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PHYSICAL AND MECHANICAL PROPERTIES OF FOUR *SALIX* SPECIES

Carlos Alberto Vargas[1], Marilzete Basso Nascimento[1], Graciela Inés Bolzon de Muñiz[2], Silvana Nisgoski[2]

Abstract: The increasing use of *Salix* species in the manufacture of various products has been attracting interest towards the *Salicaceae* family in South America. This paper reports the physical and mechanical parameters of *Salix viminalis* L. (purple osier), *Salix x rubens* Schrank (basket willow), *Salix purpurea* Linné (purple willow) and *Salix* sp., cultivated in the Canoas River Valley, in the Serra Catarinense region of the state of Santa Catarina, Brazil. The evaluations were conducted with raw material, the most commonly used format in handcrafts, and the results indicate there are differences in physical and mechanical properties among the species. *Salix viminalis* and *Salix purpurea* were similar in density and in their modulus of elasticity, and had higher values of tensile and strength modulus than *Salix x rubens* and *Salix* sp.
Keywords: wicker; density; strength.

PROPRIEDADES FÍSICAS E MECÂNICAS DE QUATRO ESPÉCIES DE *Salix*.

Resumo: O crescente uso de espécies de *Salix* na manufatura de diferentes produtos tem atraído o interesse sobre a família Salicaceae na América do Sul. Este trabalho descreve as propriedades físicas e mecânicas de *Salix viminalis* L. (purple osier), *Salix x rubens* Schrank (basket willow), *Salix purpurea* Linné (purple willow) e *Salix* sp., cultivados na região do vale do Rio Canoas, na Serra Catarinense, Brasil. As avaliações foram conduzidas com o material nos formatos comumente empregados em artesanato e indicam diferenças nas propriedades físicas e mecânicas entre as espécies. *Salix viminalis* e *Salix purpurea* foram similares em densidade aparente e módulo de elasticidade para tração e flexão e resultaram em valores maiores que *Salix x rubens* e *Salix* sp.
Palavras-chave: vime; densidade; resistência.

[1] Universidade Tecnológica Federal do Paraná (UTFPR), Curitiba, <sagravargas@gmail.com>; <marilzete131@gmail.com>.
[2] Universidade Federal do Paraná (UFPR), Curitiba, <graciela.ufpr@gmail.com>; <silvana.ufpr@gmail.com>.

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1 INTRODUCTION

In Brazil there are 19 genera and nearly 80 species of the Salicaceae family. From an economic standpoint, the *Salix* genus is the most important one, because it produces acetylsalicylic acid, a base for analgesics (SOUZA; LORENZI, 2005), besides its use to remediate contaminated soil (VERVAEKE et al., 2003; PUNSHON et al., 2003a,b). It can also be used as food for wildlife, in landscaping, carbon fixation and in fiber production for biomass (SUTILI, 2007; URSO; PAIERO, 2008).

Salix species are cultivated in several countries of Eastern Europe and the Americas, as well as in France, China and Italy. In Brazil, the cultivated species are known generically as wicker and have wide application in handcrafts. The Serra (Mountain) Catarinense region, in the southern part of the state of Santa Catarina, has the highest production of branches, with an annual harvest of around of 16,000 tonnes (metric tons), but only 10% of the crop is processed locally (NASCIMENTO, 2009). The inclusion of these crop species in the national farm credit system and the participation of city governments, research institutes, worker associations and universities has helped to consolidate *Salix* culture.

Among the places where these species were introduced in Brazil, the Canoas River Valley is the region where it is best adapted. The Agricultural Research and Rural Extension Organization of Santa Catarina (EPAGRI) conducts research to improve material quality and increase the earnings of growers and artisans. *Salix* cultivation makes use of local workers in between harvests of other crops. In 2009, 1,266 families were involved in the activity and cultivated 1,215 ha, with an annual production of 15,790 green branches (called sticks), corresponding to 6,000 tonnes of sticks ready to use (EMATER, 2009).

