A COMPARATIVE STUDY OF FOUR TREE SPECIES USED IN RIPARIAN FOREST RESTORATION ALONG URUGUAY RIVER, BRAZIL[1]

Alexandre Hüller[2], Geraldo Ceni Coelho[3], Osório Antônio Lucchese[4] e Jorge Schirmer[5]

ABSTRACT – Silvicultural and ecological knowledge about tree species is basic to restoration planning, particularly in high diversity regions. Here we present a comparison of four native tree species from the middle Uruguay River basin, Brazil-Argentine frontier: *Heliocarpus americanus* L. (Malvaceae), *Maclura tinctoria* (L.) D. Don ex Steud. (Moraceae), *Schinus terebinthifolius* Raddi (Anacardiaceae) and *Cordia trichotoma* (Vell.) Arrab. ex Steud. (Boraginaceae). We obtained data on initial growth, light interception, litterfall and litter mineral contents. *H. americanus* presented the greatest height and the lowest value of height/crown width ratio. *H. americanus* and *M. tinctoria* presented the highest light interception rate (>94 %) and highest litterfall (879 ± 151 and 792 ± 164 $g \cdot m^{-2} \cdot year^{1}$, respectively). For the set of species, the lowest litterfall occurred between July and September. *H. americanus* presented the highest K concentration (1.13%) in the litter, while *C. trichotoma* had the highest values of Ca and Mg (6.35 and 2.02 %, respectively). *S. terebinthifolius* had the lowest light interception rate and litter mineral content.

Keywords: Riparian forest restoration, litterfall and allometry.

UM ESTUDO COMPARATIVO ENTRE QUATRO ESPÉCIES ARBÓREAS UTILIZADAS NA RESTAURAÇÃO DA COBERTURA FLORESTAL RIPÁRIA DO RIO URUGUAI

RESUMO – O conhecimento silvicultural e ecológico sobre as espécies arbóreas são fundamentais para o planejamento da restauração ecológica em áreas de alta diversidade. Este estudo apresenta uma comparação entre quatro espécies arbóreas nativas da porção média da bacia do rio Uruguai: ***Heliocarpus americanus*** *L. (Malvaceae),* ***Maclura tinctoria*** *(L.) D. Don ex Steud. (Moraceae),* ***Schinus terebinthifolius*** *Raddi (Anacardiaceae) e* ***Cordia trichotoma*** *(Vell.) Arrab. ex Steud. (Boraginaceae). Foram obtidos dados sobre o crescimento inicial, a interceptação de luz, a produção de serapilheira e o seu conteúdo mineral.* ***H. americanus*** *apresentou maior crescimento em altura e menor razão entre altura e largura de copa.* ***H. americanus*** *e* ***M. tinctoria*** *tiveram a maior interceptação da luz solar (> 94%) e a maior produção de serapilheira (879 ± 151 e 792 ± 164 $g \cdot m^{-2} \cdot ano^{-1}$, respectivamente). A menor produção de serapilheira, para o conjunto das quatro espécies, ocorreu entre julho e setembro.* ***H. americanus*** *apresentou os maiores teores de K (1,13 %) na serapilheira, enquanto* ***C. trichotoma****, os maiores valores de Ca e Mg (6,35 e 2,02%, respectivamente).* ***S. terebinthifolius*** *exibiu a menor interceptação da luz solar e os menores teores de nutrientes minerais na serapilheira.*

Palavras–chave: Restauração da floresta ripária, queda de serapilheira e alometria.

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[2] Departamento de Meio Ambiente da Prefeitura Municipal de Santo Ângelo, Santo Ângelo-RS. E-mail: <alexandre.huller@hotmail.com>.

[3] Departamento de Biologia e Química da Universidade Regional do Noroeste do Estado do Rio Grande do Sul (UNIJUI). E-mail: <cenicoelho@gmail.com>.

[4] Departamento de Estudos Agrários da UNIJUÍ. E-mail: <osorio@unijui.edu.br>.

[5] IRDeR - Instituto Regional de Desenvolvimento Rural, Departamento de Estudos Agrários da UNIJUÍ. E-mail: <jschirmer2705@gmail.com>.

