4 ± 0.6 m at 48 months. On average, trees had 12.4 branches with leaves and 2.4 branches without leaves (Table 1). Basal area per tree was

Table 2. Phenotypic groups by provenance in 48-month-old *G. crinita* plantations based on k-means algorithm analysis.

A. Means of traits established based on the number of groups generated (k =4) (diameter at breast height (DBH, cm), total height (H, m), number of branches from the top with leaves (BTWL, branches), and number of upper branches without leaves (BTWOL, branches) by provenance).

Group	DBH (cm)	H (m)	BTWL (# branches)	BTWOL (# branches)
G1	13.6	10.6	28.5	1.8
G2	9.1	10	10.6	2.3
G3	13.4	10.5	16.3	2.9
G4	6.3	9.4	5.1	1.9

B. Dunn's multiple comparisons test between phenotypic groups for diameter at breast height (DBH, cm), total height (H, m), number of branches from the top with leaves (BTWL, branches), and number of upper branches without leaves (BTWOL, branches) by provenance.

Comparisons	DBH (cm)	H (m)	BTWL (# branches)	BTWOL (# branches)
	Mean rank	Mean rank	Mean rank	Mean rank
G1 vs. G2	1046*	17.7*	1472*	-459.1*
G1 vs. G3	62.1	1.1*	650.9	-630.5
G1 vs. G4	1771*	15.2*	2491*	-255.5*
G2 vs. G3	-984.4*	-16.6*	-821.1*	-171.4*
G2 vs. G4	724.1*	-2.5*	1019*	203.6*
G3 vs. G4	1708*	14.1*	1840*	375.0*

* $p < 0.05$

C. Representation (%) of phenotypic groups (G1, G2, G3, G4) by provenance.

Provenance	Site	G1%	G2%	G3%	G4%
1	*Nueva Requena*	11.9	32.3	20.9	34.8
2	*Quebrada Neshuya*	11.3	29.1	22.5	37.1
3	*Quebrada Tahuayo*	9.8	32.9	28.7	28.7
4	*Curimana River*	14.2	28.4	26.3	31
5	*Aguaytia River*	16.6	29.1	24.7	29.6
6	*Quebrada Yurac*	12.8	33.3	20.5	33.3
7	*Puerto Inca*	12.1	40.5	19.1	28.4
8	*Von Humboldt*	12.4	33.7	26.9	26.9
9	*Macuya*	11.4	35.9	23	29.7
10	*San Alejandro*	11.4	33.2	29.2	26.2
11	*CFB. hasta Km. 72*	12.5	43.8	25	18.8
12	*Carretera Nueva Requena*	5.7	45.3	22.6	26.4
13	*Carretera a Curimaná*	11.3	30	25	33.8
14	*Carretera a Tournavista*	15.7	39.8	20.5	24.1
Mean (x)		**12.1 [4]**	**34.8 [1]**	**23.9 [3]**	**29.2 [2]**

Notes: Mean (x) = Average (%) of groups; Superscripts 1, 2, 3, 4 = Hierarchy of phenotypic groups in descending order.

0.012 ± 0.002 m², corresponding to a stand basal area of 9.3 m² ha⁻¹, while the mean tree volume was 0.046 ± 0.008 m³ (Table 1). These descriptive statistics provide the baseline for subsequent analyses of site index, phenotypic grouping, and correlations with soil and environmental variables.

Phenotypic groups by provenance

Four phenotypic groups were identified (G1–G4), and they differed significantly in DBH, height, and branching traits ($p < 0.05$), except between G1 and G3 (Table 2a). Groups G1 and G3 represented the highest-quality phenotypes, while G2 and G4 were composed of lower-performing trees. Provenances such as Aguaytía River, San Alejandro, Curimaná River, and Von Humboldt contributed the largest proportions of superior trees (mainly in G1 and G3), indicating that phenotypic grouping is strongly associated with geographic origin (Table 2b, 2c). These results highlight that provenances with greater representation in G1 and G3 have higher potential for site selection and genetic improvement.

Site index

The site index (SI) varied between plots and provenances, reflecting differences in environmental and genetic factors. The SI showed a strong, positive correlation with precipitation ($r = 0.89$, $p < 0.01$) and plot ($r = 0.89$, $p < 0.01$), which in turn was related to altitude ($r = 0.85$, $p < 0.01$), indicating that wet climate and higher altitude conditions favor tree growth in the watershed. A moderate but significant association was also observed between the SI and soil chemical properties, particularly calcium, cation exchange capacity, magnesium, and pH ($r = 0.59–0.61$, $p < 0.05$), while texture, sand, potassium, and aluminum showed weak, nonsignificant negative correlations (Table 4a).

Genetic effects were less pronounced. Although provenances differed in their distribution among phenotypic groups (Table 2), their direct effect on SI was limited compared to environmental factors (Table 4b). Provenances from the Aguaytía, San Alejandro, Curimaná, and Von Humboldt rivers contributed a greater proportion of trees to the higher phenotypic groups (G1 and G3), but SI patterns between plots were more consistently explained by precipitation, altitude, and soil fertility than by provenance alone (Table 4c).

Site index was strongly associated with tree growth metrics (height, DBH, basal area, and volume), but showed no significant relationship with provenance or progeny (Table 4c).

DISCUSSION

Phenotypic groups by origin and site index

According to the results of this study, the site index (SI) of *Guazuma crinita* plantations in the Peruvian Amazon was weakly influenced by provenance; however, it contributed positively to the representation of phenotypic groups.

Table 3. Site index (SI) for *Guazuma crinita* plantations at 48 months of age, based on the upper quantile of commercially important traits height (H), diameter at breast height (DBH), basal area (BA) and commercial volume (V) by plot and sector in the Aguaytía River basin, Ucayali, Peru.

Sector	Plot	SI	H (m)	DBH (cm)	BA (m^2 ha^{-1})	V (m^3 ha^{-1})	Average ($\bar{x}$) SI	H (m)	DBH (cm)	BA (m^2 ha^{-1})	V (m^3 ha^{-1})
1	2	8.2	6	5.7	1.6	7.2	10	7.7	7	4.6	25
	3	10	8.4	7.8	4.8	27					
	4	9.6	7.9	7.4	4.5	25					
	5	12	8.8	7.5	7.6	41					
2	6	12	8.3	6.9	5.8	31	16.3	13.5	10.9	9.4	64
	7	17	15	12.5	11	74					
	8	20	17	13.2	12	88					
3	11	17	14	12.6	9.2	26	18.8	15.7	13.3	11.4	64.7
	12	17	15	13.4	12	84					
	13	20	17	14	13	63					
	15	21	16	13	11	85					

Similarly, the moderate correlation (r = 0.51) between provenance (Pv) and progeny is consistent with that reported in other studies (Rochon *et al.* 2007; Vallejos *et al.* 2009; Ugarte *et al.*, 2009). These results are consistent with previous provenance trials on *G. crinita*, which showed variation in the progeny. Studies of genetic diversity of *G. crinita* have also revealed high variation within provenances and relatively low differentiation between them (Tuisima *et al.*, 2016). This pattern helps explain why provenance itself did not have a direct effect on the site index (SI), but did influence the distribution of trees among phenotypic groups.