The value of the product varies with its quality and its processing. About 1,900 tonnes/year of very fine wicker are sold to grape growers in the neighboring state of Rio Grande do Sul. This is a lucrative business, because the wicker does not need to be debarked, so harvesting is the only work demanded. Because of the necessary work for manufacturing products, this market segment is a good alternative in the short term.

On average, each hectare of wicker is responsible for the employment of 7.65 workers/year, farm workers and artisans comprised in this number. Arruda (2001) observed that in the regions involved in wicker growing, this activity represents more than an important source of income for smallholders; it also employs a significant number of local handcraft workers.

The performance of *Salix* when made into products is related to its physical and mechanical properties. Due to its high correlation with other properties, density is an important parameter, whose variation between and within species is the result of the amount of wood material, empty spaces, mineral concentration and mainly the moisture content in the anatomical structure (MONTEOLIVA et al., 2005).

Mechanical properties are related to the performance of the material in response to external kinds of stress, such as tension, compression, bending, shear and also cleavage (ARAUJO, 2007). The modulus of elasticity is significantly different among forest species and varieties as a result of factors such as fertilization and planting space (HASELEIN et al., 2002).

Several studies evaluating nitrogen fixation ability (KULL et al., 1998, WEIH et al., 2011), biomass content (WEIH, 2009) and site influence on susceptibility to pathogens (CASAUBON et al., 2004; HÖGLUND et al., 2005) have been carried out on *Salix* species, but only a few have reported the physical and mechanical properties of *Salix* and how density affects these properties (MONTEOLIVA et al., 2002, 2005; GARAY, 2002a; BRAND et al., 2005).

The aim of this study was to evaluate the physical and mechanical properties of four *Salix* species and to compare their quality for use in the making of handcrafts, as well as to contribute with information for the producers.

2 MATERIAL AND METHODS

Salix viminalis L., *Salix x rubens* Schrank, *Salix purpurea* Linné and *Salix* sp. were studied. The samples were collected at seven sites in the region of Lages, Santa Catarina, Brazil, representing the observation units of EPAGRI (Agricultural Research and Rural Extension Organization of Santa Catarina) and partners. The tests were chosen taking into account the use of each part of the structure or filling of the product as it is used for weaving. The details about the preparation of the material are described below.

2.1 Processing of wicker sticks

The processing was based on the method used for handcrafts. The branches were immersed in boiling water for at least 30 minutes and after that they were debarked manually (Figure 1), resulting in sticks which were identified and stored in open air for one year, until the next step.

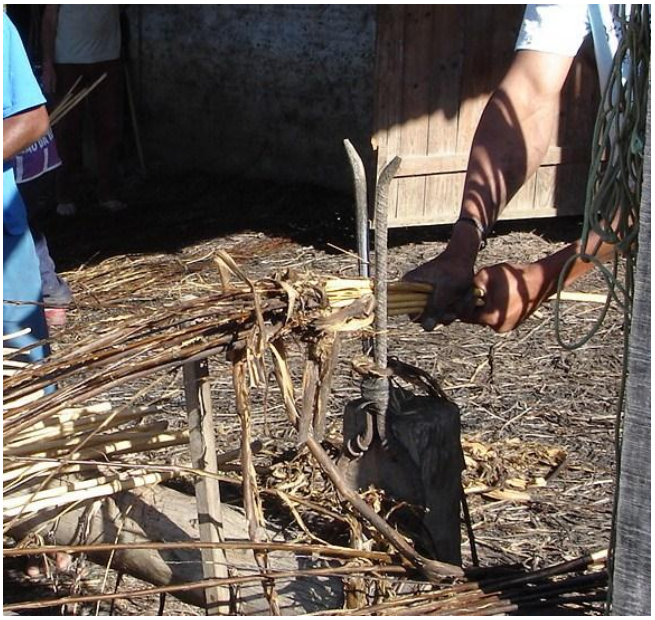

Figure 1. Bark removal.
Figura 1. Remoção da casca.

