Chapter

Mixed Forest Plantations with Native Species for Ecological Restoration in Cloud Forests of the Venezuelan Andes

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Abstract

Tropical cloud forests play a fundamental role in the hydrological cycle of mountain watersheds having the largest biodiversity per unit area. In Venezuela, cloud forests are subject to intense deforestation and fragmentation by farming and cattle-ranching causing soil erosion, water cycle alteration, and biodiversity loss. Reforestation projects used exotic species as *Pines* and *Eucalyptus*, native species were rarely planted by lacking knowledge on species requirements and management. We report the performance of 25 native cloud forest species differing in shade-tolerance, planted in mixed assemblies on degraded areas. Tree survival and the individual tree variables: total height, root-collar diameter, tree-slenderness, and crown-ratio were evaluated at 1, 2, 4.5 and 7 years-old. Data was analyzed with a repeated measures analysis of variance mixed model considering species shade-tolerance, light intensity at planting and age as explanatory factors. Survival was over 80%. Shade-intolerant species displayed faster height and root-collar diameter growth. Shade-tolerant species had larger crown ratios due to persistence of lower branches; whereas, shade-intolerant showed signs of crown recession at age 7. Slenderness values from age 4.5 were indicative of good trees stability and health across treatments. The positive results have motivated landowners to establish native species plantations in critical areas with our support.

Keywords: active restoration, reforestation, species selection, successional status, shade tolerance, facilitation, survival, tropical forests, silviculture

1. Introduction

Reforestation is the action planting trees for recovering lands that were originally covered by forests that were cleared due to land change use (e.g. agriculture) or by natural phenomena. Worldwide, most planted forests are monocultures with native or exotic species, but mixed planted forests are increasingly established [1]. Reforestation together with afforestation is a way to reduce the pressure on natural forests and satisfy the demand of forest goods and services.

Ecological restoration, on the other hand, looks for overcoming the barriers for the recovery of degraded landscapes, creating forests that meet the ecosystem functionality and structure of the former primary forest [2, 3]. In the context of ecological restoration, reforestation fit within the category of "active restoration" in which, in addition to suppressing the causes of disturbances (passive restoration), strategies are implemented to accelerate recovery and, if possible influence the trajectory of the succession [4, 5]. Active restoration is important in places in which the natural regeneration is slow or hindered by biophysical factors [3].

Mixed plantations consist in establishing two or more species in a same stand. Species within the stand can be combined in many arrangements from alternate monospecific patches, to rows or intimate assemblages with various species. Species can differ in site requirements, successional stage (pioneer, late successional), architecture, growth habits, and uses. Also, trees within the mixture can be planted at different times to create uneven-aged stands. Mixed plantations are more accepted by communities, can have larger productivity and provide a wider array of goods and services [6]. From the ecological restoration point of view, mixed plantations with native species is a useful option for recovering the functionality and diversity of tropical forests. Petit and Montagnini [7] found that native species mixed plantations have favorable social and economic functions, because they provide a variety of timber and non-timber goods and services including soil recovery, carbon sequestration, and increase in biodiversity. Mixed plantations have been successful as a restoration option for creating a forest cover under certain conditions, where forests cannot regenerate by natural successional mechanisms as is the case in degraded pasturelands. However, the silviculture and management of mixed species with native tropical cloud forests species is complex, because lack of knowledge on growing these species, availability of plant, and difficult silvicultural management, particularly in intimate mixtures.

The Andean cloud forests are considered biodiversity "hotspots" and top the list of the most vulnerable ecosystems worldwide due to their small area and the high rates of deforestation by changes in land use from forest to agriculture and livestock that is accelerating the loss and degradation of these ecosystems. Cloud forests are characterized by a persistent cloudiness year around and occur in mountainous areas with abrupt topography. The complex combination of biotic and abiotic factors originate habitats with a high spatial and temporal heterogeneity leading to a high biodiversity [8].

Reforestation experiences in the cloud forest of Venezuela have been mostly carried out with exotic species (pine, cypresses, eucalyptus, ash, acacias) in monospecific cultures, and rarely in small tracts with several species. Native species plantation were included in past projects, but they were not successful due to failure to exclude main threats, lack of knowledge of site species requirements, improper planting methods, and absence of further care and monitoring in the initial stages. In general, seedlings of tree cloud forest species are characterized by slow growth and low tolerance to direct sunlight. In Venezuela, methods for production in nursery, plantation establishment, and management for these species are unknown. In 2007, our team began research projects aimed to study systematically cloud forest species requirements. Research included the distribution of seedlings of tree species in the forest understory along a light gradient [9, 10] and ecophysiological and morphological responses to contrasting light conditions [11, 12]. In 2012, we began a project aimed to develop and execute a plan for the landscape ecological restoration in the cloud forest of Paramo El Tambor with participation of stakeholders to restore degraded areas and help to protect the wildlife and their habitats. The plan includes several strategies of passive and active restoration. Among these, we initiated the establishment of small scale trials consisting of reforesting with native species in mixtures on deforested, degraded sites

The objective of this work was to report the performance of mixed species plantations, including more than 25 native species with different requirements of shade tolerance (shade-intolerant species; shade-tolerant species; partially shade species) established on degraded areas, originally covered by exotic pastures and some isolated trees. We describe the procedures for plant production, establishment, care and evaluated growth performance at ages 1, 2, 4.5, and 7 year-old for the different shade-tolerance groups growing in sites with different levels of shade.

