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Translated from the original in spanish

Survival, mortality and growth of three forest species planted in Andean scrubland in southern Ecuador

Sobrevivencia, mortalidad y crecimiento de tres especies forestales plantadas en matorral andino en el sur del Ecuador

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ABSTRACT

The planting of three forest species in Andean scrubland in southern Ecuador was experienced in two areas: one carrying out pure planting, planting 20 plants per block species, with three repetitions; and a second area with mixed plantation 20 mixed individuals in each block. Survival, mortality, average growth and annual periodic increase in diameter and height were calculated. Survival at 3 years: *Cedrela montana* in 37 % pure plantation and mixed 10 %, *Jacaranda mimosifolia* pure plantation 58 % and mixed 55 % and *Lafoensia acuminata* pure plantation 93 % and mixed 75 %. Annual mortality: *Cedrela montana* pure plantation 33 % and mixed 77 %, *Jacaranda mimosifolia* pure plantation 18 % and mixed 20 % and *Lafoensia acuminata* pure plantation 2% and mixed 10 %. Growth in three years: *Cedrela montana* pure plantation diameter 0,18 cm and height 11,12 cm; mixed plantation diameter 0,36 cm and height 3,08 cm, *Jacaranda mimosifolia* pure plantation diameter 0,05 cm and height 0,38 cm; mixed plantation diameter -0,003 cm and height 8,34 cm, *Lafoensia acuminata* pure plantation diameter 0,08 cm and height 21,95 cm; mixed plantation diameter 0,05 cm and height 4,83 cm. There is decrease in height in *Cedrela montana* and *Jacaranda mimosifolia*, this responds to the apical death of some individuals. There are differences in survival and growth between areas, due to the species used and biophysical factors of the sites.

Keywords: survival; mortality; restoration; average growth; southern Ecuador; forest plantations.

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RESUMEN

Se experimentó la plantación de tres especies forestales en matorral andino en el sur del Ecuador, en dos áreas: una realizando plantación pura, sembrando 20 plantas por especie en bloque, con tres repeticiones y otra con plantación mixta, 20 individuos mezclados en cada bloque. Se calculó la sobrevivencia, mortalidad, crecimiento medio e incremento periódico anual de diámetro y altura. La sobrevivencia a los tres años: *Cedrela montana* en plantación pura 37 % y mixta 10 %; *Jacaranda mimosifolia* en plantación pura 58 % y mixta 55 % y *Lafoensia acuminata* en plantación pura 93 % y mixta 75 %. La mortalidad anual: *Cedrela montana* en plantación pura 33 % y mixta 77 %; *Jacaranda mimosifolia* en plantación pura 18 % y mixta 20 % y *Lafoensia acuminata* en plantación pura 2 % y mixta 10 %. Crecimiento en tres años: *Cedrela montana* en plantación pura, diámetro 0,18 cm y altura 11,12 cm; plantación mixta, diámetro 0,36 cm y altura - 3,08 cm; *Jacaranda mimosifolia* en plantación pura, diámetro - 0,05 cm y altura - 0,38 cm y en plantación mixta, diámetro -0,003 cm y altura 8,34 cm; *Lafoensia acuminata* en plantación pura, diámetro 0,08 cm y altura 21,95 cm y en plantación mixta diámetro 0,05 cm y altura 4,83 cm. Existe decrecimiento en altura en *Cedrela montana* y *Jacaranda mimosifolia*; esto responde a la muerte apical de algunos individuos. Existen diferencias de sobrevivencia y crecimiento entre áreas, debido a las especies utilizadas y a factores biofísicos de los sitios.

Palabras clave: sobrevivencia; mortalidad; restauración; matorral andino; sur del Ecuador; plantaciones forestales.