2.2 Determination of physical and mechanical properties

In the preparation of the samples, each branch was divided into four segments, comprising the initial cut for discard as well as the samples ï in order, for the density, static bending and tension parallel to grain tests. The tests were carried out at the Wood Technology Laboratory of Paraná Federal University, using 116 samples, in accordance with NBR 7190 (ABNT, 1997), as adapted by Vargas (2011).

Density

Density was considered at 12% moisture content. Samples remained in a conditioning chamber at a temperature of 20 °C (± 3 °C) and relative humidity of 65 % (± 1 %) until constant weight. The evaluation was done in accordance with NBR 7190 (ABNT, 1997) using the relation of weight, obtained with a precision balance, by volume, calculated by stereometric method using a digital caliper. Samples for the density test were taken at a distance of 3.94 ï 5.91 in (10-15 cm) from the basal pole of the branches, with diameter of 0.24 ï 0.71 in (6-18 mm) and length of 0.91 to 1.06 in (23 to 27 mm).

Static bending

This evaluation was done on a Universal Test Machine (EMIC DL2000), managed by computer, in accordance with NBR 7190 (ABNT, 1997), as adapted by Vargas (2011), and the Modulus of Elasticity (MOE) was calculated using the numeric results and the graphic

diagram of load versus displacement. The distance between supports is a function of stick diameter, so the samples were measured and divided into 13 diametric groups. The speed of testing was 0.20 in (5mm)/min, with a maximum of five minutes for all samples.

Tension parallel to grain

This evaluation was done on a Universal Test Machine (EMIC DL2000) in accordance with NBR 7190 (ABNT, 1997), as adapted by Vargas (2011), and the Modulus of Elasticity (MOE) was calculated using the numeric results and the graphic diagram of tension versus the specific deformation of samples. Tension was analyzed in splints measuring 5.9 in (150 mm) in length. The distance between grips was 3.94 in. (100 mm).

3 RESULTS AND DISCUSSION

3.1 Density at 12%

The mean density for each species and site is shown in Table 1.

Table 1. Variation of density at 12% (g/cm^3) by species and site.
Tabela 1. Variação da densidade a 12% (g/cm^3) por espécies e sítio.

SITE	*Salix viminalis*	SD	*Salix* sp	SD	*Salix x rubens*	SD	*Salix purpurea*	SD
Bocaina	0.62aA	0.02	0.52bB	0.04	0.52 aB	0.03	0.62aA	0.01
Rio Rufino-Cerro Baio	0.60aA	0.03	-	-	0.52aB	0.02	0.57abA	0.01
Lages - E.E.1	0.50bA	0.02	0.49abA	0.04	-	-	0.53bA	0.03
Lages - E.E.2	0.59aA	0.03	0.51bB	0.05	0.46abB	0.03	0.60aA	0.03
Rio Rufino Gargantilha	0.63aA	0.02	-	-	0.51abB	0.02	0.61aA	0.01
Rio Rufino - Lino	0.63aA	0.03	0.51bB	0.03	-	-	0.62aA	0.03
Urubici	0.58aA	0.03	0.45aB	0.03	0.50abB	0.02	0.64aA	0.01
TOTAL	0.59A	0.05	0.49B	0.04	0.50B	0.03	0.60A	0.04

*Equal lower case letter in columns indicate no significant difference between sites in the same species. Equal upper case letters in the rows indicate no significant difference between species at the same site, in both cases by the Tukey test at 95% probability. SD: standard deviation.

The mean result for species indicated two groups with similar values of density at 12%, *Salix viminalis* with *Salix purpurea,* and *Salix* sp. with *Salix x rubens.* The site had some influence on the property within species. The density of *Salix purpurea* is more variable among sites and for *Salix viminalis* only one site (Estação 1) has significant difference.