1. INTRODUCTION

The forest cover of Rio Grande do Sul State, in southern Brazil, is highly reduced and fragmented as a function of forest exploitation and agricultural expansion during the past decades (BRENA et al., 2003; FUNDAÇÃO SOS MATA ATLÂNTICA/INPE, 2002). A great portion of the forest cover in northwestern Rio Grande do Sul State is constituted of secondary forest at different stages (GRANELL-PÉREZ et al., 1999). Riparian forests, considered permanent protection areas according to environmental legislation, present less than 20 % cover (SCHENKEL et al., 2003).

Elevated costs (GARAY, 2006) and weed invasion (YU, 2004) are among the greatest challenges to forest restoration in the tropics. Grasses (*Brachiaria*, *Pennisetum*, *Cynodon*, *Sorghum*) are among the weeds with the greatest invasive capacity, since they commonly prevent or arrest forest re-establishment in the middle Uruguay River Basin (authors' personal observation).

Regenerative agroforestry systems (VIVAN, 1998) represent a strategy for native forest restoration, and are presently considered a valid option by Brazilian environmental laws (CONAMA Nº 369/2006). Agroforestry systems are also considered a method to reduce the costs of forest restoration (MEDRADO, 2000) and could be more effective in restoring forest diversity rather than abandoning it to secondary succession (RODRIGUES, 2005). In the Uruguay River basin, Ghisleni et al. (2003) observed an advantageous effect of annual crop cultivation in the first year on the initial growth of several native tree species, when compared to abandonment after tree planting.

In mixed native forest plantings, fast growth and higher survival of the pioneer species is expected. Pioneer species are also expected to increase soil cover, humidity and organic matter production, facilitating the late successional species, which could present higher initial growth and survival under the shade provided by the pioneers (KAGEYAMA and GANDARA, 2000).

Litter production is also a significant contribution to restoration, since litter supports soil microorganisms, and is the principal pathway for cycling mineral nutrients (LANDSBERG and GOVER, 1997). Thus, high litter production contributes to soil fertility restoration in early secondary succession (EWEL, 1976).

Litter accumulation can present negative or positive effects on germination, herbivore and recruitment, influencing abundance, distribution and richness of seedlings in tropical forests (BENITEZ-MALVIDO and KOSSMANN-FERRAZ, 1999; CINTRA, 1997; SANTOS and VÁLIO, 2002). By inhibiting germination of heliophilous plants (XIONG and NILSSON, 1997), litter can reduce weed competition.

In some situations, a mixed native tree planting can be the best method for forest rehabilitation (PARROTA and KNOWLES, 1999). Nonetheless, little is known about silviculture and ecological responses of Neotropical tree species, and this information gap makes planning of forest restoration difficult with this method.

This paper presents information on the silvicultural development and ecological contribution of four native tree species associated with a regenerative agroforestry system, employed in the recovery of Riparian forest in the middle Uruguay River basin, Doutor Maurício Cardoso county, Rio Grande do Sul State, Brazil. The principal variables addressed are initial growth, light interception, litter fall, and mineral content of litter. The results are discussed in relation to restoration practices and the successional status of the species, according to the literature.

2. MATERIAL AND METHODS

2.1. Study site description

The investigation was carried out in Londero, Doutor Maurício Cardoso county (27º 24' 33"S, 54º 24' 58"W). The climate is moist subtropical (Köppen system). The mean annual average temperature is between 18 and 21ºC and the mean annual rainfall between 1800 and 2100 mm (INMET, 2006).

The native trees were planted in August 2002, with alternate lines of two species groups: pioneer and non-pioneer species, with a spacing of 2.5 m between lines and 2.0 m between plants. The species sequence in each group was established at random.

