Dendrometry and litterfall of neotropical pioneer and early secondary tree species

Glaci Benvenuti-Ferreira[1], Geraldo Ceni Coelho[2,4], Jorge Schirmer[3] & Osório Antônio Lucchese[3]

[1]Universidade Regional do Noroeste do Estado do Rio Grande do Sul – UNIJUÍ
Ijuí, RS, Brazil, e-mail: glabenvenuti@hotmail.com
[2]Departamento de Biologia e Química,
Universidade Regional do Noroeste do Estado do Rio Grande do Sul – UNIJUÍ,
Rua do Comércio, 3000, CEP 98700-000, Ijuí, RS, Brazil
[3]Departamento de Estudos Agrários,
Instituto Regional de Desenvolvimento Rural – IRDeR,
Universidade Regional do Noroeste do Estado do Rio Grande do Sul – UNIJUÍ,
Rua do Comércio, 3000, CEP 98700-000, Ijuí, RS, Brazil
[4]Corresponding author: Geraldo Ceni Coelho, e-mail: cenicoelho@gmail.com

BENVENUTI-FERREIRA, G., COELHO, G.C., SCHIRMER, J. & LUCCHESE, O.A. **Dendrometry and litterfall of neotropical pioneer and early secondary tree species**. Biota Neotrop. 9(1): http://www.biotaneotropica.org.br/v9n1/en/abstract?article+bn01109012009.

Abstract: The increased forest cover loss in the tropical and subtropical regions has stimulated the development of restoration methods through tree plantations. Based on the successional model of forest development the use of different successional groups can be seen as a strategy to accelerate the re-composition of forests and an attempt to recover ecological conditions prior to disturbance. Tree species have particular growth rates and ecological needs, and this knowledge is important in the development of high diversity models of forest restoration. The objective of this study was to compare the initial growth and litterfall of native pioneer versus early secondary tree species in a mixed plantation system, and to determine the relationships between guilds and measurements. The comparison among species and guilds was made based on dendrometric and allometric parameters, and in terms of annual litterfall. The study was carried out in the Guarita Indian Area, Tenente Portela, Rio Grande do Sul, Brazil. Dendrometry of seven species was evaluated, including the pioneer tree species *Mimosa scabrella* Bentham, *Trema micrantha* (L.) Blume, *Schinus molle* L., *Enterolobium contortisiliquum* (Vell.) Morong, and the early secondary tree species *Peltophorum dubium* (Spreng.) Taub., *Cedrela fissilis* Vell. and *Tabebuia alba* (Cham.) Sandwith. The litterfall was quantified for the first six species. The pioneer tree species exhibited higher average height, stem diameter and crown width than the early secondary tree species. The pioneer species (except *E. contortisiliquum*) showed also higher values of average annual litterfall. A positive interspecific correlation between stem diameter and annual litterfall was observed. The data indicate that the choice of the species and guilds is significant to the quality of the restoration. Nevertheless, the aboveground architecture may depend on species-specific allometric characteristics and a distinction among guilds was not observed.
Keywords: *restoration ecology, secondary succession, allometry, successional guilds.*

BENVENUTI-FERREIRA, G., COELHO, G.C., SCHIRMER, J. & LUCCHESE, O.A. **Dendrometria e produção de serapilheira de espécies arbóreas neotropicais pioneiras e secundárias iniciais**. Biota Neotrop. 9(1): http://www.biotaneotropica.org.br/v9n1/pt/abstract?article+bn01109012009.