From a genetic perspective, phenotypic clustering based primarily on DBH and altitude provides a practical tool for identifying promising provenances. Similar approaches combining PCA and clustering have been shown to be effective in distinguishing provenances with superior performance, as in the case of *Alnus cremastogyne* clones (Zheng *et al.* 2023).

Therefore, considering the lack of correlation between the provenance, progeny and SI of the studied plantations, the SI themselves could be used to support the selection of the best sites for the establishment of commercial forest plantations, since these are directly related to the best plant traits (H, DAP, BA, V), which in turn have high positive correlations with the sector and the plot (Revilla-Chávez *et al.* 2022b, 2024a).

Edaphic correlation with site index

The positive correlations between SI and Ca^{+2}, CEC, Mg^{+2}, and pH indicate that *Guazuma crinita* attains greater total and commercial height growth in slightly acidic to neutral soils with higher base cation availability and good cation exchange capacity, conditions that improve nutrient exchange and reduce acidity-related constraints (Nano *et al.* 2016; Flores 2019). Although studies on other tropical species report associations between soil N, P and K and tree height, those nutrients drive different physiological processes and are only available in soils with a higher cation exchange capacity (Ara 1999; Idiege *et al.* 2014), which occurs in media with slightly acidic pH. Therefore, our results suggest that in the study area, edaphic limitations are more closely related to base-cation availability than to macronutrient supply.

On the other hand, we found a slightly negative correlation between SI and soil variables such as texture, sand, K^{+}, and Al^{+3}. This pattern suggests that the species performs better in loamy soils with moderate levels of sand and potassium, and shows only moderate tolerance to aluminum. Similar results were reported by Ara (1999), who emphasized the need for more information to quantify the response of *G. crinita* to increased exchangeable cations and reduced Al^{+3} in the soil.

From what was observed, soil fertility variables, particularly Ca^{+2}, CEC, Mg^{+2} and pH, showed significantly important associations with the SI, which reinforces the importance of soil quality in plantation performance. Our results are consistent with previous studies that found that the growth in height and volume of species such as *Gmelina arborea*, *Prosopis alba*, and *Calycophyllum spruceanum* were conditioned by the chemical properties of the soil (Ugarte *et al.* 2009; Senilliani *et al.* 2020; Telles *et al.* 2021)

Physiographic and climatic correlation with site index

The observed results show that environmental factors exerted a strong influence on the behavior of the *G. crinita* site index, as evidenced by the positive correlations with precipitation and

Table 4. Spearman's correlations between site index (SI) and phenotypic and edaphoclimatic variables for *Guazuma crinita* plantations at 48 months of age in the Aguaytía River basin, Ucayali, Peru.

A. Correlations between site index (SI) and edaphic variables.

Trait	SI	Depth	Texture	Clay	Sand	Mud	Ca^{+2}	CEC	K	Mg^{+2}	OC	P	pH	Al^{+3}
Plot	0.89**	0	-0.45	0.64*	-0.44	-0.18	0.76**	0.81**	-0.17	0.74**	0.48	0.13	0.72*	-0.55
SI		0	-0.38	0.49	-0.38	0.04	0.62*	0.67*	-0.15	0.61*	0.36	0.26	0.59*	-0.39
Depth			-0.18	0.36	-0.21	-0.05	-0.15	0.14	-0.71*	-0.18	-0.77**	-0.69*	-0.22	0.46
Texture				-0.62*	0.73*	-0.08	-0.69*	-0.66*	0.38	-0.63*	-0.15	0.42	-0.61*	0.32
Clay					-0.84**	-0.15	0.73*	0.94**	-0.54	0.71*	0.23	-0.48	0.63*	-0.27
Sand						-0.27	-0.7*	-0.8**	0.45	-0.71*	-0.24	0.49	-0.61*	0.24
Mud							-0.09	-0.14	0.04	-0.07	-0.11	0.09	-0.07	0.19
Ca+2								0.86**	-0.12	0.98**	0.62*	-0.09	0.95**	-0.78**
CEC									-0.41	0.85**	0.46	-0.28	0.77**	-0.48
K+										-0.05	0.33	0.59*	-0.01	-0.28
Mg+2											0.61*	-0.1	0.94**	-0.77**
OC												0.45	0.61*	-0.73*
P													-0.03	-0.2
pH														-0.85**

*P< 0.05; **P<0.01.

B. Correlations between site index (SI), elevation, precipitation, and temperature by plot.

Trait	Plot	Elevation	Precipitation	T (°C)
SI	0.89**	0.71	0.89*	0.48
Plot		0.85*	0.97**	0.66
Elevation			0.83*	0.6
Precipitation				0.66

C. Correlation between site index (SI) and provenance (Pv), progeny (Prog) and phenotypic variables in plots and sites.

Trait	Plot	SI	Pv	Prog	H	DBH	BA	V
Sector	0.94**	0.76**	0.01	0.005	0.7**	0.65**	0.65**	0.67**
Plot		0.89**	0.01	0.005	0.77**	0.69**	0.69**	0.71**
SI			0.01	0.0002	0.8**	0.7**	0.7**	0.72**
Pv				0.51**	0.02	0.02	0.022	0.022
Prog					0.002	0.01	0.013	0.012
H						0.9**	0.94**	0.953**
DBH							1.0**	0.999**
BA								0.999**

*p < 0.05; ** P<0.01.

altitude. These relationships indicate that physiographic and climatic gradients largely determine growth potential, consistent with recent findings for other tropical species that highlight local plasticity and site productivity as key determinants of forest performance (Di Fabio *et al.* 2024; Kurjak *et al.* 2024).

The positive association between the site index and altitude indicates that the higher elevations of the watershed offer more favorable conditions for the growth of *G. crinita* (Revilla-Chávez *et al.*, 2024a, 2024b). This may be linked to the lower temperatures and increased precipitation at higher elevations reducing water stress and improving nutrient cycling, which can improve tree height growth and overall productivity. This behavior is consistent with other reports showing that topographic factors influence the distribution and performance of forest species by determining their access to water and nutrients (Sánchez-Soto *et al.*, 2016; Herraiz *et al.*, 2023). Therefore, comparable results were observed in *Gmelina arborea* plantations, where dominant height and SI were strongly related to elevation and precipitation, explaining up to 70% of the observed variation (Barrios-Trilleras *et al.*, 2021). These patterns suggest that species adapted to humid tropical conditions tend to perform better at higher elevations where precipitation is more stable, while species from drier environments may show the opposite trend. However, estimating the performance of *G. crinita* plantations in similar topographical areas in other ecological zones requires genetic tests of the stability and adaptability of the progeny in the areas where the projects are planned to be developed (Revilla-Chávez *et al.* 2022b).

