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Silvicultural contributions to the reforestation with native species in the tropical mountain rainforest region of South Ecuador

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1. Introduction, problem and objectives

Ecuador is considered to be one of the global ´hotspots´ of biodiversity (Brummitt & Lughadha 2003). Despite this fact Ecuador is facing the highest deforestation rate (1.7 %) in South America (FAO 2006a). Between 1990 and 2005 the extent of forest and other wooded land in Ecuador decreased from 15 to 12.3 million hectares (FAO 2006a). The main reason for deforestation in Ecuador is the exploitation of forests and its subsequent conversion into agricultural land especially into pastures for cattle farming (Wunder 2000). For the San Francisco Valley, the area under investigation in this study, Paulsch et al. (2001) described the land-use dynamic which is typical for the montane Andean region: The first step is the exploitation of the primeval forests. Following the exploitation small scale farmers transform the exploited forests into pastures for cattle ranching. In order to improve the productivity of the pastures they plant non-native grasses, especially *Setaria sphacelata* and *Melinis minutiflora*. As a result of the regular burning of the pastures by the farmers bracken fern (*Pteridium arachnoideum*) is invading the areas more and more. After several years the decreasing productivity of the sites forces the farmers to abandon the land and to convert a new patch of forest into pastures (see also Hartig & Beck 2003).

Due to the harsh environmental conditions on the abandoned sites and the lack of seed input the natural succession is very slow and it takes several decades until a forest is recovered. Consequently, there exists an increasing amount of unproductive land, especially concerning over-used, degraded or abandoned pastures. This non-sustainable kind of land-use causes not only a loss of forest area and biodiversity but is also economically detrimental. In developing countries like Ecuador the loss of land productivity is particularly disastrous because forestry and agricultural land use is one of the main generators of income, especially in rural areas. To counteract this situation it is ecologically and economically necessary to develop alternative options for more sustainable land-uses. In general there exist different options to recover or enhance the economic potential of such unproductive sites (Weber et al. in press):

- Reliance on natural regeneration
- Reforestation with exotic or native species
- Enrichment planting

Reforestation with native tree species is considered to be one of the most promising options towards integrated land-use approaches and sustainable development. However, until the year 2000 only 167.000 ha of plantations were established successfully in

Ecuador (FAO 2003). Furthermore, these plantations consist almost exclusively of ´exotic´ species, mainly *Eucalyptus* spp. and *Pinus* spp., which are accompanied by ecological problems in many cases when planting material and planting site were not chosen properly. Only recently, more attention is given to plantations with native species (e.g. Brandbyge & Holm-Nielsen 1986, Predesur 2004). A major reason for the neglect of native species in reforestation activities is the lack of adequate knowledge on their ecology and silvicultural treatment. Therefore the general objective of this study was to improve the basic knowledge on the silvicultural characteristics of selected native tree species and their capability for reforestation of abandoned lands. For this purpose the study refers to three experimental installations that have been established by the Institute of Silviculture of the Technische Universität München within the framework of the research group FOR 402 "Functionality in a Tropical Mountain Rainforest of South Ecuador: Diversity, Dynamic Processes and Utilization Potentials under Ecosystem Perspectives" of the German Research Foundation (DFG):

i) A reforestation experiment, which represents the main part of the research. The specific research questions to be answered in this experiment are:

- Can native species cope with the harsh conditions on the abandoned sites?
- Can they compete with the commonly used exotic species in terms of survival and early growth?
- How is the success of the plantation influenced by the successional status of the area?
- Can the success be improved by the removal of the competitive ground vegetation?

ii) A herbicide experiment, which has been established as a supplementation to the reforestation experiment to exemplarily investigate the effects of a chemical treatment as an alternative to the manual clearing of the competitive ground vegetation tested in the reforestation experiment. The questions to be answered are:

- How does the chemical treatment affect the subsequent biomass production and species composition of the ground vegetation compared to the manual treatment?
- How does the chemical treatment influence the survival, growth, and biomass allocation of the seedlings of two native species (*Tabebuia chrysantha* and *Cedrela montana*) in comparison to the manual alternative.

iii) An enrichment experiment, to investigate if enrichment planting with native species in exotic plantations can be a means to convert them into more natural stands. During the last years several studies revealed that exotic trees can act as nurse trees for the regeneration of native species (Parrotta 1995, Fimbel & Fimbel 1996, Geldenhuys 1997, Cavalier & Tobler 1998, Cavalier & Santos 1999, Feyera et al. 2002a, 2002b).

The research questions in this experiment are:

- Can native species cope with the conditions in a stand of the exotic *Pinus patula*?
- Is there a difference in the performance of native seedlings planted under the closed canopy of the pines or in gaps?

The study at hand comprises 6 chapters. Following the introductory chapter, the description of the research area is presented in chapter 2, and the methodology of investigation is presented in chapter 3. In chapter 4 the results of the reforestation experiment with native and exotic species in different natural succession gradients as well as those from the herbicide and enrichment experiment are presented. In chapter 5 the findings will be discussed and chapter 6 presents the conclusions that can be drawn from the study as well as the recommendations.

2. Description of the research area

2.1. General information about Ecuador

Ecuador is located in the North West of South America abut against Colombia in the North and Peru in the South. With a total land area of 256.370 km² it is the smallest country of the Andes. Ecuador can be divided into four major natural regions (Fig. 1):

1) The Pacific Coast region, called the *Costa*, which includes the lower, western slopes of the Andes below 1.000 m elevation.

2) The Andean mountains above 1.000 m, which occupy the central part of the country, known as the *Sierra*.

3) The Amazon lowlands east of the Andes, referred to as the *Oriente*, including the lower, eastern slopes of the Andes up to 1.000 m a.s.l.

4) The Galápagos Islands, a volcanic archipelago in the Pacific Ocean, 1.000 km west of the mainland (Jørgensen & León-Yánez 1999).

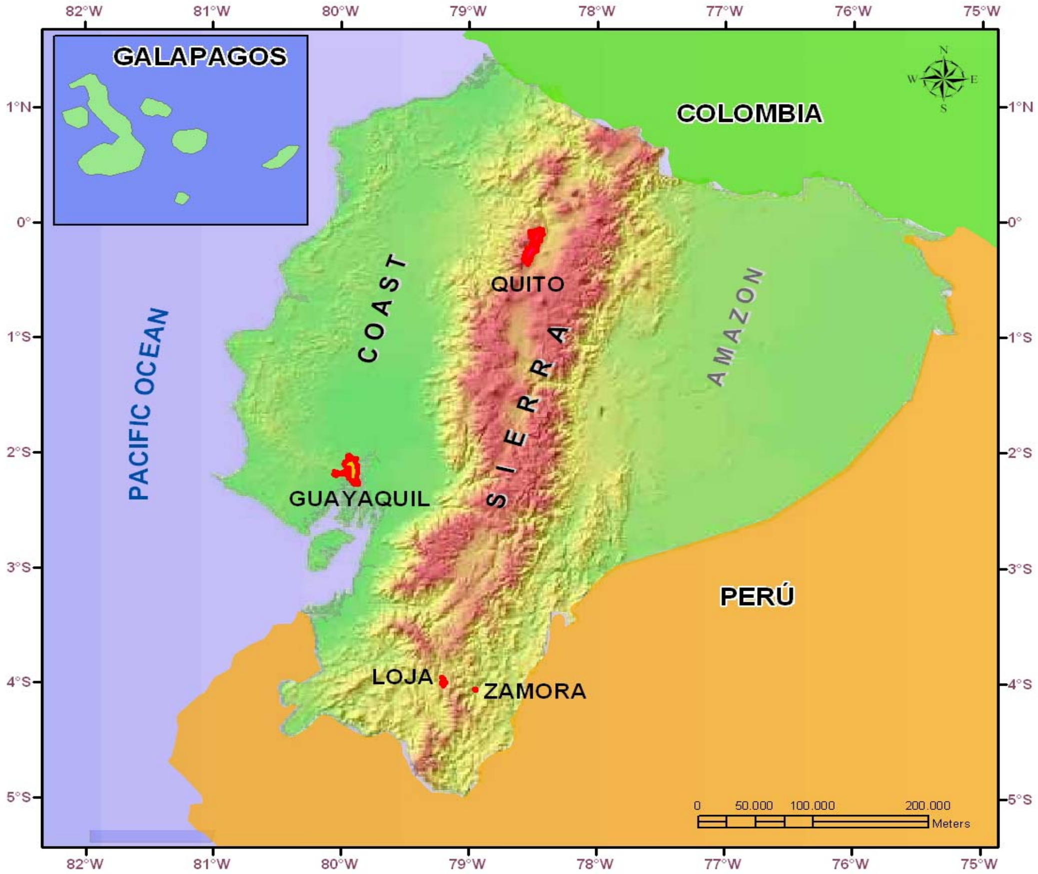


Figure 1: Ecuador and its major natural regions.

The population of Ecuador amounts to 12.2 million people corresponding to 47 inhabitants per km^2. However there exist huge differences among the different regions. Thus, 50% of the total population live in the coastal region, 45 % in the Andean region (which represents only a fifth of the surface of Ecuador), and less than 5% live in the Oriente (on nearly 50% of surface of country), and around 0.2% on the Galapagos Islands (INEC 2001).

The agricultural sector with intrinsic agriculture, fishing, and forestry is a major factor in the economy of the country. During the period 1996-2002 its contribution to the total Gross Domestic Product (GDP) was 17.4%. The forestry subsector represents 7% of the GDP of the total agricultural sector and about 2% of the national GDP (Vallejo 2002, CIMT 2004). It is estimated that about 8 % of the economically active population depend directly or indirectly from the forest sector (including forest industry and wood artisans) (Ministerio del Ambiente 2005). In addition it has to be considered, that many farms are managed for subsistence. Thus, the real importance of the sector may be been even higher as not all goods and services produced in the subsistence farming are considered in the GDP.

The original forest cover of Ecuador (i.e. before human intervention) was estimated on 90% of the land area corresponding to about 26 million hectares (Cabarle et al. 1989, Wunder 2000). In 2005 the remaining forest area was only 10.8 million hectares (FAO 2006a) from which only 3.0 million hectares can be classified as “production forests”, which are designated for the production and extraction of forest goods.

Apart from the deforestation in the pre-Columbian era the main deforestation processes occurred in the last century during the cocoa (1920s) and banana boom (1950-1965) in the coastal region (Costa) where large areas of forests have been cleared for crop production. Another wave of deforestation was driven by the opening-up of the Oriente by road construction and oil exploitation in the 1970s. However, even today deforestation is continuing at an alarming extent. During the last years Ecuador faced the highest deforestation rate in South America (1.7 % area $year^{-1}$) (FAO 2006a). The main reason for that is the conversion of forest land into agricultural land, mainly pastures, especially in the Andean Region.

Because the conversion of forests in the Andean region into agricultural land has generated significant environmental and socio economic impacts on the national level, actually long-term programmes to establish productive forest plantations are high on the political agenda (CIMT 2004). In this context it is interesting to see that 90 % of the area annually afforested in Ecuador so far has been realized in the Andean region, where the socio- economic and ecological functions of the forests are of prominent importance (FAO 2005).

2.2. The Andean region of Ecuador

In the Andean region mountain forests represent the dominant vegetation formation. According to Baquero et al. (2005) the remaining forest area in the Andean region amounts to 6 million hectares which can be assigned to the following altitudinal ranges:

Western flanks	Eastern flanks and Amazon slopes
North-Center Region: 1.800 to 3.000 m a.s.l.	North-Center Region: 2.000 to 2.900 m a.s.l
South Region: 1.500 to 2.900 m a.s.l.	South Region: 1.800 to 2.800 m a.s.l.

In the Ecuadorian Andean region at least two sub-regions can be distinguished: the North - Center region and the South region. In the North–Center region, the Andes form two distinct parallel chains: the Western Cordillera and the Eastern Cordillera. Between these cordilleras are a series of intermontane valleys, which are separated from one another by a series of high, transverse east-west-trending ridges locally referred to as knots (nudos). Both cordilleras are topped by several high quaternary volcanoes that exceed 5.000 m of altitude and are capped by glaciers. The South region is not so clearly differentiated into western and eastern cordilleras, but form a more complex pattern of ridges, some of which trend north-south and some east-west. In this region there are no high, quaternary volcanoes; the highest ridges and peaks are barely above 4.000 m a.s.l. (Jørgensen & León-Yánez 1999).

The forests in these two zones are clearly different due to rather different geological, altitudinal and floral characteristics (Becking 2004). The South region, where the research area is located, encloses territories of the provinces Azuay, Loja and partly of Zamora Chinchipe (Ministerio del Ambiente et al. 2001). Here, the altitudinal zoning of the forests is displaced downwards and characterized by higher biodiversity and floral and faunal endemism compared to the North-Center region (Ministerio del Ambiente et al. 2001, Becking 2004). According to Weigend (2002, cited in Richter & Moreira 2005) this zone represents one of the few places on earth where it is still possible to discover and describe new vascular plants. Therefore a series of botanic and ecological studies has been conducted in the South during the last decades (Espinosa 1948a, Espinosa 1948b, Madsen 1989, Madsen 1991, Madsen & Ollgaard 1994, Ulloa & Jørgensen 1995, Aguirre et al. 2002, Galvez et al. 2003). Within the South the border region between Ecuador and

Peru pertains to one of the ecologically most diverse areas in the world and it is considered as one of the ´hottest hotspots´ of biodiversity with regard to species per unit area (Brummitt & Lughadha 2003, Richter & Moreira 2005, Bussmann 2006). This is due to the fact that in this region several Andean depressions allow an interchange among flora and fauna of the Amazon region and the lower Pacific region (Bussmann 2006). The region is also characterized by a very fast transition between the humid Andes and the Deciduous Dry Forests in the lower zone of northern Peru and south-western Ecuador. For this reason south Ecuadorian mountains belong to one of the priority preservation areas of the government.

Actually 64% of the forests in Ecuador are under a protective status: 37% as areas corresponding to the National Park and Protected Areas (SNAP[1]) and 27% as protected forest called "Bosques Protectores" (Ministerio del Ambiente 2005).

2.2.1. Geomorphology and landscapes

The northern and central Andean region can be sub-divided into the Western Cordillera, the Inter-Andean basin and the Eastern Cordillera. In the West, cretaceous and eocene andesitic volcanics are overlaid by younger marine sediments and volcaniclastics. Neogene to quaternary volcanic deposits form some of the major strato-volcanoes. The Inter-Andean basin is filled with quaternary sediments and pyroclastic deposits. In this corridor between the two cordilleras is a *graben*, a zone where tectonic uplift did not occur. The Eastern Cordillera consists mainly of paleozoic metamorphic rocks probably formed during a Caledonian orogenic event (Baldock 1982, cited in Beck et al. in press).

The landscape in the Andean region is very heterogeneous in response to local soil conditions and orography, with a lot of azonal vegetation. During the last decades the landscape was also heavily impacted by human activities. The replacement of natural forests by pastures, agricultural cultivations, and forest plantations has led to an increased homogenization of the landscape.

The prevailing soils in the Andean region are Andosols and Mollisols in higher lands, and Latosols and Inceptisols in the lower plains. The Andean soils can be characterized by the pH with high concentration of free aluminum, bauxite, and chelated clays, which limit the vegetal production and makes mountain agriculture having only marginal production and subsistence, except on alluvial soils where eroded soil and volcanic ashes have been deposited due to river dragging (Sarmiento 2001). In the Southern Andes, the soils are not

[1] SNAP.- Sistema Nacional de Areas Protegidas

volcanic but in many areas of this zone they have a layer of volcanic ashes coming from the northern volcanoes. However, due to erosion it has almost totally disappeared in most areas (Hofstede 1998).

2.2.2. Climate

According to Beck et al. (in press), the major factors governing air temperature in Ecuador are topography, terrain altitude and ocean temperature. According to the altitude the following zones are distinguished:

- tierra caliente (hot land, mean annual temperature between 25 - 19°C, altitude below 1.100 m a.s.l.)
- tierra templada (temperate land, mean annual temperature between 19 -13°C, and altitude between 1.100 – 2.200 m a.s.l.)
- tierra fria (cold land, mean annual temperature between 13 - 6°C, and altitude up to 3.800 m a.s.l.)
- tierra helada (frost land, mean annual temperature between 6 - 0°C, and altitude up to 4.800 m a.s.l.)
- tierra nevada at altitudes > 4.800 m a.s.l.

In the mountain forest range the climate is also influenced by the orographic zoning and the presence of a large littoral strip with cold and warm marine streams (Sarmiento 2001). As a consequence climate conditions in the mountain forest region vary quite much on very short distances. At the flanks of the cordilleras below 3.200 m a.s.l. two marked rainy seasons are evident which register rainfall between 500 and 2.000 mm per year, average temperatures between 10 °C and 20 °C, and relative humidity between 65% and 85% (Ulloa & Jørgensen 1995). According to Cañadas (1983) and based on the Holdridge system, in the Andean region 18 from the 26 bioclimatic regions of Ecuador are represented. Because the region is located in the middle of the inner-tropical convergence zone (ITCZ), the photo-period is constant throughout the year and no cold winter period exists (Sarmiento 2001).

Another characteristic of this region is the existence of horizontal precipitation, which comes from the additional contribution of cloud humidity and can amount to 200% of the rainfall (Sarmiento 2001). For instance, in the mountain forest at the Estación Científica San Francisco (ECSF), where the research area is located the contribution of horizontal rainfall reaches values of up to 6.701 mm (Bendix et al. in press). However, precipitation patterns vary quite much with the topography (Sarmiento 2001, Rollenbeck et al. 2006). At the ECSF, the average annual precipitation amounts to 2.500 mm in the lower zone and more than 5.500 mm in higher zones. In the highest parts clouds or fog are present during almost the whole year.

As common in the tropics the annual fluctuation of temperature is lower than the daily one. Ulloa & Jørgensen (1995) report daily variations between 10° and 20°C for the Andean regions below 3.000 meters altitude and 8° and 20°C for higher regions. At the ECSF average annual temperature is 15.5°C (Ohl & Bussmann 2004).

2.2.3. Vegetation

Originally, mountain forests covered the major part of the Ecuadorian Andean region. Today its extension on the western flanks has been reduced to 49%, and in the eastern spurs to 76% (Ministerio del Ambiente et al. 2001). The Tropical Mountain Forest (TMF) has a floral composition compound by a mixture of elements from several origins (Ulloa & Jørgensen 1995). However, due to the human impact in this zone, the natural composition of species has changed. For instance in many regions introduced species have eliminated and replaced the natural ones that were formerly the basis of the local biodiversity (Sarmiento 2001).

The Ecuadorian TMF is characterized by high richness and endemism of arboreal species. It is considered to be one of the most diverse ecosystems in the world and belong to the global "*hot spots*" of biodiversity (Brummitt & Lughadha 2003, Richter & Moreira 2005, Bussmann 2006). The diversity of this ecosystem is strongly correlated with elevation; the diversity diminishes linearly with increasing altitude from 1.500 m a.s.l. to the forest top limit (Gentry 1995). For instance Jørgensen & Leon (1999) registered for the Andean region 9865 vascular plant species, which represent 64.4% of the total number of species in Ecuador. Ulloa & Jørgensen (1995) found 334 trees species and 1.071 shrubs species in zones over 2.400 meters altitude, and Fehse et al. (1999) also registered more than 200 tree species over 2.500 m a.s.l.

The Andean TMF are of great global, regional, and local importance for the provision of environmental services (Sarmiento 2001, Lojan 2003, Bussmann 2006): e. g. they capture and store rainfall and humidity, maintain water quality, reduce erosion, and provide protection against landslides, avalanches, and floodings (Sarmiento 2001, Lojan 2003). But, at the same time, they are very fragile and vulnerable ecosystems, because they are developing on very steep slopes, which are prone to erosion under heavy rainfall. This may positively or negatively influence their capability to provide their services to mountain inhabitants and hundreds of million people in the plains (FAO 2003). Furthermore they are exposed to a broad range of natural and anthropogenic disturbances, especially landslides that are caused by the heavy weight of the water capturing epiphytes and mosses detaching the trees from slopes. Although such gaps are rapidly colonized by pioneer species they are of no value for the local population (Sarmiento 2001).

Within the mountain forest range of the South region the forests at the ECSF are rather specific (Bussmann 2006). They are characterized by a very high variation of small scale vegetation units. This variation is related to vegetation zoning, steep slopes, and frequent natural landslides occurrence, which is causing mosaics of micro-climatic conditions and consequently very variable vegetation units (Becking 2004, Bussmann 2006).

According to Neill (1999), the dominant vegetation types in the Andean region are:
Lower montane rain forest (LMRF), Cloud forest (CF), North Ecuadorian grassland and quebrada vegetation, South Ecuadorian shrub vegetation and Páramos.

- The first type is distributed between 700 - 2.500 m a.s.l. on the western and eastern Andean slopes. With nearly constant high atmospheric humidity, frequent fog- and mist-associated precipitation, and dense loads of vascular epiphytes as well as bryophytes on tree branches and trunks.
- The Cloud forest also called "upper montane rain forest" and “ceja andina” (in Spanish) occurs on the high Andean slopes from 2.500 m elevation to the upper limit of closed forest (3.400 - 3.600 m a.s.l.).
- The North Ecuadorian grassland and quebrada vegetation is present in the densely populated inter-Andean valleys, where the original vegetation was removed and replaced by agricultural and pastures.
- The South Ecuadorian shrub vegetation occurs in the inter-Andean valleys of south Ecuador between 2.000 - 3.000 m elevation.
- The Páramo vegetation is distributed through the Ecuadorian Andes from about 3.400 (in the North region) to 2.800 (in the South region).

2.2.4. Land uses

Besides the natural threats mentioned before mountain forests are also under strong human pressure due to the population´s demand for resources such as firewood and space for agricultural production. Kressler & Driesch (1993) report that Andean forests have already historically been heavily affected by human activity. Brown & Kappelle (2001) state that they are one of the most fragile ecosystems in the world due to the uncommon strength of degradation processes by excessive use and conversion into agricultural fields and pastures.

In Ecuador deforestation is one of the main problems affecting this ecosystem and the country in general (Ulloa & Jørgensen 1995, Sarmiento 2001, Lojan 2003). The forest loss is not only due to commercial timber logging but also due to agricultural expansion of poor migrants or farmers. The first eliminate the original vegetation and change it into small agricultural subsistence systems; while the farmers clear large areas to establish pastures and cultivations (Ministerio del Ambiente et al. 2001). Another reason for the continued loss and fragmentation is the firewood extraction and charcoal production. If the slow growth and the long recovery periods of secondary forest in this region are considered, the situation becomes even more critical (Sarmiento 2001).

Between 1954 and 1990 the agricultural land for permanent or short-term cultivations and pastures in Ecuador was increased from 2.7 to 8.1 mill. hectares corresponding to a 5.1% annual growth rate (Ministerio del Ambiente et al. 2001). Due to this fact today all arable land that is easy accessible is already under agricultural use. Consequently, the only remaining resources for further expansion of agricultural land are fragile areas or very steep slopes. Nevertheless, colonization of new areas is pushed throughout the region not only by demographic pressures, but also by the strong desire of the farmers for better participation in the market economy. Therefore, heavy deforestation is especially observed in places where i) colonization of new land continues for the establishment of new pastures and ii) where subsistence cultivations are substituted by commercial cultivation or livestock. The dynamic followed in these cases is as follows: first, valuable timber is selectively cut down, then, firewood and charcoal are extracted, the remaining forest is then cut down and burnt; the consecutively established cultivations last for about a three-years period and finally, grazing fields are replaced by pastures with natural or exotic grasses (Wunder 1996).

In the Andean region most of the production implemented is still an extensive agriculture, with low investment and resource extracting. Therefore, more knowledge is required about techniques for a sustainable and also more productive agriculture.

2.2.5. Reforestation in Ecuador

In the past, forest plantations have been developed by several programs and plans oriented towards their increase. Despite these efforts plantations are still very limited and can by far not compensate the deforestation. Since the decade of the 1980s about 160.000 ha of forest plantations have been established in Ecuador with an average establishment rate of 3.500 ha per year (FAO 2005). However, the Ecuadorian government has recognized that during the last years the development of forest plantations has been minimal and, as a result, could not replace the importance of the native forests for timber supply or compensate the increase of demand for timber.

In the Amazon region, reforestation activities are incipient. Only the Sucumbios Forest Program (PROFORS) for the period 1988 to 1990 considered reforestation stimulation in the region; however the area established does not exceed 2.000 hectares (Revelo & Palacios 2005).

In the coastal region, reforestation activities are characterized by isolated initiatives, mainly private ones. Species planted are most frequently Teak (*Tectona grandis*), Balsa (*Ochroma pyramidale*), Pachaco (*Schizolobium parahybum*), Laurel (*Cordia alliodora*), and Cedro (*Cedrela odorata*). The dominant part of these plantations is located in the provinces of Esmeraldas, Los Rios, and Guayas (CIMT 2004). The area reforested in this region corresponds to about 8% of the total reforestation in Ecuador (Granda 2006).

The largest part, about 90% of the forest plantations has been established in the Andean region and is based on fast growing non-native species, predominantly pines (*Pinus radiata* and *Pinus patula*) and eucalypts (*Eucalyptus globulus* and *Eucalyptus saligna*). The main reason for the choice of *Eucalyptus* is its high adaptability to different soil conditions, relatively rapid growth, and high sprouting capability (Brandbyge & Holm-Nielsen 1991). Another species frequently used to a great extent and in mono-cultivations since the 1960s is Californian pine (*Pinus radiata*), which was introduced in 1905. Aguirre et al (2006) also argued that the preference of these species is due to the broad knowledge of their propagation and ecology, besides the lack of studies and knowledge on the indigenous species.

However, the above mentioned advantages of the exotic species have to be balanced with the many disadvantages they have. For instance, Brandbyge & Holm-Nielsen (1991) revealed that the natural vegetation has disappeared in areas where eucalypts have been planted. So far it has not been deeply investigated whether this is an effect of the strong competitiveness of this species or due to toxic compounds from eucalypts litter. Besides, in the period 1982/83 some pine plantations underwent an attack of *Dothistroma pini* (red band disease) caused by the high rainfall in that year. Such events must be seriously taken into consideration in mono-cultivations of *P. patula* and *P. radiata* over 4.000 m altitude. Van Voss et al. (2001) also stated that growth and development of these plantations is defective and the objectives will be hardly achieved due to wrong species selection and inadequate sites selection.

Experiences in reforestation with native species in Ecuador are only very isolated and related to particular interests of some institutions, without a comprehensive strategy and long-term vision. Some examples for this are:

- The Juan Manuel Durini Forest Foundation who established introduction trials and species precedence since 1983 in the coast region (Montenegro & Vargas 1999).
- The Jatun Sacha Foundation in the Amazon region, who carried out plantations since 1991, investigating the behaviour of more than 90 forest species in the region (Revelo & Palacios 2005).
- The Central Ecuatoriana de Servicios Agricolas (CESA) in the Andean central region, who established demonstrative plantations with around 10 native species above 2.800 meters of altitude. There were also experimental plantations of the Botanical Institute of University of Aarhus Denmark in the 80s between 1990–2002. The “Proyecto Desarrollo Forestal Comunitario” (DFC/FAO) established some plantation with native species. In addition in 1993 the Dutch FACE Foundation established the FACE Programme for Forestation in Ecuador S.A. (PROFAFOR), and since 1998 they started reforestations with native species. However, most of these experiences has been realized in the North Andean region above 3.000 m a.s.l. and with few native tree species. (CESA 1989, CESA 1991, Brandbyge & Holm-Nielsen 1991, CESA 1992, CESA 1993, Van Winkel 1997, CESA 1998, Aguirre et al. 2002a, 2002b).

Within the last two decades the rehabilitation of the ecological balance of degraded land through reforestation with native species has become an important issue (Spier & Briederbick 1980, Borja & Lasso 1990, Brandbyge & Holm-Nielsen 1991, Fehse et al. 1999, van Voss et al. 2001, Revelo & Palacios 2005, Aguirre et al. 2006). In this context several studies concerning reproductive biology of important forest species have been conducted during the last years. Species with special attention were: *Buddleja incana, Gynoxis sp. Vallea stipularis, Juglans neotropica, Cedrela montana, Tabebuia chrysantha, Podocarpus spp., Prumnopitys montana, Alnus acuminata, Myrica pubescens, Cinchona officinalis, Heliocarpus americanus, and Clethra* sp. (e.g. CESA 1989, Ordoñez et al. 2001, Cabrera & Ordoñez 2004, Ordoñez et al 2004, Samaniego et al. 2005, Jara & Romero 2005, Briceño 2005, Leischner 2005, Castillo & Cueva 2006). However, it is necessary to continue and to integrate these studies in order to develop solid knowledge for a sustainable forest development.

The establishment of native species plantations has shown the potential to improve the structure, micro-climate, and soil conditions of degraded lands (Pedraza & Williams-Linera 2003). Likewise, there is a good documentation proving that forest plantations improve conditions to develop good high diversity understory, and at the same time play an "*accelerating"* role in restoration processes of the vegetal cover (e.g. Parrotta 1992, Guariguata et al. 1995, Lugo 1997, Carnevale et al. 2002, Predaza R. & Linera W. 2003, Carperter et al 2004, Cusack & Montagnini 2004). Nevertheless, still today no serious and integrating attempts have been made in order to demonstrate the real potential of reforestations with native species, especially in comparison with exotics. Real initiatives tending towards restoration of degraded ecosystems are very scarce in Ecuador.

3. Material and methods

3.1. The study area

The study area is located in the province of Zamora Chinchipe, the most southern province of Ecuador. The experimental sites are situated in the basin of the San Francisco River, on the eastern flanks of the Andean cordillera in the vicinity of the San Francisco Research Station (ECSF, see Fig. 2) in the buffer zone of the Podocarpus National Park.

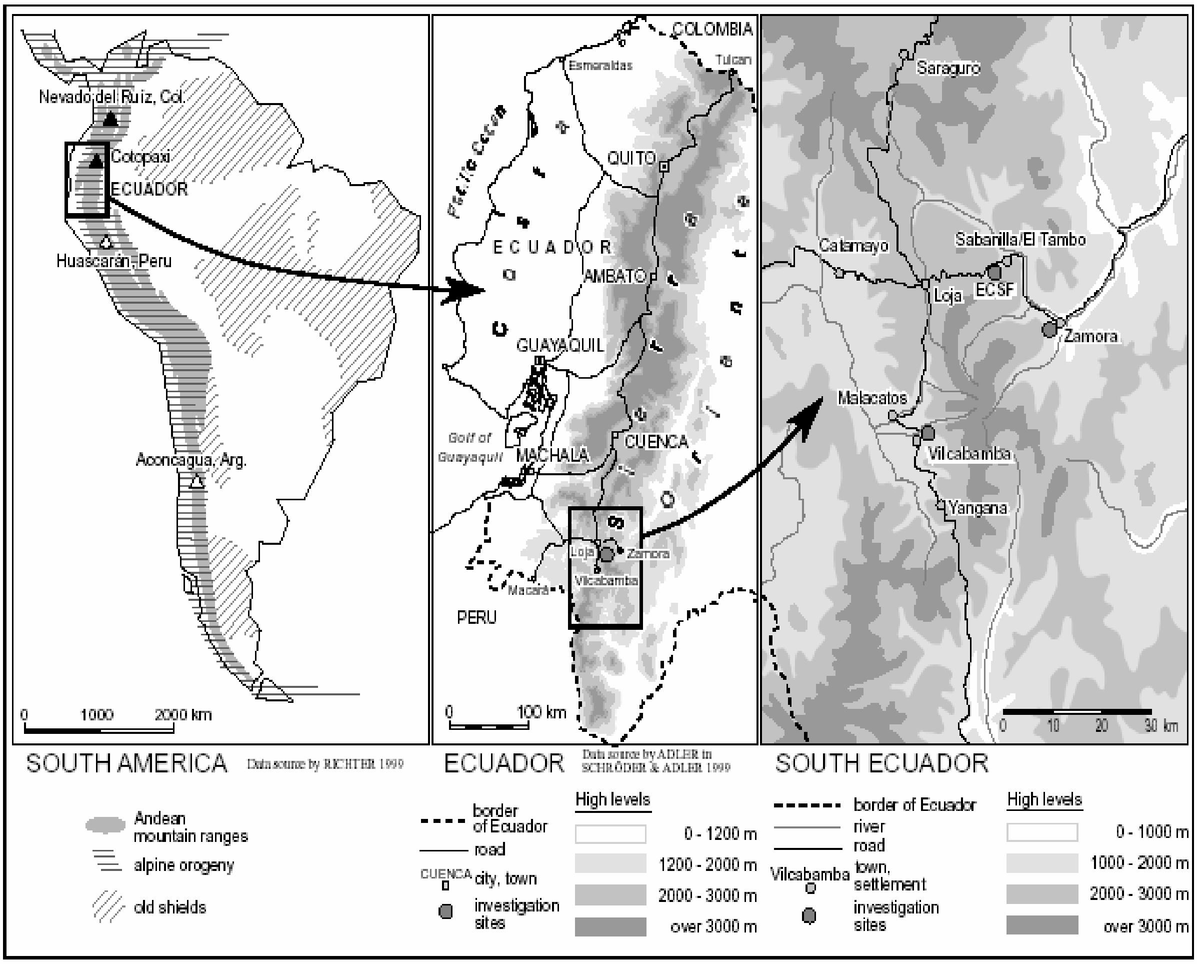


Figure 2: Ecuador partial map, showing the general location of Ecuador and the area under study (from Hagedorn 2001)

Besides an altitudinal range from 1.800 – 3.200 m a.s.l., the study area comprises also a wide gradient of human impact and disturbances. It includes areas entirely transformed into grazing land, abandoned pastures in different successional phases after abandonment, as well as natural/primeval areas without any intervention, like the natural forest of the ECSF.

For the investigations of this study four different sites have been selected:

1. A pasture actually used for livestock raising (hereafter: pasture),
2. A shortly abandoned pasture actually covered by the weed *Pteridium arachnoideum* (hereafter: fern),
3. An abandoned pasture where a young secondary forest with bushy vegetation could already establish (hereafter: shrub),
4. A 20 year old pine plantation (*Pinus patula*, with an actual density of 400 individuals per hectare).

The established experiments will be presented in more detail in the following chapters.

3.1.1. Landscapes, topography and soils

The valley of the Rio San Francisco belongs to the eastern escarpment of the Cordillera Real. It is characterized by two different manifestations of ecosystems in the tropical mountain rain forest region (Beck et al. in press): i) more or less undisturbed natural forest covering the north slopes of the valley, and ii) anthropogenic ecosystems on the opposite side of the valley, where the forest has been cleared by slash and burn.

The topography of the study sites is highly structured by deeply incised ravines, steep slopes of 20–55° and frequently arriving at 90° inclination, and narrow ridge-tops. Due to the steep slopes and geology landslides are very common resulting in a complex mosaic of successional phases of vegetation (Bussmann 2003, Werner et al. 2005).
Soils are very heterogeneous but are generally shallow, highly acidic and very poor in basic cations and effective cation exchange capacity (Schrumpf et al. 2001).

Besides, soil characteristics change with increasing altitude. For instance, decreasing profile depth, increasing acidity (with minimum pH in the root layer), increasing signs of periodic water stagnation, decreasing effective cation exchange capacity, and raising C/N-values. It is also revealed that the N-nutritional status decreases with increasing altitude due to unfavorable mineralization conditions (low pH, water assignation, low soil temperatures) (Schrumpf et al. 2001).

3.1.2. Climate

The climate at ECSF is a tropical humid characterized by 11 humid months (Hilt & Fiedler 2005). The precipitation is strongly influenced by the altitude. At 1.950 m a.s.l. mean annual rainfall amounts to 2000 mm with an extremely wet season from April to July and a less humid period from September to December (Bendix et al. 2006b). Furthermore, the ECSF area is characterized by a strong gradient of cloudiness in space and time, with increasing cloudiness along the altitudinal gradient from the valley bottom of the Rio San Francisco to the high land (Cerro del Consuelo) (Bendix et al., in press).

The mean annual air temperature varies between 19°C for tierra templadas to 13°C for tierra frias (Bendix et al. 2006a). The mean annual temperature at 1.950 m a.s.l. is 15.5ºC. The temperature maximum is in June and July, and in a very short dry season between October and November (Hilt & Fiedler 2005). However, during the main rainy season the average temperature decreases only slightly (Bendix et al. 2006b).

Table 1: Annual average of temperature and precipitation as a function of altitude (data from Bendix et al. 2006a, Bendix et al. 2006b, Hilt & Fiedler 2005 and Wolff 2006)

Altitude (m a.s.l.)	Temperature (ºC)	Precipitation from	
		Rainfall (mm)	Fog/Clouds (mm)
1.800	15.5	2000	2988
2.100	13.7	2600	3813
2.400	11.8	3320	4638
2.700	10.0	3980	5463
3.000	8.2	4640	6288

3.1.3. Natural vegetation

There exist many studies with information about the natural vegetation at the ECSF (e. g. Bussmann 2003, 2005, Paulsch 2002, Homeier 2004). Crespo (2004) did a synthesis of the types of vegetation that can be found in the ECSF according to altitude. These forest types or vegetation communities are:

- Lower evergreen montane forest (LEMF) occurring from 1.000 to 2.170 m a.s.l.. The tree canopy reaches 30 m in height. The principal tree species are: *Tabebuia chrysantha* (Bignoniaceae), *Cedrela montana* (Meliaceae), *Podocarpus oleifolius*, *Prumnopytis montana* (Podocarpaceae), among others.