INTRODUCTION

The Tropical Andes hotspot is an important ecological region with great potential for forest restoration (Conservation International, 2014). Within this ecosystem, the montane forests of northern and southern Ecuador have high levels of species richness and endemism (Gentry, 1992). However, the structure and dynamics of vegetation are strongly affected by the transformation of forest cover to other land uses, one of the main causes being fragmentation, degradation and loss of biodiversity (Reyes, 2004; Etter *et al.,* 2008).

However, recent data reveal that degraded forest areas and abandoned agricultural lands are recovering, and forms of restoration, both active and passive, are an alternative for stabilizing eroded landscapes (Silver *et al.,* 2000).

Ecological restoration is the process of recovering a degraded, damaged or destroyed ecosystem (SER, 2004). It is an activity that initiates and/or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability; it includes the improvement of ecosystem functions and services (Vasseur, 2012). It is a component of conservation and sustainable development programs worldwide (SER, 2004). The UN declares 2020-2030 as the decade of ecological restoration.

Passive restoration is the removal of the stressing agent that is limiting natural regeneration in the area. However, despite the fact that this is an economic and simple practice, several studies carried out in scenarios where passive restoration was applied show that, due to the environmental conditions of the altered sites, natural processes become slow, taking several years to establish a vegetation cover similar to the reference site (Voss et al., 2001; Günter *et al.,* 2007, 2011; Knoke *et al.,* 2014; Palacios *et al.,* 2015).

Active restoration is directed at restoring the vegetation cover or recovering the functionality of the ecosystem, which is an integral and complex process that involves a great deal of effort. Active restoration is usually applied through enrichment techniques of exotic and mixed plantations (Aguirre *et al.,* 2006; Beck et al., 2008; Mazón & Aguirre, 2016; Mazón *et al.,* 2017; Murcia *et al.,* 2017). For the Southern Region of Ecuador, enrichment planting may be an interesting option to convert exotic species plantations into more natural systems or environments, which may contribute to the restoration of biodiversity.

In the current circumstances, ecological restoration is seen as a global priority (Mazon *et al.,* 2017). At the international level, the Bonn Challenge, launched in 2011, is a global effort to restore 150 million hectares of deforested and degraded land by 2020. This challenge was extended in the New York declaration signed in 2014, with the intention of reaching an additional 200 million hectares by 2030 (Laestadius et al., 2011).

There is also target 14 of the Convention on Biological Diversity, that by 2020 it will be possible to restore and safeguard the ecosystems with the greatest risk of degradation and that produce the greatest environmental benefits (CBD, 2010); on the other hand, there is the 20-20 initiative that began in 2014, where Latin American and Caribbean countries will work together with local actors to achieve the restoration of 20 million hectares of degraded land by 2020 (WRI, 2014).

In Ecuador, ecological restoration has gained strength since the Constitucion Política del Ecuador 2008, in article 72, recognizes as an outstanding aspect the right that nature has to be restored in case of negative consequences with the environment; Likewise, the restoration of the Plan Nacional del Buen Vivir 2017-2021 (National Plan for Good Living 2017-2021) is contemplated in axis 3, objective 3, where it emphasizes ethical responsibility towards current and future generations so that life in all its forms is maintained, protected and supported, and recognizes the right of the population to live in a healthy and ecologically balanced environment (SENPLADES, 2017).

In the Southern Region of Ecuador there are many degraded areas for various reasons and the recovery of the composition and functionality of these systems at the landscape level has not been experienced, a situation that would support the planning and implementation of restoration actions (Aguirre and Mazon, 2016).

To fill this information gap, this experiment was implemented in order to evaluate the survival, mortality and initial growth in diameter and height of three forest species planted in a naturally recovering Andean shrub. The document contains initial results of three years of observation and contemplates the survival, mortality and growth of the three species under study.