The observed correlations suggest that the plots located at higher altitudes (Figure 3) offer the most favorable conditions for the establishment of commercial forest plantations, despite the fact that these variables did not show a correlation with the provenance (Pv) or with the progeny (Table 4c of this study; Revilla-Chávez *et al.*, 2024b). Taken together, these results indicate that environmental factors, especially rainfall and altitude, play a dominant role in determining IS, while genetic variation between provenances contributes only secondarily by influencing the representation of higher phenotypes within sites and suggest a dual management strategy combining site selection and phenotypic selection. Therefore, priority should be given to areas with higher rainfall, moderate to high altitudes, and fertile soils with adequate base saturation, while

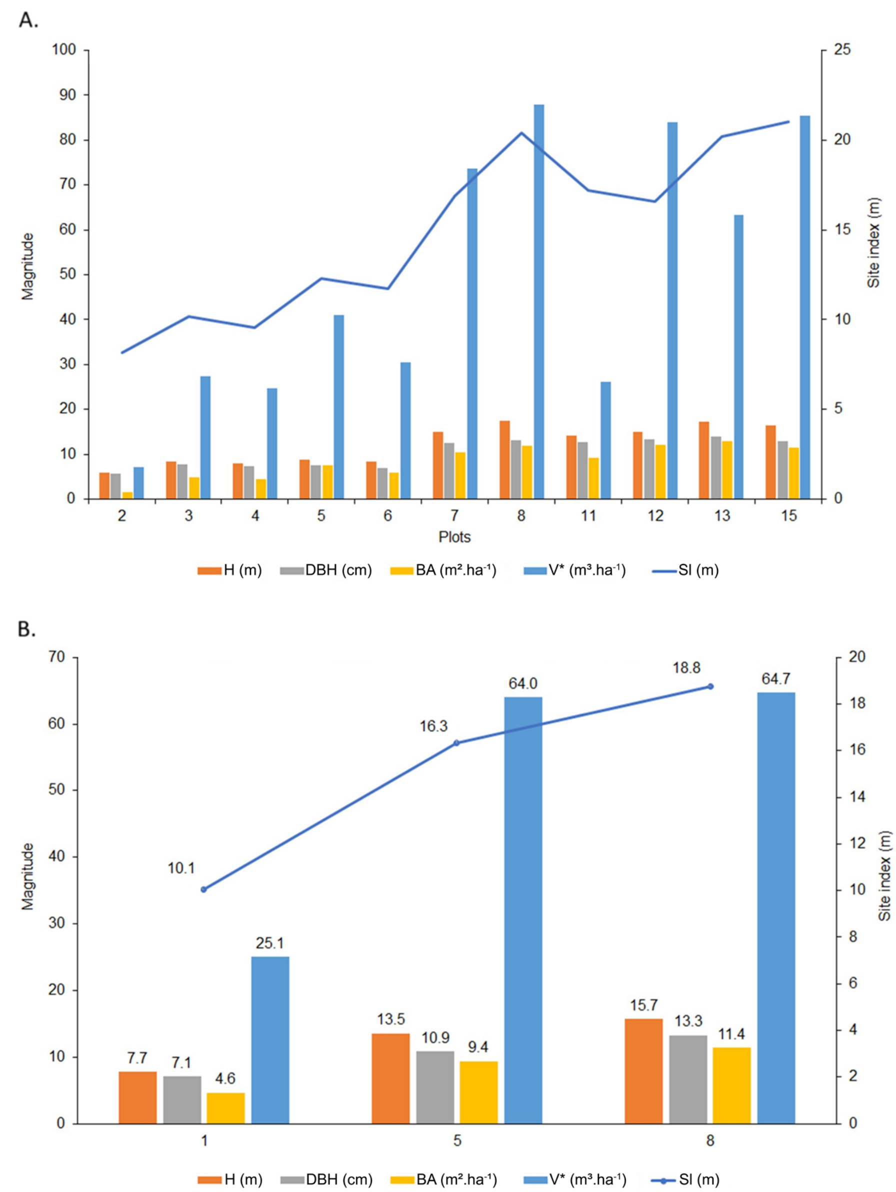

Figure 3. Silvicultural variables of 48-month-old *G. crinita* plantations in the Aguaytia River basin; A. Silvicultural variables by plot. The blue line located at the top represents the increase of the site index as the plot and sector are located at a higher altitude.

favoring provenances that contribute a higher proportion of superior phenotypes. This integrated approach aligns with the recommendations of provenance analysis methodologies (Vallejos *et al.*, 2009; Zheng *et al.*, 2023) and supports the inclusion of phenotypic grouping as a practical tool in selection strategies for commercial plantations of *G. crinita* in the Peruvian Amazon.

CONCLUSIONS

This study shows that the growth performance of *Guazuma crinita* plantations in the Peruvian Amazon is shaped by the interaction of genetic diversity and environmental conditions. These findings emphasize the importance of integrating both site selection and genetic choice in the design of tropical plantations, providing a framework for improving the productivity and sustainability of *G. crinita* and other fast-growing species in Amazonian reforestation programs.

ACKNOWLEDGEMENTS

We thank the World Agroforestry Center (ICRAF) for allowing us to use field data for the preparation of this article. We also thank Dr. Evelyn Roberta Nimmo for the English editing.

REFERENCES

Ara, M. 1999. Vigor de establecimiento de Bolaina (*Guazuma crinita*) en relación a la fertilidad del suelo en Pucallpa. Revista de Investigaciones Veterinarias del Perú 10: 63-70.

Barrios-Trilleras, A.; López-Aguirre, A.; Báez-Aparicio, C. 2021. Modelamiento de la productividad de *Gmelina arborea* Roxb. con base en variables biofísicas y de rodal. *Colombia forestal* 24: 71-87.

Bazan, R. 2017. Manual de procedimientos de los análisis de suelos y agua con fines de riego. Instituto Nacional de Innovación Agraria, Lima, Perú. 89p. https://hdl.handle.net/20.500.12955/504

Carvajal-Arroyo, D. 2022. Índice de sitio para *Cedrela odorata* L. en sistemas agroforestales con café en Pérez Zeledón, Costa Rica. *Kurú* 19: 9-17.

Cornelius, J.; Ugarte-Guerra, J. 2010. Introducción a la genética y Domesticación Forestal para la Agroforestería y Silvicultura. Manual Técnico. Centro Mundial para la Agroforestería (ICRAF), Lima, Perú. 124p.

Di Fabio, A.; Buttò, V.; Chakraborty, D.; O'Neill, G. A.; Schueler, S.; Kreyling, J. 2024. Climatic conditions at provenance origin influence growth stability to changes in climate in two major tree species. *Forests and Global Change* 7: 1422165.

Fick, S.E. and Hijmans, R.J. 2017, WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology* 37: 4302–4315.

Flores, Y. 2019. Fichas técnicas para plantaciones con especies nativas en zonas de selva baja. Instituto Nacional de Innovación Agraria-INIA, Lima, Perú. 54p. http://repositorio.inia.gob.pe/handle/20.500.12955/943

Flores, Y. 2018. Árboles nativos de la Región Ucayali. Estación Experimental Agraria Pucallpa, Pucallpa, Perú. 375p.