2. Materials and methods

2.1 Study area

2.1.1 Physical environment

The study was carried out in Paramo El Tambor, an isolated mountain massif part of the Venezuelan Andes (8°37′00″N; 71°21′00″W) facing the Maracaibo Lake with unique environmental characteristics (**Figure 1**). Politically is located in the Mérida state. The area occupies around 150 km^2 covered by dense cloud forests, *paramo* (moorlands), and wetlands.

The tropical climate is influenced by altitude (2.000–3.000 m.a.s.l.) and topography. The trade winds coming from the NE penetrate through the piedmont area facing the lacustrine plain of Lake Maracaibo. These winds come loaded with water vapor forming a persistent cloudiness that when reaching its saturation point, triggers local precipitations in the slopes and valleys. The persistent thick cloudiness induces the existence of dense cloud forests from 2000 to 2500 m a.s.l. The annual average temperature is 14.9°C and average precipitation is 1400–1560 mm with a short dry season (December–February).

The landscape consists of rounded hills, with shallow to steep slopes. The soils are derived from the Colón Cretaceous formation characterized by stratified, massive, black, non-calcareous lutites with conchoidal fractures. Predominant soils are Ultisols and Inceptisols with and Udic regime of clay-silty, clay-silty-loam to clayey

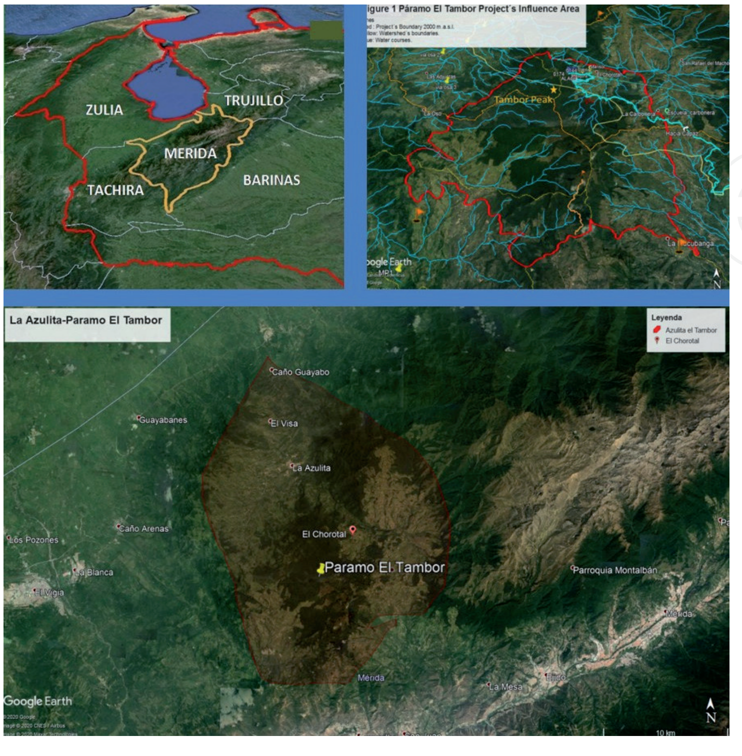

Figure 1.
Working Area Location of Páramo El Tambor, Mérida, Venezuela (Images: Google Earth, 2020).

textures highly variable in depth, structural development, and drainage. Chemically, they are highly acid (pH 4–5) with a low base saturation, high exchangeable Al, low CEC and a high organic matter content (5.5 % C) in the upper horizon [13]. There are no large rivers coming from high moorlands, and horizontal precipitation captured by the forest plays and important role in the water balance [14].

2.1.2 Vegetation

The forests are rich in evergreen tree species densely covered by epiphytes, mosses, and lichens. Tree Diversity is high with 40-60 species ha^{-1} [15]. The main tree families are Lauraceae, Melastomataceae, Euphorbiaceae, Myrtaceae, and Podocarpaceae, constituting one of the few tropical forest in Venezuela where native conifers coexist with hardwoods. The forest comprises various plant communities ranging from dense high forest (DHF) with complex stratification and a canopy 25-30 m high to sparse low stature forests with canopies < 15 m tall. The DHF has three layers: the upper layer approximately 25-30 m in height with emergent trees up to 40 m tall (mainly *Retrophyllum rospigliosii*, a conifer), an intermediate layer 20-24 m in height, and a lower layer 10-19 m. The understory comprises tree seedlings and saplings, shrubs, vines, palms, and herbaceous plants. Tree ferns (*Cyathea spp*.) and bamboos (*Chusquea spp*.) are common, the latter forming dense scrubs [13].