Resumo: A perda de cobertura florestal em regiões tropicais e subtropicais tem motivado o desenvolvimento de modelos de restauração florestal através do plantio de espécies arbóreas. Tendo como base o modelo sucessional, o uso concomitante de espécies de diferentes categorias sucessionais pode ser visto como uma estratégia no sentido de acelerar o retorno a condições prévias à perturbação. As espécies arbóreas têm ritmos de crescimento e necessidades ecológicas diferentes e este conhecimento é importante para o desenvolvimento de modelos de restauração florestal com alta diversidade. O objetivo deste estudo foi comparar o crescimento inicial e a queda anual de serapilheira de espécies arbóreas nativas pioneiras e secundárias iniciais em um sistema heterogêneo de plantio, determinando a correlação entre categorias sucessionais e medidas. A comparação entre espécies e categorias foi realizada considerando parâmetros dendrométricos e alométricos, e a queda anual de serapilheira. O estudo foi conduzido na Área Indígena Guarita, Tenente Portela-RS, Brasil, para sete espécies, incluindo as pioneiras arbóreas *Mimosa scabrella* Bentham, *Trema micrantha* (L.) Blume, *Schinus molle* L., *Enterolobium contortisiliquum* (Vell.) Morong, e as secundárias iniciais *Peltophorum dubium* (Spreng.) Taub., *Cedrela fissilis* Vell. e *Tabebuia alba* (Cham.) Sandwith. A avaliação da produção da serapilheira foi feita nas primeiras seis espécies. As espécies pioneiras apresentaram maiores médias de altura, diâmetro do fuste e largura da copa. As pioneiras (com exceção de *E. contortisiliquum*) também apresentaram valores médios mais elevados de queda de serapilheira. Uma correlação interespecífica entre diâmetro do caule e produção anual de serapilheira foi observada. Os dados indicam que a escolha das espécies e guildas tem influência significativa sobre a qualidade da restauração. Entretanto, a arquitetura da parte aérea depende das características alométricas específicas das espécies e uma distinção entre guildas não foi verificada.
Palavras-chave: *restauração ecológica, sucessão secundária, alometria, categorias sucessionais.*

Introduction

The loss of forest cover and soil fertility in the tropics has stimulated the development of different models of ecological restoration. Strategies of forest restoration include imitating natural secondary succession, direct seed sowing, monospecific or mixed tree species plantation (Holl et al. 2000, Martinez-Garza & Howe 2003), or even nucleation with key species which could favor the succession (Reis et al. 2003). In several cases, the seedling plantings constitute a necessary step to obtain satisfactory regeneration since others strategies such as direct sowing or natural regeneration have not produced the expected results (Parrotta & Knowles 1999, Camargo et al. 2002). Additionally, tree establishment contributes to a fast recovery of ecological processes and parameters e. g. the incremental accumulation of litter, nutrient cycling, and the increase in faunal and floral diversity (Carlo et al. 2003, Ruiz-Jaén & Aide 2005).

Models of restoration based on a heterogeneous pool of tree species of different successional status have been proposed in Brazil over the last two decades (Kageyama et al. 1989, Knowles & Parrotta 1995, Kageyama & Gandara 2000, Kageyama et al. 2003) and more recently in Asia (Shono et al. 2007). In these models it is assumed that the combination of guilds (pioneer, secondary and shade-tolerant tree species) can accelerate the return to the conditions prior to disturbance, in terms of floristic structure and soil biogeochemistry. Besides, some authors state that monospecific plantations, particularly some long lived pioneer tree species, can hinder the return of later successional species (Martinez-Garza & Howe 2003). On the other hand, some observations indicate that species are different in terms of contribution and interference to the restoration process (Powers et al. 1999, Meli 2003), which could be related to the successional guilds (Rodrigues & Gandolfi 2000). Few experimental tests have been made to validate these models or to determine differences among guilds which could interfere in the restoration. Given the ecophysiological heterogeneity of tree species (Falster & Westwoby 2005), the knowledge of silvicultural and ecological parameters can facilitate planning forest restoration (Knowles & Parrotta 1995).

Allometry research allows modeling the space required by the trees during development. In the forest restoration sucessional model, the early successional species shade the late successional ones in the first years (Kageyama et al. 1989). In general, pioneer tree species have higher growth rates (Botelho et al. 1996, Souza & Válio 2003, Laurance et al. 2004, Nascimento et al. 2005), and respond better to fertilizers (Walker et al. 1996). Additionally, pioneer tree species respond positively to liming, for example *T. micrantha* (Adamski & Coelho, 2008). On the other hand, there are indications that the secondary tree species are more exigent in terms of nutrient availability, due to their lower efficiency in nutrient uptake (Gonçalves et al. 1992). However, the growth superiority of the pioneer tree species may not be universal. *P. dubium* and *Cordia trichotoma* Vell. attained higher heights 18 months after plantation when compared to the pioneer tree species *Schinus terebinthifolius* Raddi and *Maclura tinctoria* (L.) D. Don (Coelho et al. 2003).