García-Cuevas, X.; Toledo-Chiu, C.; Hernández-Ramos, J.; Mendoza-Muñoz, J.A.; Hernández-Ramos, A. 2021. Índice de sitio para plantaciones forestales comerciales de *Cedrela odorata* L. en Quintana Roo, México. *Revista Mexicana de Ciencias Forestales* 12: 92-114.

GRU (Gobierno Regional de Ucayali), 2017. Zonificación ecológica económica base para el Ordenamiento Territorial de la Región Ucayali. Dirección de Gestión del Territorio de la Autoridad Regional Ambiental de Ucayali, Pucallpa, Perú. 227p. (https://sinia.minam.gob.pe/sites/default/files/sinia/archivos/public/docs/estudio_de_la_propuesta_de_zee_10.pdf). Accessed on 17 July 2024.

Herraiz, A.; Salazar-Zarzosa, P.; Mesas, F.; Arenas-Castro, S.; Ruiz-Benito, P.; Villar, R. 2023. Modelling aboveground biomass and productivity and the impact of climate change in Mediterranean forests of South Spain. *Agricultural and Forest Meteorology* 337: 109498.

Hernández-Ramos, J.; Ordaz-Ruiz, A.; García-Espinoza, G.; García-Magaña, G.; García-Cuevas, X. 2023. Índice de sitio para plantaciones forestales de *Pinus patula* en el Estado de México. *Madera Bosques* 28: e2822308.

Idiege, D.; Ijomah, J.; Amadi, D.; Agba, O., Lifu, M. 2014. Nutrient distribution of *Gmelina arborea* L. plantation on the slopes of UKPON river forest reserve of cross river state, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 8: 1-8.

Kurjak, D.; Petrík, P.; Konôpková, A. S.; Link, R. M.; Gömöry, D.; Hájek, P.; Liesebach, M.; Leuschner, C.; Schuldt, B. 2024. Inter-provenance variability and phenotypic plasticity of wood and leaf traits related to hydraulic safety and efficiency in seven European beech provenances differing in yield. *Annals of Forest Science* 81: 11.

Martínez-Zurimendi, P.; Domínguez-Domínguez, M.; Juárez-García, A.; López-López, L.; de la Cruz-Arias, V.; Álvarez-Martínez, J. 2015. Índice de sitio y producción maderable en plantaciones forestales de *Gmelina arborea* en Tabasco, México. *Revista Fitotecnia Mexicana* 38: 415-425.

Murillo-Brito, Y.; Domínguez-Domínguez, M.; Martínez-Zurimendi, P.; Lagunes-Espinoza, L.; Aldrete, A. 2017. Índice de sitio en plantaciones de *Cedrela odorata* en el trópico húmedo de México. *Revista de la Facultad de Ciencias Agrarias Universidad Nacional de Cuyo* 49: 15-31.

Nano, G.; Raulo, R.; Rengifo, J.; Rengifo, A. 2016. Propiedades Físico-Químicas del suelo en plantaciones de Bolaina blanca (*Guazuna crinita* C. Mart.) en el distrito de Yuyapichis, Huánuco. *Investigación y Amazonía* 6: 50-59.

Ramos-Huapaya, A.; Domínguez, G. 2016. Selección de árboles de bolaina blanca (*Guazuma crinita* Mart.) como candidatos a árboles "plus" para ensayos de rejuvenecimiento y brotación. *Ecología Aplicada* 15: 115-123.

Revilla, J.; Abanto-Rodríguez, C.; Guerra, W.; García, D.; Guerra, H.; Domínguez, G.; Carmo, I. 2021. Modelos alometricos para estimar el volumen de madera de *Guazuma crinita* en plantaciones forestales. *Scientia Agropecuaria* 12: 25-31.

Revilla-Chávez, J.M.; López-Galán, E.E.; Guerra-Arevalo, W.F.; García-Soria, D.G.; Rojas-Mego, K.C.; Domínguez-Torrejón, G.; Abanto-Rodríguez, C. 2021. Modelos alometricos de biomasa de árboles de *Guazuma crinita* Mart en plantaciones forestales de Ucayali, Perú. *Scientia Agropecuaria* 12: 579-587.

Revilla-Chávez, J.M.; López-Galan, E.E.; Gonzales-Alvarado, A.C.; Manturano Perez, R.D.; Sáenz-Ramírez, L.H.; Guerra-Arevalo, H.; Mori-Vásquez, J.A. 2022a. Valoración económica de plantaciones de bolaina blanca (*Guazuma crinita* Mart.) en Ucayali, Perú. *Folia Amazónica* 31: 243-257.

Revilla-Chávez, J.M.; de Moraes, M.A.; Pinchi-Ramirez, M.H.; Sebbenn, A.M. 2022b. Productivity, adaptability, and stability in *Guazuma crinita* progeny tests across three environments in the Aguaytia River Basin, Ucayali, Perú. *Silvae Genetica* 71: 72-80.

Revilla-Chávez, J.M.; Sebbenn, A. 2024a. Genetic control of quantitative and qualitative traits of *Calycophyllum spruceanum* in the Peruvian Amazon. *Crop Breeding and Applied Biotechnology* 24: e47262419.

Revilla-Chávez, J.M.; López-Galán, E.E.; Gonzales-Alvarado, A.C.; Sáenz-Ramírez, L H.; Mori-Vásquez, J.A.; Rojas-Mego, K.C.; *et al.* 2024b. Methodology for the phenotypic evaluation in *Guazuma crinita* trees in Ucayali, Peru. *Ciência Florestal* 33: e71675.

Reynel, C.; Pennington, R. T.; Pennington, T. D.; Flores, C.; Daza, A. 2003. Árboles útiles de la Amazonía peruana y sus usos: un manual con apuntes de identificación, ecología y propagación de las especies. Tarea Gráfica Educativa, Lima, Perú. 509p.

Rochon, C.; Margolis, H.; Weber, J. 2007. Genetic variation in growth of *Guazuma crinita* (Mart.) trees at an early age in the Peruvian Amazon. *Forest Ecology and Management* 243: 291-298.

Romero, L.; Ramirez, M.; Rojas, J.; Darghan, E. 2020. Análisis de Cluster. https://rpubs.com/lhromeroj/analisisdeclusterR

Telles, R.; Rodríguez, E.; Jiménez-Pérez, J.; Aguirre-Calderón, O.A.; Treviño-Garza, E.J.; de los Santos-Posadas, H.M. 2021. Características edáficas y topográficas asociadas con el crecimiento en volumen de *Gmelina arborea* Roxb, en Tlatlaya Estado de México. *Madera y Bosques* 27: e2711987.

Tuisima, L.L.T.; Čepková, P.H.; Lojka, B.; Weber, J.C.; Alves-Milho S.F. 2016. Genetic diversity in *Guazuma crinite* from eleven provenances in the Peruvian Amazon revealed by ISSR markers. *Bosque* 37: 63-70.

Sánchez-Soto, B.H.; García-Moya, E.; Reyes-Olivas, Á.; Romero-Manzanares, A.; Luna-Cavazos, M. 2016. Factores topográficos y edáficos que influyen en la estructura de especies perennes de islas de la costa de Sinaloa, México. *Botanical Sciences* 94: 63-73.