The pioneer species used were: *Heliocarpus americanus* L., *Croton urucurana* Baillon, *Inga marginata* Willd., *Inga uruguensis* Hooker et Arnott, *Sebastiania commersoniana* (Baill.) Smith et Downs, *Peschiera australis* (Müll. Arg.) Miers, *Enterolobium contortisiliquum*(Vell.) Mor., *Maclura tinctoria* (L.) D. Don ex Steud., *Schinus terebinthifolius* Raddi, *Casearia silvestris* Swartz. The non-pioneers species

planted were *Peltophorum dubium* (Spreng.) Taubert, *Jacaranda micrantha* Cham., *Tabebuia heptaphylla* (Vell.) Toledo, *Patagonula americana* L., *Erythroxylum deciduum* A. St.-Hilaire, *Machaerium stipitatum* Vogel, *Myrocarpus frondosus* Freire Allemão, *Parapiptadenia rigida* (Benth.) Brenan, *Cabralea canjerana* (Vellozo) Mart., *Campomanesia xanthocarpa* Berg, *Eugenia involucrata* DC., *Eugenia pyriformis* Camb., *Cedrela fissilis* Vell., *Cordia trichotoma* (Vell.) Arrab. ex Steud., *Eugenia uniflora* L., *Rupretchia laxiflora* Meissner, *Tabebuia alba* (Cham) Sandwith), *Prunus myrtifolia* (L.) Urban, *Allophylus edulis* (A. St.-Hilaire) Radlk., *Cupania vernalis* Camb., *Matayba elaeagnoides* Radlk., *Styrax leprosus* Hook. et Arn. and *Luehea divaricata* Mart.

Annual crops, including tomato, maize, cassava, sweet potato, papaya, beans, pumpkin and sweet pepper (*Capsicum*) were cultivated among the lines.

The especies evaluated were *S. terebinthifolius, M. tinctoria, H. americanus* and *C. trichotoma*. The first is considered a pioneer species (CARVALHO, 1994). The second is considered an early secondary species (PAULA et al, 2004), but was included in the group of the pioneer species in the planting model based on previous local observations. There is no consistent information in the literature about *H. americanus*. *C. trichotoma* is considered an early secondary species (CARVALHO, 1994).

The period of the study was between the 19th and 30th month after planting.

2.2. Growth evaluation

The attributes measured were maximum height (h) and mean geometric crown width (lm). The mean geometric width was obtained from two transverse measures. Ratio h/lm was calculated for each plant from measurements made in the 19th month after planting (n varied from 15-20 for each species).

2.3. Light interception

PAR light interception was measured between 10 and 11 am, at a distance of 1.5 m from the tree and at 0.2 m of height, on the south side (n = 10 trees). The data were obtained in May, 2004, with a LD-209 Instrutherm © luximeter. Each value, including total sun light, was obtained in triplicate.

2.4. Litterfall

Litter was gathered monthly with two 0.5 x 0.5 m traps per plant, with a total of 42 traps. The traps were at 0.5 m of height above the soil and at a distance of 1.5 m from the tree, with a 1.0 mm^2 mesh nylon screen. The plants were selected at random, and samples were obtained between February 2004 and January 2005, on 11 dates: March 22, 2004; April 24, 2004; May 29, 2004; June 08, 2004; August 10, 2004; September 11, 2004; October 08, 2004; November 17, 2004; December 25, 2004; January 27, 2005; February 25, 2005. For comparison between the species, the individual sampled values were added to obtain an annual value for each trap. The material was dried in an oven at 50 ºC prior to weight determination.

2.5. Mineral nutrient contents in the litter

The mineral nutrient contents (N, P, K, Ca, and Mg) were determined from samples from the annually mixed and homogenized pool. The chemical procedures were carried out at the UFRGS Soil Laboratory (Porto Alegre, Brazil).

The annual mineral input of each species was estimated by multiplying the mineral concentration by the annual litter production.

2.6. Statistical procedure

A completely randomized statistical design was adopted. The data were analyzed through ANOVA and the Tukey's test. The h/lm ratio data were transformed according to $X' = \sqrt{X + 0.5}$. The percentage mineral concentration data were transformed according to the arcsen procedure (ZAR, 1999).

3. RESULTS AND DISCUSSION

3.1. Growth analysis

H. americanus, *C. trichotoma* and *S. terebinthifolius* presented the greatest growth in height. The highest crown width values were observed in *H. americanus*, *M. tinctoria* and *S. terebinthifolius*. *H. americanus* and *M. tinctoria* presented the lowest values of the h/lm ratio (Table 1).