- Upper evergreen montane forest (UEMF) occurring from 2.170 to 2.650 m a.s.l.. The tree canopy reaches a height of 15 m. Some frequent tree species are *Myrica pubescens* (Myricaceae), *Myrsine andina* (Myrsinaceae), *Axinea macrophylla* (Melastomataceae), *Weinmannia elliptica*, *W. fagaroides* (Cunnoniacea), *Clethra fagifolia* (Clethraceae) among others.
- Shrub páramo (SP) is distributed from 2.650 to 3.180 m a.s.l.. Most of the shrub páramo consists of mixtures of herbs and grasses, together with mosses and lichens.

Moreover, around the ESCF, there are mosaics of different land use. For instance Paulsch (2002) distinguished: primary forest, secondary forest, pine plantation, bushes, pasture, recent and older clear cuts, fern areas, landslides and farmland.

3.2. The reforestation experiment

For the establishment of the reforestation experiment three areas in the following successional phases after abandonment were selected in the vicinity of the ECSF: pasture, fern and shrub (Fig. 3 and Fig. 4). Each site has an area of four hectares; thus the complete experiment comprises 12 hectares. A description of the main characteristics of the 3 sites is presented in Table 2.

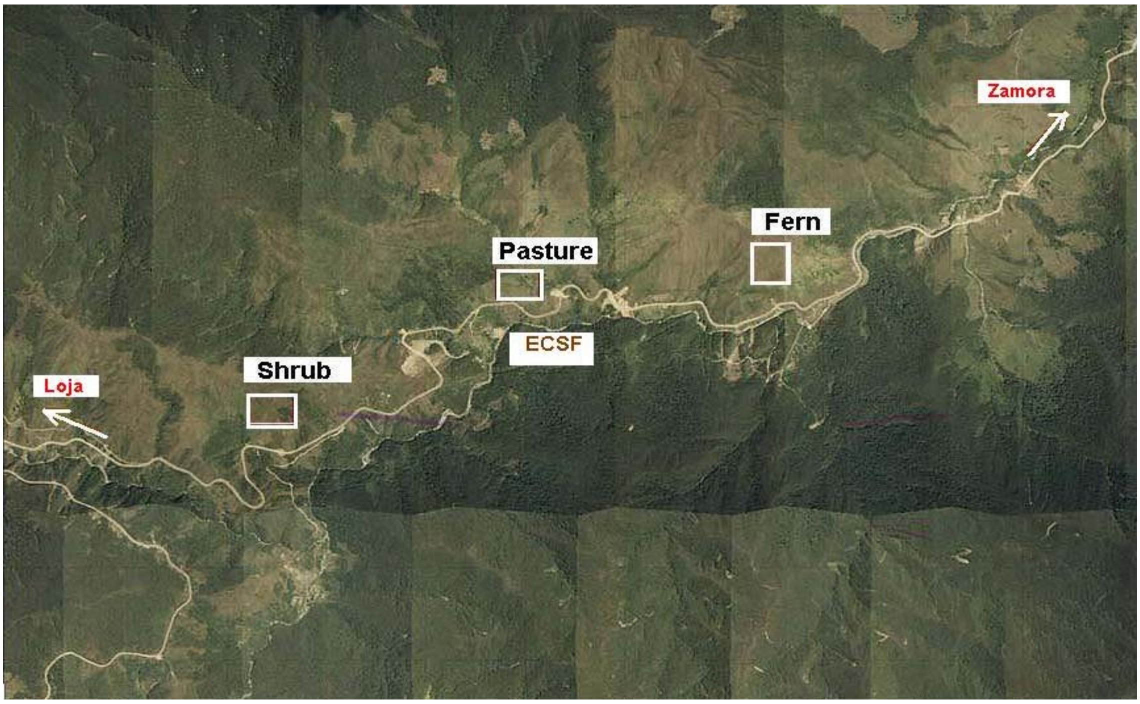


Figure 3: Localization of the three sites of the reforestation experiment.

Table 2: Characteristics of the three reforestation sites (sources: Alvarado 1999, Paulsch 2002, Flick 2003, Ortega & Medina 2003, Crespo 2004).

Characteristics	**Pasture**	**Fern**	**Shrub**
Localization	Finca Don Herminio	Finca San Ramón	Cerro “el chamusquin”
Unit Technical Mercator (UTM)	713475 9560931	714299 9561044	712269 9560293
Altitude (m a.s.l.)	1.800 - 2.100	1.850 - 2100	2.000 - 2.200
Inclination (%)	53 (6 - 90)	69 (10 - 100)	44 (5-55)
Vegetatión cover (%)	100	100	80 – 100
Dominant life-forms	grasses	Fern and few shrubs	shrub, fern and herbs
Dominant species of the vegetation	*Setaria sphacelata, Melinis minutiflora, Axonopus compressus*	*Pteridium arachnoideum, Ageratina dendroides, Baccharis latifolia.*	*Ageratina dendroides, Myrsine andina, Brachyotum sp,*
Actual use before planting	Livestock farming (caddle pasture)	Early successional state dominanted by fern	Advanced successional state dominanted by shrubs
Shannon - Index	0.87 (0.20 - 1.38)	0.84 (0.58 - 1.26)	1.89 (0.87 - 3.00)
Topography	Irregular and steep	Irregular and steep	Irregular and steep
Remnant trees	*Piptocoma discolor, Isertia laevis, Tabebuia chrysantha*	*Nectandra membranaceae, Inga sp.*	*Vismia ferruginea, Tabebuia chrysantha, Clethra sp.*

Figure 4: General view on the three reforestation sites with the plots

3.2.1. Selection of the species tested

For the selection of the species to be tested in the experiment we used a set of criteria which did not only focus on the economic potential of the species but considered also different ecological and social aspects. The criteria used for the selection were:

a. Species with wood valuated in the local, regional, and national market.
b. Light demanding species with fast growth.
c. Forest species with relevance regarding their preservation status.
d. Species which provide additional values to the ecosystem (for instance, nitrogen fixation).
e. Species useful for soil protection.
f. Multipurpose species with more than one potential use (for example, timber, firewood supply and others).
g. Species with available information about their behaviour in the field.

A list of the selected species is presented in Table 3. All of them except *H. americanus* fulfill at least two of the criteria. However *H. americanus* was selected due to its apparently fast growth and its assumed potential to quickly form a shelter for the protection of other species. A detailed description of the characteristics of the selected species is given in annex 1.

Table 3: Characteristics of the species selected for the experiments. (Tree group species: LD= light demanding, ST= shade tolerant, E= exotic. Selection criteria: a= valuable timber, b= light demanding, c= critical for preservation, d= nitrogen fixer, e= soil protection, f= multiple use, g= silvicultural characteristics well known. ECSF= Estación Científica San Francisco)

Species [2]	Local name	Family	Tree Group species	Origin of seeds	Selection criteria
Alnus acuminata	Aliso	Betulaceae	LD	La Argelia, Loja	a, b, d, e, f, g
Heliocarpus americanus	Balsilla	Tiliaceae	LD	ECSF	B
Cedrela montana	Cedro	Meliaceae	ST	ECSF	a, c, f
Juglans neotropica	Nogal	Juglandaceae	ST	La Argelia, Loja	a, c
Tabebuia chrysantha	Guayacan	Bignoniaceae	ST	ECSF	a, c
Pinus patula	Pino	Pinaceae	E	Loja	f, g
Eucalyptus saligna	Eucalipto	Myrtaceae	E	Loja	f, g

[2] The nomenclature of species is according to Missouri Botanical Garden –W3- TROPICOS database.

3.2.2. Seedling production

Because no seeds or seedlings of the selected native species were available in the local nurseries, all plants for the reforestation had to be produced within the project starting from the exploration of the seed sources, the collection and germination of the seeds, to the production of seedlings in containers. This work was done in the nursery of the project in cooperation with the Forest Engineering Career of the Loja National University. The nursery is located in Loja city at 2.100 meters a.s.l and with a mean annual temperature of 15°C, which corresponds closely to the conditions at the designated planting sites. Some results of the investigations in the nursery linked to the project have already been presented by Cabrera & Ordoñez (2004), Díaz & Lojan (2004), Briceño (2005), Leischner (2005) and Castillo & Cueva (2006).

The seedlings for the plantations on the experimental sites were grown in 560 cm^3 Polyethylene containers with a substrate that consisted of a mixture of highland black soil, bed sand, and forest humus at a relation of 2:1:1.

Because the early development of the plantations is to a certain extent influenced by the quality of the seedlings the morphological characteristics of the planting material was analyzed before planting. For this purpose a sample of eight seedlings of each tree species was selected at random to determine mainly:

a) Total height, root collar diameter (RCD) and number of leaves

b) Above and belowground biomass and

c) Root/shoot biomass relation.

3.2.3. Experimental design

The main field experiment was established as a Generalised Randomised Block Factorial Design (GRBFD) with three successional phases, two treatments (management variations), nine different tree species, and eight repetitions. In total 432 plots (10.8 x 10.8 m each) were established, 144 per successional phase. On each plot 25 seedlings were planted in pure or mixed species sets with a spacing of 1.8 x 1.8 meters. Table 4 gives an overview on all factors and combinations. Fig. 5a to 5c provide an overview on the three reforestation sites and the distribution of the plots and factor levels.

Table 4: The factors considered in the experiment.

Factor	Factor levels		Remarks
1. Successional phase	A	Pasture	
	B	Fern	
	C	Shrub	
2. Treatment (Management variants)	A	Control	Manual removal of the ground vegetation only before planting
	B	Repeated clearing	Manual removal of the ground vegetation before planting and every four months after planting over the period of two years
3. Tree species	T1	*Alnus acuminata*	Pure plantation
	T2	*Heliocarpus americanus*	Pure plantation
	T3	*Cedrela montana*	Pure plantation
	T4	*Juglans neotropica*	Pure plantation
	T5	*Tabebuia chrysantha*	Pure plantation
	T6	*Mixture 1*	Mixed plantation with *Alnus acuminata, Heliocarpus americanus* and *Cedrela montana*
	T7	*Mixture 2*	Mixed plantation with *Juglans neotropica and Heliocarpus americanus*)
	T8	*Eucalyptus saligna*	Pure plantation
	T9	*Pinus patula*	Pure plantation

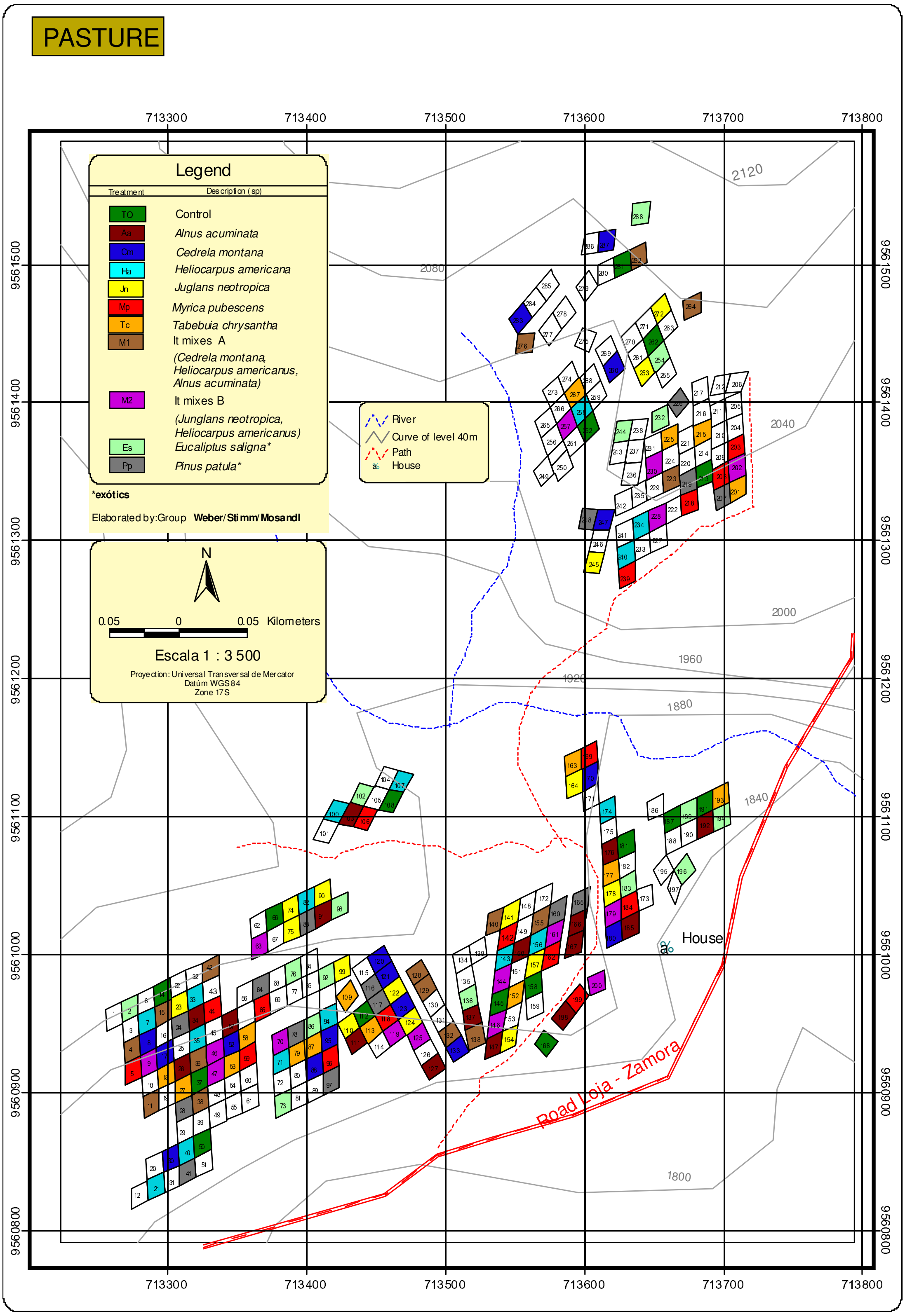


Figure 5a: Overview on the distribution of the plots and factor levels at the pasture site (*Myrica pubescens* was not included because it had only one year of plantation).

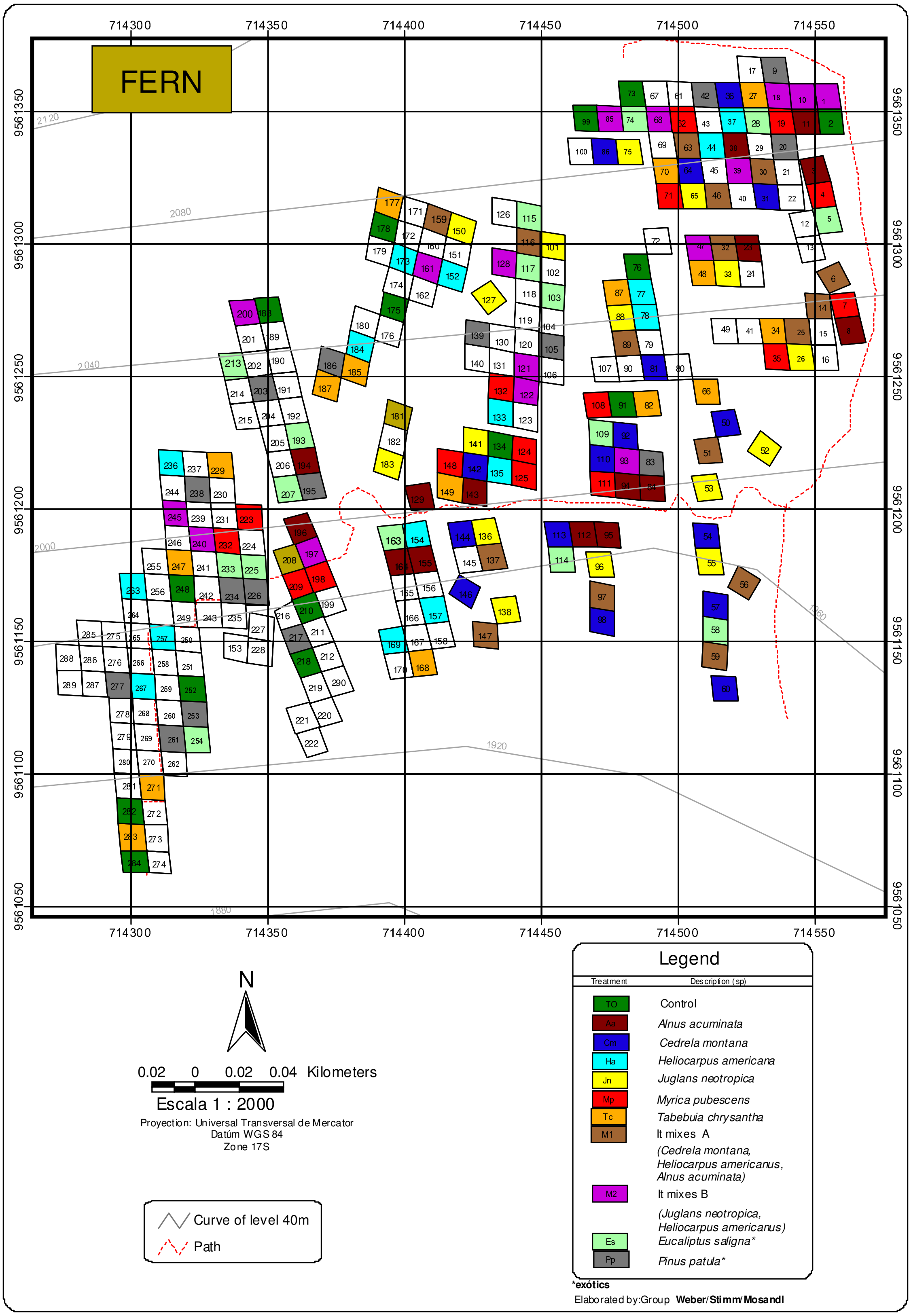


Figure 5b: Overview on the distribution of the plots and factor levels at the fern site.

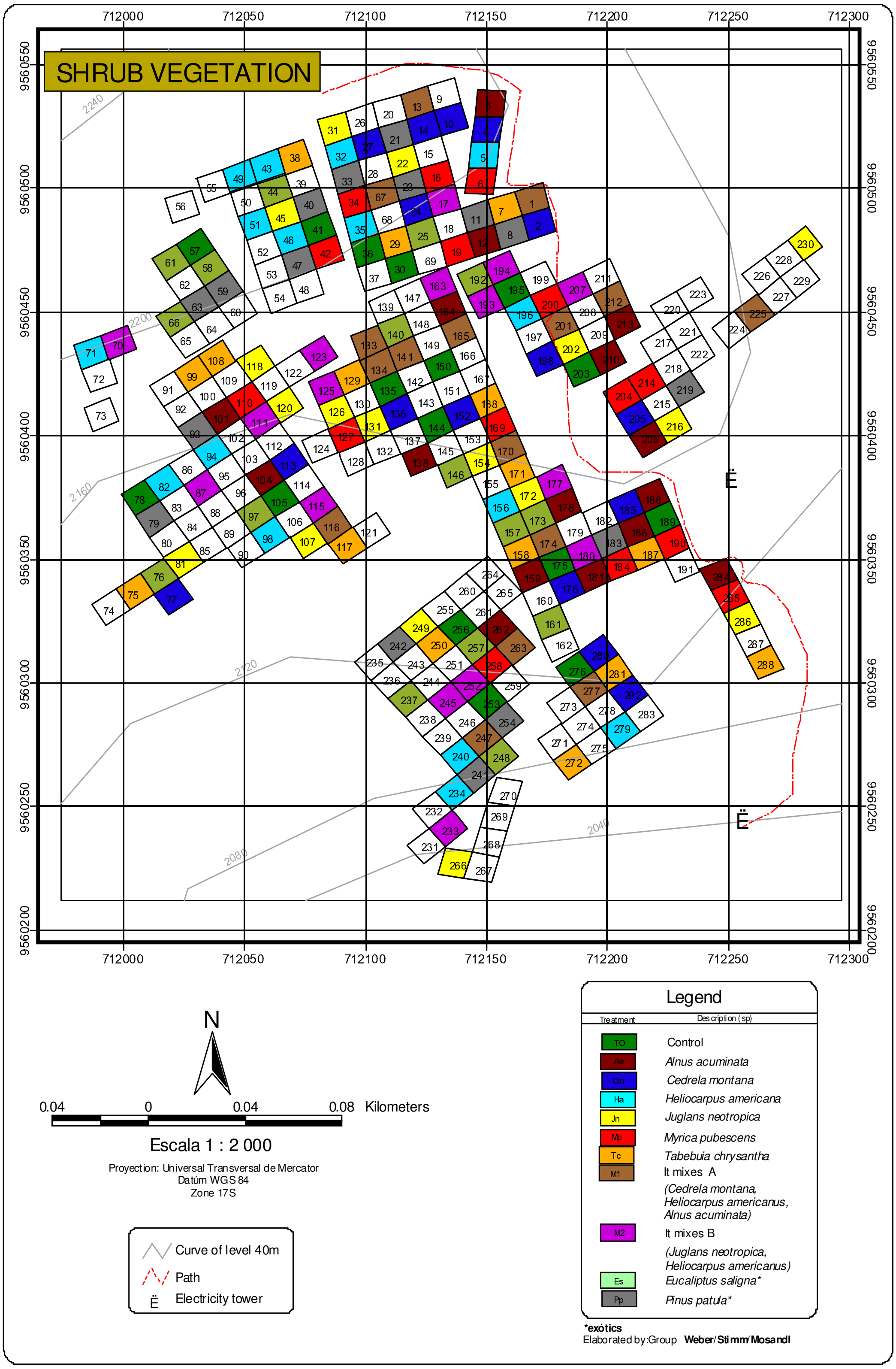


Figure 5c: Overview on the distribution of the plots and factor levels at the shrub site.

The planting in the field was performed between May and September 2003 and was realized manually by means of metal bars, making a 30x30x30 cm hole. Immediately before planting, the herbaceous ground vegetation was manually eliminated on all plots. The shrubs and woody vegetation were not removed.

3.2.4. Data collection

To analyze the development of the plants and the influence of the environmental factors five measurements were performed during the first 24 months: one immediately after planting and then every 6 months. Each measurement comprised the following parameters:

- Survival (S in %)
- Total height (h in cm)
- Root collar diameter (RCD measured at 1 cm above ground in mm)
- Number of complete leaves
- Vitality or seedlings quality in three categories (see Fig. 6):
  a) excellent seedlings,
  b) healthy seedlings,
  c) poor quality seedlings with presence of damage
- Plagues and diseases (direct observation)
  - Presence and quantification of damage by animals

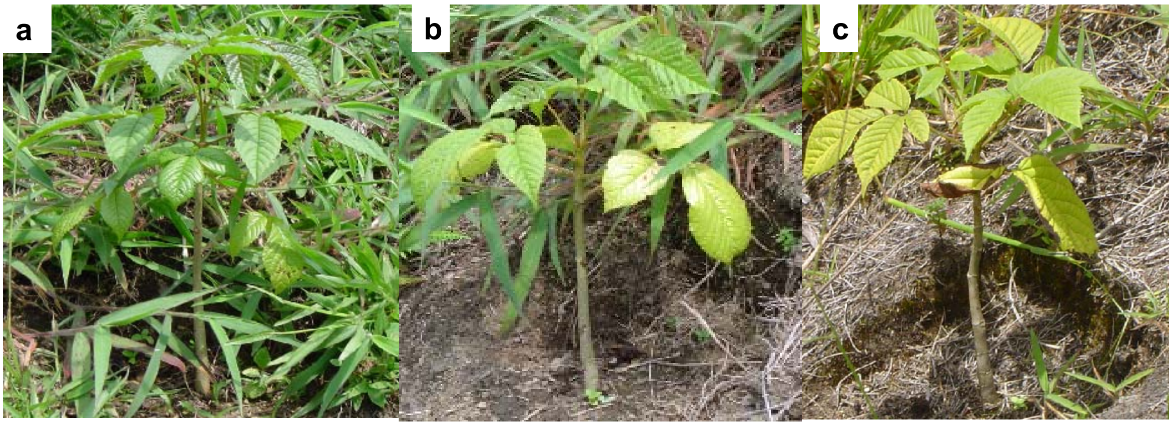


Figure 6: Examples for the evaluation of the sanitary status of *Tabebuia chrysantha* seedlings (a= excellent seedlings, b= healthy, and c= poor quality seedlings).

To be able to analyze the influences of the environmental variables and soil on survival and development of the seedlings 3 **soil samples** were taken from each plot with soil core

"Pürckhauer". The sample distribution in each plot is presented in Fig. 7. For each sample the following parameters were determined:

- Shape of land (regular, convex, concave, mixed)
- Mean inclination (%)
- Altitude (m a.s.l.)
- Woody vegetation cover (%)
- Rock cover (%)
- Micro-site of each seedling within the plot (crest, slope, and valley)
- Physical soil characteristics
    - number of horizons
    - horizon depth (cm)
    - color per horizon (Munsell table)
    - texture per horizon (% of sand, clay and silt)
    - rock presence (%)
    - available water capacity (AWC, in %, estimated according to Arbeitskreis Standortskartierung in der Arbeisgemeinschaft Forsteinrichtung 1996, Schlather et al. 2003)
    - organic matter (OM, in %, estimated according to FAO 2006b, Schlather et al. 2003)
- pH (CH_20 per horizon measured in the National University of Loja laboratory).

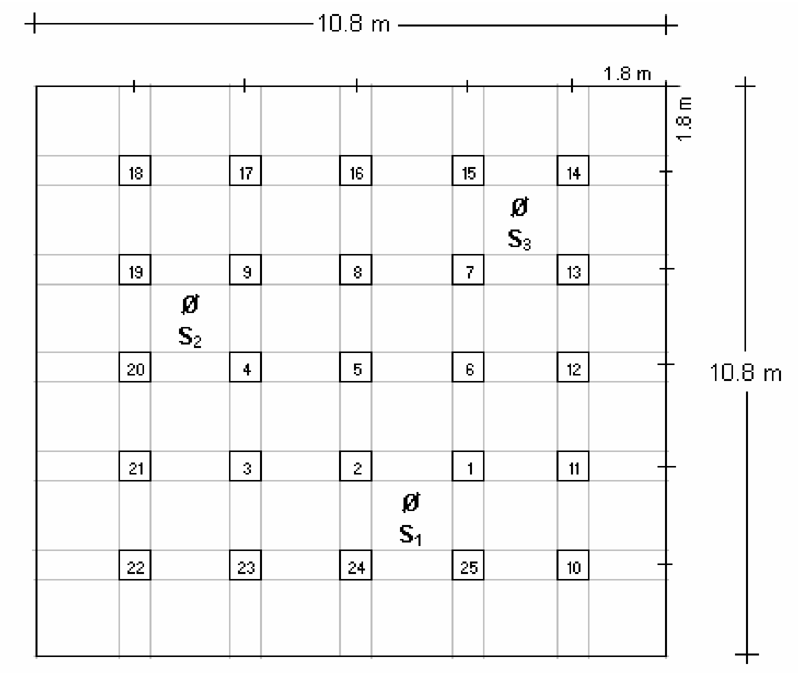


Figure 7: Soil samples distribution within each plot. (1-25: seedling number; S_1, S_2, S_3 = soil sample number).

In addition to the development of the planted seedlings we also monitored the **natural regeneration of trees and shrubs** and the soil seed bank in the three areas. For the natural regeneration, 16 randomized plots per successional phase were chosen, (8 with management of herbaceous ground vegetation, and 8 without management). The distribution of these plots is included in Fig. 5a, 5b, 5c, and correspond to control (To). The following data were collected with each measurement:

- Recruitment of new shrubs and tree species.
- Mortality since the last date of measurements.
- Height of shrub and tree (cm).
- Species.

For the **soil seed bank**, 10 plots of 10.8 x 10.8 m were selected at random at each of the three sites of the reforestation experiment. In addition to these samples 10 plots were also selected in the natural forest of the ECSF in order to enable a comparison between the seed bank at the disturbed sites and that of an undisturbed forest. In each of the 40 plots 5 soil sub-samples were collected with a metallic cylinder of 10 cm^3. The 200 samples were placed in recipients under controlled conditions of the greenhouse in the project nursery. The germination of all woody species was evaluated over a period of 210 days.

3.3. The herbicide experiment

In the reforestation experiment presented above only manual removal of the ground vegetation has been considered. For a more detailed analysis of the competitive effects of the ground vegetation on the early development of seedlings on abandoned pastures a supplementary experiment has been established. For this purpose three sites at the pasture area of the reforestation experiment that were not used for the reforestation were selected to establish three blocks of a herbicide experiment (see Fig. 8). Each of these blocks represent a position within the slope (Table 4).

Table 5: Characteristics of the blocks of the herbicide experiment.

Code	Position within the slope	Inclination (%)	Altitude (m a.s.l.)
Block 1	Lower part	30	1740
Block 2	Middle part	95	1780
Block 3	Upper part	45	1800

Figure 8: Distribution of the blocks of the herbicide experiment.

The statistical design of the experiment is a Split Plot Design with a total of 54 plots (18 plots per block). Each plot has been planted with five seedlings of the two native forest species *Tabebuia chrysantha* and *Cedrela montana* in pure plantations with a spacing of 1 x 1 m. Consequently, each species is represented by 45 individuals per block and 135 in total.

The treatments used in the experiment were:

a. Control: removal of the ground vegetation one time before planting.

b. Mechanical: manual removal before planting and every 4 months after planting.

c. Chemical: removal of ground vegetation by means of a systemic herbicide, (Glifopac, 480 g per liter) 8 days before planting; no further treatment after planting).

The factor levels a) and b) correspond to the treatment of the plots in the reforestation experiment.

The distribution of the different factor levels within the experiment is presented in Fig. 9.

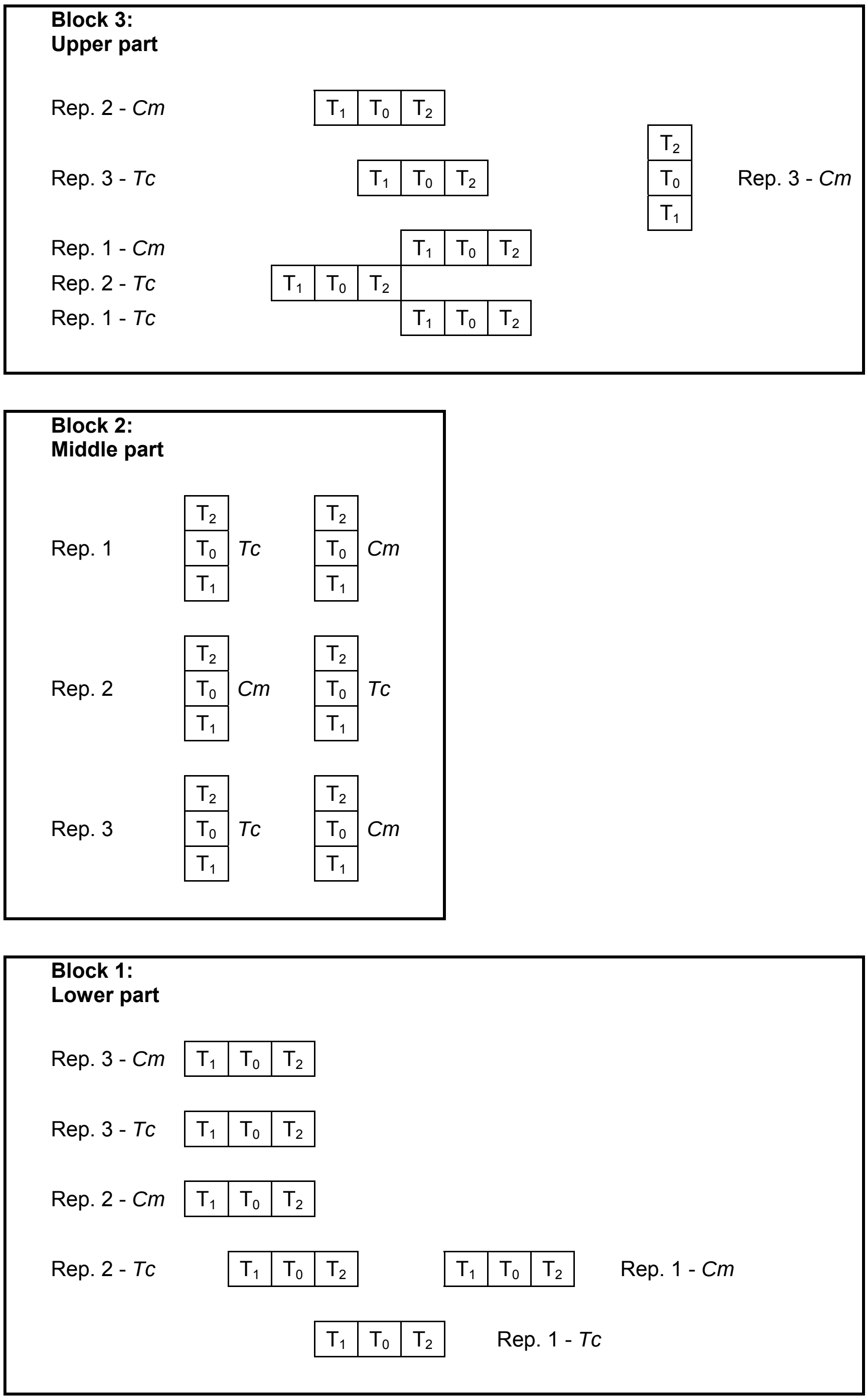


Figure 9: Design of the herbicide experiment (Rep. 1-3 = Replication 1-3; Tc = *Tabebuia chrysantha*, Cm = *Cedrela montana*; T_0 = Control; T_1 = manual treatment; T_2 = chemical treatment)

Like in the reforestation experiment the seedlings were produced in the project nursery. The planting was conducted in November 2004. For the analysis of the treatment effects three measurements were performed during the first 12 months: one immediately after planting, and subsequent measurements 6 and 12 months after planting. Each data collection comprised the following parameters:

- Height growth (in cm)
- Root collar diameter (RCD, in cm)
- Survival (in %)
- Vitality (equivalent to the reforestation experiment).
- Above and belowground biomass of ground vegetation separated for planting hole, disturbed soil, and reference area without soil disturbance one year after planting (Fig.10)
- Above and belowground biomass of the mean (height) tree one year after planting (Fig. 10)

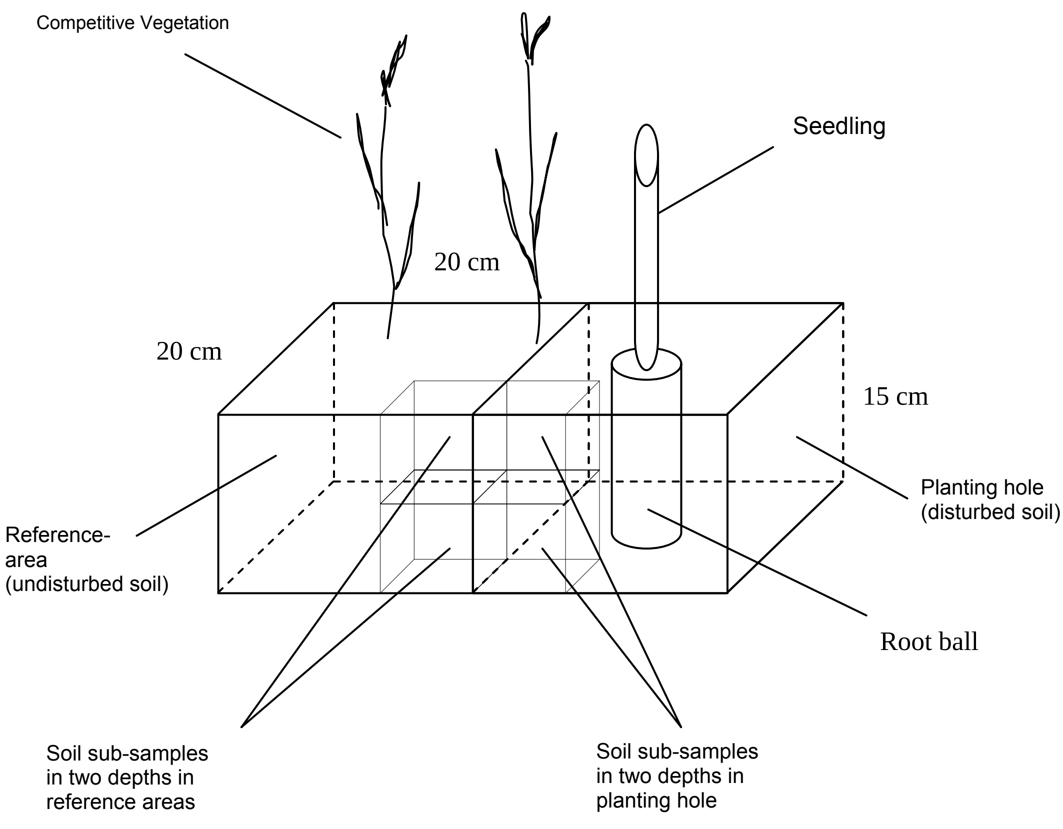


Figure 10: Sampling diagram for biomass analysis of ground vegetation and seedlings.

3.4. Enrichment planting experiment

To investigate the potential of native species for enrichment planting in exotic plantations a further experiment was established in a 20 years old *Pinus patula* plantation adjacent to the pasture site of the reforestation experiment (Aguirre et al. 2006). On eight plots, 648 individuals from nine native species were planted in subplots of 16 m^2 each under two different environmental conditions: 4 plots under the closed canopy of the pine plantation and 4 plots in small gaps. Fig. 11 provides an overview on the distribution of the plots and factor levels.