Besides the faster growth rates, pioneer tree species exhibited higher litterfall rates (Leitão Filho 1993, Martins & Rodrigues 1999). Nevertheless, empirical comparisons among guilds in relation to annual litterfall with neotropical species are rare, especially with even aged, mixed plantations.

Our work was aimed at comparing the dendrometry, allometry and litterfall of native pioneer versus early secondary tree species in a mixed plantation system, verifying relationships between the guilds and measurements. The comparison among species and guilds was made based on dendrometric and allometric parameters, and in terms of annual litterfall. The hypothesis addressed here is that the dendrometry, allometry and litterfall differentiate not only the species but also the different successional categories.

Materials and Methods

1. Sites

The studied plantations were created as an environmental amelioration and forest restoration program in the Guarita Indian Area, Rio Grande do Sul, Brazil. The sites were previously subjected to severe deforestation and soil degradation by intensive monocultures and slash-and-burn agriculture.

The Guarita Indian Area is located in the Tenente Portela, Miraguaí, Erval Seco and Redentora municipalities, in the Uruguay River basin and its affluent Guarita River, Rio Grande do Sul State, Brazil. The remnant forest is classified as Seasonal Forest. The climate is perhumid subtropical, with average annual temperatures of 19 °C and annual rainfall of 1.800 mm (Maluf 2000). Rainfall in the year of the seedling planting was 1.442 mm (2004), and thereafter it was 2.053 mm (2005) and 1.593 mm (2006), in Tenente Portela - RS, 10 km away from the studied sites (data supplied by cooperative COTRIJUÍ). The study was carried out in two sites named RC (27° 29' 46" S and 53° 37' 37" W) and FF (27° 24' 22" S and 53° 43' 37" W).

The prevalent soils in the area are classified as oxisols and inceptisols (USDA, 1999). The physico-chemical profile of the sites is shown in Table 1 (provided by UNIJUÍ Soil Laboratory, 2004, and obtained under the recommendations of Tedesco et al. 1995). The soils samples were collected on each site in the 5-20 cm depth interval, through the sum of ten subsamples of nearly 100 g each one, distributed at random. The soil subsamples were mixed and homogenized prior to the analysis.

On each site the terrain was subsoiled and 5.0 $mg.ha^{-1}$ of dolomitic lime was incorporated at a 20 cm depth. A granulated NPK fertilizer (04-14-08) was mixed with the soil around the seedling at the moment of planting.

The seedlings were produced in individual conic containers (75 cm^3) in the Viveiro Regional, IRDeR/FIDENE, Augusto Pestana and were planted at densities of 1,667/ha (3 x 2 m). The seedling's size ranged from 20 to 30 cm for all the species and they were 4-6 months old at plantation time. Each study site included an area of 3 ha that was planted (between July and August 2004) with seedlings of 38 native tree species of different successional groups in a mixed system. The survivorship after eight months was less than 50% (Lucchese et al. 2005), in this way the spacing among trees was in fact more than 3 x 2 m in the major part of the period under evaluation, and can be considered random, considering that the dead trees were distributed by chance.

Only seven species were included in this study, given the low capability of surviving or reduced growth of the others (Lucchese et al. 2005). The species evaluated were the pioneer tree *Schinus molle* L., *Mimosa scabrella* Bentham, *Trema micrantha* (L.) Blume and *Enterolobium contortisiliquum* (Vell.) Morong, and the early secondary tree *Peltophorum dubium* (Spreng.) Taub., *Cedrela fissilis* Vell. and *Tabebuia alba* (Cham.) Sandwith. Nonetheless, *T. alba* was not included in the annual litterfall quantification. The species classification into guilds followed Carvalho (1994) who oriented his classification based on Budowski (1965).