2.1.3 Socio-economic aspects

The landscape is a mosaic in which traditional agricultural production methods and old agro-social structures coexist with intensive production systems, and legal figures of strict protection; whereas, land management with ecosystem approaches are less usual. The area have been subject to intense deforestation and forest fragmentation In recent times, local people are witnessing a rapid deterioration of their surrounding environment according to perception surveys carried as part of the community service project “Sensitization for the Conservation of the Andean Cloud Forest” (unpublished data). The areas in which deforestation was more intense are clearly suffering a reduction of water supply. In addition, they are more exposed to strong winds that damage the crops by mechanical and desiccation impacts. In recent times, the area is experiencing environmental changes such as longer dry seasons and extreme precipitation events. The later, together with exposed soils have caused landslides affecting roads and properties. Associated consequences of deforestation and degradation is the apparent extinction of some local wildlife species such as amphibians and monkeys.

2.2 Species selection and plant production

For selecting the species to produce in nursery, we took into account landowner’s preferences and the findings of previous studies that analyzed the spatial distribution of seedlings of cloud forest tree species along a light gradient [8] and experiments in which seedlings of various species were grown under controlled levels of light intensity, then subjected to sudden changes in irradiation to observe their photosynthetic acclimation capacity [12]. According to these studies, we categorized the species in functional groups based on shade tolerance. Species fitted into three categories: (a) shade intolerant (SI), (b) partially shade tolerant (PT), and (c) shade tolerant (ST) (**Table 1**).

To produce plants, we collected seedlings from the forest understory because collecting viable seeds was very difficult, as many species have a very irregular cycle of flowering and seed production [19]. Seedlings were transplanted in polyethylene

Scientific name	Family	Shade Tolerance[1]	Uses[2]
Tetrorchidium rubrivenium	Euphorbiaceae	SI	WDF, FD, FA
Alchornea grandiflora	Euphorbiaceae	SI	WDF, MTB, FA
Montanoa quadrangularis	Asteraceae	SI	WDF, FD; FA
Ruagea pubescens	Meliaceae	SI	MTB; OR, FA
Cedrela montana	Meliaceae	SI	MTB, OR, FA
Inga oerstediana	Leguminosae	SI	MTB; FA, NF
Ocotea macropoda	Laureaceae	SI	MTB; FA
Miconia meridensis	Melastomataceae	SI	MTB, FA
Cecropia telenitida	Urticaceae	SI	MTB; OR
Hieronyma moritziana	Euphorbiaceae	PT	MTB, FA
Billia columbiana	Hippocastanaceae	PT	MD, MTB, FA
Casearia tachirensis	Flacourtiaceae	PT	HWR, MTB, FA
Beilschmiedia sulcata	Laureaceae	PT	HWR, FA
Nectadra laurel	Laureaceae	PT	MTB, FA
Prunus moritziana	Rosaceae	PT	MTB, OR, FA
Retrophyllum rospigliosii	Podocarpaceae	PT	MTB, OR, FA
Myrcia acuminata	Myrtaceae	PT	TB, FW, FA
Vochysia meridensis	Vochysiaceae	PT	MTB, OR, FA
Eugenia tamaensis	Myrtaceae	ST	MWR; FA
Myrcianthes karsteniana	Myrtaceae	ST	HWR, OR, MD, FA
Miconia resimoides	Melastomataceae	ST	MTB; OR
Podocarpus oleifolius	Podocarpaceae	ST	MTB, OR
Myrcia fallax	Myrtaceae	ST	MTB; MD
Aegiphila terniflora	Verbenaceae	ST	MTB, HWR, FA
Eschweilera tenax	Lecytidaceae	ST	HWR, FA

[1]*Species shade tolerance group: shade intolerant (SI), partially tolerant (PT), shade tolerant (ST).*
[2]*Species uses: fodder (FD), fauna attraction (FA), medicinal (MD), firewood (FW), nitrogen fixing (NF), ornamental (OR), multipurpose timber (MTB), hardwood for building roofs (HWR), wooden fences (WDF).*

Table 1.
List of species used for restoration in Paramo El Tambor cloud forest according to their shade tolerance and potential uses.

bags (diameter = 17 cm, height = 25 cm), in a mix 1:1 forest soil and sand. Plantlets were grown for at least six months in a nursery covered by an 80 % shade mesh allowing the pass of 214–270 μmol m^2 s^{-1} of photosynthetic photon flux (PPF), approximately 20% PPF of daily full sunlight [12]. Plants were irrigated regularly to avoid water stress. Weeds were removed manually and pest control was needed against snails and slugs.