Considering the variation of density between species within each site, there were more significant differences in Urubuci, whereas in other places the results tended to the group observed in general density for species.

Tukey´s test revealed the site has influence on the characteristics of the material, a result that has also been observed in clones of tree species of *Salix* from Argentina, Russia, New Zealand (MONTEOLIVA et al., 2002, 2005) and the Paraná River Delta (VILLEGAS; MARLATS, 2005). The density values found in this study for *Salix viminalis, Salix purpurea* and *Salix x rubens* are compatible with those obtained by Deka et al. (1994) and Garay (2002b).

Density is important in handcraft because it has influence on the handling of the material and it can also limit the use of some species in objects that need either some structural resistance or aid in weaving. According to Garay (2002a), rattan (*Calamus manan*) (a species similar to wicker in application for handcrafts) has a density of 0.34g/cm^3, but it has the disadvantage of being extracted from tropical forests, where it needs a ñmotherò tree ï which is its guide ï to grow, besides the danger in its harvesting, since in some cases it is necessary to climb the tree for the cut.

3.2 Static bending

The mean values for elasticity modulus (MOE) obtained in the static bending test by species and sites are presented in Table 2.

Table 2. MOE on static bending (MPa) between species and sites.
Tabela 2. MOE em flexão estática (MPa) entre espécies e sítios.

SITE	*Salix viminalis*	SD	*Salix* sp	SD	*Salix x rubens*	SD	*Salix purpurea*	SD
Bocaina	4559 aA	517	2526 aB	110	4011 aAB	676	5004 aA	951
Cerro Baio	4284 abAB	538	(-)	(-)	3863 aB	316	4826 abA	482
Estação 1	3641 abA	311	2857 aA	842	(-)	(-)	3260 bA	408
Estação 2	4222 abA	568	3358 aA	437	3458 aA	512	4147 abA	751
Gargantilha	4116 abAB	507	(-)	(-)	3179 aB	436	4478 abA	1142
Lino	4692 aA	770	2988 aB	495	(-)	(-)	4856 aA	1078
Urubici	3413 bA	661	3328 aA	557	3735 aA	255	3734 abA	315
TOTAL	**4132 AC**	**675**	**3078 B**	**595**	**3649 C**	**521**	**4310 A**	**938**

*Equal lower case letter in columns indicate no significant difference between sites in the same species. Equal upper case letters in the rows indicate no significant difference between species at the same site, in both cases by the Tukey test at 95% probability. SD: standard deviation.

In 85.4% of the samples, no total rupture was observed. Rupture was identified visually in 17 samples. The resistance to bending is important for the use of the material by artisans, since more flexible sticks can be used to make objects with more varied shapes. *Salix purpurea* had the largest number of samples with visual rupture (9), followed by *Salix viminalis* (5), *Salix x rubens* (2) and *Salix* sp (1).

Tukeyôs test showed that static bending stiffness is different among the studied species, and tended to group *Salix viminalis* with *S. purpurea* as a function of materialôs density, a result that was expected because the reflex of mass and volume relation is directly related to deformation caused by a tension, since cellular wall thickness is the most important agent in two cases.

The distinction of species between sites was observed only in *Salix purpurea.* The introduction of new cultivated species follows the orientations of EPAGRI, which might have influenced the results. The branches came from experimental plants and the response of species to management is distinct, depending on intrinsic characteristics of the material. Thus, the results can be useful for a better utilization of soil in the region, with the selection of adequate species for each site and final use. Another relevant factor is the absence of breaking of the material after reaching the proportional limit in the static bending test, this being important in handcraft because it is related with good product finishing. Therefore, it is necessary to study the characteristics of the species and preparation of the material for this test. Cooking is an important factor in the performance of wicker, because of possible chemical and structural changes.