In both sites, annual crop plants, mainly maize, beans and peanuts, were cultivated among the lines of tree seedlings between 2004 and 2005. However, in the FF site the annual plantation was abandoned e.g. the crop seeds were sowed but the crops were not harvested, and that is assumed here as the only difference between the sites in terms of crop cultivations.

2. Dendrometric parameters

The growth is here evaluated through an instantaneous measurement 2 years and 9 months after planting, and considering that the average size of the seedlings was not different among the species. Fifteen trees for each species were measured at both sites, totalizing 30 plants per species. Height (h), stem diameter at 1.3 m above the soil (d) and crown width (w) were measured with a metric pole, a paquimeter and a metric tape, respectively. The crown width (w) was estimated as the geometric average of two measures of North/South and East/West axes. From the primary data the indexes h/w and h/d were calculated.

3. Litterfall

Two traps of 0.5 x 0.5 m were set up under each of four trees per species, 20 cm above the soil and 50 cm from the plant, totalizing eight traps per species, and only in the RC site. The traps were set up in the proximity of the trees since the plantation was heterogeneous and the contamination by litter from other trees could be minimized in such way. In addition, any materials from other species were discarded. The traps had a nylon net bottom with 1.0 x 1.0 mm mesh. The intercepted litter (leaves, flowers, fruits, stalks) was gathered regularly at intervals of ca. 30 days between December 2005 and November 2006. The litter was dried in an air forced circulating oven during 24 hours at 40 °C, and weighed thereafter.

4. Experimental design and statistical procedures

The experimental design was completely randomized and the values data were transformed according to the square root of $(X + 0.5)$ (Zar 1995). The dendrometric and allometric data and the indexes (h, d, w, h/w and h/d) were submitted to a two-way ANOVA with species and site as independent variables. The annual litterfall data was analyzed through a one-way ANOVA. A Tukey test was used for multiple comparisons among the means ($\alpha = 5\%$).

Results

Both species and sites presented significant differences in primary dendrometric parameters (h, d, w). The two factors, species and sites, did not show a significant interaction (Table 2). Pioneer tree species attained greater height than the early secondary species after the first 33 months of growth (Figure 1). Among the pioneer species, *M. scabrella* (5.49 m) attained a significantly higher height than the other species (*S. molle* - 3.65 m, *T. micrantha* - 3.33 m and *E. contortisiliquum* - 3.43 m).

The pioneer tree species also attained larger stem diameters after 33 months (Figure 1), especially *M. scabrella* with an average value of 10.2 cm. *S. molle*, *T. micrantha* and *E. contortisiliquum* had diameters between 6.0 and 8.0 cm. The mean stem diameters of the early secondary tree species were all under 4.0 cm. Pioneer tree species likewise had larger crown widths than the early secondary species (Figure 1).

Allometric indexes differed significantly between species, but not between sites (Table 2). Furthermore, the differences among species were not related to the sucessional status. As a whole, pioneer tree species were not different from the early successional tree species (Figure 1). *T. alba* had the highest h/w value, and *P. dubium* and *T. alba* had the highest h/d values (Figure 1).

Species showed significantly different mean values of annual litterfall (one-way ANOVA, $F = 61.11$, $df = 47$, $P < 0.0001$). Although pioneer tree species as a group were not significantly different from early secondary tree species, the pioneer tree species had remarkably higher litterfall deposition values, with the exception of *E. contortisiliquum* (Figure 1).

Across species, all dendrometric variables were high correlated with litter production: crown width ($r^2 = 0.81$, $P = 0.015$), stem diameter ($r^2 = 0.79$, $P = 0.019$) and height ($r^2 = 0.77$, $P = 0.022$).

Table 1. Physico-chemical profile of the soils in the experimental areas, Guarita Indian Area, Rio Grande do Sul State, Brazil, June 2004.