2.3 Site selection, plantation establishment, maintenance and monitoring

Sites for planting were chosen together with stakeholders on deforested, degraded areas limiting with springs and having strong limitations for farming activities. The sites were 1200 to 1500 m^2 each, at 2250 to 2300 m a.s.l. Areas were covered by grasses, usually kikuyu grass (*Pennisetum clandestinum*), shrubs, vines (e.g., *Rubus fruticosus*) and isolated trees. Sites varied in slope (30-80%) with soils poor in organic matter and nutrients. Most sites were exposed to direct sunlight; however, tree crowns close or within the planting areas projected shade that reduced the incident light at ground level. In the chosen sites, we delimited the area and made a topographic survey. Pastures and vines were cut with a grass-cutting machine. Trees and shrubs from natural regeneration were left. The areas were delimited with wired fences to exclude cattle. In addition, we estimated the light environment in the sites by using as a surrogate the percentage of canopy openness (%CO) [8]. This variable provides a good characterization of the potential penetration of solar radiation through canopies and its incidence on a given point [16]. For estimating the %CO, we took hemispherical photographs on the vertices of a superposed 5.0 m square-grid covering the planting areas (n= 140). We used a digital camera with a fisheye lens mounted on a tripod and leveled with the top of the lens standing 150 cm above the ground. The photos were processed with Gap Light Analyzer (GLA) v. 2.0 [17]. For detailed procedures see [9, 18].

For site preparation no tillage was done, so the soil was disturbed only when opening the planting holes. Around the holes, grasses and other weeds were removed from root. Planting was done during the rainy season.

In all areas, plants were established following a horizontal (slope corrected) triangular spacing of 1.5 m (5.128 trees ha^{-1}). A regular spacing was preferred over an irregular one for controlling variables of stand density and competition and easiness for monitoring. Also, landowners showed a marked preference for regular spacing. The selected planting density is very high for tropical plantations standards (600-2500 tree ha^{-1}), but we looked to ensure survival of sufficient trees to reach faster shading for controlling pastures, and to observe competition/facilitation interactions as soon as possible.

Planting areas were subdivided in plots (~200 m^2 each, ~100 trees per plot). Plots were assigned to levels of light intensity (LI) based on %CO at planting time. Three levels of LI were differentiated: (a) High Light (HL, above 50% CO); (b) Medium Light-(ML, 40–50 % CO); and, Low Light intensity (LL <40 % CO).

In plantation rows, within each plot, two trees of the same species were planted consecutively forming a "group". Groups were alternated randomly, but with the restriction that at least two groups from each shade tolerance category should be included within plots classified within a given light intensity level (**Figure 2**). Planting two trees looked to improve the probabilities of at least one tree surviving, so maintaining a regular distribution within the plantation. The less promising tree will be eliminated when thinning is needed. The approximate planting ratio of SI, PT, and ST was 5:3:2, as ST species were more difficult to grow in nursery until reaching the desired size (20–40 cm tall). Mechanical-manual control of weeds was needed at least every six months until age 2. Cleanings consisted of eliminating vines and weeds rooted around the tree stem in a circle of 50 cm radius. Weeding was done prior to each measurement time to facilitate access to the trees. No chemicals were used for controlling pests or plagues that periodically affected some species. Irrigation, was needed only during the first dry season after planting. A replanting was done six months after planting to replace dead plants.

2.4 Measurements and statistical design

We sampled 12 plots (~200 m^2 each, ~80–90 trees per plot) covering all combinations of light intensity (LI), species shade-tolerance (STOL), and ages. All plots included species of the three groups of shade tolerance; however, not all species were present in a given plot. The trials were re-measured at ages 1, 2, 4.5 and 7 years. Percent

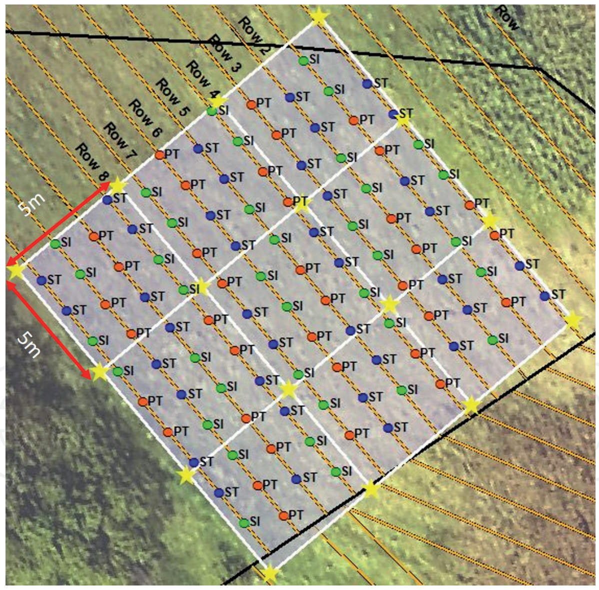

Figure 2.
Spatial arrangement of groups of plants within a plot. Spacing is triangular (1.5 m) and distance between rows is 1.3 m. Legend: hemispherical photographs (☆) taken on the vertices of the white grid, planted rows (▬), fences (▬), shade intolerant (●), partially tolerant (●), and shade tolerant plants (●).

tree survival was determined for each combination of light intensity and shade tolerance group as the percentage of surviving trees at a given age with respect to the initial number of planted trees. For each tree, we measured (a) total height in meters (HT), (b) root collar diameter in cm (RCD) and computed (a) tree slenderness coefficient (TSC) calculated as total height (m) divided by root collar diameter (m), and (b) crown ratio (CR) calculated as live crown length (m) divided by total height (m).