MATERIALS AND METHODS

Study Area

The Parque Universitario "Francisco Vivar Castro" (PUFVC) is located in the sector "La Argelia", parish "San Sebastián", in the canton "Loja"; it is owned by the Universidad Nacional de Loja, has an area of 99.13 ha, in an altitudinal range of 2 130 to 2 520 meters above sea level. It is located between UTM coordinates: 700 592 - 9 554 223N, 700 970 - 9 553 139S - 701 309 - 9 553 171E, 699 961 - 9 554 049W (Aguirre, Yaguana and Gaona, 2016) (Figure 1). The intervention area is a scrub under the product of plant succession after having been planted with *Pinus radiata* and withstanding three forest fires in the span of seven years.

The areas under study are located in the low montane dry forest (bs-MB) life zone (Cañadas, 1983); it has an average annual temperature of 16.6°C, average annual precipitation of 955 mm/year (Palacios, 2012). The soil is of metamorphic rock parental material, low fertility, moderately deep (60 cm), loamy texture, sandy loam and clay loam, acid pH. These are colluvial soils where there has been the constant action of geomorphological phenomena that have modified the physiography with large landslides and the action of rainfall erosion, which has resulted in the formation of estoraques and hills (Guarnizo and Villa, 1995; Aguirre, 2001).

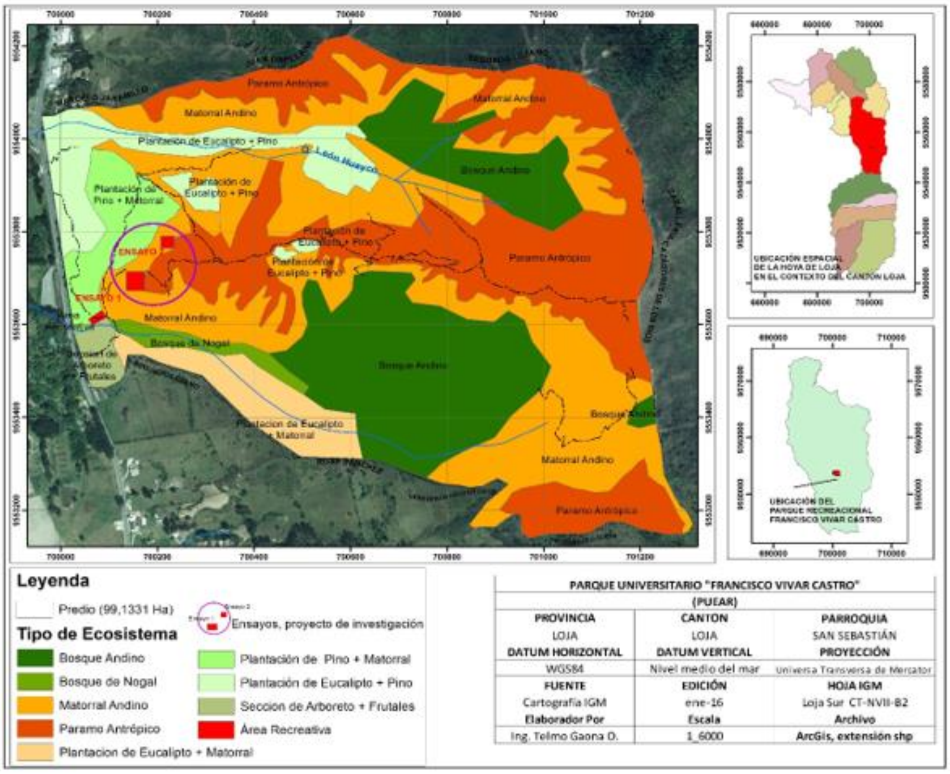

Fig.1. - Ecosystems of the "Francisco Vivar Castro" University Park. The research trials are located in the Andean scrubland ecosystem

Design of the tests in the Andean scrub of the PUFVC

Trials were established in blocks. Three forest species were used: *Cedrela montana* Moritz ex Turcz (white cedar), *Lafoensia acuminata* (Ruiz & Pav.) DC. (guararo) and *Jacaranda mimosifolia* D. Don. (arabisco), which are species used in forestry activities in the area and known to the population. In the first trial of 42 x 33 m (Figure 2), three repetitions per species were installed, giving a total of nine blocks, planting 20 individuals of each species at a 3 x 3 m spacing. In the second trial of 27 x 21 m, three blocks were installed, in each block the three forest species were combined with a total of 20 individuals of each experimental species (Figure 3).