The results of the static bending modulus of elasticity indicate that *Salix viminalis* and *Salix purpurea* are more difficult to handle than *Salix* sp. and *Salix x rubens,* a similar finding to that of Nascimento (2009) and corroborated by the artisans, who described *Salix x rubens* as more brittle and *Salix* sp. as more malleable among the studied species. Garay (2002a) reported greater flexibility for *Calamus manan* (ratan) in comparison with *Salix viminalis.*

3.3 Tension parallel to grain

Rupture occurred in two distinct ways: in the longitudinal direction (Figure 2A) ï the most common ï and in the transversal direction (Figure 2B). The observed model indicates that structural collapse begins at the point where there is a structural change in the stick.

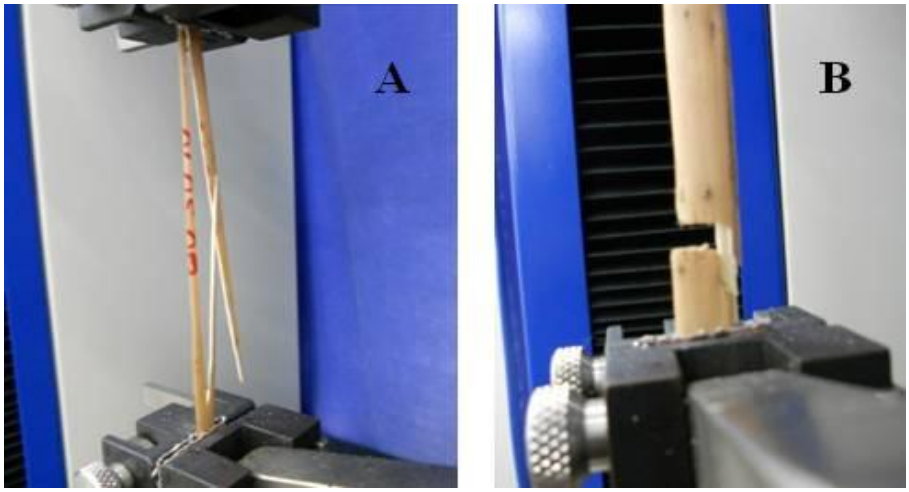

Figure 2. Longitudinal (A) and transversal (B) rupture of sticks.
Figura 2. Ruptura longitudinal (A) e transversal (B) das fitas.

For the tension parallel to the grain modulus of elasticity (Table 3), the influence of the site was only observed in *Salix viminalis*. In general, Tukeyôs test tended to group *Salix viminalis* with *S. purpurea* and *Salix x rubens* with *Salix* sp., the same as observed for density.

Table 3. MOE on tension parallel to grain (MPa) among species and sites.

Tabela 3. MOE em tração paralela às fibras (MPa) entre espécies e sítios.

SITE	*Salix viminalis*	SD	*Salix* sp.	SD	*Salix x rubens*	SD	*Salix purpurea*	SD
Bocaina	2214 abAB	263	1566 aB	99	1847 aB	140	2631 aA	416
Cerro Baio	3027 bA	314	(-)	(-)	2255 aB	189	2751 aAB	438
Estação 1	2170 aA	496	1762 aA	225	(-)	(-)	2205 aA	637
Estação 2	2014 aA	408	2168 aA	491	2006 aA	442	2742 aA	369
Gargantilha	2453 abA	322	(-)	(-)	2132 aA	232	2571 aA	467
Lino	2401 abA	563	1941 aA	230	(-)	(-)	2480 aA	264
Urubici	2051 aA	220	1938 aA	249	2314 aA	605	2059 aA	365
TOTAL	**2333 AC**	**479**	**1917 B**	**338**	**2111 AB**	**376**	**2487 C**	**469**

*Equal lower case letter in columns indicate no significant difference between sites in the same species. Equal upper case letters in the rows indicate no significant difference between species at the same site, in both cases by the Tukey test at 95% probability. SD: standard deviation.