The TSC is an important indicator of tree stability. In general, a tree with a low TSC usually indicates lower center of gravity with a longer crown length, and a better developed root system increasing resistance to falling by strong winds and other factors [19–21]. The CR varies between 0 and 1, with a large live crown ratio indicating a healthy tree able to respond to favorable changes such as canopy openings [22].

To analyze the data, a factorial analysis of variance (ANOVA) mixed model was used in which STOL and LI factors were considered as fixed effects. Re-measurement age was considered a repeated effect, as the same plants and plots were re-measured at the various ages. Only the largest tree in each group of two of a same species was chosen for data analysis, as it was assumed that this expressed best the growth potential under the site conditions predominating in the plot. The second tree, if survived, usually grew less due to slow initial growth, or mechanical damage. Also, damaged trees were discarded from analysis (e.g., broken trees).

Data were stored in a spreadsheet and processed in SAS v. 9.1 [23]. For each variable, several models with varying structure of the variance-covariance matrix were tested. The best model was that with the lower value of the Akaike and Bayesian information criteria (AIC and BIC) [24]. For each variable, simple effects (shade tolerance, light intensity, and age) and resulting interactions within and across age were analyzed for shade tolerance and light intensity. The model takes into account the correlation between repeated measurements normality and variance heterogeneity along time [25]. As the design is unbalanced, a Tukey-Kramer test based on marginal means (least squares means) [26] allowed comparisons for differences among shade-tolerance groups and light intensity at similar re-measurement times. Probability values (p-values) indicated the statistical significance of effects and interactions. For simplicity in means comparisons, p-values ≥ 0.05 indicated no significant differences, p-value < 0.05, significant differences, and p-value < 0.01, highly significant differences.

3. Results and discussion

3.1 Survival

Survival was high for all categories of shade tolerance within different levels of light intensity averaging over 70% for all plots after year 4.5 (**Table 2**). Only one plot was discarded from analysis because flooding caused high mortality (>50%). In the remaining plots, the SI species had a survival above 85% after 4.5 years with a slightly better survival in LL. Also, PT species showed better survival in LL (above 90%), but only 73–77% in HL and ML. Shade Tolerant species presented the lower values of survival in HL; nonetheless, values remained above 70 % after year 4.5. In ML this group maintained over 80 % survival, and above 90% in LL. Only two species *M. resimoides* and *E. tenax* (n > 10 each) had 100% mortality before the second year. After age 2, most mortality was due to mechanical damage by the fall of large branches from the isolated trees and occasional herbivory and cramping by cattle that passed the fences. There are very few studies for mixed plantations in tropical cloud forests that report survival results of native species after four years-old.

In a Mexican cloud forest [27] evaluated mixed plantation trials with up to nine native species and found an average survival of 93% three years after planting. They concluded that if plants survive the establishment phase, mortality in further years is low. In the same study, the authors reported that in a trial with the native species *Alnus acuminata* and *Quercus xalapensis* growing on native and exotic abandoned grass, the combined survival was 92 and 48 % after 46 weeks since planting. Higher mortality on exotic grass varied between species due to competition and herbivory from rats. Also in a Mexican cloud forest [28] planted *Alnus acuminata* and *Trema micrantha* as facilitating species for the establishment of intermediate and late successional species (ILS). At age 2 (96 weeks), survival was 94 and 77% respectively for the facilitating species. On the other hand, the survival of the three ILS was significantly higher (>60%) under the shade of *A. acuminata*, and 40–50% under *T. micrantha*. When planted on open field survival was only 11 to 22% for the ILS. They attributed the low survival in the open field to water stress accompanied with herbivory. In the Atlantic semi-deciduous forest of Brazil, [29] compared the