Tabela 1. Perfil físico-químico dos solos das áreas experimentais na Área Indígena Guarita, Rio Grande do Sul, Brasil.

	clay %	pH	P	K	O.M.	Al	Ca	Mg	H + Al	CEC (pH 7,0)
			(mg.dm^{-3})		(%)	(cmolc.dm^{-3})				
RC	56	5.2	< 3.0	200	2.1	0.1	4.3	0.6	4.9	10.3
FF	22	5.8	5.2	196	3.0	0.0	8.5	2.2	3.9	15.1

Table 2. Two-way ANOVA summary for the effects of species, site and its interaction on height (h), stem diameter (d), crown width (w) and the allometric indices.

Tabela 2. Sumário dos efeitos de espécie, sítio e sua interação sobre a altura (h), diâmetro do caule (d), largura da copa (w) e os índices alométricos, analisados por ANOVA de dois fatores.

	Mean square					
	DF	h	d	w	h/w	h/d
Species (Sp)	6	56.44***	292.00***	42.53***	8.62***	12.86***
Sites (Si)	1	16.04***	112.20**	16.63***	1.40$^{n.s.}$	1.78$^{n.s.}$
Sp x Si	6	0.95$^{n.s.}$	12.95$^{n.s.}$	1.34$^{n.s.}$	0.21$^{n.s.}$	1.38$^{n.s.}$
Error	196	0.54	9.73	0.74	0.76	1.18
Total	209	-	-	-	-	-

n.s. indicates P > 0.05, **P < 0.001 and ***P < 0.0001.