SENAMHI (Servicio Nacional de Meteorología e Hidrología). 2018. Mapa de clasificación climática del Perú. SENAMHI, Lima, Perú. 9 p.

Senilliani, M.G.; Bruno, C.; Brassiolo, M. 2020. Factores edáficos y su impacto en la altura dominante en plantaciones de *Prosopis alba*. *Madera y Bosques* 26: e2632054.

Ugarte, J.; Weber, J.; Sotelo, C.; Cornelius, J. 2009. Domesticación participativa de especies forestales. Una estrategia para el desarrollo de mercado forestal. *Tecnología y Sociedad, Soluciones Prácticas* 16: 31-41.

Vaca, R.A.; Golicher, D.J.; Macario-Mendoza, P.A.; Estrada-Lugo, E.I.J.; Bello-Baltazar, E.; Sánchez-Pérez, L.C.; et al. 2020. Calidad de sitio para caoba (*Swietenia macrophylla* King) en bosques naturales de Quintana Roo. *Revista de Silvicultura Sostenible* 41: 33–50.

Vallejos, J.; Badilla, Y.; Picado, F.; Murillo, O. 2009. Metodología para la selección e incorporación de árboles plus en programas de mejoramiento genético forestal. *Agronomía Costarricense* 34: 105-119.

Zheng, Y.; Feng, M.; Li, X.; Huang, X.; Chen, G.; Bai, W.; *et al.* 2023. Phenotypic variation analysis and excellent clone selection of *Alnus cremastogyne* from different provenances. *Plants* 12: 3259.

RECEIVED: 22/07/2024
ACCEPTED: 22/10/2025
ASSOCIATE EDITOR: Francesco Ripullone

DATA AVAILABILITY: The data that support the findings of this study are available from the Graduate Program in Forest and Forest Resources Management, Universidad Nacional Agraria La Molina (Av. La Molina, District of La Molina, Lima 25012, Peru). Data are curated by Edinson E. López-Galán. The datasets include measurements of dominant height, diameter at breast height (DBH), and other dendrometric variables from Guazuma crinita plantations in the Aguaytía River basin, Ucayali region, Peru. Data are available from the corresponding author upon reasonable request (edulopezg@gmail.com).

AUTHOR CONTRIBUTIONS: Edinson E. López-Galán - investigation, methodology, data curation, validation; **Jorge M. Revilla-Chávez** - investigation, writing – original draft, validation; **Gilberto Domínguez-Torrejon** - methodology, conceptualization; **Héctor E. Vidaurre-Arévalo and Leoncio J. Ugarte-Guerra** - supervision, project administration; **Jorge Bendezú** - formal analysis, software, visualization; **Jorge J. Revilla-Macedo** - data curation, investigation; **Alexandre M. Sebbenn** - formal analysis, writing – review & editing, visualization.

APPENDIX

López-Galán *et al*. Analysis of the Guazuma crinita site index as a predictor of forest plantation quality in the Aguaytía River basin, Ucayali, Peru.

Table A1. Latitude and longitude data for Guazuma crinita trees, collection 1998.

Species	Collection	Site	Fam	Date	Degrees	Minutes	Latitude decimal	Degrees	Minutes	Longitude decimal
BS	98	1	1	08.24.98	8	11.430	8.19050	74	49.910	74.83183
BS	98	1	2	08.25.98	8	20.390	8.33983	74	55.980	74.93300
BS	98	1	3	08.26.98	8	22.510	8.37517	75	0.490	75.00817
BS	98	1	4	08.27.98	8	20.390	8.33983	74	55.990	74.93317
BS	98	1	5	08.27.98	8	22.430	8.37383	74	50.900	74.84833
BS	98	1	6	08.24.98	8	11.138	8.18563	74	50.113	74.83522
BS	98	1	7	08.24.98	8	11.205	8.18675	74	49.848	74.83080
BS	98	1	8	08.25.98	8	19.917	8.33195	74	56.149	74.93582
BS	98	1	9	08.25.98	8	19.965	8.33275	74	56.050	74.93417
BS	98	1	10	08.25.98	8	19.865	8.33108	74	56.193	74.93655
BS	98	1	11	08.26.98	8	21.235	8.35392	75	1.233	75.02055
BS	98	1	12	08.26.98	8	21.058	8.35097	75	1.094	75.01823
BS	98	1	13	08.26.98	8	21.169	8.35282	75	1.234	75.02057
BS	98	1	14	08.26.98	8	21.238	8.35397	75	1.236	75.02060
BS	98	1	15	08.27.98	8	20.021	8.33368	74	56.083	74.93472
BS	98	1	16	08.27.98	8	20.390	8.33983	74	55.990	74.93317
BS	98	1	17	09.04.98	8	16.812	8.28020	74	52.138	74.86897
BS	98	2	1	08.20.98	8	28.863	8.48105	75	0.261	75.00435
BS	98	2	2	08.20.98	8	21.696	8.36160	75	0.402	75.00670
BS	98	2	3	08.20.98	8	30.664	8.51107	75	0.018	75.00030
BS	98	2	4	08.20.98	8	30.365	8.50608	74	59.609	74.99348
BS	98	2	5	08.20.98	8	30.455	8.50758	74	59.460	74.99100
BS	98	2	6	08.21.98	8	29.192	8.48653	75	0.142	75.00237
BS	98	2	7	08.21.98	8	30.000	8.50000	75	0.000	75.00000
BS	98	2	8	08.21.98	8	31.080	8.51800	74	59.119	74.98532
BS	98	2	9	08.22.98	8	29.981	8.49968	75	0.041	75.00068
BS	98	2	10	08.21.98	8	29.167	8.48612	75	0.381	75.00635
BS	98	2	11	08.22.98	8	31.345	8.52242	74	58.689	74.97815
BS	98	2	12	08.22.98	8	31.714	8.52857	74	58.693	74.97822
BS	98	2	13	08.22.98	8	31.800	8.53000	74	58.700	74.97900
BS	98	3	1	08.29.98	8	21.670	8.36117	74	57.820	74.96367
BS	98	3	2	08.29.98	8	21.670	8.36117	74	57.820	74.96367
BS	98	3	3	08.29.98	8	22.720	8.37867	74	56.840	74.94733
BS	98	3	4	08.29.98	8	20.730	8.34550	74	50.810	74.84683
BS	98	3	5	08.28.98	8	43.527	8.72545	75	1.199	75.01998
BS	98	3	6	08.29.98	8	43.441	8.72402	75	1.277	75.02128
BS	98	3	7	08.29.98	8	43.575	8.72625	75	1.227	75.02045
BS	98	3	8	09.08.98	8	50.530	8.84217	75	5.290	75.08817
BS	98	3	9	09.08.98	8	43.410	8.72350	75	1.230	75.02050
BS	98	3	10	09.11.98	8	45.250	8.75417	74	47.460	74.79100
BS	98	3	11	09.11.98	8	38.890	8.64817	74	58.800	74.98000