Shade tolerance	Light intensity	Trees planted	Age (years)			
			1.0	2.0	4.5	7.0
IS	HL	121	92.1 ± 7	91.0 ± 9	88.4 ± 9	79.2 ± 10
	ML	223	95.9 ± 4	93.9 ± 6	89.4 ± 8	90.0 ± 5
	LL	132	100.0 ± 0	100.0 ± 0	97.8 ± 3	91.3 ± 4
PT	HL	82	84.3 ± 10	81.6 ± 6	73.6 ± 14	64.9 ± 18
	ML	120	91.2 ± 9	86.8 ± 12	76.9 ± 11	78.7 ± 4
	LL	55	98.6 ± 2	97.1 ± 4	94.6 ± 1	94.3 ± 2
ST	HL	51	76.0 ± 9	76.0 ± 9	73.5 ± 5	70.0 ± 5
	ML	101	98.5 ± 3	91.2 ± 8	82.9 ± 4	80.2 ± 8
	LL	55	97.5 ± 4	96.1 ± 2	94.6 ± 1	91.4 ± 1

[1]*Species shade tolerance group: shade intolerant (SI), partially tolerant (PT), shade tolerant (ST).*
[2]*Light intensity: high light (HL), medium light (ML), low light (LL).*

Table 2.
Percent survival ± standard deviation (n = 11 plots) for combinations of shade tolerance and light intensity at the ages of measurement.

survival of 36 native species from different successional stages established as mixed plantations on degraded sites. Before planting they plowed and fertilized the sites. Fifteen after planting survival was around 55% for pioneer and secondary species, and only 12% for the late successional ones. The high survival rates for most species in the present report was due to a relatively intense monitoring and maintenance within the first two years after planting. The main silvicultural treatments included avoiding water stress with irrigation in the first dry season after planting and controlling aggressive weeds and grass at least for two years. Keeping cattle exclusion was also critical. Although insects and pests attacked particular species at different times, they rarely caused mortality. Finally, in areas shaded by mature trees, the fall of large branches caused mechanical damage to some trees which eventually died.

3.2 Tree level variables

For all variables measured on individual trees, a mixed model with an autoregressive first-order residual variance-covariance matrix performed best than alternative structures (lowest AIC and BIC criteria). The type III test for fixed effects showed highly significant differences for simple effects, except for CR with $p > 0.05$ (**Table 3**). The interaction STOL × AGE was significant for all variables; whereas, LI × AGE was significant ($p < 0.05$) for TH, and highly significant for the rest of variables. The interaction STOL × LI was also significant for all variables except for TSC ($p > 0.05$). The interaction STOL×LI×AGE was not significant. The LI factor is based on values of %CO at the beginning of the plantations, and although changes in light incidence above the canopy (isolated trees) were minimum, the largest planted trees of SI species began to reduce the amount of light received by smaller trees included most of the ST. Mixtures of shade intolerant, early successional species and shade-tolerant, late-successional species, could facilitate the survival and growth of the latter [30].

These results indicate that trees from the three STOL groups underwent significant changes in the evaluated variables along age and across plots differing in initial LI levels, with the SI species showing faster growth at all levels of LI.

The most insightful results were for the STOL x AGE interactions where the averaged values of variables for each STOL group were compared within and along ages (**Figure 3a,b**). The STOL groups did not differ significantly in TH the first year after planting; but, after age two, the SI group presented significantly larger heights than the PT-ST groups (**Figure 3a**). Differences in TH among the three groups become larger at ages 4.5 and 7 years, with SI species growing faster than PT, and the ST species showing the lower height growth. Despite differences in total height the three groups appear to be growing at an increased rate with age. After 7 years

Variable[1]	STOL	LI	AGE	STOL x AGE	LI x AGE	STOL x LI
TH (m)	<.0001	0.0001	<.0001	<.0001	0.0152	0.0005
RCD (cm)	<.0001	<.0006	<.0001	<.0001	<.0001	0.0200
TSC	0.0015	<.0001	<.0001	<.0001	<.0001	*0.0917*
CR	<.0001	*0.4635*	<.0001	<.0004	0.0083	0.0168

[1]*Variables: total height (TH), root collar diameter (RCD), tree slenderness coefficient (TSC), crown ratio (CR).*
[2]*Factors and interactions: shade tolerance (STOL), light intensity (LI).*

Table 3.
Simple effects and interactions for the analyzed variables. Triple interaction not included. Means comparisons p-values ≥ 0.05 indicated no significant differences, p-value < 0.05, significant differences, and p-value < 0.01, highly significant differences.