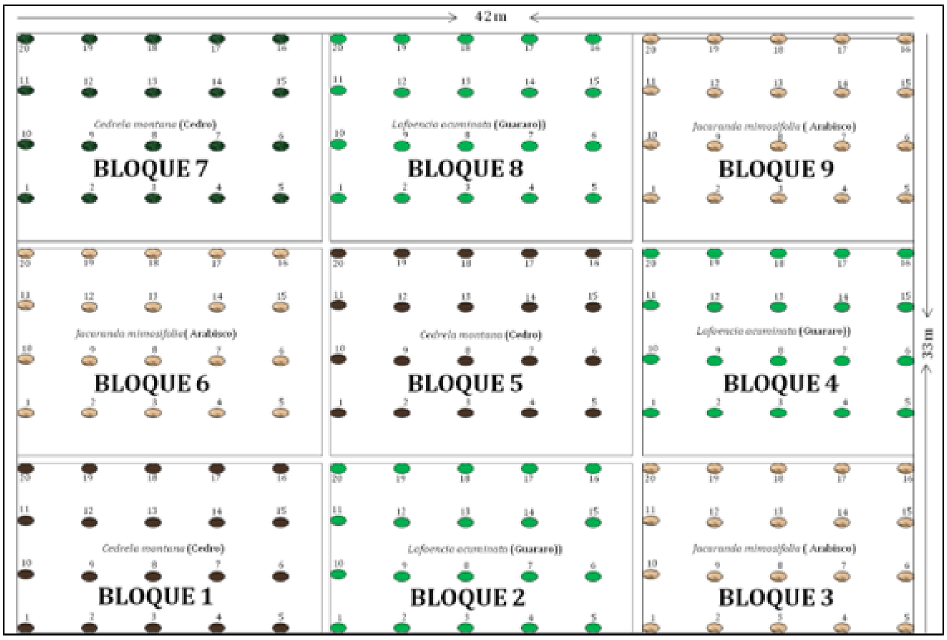

Fig. 2. - Forest species from the first trial established in the Parque Universitario

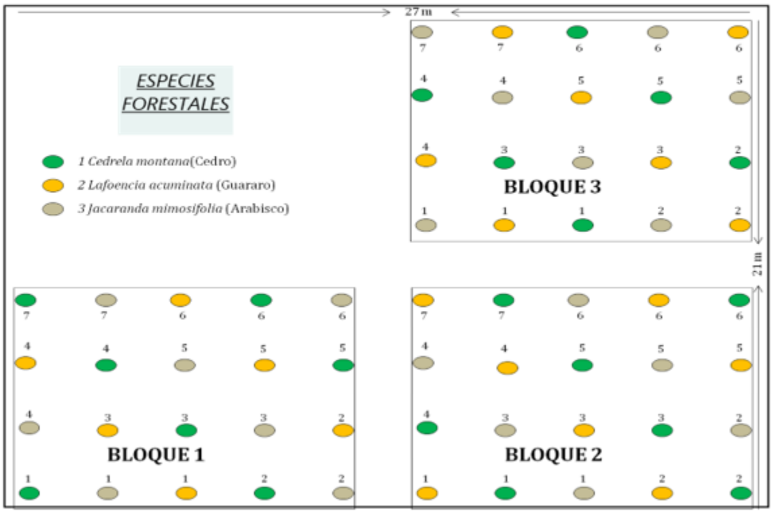

Fig. 3. - Forest species from the second trial established in the Parque Universitario

Determination of growth of established species

Two measurements were made: at the beginning of the experiment and three years after the trial was established. For each sampling unit, the diameter, total height, basal area and volume of all the individuals of the species under study were evaluated; those indicated in figures #2 and #3. The height was measured with a tape measure and the diameter at the base of the plant using a calibrator.