The species tested were: *Alnus acuminata*, *Cedrela montana*, *Cinchona officinalis, Cupania cf americana*, *Heliocarpus americanus, Isertia laevis, Myrica pubescens, Piptocoma discolor* and *Tabebuia chrysantha*. A description of the species not included in the reforestation experiment (Annex 1) can be found in Annex 2.

The enrichment planting was done in May 2004. Likewise the other experiments ground vegetation has been removed manually before planting and every 4 months after planting over a period of 24 months.

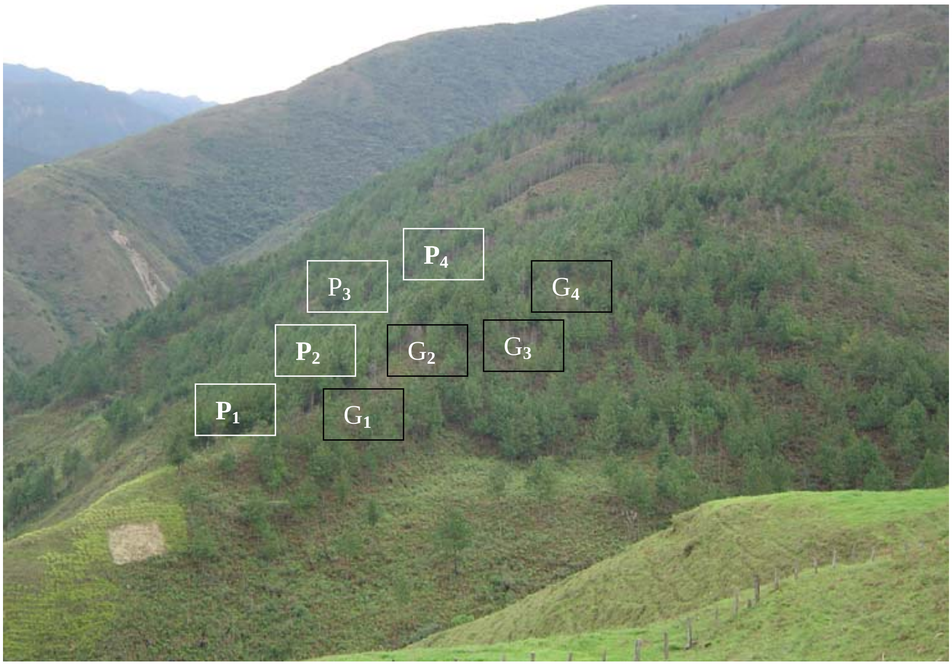


Figure 11: Distribution of the experimental plots of the enrichment planting experiment (P_{1-4} plots under closed canopy; G_{1-4} plots in gaps)

The experimental design used is a Generalised Randomised Block Design. The factors are: crown cover (1 = under the closed canopy of pine plantation; 2 = in gaps) and tree species (nine species).

Four inventories of the seedlings were performed during the first 24 months: one immediately after planting to document the initial situation followed by further inventories at ages of 6, 12 and 24 months. The parameters measured were the same as in the herbicide experiment but no biomass analysis was performed. Furthermore, soil physical (e.g. texture and organic matter) and chemical analysis (pH, Nitrogen and Phosphorus) were performed.

3.5. Statistical analysis

As already mentioned the statistical design for the reforestation experiment is a Generalised Randomised Block Factorial Design (GRBFD). Analysis of variance for the final status after 24 months was used for testing the hypotheses regarding the effects of the main factors (successional phase, treatment and tree species) and their interactions.

For the statistical analysis we also categorized the several species in three different groups:

- Light demanding (*Alnus acuminata* and *Heliocarpus americanus*)
- Shade tolerant (*Cedrela montana, Juglans neotropica* and *Tabebuia chrysantha*)
- Exotics (*Eucalyptus saligna* and *Pinus patula*)

To normalize the data and to homogenize the variances, the following transformations were used:

- survival rate : $2 \sin^{-1}$ survival rate$^{1/2}$ (according to El Kateb et al. 2004)
- root collar diameter : square root
- Total height : natural logarithm (ln)

In addition to the multivariate variance analysis for the final status after 24 months we also applied multivariate repeated measures analysis of variance in order to analyze the effect of the time on the seedling's development. The factor time included five different periods of measurements (0, 6, 12, 18 and 24 months) using the PROG GLM of SAS (SAS Institute 2002, Krämer et al. 2005)

Differences within the significant groups were tested by means of contrasts. Where applicable the data were also aggregated to test several groups (e.g. exotics versus natives, or light demanding versus shade tolerant).

Moreover, to evaluate the effects of the environmental and soil variables on the survival and growth of tree species we performed a multiple principal component analysis (PCA) using Minitab statistical software vers: 13 (Minitab 2006). Also, we applied binary logistic regressions for each tree species to analyze the effect of that variable on the seedlings survival using SPSS vers. 12 (Ferran 1997).

To test the effects of the factors in the herbicide experiment (blocks, treatment, and species) at the end of the observation period (12 months) a variance analysis was applied using the ANOVA procedure (General Linear Model) of SPSS vers. 12 (Ferran 1997, Huizingh 2007)

Likewise the reforestation experiment, in the enrichment experiment the effects of the factors on the performance of the seedlings was analyzed with the multivariate repeated measurement analysis of variance. However, in this experiment the factor time included only four different measurements (0, 6, 18 and 24 months). In addition a logistic regression was used to evaluate the relation of the behaviour of seedlings and environmental variables. For this procedure the General Linear Model of SPSS was used as well (Ferran 1997).

The use of different statistical programmes (SAS, SPSS, Minitab) was caused by the fact that at the home university of the author in Ecuador SAS was not available. Consequently, all analyses already made in Ecuador have been done with SPSS and Minitab. However, at the institute of silviculture of the Technische Universität München the SAS programme is used as the standard. Thus, for the analyses conducted during the stay at this institute this programme was employed. [1]

[1] I want to thank very much MSc Hany el Kateb for his intensive support with the SAS programme and the consultancy in statistical aspects

4. Results

4.1. Reforestation experiment

4.1.1. Natural regeneration on the study sites

4.1.1.1. Analysis of the soil seed bank

According to Holl et al. (2000), one of the major obstacles for the natural regeneration of abandoned land is the deficiency of adequate seed input due to large distances to forests edges. However, when the disturbance of the soil to the former land use has not been too intensive, the remaining seed bank in the soil may help to accelerate the natural revegetation. Therefore, we also analysed the soil seed bank at the three sites of the reforestation experiment and for comparison also in the natural forest of the ECSF

The results of this analysis are presented in Table 6. As can be seen the number of germinated seeds as well as the species composition differed clearly among the four sites. The number of seedlings increased according to the successional phase from about 38.000 in the pasture samples to more than 430.000 individuals per hectare in the samples from the forest. In total the seedlings germinated in the greenhouse comprised 15 species from 15 genera and 10 families. The dominant families were Asteraceae and Melastomataceae which contributed 40% of all species. Only two species (*Brachyotum and Rubus*) could be identified at all three sites of the reforestation experiment. As expected the proportion of tree species was highest in the forest samples (98%). In the samples from the pasture 18.000 individuals per hectare could be analysed, but all of them were from only one species: *H. americanus*. Likewise, in the fern samples 10.000 tree seedlings of *Miconia* sp. were produced while in the shrub samples 37.000 tree individuals per hectare from 5 different species could successfully germinate. In the forest samples all seedlings were trees, except those from *Meriana* sp. which contributed 2% of the total number of seedlings. It is surprising that despite the high number of *Heliocarpus* seedlings for the pasture and the forest no individual could be found in the fern and the shrub samples.

Table 7 shows the Sørensen and the Shannon Indexes for the four sites. Thus, the shrub and the forest samples produced the highest diversity. According to the Sørensen index the similarity was highest between the fern and shrub site samples (SI = 71%). The similarity between the shrub and the natural forest site was very low (SI=13%) although these sites had the highest number of germinated seedlings per hectare.

Table 6: Number of seedlings (N/ha) germinated from soil samples of four different sites in the nursery (Life form: S= shrub, T= tree; Dispersion: b = birds, g = gravity, m = mammal, w= wind; N=200).

Familia	Species	Life form	Disper-sion	Pasture	Fern	Shrub	Forest
Asteraceae	*Ageratina dendroides*	S	w		11.459	35.651	
	Baccharis latifolia	S	w		17.825	40.744	
	Piptocoma discolor	T	w				15.279
Caprifoliaceae	*Viburnum pichinchensis*	T	m			10.186	
Clethraceae	*Clethra revoluta*	T	w			6.791	
Clusiaceae	*Vismia sp.*	T	m				10.186
Euphorbiaceae	*Hyeronima sp.*	T	b				10.186
Melastomataceae	*Brachyotum campanulare*	S	w	10.186	10.186	11.884	
	Meriania sp.	S	w				10.186
	Miconia sp.	T	w		10.186	10.186	50.929
Meliaceae	*Cedrela sp.*	T	w				5.093
Moraceae	*Rubus sp.*	S	b	10.186	25.465	25.465	
Rosaceae	*Hesperomeles sp.*	T	b, m			5.093	
Rubiaceae	*Palicourea sp.*	T	g			5.093	
Tiliacaeae	*Heliocarpus americanus*	T	w	18.335			330.405
Total shrubs				20.372	64.935	113.742	10.186
Total trees				18.335	10.186	37.348	422.078
TOTAL				38.706	75.121	151.091	432.264

Table 7. Sørensen and Shannon index calculated from the seedlings germinated from the soil seed bank at the four sites (different letters represent significant differences among the sites; N=200).

	Sørensen index (SI)				Shannon index (H`)		
	Pasture	Fern	Shrub	Forest	H'	VC (%)	Sig.
Pasture	1				0.5	17	a
Fern	50	1			0.7	16	a
Shrub	33	71	1		1.0	23	b
Forest	20	17	13	1	0.9	22	b

4.1.1.1. Natural regeneration on the control plots

According to many studies (e.g. Holl et al. 2000, Kappelle 2001, Günter et al. 2007) the natural succession of abandoned pastures is assumed to progress very slow. In order to compare the development of the reforestation with the natural succession the structure, composition and dynamic of the tree and shrub vegetation was monitored on the control plots at all sites. Fig. 12 shows the development of recruitment, mortality and density during the observation period.

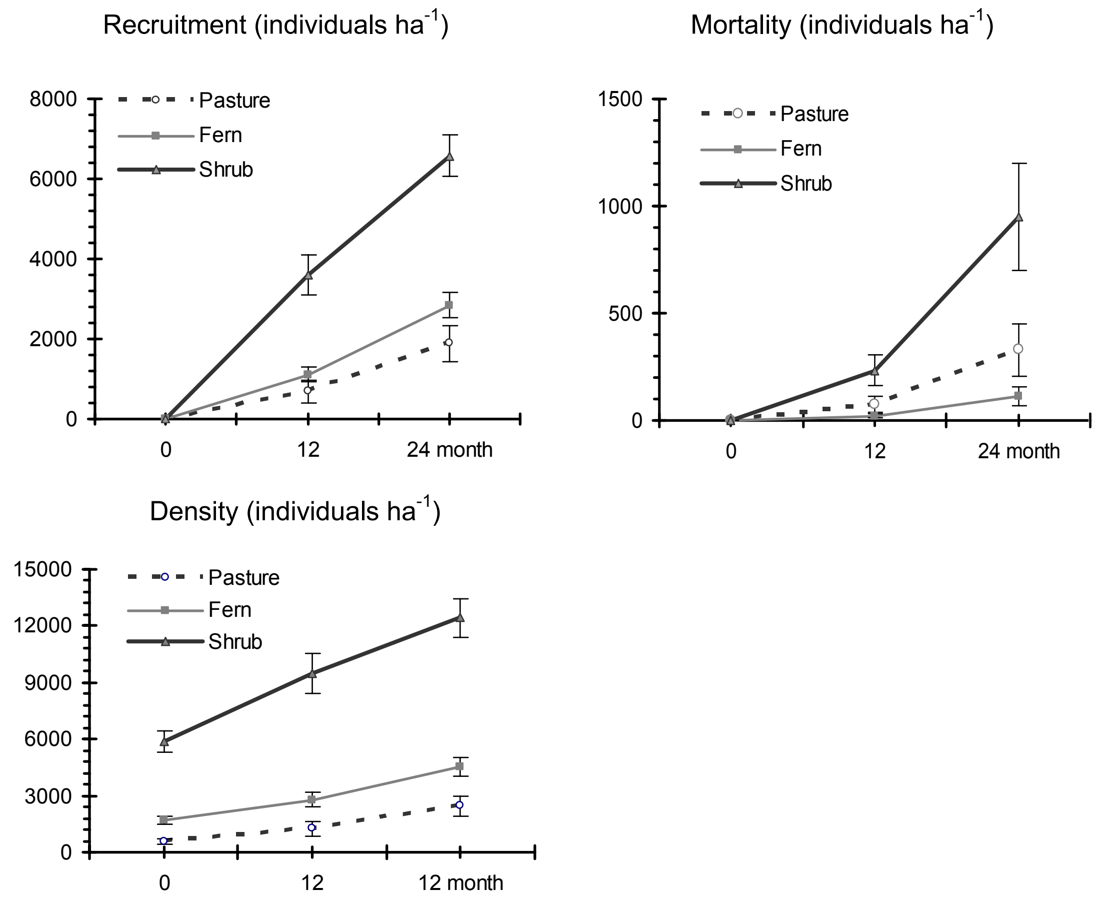


Figure 12: Means and standard error of recruitment, mortality and density of the tree and shrub vegetation on control plots (n=16) at the three sites during two years of evaluation (the graphs have different scales).

At the shrub site about 6.000 individuals were already present at the beginning of the observation period; at the fern site 2.000 individuals. At the shrub site 64% of those (3752 individuals) were tree species and 35% (2136 individuals) shrubs. At the pasture site almost none woody plants were present at the beginning. 96% of the individuals found were shrubs and 4% trees. Recruitment showed also a decreasing gradient from the shrub to the pastures site. During the observation period of 24 months more than 6000 individuals (2857 trees, 3725 shrubs) could establish at the shrub site and more than 2000 at the fern site (Table 8). Even at the pasture a recruitment of 18 trees and 1788 shrubs could be registered. However, mortality was also high at the pasture compared to the fern.

Table 8: Mean values of recruitment and mortality at the three successional phases during 24 months (VC= variation coefficient; n=16).

Succe-ssional phase	Life form	Recruitment (individuals ha^{-1})				Mortality (individuals ha^{-1})			
		0-12 month		12-24 month		0-12 month		12-24 month	
		mean	VC (%)	mean	VC (%)	mean	VC (%)	mean	VC (%)
Pasture	Shrubs	689	162	1182	87	74	193	328	145
	Trees	7	361	11	273				
	total	695	165	1193	88	74	193	328	145
Fern	Shrubs	911	47	1600	44	22	179	81	185
	Trees	195	278	141	207			33	294
	total	1106	64	1741	45	22	179	114	164
Shrub	Shrubs	1914	52	1811	34	5	400	92	187
	Trees	1686	79	1171	46	228	123	857	119
	total	3601	54	2982	33	233	121	949	106

The repeated measurement analysis revealed a significant effect of the successional phase on the annual plant establishment and mortality. The recruitment, mortality and density were significantly superior in shrub than pasture and fern, and there was no significant difference in mortality between pasture and fern (Table 9). Concerning the manual treatment of the ground vegetation only the mortality was significantly affected ($p<0.001$). However, this effect has to be evaluated very careful as it can not be excluded that some mortality was due to the treatment itself when the workers did not give enough attention to young saplings. It is also interesting that the annual establishment was not significantly different between the shrub and fern site.

Table 9: Summary of multivariate analysis of variance according to repeated measures for recruitment, mortality and density of tree and shrub vegetation on control plot (significant values are presented in bold; n=8).

Source of variation	p-value		
	Recruitment	Mortality	Density
Time	**0.000**	**0.000**	**0.000**
Time* Succession phase	**0.003**	**0.000**	**0.011**
Time * Treatment	0.617	**0.000**	0.471
Time * Succession * Treatment	0.651	**0.000**	0.564
Multiple comparisons (Tukey test)			
Pasture vs Fern	**0.046**	0.367	**0.001**
Pasture vs Shrub	**0.000**	**0.001**	**0.000**
Fern vs Shrub	0.131	**0.000**	0.090

At the end of the observation period, in total 49 species from 44 genera and 29 families were present. The dominant three families were Asteraceae, Melastomataceae and Ericaceae which contributed 34% of all species and 31% of the genus (Table 10). At the shrub site 90% of all species included were represented at the last measurement. At the fern site 39% of the species were represented and at the pasture only 35%. It is also important to see that at the shrub site 47% of the species were trees compared to only 8% at the pasture and 16% at the fern site (Table 10). However, as already mentioned mortality was also highest at this site which means that many individuals can establish but are not able to survive for a long time due to the strong competition. Table 10 provides a detailed overview on the species composition at the three sites. As can be seen *Myrsine andina* was present at all sites but at the shrub site density was much higher than at both others sites. *Nectandra* sp., a valuable species showed good and equivalent recruitment (43 ind. ha^{-1}) at the fern and shrub but none at the pasture; no mortality appeared at both sites; thus mean height of this species was already 168 cm at the fern and 226 cm at the shrub site. Other species such as *Tabebuia chrysantha, Clethra revoluta, Hyeronima moritziana* and *Inga acreana* had densities of 87 ind. ha^{-1} at the shrub site but no new recruitment could be observed during the observation period. *Piptocoma discolor* could only establish at the pasture and fern but not at shrub area. There were tree species, e.g. *Alchornea pearcei* and *Myrica pubescens,* that could establish for a short time but then suffered high mortality so that at the end of the observation no seedlings were left.

Table 10: Shrub and tree taxa on control plots at the different sites after two years of evaluation. Means are presented in individuals per hectare (n=16. Life form: T= tree, S=shrub. Dispersion: w= wind, m= mammal, g=gravity, b=birds. P= pasture, F=Fern, S=Shrub)

Family	Species	Life form	Disper-sion	Recruitment (individual ha^{-1})			Total mortality (individual ha^{-1})			Density (individual ha^{-1})			Mean height (cm)		
				P	F	S	P	F	S	P	F	S	P	F	S
Actinidiaceae	Saurauia sp	T	m									87			89
Agavaceae	Yucca sp	S	w							260			150		
Alzateaceae	Alzatea verticillata	S	w									87			132
Aquifoliaceae	Ilex amboroica	T	m									87			50
Araliaceae	Schefflera cf. ferruginea	T	w									87			146
Asteraceae	Ageratina dendroides	S	w	208	960	651	17	60		477	2738	3123	64	121	188
	Baccharis latifolia	S	w	217	35	14	80		29	622	121	87	69	82	63
	Baccharis obtusifolia	S	w	87	32	174	43			217	181	174	85	83	48
	Cuatrecasantus flexipapus	S	w			87						145			52
	Eupatorium inulaefolium	S	w			58						101			75
	Liabum kingii	S	w	310	292	211	62	8	25	607	386	235	51	50	44
	Piptocoma discolor	T	w	43	87					174	87		110	26	
Bignoniaceae	Tabebuia chrysantha	T	g									87			102
Caprifoliaceae	Viburnum pichinchensis	T	m			121				87		226	60		159
Chloranthaceae	Hedyosmum goudotianum	T	w		87						87			43	
Clethraceae	Clethra revoluta	T	w									87			212
Clusiaceae	Clusia alata	T	g			72			14			304			76
	Clusia latipes	T	g			108						195			54
Cornaceae	Cornus sp	S	g				260			260			85		
Cyatheaceae	Cyathea caracasana	S	w			65						336			164
Ericaceae	Bejaria resinosa	S	m	202	96	143	87	19		405	424	496	35	59	80
	Cavendisha bracteata	S	m									87			50
	Macleania salapa	S	m		87	43					87	108		36	37
	Vaccinium floribundum	S	m			58						130			55
Euphorbiaceae	Alchornea pearcei	T	w			43			43			130			187
	Hyeronima moritziana	T	b									87			260
Fabaceae	Inga acreana	T	m.g									87			70
	Inga sp	T	m,g			43					174	87		90	98
Flacourtiaceae	Casearia sp.	S	m				87								
Gentianaceae	Macrocarpae bubops	S	w			62						174			103
Lauraceae	Endlicheria formosa	S	g						43			87			165
	Nectandra sp	T	g		43	43					130	87		168	226
Melastomataceae	Brachyotum campanulare	S	w	241	43	480	154		12	752	304	706	66	79	65
	Meriania sp	S	w	174	87	58				174	87	434	78	15	63
	Miconia caelata	T	w			651						651			111
	Miconia sp	T	w		43	54			22		434	195		80	114
	Monochaetum lineatum	S	w	226	186	208				226	248	243	73	98	81
	Tibouchina laxa	S	w	152	174	174			43	390	521	694	48	100	120
Monimiaceae	Mollinedia sp	S	b			43						174			89
Moraceae	Rubus floribundus	S	b	371	108	156	47		52	379	152	260	51	68	92
	Rubus peruvianus	S	b	521		651				911		651	58		35
Myricaceae	Myrica pubescens	T	g			87				87	174	130	110	89	72
Myrsinaceae	Myrsine andina	T	b	87	318	737		87	819	87	1287	5330	45	89	150
Proteaceae	Roupala sp	T	w								87	87		35	240
Rosaceae	Hesperomeles obtusifolia	T	b,m			87						226			118
Rubiaceae	Palicourea myrtifolia	T	g			156			6			619			153
	Psychotria sp	T	g						87			87			137
Sapindaceae	Mataiba sp	T	w			87						87			50
Symplocaceae	Symplocos sp	T	g									87			80

Fig. 13 shows the Shannon index subject to the three sites and the two treatments. From that it can be seen that the diversity at the shrub site was significantly higher than on both other sites. However the management of ground vegetation had no significant effect on the diversity at the three sites.

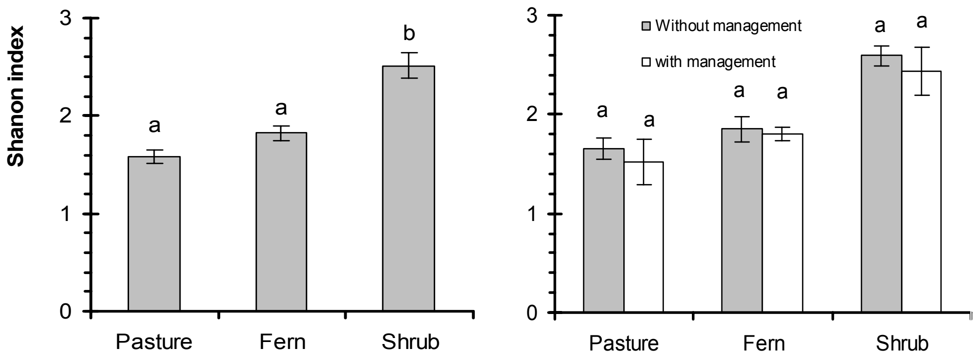


Figure 13: Mean Shannon index for the three sites (left) and separated by the treatment (right) (different letter represent significant difference among sites and treatment at $p<0.05$; n= 16 for site; and n=8 for treatment).

Based on the measurements at the control plots species-area curves were calculated for all three sites (Fig. 14). As can be seen, there was no difference between pasture and fern. At the pasture no further increase of the number of species could be registered above 1200 m^2. However, at the fern site there was still a slight increase similar to the shrub site where the number of species still increased slightly above 1600 m^2.

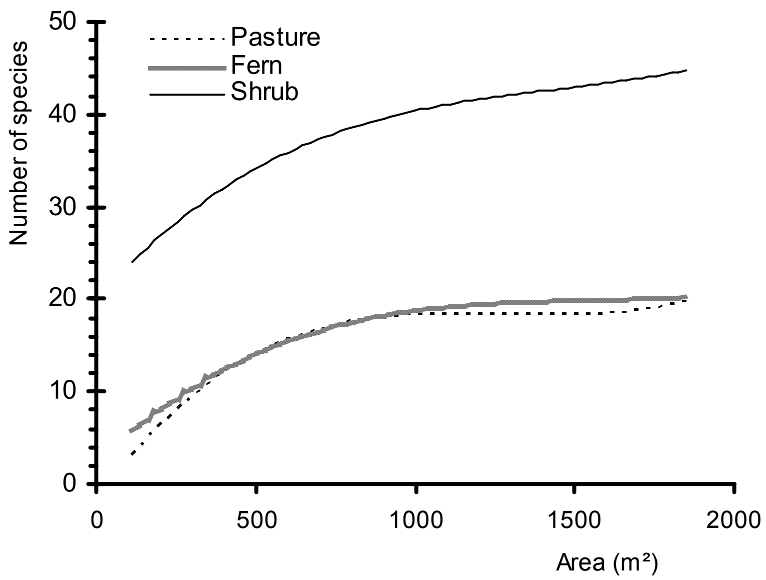


Figure 14: Comparison of species area-curve of three successional phases (n=16)

4.1.2. Initial conditions of the seedlings at time of planting

Because the tree species selected for the reforestation experiment belong to different groups of life strategies the characteristics of the seedlings at planting varied accordingly in terms of size and allocation of biomass to the different plant compartments. Table 11 provides an overview on the initial conditions of the seedlings immediately after planting.

Table 11: Characteristics of the seedlings at time of planting in the reforestation experiment (VC = variation coefficient; RCD = root collar diameter; N = number of individuals, species have more individuals because they are also used for the mixture plots).

Tree group	Species	Total height (cm)	VC (%)	RCD (cm)	VC (%)	H/RCD ratio	VC (%)	N
Light	*Alnus acuminata*	49.6	35.1	0.53	30.2	96	30	1584
demanding	*Heliocarpus americanus*	39.9	32.3	0.63	23.8	64	26	1968
Shade	*Cedrela montana*	34.0	46.8	0.68	22.1	51	44	1824
tolerant	*Juglans neotropica*	41.8	52.4	0.74	20.3	53	52	1824
	Tabebuia chrysantha	16.7	21.0	0.58	19.0	30	25	1200
Exotics	*Eucalyptus saligna*	35.4	22.9	0.34	20.6	106	21	1200
	Pinus patula	28.4	26.4	0.41	26.8	71	23	1200

As can be seen in Table 11 there is no definite difference among the three tree groups with regard to height and root collar diameter (RCD). In fact, *A. acuminata* had the greatest height and *T. chrysantha* the least, but the seedlings of *J. neotropica* were higher than those of *H. americanus*. Likewise the root collar diameter of *C. montana* and *J. neotropica* was higher than that of the two light demanding species, while *T. chrysantha* was lower than *H. americanus*. The two exotics had the lowest RCD. The variation coefficient reveals that the seedlings of the exotics were more homogeneous compared to the native species except *T. chrysantha*. However, a distinct difference among the three groups can be identified from the H/RCD ratio. Here, the species of the shade tolerant group showed the lowest values. Obviously, these species invest more into the root biomass already in the nursery. In general this is confirmed by the results of the biomass analyses of the seedlings sampled in the nursery (Table 12).

As can be seen in Table 12 *J. neotropica* and *T. chrysantha* have the highest root biomass. This is especially astonishing for *T. chrysantha* as their total height was significantly lower than that of all other species. However, this might be an effect of its higher wood density.

Table 12: Means of aboveground and belowground biomass of seedlings at planting (AGB = above-ground biomass; BGB = belowground biomass; TB = total biomass; VC= variation coefficient; n=8)

Tree group	Species	AGB (g)	VC (%)	BGB (g)	VC (%)	Root/shoot relation	VC (%)	TB (g)	VC (%)
Light demanding	*Alnus acuminata*	2.5	36.1	1.3	45.7	0.57	42.2	3.8	32.7
	Heliocarpus americanus	1.7	61.9	1.3	51.5	0.87	25.3	3.0	56.6
Shade tolerant	*Cedrela montana*	2.0	35.5	0.9	29.2	0.49	24.8	2.9	31.0
	Juglans neotropica	2.2	25.7	1.4	35.1	0.66	31.9	3.6	25.7
	Tabebuia chrysantha	2.3	24.3	1.4	42.4	0.60	30.0	3.6	28.8
Exotics	*Eucalyptus saligna*	1.7	49.3	1.1	50.1	0.65	30.2	2.8	48.5
	Pinus patula	1.9	17.8	1.2	32.3	0.68	33.1	3.1	19.9

4.1.3. Status of the seedlings in the reforestation after two years

This chapter shall provide a general overview on the status of the seedlings of the different species two years after planting. The effects of the various experimental factors on the development of the seedlings will be presented in detail in the following chapters where also the effect of time will be considered. Fig. 15 shows the mean characteristics of all plants of each species.

As can be seen in Fig. 15 there are huge differences in the survival rate among the species. Survival of the exotics species was 92%, and there was no significant difference between *E. saligna* and *P. patula* (p=0.965). However, the survival of the native shade tolerant *T. chrysantha* (94%) was even a bit higher. Surprisingly, the survival of the two light demanding species was significantly lower (57%) than that of all other species (except *J. neotropica* with 44%), and there was no significant difference between de *A. acuminata* and *H. americanus* (p=0.987).

Concerning height and RCD the two exotics and *A. acuminata* showed the best performance. While both exotics and *A. acuminata* have already more than 1.2 m in height the shade tolerant species and *H. americanus* are only around 40 cm. However, regarding RCD the differences among the species are smaller. For this parameter remarkable differences can be observed only between *P. patula*, *A. acuminata* and the other species.

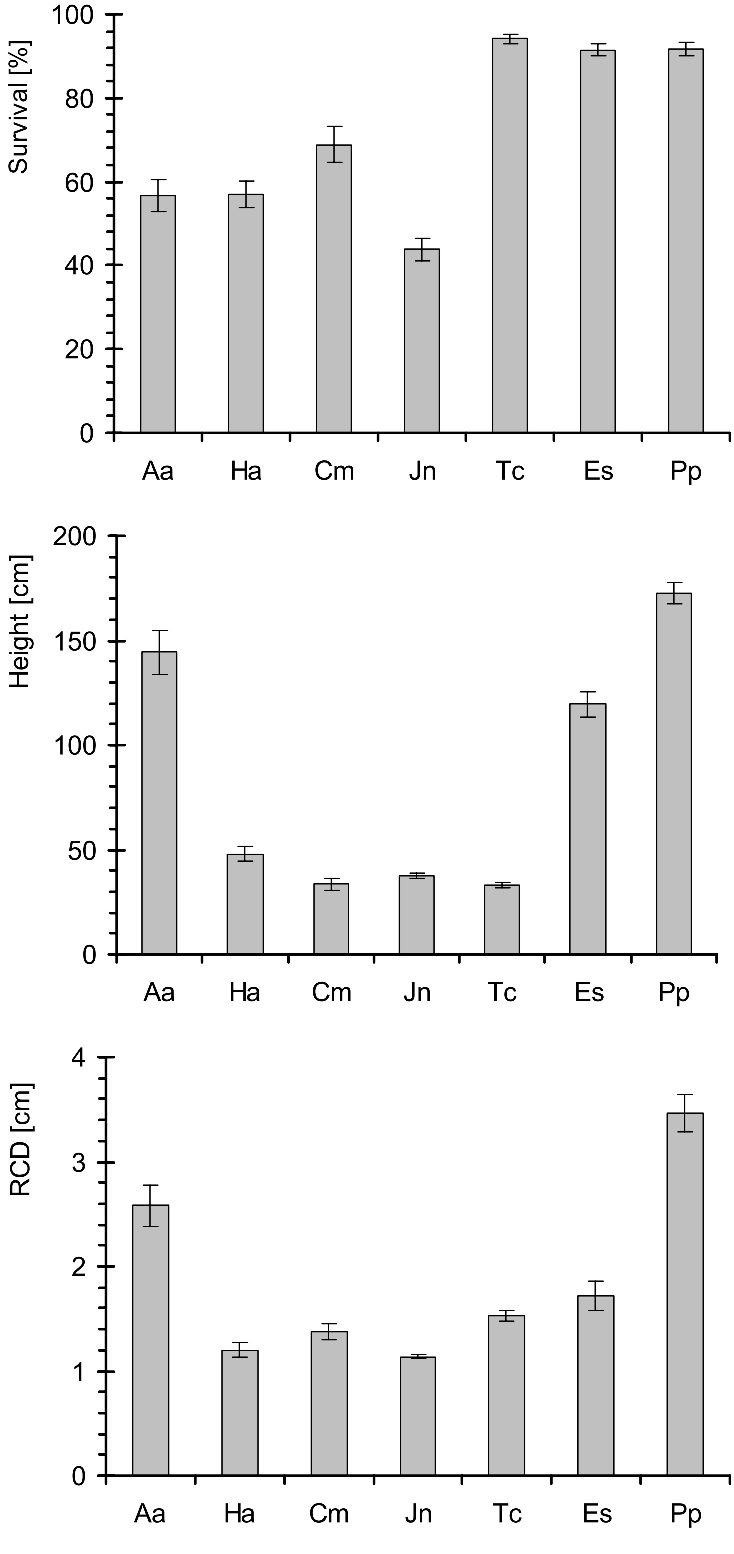


Figure 15: Survival, total height and root collar diameter (RCD) of all species two years after planting (the bars show means and standard error, n=48 plots; Aa = *Alnus acuminata*, Cm = *Cedrela montana*, Ha = *Heliocarpus americanus*, Jn = *Juglans neotropica*, Tc = *Tabebuia chrysantha*, Es = *Eucalyptus saligna*, Pp = *Pinus patula*).

With regard to the further development of the plots it is important to analyze how the mortality is distributed among the plots. Therefore, Table 13 shows the number of plots with the corresponding number of surviving plants.

Table 13: Number of plots in relation to the number of surviving seedlings (n = 48 plots)

Species	Mean survival (%)	Number of surviving plants				Total number of plots
		<2	3 - 5	6 -10	> 10	
A. acuminata	56.6	2	4	11	31	48
H. americanus	57.0	7	2	6	33	48
C. montana	68.9	1	1	5	41	48
J. neotropica	43.8	2	3	14	29	48
T. chrysantha	94.2				48	48
E. saligna	91.5				48	48
P. patula	91.7				48	48

If it is assumed that for a full stocking in the final stand only 100 to 200 individuals per hectare are needed it could be sufficient if at least one or two individual per plot will survive on the long run. According to Table 13 on the predominant majority of the plots more than 5 individuals survived the first two years. Even for the species with high mortality (*H. americanus* and *J. neotropica*) there were only few (7 resp. 2) plots were less than two individuals survived. Only for *H. americanus* 3 plots have been registered where no plants at all survived.

As already mentioned not all individuals will be needed to achieve a full stocking in the final stand. According to the common experience the surviving trees will be the most vital and competitive trees. In Fig. 16 the total plot means for height and RCD per species are compared with the means of the highest individual per plot. For all species the maximum height was more than 45% superior to the mean height. For *A. acuminata*, *T. chrysantha* and *P. patula* the mean height of the highest plants was more than 80% superior to the total mean height. Surprisingly, in relation to the other groups the shade tolerant species showed the biggest difference between maximum and mean growth. Results for root collar diameter were similar to that for the height. The mean RCD of the highest seedlings of C. *montana* and *E. saligna* was more than 60% superior to the total mean RCD.

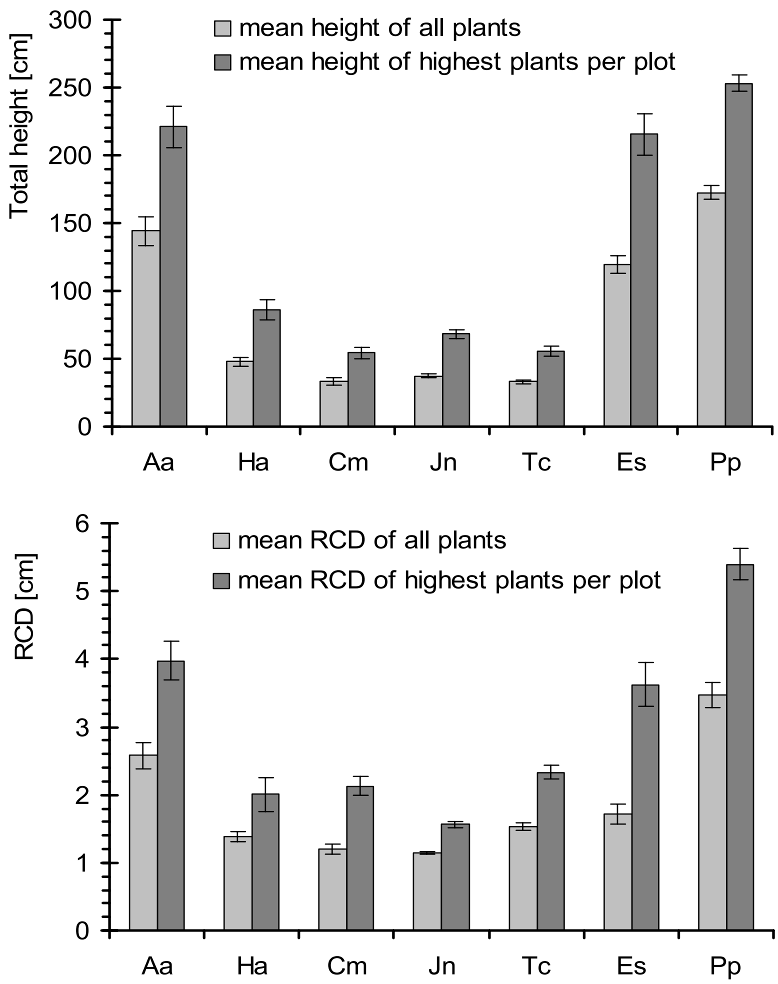


Figure 16: Comparison of the mean height and RCD of all plants and the corresponding means of the highest plants per plot (Aa=*Alnus acuminata*, Cm=*Cedrela montana*, Ha=*Heliocarpus americanus*, Jn=*Juglans neotropica*, Tc=*Tabebuia chrysantha*, Es=*Eucalyptus saligna*, Pp=*Pinus patula*; bars show means and standard error; n= 48 plots).