S. terebinthifolius is classified as a pioneer species and *C. trichotoma* as a secondary species (CARVALHO, 1994). However, despite its succession classification, *C. trichotoma* has a high initial growth potential. On the other hand, the higher value of the h/lm ratio indicates

high apical dominance, which is a feature of early secondary species (BUDOWSKY, 1965) and could be an adaptation to escape from shaded understory conditions (POORTER et al., 2005).

The high values of crown width and low values of h/lm ratio of *H. americanus* and *M. tinctoria* are typical features of pioneer species and could favor the establishment and rehabilitation of the forest (BARBOSA, 2000). However, since *M. tinctoria* is a long-lived species (CARVALHO, 1994) must be included in restoration with caution: excessive or exclusive use of long-lived pioneers could arrest the succession and re-establishment of late successional species (MARTINEZ-GRAZA and HOWE, 2003).

The height growth of *C. trichotoma* was appreciably greater than in the data summarized by Carvalho (1994). The height growth of *S. terebinthifolius* was also significant, among the greatest data reported by that author for this species.

3.2. Light interception

Shading capacity is a major factor for forest ecosystem recovery. *H. americanus* and *M. tinctoria* intercepted more than 94 % of sun light (Table 2). *C. trichotoma* has an intermediate position intercepting nearly 90 % of sun light (Table 2). This could be related to the low crown width of this species (Table 1). On the other hand, as it is a deciduous species, this value probably presents a reduction in shading during winter (July to September). *S. terebinthifolius* showed the lowest light interception rate, in spite of the intermediate value of crown width, suggesting a low leaf area index, which in turn could be related to the small leaf size. The data indicates a minor contribution to soil protection by this species. These results should be considered with caution, however, as they represent only one period of measurements.

3.3. Litterfall

H. americanus and *M. tinctoria* had the highest values of annual litter production (Figure 1). Those values are higher than for the pioneer commercial species in monocultural plantations older than the mixed system studied. For example, 7-year-old *Acacia mearnsii* produced 414 $g \cdot m^{-2} \cdot year^{1}$ (VIEIRA et al., 2005); 7-year-old *Mimosa scabrella*, 346 $g \cdot m^{-2} \cdot year^{1}$; 13-year-old *Eucalyptus saligna* reached a 710 $g \cdot m^{-2} \cdot year^{1}$ production (SOUZA and DAVIDE, 2001).

H. americanus presented the highest litter production in November through January and also in April, reaching 127 g/m² in December. *M. tinctoria* presented a similar phenology of litter production, with a maximum in December (191 g/m²).

The deciduous *C. trichotoma* presented a litter production peak between May and June, followed by a noticeable reduction.

S. terebinthifolius presented the lowest annual litter production; nonetheless, it was the species with a more regular phenology, and also a superior litter production in October (117 g/m²), a month with low production by the other species (Figure 2). This feature indicates a complementary contribution obtained by adding the species to the system, which could be significant in the spring time, a period with high germination and growth of weeds.

In contrast to the majority of native forests in Southern Brazil, which presents higher litterfall during August and September (KÖNIG et al., 2002; ARATO et al., 2003; VITAL et al., 2004; SANTOS and VÁLIO, 2002; PAGANO and DURIGAN, 2000; SOUZA and DAVIDE, 2001), the set of species studied showed the lowest litterfall in this period (Figure 2).

Table 1 – Average (± standard deviation) values of height (h), geometric crown width (l m) and h/l m ratio, 19 months after planting, Londero, Dr. Maurício Cardoso-RS, 2004, n= number of sampled plants. Letters indicate significant differences by theTukey's test ($P < 0.05$)

Tabela 1 *– Valores médios (± desvio-padrão) de altura (h), largura média da copa (l m) e razão h/l m, de cada espécie avaliada, 19 meses depois do plantio, Londero, Dr. Maurício Cardoso-RS, 2004. n = número de indivíduos amostrados. Letras indicam diferenças significativas conforme teste de Tukey (P < 0,05)*

	n	h	(cm)	lm	(cm)	h/lm	
H. americanus	20	401.2	± 28.0 a	362.9	± 46.8 a	1.10	± 0.42 a
M. tinctoria	15	297.9	± 46.3 b	323.8	± 46.3 ab	0.92	± 0.09 a
C. trichotoma	15	367.9	± 61.7 a	248.5	± 62.6 c	1.53	± 0.23 bc
S. terebinthifolius	15	359.0	± 61.0 a	299.8	± 50.8 b	1.22	± 0.24 ab