With the data obtained, the average annual growth of volume, diameter, basal area and height was calculated, using the formulas proposed by Quezada et al. (2012) (Table 1).

In addition, confidence limits were established for each of the estimators of the dasometric variables.

Mortality (m) was calculated using a logarithmic model (Lieberman and Lieberman 1987; Sheil *et al.,* 1995; Condit et al., 1999; Hoshino *et al.,* 2002; Marín *et al.,* 2005), over a three-year period (2016-2019). Mortality with the number of trees per area was calculated by applying equation #1:

$$m = \frac{\ln No - \ln Ns}{t} \qquad (1)$$

Where:
m = mortality, expressed as %/year
ln = Natural Logarithm
No = Number of individuals in first data collection
Ns = Number of original individuals surviving at the end of the period
t = Plantation age in years

Survivance: it was determined based on the percentage relationship between the number of established plants and the number of live plants found at the time of measurement.

Variables considered in the research

The variables that were measured and calculated in the research at the Parque Universitario "Francisco Vivar Castro" are: diameter at the base of the stem (D cm), total height (AT m), mean annual increase (IMA) and periodic annual increase (IPA).

Growth calculations and increases of the analysed variables

With the data obtained from the initial and current records, the growth and increase, at the level of individuals and species, within the trial was calculated (Table 1). For these analyses, the initial growth was considered to be the first measurement (when the trial was installed) and the final growth was considered to be the last measurement (three years of planting). The calculations were made for each individual by applying the formulas set out in table #1 and the values analyzed comprise the averages in both individuals and by species.

Table 1. - Formulas for the calculation of the parameters evaluated in the follow-up of the investigation

Parámetros	Fórmulas	Leyenda (explicación)
Crecimiento en Diámetro (cm)	$Cr.D = Df - Di$	Df = Diámetro al final del período Di = Diámetro al inicio del período
Crecimiento en Altura (cm)	$Cr.H = Hf - Hi$	Hf = Altura al final del período Hi = Altura al inicio del período
Crecimiento del Área basal (cm^2)	$Cr.G = Gf - Gi$	Gf = Área basal final Gi = Área basal inicial
Crecimiento medio anual de volumen (cm^3), altura (cm), D (cm) y área basal (cm^2)	$CMA = CF/t$	CMA = Crecimiento medio anual Cf = Crecimiento final t = Edad de la especie en años
Incremento Periódico Anual: volumen (cm^3), altura (cm), D (cm) y área basal (cm^2)	$IPA = Crf - Cri/t$	IPA = Incremento Periódico Anual Crf = Crecimiento final Cri = Crecimiento inicial t = Número de años del período

Source: Quesada *et al.* (2012)

Data Analysis

It was made the description of the survival rate, mortality, diameter growth, basal area, volume and height of each forest species, also calculated the average annual increase of growth in diameter at the base of the plant, height, volume and basal area. This study allowed us to determine the species with the highest annual growth in the different blocks. A Variance Analysis (ANOVA) was performed in order to identify significant differences at the species level and their adaptation to plantation systems, either using a single species or in combination. A regression analysis was also performed between diameter as a dependent variable and height as an independent variable. The statistical software INFOSTAT was used for the analysis.

RESULTS

Mortality and survival of the three forest species

The mortality and survival variables evaluated in the period 2016-2019, indicated that: *Cedrela montana* has the highest levels of mortality per year in pure plantations and associated stands, followed by *Jacaranda mimosifolia*, which has a medium survival level and finally *Lafoensia acuminata,* which registered higher survival values in associated plantations and pure stands, the latter being the best with 93 % survival (Table 2).