Table A1. Continued

Species	Collection	Site	Fam	Date	Degrees	Minutes	Latitude decimal	Degrees	Minutes	Longitude decimal
BS	98	4	1	08.31.98	8	21.670	8.36117	74	57.820	74.96367
BS	98	4	2	08.31.98	8	25.000	8.41667	75	7.450	75.12417
BS	98	4	3	08.31.98	8	25.000	8.41667	75	7.450	75.12417
BS	98	4	4	08.31.98	8	26.030	8.43383	75	7.360	75.12267
BS	98	4	5	09.01.98	8	24.850	8.41417	75	7.430	75.12383
BS	98	4	6	09.01.98	8	24.850	8.41417	75	7.430	75.12383
BS	98	4	7	09.01.98	8	25.770	8.42950	75	9.500	75.15833
BS	98	4	8	09.01.98	8	25.480	8.42467	75	9.140	75.15233
BS	98	4	9	08.31.98	8	24.949	8.41582	75	7.415	75.12358
BS	98	4	10	08.31.98	8	24.120	8.40200	75	7.020	75.11700
BS	98	4	11	08.31.98	8	24.983	8.41638	75	7.532	75.12553
BS	98	4	12	09.01.98	8	25.655	8.42758	75	9.400	75.15667
BS	98	4	13	09.01.98	8	25.595	8.42700	75	9.376	75.15700
BS	98	4	14	09.01.98	8	25.534	8.42557	75	9.353	75.15588
BS	98	4	15	09.01.98	8	25.148	8.41913	75	9.023	75.15038
BS	98	4	16	09.01.98	8	24.410	8.40683	75	8.590	75.14317
BS	98	4	17	09.01.98	8	24.410	8.40683	75	8.590	75.14317
BS	98	4	18	09.12.98	8	37.220	8.62033	74	59.000	74.98333
BS	98	4	19	09.12.98	8	37.200	8.62000	74	58.050	74.96750
BS	98	4	20	09.12.98	8	37.220	8.62033	74	58.010	74.96683
BS	98	5	1	08.31.98	8	52.290	8.87150	75	29.740	75.49567
BS	98	5	2	08.31.98	8	31.980	8.53300	75	30.390	75.50650
BS	98	5	3	08.31.98	8	51.850	8.86417	75	31.430	75.52383
BS	98	5	4	09.01.98	8	50.580	8.84300	75	31.210	75.52017
BS	98	5	5	09.01.98	8	50.490	8.84150	75	31.130	75.51883
BS	98	5	6	09.01.98	8	50.170	8.83617	75	31.360	75.52267
BS	98	5	7	09.01.98	8	50.170	8.83617	75	31.360	75.52267
BS	98	5	8	09.01.98	8	45.592	8.75987	75	29.293	75.48822
BS	98	5	9	09.02.98	8	39.340	8.65567	75	25.550	75.42583
BS	98	5	10	09.02.98	8	39.880	8.66467	75	26.880	75.44800
BS	98	5	11	09.03.98	8	45.450	8.75750	75	29.000	75.48333
BS	98	5	12	09.03.98	8	46.560	8.77600	79	29.440	79.49067
BS	98	5	13	09.04.98	8	49.170	8.81950	75	4.710	75.07850
BS	98	5	14	09.04.98	8	46.540	8.77567	75	29.090	75.48483
BS	98	5	15	09.04.98	8	49.150	8.81917	75	4.700	75.07833
BS	98	5	16	09.04.98	8	45.720	8.76200	75	28.940	75.48233
BS	98	5	17	09.05.98	8	57.240	8.95400	75	30.010	75.50017
BS	98	5	18	09.05.98	8	44.420	8.74033	75	29.190	75.48650
BS	98	5	19	09.05.98	8	49.470	8.82450	75	4.710	75.07850
BS	98	6	1	08.30.98	9	3.670	9.06117	75	30.880	75.51467
BS	98	6	2	08.30.98	9	2.540	9.04233	75	30.120	75.50200
BS	98	6	3	08.30.98	9	2.430	9.04050	75	30.140	75.50233
BS	98	7	1	08.09.98	9	30.779	9.51298	74	58.946	74.98243
BS	98	7	2	09.09.98	9	14.567	9.24278	74	57.037	74.95062
BS	98	7	3	09.09.98	9	14.865	9.24775	74	56.350	74.93917
BS	98	7	4	09.09.98	9	15.482	9.25803	74	55.681	74.92802

Table A1. Continued

Species	Collection	Site	Fam	Date	Degrees	Minutes	Latitude decimal	Degrees	Minutes	Longitude decimal
BS	98	7	5	09.09.98	9	15.624	9.26040	74	55.605	74.92675
BS	98	7	6	09.09.98	9	15.696	9.26160	74	55.525	74.92542
BS	98	7	7	09.09.98	9	15.763	9.26272	74	55.600	74.92667
BS	98	7	8	09.09.98	9	15.885	9.26475	74	55.426	74.92377
BS	98	7	9	09.09.98	9	16.707	9.27845	74	55.384	74.92307
BS	98	7	10	09.11.98	9	17.625	9.29375	74	58.858	74.98097
BS	98	7	11	09.11.98	9	19.166	9.31943	74	59.324	74.98873
BS	98	7	12	09.12.98	9	30.379	9.50632	74	56.866	74.94777
BS	98	7	13	09.12.98	9	29.934	9.49890	74	59.248	74.98747
BS	98	7	14	09.12.98	9	29.882	9.49803	74	58.195	74.96992
BS	98	7	15	09.12.98	9	30.316	9.50527	74	57.566	74.95943
BS	98	7	16	09.12.98	9	30.390	9.50650	74	57.395	74.95658
BS	98	7	17	09.12.98	9	28.935	9.48225	74	56.557	74.94262
BS	98	7	18	09.13.98	9	27.140	9.45233	74	56.217	74.93695
BS	98	8	1	09.02.98	8	49.470	8.82450	75	4.710	75.07850
BS	98	8	2	09.05.98	8	50.157	8.83595	75	5.032	75.08387
BS	98	8	3	09.07.98	8	49.540	8.82567	75	4.790	75.07983
BS	98	8	4	09.07.98	8	49.540	8.82567	75	4.790	75.07983
BS	98	8	5	09.07.98	8	50.530	8.84217	75	5.290	75.08817
BS	98	8	6	09.07.98	8	48.720	8.81200	75	7.230	75.12050
BS	98	8	7	09.07.98	8	49.400	8.82333	75	5.750	75.09583
BS	98	8	8	09.07.98	8	46.710	8.77850	75	1.140	75.01900
BS	98	8	9	09.02.98	8	49.939	8.83232	75	4.487	75.07478
BS	98	8	10	09.03.98	8	93.638	9.56063	75	5.074	75.08457
BS	98	8	11	09.03.98	8	50.794	8.84657	75	5.468	75.09113
BS	98	8	12	09.03.98	8	50.934	8.84890	75	5.724	75.09540
BS	98	8	13	09.03.98	8	50.787	8.84645	75	6.542	75.10903
BS	98	8	14	09.05.98	8	51.299	8.85498	75	7.146	75.11910
BS	98	8	15	09.05.98	8	51.683	8.86138	75	7.549	75.12582
BS	98	8	16	09.05.98	8	51.646	8.86077	75	7.839	75.13065
BS	98	8	17	09.05.98	8	51.895	8.86492	75	6.977	75.11628
BS	98	9	1	09.11.98	8	52.540	8.87567	75	2.720	75.04533
BS	98	9	2	09.11.98	8	54.770	8.91283	75	2.470	75.04117
BS	98	9	3	09.11.98	8	59.790	8.99650	75	2.410	75.04017
BS	98	9	4	09.11.98	9	0.070	9.00117	75	1.940	75.03233
BS	98	9	5	09.11.98	9	0.840	9.01400	75	1.880	75.03133
BS	98	9	6	09.11.98	9	0.690	9.01150	75	1.840	75.03067
BS	98	9	7	09.11.98	9	0.380	9.00633	75	1.940	75.03233
BS	98	9	8	09.11.98	9	0.310	9.00517	75	1.940	75.03233
BS	98	9	9	09.11.98	9	1.870	9.03117	75	1.870	75.03117
BS	98	9	10	09.12.98	9	1.980	9.03300	75	1.800	75.03000
BS	98	9	11	09.12.98	9	2.090	9.03483	75	1.730	75.02883
BS	98	9	12	09.12.98	9	1.430	9.02383	75	1.740	75.02900
BS	98	9	13	09.12.98	9	3.300	9.05500	75	1.700	75.02833
BS	98	9	14	09.12.98	9	3.050	9.05083	75	1.680	75.02800
BS	98	9	15	09.12.98	9	2.680	9.04467	75	1.810	75.03017