Table 2 – Proportion of sun light under the crown (n=10), Londero, Dr. Maurício Cardoso-RS, 2004. The maximum sun light intensity outdoor was between 56 and 76 klux. Letters indicate differences by the Tukey's test ($P < 0.05$)

Tabela 2 *– Proporção da luz solar sob a copa (n=10), Londero, Dr. Maurício Cardoso-RS, 2004. A máxima intensidade de luz solar ao ar livre observada foi entre 56 e 76 klux. Letras indicam diferenças no teste de Tukey (P < 0,05)*

Species	Light Intensity Under the Crown (%)
H. americanus	5.62 a
M. tinctoria	5.45 a
C. trichotoma	10.49 ab
S. terebinthifolius	26.66 c

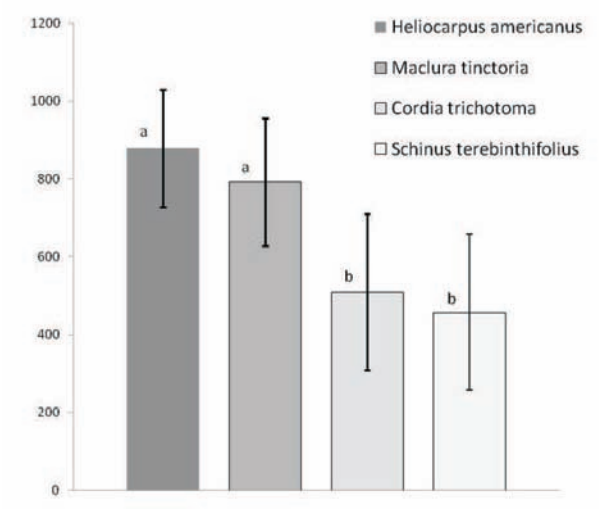

Figure 1 – Annual litterfall production ($g \cdot m^{-2}$) from February, 2003 to January, 2004 for different tree species, Dr. Maurício Cardoso, RS, Brazil. Vertical bars represent standard deviation. Letters indicate differences by the Tukey's test ($P < 0.05$).

Figura 1 *– Produção anual de serapilheira ($g \cdot m^{-2}$), no período de fevereiro de 2003 a janeiro de 2004, das quatro espécies avaliadas, em Dr. Maurício Cardoso, RS, Brasil. A barra vertical indica o desvio-padrão e as letras indicam diferenças no teste de Tukey (P < 0,05).*

Litter decomposition could lead to a significant reduction in litter cover on the soil. Giacomini (2006) demonstrated that 50 % of the litter was decomposed in 240 days in Ijuí-RS, near the site of the present study. Since litterfall is variable along the year, in that same experiment (a monospecific plantation) the accumulated litter on the soil showed variations of 70 % in less than a year (COELHO and BORGES, 2006).

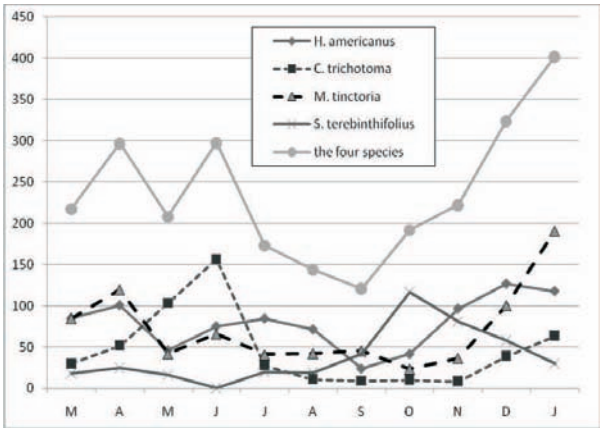

Figure 2 – Litterfall production ($g \cdot m^{-2}$) of four species along the year, Dr. Maurício Cardoso, RS, Brazil.

Figura 2 *– Produção de serapilheira ($g \cdot m^{-2}$) das quatro espécies arbóreas ao longo do ano, Dr. Maurício Cardoso, RS, Brasil.*

3.4. Mineral nutrients in the litter

H. americanus and *M. tinctoria* presented the highest K content in the litter. Also, together with *C. trichotoma*, they presented the highest N content (Table 3).