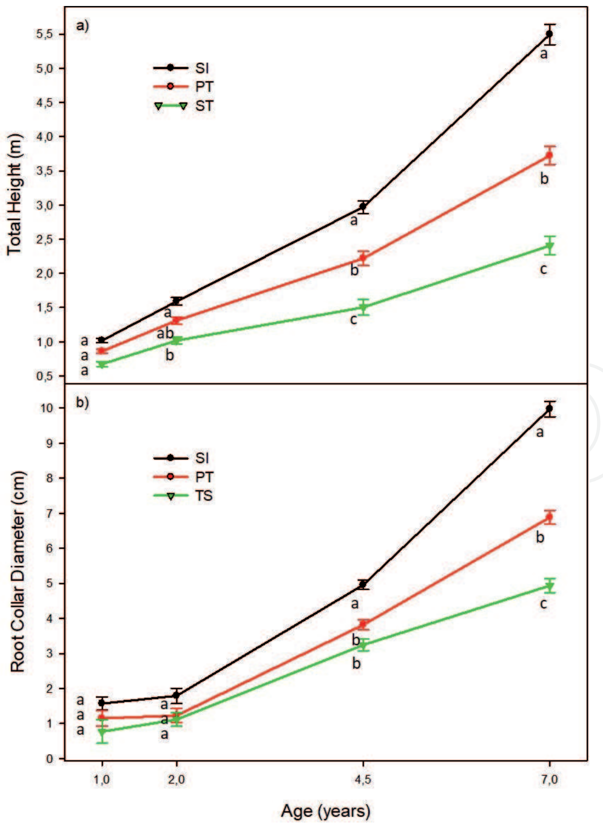

Figure 3.
Changes in total height and root collar diameter among shade tolerance species groups with age. (a) Total height, (b) root collar diameter. [1]Species shade tolerance group: shade intolerant (SI), partially tolerant (PT), shade tolerant (ST). [2]Similar letters below the lines indicate statistically not significant differences (p>0.05) among shade tolerance groups; whereas, different letters indicate significant differences (p < 0.05) according to the Tukey-Kramer test.

average height increments can be considered low (< 1 m yr^{-1}) when compared with the growth increments for lowland tropical species (2–4 m yr^{-1}) and the growth of exotic species such as cypresses and pines. However, SI species had many trees close to 10 m tall at age 7. These trees also developed large, wide crowns (e.g., *M. quadrangularis, T. rubrivenium, M. meridensis*). Likewise, for RCD there were no differences among STOL groups for ages 1–2; whereas at ages 4.5 and 7, in which the three groups, with SI having a larger RCD than the other groups (**Figure 3b**).

When considering the STOL × LI interaction effect on the performance of TH and RCD, the Tukey test indicated no statistically significant differences (p > 0.05) at ages 1 and 2 years among the STOL groups, independently of LI for any of these variables. However, at ages 4.5 and 7, SI species showed significantly better performance in both variables than PT-ST species. Likewise, no significant differences were found for HT and RCD between PT and ST species across LI levels.

The TSC had not significant differences among groups at age 1 (**Figure 4a**). At age 2, all species increased their TSC (above 1.0), with a significantly higher increment for the ST-PT species over the SI species. Possibly, TSC at age 1 reflected the values that trees had in the nursery. Larger TSC for the second year could be due to a faster growth in height relative to RCD growth, indicating a faster stem elongation and formation of leaves at the top of the trees. By ages 4.5 and 7, TSC decreased again and stabilized for all groups, with no significant differences among them. The lower TSC indicates that the trees have more stability and are showing an adequate growth pattern [20].

Finally, the live crown ratio (**Figure 4b**) was significantly higher (>0.6) for the ST group than for PT-SI. By age 4.5 however, there was a considerable increase in CR for the PT and SI groups with no significant differences among STOL groups. Nonetheless, SI species had the lowest CR. At age 7, CR was similar (above 0.7) for

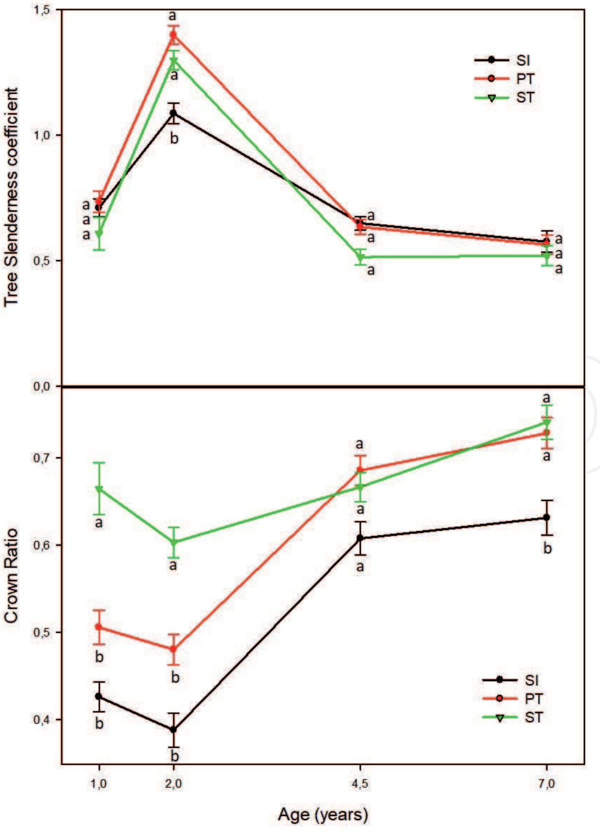

Figure 4.
Changes in tree slenderness coefficient and crown ratio among shade tolerance species groups with age. (a) Tree slenderness coefficient, (b) crown ratio. [1]Species shade tolerance group: Shade Intolerant (SI), Partially Tolerant (PT), Shade Tolerant (ST). [2]Similar letters below the lines indicate statistically not significant differences (p>0.05) among shade tolerance groups; whereas, different letters indicate significant differences (p < 0.05) according to the Tukey-Kramer test.