Table 2. - Mortality and survival of three forest species under restoration

Especie	Plantación	Inicio período	Final período	Sobrev (%)	Mort %/año
Cedrela montana	Mixta	20	2	10,00	76,75
	Pura	60	22	36,67	33,44
Jacaranda mimosifolia	Mixta	20	11	55,00	19,93
	Pura	60	35	58,33	17,97
Lafoensia acuminata	Mixta	20	15	75,00	9,59
	Pura	60	56	93,33	2,30

Growth and increase in diameter, height, basal area and volume of forest species

In relation to the growth and increase of dasometric variables, the results indicate a negative trend, both for *Cedrela montana* and for *Jacaranda mimosifolia*, mainly in the growth in height, which responds to apical death of individuals and, therefore, measurement of heights in shoots. The growth in diameter until the evaluation period was not very significant, being greater for *Cedrela montana* in combined plantations (Table 3).

Table 3. - Growth and increase in diameter and height of three forest species

Especie	Tipo	Cr_d	Cma_d	Ipa_d	Cr_altura	Cma_h	Ipa_h
Cedrela montana	Mixta	0,36	0,23	0,12	-3,08	11,00	-1,03
	Pura	0,18	0,17	0,06	11,12	11,71	3,71
Jacaranda mimosifolia	Mixta	-0,003	0,11	0,00	8,34	6,70	2,78
	Pura	-0,05	0,08	-0,02	-0,38	4,02	-0,13
Lafoensia acuminata	Mixta	0,05	0,11	0,02	4,83	7,91	1,61
	Pura	0,08	0,12	0,03	21,95	13,37	7,32

CR_D: Growth in basal diameter (cm); CMA_d; Diameter mean annual growth (cm); IPA_d: Diameter mean annual growth (cm); CR_H: Growth in height (cm); CMA_H: Altimetric mean annual growth (cm); IPA_H: Altimetric mean annual growth (cm); IPA_H: Altimetric mean annual growth (cm).

A pattern similar to diameter and height was observed in the growth and increase of basal area and volume. There is a negative trend for both *Cedrela montana* and *Jacaranda mimosifolia*, mainly in volume growth and Annual Periodic Increase (ADI). The basal growth in the evaluation period is not very significant, being higher for *Lafoensia acuminata*, followed by *Cedrela montana* in pure plantations (Table 4).

Negative values respond to individuals who suffered apical death and at the end of the evaluation were recorded values lower than the initial. This implies that some individuals possibly suffered stress and/or adaptation problems until they returned to their development.

Table 4. - Growth and increase in basal area and volume of three forest species

Especie	Tipo	CR_G	CMA_G	IPA_G	CR_Vol.	CMA_Vol.	IPA_Vol.
Cedrela montana	Mixta	-0,92	0,30	-0,31	-22,59	8,09	-7,53
	Pura	1,00	2,04	0,33	155,88	80,68	51,96
Jacaranda mimosifolia	Mixta	-0,70	0,32	-0,23	2,43	5,35	0,81
	Pura	-2,09	0,71	-0,70	-4,89	10,59	-1,63
Lafoensia acuminata	Mixta	0,06	0,42	0,02	5,56	7,34	1,85
	Pura	2,65	2,27	0,88	187,73	80,23	62,58

CR_G: Growth in basimetric (cm2); CMA_G: Average annual basimetric growth (cm2); IPA_G: Periodic annual basimetric growth (cm2); CR_Vol: Volumetric growth (cm3); CMA_Vol: Average annual volumetric growth (cm3); IPA_Vol: Periodic annual volumetric growth (cm3).

Statistical analysis

According to the Variance Analysis (ANOVA), significant differences in plant heights per site were found: *Jacaranda mimosifolia* reported better growth in height in mixed stands with *Cedrela montana* and *Lafoensia acuminata*. With respect to the diameter of the species, there were no significant differences in the two types of plantation for the species studied (Table 5).