4.1.4. Effect of the successional phases on the performance of the seedlings

4.1.4.1 Situation after two years

Fig. 17 presents the mean survival, height and root collar diameters (RCD) for all species at the three successional sites. As can be seen there are distinct differences among the sites. Survival of all species was lowest on the pasture, except *A. acuminata* and *J. neotropica* which had the lowest survival on the fern respectively the shrub site. On all sites *T. chrysantha, E. saligna* and *P. patula* showed the best survival. In contrast to the survival almost all species showed the best heights on the pasture site, even though the differences are very small for some species. Results for root collar diameter were similar to the height. Only *J. neotropica* had the lowest RCD on the pasture.

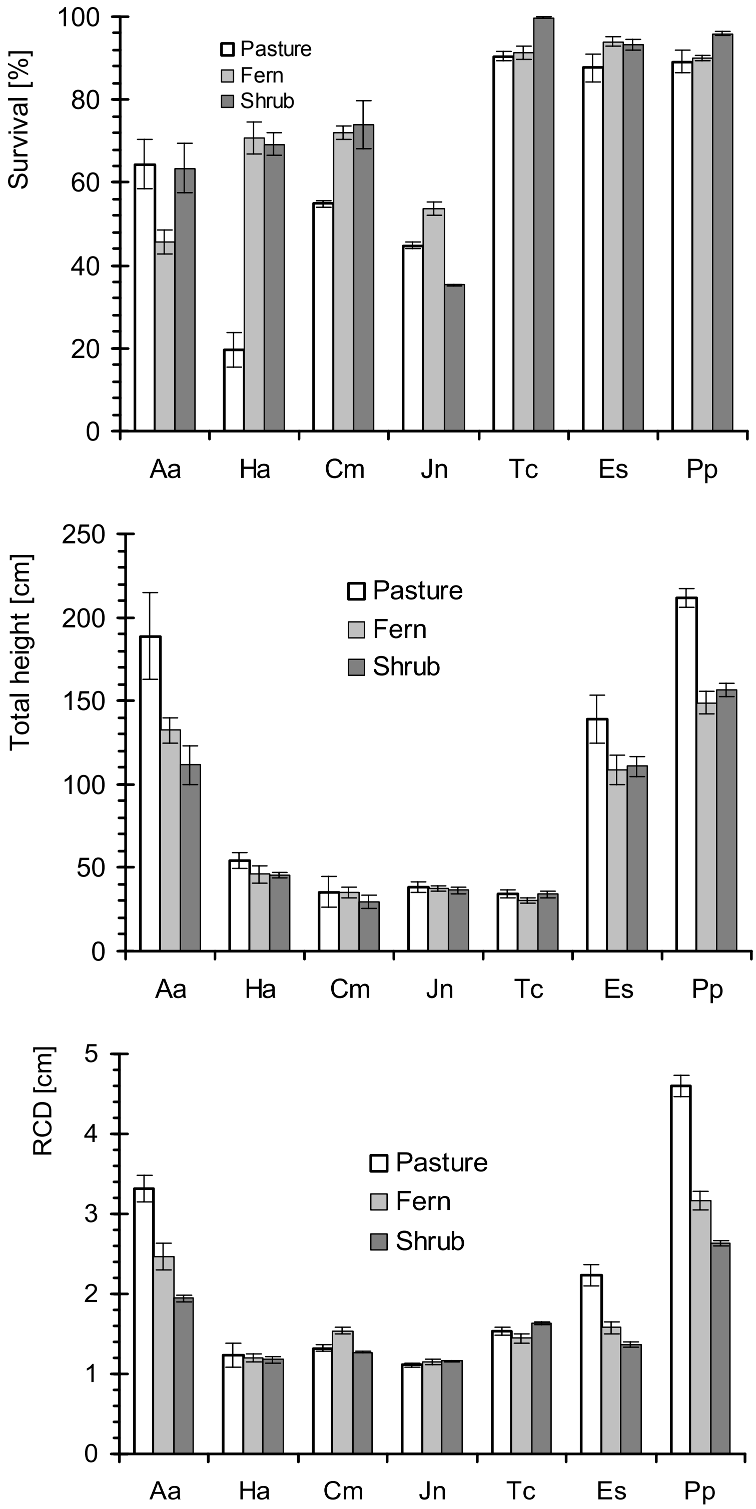


Figure 17: Survival, total height, and root collar diameter (RCD) at the different sites two years after planting (shown are means and standard error; Aa = *Alnus acuminata*, Cm = *Cedrela montana*, Ha = *Heliocarpus americanus*, Jn = *Juglans neotropica*, Tc = *Tabebuia chrysantha*, Es = *Eucalyptus saligna*, Pp = *Pinus patula*).

Table 14 presents the mean plant parameters summarized for the three tree groups. Table 15 shows the results of the variance analysis. As can be seen from these tables for all analysed parameters significant differences between the pasture and the two other sites could be found, while differences between fern and shrub were not significant except for RCD. Survival of the light demanding and the exotic species increased with advanced successional level of the site. Only for the shade tolerant species conditions seemed to be best at the fern site. In contrast to survival the height of all three groups decreased with advanced succession. Surprisingly, survival of the shade tolerant species at the pasture was significantly (p=0,018) higher than that of the light demanding species. Alike, the light demanding had better survival at the shrub site compared to the pasture. However, this can be explained by the low survival of *H. americanus* on the pasture which was significantly lower than that of *A. acuminata*. Concerning height and RCD the exotics showed significantly higher means than the native species and the shade tolerant significantly lower than the light demanding species.

Table 14: Means and variation coefficient (VC) for survival, total height and root collar diameter (RCD) of the three groups at the different sites two years after planting.

Group	Survival (%)						Total height (cm)					
	Pasture		Fern		Shrub		Pasture		Fern		Shrub	
	Mean	VC (%)	Mean	VC (%)	Mean	VC (%)	Mean	VC (%)	Mean	VC (%)	Mean	VC (%)
Light demanding	42	45	58	34	66	39	122	57	89	24	78	39
Shade tolerant	63	30	72	19	69	17	36	37	34	32	34	21
Exotics	88	13	92	14	95	7	175	23	129	24	134	15
means	65	26	74	20	77	18	111	33	84	23	82	21

	RCD (cm)					
Light demanding	2.28	58.3	1.83	23.5	1.56	26.9
Shade tolerant	1.32	27.3	1.38	21.0	1.36	14.0
Exotics	3.42	35.7	2.37	22.8	2.00	19.5
means	2.34	37.6	1.86	21.5	1.64	18.9

Table 15: Summary of analysis of variance for survival, total height and root collar diameter (RCD) after two years (significant values are presented in bold).

Source of variation	p-value		
	Survival	Total Height	RCD
Successional phase			
Pasture vs. Fern + Shrub	**<0.0001**	**0.0001**	**<0.0001**
Fern vs. Shrub	0.2718	0.5999	**0.0316**
Species			
Natives vs. Exotics	**<0.0001**	**<0.0001**	**<0.0001**
Light demanding vs. Shade tolerant	**<0.0001**	**<0.0001**	**<0.0001**
Alnus vs. *Heliocarpus*	0.0717	**<0.0001**	**<0.0001**
Tabebuia vs. *Cedrela* + *Juglans*	**<0.0001**	0.9726	**0.0029**
Cedrela vs. *Juglans*	**<0.0001**	**0.0156**	0.0500
Eucalyptus vs. *Pinus*	0.7956	**<0.0001**	**<0.0001**
Treatment			
Without treatment vs. With treatment	0.1920	0.9787	**<0.0001**
Species * Treatment			
Natives vs. Exotics * Treatment	**0.0033**	0.4528	**0.0262**
Light demanding vs. Shade tolerant * Treatment	0.0941	0.0869	0.4175
Alnus vs. *Heliocarpus* * Treatment	0.5306	0.3014	0.8176
Tabebuia vs. *Cedrela* + *Juglans* *Treatment	0.3353	**0.0002**	**0.0430**
Cedrela vs. *Juglans* * Treatment	0.4297	0.2033	0.7073
Eucalyptus vs. *Pinus* * Treatment	0.2548	0.2920	**0.0021**
Successional phase * Species			
Pasture*Natives vs. Exotics	0.1676	**0.0235**	**<0.0001**
Fern * Natives vs. Exotics	0.8797	0.4462	0.2131
Pasture * Light demanding vs. Shade tolerant	**0.0180**	**0.0318**	**0.0064**
Fern * Light demanding vs. Shade tolerant	0.1550	0.2167	0.2128
Pasture * *Alnus* vs. *Heliocarpus*	**<0.0001**	**0.0148**	**0.0021**
Fern * *Alnus* vs. *Heliocarpus*	**0.0437**	0.2028	0.1194
Pasture * *Tabebuia* vs. *Cedrela* + *Juglans*	0.5035	0.9711	0.7857
Fern * *Tabebuia* vs. *Cedrela* + *Juglans*	**0.0194**	0.2814	0.2054
Pasture * Cedrela vs. *Juglans*	0.0568	0.6724	0.8350
Fern * *Cedrela* vs. *Juglans*	**0.0440**	0.9588	0.3472
Pasture * *Eucalyptus* vs. *Pinus*	0.8248	0.3376	0.0136
Fern * *Eucalyptus* vs. *Pinus*	0.1448	0.8060	0.4161
Successional phase * Treatment			
Pasture * Without treatment vs. With treatment	0.8519	0.4183	0.6856
Fern * Without treatment vs. With treatment	0.3740	0.6819	0.9601
Successional phase * Species* Treatment	0.9890	0.3038	0.7331

4.1.4.2. Development of the seedlings during the 24 months

The previous chapter considered only the situation of the seedlings at the last data measurement. As all seedlings have been measured five times a repeated measurement analysis was applied to analyse the effect of time on the development.

In Fig. 18 it can be seen that at the pasture survival of all tree groups (except the exotics) was higher during the first six months of development compared to the other sites but then started to rapidly decrease. At the fern and shrub site survival was a bit lower in the first year but did not decrease tremendously during the following time. The differences between the fern and the shrub site were not significant (see Table 16). If we differentiate among the three groups the shade tolerant species were superior to the light demanding at all sites although there were also huge differences among the various species.

The growth characteristics among the successional phases did not differ significantly within the 1st year, but in the 2nd the development at the pasture became increasingly better than at the other two sites. Comparing the growth performance of the different tree groups we can see that the shade tolerant group showed the lowest growth. The light demanding *H. americanus* was at the same level as the shade tolerant species but this was compensated by the excellent growth of *A. acuminata*. The shade tolerant *J. neotropica* showed even a reduction of the mean height during the first year because many seedlings experienced a die-back of the shoots. Within the exotics it is notable that the growth of *P. patula* showed a strong increase after the first year. It is also remarkable that the development of the RCD of the light demanding species at the pasture site was better than that of the exotics at the fern and shrub sites.

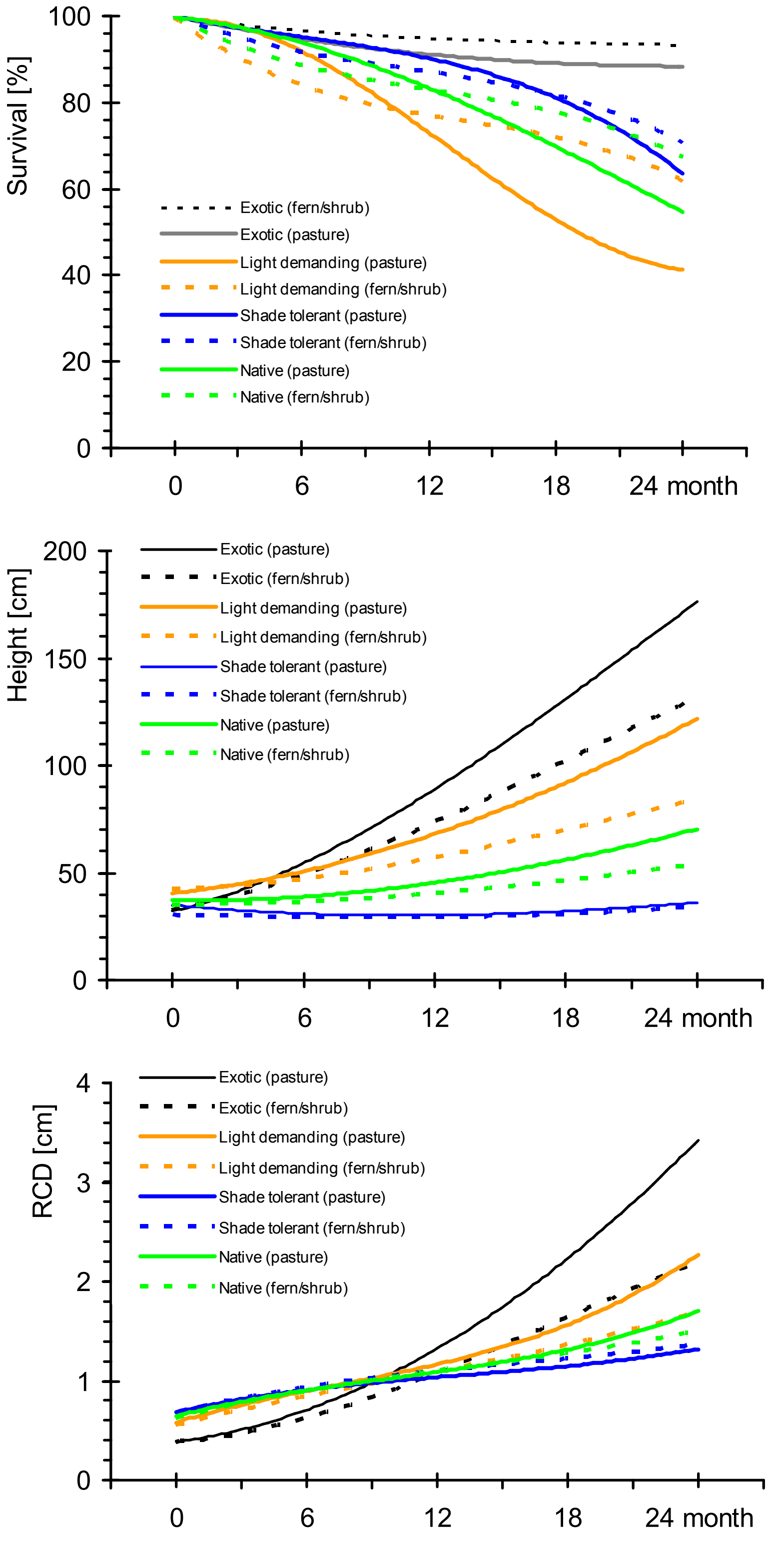


Figure 18: Survival, height, and root collar diameter (RCD) of the various groups of species at the different sites during the observation period (the curves shows polynomial functions, sites without significant differences have been summarized in one curve)

Table 16: Summary of multivariate analysis of variance according to repeated measures analysis (significant values are presented in bold).

Source of variation	p-value		
	Survival	Total height	RCD
Time	**<0.0001**	**<0.0001**	**<0.0001**
Time * Successional phase			
Time*Pasture vs. Fern + Shrub	**<0.0001**	**0,0231**	**<0.0001**
Time*Fern v Shrub	0.2802	0.7044	**0.0091**
Time * Species			
Time * Natives vs. Exotic	**<0.0001**	**<0.0001**	**<0.0001**
Time * Light demanding vs. Shade Tolerant	**<0.0001**	**<0.0001**	**<0.0001**
Time * *Alnus* vs. *Heliocarpus*	**<0.0001**	**<0.0001**	**<0.0001**
Time * *Tabebuia* vs. *Cedrela* + *Juglans*	**<0.0001**	**<0.0001**	**<0.0001**
Time * *Cedrela* vs. *Juglans*	**<0.0001**	**<0.0001**	**<0.0001**
Time * *Eucalyptus* vs. *Pinus*	0.8115	**<0.0001**	**<0.0001**
Time * Treatment			
Time* Without treatment vs. With treatment	0.1568	0.1795	**<0.0001**
Time*Species*Treatment			
Time* Natives vs. Exotics * Treatment	**0.0270**	0.1144	0.2064
Time* Light demanding vs. Tolerant * Treatment	**0.0002**	**0.0006**	0.7497
Time * *Alnus* vs. *Heliocarpus* * Treatment	**0.0003**	**0.0459**	0.4265
Time* *Tabebuia* vs. *Cedrela*+*Juglans* *Treatment	0.6751	**0.0003**	0.4089
Time* *Cedrela* vs. *Juglans* * Treatment	0.2525	0.0620	0.9408
Time* *Eucalyptus* vs. *Pinus* * Treatment	0.8425	0.5971	**0.0005**
Time*Successional phase * Species			
Time* Pasture*Light demanding vs. Exotics	**0.0035**	**0.0016**	**<0.0001**
Time* Fern* Light demanding vs. Exotics	0.5765	0.3431	0.0500
Time* Pasture* Light demanding vs. Tolerant	**<0.0001**	**0.0013**	**0.0338**
Time* Fern * Light demanding vs. Tolerant	0.5243	0.1671	0.1672
Time* Pasture * *Alnus* vs. *Heliocarpus*	**<0.0001**	**<0.0001**	**<0.0001**
Time* Fern * *Alnus* vs. *Heliocarpus*	**0.0105**	**<0.0001**	**0.0496**
Time* Pasture * *Tabebuia* vs. *Cedrela*+*Juglans*	0.5803	0.8619	0.1736
Time* Fern * *Tabebuia* vs. *Cedrela*+*Juglans*	0.1825	0.7994	0.2819
Time* Pasture * *Cedrela* vs. *Juglans*	0.4926	0.1502	0.6645
Time* Fern * *Cedrela* vs. *Juglans*	0.2100	0.3536	0.8269
Time* Pasture **Eucalyptus* vs. *Pinus*	0.6694	0.5541	**<0.0001**
Time* Fern **Eucalyptus* vs. *Pinus*	0.6496	0.0922	0.5678
Time*Successional phase * Treatment			
Time* Pasture* Without treatment vs. With treatment	**0.0089**	0.3295	**0.0271**
Time* Fern* Without treatment vs. With treatment	0.9471	0.2844	0.4963
Time*Successional phase * Species * Treatment	0.0705	0.7088	0.5648

4.1.5. Effect of treatment on the performance of seedlings

4.1.5.1. Situation after two years

Fig. 19 shows the differences between the treated and untreated plots for all species. All species except the two exotics showed a better survival on the plots with treatment. However, this effect was significant only for the light demanding species *A. acuminata* and *H. americanus* ($p<0.05$)[2]. While RCD of all species was positively influenced by the treatment the effect on height varied among the species. *C. montana, J. neotropica* and *E. saligna* showed better heights on the non-treated plots, while all other species grew better with treatment.

In Table 17 the parameters are presented for the three tree groups. From this it can be seen that the light demanding species had the highest profit from the treatment. This is surprising as they were expected to cope best with the situation at the sites. However, survival and RCD of the shade tolerant species were also better at the treated plots but in relation to the light demanding the treatment effect was smaller. The exotics could profit from the treatment only in terms of RCD. The results of the variance analysis for the treatment effect were also included in Table 15 before. According to that, significant interactions between the treatment and the several groups of species could only be revealed for survival and RCD of the natives and the exotics and RCD of *T. chrysantha* and the two other shade tolerant species as well as for *E. saligna* and *P. patula*.

Table 17: Mean survival, total height and root collar diameter (RCD) of the three groups two years after planting (VC = variation coefficient)

Group	Survival (%)				Total height (cm)				RCD (cm)			
	treatment				treatment				treatment			
	without		with		without		with		without		with	
	mean	VC (%)	mean	VC (%)	mean	VC (%)	mean	VC (%)	mean	VC (%)	mean	VC (%)
Light demanding	50	50	62	29	94	43	99	41	1.7	38	2.1	39
Shade tolerent	67	24	70	20	36	34	34	26	1.3	23	1.4	19
Exotics	93	11	90	11	148	23	144	19	2.3	33	2.9	23
Total means	70		74		93		92		1.7		2.1	

[2] Based on a separate Variance Analysis with all species

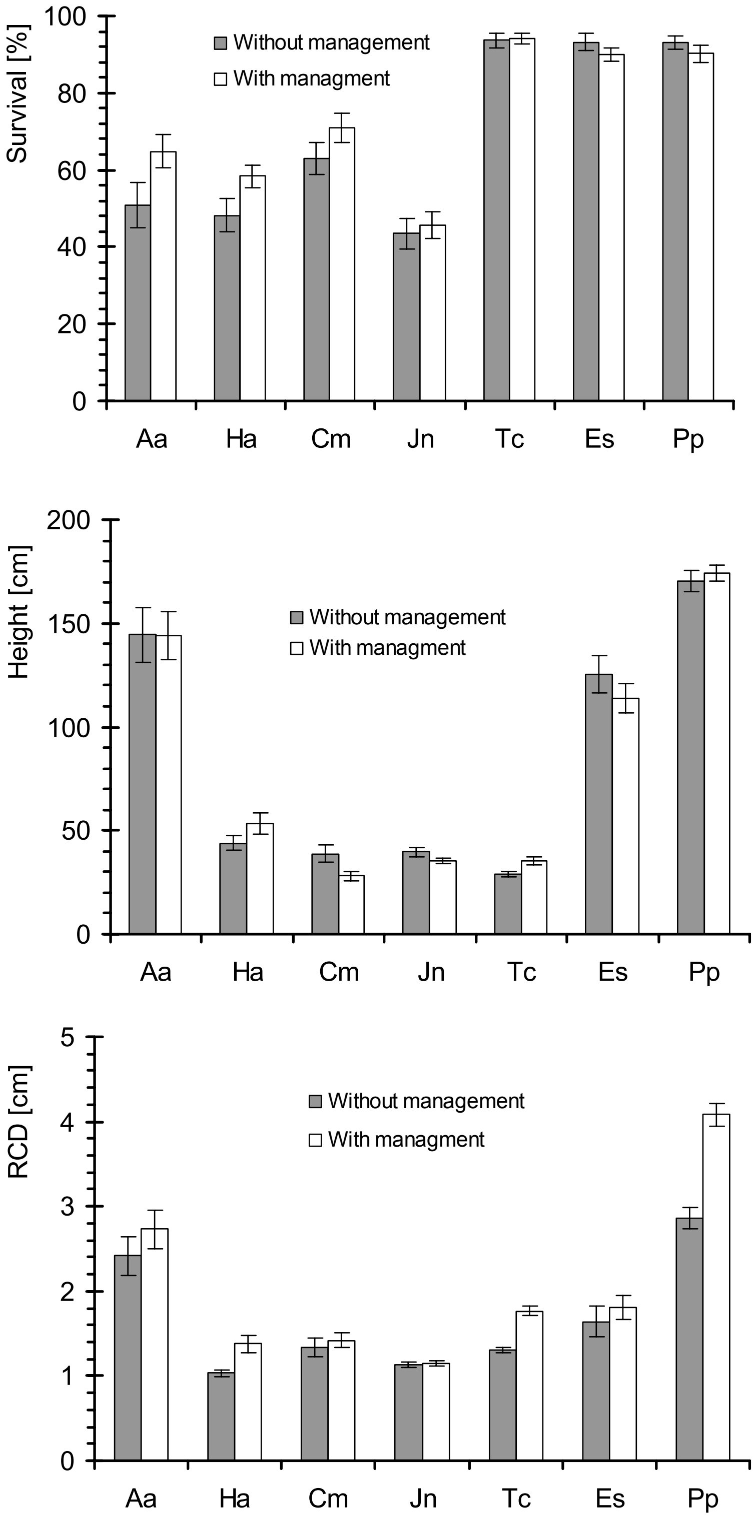


Figure 19: Comparison of survival, height, and root collar diameter (RCD) of seedlings two years after planting subjected to two different treatments (shown are means and standard error; Aa = *Alnus acuminata*, Cm = *Cedrela montana*, Ha = *Heliocarpus americanus*, Jn = *Juglans neotropica*, Tc = *Tabebuia chrysantha*, Es = *Eucalyptus saligna*, Pp = *Pinus patula*).

4.1.5.2. Development of the seedlings during the whole observation period subjected to the different treatments.

Fig. 20 shows the development of the seedlings during the whole observation time for the different tree groups and the treatment applied. It can be seen that the difference in the survival between the treated and untreated plots of the light demanding species appeared only after 12 months.

Considering all plants the development of survival and height was not significantly affected by the treatment (Table 16). A similar behaviour could be observed for RCD of all groups. Here the differences between the treated and untreated plots started also to increase only after 12 months. In Fig. 20 it can also be seen that the height of the shade tolerant trees was more or less stagnating during the first 18 months independent from the treatment. The differences in the height between the plot of the exotics developed already within the first 6 months and since then the relation did not change any more.

4.1.6. Comparison between pure and mixed species plots

In the previous chapters only the pure species plots were considered. In this chapter the situation of the species in the pure plots will be compared with that in the mixed ones.

After two years no distinct effects of the mixture on the seedlings performance could be recognized compared to the pure plots (Fig. 21). This is not astonishing as due to the wide spacing of 1.8 x 1.8 m and the slow growth of the plants interactions among the species are still very limited. However, mixture effects are expected with the closure of the crowns or when the roots start to interact directly or indirectly in the soil. However, as can be seen in Fig. 21 and Table 18 significant differences between the pure and mixed plots could be identified for *J. neotropica* where all parameters were worse in the mixture. *A. acuminata* had a significant lower survival on the pure plots and *C. montana* was significantly higher on the mixture. *H. americanus* had the best performance of all parameters in mixture 2 but these effects are not significant.

A different effect of the successional phase on the pure and mixed plots could be identified for the survival of *C. montana* and *H. americanus* where the pasture showed the lowest survival compared with fern and shrub. And only for *J. neotropica* the survival at the fern site was significantly different from that at pasture and shrub. Also height and RCD of *J. neotropica* and *A. acuminata* showed differences between sites where the fern lead to significant reductions in the mixtures (Table 18).

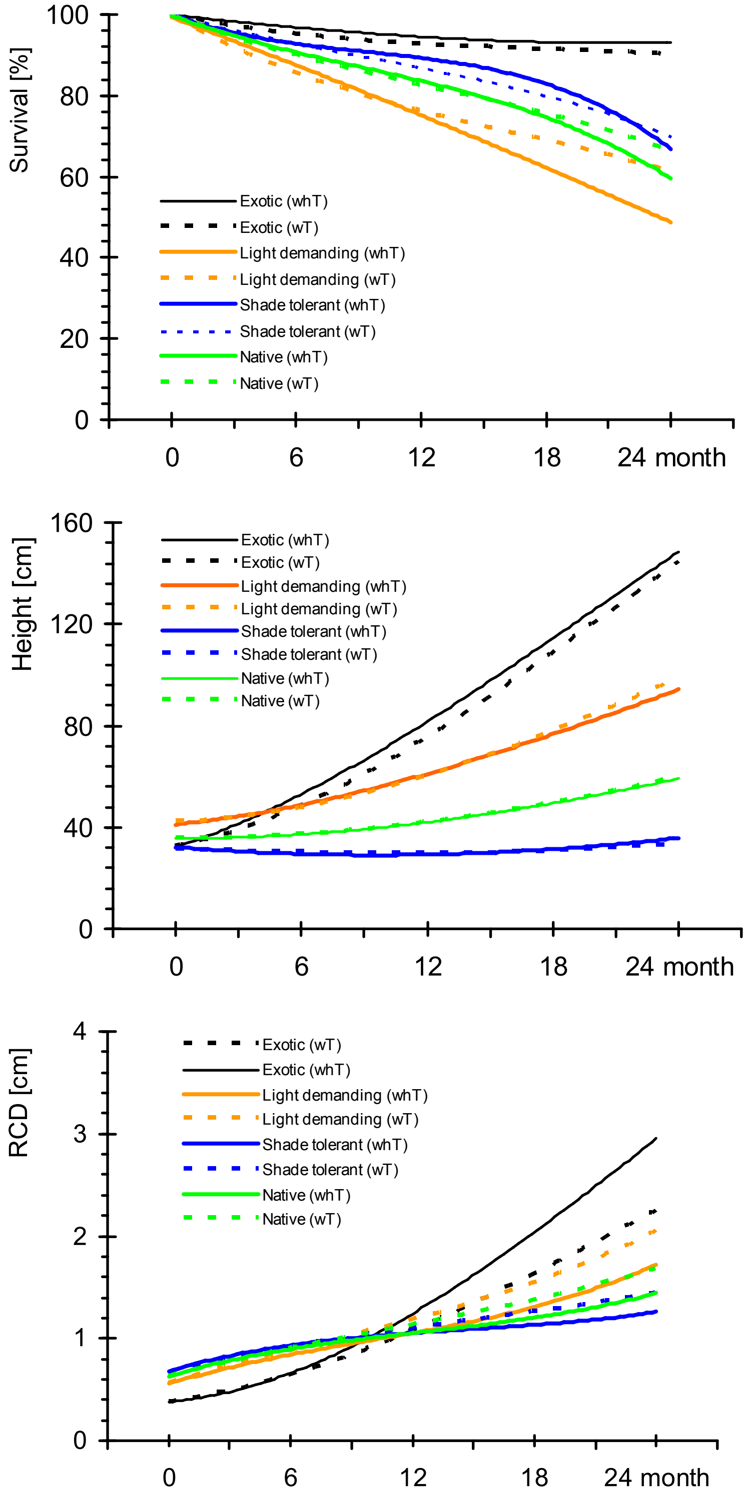


Figure 20: Development of survival, total height, and root collar diameter (RCD) for groups of plants within the observation period for two different treatments (whT = without treatment; wT = with treatment).

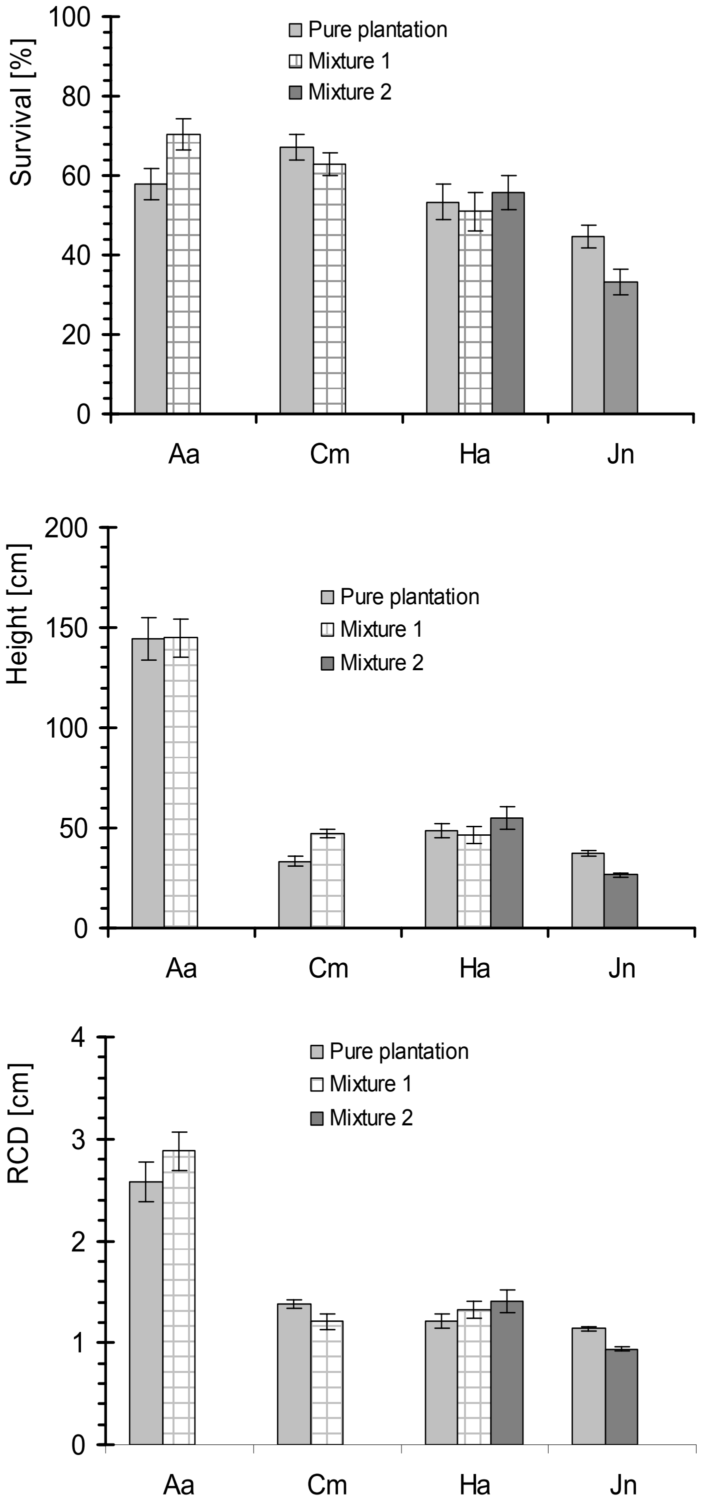


Figure 21: Mean survival height and root collar diameter (RCD) in the pure and mixed plots two years after planting (shown are means and standard error; mixture 1= *A. acuminata* x *C. montana* x *H. americanus*; mixture 2 = *H. americanus* x *J. neotropica*)

Table 18: Results of the analysis of variance for pure and mixed species at two years after planting (significant values are presented in bold).

Source of variation	p-value								
	Alnus acuminata			*Cedrelaf montana*			*Juglans neotropica*		
	Survival	Total height	RCD	Survival	Total height	RCD	Survival	Total height	RCD
Succession phase									
Pasture vs. Fern + Shrub	0.2552	**<0.0001**	**0.0005**	**0.0048**	0.4222	0.0634	0.1564	**0.0045**	**0.0017**
Fern vs. Shrub	0.1102	**0.0381**	**0.0057**	0.7574	0.3808	**0.0200**	**0.0123**	0.4625	**0.0217**
Species									
Pure vs. mixed	**0.0179**	0.8298	0.1615	0.2260	**<0.0001**	0.0566	**0.0011**	**<0.0001**	**<0.0001**
Treatment									
Without treatment vs. with treatment	0.0528	0.0923	**0.0278**	**0.0083**	**0.0294**	0.0813	**0.0015**	0.7462	**0.0010**
Species * Treatment	0.5983	0.2484	0.4988	0.6840	0.1647	0.6021	**0.0002**	0.0283	**0.0039**
Succession * Species									
Pasture*Pure vs. mixed	0.7798	0.7022	0.6178	0.3443	0.8164	0.5263	0.1317	**0.0048**	**<0.0001**
Fern *Pure vs. mixed	0.3397	0.8814	0.4257	0.3978	0.1869	0.9230	0.3888	0.1884	0.0582
Succession *Treatment									
Pasture* Without treatment vs. with treatment	0.5140	0.1204	0.2001	0.9231	0.1613	0.5692	0.9373	0.2935	0.0735
Fern * Without treatment vs. with treatment	0.0769	0.5425	0.9857	0.1838	0.6504	0.3869	0.8330	0.0963	0.1889
Successional phase * Species * Treatment	0.5262	0.8418	0.8124	0.7080	0.6091	0.7886	0.9991	0.0064	**0.0006**

Source of variation	p-value		
	Heliocarpus americanus		
	Survival	Total height	RCD
Succession			
Pasture vs. Fern + Shrub	**<0.0001**	0.0706	0.0772
Fern vs. Shrub	0.3913	0.1016	0.4426
Species			
Pure vs. Mixed 1:2	0.8397	0.7203	0.0368
Mixed 1 vs. mixed 2	0.5621	0.0726	0.5094
Treatment			
Without treatment vs. with treatment	**0.0122**	**0.0056**	**0.0005**
Species * Treatment			
Pure vs. mixed 1:2* Treatment	0.9171	0.5528	0.8195
mixed 1 vs. mixed 2 *Treatment	**0.0011**	0.9191	0.1160
Succession * Species			
Pasture*Pure vs. mixed 1:2	0.6646	0.3667	0.1719
Fern *Pure vs. mixed 1:2	0.7998	0.4597	0.5241
Pasture*mixed 1 vs. mixed 2	0.0683	0.1667	0.8231
Fern*mixed 1 vs. mixed 2	0.7998	0.4597	0.5241
Succession *Treatment			
Pasture* Without treatment vs. with treatment	0.9248	0.3007	0.2111
Fern* Without treatment vs. with treatment	0.0514	0.0654	0.3223
Successional*Species* Treatment	0.2371	0.0614	0.1292

In contrast to the pure plots, the treatment had a significant effect on all parameters of *H. americanus* on the mixed plots with better survival and growth under the treatment. *C. montana* and *J. neotropica* showed better growth in height and A. *acuminata* and *J. neotropica* in RCD on the treated plots.

4.1.7. Effects of micro-site conditions

To analyze the influence of the different site conditions on the plant performance in more detail, a principal component analysis (PCA) for each tree group based on the micro-site conditions measured for each plot was performed.

Table 19 presents the mean site conditions of the plots at the three successional areas. As can be seen the mean characteristics differed significantly among the successional sites. From the high variation coefficient of the same characteristics it can be concluded that the conditions are varying very much even within each of the sites.