Table A1. Continued

Species	Collection	Site	Fam	Date	Degrees	Minutes	Latitude decimal	Degrees	Minutes	Longitude decimal
BS	98	9	16	09.12.98	9	2.670	9.04450	75	1.830	75.03050
BS	98	9	17	09.12.98	9	4.490	9.07483	75	1.830	75.03050
BS	98	9	18	09.12.98	9	8.020	9.13367	75	0.700	75.01167
BS	98	9	19	09.12.98	9	8.120	9.13533	75	0.680	75.01133
BS	98	9	20	09.15.98	8	37.250	8.62083	75	59.000	75.98333
BS	98	9	21	09.15.98	8	37.220	8.62033	74	59.000	74.98333
BS	98	9	22	09.15.98	8	8.240	8.13733	75	0.720	75.01200
BS	98	9	23	09.15.98	9	8.180	9.13633	75	0.580	75.00967
BS	98	9	24	09.15.98	9	8.280	9.13800	75	0.680	75.01133
BS	98	9	25	09.15.98	9	9.060	9.15100	75	0.410	75.00683
BS	98	9	26	09.15.98	9	9.100	9.15167	75	0.420	75.00700
BS	98	9	27	09.15.98	9	9.150	9.15250	75	0.470	75.00783
BS	98	9	28	09.15.98	9	8.720	9.14533	75	0.100	75.00167
BS	98	9	29	09.15.98	9	8.700	9.14500	75	0.090	75.00150
BS	98	9	30	09.22.98	8	53.670	8.89450	75	19.030	75.31717
BS	98	9	31	09.22.98	9	11.690	9.19483	75	0.090	75.00150
BS	98	9	32	09.23.98	9	18.580	9.30967	75	0.690	75.01150
BS	98	9	33	09.23.98	9	23.140	9.38567	74	59.520	74.99200
BS	98	9	34	09.23.98	9	19.020	9.31700	75	0.630	75.01050
BS	98	9	35	09.23.98	9	23.560	9.39267	75	0.140	75.00233
BS	98	9	36	09.23.98	9	23.590	9.39317	75	0.060	75.00100
BS	98	9	37	09.23.98	9	23.770	9.39617	75	0.200	75.00333
BS	98	9	38	09.23.98	9	23.600	9.39333	75	0.060	75.00100
BS	98	9	39	09.23.98	9	23.740	9.39567	75	0.290	75.00483
BS	98	9	40	09.23.98	9	23.510	9.39183	75	0.130	75.00217
BS	98	9	41	09.24.98	9	28.510	9.47517	75	1.330	75.02217
BS	98	9	42	09.23.98	9	23.510	9.39183	75	0.130	75.00217
BS	98	9	43	09.24.98	9	21.350	9.35583	75	1.710	75.02850
BS	98	9	44	09.23.98	9	23.600	9.39333	75	0.260	75.00433
BS	98	9	45	09.24.98	9	20.190	9.33650	75	1.130	75.01883
BS	98	9	46	09.23.98	9	22.710	9.37850	75	1.230	75.02050
BS	98	9	47	09.24.98	9	20.190	9.33650	75	1.130	75.01883
BS	98	9	48	09.24.98	9	20.180	9.33633	75	1.130	75.01883
BS	98	9	49	09.24.98	9	20.180	9.33633	75	1.130	75.01883
BS	98	10	1	09.08.98	8	51.530	8.85883	75	8.110	75.13517
BS	98	10	2	09.08.98	8	51.480	8.85800	75	8.140	75.13567
BS	98	10	3	09.08.98	8	51.340	8.85567	75	8.880	75.14800
BS	98	10	4	09.08.98	8	51.150	8.85250	75	8.970	75.14950
BS	98	10	5	09.08.98	8	51.140	8.85233	75	9.040	75.15067
BS	98	10	6	09.08.98	8	51.070	8.85117	75	9.000	75.15000
BS	98	10	7	09.08.98	8	51.050	8.85083	75	9.170	75.15283
BS	98	10	8	09.08.98	8	51.060	8.85100	75	9.180	75.15300
BS	98	10	9	09.08.98	8	51.070	8.85100	75	9.190	75.15300
BS	98	10	10	09.09.98	8	51.090	8.85200	75	9.250	75.15400
BS	98	10	11	09.09.98	8	51.090	8.85200	75	9.600	75.16000
BS	98	10	12	09.10.98	8	51.680	8.86133	75	7.020	75.11700