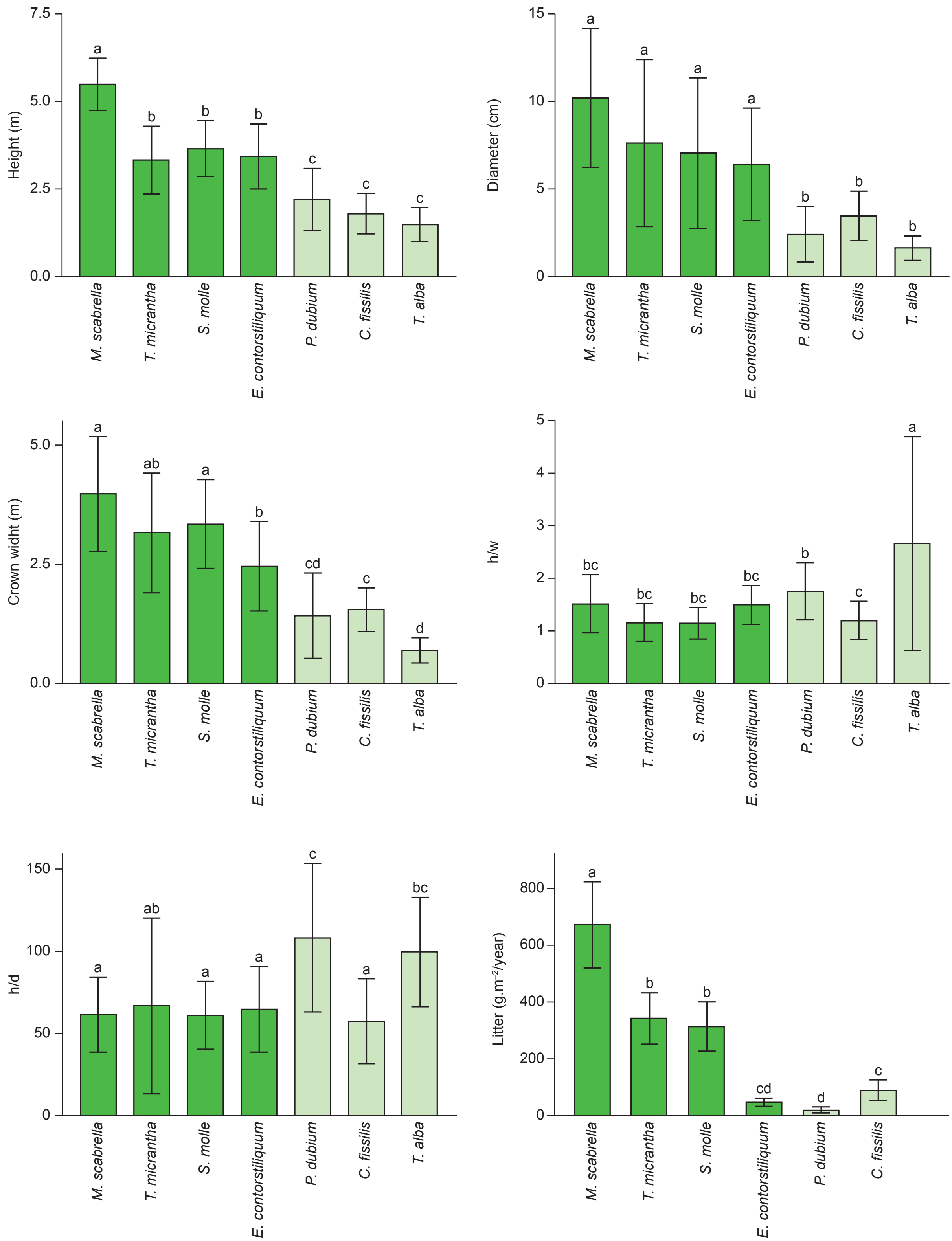

Figure 1. Dendrometric parameters, height (h), stem diameter (d) and crown width (w), allometric ratios, h/w and h/d, and annual litterfall at Guarita Indian Area, Brazil. The letters indicate differences on the Tukey test ($\alpha = 0.05$). The pioneer tree species are represented by dark columns and early secondary tree species by light columns.

Figura 1. Parâmetros dendrométricos – altura (h), diâmetro do caule (d), largura da copa (w), índices alométricos (h/w e h/d), e produção anual de serrapilheira na Área Indígena Guarita, Brasil. As letras indicam diferenças com base no teste de Tukey ($\alpha = 0.05$). As espécies pioneiras são representadas por colunas escuras e as secundárias iniciais por colunas claras.

Discussion

1. Dendrometry and allometry

The allometric ratios (h/w and h/d) can indicate how a plant allocates its energy. There can be a more pronounced investment in height, in stem structure or in lateral ramifications, which could modify the relative crown width. The h/w index is sometimes used to evaluate the growth features of the trees, and may be related to the successional status (Davies et al. 1998; Barbosa 2000, Yamada et al. 2000).

As ephemeral and light demanding species, pioneer tree species are supposed adapted to quickly occupy open spaces. However, differences in terms of h/w between the pioneers and early successional tree species as groups were not observed in Guarita plantings. Only *T. alba* had a higher h/w mean value, matching the monopodial architecture reported in this species (Longhi 1995). The results indicates that the pioneers tree species simply grow more rapidly in height, stem diameter and crown width, but maintain a similar architecture to the slower growing early successional species *P. dubium* and *C. fissilis* when submitted to an equivalent condition.

On the other hand, two early successional species, *T. alba* and *P. dubium* did exhibit significantly higher h/d ratios. This data suggests a different architecture, e.g. greater height for a given stem diameter, which could be an adaptation to the light competition during early life stage and/or early succession stage. High h/d ratio is positively related with shade tolerance (Davies et al. 1998). These species may not require full sunlight to the initial growth and thus may develop in more shaded forest environments, a feature typical of non-pioneer tree species (Denslow 1980, Gandolfi 2000, Yamada et al. 2000).

An interaction between sites and species was not observed (Table 2), what suggests that differences among species do not depend on site on which the plants were grown.

The low h/w and h/d values of *C. fissilis* may be explained by the incidence of the insect borer *Hypsipyla grandella* Zeller, which destroys the terminal buds (Carvalho 1994, Durigan & Pagano 2004). These larvae damage the apical meristem, reducing the height growth and promoting the development of lateral buds. This Lepidoptera was observed in our study sites.