Table 19: Mean micro-site conditions at the successional sites (means with different letters differ significantly between successional site at $p<0.05$; VC= variation coefficient).

Variables	Pasture			Fern			Shrub		
	mean	VC (%)	Sig.	mean	VC (%)	Sig.	mean	VC (%)	Sig.
Shape of land	2.8	30.9	a	3.2	41.4	b	2.3	46.3	c
Inclination (%)	52.5	35.0	a	69.6	23.0	b	44.5	50.3	c
Altitude (m s.a.l.)	1957	3.4	a	2021	2.3	b	2145	1.6	c
Shrub cover (%)	0.2	459.0	a	4.9	182.6	b	20.7	81.3	c
Rock cover (%)	1.2	572.5	a	0.5	706.4	ac	0.4	494.8	c
Position within plot	2.1	20.8	a	2.1	22.7	a	2.1	24.9	a
Rooting depth (cm)	35.7	45.9	a	26.3	40.7	b	22.1	46.7	c
Size horizon 1(cm)	41.8	41.8	a	32.2	39.4	b	28.9	40.7	c
Clay (%)	33.9	23.2	a	35.8	17.9	b	44.8	17.4	c
Sand (%)	33.2	40.5	a	29.0	29.0	b	15.5	51.8	c
Silt (%)	33.0	27.3	a	35.1	22.2	b	39.7	12.2	c
Rock (%)	3.0	187.7	a	2.0	188.2	b	1.6	200.1	b
Organic matther (%)	4.6	18.9	a	4.5	18.8	a	4.3	22.7	b
Available Water Capacity (mm)	72.5	40.7	a	60.0	33.0	b	53.4	30.8	c
pH	4.9	7.6	a	4.8	6.9	b	4.6	10.1	c

Fig. 22 shows the results of the PCA for the three tree groups. Due to the high heterogeneity of the site conditions for all groups ten components were needed to explain >90% of the variance. Shape of land, position, rock presence (rocks cover + rocks in the soil) organic mater and slope provide the smallest contribution in the two first components. The rooting depth as well as the water capacity of the soil seems to be the major influencing factors. Another important factor is the soil texture, where the content of sand and clay or silt have antagonistic behaviour, similar to altitude and pH. Surprisingly, the distribution of the factors for the shade tolerant species is more similar to that of the exotics than to the light demanding.

In addition to the PCA we also applied a logistic regression to better explain the influence of the micro-site on the survival. Table 20 shows the results of the logistic regression. As can be seen only the models for *C. sc montana, H. americanus and E. saligna* showed significant results according to Nagelkerke while those for *T. chrysantha, P. patula* did not. However, this may be due to the fact that the latter species had only very low mortality.

Table 20: Summary of logistic regression results for survival (models acceptable are presented in bold).

	Nagelkerke R^2
Alnus acuminata	0.08
Cedrela montana	**0.25**
Heliocarpus americanus	**0.31**
Juglans neotropica	0.09
Tabebuia chrysantha	1.00
Eucalyptus saligna	**0.18**
Pinus patula	0.84

Table 21 presents the results of the logistic regression for the three species with significant Nagelkerke R^2 values. As can be seen the influence of the environmental and soil factors on the survival did not follow a distinct pattern for all the species. Thus, the survival probability of *C. montana* decreases with increasing altitude (by factor -0.01) and pH (by factor -2.21). *H. americanus* shows decreasing survival probability (factor 0.97) with increasing AWC (available water capacity) and increasing inclination improves the survival probability of *E. saligna* by factor 1.04.

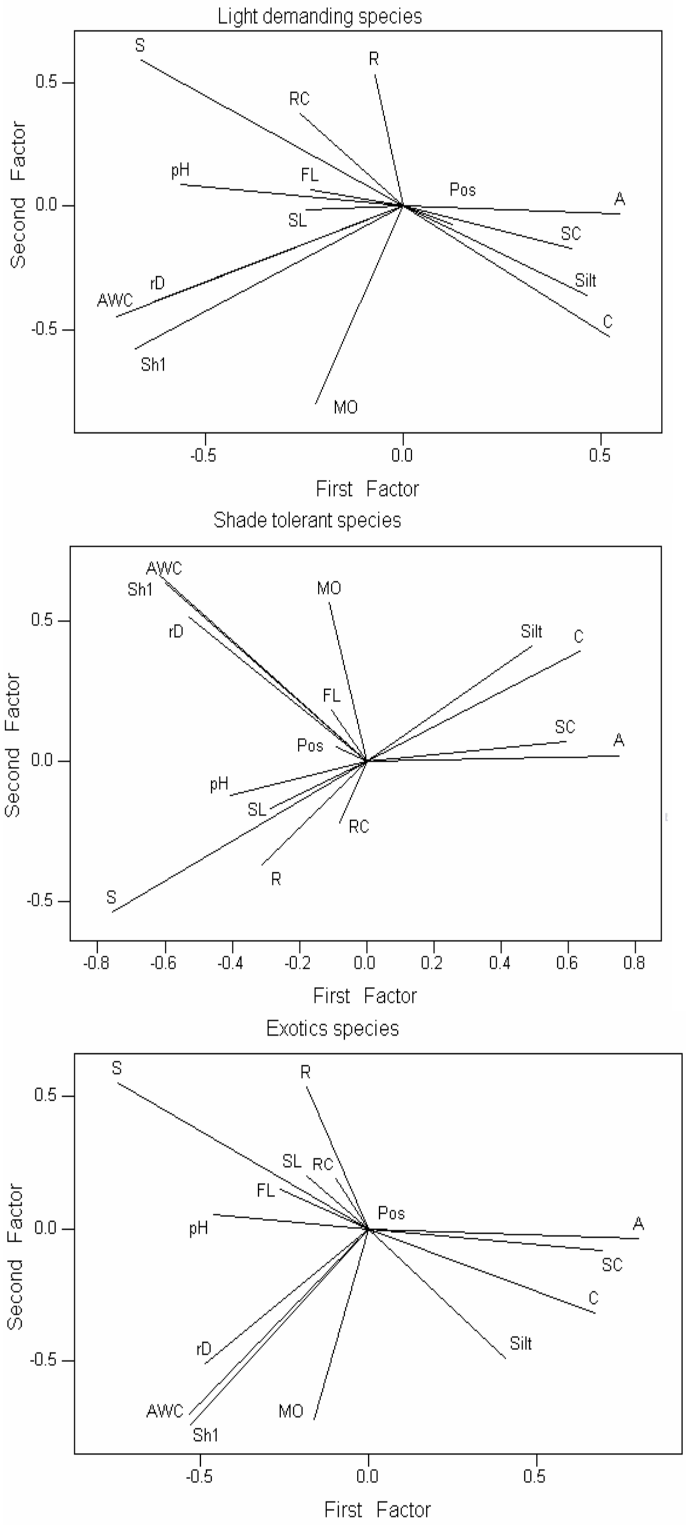


Figure 22: Distribution of variables of the two principal components (A= altitude, FL= shape of land, I= inclination, Pos = Position within plot; SC= shrub cover, RC=rock cover, rD= rooting depth, sH= size horizon C=clay, S= sand, AWC= available water capacity, MO= organic matter, R=rocks in the soil)

Table 21: Summary of logistic regression results for survival: environmental variables and soil characteristics as explanations of success of seedlings (significant values are presented in bold).

Species	Variable	e^{β}	B	S.E.	Wald	Sig.
C. montana	Inclination	1.00	0.00	0.01	0.0	0.9437
	Altitude	**0.99**	**-0.01**	**0.00**	**4.5**	**0.0335**
	SC	1.00	0.00	0.02	0.1	0.8173
	Rooting depth	1.00	0.00	0.02	0.0	0.9698
	Clay	101760.21	11.53	8.57	1.8	0.1787
	Sand	98460.67	11.50	8.57	1.8	0.1799
	Silt	104955.36	11.56	8.57	1.8	0.1775
	MO	0.76	-0.28	0.21	1.8	0.1836
	AWC	0.98	-0.02	0.01	3.0	0.0827
	pH	**0.11**	**-2.21**	**0.62**	**12.7**	**0.0004**
H. americanus	Inclination	1.01	0.01	0.01	0.5	0.4712
	Altitude	1.00	0.00	0.00	0.0	0.9922
	SC	1.04	0.04	0.02	3.3	0.0694
	rDepth	0.98	-0.02	0.02	1.1	0.3014
	Clay	1.13	0.12	0.23	0.3	0.6021
	Sand	1.09	0.09	0.23	0.1	0.7076
	Silt	1.11	0.10	0.23	0.2	0.6627
	MO	1.58	0.46	0.34	1.9	0.1737
	AWC	**0.97**	**-0.03**	**0.01**	**4.2**	**0.0415**
	pH	0.95	-0.05	0.65	0.0	0.9395
E. saligna	**Inclination**	**1.04**	**0.04**	**0.02**	**4.7**	**0.0296**
	Altitude	1.00	0.00	0.00	0.2	0.6475
	SC	1.03	0.03	0.04	0.6	0.4441
	Rooting depth	1.00	0.00	0.03	0.0	0.8584
	Clay	0.38	-0.98	4.32	0.1	0.8211
	Sand	0.39	-0.94	4.32	0.0	0.8269
	Silt	0.41	-0.88	4.31	0.0	0.8375
	MO	1.17	0.16	0.43	0.1	0.7073
	AWC	0.99	-0.01	0.02	0.6	0.4278
	pH	0.34	-1.08	0.86	1.6	0.2107

Table 22 shows the coefficients of the linear correlation between the total increment in height and environmental and soil parameters, independently from the treatment applied. As can be seen there exists no single parameter that is correlated with the growth of all species. However, there are some negative significant correlations, thus inclination had negative significant correlations with the growth of *H. americanus, J. neotropica, T. chrysantha* and *E. saligna*. Even though the altitude had a small variation range of 340 m (between 1860 – 2200), it showed negative correlation with the height growth of A*. acuminata, C. montana, J. neotropica*, and the both exotic species. The shrub cover showed positive correlation with one shade tolerant species (*T. chrysantha*), while with *A. acuminata* it showed negative correlation. In addition the growth of *C. montana, J. neotropica, E. saligna and P. patula* was correlated with the rooting depth of the soil. *J. neotropica* showed a positive correlation with available water capacity (AWC). Also we found positive correlations of pH with the both species that showed the best growth (*A. acuminata* and *P. patula*).

Table 22: Pearson correlation coefficients (R) between selected soil and environmental factors and the height increment for all species (Inc = inclination, Alt = Altitude, SC= shrub cover, RD = rooting depth, MO= organic matter, AWC= available water capacity; significant values are presented in bold).

	Aa		Cm		Ha		Jn		Tc		Es		Pp	
	R	sig.	R	sig.	R	sig.	R	sig.	R	sig.	R	sig.	R	sig.
Inc.	0.00	0.990	-0.09	0.302	**-0.20**	**0.018**	**-0.21**	**0.012**	**-0.35**	**0.000**	**-0.31**	**0.000**	0.08	0.313
Alt.	**-0.36**	**0.000**	**-0.27**	**0.001**	-0.11	0.183	**-0.20**	**0.018**	0.02	0.817	**-0.32**	**0.000**	**-0.27**	**0.001**
SC	**-0.17**	**0.048**	-0.11	0.197	0.06	0.512	0.00	0.961	**0.25**	**0.003**	-0.07	0.410	-0.15	0.075
RD	0.15	0.092	**0.26**	**0.002**	0.15	0.067	**0.29**	**0.001**	0.02	0.781	**0.23**	**0.005**	**0.16**	**0.048**
Clay	-0.11	0.202	-0.08	0.351	0.13	0.118	0.03	0.758	0.09	0.285	-0.06	0.455	-0.12	0.152
Sand	0.13	0.135	0.09	0.278	-0.07	0.385	-0.01	0.864	-0.01	0.949	0.00	0.970	0.07	0.430
Silt	-0.04	0.672	-0.06	0.483	-0.03	0.726	0.00	0.978	-0.09	0.266	0.06	0.485	0.03	0.747
MO	0.14	0.107	0.13	0.118	0.13	0.122	0.14	0.091	-0.09	0.280	0.16	0.053	-0.01	0.862
AWC	0.16	0.058	0.13	0.113	-0.03	0.728	**0.23**	**0.006**	-0.09	0.265	0.14	0.103	0.04	0.651
pH	**0.24**	**0.006**	-0.09	0.309	0.13	0.132	-0.04	0.647	-0.05	0.538	-0.11	0.181	**0.17**	**0.046**

4.1.8. Health status of the seedlings after two years

As has been demonstrated in many studies, seedlings on abandoned areas have to cope with very harsh conditions which do not only affect their growth performance but also the vitality or health status. Consequently, the seedlings quality has also been evaluated. The health status two years after planting is presented in Table 23. As can be seen the proportion of bad quality plants was very low for most species. Only *A. acuminata, H. americanus* and *J. neotropica* had higher proportions of plants with bad health status. For these species also differences among the three successional sites could be observed although they were not statistically significant (Table 24). While the proportion of plants with bad health status increased for *H. americanus* and *J. neotropica* from shrub over fern to pasture, *A. acuminata* showed a contrary behaviour. Here the shrub site had the most bad plants.

The treatment did also not show a significant effect on the health status although *J. neotropica* and *C. montana* had higher proportions of bad plants on the pasture plots with treatment. At this site more than half of the *J. neotropica* seedlings did not have satisfying quality. For all other species the total number of bad seedlings was lower or equal at the plots where the ground vegetation had been removed repeatedly (with management). If the data are analysed with regard to the three groups of tree species significant differences ($p < 0.05$) could be observed between the natives and the exotics, where the latter showed the better condition. Within shade tolerant species, *T. chrysantha* had significant better vitality than *C. montana* and *J. neotropica*.

Table 23: Mean proportion (%) of seedlings with bad health status (minor vitality or presence of damages) after two years subjected to the successional phases and the treatment.

	Without treatment				With treatment			
Species	Pasture	Fern	Shrub	Mean	Pasture	Fern	Shrub	Mean
Alnus acuminata	1	13	23	12	1	1	28	10
Heliocarpus americanus	31	28	12	24	2	1	3	2
Cedrela montana	4	5	6	5	13	3	5	7
Juglans neotropica	27	23	17	22	54	19	32	35
Tabebuia chrysantha	3	2	0	2	2	2	0	1
Eucalyptus saligna	2	2	2	2	3	1	3	2
Pinus patula	0	0	0	0	0	0	1	0

Table 24: Results of the analysis of variance for vitality of seedlings after two years (significant values are presented in bold).

Source of variation	p-value
Successional phase	
Pasture vs. Fern + Shrub	0.252
Fern vs. Shrub	0.1769
Species	
Natives vs. Exotics	**<0.0001**
Light demanding vs. Shade tolerant	0.9736
Alnus vs. *Heliocarpus*	0.5045
Tabebuia vs. *Cedrela + Juglans*	**<0.0001**
Cedrela vs. *Juglans*	**<0.0001**
Eucalyptus vs. *Pinus*	0.4768
Treatment	
Without treatment vs. with treatment	0.3874
Species*Treatment	
Natives vs. Exotics * Treatment	0.4431
Light demanding vs. Tolerant * Treatment	**<0.0001**
Alnus vs. *Heliocarpus* * Treatment	**0.0004**
Tabebuia vs. *Cedrela + Juglans* *Treatment	0.0824
Cedrela vs. *Juglans* * Treatment	**0.0461**
Eucalyptus vs. *Pinus* * Treatment	0.9586
Successional phase * Species	
Pasture*Natives vs. Exotics	0.4405
Fern * Natives vs. Exotics	0.5554
Pasture * Light demanding vs. Shade tolerant	**0.001**
Fern * Light demanding vs. Shade tolerant	0.2649
Pasture * *Alnus* vs. *Heliocarpus*	**0.0005**
Fern * *Alnus* vs. *Heliocarpus*	**<0.0001**
Pasture * *Tabebuia* vs. *Cedrela + Juglans*	0.05
Fern * *Tabebuia* vs. *Cedrela + Juglans*	0.3934
Pasture * Cedrela vs. *Juglans*	**0.0153**
Fern * *Cedrela* vs. *Juglans*	0.7546
Pasture * *Eucalyptus* vs. *Pinus*	0.9506
Fern * *Eucalyptus* vs. *Pinus*	0.9502
Successional phase * Treatment	
Pasture * Without treatment vs. with treatment	0.264
Fern * Without treatment vs. with treatment	**0.0155**
Successional phase * Species* Treatment	0.2411

4.2. Herbicide experiment

In the reforestation experiment the manual removal of the ground vegetation did not show a clear significant effect on the growth of the seedlings. In this context a side experiment with *C. montana* and *T. chrysantha* seedlings was established to exemplarily investigate the effects of a chemical treatment as an alternative to the manual clearing. This experiment considered also the biomass production of the ground vegetation and the seedlings.[3]

Fig. 23 presents the characteristics of the seedlings under the different treatments one year after planting. Similar to the reforestation experiment *C. montana* had a higher mortality than *T. chrysantha* but survival of the seedlings of both species was very high without a significant influence (p=0.62) of the treatment. In contrast, height and RCD were significantly higher under the chemical treatment while there was no difference between the control and the manual treatment (Table 25 and Fig. 23). Besides the treatment the location in the experiment (block) had also a clear effect. The growth parameters of the plants in the steep slope (block 2) were significantly lower than that of the two other blocks. This supports also the results of the PCA in the reforestation experiment presented in chapter 4.1.7 that the inclination of the slope has an important effect on the seedling´s performance.

The analyses of the above and belowground biomass of the ground vegetation and the seedlings conducted in this experiment allow a much better insight in the competitive effects between these components. As can be seen in Fig. 24 both treatments led to a reduction of the biomass of the ground vegetation. However, the effect was predominantly concentrated on the aboveground biomass and the belowground biomass between 0 and 7.5 cm depth. Only in the manually treated *T. chrysantha* plots the biomass reduction in the category 7.5 - 15 cm of depth was higher than in the category 0 - 7.5 cm. In the chemically treated plots under this species the aboveground biomass of the ground vegetation was also higher than in the manually treated plots. The roots of both tree species were able to penetrate the root tomentum of the ground vegetation and to colonize the deeper soil even if their biomass proportion is still low. This effect can also be seen in Fig. 25 which shows the vertical and horizontal expansion of the tree roots. According to that also the manual treatment had an effect, especially on *T. chrysantha*

[3] The measurements and analyses were made in the context of the Master´s thesis of Thomas Eckert (2006) initiated and supervised by the author.

where rooting depth and width were significantly better on the treated plots compared to the control ($p<0.05$). If the mean height of the plants is considered, the extension of the root system is astonishing. E.g. with a mean height of 51 cm of *T. chrysantha* on the chemical plots the vertical extension of the root was already about 80 cm and the roots went 60 cm into the depth. However the total biomass of the trees did not show a significant reaction to the manual treatment, in contrast to that of the chemical treatment. It is interesting to see that the proportion of the tree biomass of the total plot biomass of the manual treatment increased from 0.9% (control), 3.5% (manual) to 26.5% for *T. chrysantha* and 1.0%, 1.1% and 16.4% respectively for *C. montana* although the biomass of the ground vegetation in the chemically treated plots was only slightly lower than in the manually treated (Fig. 24 and Table 26).

Table 25: Results of the analysis of variance for survival, total height and root collar diameter (RCD) of the tree seedlings subject to different treatment of the ground vegetation (significant values are presented in bold).

Source of variation	p-value		
	Survival	Total height	Root collar diameter
Block	0.9341	**0.0017**	**0.0000**
Species	**0.0290**	0.1424	**0.0023**
Treatment	0.6274	**0.0000**	**0.0000**
species * treatment	0.6274	0.1323	**0.0046**
Multiple comparisons (Tukey test)			
Block 1 vs. Block 2	0.980	**0.011**	0.000
Block 1 vs. Block 3	0.983	0.860	0.894
Block 2 vs. Block 3	0.928	**0.003**	**0.000**
Control vs. manual treatment	0.983	0.783	0.070
Control vs. chemical treatment	0.742	**0.000**	**0.000**
Manual vs. chemical treatment	0.634	**0.000**	**0.000**

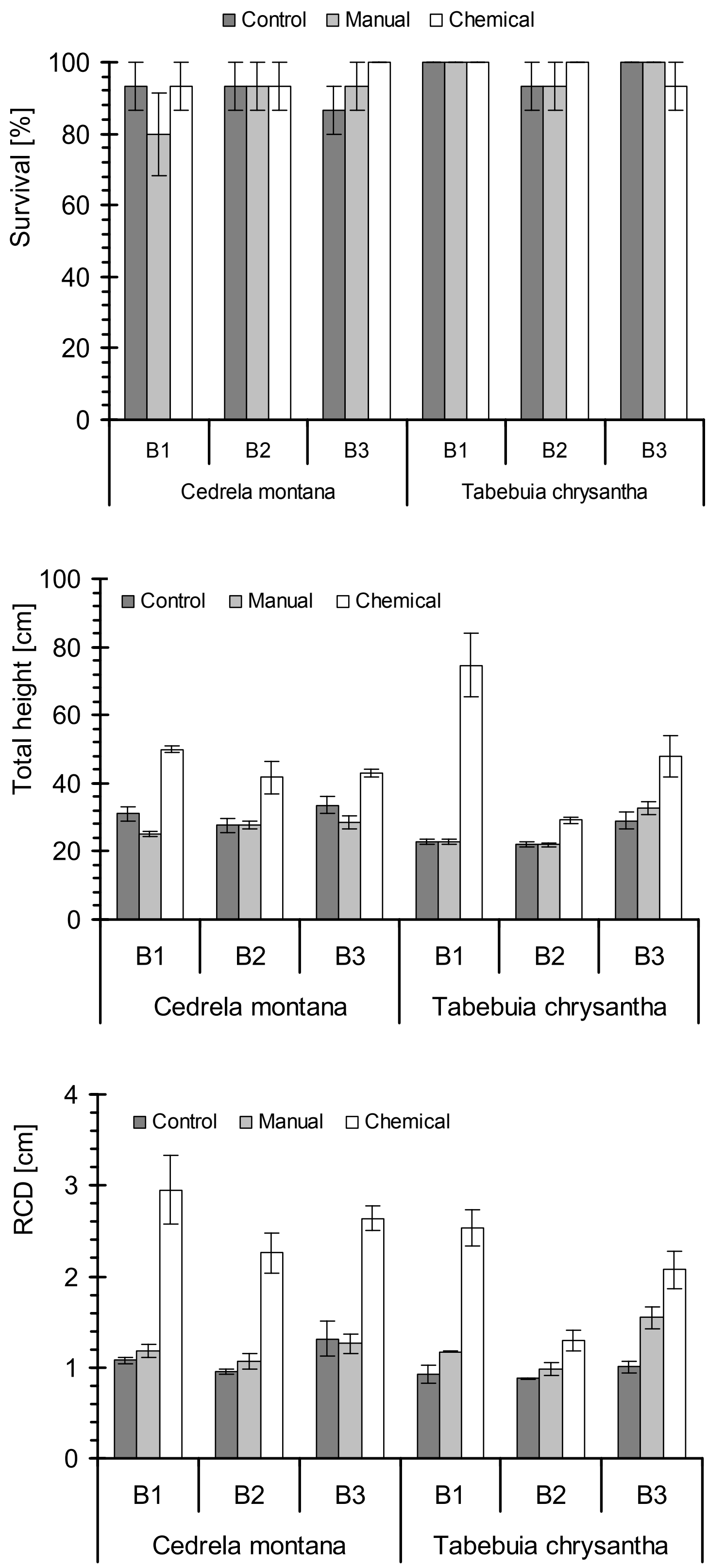


Figure 23: Means of survival, total height and root collar diameter (RCD) of *C. montana* and *T. chrysantha* subjected to different treatments of the ground vegetation and location within the experiment, 12 months after establishment of the herbicide experiment (B1 = block1 lower part of slope; B2 = block2 middle part of slope; B3 = block3 upper part of slope)

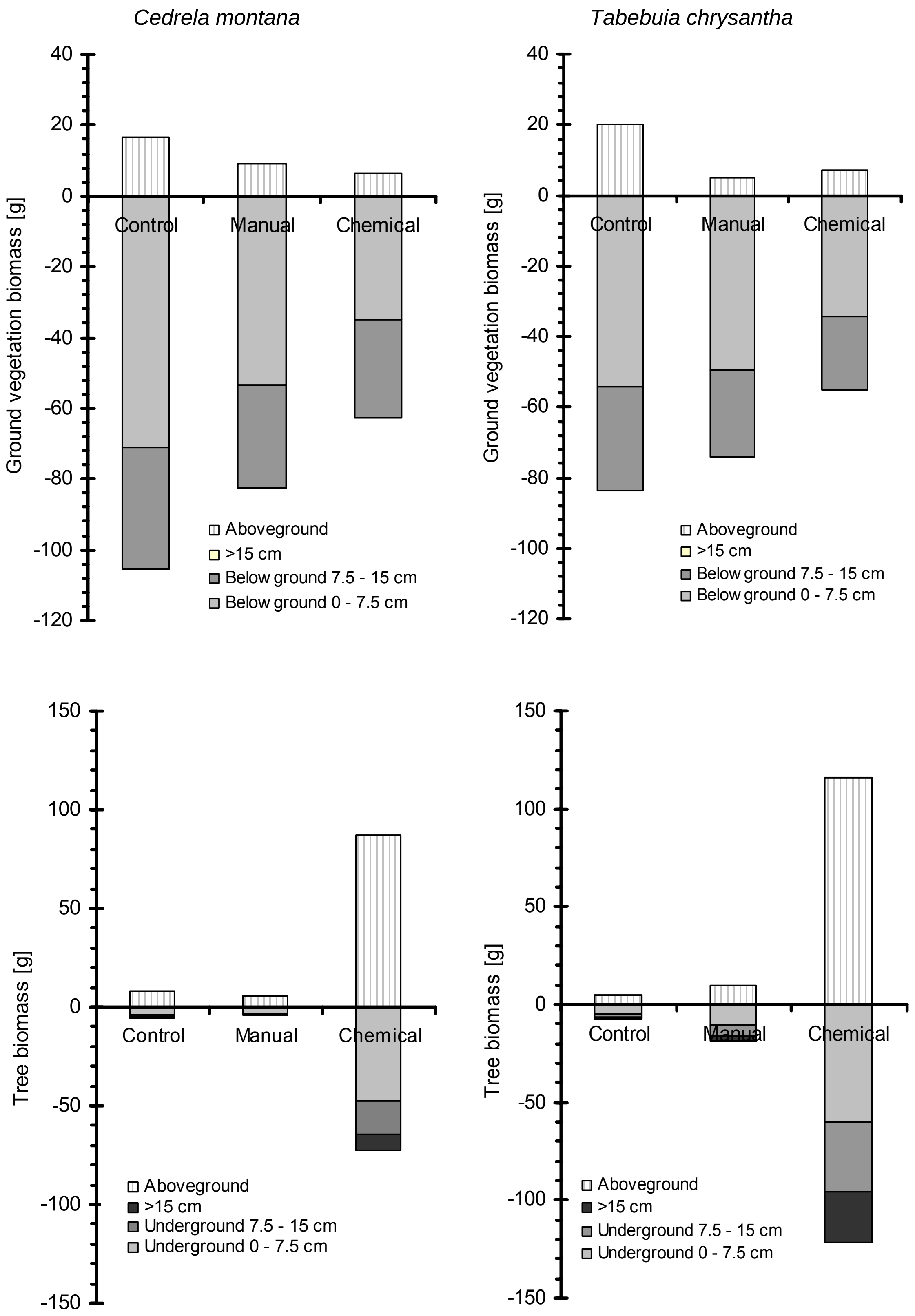


Figure 24: Total biomass of the ground vegetation (above) and the seedlings (below) related to soil depth.

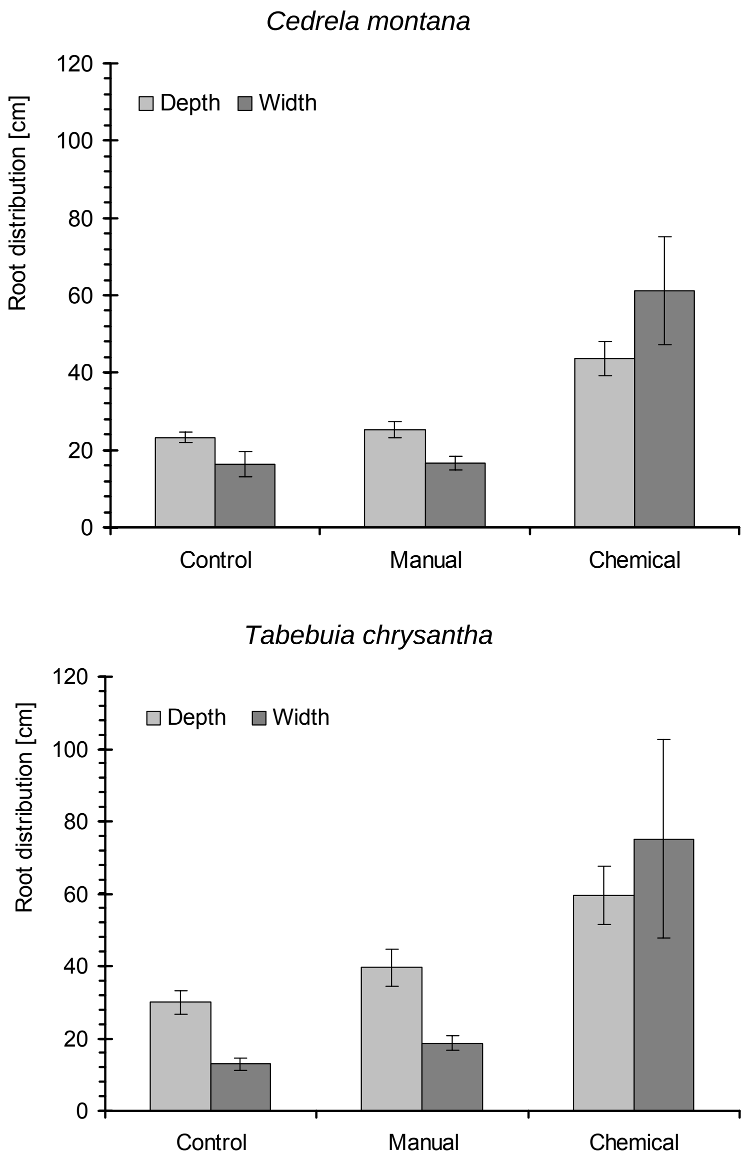


Figure 25: Vertical and horizontal distribution of the tree roots under different treatments (shown are means and standard error).

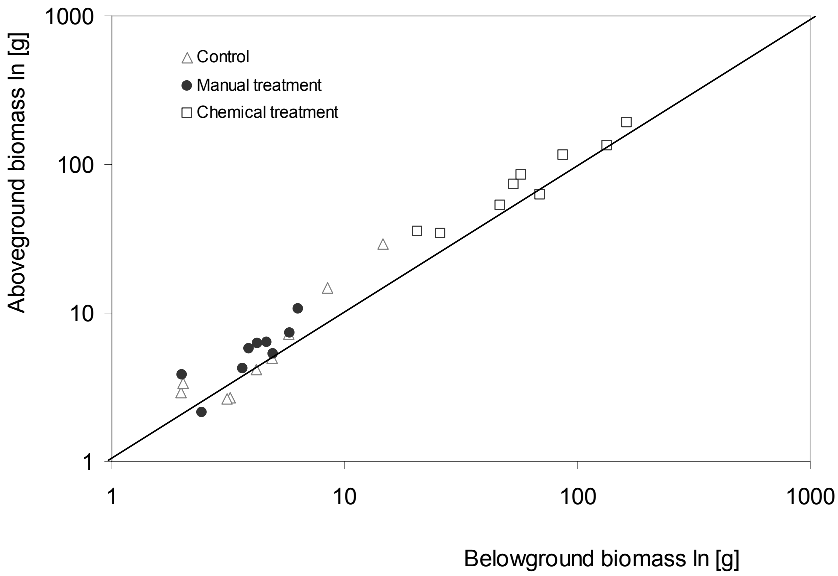
Table 26: Results of the analysis of variance for biomass of the ground vegetation and seedlings subjected to different treatments of the ground vegetation (significant values are presented in bold).

Source of variation	Ground vegetation				Seedlings				
	Above-ground	Underground			Above-ground	Underground			
		0 - 7.5 cm	7.5 –15 cm	Total		0 - 7.5 cm	7.5 –15 cm	> 15 cm	Total
Block	**0.001**	**0.023**	**0.019**	**0.029**	0.103	0.052	0.158	0.376	0.055
Treatment	**0.002**	**0.002**	**0.075**	0.050	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Species	0.294	0.266	0.183	0.150	0.826	0.114	**0.021**	0.107	**0.021**
Treatment * Species	0.172	0.697	0.997	0.902	0.586	0.133	0.229	0.636	0.086
Multiple Comparisons (Tukey test)									
Control vs. Manual	**0.004**	0.281	0.511	0.304	0.476	0.569	0.417	0.646	0.201
Control vs. Chemical	**0.003**	**0.002**	0.063	**0.004**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**
Manual vs. Chemical	0.955	**0.020**	0.350	0.056	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**

A very interesting effect of the behaviour of the two tree species and their reaction to the treatments can be identified when the relation of biomass allocation to above- and belowground biomass is regarded. In Fig. 26 it can be seen that in the control and manually treated plots, where the competition with the ground vegetation is considered to be more intensive compared to the chemical treatment, *C. montana* invested more into the aboveground biomass but *T. chrysantha* more into the roots. This is considered to be a species specific reaction to cope with competitive ground vegetation.

As can be seen in Table 27 the relation width/depth became bigger with the chemical treatment for both species. *C. montana* invested more in width of its roots and *T. chrysantha* in depth of its roots. In addition, for both species the volume could be increased significantly with the application of the chemical treatment (Table 28). *C. montana* showed better volume values in the control and manual treatment, while *T. chrysantha* had 200% more volume than *C. montana* on the chemical treatment, increasing the probability to have better availability of nutrients.

Cedrela montana



Tabebuia chrysantha

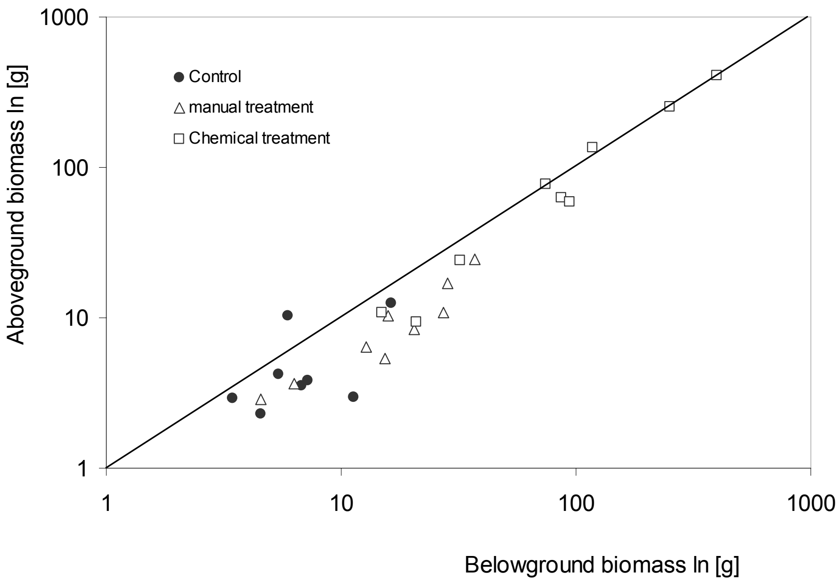


Figure 26: Biomass allocation of *C. montana* and *T. chrysantha* to above and belowground biomass after one year of planting subjected to three different treatments of the ground vegetation.

Table 27: Relation width/depth and volume of root system for two natives species (VC= variation coefficient; Volume = (π x r^2 x h)/3, where r= W/D and h= depth; n=9 seedlings).