Palma et al. (2000) observed a Ca content of 4.5 % for *M. tinctoria*, an extremely high value when compared to other forest species (GONÇALVES et al., 1992). Nevertheless, the values here reported are even higher (Table 3). The high Ca content could be related to the capacity of Moraceae to accumulate Ca in the form of carbonate (cystoliths) and oxalate crystals (WU et al., 2006). The species with highest Ca and Mg concentration in the litter was *C. trichotoma* (Table 3), which also present cystoliths.

H. americanus presented the highest amount of estimated annual N, P and K returned to the soil through litter. On the other hand, *C. trichotoma* had the highest values in annual estimated amounts of Ca and Mg in the litter (Table 4). The return of Ca is extremely important in increasing the exchangeable Ca as well as pH maintenance in the topsoil (VANLAUWE et al., 2005).

3.5. Successional status and restoration

The growth, litterfall, light interception values for *M. tinctoria* indicate a pioneer status for this species (but see PAULA et al. 2004), in spite of its longevity (CARVALHO, 1994). Longevity, however, does not necessarily exclude the concept of pioneer, and some authors admit the existence of long-lived pioneers in tropical forests (WEBB et al., 1972; SWAINE and HALL, 1983).

Table 3 – Litter mineral content (%) of different tree species, Dr. Maurício Cardoso, RS, 2005. Letters indicate differences by the Tukey's test ($P < 0.05$)

Tabela 3 *– Conteúdo mineral da serapilheira (%) das diferentes espécies florestais, Dr. Maurício Cardoso, RS, 2005. Letras indicam diferenças no teste de Tukey (P < 0,05)*

Species	N	P	K	Ca	Mg
H. americanus	1.52±0.35a	0,23±0.03a	1.13±0.35a	2.57±0.30 d	1.02±0.11b
M. tinctoria	1.49±0.08a	0.19±0.03a	0.50±0.17 b	5.18±0.43 b	0.80±0.05c
C. trichotoma	1.35±0.42ab	0.14±0.02b	0.21±0.12 c	6.35±0.59a	2.02±0.15a
S. terebinthifolius	1.11±0.16 b	0.21±0.06a	0.33±0.08 bc	3.49±0.40c	0.68±0.11 d

Table 4 – Estimate of the mineral amount returned to the soil through litter ($g \cdot m^{-2} \cdot year^{-1}$) for the different tree species, Dr. Maurício Cardoso, RS, Brazil, 2005

Tabela 4 *– Estimativa do conteúdo mineral total ($g \cdot m^{-2}$ ano^{-1}) retornado para o solo para as diferentes espécies florestais, Dr. Maurício Cardoso, RS, Brasil, 2005*

Species	N	P	K	Ca	Mg
H. americanus	13.3	2.0	9.9	22.5	8.9
M. tinctoria	11.8	1.7	4.4	45.4	7.0
C. trichotoma	6.9	1.2	1.8	55.7	17.7
S. terebinthifolius	5.1	1.9	2.9	30.6	6.0

S. terebinthifolius presents significantly lower light interception and annual litterfall. Also, its contribution to the mineral cycling is less. The great contribution of this species could be the litterfall increase during spring time. Additionally, as a zoochorous species, it is an attraction for frugivorous birds and could aid in the colonization by other forest species (REIS et al. 2003).

4. CONCLUSIONS

H. americanus presented the best performance in relation to this set of goals, with this highest maximum height, crown width, light interception, litterfall and N, P and K transfer to the topsoil.

M. tinctoria also showed significant growth, litterfall, light interception, and a high contribution to Ca cycling.

C. trichotoma showed a significant contribution to litterfall and especially to Ca and Mg cycling. Notwithstanding its low contribution to shading can be explained at least partially by its smaller crown width.

The set of species studied showed a significant reduction in litter fall between July and October, which could favor weed invasion. As Southern Brazil forests present a high litterfall in this period, a search for complementary early successional species to occupy this gap in litter production is recommended.

The results obtained corroborate the important contribution of ecologically complementary species in mixed systems of tree planting for forest restoration.

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