4 CONCLUSIONS

The results of the studied properties on *Salix viminalis*, *Salix* sp., *Salix x rubens* and *Salix purpurea* showed that they are adequate for use in handcraft and that there is no best site.

The density at 12% and strength of *Salix viminalis* and *Salix purpurea* are compatible with their mechanical properties and indicate they can be used in applications where more structural resistance is required, differently from *Salix x rubens* and *Salix* sp.

Despite these differences, all four species can be used to make handcrafts, and, consequently, to improve the regionôs economy. Moreover, further studies should be conducted, aiming at the genetic improvement of the species in relation to the number of ramifications, yield and natural resistance, as well as at the effects of environmental conditions (soil and climate), at the development of better growing methods and its contribution to material resistance and flexibility.

5 REFERENCES

ARAUJO, H. J. B. Relações funcionais entre propriedades físicas e mecânicas de madeiras tropicais brasileiras. **Revista Floresta**, v.37, n.3, p. 399-416, 2007.

ARRUDA, A. E. **Importância econômica da cultura do vime para a agricultura familiar de Rio Rufino**. 2001. 39f. Monografia de Especialização - Universidade do Oeste de Santa Catarina, São Joaquim, 2001.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 7190:** Projeto de estruturas de madeira**.** Anexo B. Rio de Janeiro: ABNT, 1997. 107p.

BRAND, M. A.; BITTENCOURT, E.; ESPINDOLA, C. Descrição das características tecnológicas e estudos de novas aplicações e utilização do cultivar *Salix x rubens*. **Relatório Técnico.** Lages, UNIPLAC, 2005.

CASAUBON, E. A.; CUETO, G. R.; HODARA, K.; GONZALEZ, A. C. Influencia de la calidad de sitio en el ataque de *Platypus mutatus* Chapuis (Coleoptera, Platypodidae) a una plantación de sauces (*Salix babylonica* x *Salix alba* cv 131/27). **Ecología Austral,** n.14, p. 113-120, 2004.

DEKA, G. C.; WONG, B. M.; ROY, D. N. Variation of specific gravity, fibre length and cell wall thickness in young *Salix* clones. **Journal of Wood Chemistry and Technology,** v.14, n.1, p. 147-158, 1994.

EMPRESA DE ASSISTÊNCIA TÉCNICA E EXTENSÃO RURAL (EMATER). **Epagri capacita produtores de vime em agroecologia**. Available at: <http://www.emater.pi.gov.br/noticia.php?id=520>. Retrieve in nov 2011.

GARAY, R. M. Comparación de potencialidades de empleo industrial de mimbre y ratan. In: INFOR. Sauce-Mimbre Salix spp. Silvicultura y Producción. Proyecto FONDEF/FDI/INFOR/CORFO ñDesarrollo integral del Cultivo y la Industrialización del Sauce-mimbreò, 2002, Santiago, Chile. **Anaisé** Santiago: Marta Abalos R, 2002a.

GARAY, R. M. Caracterizacion físico-mecanica de Salix spp. In: INFOR. Sauce-Mimbre Salix spp. Silvicultura y Producción. Proyecto FONDEF/FDI/INFOR/CORFO: ñDesarrollo integral del Cultivo y la Industrialización del Sauce-mimbreò, 2002, Santiago, Chile. **Anaisé** Santiago: Marta Abalos R, 2002b.

HASELEIN, C. R; BERGER, R; GOULART, M; STHAL, J; TREVISAN, R; SANTINI, E. J; LOPES, M. C. Propriedades de flexão estática da madeira úmida e a 12% de umidade de um clone de *Eucalyptus saligna* Smith sob o efeito do espaçamento e da adubação. **Ciência Florestal**, v.12, n.2, p. 147-152, 2002.

HOGLUND, S.; LARSSON, S.; WINGSLE, G. Both hypersensitive and non-hypersensitive responses are associated with resistance in *Salix viminalis* against the gall midge *Dasineura marginemtorquens*. **Journal of Experimental Botany**, v.56, n.422, p. 3215ï 3222, 2005.