Treatment	*Cedrela montana*				*Tabebuia chrysantha*			
	Width/Depth	VC (%)	Volume (dm^3)	VC (%)	Width/Depth	VC (%)	Volume (dm^3)	VC (%)
Control	0.66	52	0.34	110	0.45	40	0.11	109
Manual	0.67	23	0.23	81	0.49	20	0.20	58
Chemical	1.36	52	11.7	165	1.12	84	33.1	240

Table 28: Results of the analysis of variance for width/depth relation and volume of the tree seedlings (significant values are presented in bold)

Source of variation	P-value			
	Cedrela montana		*Tabebuia chrysantha*	
	W/D	Volume	W/D	Volume
Treatment	**0.000**	**0.000**	**0.027**	**0.006**
Control vs. Manual	0,999	0.982	0.985	0.087
Control vs. Chemical	**0.013**	**0.002**	**0.041**	**0.017**
Manual vs. Chemical	**0.013**	**0.001**	0.058	**0.024**

Besides the effects on the biomass the different treatments had also an effect on the structure and floristic composition of the ground vegetation. After one year in the plots without chemical treatment the floristic composition of the ground vegetation was still dominated by the pasture grasses *Setaria sphacelata* and *Melinis minutiflora*. Only at the chemical plots *S. sphacelata* was eliminated and substituted by native grasses and other plants (Fig. 29). In fact, vegetation height was reduced at the treated plots by >30% compared to the control plots but coverage was reduced only at the *T. chrysantha* plots (Table 27). Under *C. montana* coverage was even higher at the treated plots. While the statistical analysis did not reveal significant differences for the structural parameters height and cover of the ground vegetation (Table 30)

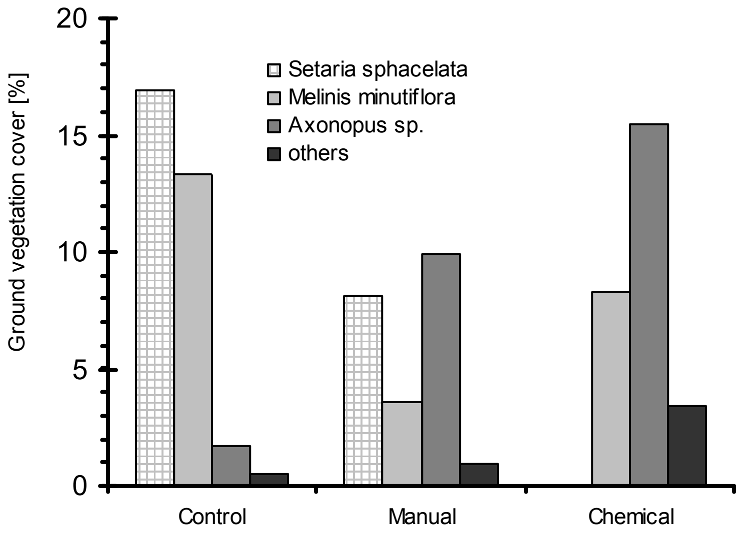


Figure 27: Proportion of the dominant species of the total cover subject to treatment

Table 29: Height, cover and floristic composition of the ground vegetation in the two species plots one year after treatment (Ss= *Setaria sphacelata*; Mn= *Melinis minutiflora*; Ac= Axonopus compressus; Ah= *Achyrochine halli*; Ds= *Drymaria stellarioides*; Pa= *Pteridium arachnoideum,* Bp= *Bidens pilosa*; An= *Andropogon sp*. Hl= *Holcus lanatus*, As= Asteraceae).

	Cedrela montana					*Tabebuia chrysantha*				
Treatment	Height (cm)	CV (%)	Cover (%)	CV (%)	Floristic composition	Height (cm)	CV (%)	Cover (%)	CV (%)	Floristic composition
Control	60.4	41	22	156	Ss, Mn	65.3	33	43	93	Ss, Mn, Ac, Pa
Manual	39.6	70	24	96	Ss, Mn, Ac, Ds, Pa	31.3	29	21	114	Ss, Mn, Ac, Ah, Ds, Bp
Chemical	27.9	49	29	105	Mn, Ac, Ah, Ds, Bp, As	31.9	36	26	110	Mn, Ac, Ah, An, Hl, As

Table 30: Result of the analysis of variance for height and cover of the ground vegetation (significant values are presented in bold).

source of variation	p- value	
	Structure	
	height	Cover
Block	0.413	0.183
Treatment	0.136	0.704
Species	0.496	0.965
Treatment * Species	0.143	0.667

In some treatments the total biomass of the ground vegetation was closely related to the height of trees. In Fig. 28 the regression functions of the significant correlations are shown. Table 31 present all equations.

Table 31: Regressions for the estimation of total biomass for *C. montana* and *T. chrysantha* (x= height in cm, y= biomass in g; significant values are presented in bold; n= 9 seedlings per species and treatment).

Species	Treatment	Model	R2	p-value
Cedrela montana	Control	y = 60,651Ln(x) - 199,79	**0.50**	**0.040**
	Manual	y = 7,3478Ln(x) - 14,784	0.07	0.465
	Chemical	y = 471,63Ln(x) - 1670,5	**0.68**	**0.003**
Tabebuia chrysantha	Control	y = 18,01Ln(x) - 46,786	0.26	0.223
	Manual	y = 74,78Ln(x) - 220,45	**0.63**	**0.017**
	Chemical	y = 493,43Ln(x) - 1703,3	**0.77**	**0.000**

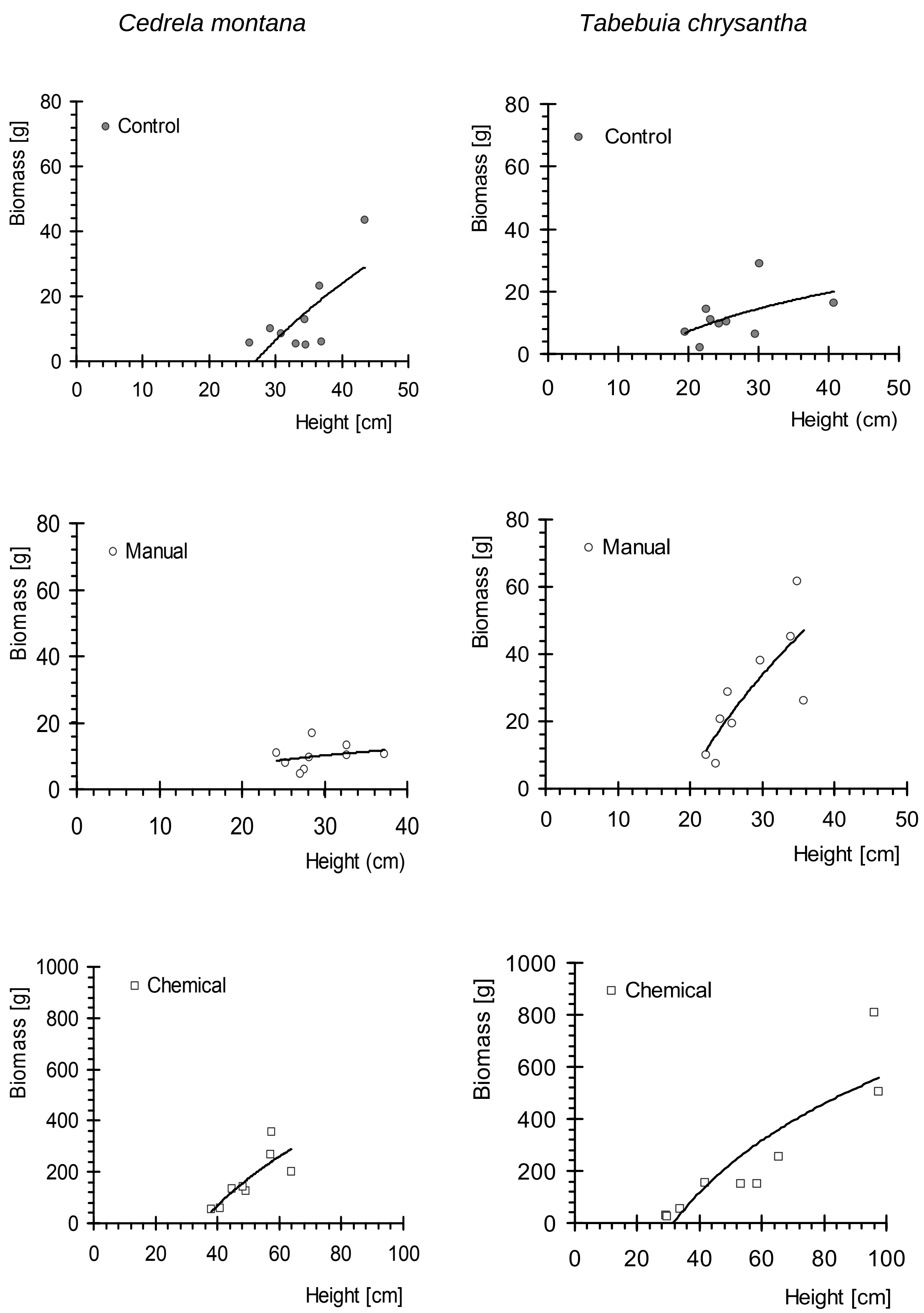


Figure 28: Relationship between total height of the trees and total biomass for the two native species one year after planting (the graphs have different scales, n= 9 seedlings).

Table 32 shows the results of the analysis of the foliar nutrients concentrations of the seedlings. The analysis of variance did not reveal any significant effects regarding species or treatment on the nutritional status. However for both species a clear decrease of the phosphorus could be registered from control to chemical treatment. This dilution can be an effect of the higher biomass production under the chemical treatment. For the subsequent analysis in the next years attention shall be given to this aspect.

Table 32: Mean foliar nutrients concentrations for 2 natural tree species after one year of plantation.

Species	Treatment	N	C (%)	N (%)	K (µg/g)	Ca (µg/g)	Mg (µg/g)	P (µg/g)	S (µg/g)	C/N
Tabebuia chrysantha	Control	5	44.6	1.63	15028	8726	3865	2272	1489	27.34
	Manual	5	44.7	1.47	8596	12281	4912	1762	1371	30.40
	Chemical	5	44.5	1.57	10331	12680	4660	1455	1604	28.33
Cedrela montana	Control	4	43.2	2.44	12978	20543	5650	4010	1932	17.71
	Manual	3	46.3	1.64	10465	12990	2889	2336	1606	28.26
	Chemical	8	46.6	1.75	9847	14326	3490	1959	1439	26.65

4.3. Enrichment Experiment

During the last years several studies emphasising the potential of exotic plantations to promote reforestation of degraded and abandoned land have been published (e.g., Fimbel & Fimbel 1996, Lugo 1997, Parrotta et al. 1997, Feyera et al. 2002a). Sometimes exotics like pines or eucalypts are better suited to cope with the harsh conditions on such land than many native species. Consecutively, the natural regeneration of native species can establish and develop under their shelter enabling forest managers to transform the plantations into more natural ecosystems with native commercial trees in a medium term. Therefore, we also monitored the development of seedlings of native species planted under the shelter and in gaps of a pine plantation.

Table 33 provides an overview on the environmental characteristics at the two stand structures. As can be seen the gap and the closed canopy plots differ only in regard to canopy cover and slope. All other site parameters did not show significant differences ($p>0.05$).

Table 33: Mean characteristics of the plots in the gaps and under the canopy (different letters represent significant differences at $p<0.05$).

Variables	Gap		Closed canopy		Sig.
	mean	CV (%)	mean	CV (%)	
cover	10.5	52.4	22.1	34.8	b
slope	57	64.9	44	40.9	b
altitude	2073	0.7	2057	0.7	a
Sand (%)	56.5	100.0	47.0	22.3	a
Silt (%)	31.5	13.0	41.5	18.6	a
Clay (%)	12.0	40.8	11.5	49.6	a
pH	4.43	6.8	4.44	13.5	a
MO (%)	10.4	9.6	9.0	13.3	a
N	130.3	10.2	116.5	11.9	a
P_2O_5 (ug/ml)	2.9	21.0	5.4	38.5	a
K_2O (ug/ml)	41.5	47.7	44.8	51.2	a

Two years after planting the overall survival was not significantly different among the micro-sites (p= 0.537, Table 34). However, surprisingly survival of the light demanding species was better under the closed canopy (except *A. acuminata* and *P. discolor*) while that of the shade tolerant *C. montana* and *C. officinalis* was better in the gaps (Fig. 29). *C. officinalis* experienced high mortality under both conditions.

One of the interesting aspects is that in the gaps no mortality at all could be observed within the first 6 months, while under the canopy *P. discolor*, *C. officinalis* and *H. americanus* experienced already losses of 11 %, 19 %, resp. 3 % during this time. Mortality continued constantly until the end of the observation period. In the gaps the highest mortality appeared between month 6 and month 12. Subsequently survival remained almost stable in the gaps, except *I. laevis*. When the survival in this enrichment planting is compared to that in the reforestation experiment the situation in the gaps was superior to the corresponding seedlings at all three successional sites.

With regard to the development of the height and root collar diameter of the species it is obvious that both parameters were better in the gaps. Especially *A. acuminata* and *P. discolor* showed excellent growth and reached already mean heights of 234 cm and 165 cm respectively, which is more than 2.5 times that of the plants under the canopy and 1.6 times of that in the reforestation experiment.

Looking at the height/RCD ratio (Table 35) it is interesting that many species had higher values under the canopy. Only *C. cf americana* and *C. montana* had clearly higher values in the gap. These species had a very low increment in RCD compared to the canopy. *T. chrysantha* has also a slightly increased ratio under the canopy but its RCD increment of 1.1 cm was similar to that of the light demanding species. These results are consistent with the findings in the herbicide experiment that under competition *C. montana* invests more into aboveground biomass and *T. chrysantha* more into the roots.

Table 34: Summary of analysis of variance for survival, total height and root collar diameter (RCD) after two years (significant values are presented in bold).

Source of variation	p-value		
	Survival	Total height	RCD
Micro-site	0.537	**0.000**	**0.000**
species	**0.000**	**0.000**	**0.000**
Micro-site * species	**0.010**	0.070	**0.001**

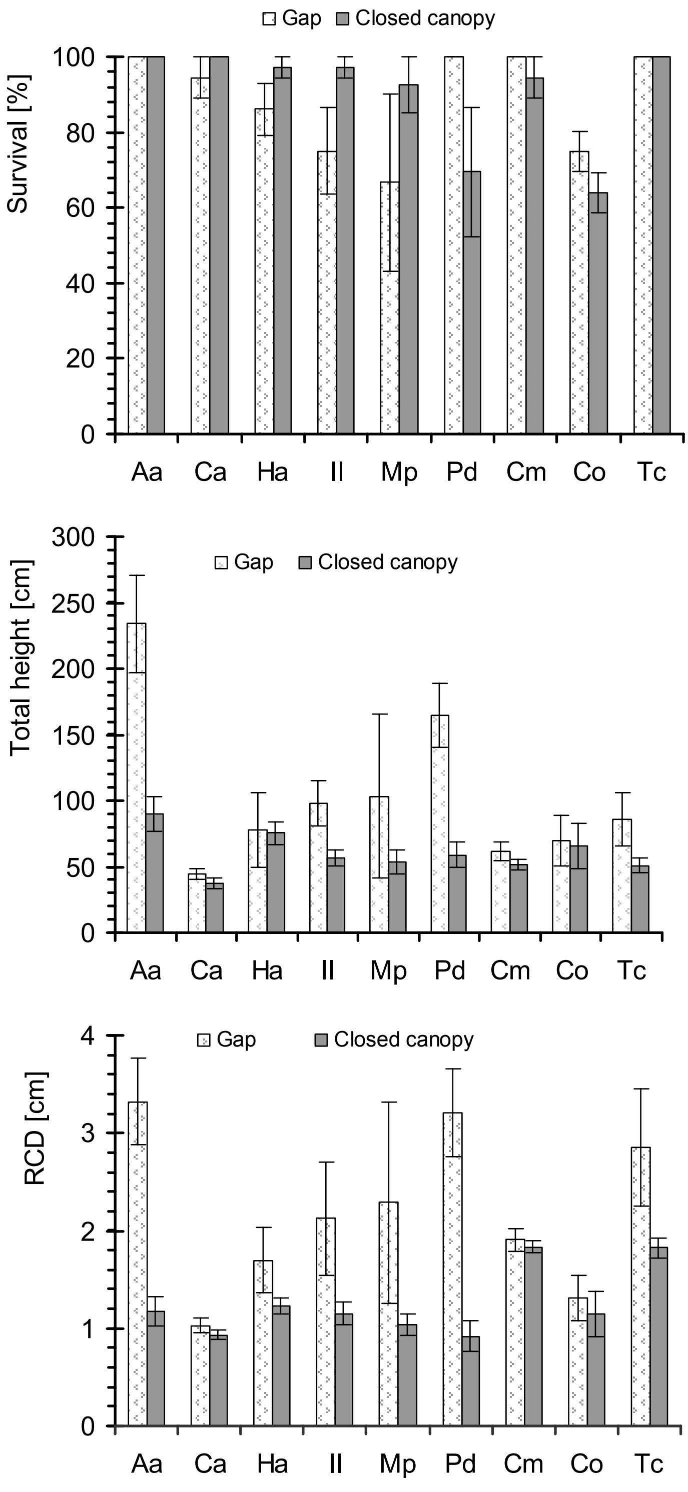
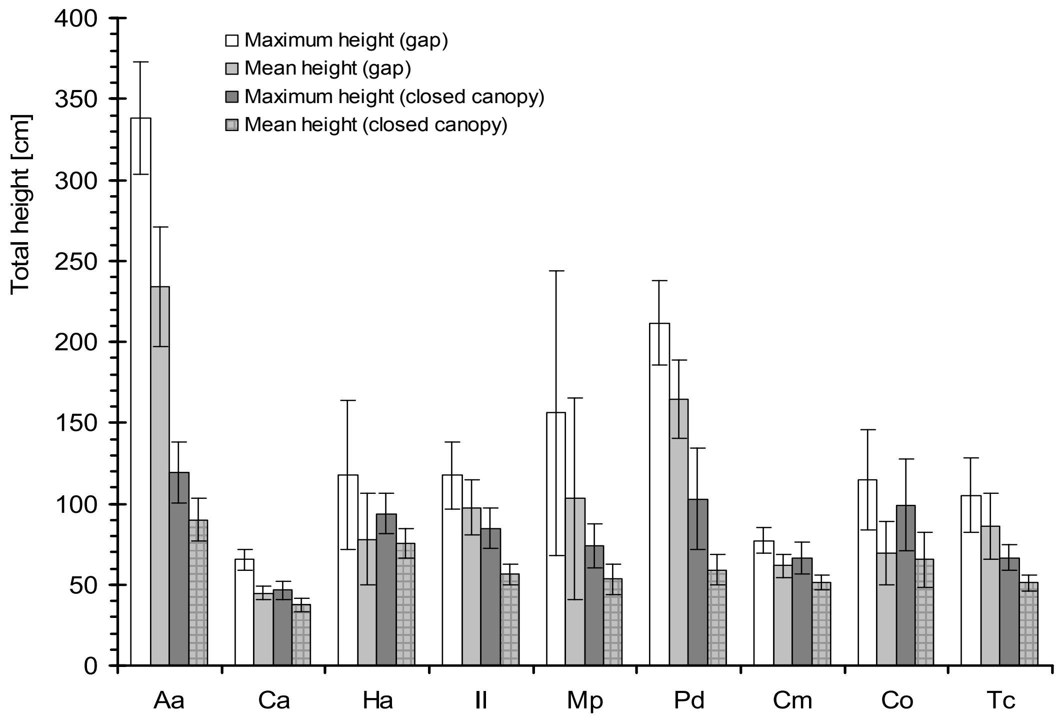


Figure 29: Means of survival, total height and root collar diameter (RCD) for nine native tree species at different micro-site conditions two years after planting (shown are means and standard error. Aa= *Alnus acuminata*, Ca= *Cupania cf americana* Ha= *Heliocarpus americanus*, Il= *Isertia laevis*, Mp= *Myrica pubescens*, Pd= *Piptocoma discolor*, Cm= *Cedrela montana*, Co= *Cinchona officinalis*, Tc= *Tabebuia chrysantha*).

Table 35: Mean and maximum Height/RCD ratio for nine native species two years after planting (VC = variation coefficient)

Species	Mean				Maximum			
	Gaps		Canopy		Gaps		Canopy	
	H/RCD	VC (%)	H/RCD	VC (%)	H/RCD	VC (%)	H/RCD	VC (%)
Alnus acuminata	70,0	8	75,8	6	73,3	10	73,1	16
Cupania cf americana	43,3	11	39,9	15	50,3	7	42,2	24
Heliocrapus americanus	42,2	32	60,6	13	48,8	32	59,8	17
Isertia laevis	49,1	21	48,9	7	47,1	32	52,0	13
Myrica pubsescens	41,3	30	51,8	33	53,8	14	50,7	47
Piptocoma discolor	51,2	15	64,6	11	50,7	18	68,7	20
Cedrela montana	32,5	23	28,0	11	30,7	22	26,7	15
Cinchona officinalis	51,9	28	55,8	27	61,1	15	63,2	55
Tabebuia chrysantha	29,7	10	27,7	10	31,7	12	30,9	10

In Ecuador the common spacing in plantations is 3 x 3 m corresponding to about 1.100 plants per hectare. Consequently, from the view of a forest practitioner it was sufficient to just focus on the dominant trees per plot. Therefore, in Fig. 30 the maximum height and RCD of the highest plant per each plot is presented. As can be seen all species except *C. cf americana* and *C. montana* have already more than 1 meter of height and the highest trees are already more than 3 m tall. For most species also the relation between the height in the gap and under the canopy increased. Only for *I. laevis* and *T. chrysantha* the relation decreased slightly. In addition, the variation of the growth parameters under the canopy was clearly lower compared to the gap. Thus under the canopy the growth was more homogenous.



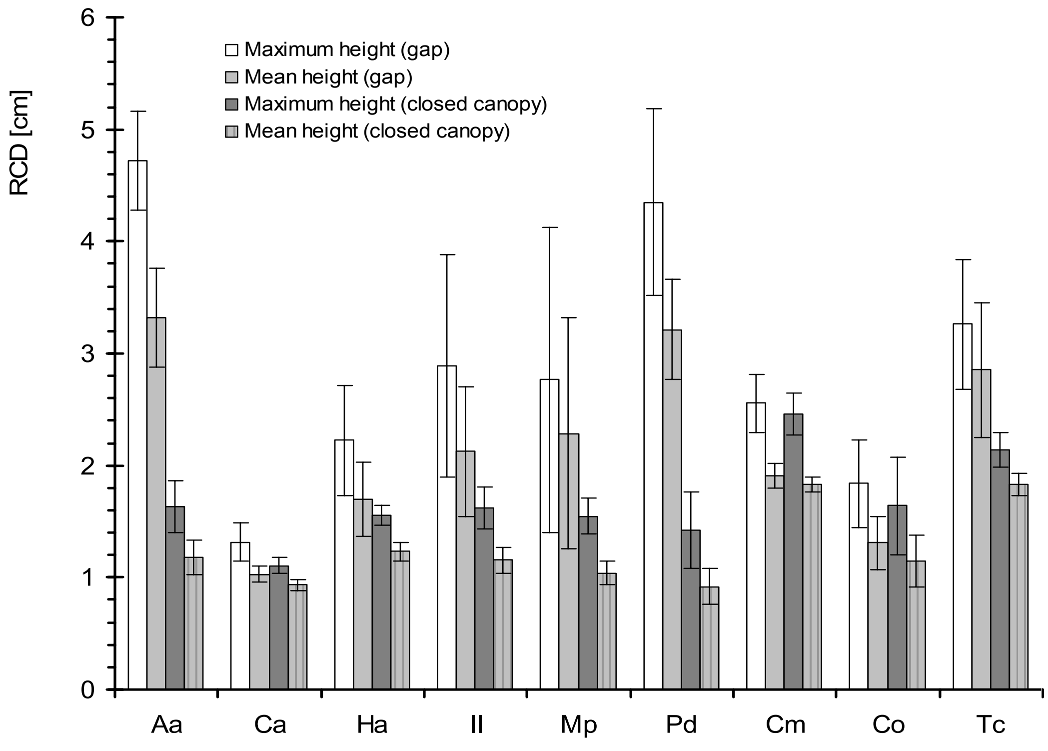


Figure 30: Maximum and mean growth in height and RCD of seedlings two years after planting in the gap and under the closed canopy (Aa= *Alnus acuminata*, Cm= *Cedrela montana*, Co= *Cinchona officinalis*, Ca= *Cupania cf americana*, Ha= *Heliocarpus americanus*, Il= *Isertia laevis*, Mp= *Myrica pubescens*, Pd= *Piptocoma discolor*, Tc=*Tabebuia chrysantha).*

Beside the growth parameters the surviving seedlings of all species showed also a better health status in the gap (Table 36). This is not only true for the light demanding but also for the shade tolerant species, e.g. the shade tolerant *C. montana* obviously preferred the gap condition because under the canopy 25 % of the plants were of poor health. Only *P. discolor* had an even higher share (32%) of plants in category c.

Table 36: Quality of the surviving individuals 24 months after planting (n= number of seedlings; a= excellent, b= healthy saplings, c= saplings of poor quality and with presence of damage).

Species	Quality/health status (%)							
	Gap				Closed canopy			
	n	a	b	C	n	a	b	c
Alnus acuminata	*36*	50	50	0	36	0	94	6
Cupania cf americana	*31*	23	77	0	36	0	100	0
Heliocarpus americanus	*31*	16	65	19	35	3	89	9
Isertia laevis	*28*	43	57	0	35	6	91	3
Myrica pubescens	*25*	75	8	17	25	0	100	0
Piptocoma discolor	*36*	83	14	3	25	4	64	32
Cedrela montana	*36*	83	17	0	36	72	3	25
Cinchona officinalis	*27*	4	96	0	23	9	74	17
Tabebuia chrysantha	*36*	97	3	0	36	69	28	3
Total	286	53	43	4	287	18	71	10

As presented in Table 33 significant differences between the micro-site conditions in the gap and closed canopy plot could only be observed for cover and slope. However, to identify effects of the soil and environmental conditions, we computed the Pearson correlation coefficients for all site factors and height and RCD. The results are present in Table 37. For the canopy plots no significant correlations could be found. At the gap plots significant positive correlations could be revealed for cover and slope with height and RCD. The shape of land was negatively correlated with RCD where it had better values on more flat land.

Table 37: Pearson correlations (R) between selected soil/environmental factors and height and root collar diameter (RCD) increment at two stand conditions for all species (significant values are presented in bold).

Variable	Gap				Canopy			
	Height		RCD		Height		RCD	
	R	sig.	R	sig.	R	sig.	R	sig.
Cover	**0,36**	**0,031**	**0,40**	**0,019**	0,07	0,697	0,26	0,134
Shape of land	-0,32	0,059	**-0,46**	**0,006**	-0,10	0,576	0,01	0,973
Slope	**0,39**	**0,020**	**0,50**	**0,002**	0,10	0,571	0,28	0,103
Shape of slope	0,25	0,147	0,30	0,078	-0,05	0,760	-0,22	0,202
Altitude	-0,16	0,349	0,01	0,952	-0,13	0,444	-0,23	0,194
Clay	-0,18	0,293	-0,19	0,268	0,17	0,335	0,02	0,906
Sand	0,18	0,290	0,18	0,306	-0,12	0,475	0,06	0,713
Silt	-0,10	0,585	-0,07	0,673	0,04	0,799	-0,11	0,546
pH	-0,12	0,479	-0,11	0,540	0,10	0,560	0,04	0,815
MO	-0,23	0,190	-0,30	0,076	0,00	0,991	0,08	0,649
N	-0,24	0,169	-0,32	0,065	0,06	0,739	0,11	0,545
P2O5	-0,03	0,852	-0,04	0,807	0,03	0,882	0,12	0,486
K2O	-0,03	0,885	-0,04	0,835	0,08	0,639	0,03	0,887

5. Discussion

5.1. Methodology

5.1.1. Studies on the reforestation of abandoned land

During the last two decades many attempts have been made to enhance the experiences concerning the silvicultural possibilities for the reforestation of degraded land in the tropics. These attempts include different strategies like natural regeneration, reforestation, ecological restoration and agroforestry systems (e.g. Lugo 1992, Montagnini 1992, 2001, Aide & Cavalier 1994, Brown & Lugo 1994, Zimmerman et al. 2000, Lamb et al. 2005, Weber et al. in press). While the earlier efforts were more directed towards plantations with valuable timber species during the last decades so called ´unproductive environment rehabilitation´ approaches have been extended, considering not only the economic contributions of the activities, but also the ´values´ of recovering of biodiversity and provision of environmental services (Evans & Turnbull 2004).

Natural regeneration processes have been studied widely, mainly to explore the potentialities of different degraded environments to rebuild forest ecosystems without external silvicultural intervention (e.g. Brown & Lugo 1990, Nepstad et al. 1990, Finegan & Delgado 2000, Guariguata & Ostertag 2001, Günter et al. 2007).

Investigations concerning active reforestation measures concentrated mainly on the identification of species suitable for the reforestation of degraded land, the evaluation of their productivity in terms of biomass production, the generation of ´technological packages´ for species of commercial value and only recently also towards the provision of environmental services (e.g. Montagnini 1992, Parrotta 1992, Cavalier 1995, Murcia 1997, Davidson et al. 1998).

Studies on ecological restoration were mostly dedicated to the generation of information on the floristics and ecology of the original ecosystems, the sequential patterns of the regeneration of different species or of ecosystem aspects including the fauna. Other objectives were the identification of the barriers and causes that stop or hamper the natural processes of succession as well as the strategies to rehabilitate the protective and productive functions of the ecosystems (e.g. Aide & Cavalier 1994, Rhoades et al. 1998, Holl et al. 2000, Posada et al. 2000).

Recently, agroforestry systems have gained special attention as a strategy for the rehabilitation of degraded land and the integration of forestry and agricultural land uses by introducing arboreal elements into agricultural production systems (e.g. Evans & Turnbull 2004, Lamb et al. 2005, Montagnini et al. 2006).

In spite of all these efforts and the achieved progresses, reforestation in the tropics, and this is even more true for mountainous areas, is still considered to be of minor economic importance compared to any other land use system. Being relegated to degraded sites where the biological, physical and chemical properties of the soil are considerably reduced (Barrow 1991, Stocking & Murnaghan 2000) reforestation activities represent complicated processes that face multiple difficulties during its implementation (Verzino et al. 2004). Especially when large scale reforestation projects are considered, its success is also influenced by the fact that degraded areas are very often not homogeneous but constitute of a mosaic of different sites: from intensively degraded soils to still more or less productive areas, patches with relict of the former uses (e.g. pasture grasses), patches with forest remnants, or secondary vegetation. Besides these biological factors, reforestation strategies at a regional or national scale must also to take into account socio-economic factors. For instance, small landholders or farmers are usually not able to cover high initial costs for plantations or to invest very much time for its maintenance and tendance.

The results presented in this study report the initial performance of the established plantations during the first two years. However, the design of the experiment and the size of the planted area allow to monitor the development on a medium term (10 to 15 years). The experimental area of more than 12 hectares includes all typical types of abandoned land in the San Francisco valley and can also be regarded to be representative for the situation in the whole study area. In contrast to other studies, e.g. Fehse et al. 2002 who investigated the potential of *Alnus acuminata* for C-sequestration or Otsamo et al. 1997 who tested the early growth potential of tree species for further experiments, the species selected for this study comprise a wide variety of characteristics: natives and exotics, different life strategies (light demanding, shade tolerant), potential uses (timber production, provision of non-timber forest products, site rehabilitation). This permits an integrative evaluation of their capability to cope with the environmental conditions at different sites as well as of their potential to meet the demands of the landholders. The experiment allows also a direct comparison of the seedlings performance between the native and the exotic species but also between mixed and pure plantations under three successional site conditions

Although forest plantations in the Ecuadorian Sierra have been generally established with a spacing of 3 x 3 m (van Voss et al. 2001) in our study we chose a spacing of 1.8 x 1.8 m which coincides with that of most experimental studies (e.g. Davidson et al. 1998, Foroughbakhch et al. 2001, 2006, Aguirre et al. 2002b). This allowed a reduction of the plot size and thus to obtain more homogenous conditions within the plots, because the extreme variations in the site conditions in the study area were already described by Beck et al. (in press).

Another aspect was that canopy cover and canopy density are considered to be the most important factors for encouraging soil stabilization and vegetation recruitment in the understorey (Montagnini & Sancho, 1990, Fisher 1995, Jones et al. 2004). The closer spacing will result in earlier crown closure and thus also intensify the competition between the trees and the ground vegetation as well as the expected interactions among the different tree species in the mixed plots.

The common practice in most of the reforestation experiments is to replace dead seedlings during the first six months after planting. However, in our study this could not be practiced as no adequate seedlings were available. Because most species could not be obtained from local nurseries we were completely reliant on the seedlings produced in the project nursery. However, from the planting only few surplus seedlings were left. Another common practice in plantation establishment is the application of herbicides before or of fertilizers at or shortly after planting (Shepherd 1986, Arriaga et al. 1994, Ruiz 2002, Wishnie et al. 2007). In the reforestation and the enrichment experiment we did neither use herbicides nor fertilizers as our objective was to analyse the natural potentials of the species. However, the effects of a chemical treatment of the ground vegetation on the seedlings performance have been investigated in the herbicide experiment which was additionally established at a smaller scale.

Actually, the established trials represent one of the bigger and most complex experiments in the Sierra of Ecuador. Due to its size and design with 3 sites, 2 treatments, 9 species and 8 repetitions (with a total of 432 degrees of freedom) we presume that the results do adequately characterize the fundamental behaviour of the different species behaviour under the given conditions.

5.1.2. Seedlings production

One of the most common difficulties faced in studies interested in the potential of local native tropical forest species for afforestation is the non-availability of forest reproductive material i.e. seedlings with similar physiognomic and genetic characteristics in terms of age, size, and adequate origin of the seeds. This fact is mainly due to the high species specific variation in the reproductive and ecological cycles (Duryea & Landis 1984). As several studies in the ECSF area and its bigger surrounding revealed the flowering and fruiting of individuals from the same species can vary by several months within a very small area in relation to altitude and climatic patterns (Cabrera & Ordoñez 2004, Diaz & Lojan 2004, Günter et al. 2004, Bendix et al. 2006b, Cueva et al. 2006). Another problem is the low abundance of individuals of the same species in the highly diverse natural forests which also limits the number of seeds that can be harvested.

In our study all seedlings were propagated in the project nursery from seeds, using similar substrates. With the exception of *A. acuminata* and *J. neotropica*, all seeds were collected from five trees of each species in the forest of the ECSF: These trees have already been selected and described in the context of several diploma theses conducted within the project (e.g. Cabrera & Ordoñez 2004, Diaz & Lojan 2004, Jara & Romero 2005). Although the seed sources were located within a maximum distance of 5 km to the experimental sites the fruiting, respectively the time of seed harvesting differed among the species. This resulted in different ages of the seedlings at time of planting. For example fruits of *T. chrysantha* were harvested between December and January whereas those of *H. americanus* were collected between May and October (Cabrera & Ordoñez 2004). With regard to the size of the seedlings at the leaving of the nursery the differences in age were partially compensated by the different growth behaviour linked with the corresponding life strategy of the species. For example *T. chrysantha* (shade tolerant species) required nearly one year to reach the required size for plantation, whereas *H. americanus* (light demanding species) needed only six months. A covariance analysis applied did not reveal any significant effect of the initial height at planting on the seedlings performance.

Similar to the reforestation experiment no herbicides or fertilizers were used in the nursery. A detailed description of the nursery and the conditions for seedling production is given in Leischner (2005).

5.2. Results

5.2.1. Obstacles for reforestation in abandoned pastures.

As described in many studies in the tropics there exists a huge amount of abandoned pastures that could be used for reforestation purposes (e.g. Aide & Cavalier 1994, Rhoades et al. 1998, Aide 2000). Consequently, the situation presented in chapter 2.2.4 is not only typical for Southern Ecuador but for many other regions as well. Also the problems related with the reforestation of such type of land are quite similar. Likewise our study area, abandoned land in other regions is also very often dominated by exotic pasture grasses such as *Setaria sphacelata*, or ferns like *Pteridium* (e.g. Rhoades et al.

1998, Ross 2004, Slocum et al. 2006). As has been revealed in several studies the most important barriers impeding the restoration of tropical montane forests on degraded pastures can be summarized as follows:

- The amount and intensity of light. Rhoades et al. (1998) showed in the North-West of Ecuador that some species are incapable to tolerate high temperatures or radiation. They registered mortality of 100% for seedlings planted in open pasture.
- Soil moisture content. For instance Martinez et al. (2002) found that height growth of seedlings of several *Pine* species were severely affected by soil moisture deficits.
- Absence of mycorrhizas. Many species depend on mycorrhizas as they represent an extension of their root system and enhance the assimilation of nutrients, especially of phosphorus (Smith & Read 1997, Kottke & Haug 2004, Ramos-Zapata & Guadamarra 2004). According to Carpenter et al. (2004) most native species need a specific type of mycorrhiza to survive in the field.
- Damages by herbivores (Hendrix & Marquis 1983, Gerhardt 1993, Holl & Quiros-Nietzen 1999).
- Strong root competition between the ground vegetation and the seedlings (Nepstad 1989, Hooper et al. 2002).
- Adverse soil characteristics like flat soils, high rock content, soil compaction and unsuitable soil structure (proportion of clay, silt and sand) (Aide & Cavalier 1994, Aide et al. 1995, Rhoades & Coleman 1999).

In the meantime there exist several studies that investigated the possibilities to overcome these problems by employing native species that are expected to be adapted to the local conditions (e.g. Lamb 1998, Pedraza & Williams-Linera 2003, Alice et al. 2004). Nevertheless, except some few examples to date reforestation activities are still nearly exclusively based on exotics. Currently more than 80% of the plantations in the tropics are with exotic species of the genus *Pinus, Eucalyptus* and *Tectona grandis* (Evans & Turnbull 2004).

5.2.2. Natural regeneration of abandoned pastures

The natural regeneration is the most ´simple´ but also most time consuming way to regain a satisfying forest cover on abandoned pastures. The natural regeneration depends mainly on seed production and dispersal, soil and light conditions, genetic factors, and climatic factors (Kumar 1996). However, it is well documented that the natural regeneration of degraded land is limited due to adverse physical factors such as extreme temperatures, high insolation, seasonal drought, and deficiencies in soil nutrients. As already mentioned in the previous chapter biological disruptive factors are especially insufficient seed dispersal, excessive seed and seedlings predation, absence of arbuscular mycorrhizas and excessive root competition with ground vegetation (Nepstad et al. 1990, Aide & Cavalier 1994, Parrotta et al. 1997, Holl 2002). Wadsworth (2000) stated that, apart from the time needed for succession, secondary forests originating from natural regeneration of degraded tropical land contain only few trees with interesting commercial values.