2. Litterfall

Our data is in agreement with the hypothesis that the pioneer tree species have higher litterfall deposition (Leitão Filho 1993, Martins & Rodrigues 1999), with the exception of data from *E. contortisiliquum*. Meanwhile, there is some controversy in the classification of this species among the pioneer tree species or the secondary tree species (Carvalho 1994, Ruchel et al. 2007). The contribution of *E. contortisiliquum* to nutrient cycle and soil carbon accumulation tends to be lower than the other pioneer tree species analyzed.

The higher litterfall of the pioneer tree species is related to a high foliage turnover and a short leaf life span (Chabot & Hicks 1982), which implies a salient contribution to increase the fertility of the upper soil horizons especially in the secondary succession (Ruiz-Jaén & Aide 2005).

The highest litterfall of *M. scabrella* (671 $g.m^{-2}$/year) is far distinguished from the other tree species. This species, planted at a site degraded by bituminous schist in Paraná State, reached an average litterfall of 630 $g.m^{-2}$/year between four and five years of age (Chiaranada et al. 1983) and 479 $g.m^{-2}$/year between four and nine years of age at the same site (Poggiani et al. 1987), and also 705 $g.m^{-2}$/year between two and three years old in Botucatu, São Paulo State (Bertalot et al. 2004).

The early secondary forests tend to present lower litter deposition than the mature forest (Ruiz-Jaén & Aide 2005). The litter deposition of *M. scabrella* with ca. 2 years old approaches the mature forest since the litterfall in the Seasonal Forest ranges between 776 and 920 $g.m^{-2}$/year (Cunha et al. 1993, König et al. 2002). Nevertheless, the litterfall could be overestimated in the present study by the position of the litter traps close to the trees. In spite of that, the data indicates that *M. scabrella* could represent a noteworthy contributor in the succession process, especially to above-ground biomass accumulation and nutrient cycling, when compared with the other evaluated species.

M. scabrella in monocultural plantations presents a putative high biomass accumulation (Somarriba & Kass 2001) and a high contribution in terms of nitrogen accretion due to its symbiotic fixation (Carvalho, 1994).

The significant correlation between stem diameter and annual litterfall among the different tree species suggests that such correlation could be true in interspecific comparisons, at least among pioneer and early secondary tree species, as the intraspecific correlation observed by Adu-Bredu & Hagihara (2003). On the other hand, crown width seems to be as good predictor of litter production as stem diameter, in these early stages of succession.

M. scabrella and *T. micrantha* are short-lived species (Carvalho, 1994), which presented fast growing and high litterfall. In such way these pioneer tree species fulfill important goals in the forest restoration (Parrotta & Knowles 1999, Martinez-Graza & Howe 2003): fast basal area and biomass accumulation and avoidance of succession obstruction caused by plantations with only long-lived pioneer tree species.

The greater dendrometric values and annual literfall of the pioneers tree species suggest that the inclusion of such species can accelerate the succession process through nutrient cycling and biomass accumulation. Further researches could contribute by confirming if differences observed in the initial growth period, reported in the present paper, will result in a significant interference in the long-term succession processes. In addition, other comparisons in the same environmental conditions could test if there are differences in the architecture of late sucessional species and the pioneer and early secondary species.

Conclusions

In general, pioneer tree species presented higher values than early successional tree species in the dendrometric characteristics height, crown width and stem diameter. On the other hand, the two groups share similar allometric ratios. Pioneer tree species also tend to produce higher annual litterfall, and there is a correlation between dendrometric parameters and litterfall. Therefore, the choice of guilds can be significant to restoration plans.

Acknowledgements

To the Kaigang community for the permission to carry out the study, to Fundação de Apoio à Pesquisa do Estado do Rio Grande do Sul - FAPERGS (ProCoredes 04/0556.3) for the financial support and first author fellowship, to José Antonio Gonzales da Silva and Sandra V. Fernandes (UNIJUÍ – Universidade Regional do Noroeste do Estado do Rio Grande do Sul) who provided statistical assistance and the soil information, respectively. Ubiratã Soares Jacobi (Fundação Universidade de Rio Grande) reviewed the manuscript and Letícia Lanius and Andressa Felipin made the English review.

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Data Received 13/03/08
Revised 13/12/08
Accepted 21/01/09