KULL, O.; KOPPEL, A.; NOORMETS, A. Seasonal changes in leaf nitrogen pools in two *Salix* species. **Tree Physiology** n.18, p. 45-51, 1998.

MONTEOLIVA, S.; SENISTERRA, G.; MARQUINA, J.; MARLATS, R.; VILLEGAS, S. Estudio de la variación de la densidad básica de la madera de ocho clones de sauce (*Salix* spp.). **Revista de la Facultad de Agronomía**, v.105, n.1, p. 77-82, 2002.

MONTEOLIVA, S.; SENISTERRA, G.; MARLATS, R. Variation of wood density and fibre length in six willow clones (*Salix* spp.) **Iawa Journal,** v.26, n.2, p. 197-202, 2005.

NASCIMENTO, M. B. **Aspectos técnicos e sociais para a sustentabilidade da produção e do artesanato do vime**. 2009. 246f. Tese (Doutorado em Ciências Florestais) - Universidade Federal do Paraná, Curitiba, 2009.

PUNSHON, T.; BERTSCH, P. M..; LANZIROTTI, A.; MCLEOD, K.; BURGER, J. Geochemical signature of contaminated sediment remobilization revealed by spatially resolved X-ray microanalysis of annual rings of *Salix nigra*. **Environmental Science and Technology,** n. 37, p. 1766ï 1774, 2003a.

PUNSHON, T.; GAINES, K. F.; JENKINS JR, R. A. Bioavailability and trophic transfer of sediment-bound Ni and U in a southeastern wetland system. **Archives of Environmental Contamination and Toxicology,** n.44, p. 30ï 35, 2003b.

SOUZA, V. C.; LORENZI, H. **Botânica sistemática:** guia ilustrado para identificação das famílias de Angiospermas da flora brasileira, baseado em APG II. Nova Odessa: Instituto Plantarum, 2005. 640p.

SUTILI, F. **Bioengenharia de solos no âmbito fluvial do sul do Brasil**. 2007. 95f. Tese (Doutorado em Engenharia Florestal) ï Universidade de Santa Maria, Santa Maria, 2007.

URSO, T.; PAIEIRO, P. **Il legno di salicace: utilizzacioni tradizionali e prospettive future. In:** ATTI DEL TERZO CONGRESSO NAZIONALE DI SELVICOLTURA, 2008, Firenze, Italia. **Anaisé** Firenze: Academia Italiana d Scienze Forestali, Firenze, 2008. p. 1555-1559.

VARGAS, C. A. **Adaptação da norma NBR 7190 para avaliação de espécies de *Salix* (vime) visando a utilização em artesanato.** 2011**.** 77f. Dissertação (Mestrado em Ciências Florestais) - Universidade Federal do Paraná, Curitiba, 2011.

VERVAEKE, P.; LUYSSAERT, S.; MERTENS, J.; MEERS, E.; TACK, F. M. G.; LUST, N. Phytoremediation prospects of willow stands on contaminated sediment: a field trial. **Environmental Pollution** n.126, p. 275ï 282, 2003.

VILLEGAS, M. S.; MARLATS, R. Altura de extracción de la muestra para evaluación de densidad básica y blancura en madera de *Salix* sp. **Bosque**, v.26, n.3, p. 121-132, 2005.

WEIH, M. Genetic and environmental variation in spring and autumn phenology of biomass willows (*Salix* spp.): effects on shoot growth and nitrogen economy. **Tree Physiology**, n.29, p. 1479ï 1490, 2009.

WEIH, M.; ASPLUND, L.; BERGKVIST, G. Assessment of nutrient use in annual and perennial crops: A functional concept for analyzing nitrogen use efficiency. **Plant Soil**, n.339, p. 513ï 520, 2011.