In the study at hand the natural regeneration analysed at the different successional sites revealed clear relations to the site conditions. For instance, at the pasture and fern site not enough natural regeneration of tree species to achieve a satisfying forest stand could be found. At the shrub site the recruitment of seedlings was in fact plenteous, but the abundance of valuable species was insufficient. These findings are in line with the results of Günter et al. (2007) who analysed the natural succession of a secondary forest close to the ECSF 38 years after abandonment of the former pasture. They also registered insufficient numbers of valuable forest species. Apart from that the secondary forests can of course provide valuable contributions to the protection of the site and the improvement of biodiversity. However, from the view of a forest manager they are not acceptable.

Nevertheless, before going to start cost intensive planting the potential of the corresponding sites to recover naturally should be closely evaluated. In many cases the proportion of valuable species in a secondary can also be enhanced by enrichment planting as far as the species composition and the site conditions are adequate (Parrotta et al 1997, Lamb 1998, Gomez-Aparicio et al 2004, Martínez-Garza 2005).

5.2.3. Performance of the native species tested in the reforestation experiment

With the exception of *A. acuminata* that has been studied in Colombia (e.g. Del Valle 1988, Murcia 1997), Costa Rica (e.g. Russo 1990), and Ecuador (e.g. Dunn et al. 1990, Añazco 1996, Aguirre et al. 2002b, Fehse et al. 2002), *H. americanus* in Ecuador (Davidson et al. 1998), and *T. chrysantha* in Indonesia (Otsamo et al. 1997) no studies were found for all other tested species concerning their potential for reforestation of abandoned pastures under similar environmental conditions in Ecuador. Therefore, to be able to discuss and integrate the results concerning the behaviour of the several species in a broader context in the following paragraphs very often reference will be made to experiences with other species of the same genus.

A. acuminata has the reputation to have a good ability to adapt to and grow well at an ample range of environmental conditions (Dunn et al. 1990, Lamprecht 1990, Añazco 1996, Fournier 2002). However, in our study we registered a survival of only 58 %. An even lower survival of 30% has been reported by Aguirre et al. (2002b) for experimental reforestations in ecosystems over 3400 m a.s.l. in the North of Ecuador. These low rates of survival were related to the water availability and soil compaction. At a humid site without soil compaction near Oyacachi, Ecuador, at 2000 m elevation Fehse et al. (2002) registered very high colonization rates of *A. acuminata* (>20.000 individuals per hectare) within the first two years after a natural landslide. Apart from the relatively high mortality the surviving seedlings of *A. acuminata* in our study exhibited an excellent performance. They showed the best growth which was only surpassed by the seedlings of *P. patula.* This is in line with the results of Carpenter et al. (2004) and Murcia (1997). They considered *A. acuminata* as a good option, especially for the reforestation of poor soils due to its ability to fix nitrogen. Likewise Fehse et al. (2002) considered it a suitable catalyst species for tropical forest regeneration in high altitude forests.

The light demanding species ***H. americanus*** was expected to have a good adaptability to the conditions at the reforestation plots, especially at the pasture. In reforestations on abandoned land in the Amazonian region of Ecuador *Heliocarpus* showed high survival rates (90%) and excellent growth in height (1 meter per year) (Davidson et al. 1998). However, those sites were at a lower altitude (1300 m a.s.l.), more humid (3000 mm/year), and warmer (mean temperature 22°C). In our study the behaviour of this species was disappointing with a survival of 53% and low growth performance. The author concludes that this species has clear preferences for certain micro-sites (niches). For instance in the three plots with drainage problems the seedlings experienced a mortality of 100 %. Also the nitrogen availability could be a reason for the bad performance. For instance, Rhoades et al. (1998) report that the nitrogen availability within pastures with *Setaria sphacelata* was reduced by 20% compared to the soil of natural montane forest. This conclusion is supported by the fact that in our study at one plot with a comparatively good nutritional status (due to natural fertilization by cattle dung) the total mean in height was 187 meters, which was quite similar to the growth registered in the natural forest of the ECSF close to a water creek where Cabrera (pers. comm.) registered a height growth of 2 meters per year. These findings are also in line with the common experience of the local foresters that *H. americanus* has a preference for sites with good drainage and constant humidity.

Surprisingly, the shade tolerant native species ***T. chrysantha*** showed the best survival (94%) of all species. This demonstrates its ability to establish in degraded areas under very heterogeneous conditions. Otsamo et al. (1997) also reported good survival rates in plantations with *T. chrysantha* in Indonesia at sites with a precipitation of 2128 mm per year and a dry period of 5 months. The high survival of this species may be explained by the presence of arbuscular mycorrhizas in the roots. A corresponding sampling of the seedlings at the pasture site revealed that all roots of *T. chrysantha* contained abundant arbuscular mycorrhizas (Huag pers. comm.). This is a result of the fact that, as mentioned before (Chapter 3.2.2.), for the production of the seedlings in the nursery we used a substrate with soil from the natural forest with *T. chrysantha* containing ample mycorrhizas which inoculated the roots of the seedlings (Kottke et al. in press). However, in contrast to the excellent survival the growth of the seedlings was quite modest, which is also in line with the results of Otsamo. We conclude that in our experiment this is due to the strong root competition with the ground vegetation. As could be revealed in the herbicide experiment (chapter 4.2.) the chemical elimination of the root competition improved the growth of *C. montana* and *T. chrysantha* significantly. However, the moderate growth might also represent a species-specific behaviour because a series of seedlings planted along the pathway to the ECSF also needed 3-4 years, before they started to show good shoots in height and expansion of the crown. Furthermore, as presented in chapter 4.2., under the competition of the ground vegetation *T. chrysantha* invested more into the belowground than in the aboveground biomass.

The genus ***Cedrela*** has the reputation to hardly adapt to the conditions in reforestations (Nieto & Rodriguez 2002a, Revelo & Palacios 2005), especially in pure plantations as it is frequently attacked by *Hypsipyla grandella* (Flores 2002). For that reason it is generally recommended to be planted in association with other species (Revelo & Palacios 2005). In our study the mean survival was almost 70%, and no significant difference could be seen between the pure and mixed plots. Within the observation period of this study no infestation by *Hypsipyla* was registered. However, there is evidence that the plague affects preferably seedlings that exceed 2 meters of height (Cintron 1990, Browder & Pedlowski 2000). Likewise *T. chrysantha* we explain the low growth performance with the root competition of the ground vegetation.

The behaviour of ***J. neotropica*** was characterized by its minimal survival and poor growth. This contrasts with the good development of the species that has been reported from plantations in New Zealand in the Auckland region with seed provenances from Ecuador (National Research Council 1989). In New Zealand, the trees reached a height growth of up to 1.5 m/year (at 10 years of age the plants had 10 meters height). For *J. piriformis* Pedraza & Williams-Linera (2003) reported also good survival rates of 76% on abandoned pastures in Veracruz, Mexico, but their sites were at a mean altitude of 1500 m a.s.l. Due to the excellent behaviour of *Juglans* in their observations these authors recommend *Juglans* for rehabilitation of degraded soil. The poor performance of the seedlings reached in our plantations at the ECSF could be related to the superficial depth of soil and the deficient drainage properties. From studies in Costa Rica it is known that *Juglans* requires optimal soil and water availability for good performance (CATIE 1997, Nieto & Rodriguez 2002b).

The results for the native species show that the micro-site conditions apparently play a fundamental role for the performance of the single species.

The behaviour of the two exotic species (*E. saligna* and *P. patula*) will be discussed in a later chapter (5.2.7.).

5.2.4. Influence of the successional status of the sites

Several studies in tropical lowland and montane forests already revealed that silvicultural interventions for the rehabilitation of degraded land must be very well adapted to the environmental conditions of the sites, which are closely linked to the intensity and duration of the former land-use (Knowles & Parrotta 1995, Montagnini et al. 1995, Haggar et al. 1998, Leopold et al. 2001, Montagnini 2001, McDonald et al. 2003, Montagnini et al. 2003). The three successional sites of the reforestation experiment represent the most typical types of abandoned land that are available for reforestation in the study area.

The opposed trends of increasing survival but decreasing growth between the pasture and the fern and the shrub site in our study can be explained by the different floristic composition of the vegetation at the sites (Flick 2003) on the one hand and the differences in the light exposure and humidity conditions in soil and air on the other hand. At the pasture the competition was predominantly determined by the *Setaria* grass. However, due to the cutting of the ground vegetation before planting the competition during the observation period was primarily dominated by the belowground effects. Consequently, the low survival of *A. acuminata, H. americanus* and *J. neotropica* at the pasture may be mainly related to the limited soil humidity linked with the compaction of the soil which was caused by the recent cattle use. Another critical soil factor may have been the nitrogen availability. As already mentioned before, Rhoades et al. (1998) reported that the nitrogen availability in pastures with *Setaria sphacelata* was reduced by 20% compared to that in the natural forest. This fact can also explain the significantly better performance of the N-fixing *A. acuminata* in our study.

The finding that the surviving seedlings at the pasture showed better growth than those at the fern and shrub site can be explained by the higher solar radiation at the open pasture compared to both other sites. As it is known from many studies plants are able to adapt their photosynthesis to high radiation (e.g. Lichtenthaler 1996, Larcher 2003). Thus, immediately after planting photoinhibition may even have contributed to the higher mortality at the pasture, but successively the surviving seedlings seem to have adapted to the high insolation.

At the fern site the lower growth of the seedlings can, in addition to the before mentioned shade effect, also be related to the direct competitive effect of *Pteridium* that constitutes a weed all over the world (Shepherd 1986, Hartig & Beck 2003, Roos 2004, Rodriguez Da Silva & Da Silva Matos 2006). Its competitive strength results from the deep rhizomes that goes down to one meter of depth. This enables *Pteridium* to survive even intensive fires. Furthermore its roots form a dense network which releases allelopathic substances. According to many studies these characteristics inhibit the natural regeneration and growth of any type of native vegetation and forest species in areas occupied by *Pteridium* (Ferguson et al. 2005, Rodriguez Da Silva & Da Silva Matos 2006, Slocum et al. 2006).

Castro et al. (2002) argued that the interactions between shrub vegetation and seedlings can be positive in one case (facilitation) and negative in other cases (competition). This corresponds to our observation at the shrub site. Most of the species planted showed better survival rates at the shrub site in the initial phase, where the shrubs lead to a diminution of hydric and thermal stress, and offer mechanical protection against wind or consumption by herbivors. These effects have also been argued in other studies (e.g. Jordano et al. 2002, Hernández et al. 2004, Gómez - Aparicio et al. 2005, Padilla & Pugnaire 2006). In addition a shrub canopy can help to avoid photoinhibition due to high insolation. Accordingly, Pedraza & Willians-Linera (2003) found that the native species showed higher survival rates in sites with a protection of the shrub. However, Loik & Holl (2001) report from their study with four native species in different stages of secondary succession in Costa Rica that shrubs did not provide a facilitative effect for growth or photosynthesis for ~1.5-year-old seedlings. They also concluded that the performance of seedlings during succession is not only based on physiological responses in the photosynthesis but also on complex interactions of facilitative and competitive effects. Because it is not always possible to balance the facilitative and competitive effects between tree seedlings and shrubs very often elimination or reduction of existing shrub vegetation is recommended to assure the establishment of forest plantations. Andresen et al. (2005) for instance suggest a selective management of the shrub vegetation.

5.2.5. Influence of the manual and chemical treatment of the ground vegetation

The establishment of a forest plantation represents an investment into the land. Consequently, in order to not jeopardize this investment it is very common to implement measures to diminish the competition with weeds, especially during the first years until the seedlings are established. This is usually presumed when they reached about two meters of height (Shepherd 1986, Wadsworth 2000, Davel 2006). Positive effects of the management of the ground vegetation have been documented in many studies. Deyoe (1986) argued that in New Zealand the elimination of competitors during the first 2-4 years can duplicate the volume production on good sites and triplicate on poor sites. Shepherd (1986) showed that the elimination of the competitive vegetation improved the success of young *P. radiata*. In Argentina weeds caused significant losses in the survival and growth of *Populus* and *Salix* plantations (Achinelli et al. 2006). Wadsworth (2000) presented the case of three years old *Cupressus lusitanica* in Colombia, where the height of the trees in untreated areas exceeded the height of the grass *Melinis minutifolia* but lacked vigor and showed chlorosis. However, when the grass was eliminated the diameter growth of the seedlings increased by 50% compared to seedlings without treatment. The advantages of the management of the ground vegetation are inter alia attributed to the higher water content in the soils that favors the formation of a greater leaf area (Letourneau & Andenmatten 2002).

Posada et al. (2000) stated that mechanical and chemical methods can reduce grass biomass but are costly and thus only suitable for small-scale projects. They recommend extensive grazing to reduce the biomass of the grasses or to use less competitive grasses for pastures, like e.g. *Melinis minutiflora* which allocates much less biomass to stolons than *Setaria*. To come to adequate decisions the profits and expenditures of different treatment options must be balanced with the related expenditures. However, their recommendations are not applicable to sites that are already abandoned as no management is applied any more but they could be an interesting option for areas shortly before abandonment to achieve a smooth transition to the reforestation.

In the study at hand a defined pattern of the effect of the manual management of the competitive vegetation on the performance of the seedlings applicable to all species could not be demonstrated. The patterns were rather dependent from the species. For example a significant effect of the elimination of the ground vegetation could be analysed for the light demanding species *A. acuminata* and *H. americanus* while the survival of the shade tolerant species was not significantly influenced by the treatment. *C. montana* and *J.*

neotropica presented even better growth in height and health status in the untreated plots. In the plots with treatment the *J. neotropica* seedlings had almost no foliage. The two exotic species showed better survival rates without the treatment. Similar results were also found by Pezzutti & Caldato (2004). They reported that the control of the weeds did not influence the survival of plantations of *P. taeda* and *P. elliottii*. Also Rose & Ketchum (2002), found no effect of the management on the survival of *Pinus ponderosa*. However, in our study, in contrast to the survival, the growth of *P. patula* was better in plots with treatment. This coincides with the findings of Alvarez et al. (2004) that the weed control increased the growth of diameter and height of *P. radiata*. Rose & Ketchum (2002) reported as a result of the treatment of the ground vegetation improved growth of *Pinus ponderosa* in the USA and Davel et al. (2006) for the same species in Patagonia, Argentina.

The author explains the absence of significant effects with the limitation of the manual treatment to the aboveground (aerial) competition. As the results of the herbicide experiment revealed the relevant competition on our sites seems to happen predominantly in the subsurface. Griscom et al. (2005) in contrast concluded from similar experiments on pastures in the dry tropical zone of Panama that the positive effect of the herbicide application on the survival and growth of the plants was caused by the increased light levels compared to the non-herbicided plots. These obvious differences underline the request of Parrotta et al. (1997) for a systematic evaluation of the effects of site preparation. Anyway, in our experiment the glyphosate treatment increased the growth and biomass production of *C. montana* and *T. chrysantha* significantly.

Unfortunately, in this study it was not possible to clarify whether the effects of the chemical treatment are caused by the reduced competition for water and soil nutrients or due to an enhanced release of nutrients linked with the decomposition of the increased amount of dead roots as a result of the chemical treatment. Rose & Ketchum (2002) stated that the nutrient concentration in the leaves has not been affected by the treatment of the ground vegetation.

Because the results of the herbicide experiment are limited to *C. montana* and *T. chrysantha* an extension of the investigations to the other species would be highly desirable for the subsequent phases of the research. The different strategies of the two species to cope with competition that have been presented in this study underline the necessity for a careful selection of the species to harmonize the requirements of the species with the site conditions.

5.2.6. Differences between light demanding and shade tolerant species

It is well known and accepted that tree species can be categorized in groups that share general patterns of biological and ecological characteristics like natural regeneration, growth potential, certain wood properties, or potential uses (Bazzaz & Pickett 1980, Finegan 1997, Guariguata 1999). Because the environmental conditions at the three successional sites are also characterized by different light regimes, in this study we distinguished between light demanding (further also referred to as ´pioneers´) and shade tolerant species. Pioneer species are considered to have physiologic characteristics that allow them to establish and develop in open areas with high light intensity and/or disturbed habitats, e.g. regarding soil degradation or compaction (Bazzas & Pickett 1980, Davidson et at. 1998). Even under such conditions they can reach high growth rates compared to tolerant species (Bazzaz & Pickett 1980, Alder et al. 2002). This potential is attributed to their ability to a fast acquisition of nutrients (Bazzaz & Pickett 1980). However, usually they have lower wood densities and life cycles than shade tolerant species. One reason for the lower growth of the shade tolerant species, at least in the early phases of their development, is the fact that they invest their resources in producing wood of better density respective quality.

Corresponding to these characteristics Davidson et al. (1998) reported from forest plantations in the Ecuadorian Amazon region better survival and growth in height and RCD of pioneer species compared to that of shade tolerant. The pioneers had also a better nutrient status in the foliage than the shade tolerant. These results contrast with that obtained in our study, where the survival of the light demanding species *A. acuminata* and *H. americanus* was inferior to that of the shade tolerant *C. montana* and *T. chrysantha*. For the latter species excellent survival was also registered in Indonesia (Otsamo et at. 1997). The author attributes the low mortality to the good colonization of the *T. chrysantha* roots with mycorrhizas. Davidson et al. (1998) awarded the species also high adaptability to varying light conditions. Fredericksen et al. (2001) stated that most shade tolerant species in the tropics grow better under higher illumination but are also able to tolerate low insolation conditions.

In contrast to survival the growth of the pioneer species was superior to that of the shade tolerant. Similar behaviour was found in most studies (Lugo & Zimmerman 2002, Coomes & Grubb 2003, Nogueira et al 2004, Moreira dos Santos et al 2006). However, one has to be aware that colonization of ephemeral and isolated sites, precocious reproduction, and fast growth in the first phase of development but early culmination of the production are typical characteristics attributed to the pioneers. The shade tolerant on the other hand exhibit slower growth rates in their immature stages but later culmination of growth which enables them to develop to individuals of big stature at maturity (Finegan 1997). This makes it necessary to continue the monitoring of the performance of the seedlings in the reforestation and enrichment experiment for several years more.

5.2.7. Differences among the native and exotics species

The afforestation practice in the Andes of Ecuador is still almost completely based on the use of exotic species (*Pinus patula, P. radiata, Eucalyptus globulus*, *E. saligna* and *Cupressus lusitanica*), while native species are merely used for agroforestry or at an experimental scale. The widespread use of the exotic tree species is mainly due to the good knowledge about its silviculture, fast growth, and industrial use on the one hand and the lack of corresponding knowledge for the native species on the other hand. A neglect of many studies exploring the potential of native species for reforestation was that they did not test them directly against exotics. The study at hand allows a direct comparison which will enable us to balance the ecological, economic and socio-economic advantages and disadvantages of both groups in the long run. For instance, Farley & Kelly (2004) found under plantations with *Pinus radiata* in the Ecuadorian Andes that the water retention of the soil and soil organic carbon declined drastically with stand age. Chacón-Vintimilla et al (2003) found lower pH, lower cation concentrations, decreased N-mineralization rates, and lower microbial biomass as well as increased litter accumulation under *Eucalyptus globulus* and *Pinus patula* in the Sierra of South Ecuador. They even question the capability of soils under these species to support subsequent rotations or the growth of other species.

In the presented reforestation experiment, the performance of the two exotics during the first two years of the plantations was better than that of most natives. However, *T. chrysantha* had a higher survival than both exotics and the growth of *A. acuminata* was significantly superior to that of *E. saligna* and only slightly inferior to that of *P. patula.* This is interpreted as a clear hint that natives are able to compete with the exotic species when the species-specific characteristics and the conditions at the sites are carefully considered. For Ecuador with its tremendous diversity of 2736 native tree species (Jørgensen & León Yanez 1999) and still more than 200 species in areas above 2500 m a.s.l. (Fehse et al. 1999) it can be assumed that species for all types of conditions are available. However, there is a huge need for more experiences and investigations.

5.2.8. Influence of species mixture

The advantages of mixed plantations in comparison to pure ones are attested in many studies (e.g. Kumar 1995, Alice et al. 2004, Kelty 2006). For instance, mixed plantations are considered to promote higher species diversity in the understorey regeneration. The main reasons are a bigger variety of habitats and micro-climatic conditions, which also favour the presence of seed dispersers (e.g. birds and bats). Mixed stands are also considered to show better growth and resistance against disturbances like wind or plagues (Guariguata et al. 1995, Montagnini 2001, Alice et al. 2004, Lamb et al. 2005). As experiments in Costa Rica suggested mixtures with native species have the potential to offer a wider spectrum of benefits and uses than monocultures (Lamb et al. 2005). Alice et al. (2004) found that mixed plantations with 3 native species had also higher productivity in terms of basal area and volume than pure plantation.

In this study we found that the survival and growth of *A. acuminata* was better in the mixed plantations. However, as the differences were not significant they might also be explained by differences in the micro-site conditions. *J. neotropica* on the other hand presented significantly worse performance at the mixed plots. Bearing in mind that our plantations were only two years old distinct effects of the mixtures can not yet be expected and therefore the results have to be evaluated with caution.

5.2.9. Enrichment of pine plantations with native species

On extremely degraded land Sabogal (2005) considered exotic species as an adequate option to restore a forest cover within a reasonable time. Despite the reservations against exotics mentioned very often, there are evidences that such plantations can also contribute to a reversion of the degradation processes through the stabilization of the soils, the increase of the level of organic matter, and the improvement of the pH or of the nutritional status of the soil (Montagnini & Sancho 1990, Parrotta 1992, 1993, Lugo 1997, Feyera et al. 2002a, Carpenter et al. 2004). Recent studies attested also a facilitative effect on the natural regeneration in the understorey (Lugo 1997, Feyera et al 2002b, Carpenter et al. 2004). Consequently, the establishment of plantations with exotic species and the subsequent enrichment with native species could also be a promising option to reforest abandoned pastures and to rehabilitate biodiversity.

The results of the enrichment experiment presented in this study show that survival, growth and health status were superior to that of the corresponding species in the reforestation experiment. With regard to growth all species preferred the conditions in the gaps. There, *A. acuminata* for instance achieved an annual increment in height of 148 cm/year, a value similar to that registered at good site conditions in Colombia (Ruiz 2002). The good performance of the seedlings in the gaps of the pine plantation can be explained with the improvement of the environmental conditions, like e.g. increased humidity or lower temperature as well as with the reduced competitive ground vegetation, while the light requirements were not as much restricted as under the closed canopy. Wadsworth (2000) achieved similar results in his study and attributed this to the fact that the roots of the exotics can take up nutrients from deeper soil layers which are not available any more for plants with shallow root systems like young seedlings.

These findings support the statement of Carpenter et al. (2004) that a pre-preparation of the degraded lands by planting *Pinus* and their subsequent enrichment with native species may have more success than planting natives directly on open sites. The results offer also an interesting option to convert the existing plantations with exotics in the southern region of Ecuador into more natural stands.

6. Conclusions and Recommendations

The conclusions that can be drawn from this study shall be presented according to the research questions formulated in chapter 1.

Can native species cope with the harsh conditions on the abandoned sites?

Although the results for the five native species tested in this study vary among the different sites and treatments, it can be concluded that native species are able to cope with the conditions on abandoned pastures. However, the planting must consider the specific characteristics and requirements of each species as well as the micro-site conditions at the planting sites. No obvious general pattern of the behaviour of the native species subject to the various conditions in the experiments could be observed, but each species presented preferences for specific ecological niches that are facilitating or limiting its ability to cope with the conditions. For instance, as *T. chrysantha* showed excellent survival rates at all successional sites it can be recommended for the whole range of the conditions. In general, *C. montana*, *A. acuminata* and *H. americanus* showed acceptable results as well, even though their survival rates were lower. However, according *H. americanus* cannot be recommended for afforestation of open pastures and *A. acuminata* for fern sites as they experienced significantly higher mortality at these sites. The only native species that had problems at all sites was *J. neotropica.* However, concerning this species further investigations are recommended to investigate if this was really an effect of the site conditions or if the problems were related to the planting material.

Considering the high arboreal diversity of the Andean tropical mountain forests with more than 200 native species with high potential for consideration in reforestation and restoration programs (Fehse et al. 1999), there can be no real doubt that at least one native species will be available for each site which can cope with the respective conditions.

Can the natives compete with the commonly used exotic species in terms of survival and early growth?

With regard to survival the only species that could compete with the two exotics was *T. chrysantha*. Indeed, the mean survival of this species was even higher than that of the two exotic species.

Concerning the growth in height and root collar diameter the only species that could compete with the exotics was *A. acuminata*. Compared to *E. saligna* the growth of *A. acuminata* was even higher and it was only slightly inferior to *P. patula.* The growth of all other native species was significantly lower than that of the exotics. However, because this study covered only the performance during the first 24 months since planting, it cannot be excluded that this might be an effect of different biomass allocation strategies. As the biomass analyses revealed the native species, especially the shade tolerant, invested more into the root system than in the aboveground biomass compared to the exotics. The author concludes that this was also the reason for the excellent survival rates of *T. chrysantha* at all sites. Thus, it cannot be excluded that the lower growth of the native species will be compensated in the subsequent phases due to more intensive root systems. Therefore, it is necessary to continue to monitor the performance of the plantations at least on a medium-term basis.

Besides the growth in height and diameter a comparative evaluation of the native and exotic species must also consider the fact that, due to their better wood quality, the market price for timber of the native species is much higher than that of the exotics. For instance, actually in the city of Loja the price for one timber unit of *Cedrela* is on average 3 times higher than that of one unit of *Pinus* or *Eucalyptus*. If such economic aspects are considered among other beneficial externalities of plantations with native species, they can be considered to be a competitive alternative to the exotic ones.

How is the success of the plantation influenced by the successional status of the area?

There was a clear trend for better survival with proceeding succession of the planting site. Most species showed highest survival at the shrub site. Only for *A. acuminata* survival at the pasture was equal to the shrub site. This result is explained with the intensive competition of the pasture grass *Setaria sphacelata* and its characteristic to reduce the nitrogen availability for the seedlings on the one hand and the protective effects of the shrub vegetation against extreme radiation as it is appearing at the pasture on the other hand.

In contrast to the survival the growth performance of almost all species showed a negative trend in response to the advanced successional phase of the planting site. Only the two tolerant species *C. montana* and *T. chrysantha* presented slightly lower growth of the root collar diameter at the pasture compared to the fern respectively shrub site. The negative trend of growth can be explained with the reduced light conditions due to the shading effect of the shrubs. However, this effect could easily be regulated with a selective reduction of the most competitive shrub individuals.

Consequently, reforestation activities should not only be focus on recently abandoned land but also include advanced stages of succession. However, in this case tending measures should be applied as soon as the planted seedlings are well established.

Can the success be improved by the removal of the competitive ground vegetation?

The survival of all native species could be increased by the manual removal of the ground vegetation even though this effect was statistically significant only for the two light demanding species *A. acuminata* and *H. americanus.* Obviously, the latter species were able to profit from the enhanced light conditions resulting from the elimination of the competitive vegetation while the shade tolerant could not as much because, according to several studies (e.g. Larcher 2003), they need more time for adaptation. Because both exotics showed even a slightly negative response to the treatment removal of the ground vegetation can be neglected for these species

In contrast to the survival the growth performance did not show a distinct response to the treatment. Height growth of *C. montana, J. neotropica,* and *E. saligna* showed better result in parcels without treatment of the ground vegetation, while the remaining species had better values with treatment. Regarding root collar diameter all species showed better values without treatment. There are some hints that the effects of the manual treatment could be improved by a shorter cutting cycle of the ground vegetation, especially as far as *Setaria* is concerned (Marin pers. comm.). However, as this would also lead to a further increase of the establishment costs it cannot be considered as a realistic option.

How does the chemical treatment affect the subsequent biomass production and species composition of the ground vegetation compared to the manual treatment?

Both manual and chemical treatment led to a significant reduction of the biomass of the ground vegetation compared to the control. However, the differences did not significantly differ between the manual and the chemical treatment. The effect of both treatments was predominantly concentrated on the aboveground biomass and the upper layer of the belowground biomass (0 - 7.5 cm of depth) while the deeper roots were not intensively affected.

Although both treatments had an effect on the floral composition of the ground vegetation, the elimination of the most competitive *Setaria* could only be observed for the chemical treatment. However, at the plots with manual treatment the proportion of the two exotic grasses *Setaria* and *Melinis* could be reduced as well to the advantage of the native pasture grass *Axonopus sp*., which has a less aggressive root system. At the chemically treated plots a remarkable increase of other native species could also be observed. Consequently, to eliminate the *Setaria* chemical treatment seems to be the only option, especially because the already mentioned shortening of the cutting cycle of the ground vegetation will not be viable due to the high expenditures required.

How does the chemical treatment influence the survival, growth, and biomass allocation of the seedlings of two native species (*Tabebuia chrysantha* and *Cedrela montana*) in comparison to the manual alternative.

Under all treatments in this experiment all planted seedlings survived. The growth of both species was significantly improved by the chemical treatment while no significant difference could be analysed between control and manual treatment. However, the different treatments of the ground vegetation did not only influence the growth of the seedlings but also the allocation of below- and aboveground biomass. While *C. montana* invested more into the aboveground biomass in all treatments, *T. chrysantha* invested more into the root biomass in the control and manually treated plots. It is concluded that these differences exhibit a species-specific behaviour of both species to cope with different conditions of competition. This characteristic is also considered to be the reason for the excellent survival rates of *T. chrysantha* at all sites of the reforestation experiment.

Can native species cope with the conditions in a stand of the exotic *Pinus patula*?

All native species planted under the closed canopy and in gaps of the *P. patula* plantation showed an excellent performance. They reached higher survival rates and better growth than the seedlings planted in the different successional sites of the reforestation experiment. They also exhibited a better health status than the seedlings in the reforestation experiment. Consequently, it can be concluded that enrichment planting can be an interesting option to convert the existing plantations with exotics in the southern region of Ecuador into more natural stands, which may also contribute to the restoration of the biodiversity.

Is there a difference in the performance of native seedlings planted under the closed canopy of the pines or in gaps?

With the exception of *P. discolor*, *C. montana* and *C. officinalis* which had a higher survival in the gaps all other species showed better survival under the closed canopy. However, there was a distinct difference in the growth in height and RCD: All species showed better growth performance in the gaps, it is concluded that this is a result of increased humidity conditions, lower temperature and the reduced competitive ground vegetation, while at the same time the light requirements were not as much restricted as under the closed canopy. However, the further measurements have to confirm that the good growth can also be maintained over a longer period of time until the harvesting of the pines or if prior selective tending measures are required. Further investigations may also be required to define optimal gap sizes and to identify the specific light requirements of the several species.

Implications of the study for the further development of forestry in Andean Ecuador

Apart from the results concerning the direct research questions there are also conclusions that can be drawn from this study with regard to the further needs for research as well as for development of the forestry sector in the Andean region of Ecuador and the intended consideration of larger plantations with native species:

As the results presented before showed the species studied had different patterns of behaviour, ecological needs and adaptation strategies. If the high diversity of the site conditions in the study region is considered as well it becomes clear, that a lot of efforts have to be spent into research and planning. The planning must not only consider the heterogeneity of the landscape but also a wide variety of technical aspects of silviculture:

- The results of this study support the findings of several other authors that, apart from the slow progress of the succession, the resulting secondary forests does not contain a sufficient amount of valuable species. Consequently, reliance on natural succession will not be an acceptable option when the fast recovery of the productive function of abandoned areas is required because. However, it may be adequate when the focus is on the rehabilitation of the ecological forest functions or biodiversity.
- To be able to ensure the provision of suitable planting material of native species in terms of number, quality, and provenances of seedlings it is urgent to invest into the evaluation of the reproductive biology of potential species and the establishment of seed orchards for the most important species.

- The seedlings used for the experiments of this study included only a very small genetic variation as they originated from only five trees. Large scale plantations must however be based on a large number of selected individuals comprising the wide variety of the natural genetic information.
- From the excellent performance of *T. chrysantha* which is explained with the presence of adequate mycorrhizal fungi it can be concluded that the success of other species can be improved as well through the inoculation of the seedlings in the nursery. Thus, investigations shall be undertaken to identify the species specific mycorrhiza communities of the native species.
- Further investigations are required concerning the optimization of the substrate and the containers in the nurseries, the adequate treatment of the ground vegetation using different methods according to the objective of the forest activity, the optimization of the time of plantation, and the use of fertilizers.
- Attention shall also be given to the reconversion of the exotic plantations into more native stands by means of enrichment planting. As could be shown in this study, the exotics can facilitate the establishment of plantations with native species. However, enrichment planting can also be considered as a suitable option to enhance the proportion of valuable species in secondary forests.

It is assumed that the consideration of the before mentioned aspects will also stimulate the attractiveness of reforestation activities for investors or landholders. Further strategies that could contribute to achieve this objective are:

- The development of institutional, legal and political instruments that promote the security of landownership, or facilitate the obtaining of credits. They can also eliminate the incentives that favor the further deforestation and degradation of the forests and can help to establish market potentials for the commercialization for the divers forest products.
- To provide information and technical assistance for interested actors about the selection of convenient species, their silvicultural requirements and their market values.
- To develop replicable silvicultural systems for the conditions of each region based on experiments and systematic aggregation of knowledge. Such systems shall also consider species with multiple uses and integrate different forms of land use (e.g. agroforestry systems on the base of traditional and modern knowledge).
- To generate alternative sources for income from forests, like payments for the environmental services of the plantations (e.g. water, CO_2-fixation, biodiversity, etc.).

7. Summary

Ecuador is considered as one of the global "hots spots" of biodiversity; however it also has the highest deforestation rate of South America. The main reason for the deforestation is the exploitation of the forests and their conversion into agricultural systems, especially pastures for cattle production. In the San Francisco valley (study area) the dynamic of this land use starts with the exploitation of the natural forests and is continued by the transformation of the remaining forest into pastures. At a later stage exotic grasses (*Setaria sphacelata* and *Melinis minutiflora*) are introduced to improve the productivity of the pastures. Due to the regular burning of the pastures by farmers the areas are gradually invaded by the bracken fern (*Pteridium arachnoideum*). After several years the pastures lose their productivity and the farmers abandon the land. They look for new forest areas and the described cycle starts over again.

Due to the harsh environmental conditions at the abandoned sites and lacking seed input the natural succession is very slow and it takes several decades until a new forest cover is achieved. Under these conditions the reforestation with native species is considered as one of the most promising alternatives for the recovery of such degraded sites into productive areas. However, in Ecuador, and especially in its southern region, to date forest plantations have been established exclusively with exotic species of the genus *Pinus* and *Eucalyptus*. Among the main reasons for the neglect of native species in reforestation activities is the lack of knowledge about their ecology and silvicultural characteristics. Therefore, the main objective of this investigation was to improve the basic knowledge of the silvics of selected native species. Specifically, the study should answer the following questions:

1. Can native species cope with the harsh conditions on the abandoned sites?
2. Can they compete with the commonly used exotic species in terms of survival and early growth?
3. How is the success of the plantation influenced by the successional status of the area?
4. Can the success be improved by the removal of the competitive ground vegetation?
5. How does the chemical treatment affect the subsequent biomass production and species composition of the ground vegetation compared to the manual treatment?

6. How does the chemical treatment influence the survival, growth, and biomass allocation of the seedlings of two native species (*Tabebuia chrysantha* and *Cedrela montana*) in comparison to the manual alternative
7. Can native species cope with the conditions in a stand of the exotic *Pinus patula*?
8. Is there a difference in the performance of native seedlings planted under the closed canopy of the pines or in gaps?

To give answers to the above mentioned research questions three experiments we implemented in the surroundings of the San Francisco valley near the scientific station Estacion *Cientifica San Francisco* (ECSF) in the buffer zone of the Podocarpus National Park in Southern Ecuador.

The first experiment (**reforestation experiment**) constitutes of 12 hectares in total, distributed to three areas of 4 hectares each, where each area represents a different successional stage after abandonment. The areas included:

i) A recently abandoned pasture with *Setaria sphacelata* and *Melinis minutiflora* (pasture)

ii) An abandoned pastures heavily covered by the bracken fern *Pteridium arachnoideum* (fern) and

iii) An abandoned pasture in advanced succession with presence of a shrub vegetation (shrub)

Besides the three successional stages of the planting sites the experiment considered

- Two variants of treatment of the ground vegetation (0= manual clearing only one time before planting; 1= manual clearing before planting and every 4 months during the first two years)
- Five native species from which two (*Alnus acuminata* and *Heliocarpus americanus*) can be classified as light demanding species because they naturally regenerate especially in natural clearances and three as shade tolerant species (*Cedrela cf montana*, *Juglans neotropica* and *Tabebuia chrysantha*) due to its preference to regenerate under a closed canopy. These native species were planted in pure and mixed plantations.
- Two exotic species (*Pinus patula* and *Eucalyptus saligna)* which represent the predominantly used species for reforestations in the study area and the Sierra of Ecuador.

The second experiment (**herbicide experiment**) was established to answer the research questions five and six. For this experiment, three sites at the pasture area of the reforestation experiment were selected to establishment three blocks, each representing a distinct position within the slope. For this experiment 45 seedlings of each of the two native species *C. montana* and *T. chrysantha* were planted in every block to test the effects of three different treatments of the ground vegetation: 0= manual removal of the ground vegetation only one time before planting; 1= manual clearing before planting and every 4 months during the first two years; 2= chemical treatment of the ground vegetation with a systemic herbicide (Glifopac, 480 g/l) 8 days before planting. The treatments 0 and 1 correspond to the treatments used in the reforestation experiment.