Table A1. Continued

Species	Collection	Site	Fam	Date	Degrees	Minutes	Latitude decimal	Degrees	Minutes	Longitude decimal
BS	98	10	13	09.10.98	8	51.660	8.86100	75	7.910	75.13183
BS	98	10	14	09.10.98	8	50.270	8.83783	75	7.090	75.11817
BS	98	10	15	09.10.98	8	51.400	8.85667	75	3.730	75.06217
BS	98	10	16	09.10.98	8	50.970	8.84950	75	8.760	75.14600
BS	98	10	17	09.10.98	8	50.950	8.84917	75	9.700	75.16167
BS	98	11	1	09.11.98	8	43.410	8.72350	75	1.230	75.02050
BS	98	11	2	09.11.98	8	43.410	8.72350	75	1.230	75.02050
BS	98	11	3	09.11.98	8	44.050	8.73417	75	0.270	75.00450
BS	98	11	4	09.12.98	8	39.810	8.66350	75	0.590	75.00983
BS	98	11	5	09.12.98	8	43.570	8.72617	75	0.690	75.01150
BS	98	11	6	09.12.98	8	43.570	8.72617	75	0.670	75.01117
BS	98	11	7	09.12.98	8	37.490	8.62483	75	10.540	75.17567
BS	98	12	1	09.04.98	8	22.040	8.36733	74	56.090	74.93483
BS	98	12	2	09.04.98	8	21.923	8.36538	74	56.531	74.94218
BS	98	12	3	09.04.98	8	21.845	8.36408	74	56.577	74.94295
BS	98	12	4	09.04.98	8	21.024	8.35040	74	57.320	74.95533
BS	98	13	1	09.02.98	8	35.330	8.58883	75	0.500	75.00833
BS	98	13	2	09.02.98	8	35.340	8.58900	75	0.510	75.00850
BS	98	13	3	09.02.98	8	35.460	8.59100	75	0.460	75.00767
BS	98	13	4	09.02.98	8	35.345	8.58908	75	0.402	75.00670
BS	98	13	5	09.12.98	8	37.220	8.62033	74	59.000	74.98333
BS	98	13	6	09.12.98	8	36.430	8.60717	74	53.260	74.88767
BS	98	13	7	09.12.98	8	36.420	8.60700	74	52.250	74.87083
BS	98	14	1	09.08.98	8	43.410	8.72350	75	1.230	75.02050
BS	98	14	2	09.08.98	8	37.400	8.62333	75	0.160	75.00267
BS	98	14	3	09.08.98	8	36.480	8.60800	75	0.220	75.00367
BS	98	14	4	09.08.98	8	43.410	8.72350	75	1.230	75.02050
BS	98	14	5	09.09.98	8	40.870	8.68117	75	48.010	75.80017
BS	98	14	6	09.11.98	8	40.330	8.67217	75	5.380	75.08967
BS	98	14	7	09.11.98	8	45.480	8.75800	74	47.760	74.79600

Table A2. Climatic data of the experimental plots of *Guazuma crinita*.

Site	Plot	Coordinate UTM		Progeny	Temperature (°C)	Rainfall (mm ha^{-1} year^{-1})	Altitude (m)	Climate classification
		East	Nort					
1	2	516260	9077069	85	> 26	1945	191	B(o,i) C'H3
	3	517074	9077328	143	> 26	1935	199	B(o,i) C'H3
	4	517239	9077741	139	> 26	1935	192	B(o,i) C'H3
	5	497889	9054216	189	26–25	2447	211	B(o,i) C'H3
2	6	497516	9054170	189	26–25	2447	205	B(o,i) C'H3
	7	498937	9051877	184	26–25	2458	198	B(o,i) C'H3
	8	488915	9048933	188	> 26	2765	222	B(o,i) C'H3
3	11	487388	9022150	191	26–25	3162	285	B(o,i) C'H3
	12	487362	9021936	193	26–25	3162	302	B(o,i) C'H3
	13	486621	9021206	190	26–25	3211	296	B(o,i) C'H3
	15	472462	9024201	165	26–25	3614	236	B(o,i) C'H3

Source: Fick and Hijmans (2017), and SENAMHI (2018); Where: B(o,i) C'H3 corresponds to a warm, humid to very humid climate, with high temperatures all year round (between 25 and 28 °C) and abundant rainfall (> 2500 mm year^{-1})

Table A3. Analysis of soils in experimental plots of *Guazuma crinita*.

Plot	Depth	Clay	Silt	Sand	Texture	pH	P	Al	K	Ca	Mg	CEC	Al^{+}	CO
2	0-15	13.4	11.8	74.8	F-A	4.9	4.91	0	0.3	1.48	0.9	2.96	10.1	1
	15-30	21.4	29.8	48.8	F-Arc-A	4.5	3.5	2	0.3	0.64	0.5	3.53	59.4	0.5
3	0-15	19.4	41.8	38.8	F	4.7	4.77	1	0.2	2.64	1.1	4.68	14.9	1.2
	15-30	35.4	33.8	30.8	Arc-F	4.5	1.82	5	0.1	1.68	1.1	7.86	63.6	0.5
4	0-15	13.4	43.8	42.8	F	4.8	5.61	0	0.4	1.76	1	3.52	11.4	1
	15-30	23.4	41.8	34.8	F	4.4	2.1	4	0.2	0.36	0.4	4.44	78.7	0.5
5	0-15	19.4	23.8	56.8	F-A	4	11.2	3	0.3	0.48	0.4	4.37	73.2	1.1
	15-30	27.4	27.8	44.8	F-Arc-A	4	3.36	5	0.1	0.12	0.1	5.45	93.6	0.7
6	0-15	19.4	25.8	54.8	F-A	4.2	7.85	2	0.3	1.36	0.8	4.57	45.9	1.4
	15-30	27.4	29.8	42.8	F-Arc-A	4.1	3.22	5	0.1	0.28	0.2	5.22	88.1	0.8
7	0-15	37.4	41.8	20.8	F-Arc	5.1	6.73	1	0.2	9.48	2.2	12.7	6.3	1.7
	15-30	41.4	39.8	18.8	Arc	4.6	3.08	7	0.1	4.96	1.2	13.4	53.1	0.7
8	0-15	21.4	43.8	34.8	F	5.4	11.4	0	0.3	5.68	1.7	7.81	2.6	1.5
	15-30	29.4	37.8	32.8	Arc-F	4.9	2.24	4	0.2	3.08	1.1	8.28	47.1	0.6
11	0-15	43.4	33.8	22.8	Arc	6.7	5.47	0	0.3	27.1	3	30.6	0.65	1.9
	15-30	47.4	27.8	24.8	Arc	6.5	2.24	0	0.1	27.5	2.7	30.5	0.7	1.1
12	0-15	71.4	27.8	0.8	Arc	6.7	2.66	0	0.2	47.6	4.8	52.8	0.4	2.4
	15-30	75.4	23.8	0.8	Arc	6.4	0.42	0	0.1	55.1	3.3	58.7	0.3	1.5
13	0-15	37.4	25.8	36.8	F-Arc	6.5	7.99	0	0.4	17	3.3	20.9	1	1.6
	15-30	39.4	25.8	34.8	Arc-F	6.3	1.96	0	0.2	19.4	3.5	23.4	0.9	0.9
15	0-15	25.4	31.8	42.8	F	6.3	14.7	0	0.2	11	1.5	12.9	1.55	1.9
	15-30	31.4	29.8	38.8	Arc-F	5.4	8.13	2	0.1	9.2	1.2	12	12.5	0.7

Depth in cm; Texture: F= Frank; Arc=Clay; A=Sand, given in %; Texture: It is calculated based on the proportion of clay, silt, sand based on the USDA textural triangle; P: Available phosphorus (ppm); Al: Aluminum (cmolc L^{-1}); K: Potassium (cmolc L^{-1}); Ca: Calcium (cmolc L^{-1}); Mg: Magnesium (cmolc L^{-1}); CEC: sum of exchangeable cations; Al^{+}(%): Aluminum saturation percentage; CO %: Percentage of organic matter.