Table 5. - Analysis of variance at species level and type of plantation for the variables in height and diameter of the plants

Variable	Especie	Plantación	Medias	E.e.	Significancia (0,05)
Altura	*Cedrela montana*	Mixta	3,3	± 2,68	a
		Pura	12,88	± 2,47	a
	Jacaranda mimosifolia	Mixta	11,05	± 2,68	b
		Pura	7,03	± 2,47	a
	Lafoensia acuminata	Mixta	17,8	± 2,68	b
		Pura	37,43	± 2,47	b
Diámetro	*Cedrela montana*	Mixta	0,07	± 0,04	a
		Pura	0,18	± 0,03	a
	Jacaranda mimosifolia	Mixta	0,17	± 0,04	ab
		Pura	0,14	± 0,03	a
	Lafoensia acuminata	Mixta	0,24	± 0,04	b
		Pura	0,34	± 0,03	b

Equal letters there are no differences, different letters there is a significant difference

Analyses of variables by species and by site show significant differences for *Lafoensia acuminata,* which has the highest values in height and diameter compared to the other two species, suggesting that it is the species with potential for restoration programs (Figure 4). With these results it can be inferred that *Lafoensia acuminata* and *Cedrela montana* have a better behavior in a pure plantation than in a mixed plantation; while *Jacaranda mimosifolia* develops better in combined plantations.

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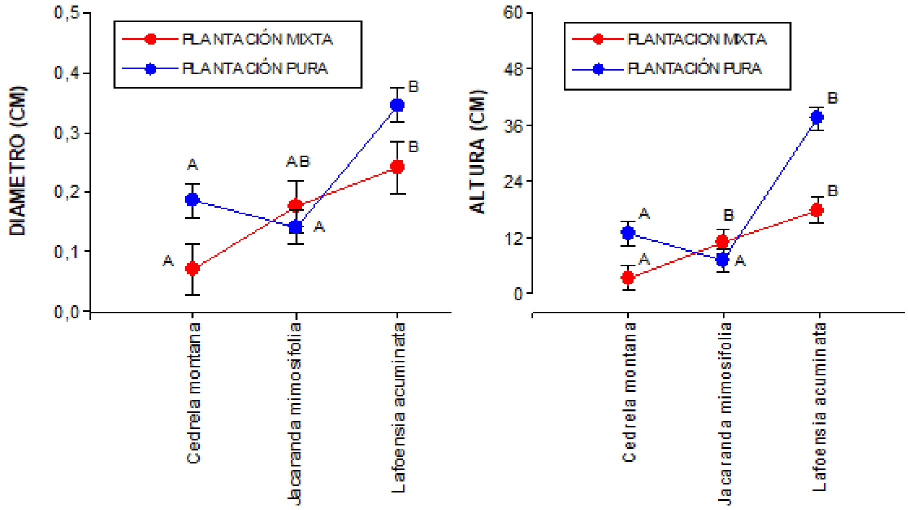

Fig. 4. - Analysis of variance between species and by type of plantation evaluated

Regression analyses reported a significant positive correlation between the variables diameter and height; that is, for each increase in diameter the model indicates an increasing trend in height for the species under study (Figure 5).