The third experiment (**enrichment experiment**) was implemented in a 20 years old *Pinus patula* plantation adjacent to the pasture site of the reforestation experiment. On 8 plots, individuals from nine native species were planted under two different environmental conditions (1= under the closed canopy of the pine plantation; 2= in small gaps of the pine stand). In addition to the native species that are used in the reforestation experiment *(except J. neotropica)* the following species were tested: *Cupania cf americana, Cinchona officinalis, Isertia laevis, Myrica pubescens* and *Piptocoma discolor.*

The observation time for this study comprised 24 months for the reforestation and the enrichment experiment and 12 months for the herbicide experiment.

The results of the **reforestation experiment** document that most native species were able to cope with the harsh conditions at the different sites. However, no distinct behaviour of all species could be identified. They rather showed species specific patterns of behaviour, ecological needs and adaptation strategies. Even the species within the groups of light demanding and shade tolerant species showed different characteristics. For instance, the two light demanding species *A. acuminata* and *H. americanus* showed similar survival, but the growth of *A. acuminata* was significantly superior to that of *H. americanus.* With maximum growth rates of up to 1.50 meters per year *A.acuminata* achieved values that are competitive to that of the exotic species. In contrast, the growth of *H. americanus* was very low and far away from that observed in gaps of the natural forest of the ECSF (2 m of height per year). With a mean survival of 94 % the shade tolerant *T. chrysantha* achieved excellent values at all three sites and surpassing all other species including the exotics. This species can tolerate a wide range of environmental conditions which, in addition to its excellent wooden quality, makes it a very potential species for reforestation programmes. However, its growth performance was much lower than that of the exotics and *A. acuminata* but competitive to that of *H. americanus*. The

other two shade tolerant species *C. montana* and *J. neotropica* had lower survival rates than *T. chrysantha* but similar growth.

The successional status of the planting site had a significant effect on the behaviour of the planted forest species: there was a clear trend for better survival with proceeding succession of the planting site. Most species showed highest survival at the shrub site. Only for *A. acuminata* survival at the pasture was equal to the shrub site and *J. neotropica* had the lowest survival at the shrub site. This result is explained with the intensive competition with *Setaria sphacelata* at the pasture and its characteristic to reduce the nitrogen availability for the seedlings but also with the protective effects of the shrub vegetation against the extreme radiation that can be registered at the pasture. In contrast to the survival the growth performance of almost all species showed a negative trend in response to the advanced successional phase of the planting site. Only the two tolerant species *C. montana* and *T. chrysantha* presented slightly lower growth of the root collar diameter at the pasture compared to the fern respectively shrub site. The exotics, especially *P. patula,* showed a good growth performance from the time of planting while all other species, except *A. acuminata*, needed more than on year to overcome the planting shock.

The manual treatment of the ground vegetation had a positive influence on the survival of all native species. However, this effect was significant only for the two light demanding species *A. acuminata* and *H. americanus.* In contrast to the natives, the exotic species had better survival in the plots without treatment. The height growth of the seedlings showed different behaviour in response to the treatment. *C. montana, J. neotropica* and *E. saligna* showed better height growth in the plots without treatment of the ground vegetation, while for the remaining species it was better in the plots with treatment. Concerning the root collar diameter, all species showed higher values with the removal of the ground vegetation. All these differences became more evident in the second year of plantation.

The comparison between the pure and mixed plots did not reveal obvious effects until the end of the observation period of this study. This can be explained by the still limited interaction among the species due to the spacing of 1.8 x 1.8 m. Sound effects of the mixtures are only expected with the closing of the canopy and the competitive interaction of the roots. The results achieved so far are non-uniform: all parameters (survival, height and root collar diameter) of *J. neotropica* were better in the pure plots, while *A. acuminata* presented better results in the mixture.

The results of the **herbicide experiment** revealed that the growth of both species was significantly improved by the chemical treatment while no significant difference could be analysed between control and manual treatment. However, the different treatments of the ground vegetation did not only influence the growth of the seedlings but also the allocation of below and aboveground biomass. While *C. montana* invested more into the aboveground biomass in all treatments, *T. chrysantha* invested more into the root biomass in the control and manually treated plots. This is interpreted as a species- specific behaviour to cope with different conditions of competition. This characteristic can also considered to be the reason for the excellent survival of *T. chrysantha* at all sites of the reforestation experiment.

Both manual and chemical treatment resulted also in a significant reduction of the biomass of the ground vegetation compared to the control. However, the differences did not significantly differ between the manual and the chemical treatment. The effect of the both treatments was predominantly concentrated on the aboveground biomass and the upper layer of the belowground biomass (0 - 7.5 cm of depth) while the deeper roots were not intensively affected. Both treatments led also to a change in the floral composition of the ground vegetation. At the plots with manual treatment the proportion of the two exotic grasses *Setaria* and *Melinis* could be reduced to the advantage of the native pasture grass *Axonopus sp*., which has a less aggressive root system. However, an elimination of the *Setaria* could only be achieved with the chemical treatment.

The behaviour of the native species under the pine plantations in the **enrichment experiment** should a significant influence of the micro-site condition (under canopy/gap). Interestingly the survival of the light demanding species was better under closed canopy (except *A. acuminata* and *P. discolor)* while the shade tolerant *C. montana* and *C. officinalis* presented better survival in gaps. The growth in height and RCD of all nine planted species showed better performance in gaps, especially *A. acuminata* and *P. discolor*, which had 2.5 times higher growth compared to the closed canopy. Consequently, all tested species could cope very well with the conditions in the pine stand. From these results it can be concluded that enrichment planting could be a suitable means to reconvert the prevailing pine plantations into more natural ecosystems with higher functionality.

Summarizing the results of this study show that native species can be considered as valuable option for the reforestation and rehabilitation of different types of abandoned land in the Andean region of South Ecuador

8. Resumen

Ecuador es considerado como uno de los “hots spots” de biodiversidad en el mundo, sin embargo también tiene la tasa de deforestación mas alta de América del Sur. Entre las principales razones para la deforestación en el Ecuador esta la explotación de los bosques y su conversión en sistemas agropecuarios especialmente pasturas para la producción ganadera. En el valle del Río San Francisco (área de estudio, y como en muchas áreas del trópico) la dinámica del uso del suelo empieza con la explotación de los bosques naturales; seguida por la transformación de estos en pasturas para la producción ganadera; posteriormente para mejorar la productividad de las pasturas se introducen pastos exóticos especialmente *Setaria sphacelata* y *Melinis minutiflora*; luego como resultado de regulares quemas, estas áreas son invadidas por el helecho *Pteridium arachnoideum*. Después de algunos años estas áreas pierden su productividad, entonces los campesinos abandonan las tierras y buscan nuevas áreas boscosas y empieza nuevamente el ciclo antes descrito.

Debido a las difíciles condiciones ambientales de los sitios abandonados, la sucesión natural es muy lenta y puede tomar varios años hasta lograr establecer una cubierta forestal. Bajo estas condiciones la reforestación con especies nativas es considerada como una de las alternativas más promisorias para reconvertir estos ambientes degradados en áreas productivas. Sin embargo en el Ecuador y en la región sur del Ecuador las plantaciones forestales han sido establecidas casi exclusivamente con especies exóticas de los géneros *Pinus* y *Eucalyptus*. Entre una de las principales razones por la desatención hacia el uso de las especies nativas en actividades de reforestación es la falta de conocimientos de su ecología, silvicultura y propagación. Por lo tanto, el objetivo principal de esta investigación fue mejorar los conocimientos básicos de la silvicultura de seleccionadas especies nativas, así como conocer sus capacidades de ser utilizadas en la rehabilitación de áreas abandonadas. El estudio se fundamento en las siguientes preguntas.

1. ¿Pueden las especies nativas adaptarse a las duras condiciones de los ambientes abandonados?
2. ¿Pueden las especies nativas competir con las exóticas comúnmente usadas en términos de sobrevivencia y crecimiento inicial?
3. ¿Cuál es la influencia del estado sucesional de los sitios de plantación en el desarrollo de las especies?

4. ¿Pueden las técnicas de manejo de la vegetación competitiva mejorar el desarrollo de las especies forestales?
5. ¿Puede el tratamiento químico afectar la composición florística y la producción de biomasa de la vegetación competitiva en comparación con el tratamiento manual?
6. ¿Puede el tratamiento químico influenciar en la sobrevivencia, crecimiento y asignación de biomasa de *Tabebuia chrysantha* y *Cedrela montana*?
7. ¿Pueden las especies nativas adaptarse bajo plantaciones de *Pinus patula*?
8. ¿Existe diferencia en el comportamiento de las especies nativas plantadas bajo el dosel y claros de plantaciones de pino?

Para dar respuesta a estas preguntas se implemento tres experimentos en los alrededores del valle del Río San Francisco en la Estación Científica San Francisco (zona de amortiguamiento del Parque Nacional Podocarpus) en la región sur del Ecuador.

El primer experimento (llamado **reforestación**) constituyó de 12 hectáreas repartidas en tres áreas de 4 hectáreas cada una y con diferentes estadios sucesionales; las áreas incluyeron:

i) pasturas de *Setaria sphacelata* y *Melinis minutiflora* (pasturas);

ii) pasturas abandonadas cubiertas por el helecho *Pteridium arachnoideum* (llashipales) y

ii) áreas abandonadas con presencia de vegetación arbustiva (matorral).

Además de los tres estadios sucesionales, el diseño experimental consideró:

- Dos variantes de manejo de la vegetación competitiva (0= manejo manual solo al inicio de la plantación; 1= manejo manual con machete cada 4 meses durante los dos primeros años)
- Cinco especies nativas, de las cuales dos (*Alnus acuminata* y *Heliocarpus americanus*) fueron clasificadas como especies pioneras o demandantes de luz, especialmente porque se regeneran en claros naturales; y tres que pueden ser clasificadas como especies de sombra o tolerantes (*Cedrela montana, Juglans neotropica* y *Tabebuia chrysantha*), debido a su preferencia por regenerarse en bajo un dosel cerrado. Las especies fueron arregladas en plantaciones puras y mixtas.
- Además se plantaron *Pinus patula* y *Eucalyptus saligna*, las dos especies exóticas mas utilizadas en la reforestaciones a gran escala en la región y en la sierra del Ecuador.

El segundo experimento (**manejo de la vegetación**) fue establecido para contestar la 5ta y 6ta pregunta. Para este experimento se seleccionaron tres sitios en el área de las pasturas del experimento de reforestación, que representan tres bloques con diferente posición con respecto a la pendiente del terreno. Para este experimento 45 plántulas por cada especie nativa (*C. montana* y *T. chrysantha*) fueron plantadas en cada bloque, para evaluar el efecto de tres diferentes tratamientos de la vegetación competitiva (0= manejo manual solo al inicio de la plantación; 1= manejo manual con machete cada 4 meses durante el primer año, 2= tratamiento químico de la vegetación competitiva con aplicación de Glifopac, 480 g/l (herbicida sistémico) ocho días antes de la plantación. Los tratamientos 0 y 1 corremponden a los usados en el experimento de reforestación.

El tercer experimento (**enriquecimiento**) fue instalado en una plantación de *Pinus patula* adyacente al área de pasturas del experimento de reforestación. Nueve especies nativas fueron plantadas en 8 parcelas individuales bajo dos micro-condiciones ambientales (1= bajo dosel de plantación; 2= en pequeños claros). Adicionalmente a las especies usadas en el experimento de reforestación (excepto *J. neotropica*), las siguientes especies fueron plantadas: *Cupania cf americana, Cinchona officinalis, isertia laevis, Myrica pubescens* y *Piptocoma discolor*.

El tiempo de observación de este estudio, comprende 24 meses para el experimento de reforestación y el experimento de enriquecimiento y 12 meses para el experimento de tratamiento químico de la vegetación competitiva.

Los resultados del experimento de **reforestación** documentan que la mayoría de las especies nativas fueron capaces de adaptarse a las duras condiciones de los diferentes sitios. Sin embargo no se pudo evidenciar un comportamiento general para todas las especies. Las especies demostrarón especificos patrones de comportamiento, necesidades ecológicas y estrategias de adaptación. Incluso dentro de cada grupo de las pioneras y tolerantes se evidenció diferentes comportamientos. Por ejemplo las dos especies pioneras *A. acuminata* y *H. americanus* tuvieron similar sobrevivencia pero el crecimiento de *A. acuminata* fue significativamente superior al de *H. americanus. A. acuminata* alcanzó tasas máximas de crecimiento en altura que superan 1.5 metros comparables con las que pueden alcanzar las especies exóticas. En contraste el crecimiento de *H. americanus* fue muy bajo al observado en claros del bosque natural de la ECSF, donde alcanza hasta 2 m de altura por año. Con sobrevivencia media de 94% *T. chrysantha* (especie tolerante) alcanzó excelentes valores en todos los tres sitios y sorpresivamente superó a todas las especies incluyendo a las exóticas. Esta especie puede tolerar un amplio rango de condiciones ambientales y si a ello se adiciona la excelente calidad de su madera, hacen de esta, una especie potencial para ser usada en programas de reforestación a gran escala. Sin embargo su crecimiento fue menor que las especies exóticas y *A. acuminata,* pero comparable con el comportamiento de *H. americanus*. Las dos restantes especies *C. montana* y *J. neotropica* experimentaron menores tasas de sobrevivencias que *T. chrysantha,* pero similares crecimientos.

El estado sucesional de los sitios de plantación evidenció diferentes efectos en el comportamiento de las especies plantadas. Se evidencio una tendencia definida para la sobrevivencia en función del avance de la sucesión. La mayoría de las especies demostraron altas sobrevivencias en los ambientes con matorral. Solo la sobrevivencia de *A. acuminata* fue similar en las pasturas y los llashipales. Estos resultados se explican por la intensa competición con el pasto *Setaria sphacelata* en las pasturas lo cuál se traduce en la reducción de la disponibilidad de nitrógeno para las plántulas, pero también se explican debido al efecto protector de la vegetación arbustiva de las extremas condiciones de alta radiación registrada en las pasturas. En contraste con la sobrevivencia, el crecimiento experimentado por todas las especies esta negativamente correlacionado con el estadio sucesional de los sitios de plantación. Solo las dos especies tolerantes *C. montana* y *T. chrysantha* presentaron relativamente bajo crecimiento en diámetro en las pasturas comparadas con los dos restantes sitios. Las especies exóticas especialmente *P. patula* demostró buen crecimiento en el tiempo de evaluación mientras que las restantes especies excepto *A. acuminata* requieren periodos superiores a un año para superar el shock de plantación.

El tratamiento manual de la vegetación competitiva evidenció un positivo efecto en la sobrevivencia de todas las especies nativas, sin embargo solo fue significativo para las dos especies pioneras *A. acuminata* y *H. americanus*. En contraste a las especies nativas, las especies exóticas tuvieron mejor sobrevivencia en las parcelas sin tratamiento. El crecimiento en altura de las plántulas demostró diferentes comportamientos en respuesta al tratamiento, así por ejemplo *C. montana, J. neotropica* y *E. saligna* alcanzaron mejores crecimientos en altura en parcelas sin tratamiento de la vegetación competitiva.

Los resultados del experimento de **manejo de la vegetación** reveló que el crecimiento de las dos especies nativas *C. montana* y *T. chrysantha* fue significativamente mejorado por el tratamiento químico de la vegetación, mientras que no se evidenció efecto significativo entre el control y el tratamiento manual. Sin embargo los diferentes tratamientos de la vegetación competitiva no solo influenciaron en el crecimiento de las plántulas sino también en la distribución de la biomasa aérea y subterránea. Mientras que *C. montana* en todos los tratamientos invierte más en producir biomasa aérea, *T. chrysantha* invierte más en la producción de biomasa subterránea en las parcelas control y bajo tratamiento manual. Este comportamiento puede ser interpretado como una adaptación específica para poder competir y cubrir zonas mas profundas. Esta característica puede también estar relacionada con el excelente comportamiento de la sobrevivencia que alcanzó *T. chrysantha* en todos los sitios donde fue plantada.

Los dos tratamientos (manual y químico) condujeron a una significante reducción de la biomasa de la vegetación competitiva comparada con el control. Sin embargo no se evidenció diferencia significativa entre el tratamiento manual y el químico. El efecto de los tratamientos fue predominante concentrado en la biomasa aérea y en la biomasa subterránea entre 0 y 7.5 cm de profundidad; mientras que a mayores profundidades no se evidenció un efecto significativo. También los dos tratamientos condujeron a un cambio de la composición florística de la vegetación competitiva. En las parcelas con tratamiento manual la proporción de las especies de pastos exóticos *Setaria* y *Milinis* fueron reducidas. Sin embargo la eliminación de *Setaria* solo pudo ser lograda con el tratamiento químico.

El comportamiento de las especies nativas bajo plantaciones de **enriquecimiento** de pinos evidenció un significativo efecto del micro-sitio, donde sorpresivamente la sobrevivencia de especies pioneras fue mejor bajo el dosel de la plantación con excepción de *A. acuminata* y *P. discolor*: mientras que *C. montana* y *C. officinalis* (especies tolerantes) presentaron mejores sobrevivencias en claros. En cambio el crecimiento en altura y diámetro de todas las 9 especies plantadas demostraron mejores crecimientos en claros; especialmente *A. acuminata* y *P. discolor,* las cuales experimentaron hasta 2.5 veces el crecimiento en altura presentado bajo el dosel de plantación. Con estos resultados se puede concluir que el enriquecimiento puede ser una estrategia para emprender procesos de conversión de plantaciones de pinos en ecosistemas más naturales y con mayor funcionalidad.

En resumen los resultados de este estudio demuestran que las especies nativas pueden ser consideradas opciones viables para la reforestación y rehabilitación de diferentes tipos de tierras abandonadas en la región andina del Sur de Ecuador.

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10. Annexes

Annex 1: Species used in the reforestation experiment

Alnus acuminata Kunth

Local names

English: alder, andes alder

Spanish: aile, aliso, ilite, jául, lambràn, lambré, ramrám

Natural distribution and ecological requirements

A. acuminata is native in the high mountains of tropical America from Mexico to Northern Argentina (CATIE 2000a, Salazar & Jøker 2000). It is a fast growing pioneer species that regenerates in open and disturbed areas and which makes it a common tree of montane second growth forests (ICRAF 2007a). It grows in elevations between 700 to 3200 m a.s.l. at temperatures between 4° to 27°C and prefers deep soils with good drainage and high organic matter and pH between 4.6 and 7.0 (Russo 1990, Ruiz 2002). In Ecuador it grows in an ample range until 3400 m a.s.l.

Phenology

A. acuminata is a monoic species. It has more than one flowering per year (Fournier 2002). In southern Ecuador the flowering occurres from September until March and the fructification from December until May (Diaz & Lojan 2004).

Plant propagation

The species can be propagated by seeds, cuttings and natural regeneration. It has more than 2.5 million of seeds per kg (Fournier 2002). The seeds are recalcitrant and lose their viability within few months. Thefore they must be stored in airtight containers at 5°C. No seed pretreatment is necessary. Besides, bare-rooted seedlings and stumps can be used for propagation and direct planting (ICRAF 2007, Añazco 1996). With a height of 20 cm the seedlings are in good condition for planting in the field (Nieto & Rodriguez 2002c).

Plantation and management

A. acuminata had been planted in pure and mixed stands as well as in agroforestry systems (Russo 1990). In Colombia is already planted since the 50s (Del Valle & Gonzalez 1988). The growth amounts to 18 m³/ha*yr (Dunn et al. 1990). Del Valle & Gonzalez (1988), showed mean growth between 10 to 15m³/ha*yr in rotations of 20 years. Van Winkel (1997) found that the potential growing in southern Ecuador could be 10-15 m³/ha*yr. According to Lamprecht (1990) this pioneer species could be more efficient than *Cupressus lusitanica*, *Eucalyptus globulus* and *Pinus patula* in sites between 2000-3000 m a.s.l.. However, in the understory it can be attacked by herbivores, insects on leaves, or fungi such as *Rosellinia bunodes, Colletotrichum* sp and *Phomopsis* sp, which can limit of its growth (CATIE 2000a, Fournier 2002, Nieto & Rodriguez 2002c).

Importance and uses

The potential of *A. acuminata* had been recognized, principally for its capacity of nitrogen fixation, which is estimated to amount to 279 Kg/ha*yr (Russo 1994). It is widely used in plantations and agro-forestry systems. In Colombia is also used for restoration of degraded soils and control of soil erosion (Salamanca & Camargo 2002), in Ecuador for fuelwood (Dunn et al. 1990). According to Reynel & Leon (1990), this species contributed 89.7 of matter organic and 2.31 kg/ha/year of Nitrogen to the soil. The wood is moderately light, with specific gravity between 0.34 to 0.6 g/cm³, and has multiples uses (e.g. building of windows, door, poles paper pulp, fire woods, etc.)

Cedrela montana Moritz ex Turcz

Local names

Spanish: cedro, cedro de montana,
cedro de tierra fría.

Natural distribution and ecological requirements

C. montana is naturally growing from Mexico until North of Argentina. This species grows in altitudes between 1600 to 2800 m with annual precipitation of 500 to 2000 mm and annual temperature of 10 to 20°C. It prefers soils with sandy texture, good drainage, fertility, and also a neutral or alkaline pH (Nieto & Rodriguez 2002a). In Ecuador it grows between 1000 to 3500 m a.s.l. (Borja & Lazo 1990).

Phenology

In the ECSF region (southern Ecuador) the fructification occurres from January to July and in Vilcabamba from December to June (Cabrera & Ordóñez 2004, Diaz & Lojan 2004). The fruits are collected from the trees shortly before they ripen and open (Nieto & Rodriguez 2002a).

Plant propagation

The species can be propagated by seeds and cutting shoots. One kg of seeds has more than 25000 seeds. The seeds must be stored at a temperature of 4 to 5°C, because they lose their viability fast. This species has high rates of germination. Thus, Briceño (2005) registered germination rates between 80 to 95% and the seeds germinated within 5 to 30 days (Nieto & Rodriguez 2002a).

Plantation and management

C. montana has been planted in pure stand. However, this is not recommended because the genus is susceptible to attacks of the *Hypsipyla* budworm larvae (Flores 2002). The *Hypsipyla* nourish of apical meristems and can cause delayed growth and the dying of plants. According to Salamanca & Camargo (2002) this species is a shade tolerant species, and its requests facilitating micro-climatic conditions. Barthloh et al. (2001) presents the example of an 32 years old stand of *C.montana* in Venezuela with approximately 400 trees/ha, a mean DBH of 15 cm and a height of 8 m.

Importance and uses

The species is used to produce furniture, plates such as ornamental and silage (Nieto & Rodriguez 2006a).

Heliocarpus americanus L.

Local names

Spanish: Balsilla, Balsa

Natural distribution and ecological requirements

H. americanus is native in the Andes and Amazonian region. The species is growing between 0 to 2500 m a.s.l., on poor and not very deep soils (Jørgensen & Leon 1999). It is classified as heliophilic and pioneer which colonizes natural and artificial gaps (Killeen et al. 1993, Park et al. 2005).

Phenology

The flowering in the ECSF occurres from February to June and the fructification from May to October (Cabrera & Ordóñez 2004).

Plant production

The propagation can be realized by seeds. However, Cabrera & Ordóñez (2004) reported low rates of germination. Also Ricardi (1999) obtained germination rate of 25%.

Plantation and management

The species is not frequently used for reforestation. However, Davidson et al. (1998) obtained survival rate of 75%. He stated that the major advantage of this species is that it can very rapidly form a dense canopy, and its leaves are relatively rich in nitrogen, phosphate, potassium and magnesium, and could therefore contribute to soil protection and enrichment.

Importance and uses

The wood density is 0.29 g/cm^3 (Richter & Dallwitz 2000). Although the species does not have good wood quality, it can be used for the recuperation of damages and degraded areas.

Juglans neotropica Diels

Local names

English: walnut, tropical walnut

Spanish: nogal, cedro nogal, cedro negro

Natural distribution and ecological requirements

The species is native from Ecuador, Colombia, Perú and Bolivia (CATIE 2000b). It has been developed at altitudes of 1600 to 2500 m a.s.l. with annual temperatures between 14 to 22°C, soils with loose texture, and neutral to slightly acid pH (Nieto & Rodriguez 2002b). In Ecuador it grows between 800-3000 m a.s.l. (Borja & Lazo 1990).

Phenology

In the ECSF region the flowering occurres from November to February and the fruiting occurres between January and June (Diaz & Lojan 2004)

Plant propagation

J. neotropica is propagated by seeds. One kg contains 50 to 200 seeds. The germination rates reach until 80%. A pre-germination treatment recommended is the scarifying of the seeds with sandpaper, but also placing the seed in moist sand for 4 months at 2 to 6 °C.

Plantation and management

There exists no commercial stand in its natural area. However, it has been planted in New Zealand, where it showed fast growth, achievef height grwoth of 1.5 m/yr during the first five first years (National Research Council 1989). In Ecuador, it is widely cultivated at small scale. Moreover, *J. neotropica* is very much susceptible to fire and is used in some restricted agro-forestry combinations due to allelopathic risks (Nieto & Rodriguez 2006b).

Importance and uses

The wood is used for decorative carpentry, production of furnitures and decorative frames (National Research Council 1989). From the leaves extracts and medicinal pigments can be obtained (Sørensen & Schjellerup 1995). The roots of Juglans are associated with ectomycorrhizae (Francis & Alemañi 1994).

Tabebuia chrysantha (Jacq.) Nichols

Local names

Spanish: guayacan, tajibo, guayacan Amarillo, roble amarillo, amarillo, cortez

Natural distribution and ecological requirements

T. chrysantha is distributed from Mexico to South of Brazil in dry and humid climate, between 0 to 1000 m a.s.l., with annual precipitations of 1500-3000 mm, and annual temperatures between 18-23 ºC (CATIE 2000c). In Ecuador, the species grows in different ecologica conditions, e.g. in dry and arid environments, and at very humid sites like the ECSF in southern Ecuador. Most species of *Tabebuia* are durable heliophytes of low growth and require larger gaps for good development (Justiniano et al. 2000).

Phenology

T. chrysantha is a deciduous species (Sánchez et al. 2004). The flowering is related with the dry season. In the ECSF, the harvesting of seeds can be realized from December to January (Cabrera & Ordoñez 2004).

Plant propagation

The species can be propagated by seeds and stakes. However, the germination is very variable. Thus, Ricardi (1999) found only 7% germination while Briceño (2005) registered germination percentages over 90%. This aspect can be related with the short seed viability of about three months (Cabrera & Ordoñez 2004; Justiniano et al. 2000). According to CATIE (2000c) the seedlings need 6 months in the nursery befor planting in the definite field.

Plantation and management

Stands of *T. chrysantha* in Puerto Rico had annual growth in height of 0.5 m and 1 cm in diameter, and 1.5 m^2 of basal area per hectare; while in natural forest the annual increase in diameter was from 0.28 to 0.39 cm (Weaver 1990).

T. rosea in Sri Lanka showed growth rates of 9 m in 3 years (ICRAF 2007b), while in Colombia pure stands grew 1.7 m/year in height and 1.9 cm/year in diameter. Some species of Tabebuia showed good performance on open sites, but obtained stem with branches (Justiniano et al. 2000). Regeneration is abundant in natural gaps and the growth rate varies according to defoliation during the year, for example in October it increases considerably (Merkl 2000).

Importance and uses

The wood of *Tabebuia* genus is one of the hardest and heaviest of the Neotropics. For this reason it is used to produce furniture and marine construction. The wood is hard and heavy with a specify weight of 0.95 to 1.25 g/cm^3

Eucalyptus saligna Sm.

Local names

English: Sydney blue gum, saligna gum, blue gum

Spanish: saligna, eucalipto

Natural distribution and ecological requirements

E. saligna is native from Australia in regions with altitude between 0 to 2100 m a.s.l.; precipitation from 800 to 4000 mm; annual temperature of -2 to 33 °C; soils generally moist, tolerating acidity (ICRAF 2007c, Ruiz 2002).

Phenology

Seed production commences when the tree is about 8 years old. The maturation of the capsules is about 6 months after the flowering.

Plant propagation

The species can be propagated by seed and spikes from superior trees. There are more that 60000 seeds in one kilogram. The germination begins from 4 to 16 days (Nieto & Rodriguez 2002d). However, the germination rate is only about 20-25% (ICRAF 2007c).

Plantation and management

There are more than half a million hectares of successful plantations outside Australia (ICRAF 2007c). The annual average growth ranges from 10 to 55m³/ha (Ruiz 2002). The species has proved to be highly suited for short rotation plantations in tropical regions; thus rotations of 6-10 years are used for producing fuel wood and pulpwood (ICRAF 2007). The plantations of *E. saligna* had been damaged by some pest and diseases.

Importance and uses

The wood density ranges from 0.5 to 1.0 g/cm³. It is used for furniture, frame to musical tools, boards, pulp (ICRAF 2007c, Ruiz 2002). It si also used for light constructions (Nieto & Rodriguez 2002d).

Pinus patula Schiede and Deppe.

Local names

English: Mexican weeping pine, jelecote pine, pine

Spanish: pino triste, pino patula, pino chino, ocote, pino.

Natural distribution and ecological requirements

P. patula originates from Mexico. Its ecological requirements are: altitude from 900 to 3200 m a.s.l.; annual average precipitation of 750 to 2000 mm; annual temperatures between 10 to 28 °C; deep soils with good drainage, acid and good moisture (Ruiz 2000)

Phenology

P. patula is a monoic species. The female flowers are usually borne in the upper crown, and the male ones in the lower crown (Gillespie 1992, ICRAF 2007d). The flowering in natural region occurs from January to April (Gillespie 1992).

Plant propagation

The species is propagated by seeds and it has a germination rates from 75 to 90%. Pre-sowing treatment is not necessary (Gillespie 1992, ICRAF 2007d).

Plantation and management

Species is planted outside of Mexico in pure and mixed stands, and it have been successful in many places until 40° south and North (Gillespie 1992). In the tropical regions it achieves fast growth, for instance increases of 35 m^3/ha at good sites (Gillespie 1992). According to Lamprecht (1990), in rotation of 30 years, the total output was between 460-490 m^3/ha and the annual increment was 10-40 m^3/ha. The species has a good growing in soils with litter accumulate, but with the significant proportion of Nitrogen and Phosphor (Dames et al. 2002). There is evidence ofor presence of micorrhizal fungi that improve the growth. It is heliophyt with fast growth.

Importance and uses

P. patula is an appreciated species due to its fast growth and its multiples uses. The wood density is from 0.4 to 0.6 g/cm^3 (Ruiz 2002). The wood is used for light constructions, fuel wood, pulp, paper and sawtimber (Gillespie 1992, ICRAF 2007)

Annex 2: Additional species used in the enrichment experiment

Cinchona officinalis L.

Local names

English: red cinchona ark

Spanish: quina, quino, quinina, cascarilla.

Natural distribution and ecological requirements

The genus *Cinchona* is native at the eastern slopes of the Amazonian area of the Andes from Colombia to Bolivia (ICRAF 2007e). In Ecuador its main distribution is the southern Ecuador in regions with high precipitation and moisture. *C. pubescens* grows in altitudes between 300-3900 m a.s.l. mean annual temperature of 10 – 23 ºC and annual rainfall from 1020 to 3800 mm.

Phenology

In South Ecuador the flowering and fruiting occurres during all the year, except on March (Díaz & Lojan 2004). The fruits mature about 7-8 months after flowering. Seed are surrounded by a paper wing facilitating wind pollination.

Plant propagation

C. officinalis is commonly propagated by seeds and cuttings (INEFAN 1996). Its germination is about 50%, thus Díaz & Lojan (2004) found germination rates of 40% starting after 12 dayw and culminate at 30 days. Leischner (2005) registered survival of up to 90%.

Plantation and management

The *Cinchona* species are cultivated in many tropical countries for their commercial value. Thus, *C. pubescens* has long been cultivated as the source of quinine, an anti-malarial drug. It was introduced to Europe in 1640s. Large plantations in India, Java and Sri Lanka (Ceylon) supplied almost 95% of the world's requirements of quinine until the Second World War (ICRAF 2007e). However, sometimes this species showed aggressive behaviour concerning indigenous vegetation, e.g., in the Hawaiian Islands (Starr et al. 2003). *C. pubescens* grows in average among 1-2 m per year. And there are many systems for planting, for instance in Congo a common intensive system consists in planting between 10000-12000 seedlings per hectare and 10 year harvesting (ICRAF 2007e).

Importance and uses

The quinine is the principal product, the quinine is an alkaloid used to control malaria (Madsen 2002). Besides, these species are used for production of quinine water, tonic water and as food additive (ICRAF 2007e). Cinchona is included in ´Top Ten Plants´ that have influenced Humankind (Minter 2005).

Cupania cf americana L.

Local names

English: candlewood, maraquil

Spanish: guara

Natural distribution and ecological y requirements

The genus *Cupania* is distributed predominantly in neotropic regions (Sommer & Ferrucchi 2003). *C. americana* grows from center America to Venezuela, in areas with an annual precipitation of 1400-2600 mm. This species is relatively indifferent to soil conditions (Francis 1999).

Phenology

In Southern Ecuador the flowering is from December to March and the fruiting is between May to November (Díaz & Lojan 2004).

Plant propagation

The propagation of *C. americana* can be done by seeds. The germination rate is between 25 to 56 % and appears during 58 days (Ricardi 1999, Francis 1999). In south Ecuador Diaz & Lojan (2004) found high germination rates with fresh seeds and seeds under cold storage for three months.

Plantation and management

C. americana has been planted in Costa Rica and showed a growth in height of 0.34 m per year during the first 7 years. However in experiments in Trinidad and Tobago it grew about 1 m per year (Francis 1991). In natural forests this species has increments in height of 23 cm/year. The species is attacked by insects and the wood is susceptible for *Cryptotermes brevis*.

Importance and uses

The wood has specific gravity between 0.55-079 g/cm³. It is moderately light and easy for work (Francis 1991).

Isertia leavis (Triana) B. Boom

Local names

Spanish: Lechoso, tabaquillo, Asaquiro,

Natural distribution and ecological requirements

I. laevis is distributed from southern Nicaragua through South America as far as northern Bolivia and occurs in humid forests, mainly in disturbed sites (Gentry 1993, Killeen et al. 1993). In Bolivia it grows in tropical mountain rainforests in 1600 m s.a.l. (Killeen et al. 1993). In the ECSF area it grows in an altitudinal range between 1600 to 2000 m a.s.l., and in disturbed sites and like remnants trees.

Phenology

The species has its flowering during most all year, except July, August and September. In the ECSF the flowering occurres during all the year, except from September to December, and the fruiting occurres also all year, except March and April (Cabrera & Ordoñez 2004).

Plant propagation

The propagation can be done by seeds. Cabrera & Ordóñez 2004 found 11% of germination in the laboratory.

Plantation and management

I. laevis is not used in plantations. However, in the ECSF, the species showed good performance, especially when planted in gaps und pine (Aguirre et al. 2006).

Importance and uses

The leaves had been used as anti-cancer, and for skin infection. Moreover the genus *Isertia* is used to recover areas affected by fire.

Myrica pubescens H & B ex Willdenow

Local names

Spanish: laurel de cera, cebillo, cebo

Natural distribution and ecological requirements

M. pubescens occurs naturally in Southern America. This species showed well adaptation in regions with elevations between 1.500 and 3.100 m a.s.l., poor soilsa nd landslides. It colonizes disturbed sites in the first steps of succession (Killeen et al. 1993, Jorgensen & Leon 1999).

Phenology

The phenology of this species is variable; for example at the ECSF the flowering occurs from October to June and fruiting from December to April (Cabrera & Ordóñez 2004). In contrast, in Vilcabamba the flowering and fruiting is present during all year (Diaz & Lojan 2004).

Plant propagation

The species can be propagated by seeds. There are more that 50000 seeds/kg and 2 kg per tree (Ordóñez et al. 2001). Mogrovejo (1999) found germination rates of 30%.

Plantation and management

There is on documentation for commercial plantation of *M. pubescens*. However in experimental plantations Aguirre et al. 2006 found survival rates over 90% and growth in height of around 50 cm per year. Also Gurvich et al. 2003 found that the species would be likely to establish under more limiting conditions through their slow growth and stress tolerance.

Importance and uses

M. pubescens has a large root system and can form symbiosis with nitrogen fixing bacteria. Therefore, the species is indicating to the recuperation of areas with erosion (Muñoz & Luna 1999). Furthermore, its fruits are used for medical purposes and for preparing extracts of aromatic essences (Killeen et al. 1993).

Piptocoma discolor (Kunth) Pruski

Local names

Spanish: laurel de cera, cebillo, cebo

Natural distribution and ecological requirements

P. discolor is native in the coastal, mountainous and Amazonian regions of Ecuador (Jørgensen & León-Yanez 1999). It is a pioneer species of second growth.

Phenology

Piptocoma flowers during the less humid months. It requires 3-4 months from flowering to maturation of the achenes (Bendix et al. 2006). In the ECSF the species has the flowering between June and September, the fruiting from August to February (Cabrera & Ordóñez 2004).

Plant propagation

This species can be propagated by seeds. Cabrera & Ordóñez (2004) found 22% of germination under laboratory conditions.

Plantation and management

Davidson et al. (1998) in plantation experiments in the Amazonian region of Ecuador found that survival rate of *P. discolor was* 96 % in the first 2.5 years after planting and the growth in height was of 320.7 cm and in diameter was of 72.9 mm. He also described the species as a fast growing pioneer, which should be promoted to reestablish tree cover in degraded lands. In addition the species has a good natural regeneration which could be an option for natural forest establishment.

Importance and uses

The wood is used for construction purposes (Killen et al. 1993). It is rather soft and used for boarding and fruit crates. The species has a high content of alkaloids and tannin (Merkl 2000).

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