ST and PT and clearly higher than for SI species (0.6). The large CR for ST species is explained by the trend to have persistent leaves and branches along most of the stem along the years. This finding is supported by [31] who working with the plasticity traits of saplings from the tropic humid forest in the French Guiana determined that crown depth in shade tolerant species was a trait that depended on the leaf lifespan rather than crown elongation. In PT, and specially SI, the rapid height growth was accompanied by a large development in crown length; however by age 7, SI trees displayed signs of crown recession, as shaded leaves on the lower branches were dying quickly. Conversely to shade tolerant trees, [31] shorter crowns in SI species was attributed to a shorter lifespan of leaves. Usually, trees showing CR above 0.5 can be considered healthy; whereas, values below 0.3 indicate trees that are under strong competition. In addition, a characteristic shade intolerant species is the trend to reduce faster their CR under competition, because lower limbs tend to die due to insufficient light for having a net positive C assimilation.

At age 1, the TSC coefficient was significantly larger at ML for the three STOL groups than at HL or LL; differences were significantly higher slenderness in ML than in HL or LL; whereas, PT and ST species. At age 2, TSC remained stable for all STOL groups in the ML level, but the values increased significantly for all groups in HL and LL. At ages 4.5 and 7 no differences in TSC were found for any of the STOL groups in any LI level. Finally, at age 1 and 2, CR had significantly larger values in ML than in HL or LL. For ages, 4.5 and 7, there were no significant differences within light levels for any of the STOL groups.

The relatively low effect of LI levels on the performance of SI species support findings by [32] who suggest these species had an inherent fast growth rate determined mainly by morphological traits, but these growth rates are maintained at the expense of defense and storage allocation. As we could observe, SI species suffered from selective herbivory by cattle (i.e., leaves of trees from SI species were eaten; whereas those of PT-ST were not). On the other hand, as mentioned by the same author, survival of SI species cannot be attributed to a high net C balance

By age 7, the crown of SI species were in contact and forming an upper layer of dominant trees; whereas, PT and ST species conformed an intermediate layer. Although competition for light was not evident from the observed crown ratio values; the SI trees showed a large loss of leaves on their lower branches; whereas these persisted in trees of PT and ST, keeping large crown ratios despite being shaded. Only, between ages 5 and 7, the shade created by the new plantation has eradicated pastures, except in sites canopy holes created by tree mortality or in the borders of the planted sites. Natural regeneration of some tree and shrub species began after year two, and when taken into account increase stand density above 100%. In highly shaded areas, the presence of herbaceous plants is rather scarce and a fine layer of litter is forming.

4. Conclusions

Our research with tree native species and establishment of demonstrative trials in cloud forests show promising that reforesting with native species is a viable alternative for restoring degraded areas and the recovery of tree biodiversity given adequate planning, management and monitoring (**Figure 5**).

The most critical aspects for the initial success of these plantations consists on maintaining cattle exclusion for at least five years after establishment, irrigating during the first dry season, and keeping control of grasses and vines at least for two years.

Different mixed shade tolerance groups of tree species can stand conditions of sites dominated by pastures under high level of sunlight exposure; however, SI species appear to have faster growth rates than PT or ST species independently of shade conditions.

Figure 5.
State of development of one of the mixed plantations: (a) one year old, (b) 2 years old, (c) 4.5 years old, (d) 7 years old.

Planting mixed forests is a good option for recovering degraded sites in which the forest has disappeared and conditions for unassisted tree regeneration is not possible. More than scaling up to cover larger extensions, many landowners can establish small plantations in critical areas. Many of these plantations can act as small nucleus for maintaining and dispersing rare, shade-tolerant, late successional species that usually are difficult to regenerate without specific silvicultural treatments.

Mixed planted forests have a very positive response from local people who view these plantations as a very satisfying way of recover the forests as pointed by [33] in a similar work in the Andean cloud forest of Ecuador.

Among other benefits mixed planted forests with native species, provide food and shelter for wildlife, have better social acceptance because they are part of the natural landscape, and provide a variety of goods and services (e.g., shade, soil protection, medicinal properties).

Mixed plantations are complementary with other methods such as those of assisted regeneration in degraded forests or passive restoration used to recover large areas.

Acknowledgements

We are grateful to Ancelmo Dugarte and Dani Dugarte for their invaluable assistance in fieldwork. This work was partially funded by Consejo de Desarrollo Científico, Humanístico, Tecnológico y de las Artes, University of Los Andes (CDCHTA-ULA) (Grant F0–746–17–01-A).

Conflict of interest

The authors declare no conflict of interest.

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