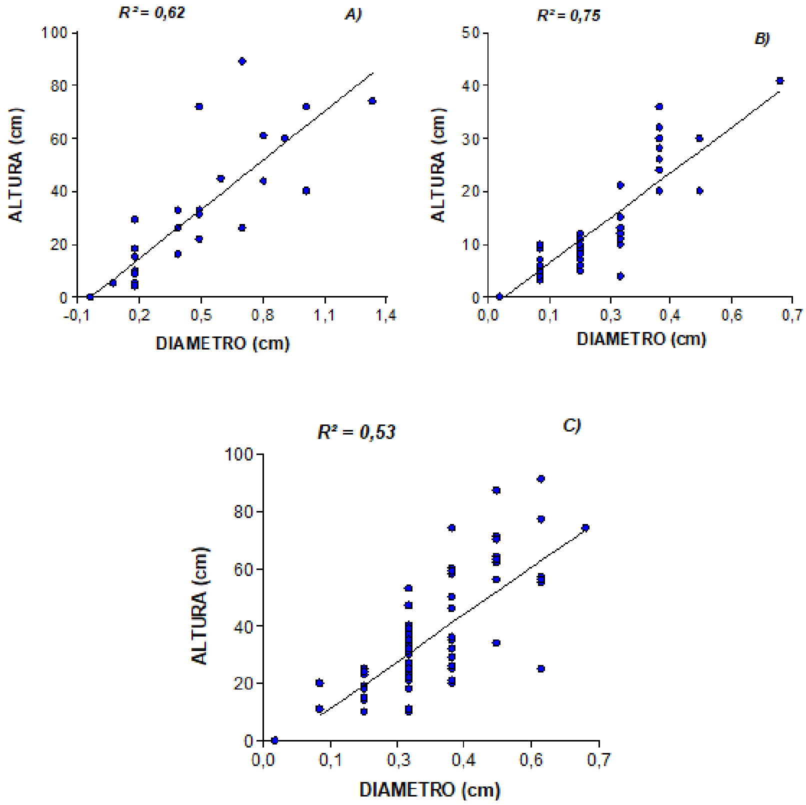

Fig. 5. - Regression analysis of the species under study: A) *Cedrela montana*, B) *Jacaranda mimosifolia* and, C) *Lafoensia acuminata*

DISCUSSION

The study of the adaptation of forest species in landscape restoration processes is key to determining the most suitable and least costly species. The results obtained place *Lafoensia acuminata* as the species with the greatest survival, according to site conditions, either in mixed plantations or in pure stands, coinciding with what was reported by Aguirre y León (2010) and Aguirre y León (2011).

In the case of *Cedrela montana*, it responds best in pure stands; however, its mortality is high in both types of plantation. These results agree, to a certain extent, with that recorded by González *et al.,* (2010), who obtained a survival of 53 %; however, the conditions of the site are different. In the case of *Jacaranda mimosifolia*, it presents better adaptability in combined plantations; possibly the species requires for its development the association with other species.

In relation to diameter growth, no major significance was observed for the three species under study; but for the height variable *Lafoensia acuminata* has the highest values followed by *Cedrela montana*, both are the result of pure plantations; while *Jacaranda mimosifolia* obtained higher values in mixed plantations. These results can have a direct response with the density of the plantation that when generating competition for light stimulates growth in length.

In terms of basimetric and volumetric growth, the species maintain the same pattern as height, placing *Lafoensia acuminata* as the species with the best growth response, followed by *Cedrela montana* and *Jacaranda mimosifolia*, which have lower values, even negative ones, due to the mortality of the apical parts, results that differ from those published by Mostacedo and Pinar (2001), who report a low mortality for this species.

Lafoensia acuminata, registered the best growth with respect to the height of the seedlings. However, it does not show significant differences in plantation types, with the exception of *Jacaranda mimosifolia*, which presents a difference when it is in mixed plantation. This absence of differences between plantation types may be associated with environmental variables that are not controlled such as: soil type, depth, humidity, intra- and inter-specific competition that do not allow inference on the effect of the plantation type on the survival and growth of the species under study.

Lafoensia acuminata is the species that shows good adaptability in scenarios under restoration, either in pure plantations or combined; in this initial phase of research, the species also presents the highest results in survival and growth.

Cedrela montana and *Jacaranda mimosifolia* have high mortality and limited growth.

Jacaranda mimosifolia can be used for recovery activities, but in mixed plantations.

The results of this research do not recommend the use of *Cedrela montana* for planting systems.

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