Effects of Weed Control and Fertilization on Wood and Chemi-mechanical Pulp Properties of a *Populus deltoides* Clone

María S. Villegas [a,*], Silvia E. Monteoliva [a,b], Fabio G. Achinelli [a], Fernando Felissia [c] and Maria C. Area [b,c]

Weed control and fertilization usually lead to an increase in the growth rate of trees and, consequently, to a possible modification of the quality of the wood and its end products. The effect of weed control and fertilization practices were determined on tree growth parameters, wood density, fiber weight, fiber length, and chemical wood composition, as well as the chemi-mechanical pulp properties, for 8-year-old *Populus deltoides* \`Delta Gold´ grown in Argentina. Four treatments belonging to a randomized complete block design trial were analysed: no weeding after planting (C), mechanical weed control (M), chemimechanical weed control (CHM), and fertilized + chemimechanical weed control (CHM-F). Soda-sulfite chemi-mechanical pulps were produced from said trees. Handsheets were prepared from the pulps, and their physical, mechanical, and optical properties were determined following international standards. Several wood and pulp properties were influenced by the studied silvicultural practices. In the context of this study, silvicultural treatments applied to *Populus deltoides* 'Delta Gold' (formerly 'Stoneville 66') trees can be applied to increase productivity (volume and fibrous output) without detrimental consequences to wood and pulp properties, except for a slight reduction in brightness.

Keywords: Populus deltoides, Weed control, Fertilization, Productivity, Wood properties, Chemi-mechanical pulp (CMP) properties

Contact information: a: Facultad de Ciencias Agrarias y Forestales, Universidad Nacional de La Plata, C.C. 31, CP 1900 La Plata, Buenos Aires, Argentina; b: Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina; c: Programa de Celulosa y Papel, Instituto de Materiales de Misiones, IMAM (UNaM-CONICET). Félix de Azara 1552, CP 3300 Posadas, Misiones, Argentina;
** Corresponding author: silvillegas@agro.unlp.edu.ar*

INTRODUCTION

The use of fast-growing trees such as the species of the *Populus* genus and their clones in conjunction with intensive forestry practices has been postulated as a means to meet the increasing demand for wood products (Pitre *et al.* 2007). The application of nitrogen (N) fertilizers and the control of herbaceous vegetation have received considerable attention as two different approaches that can enhance the growth rate and the productivity of forest plantations (Little *et al.* 2003; Bilodeau-Gauthier *et al.* 2011).

Populus deltoides 'Delta Gold' (formerly 'Stoneville 66') is one of the most cultivated clones in Argentina. The short-rotation poplar plantations located in the Delta of Paraná River, at the centre-north of Buenos Aires and south of Santa Fe, are increasingly being subjected to fertilization and weed control practices. These plantations are mainly harvested to produce chemi-mechanical pulp (CMP) for newsprint paper (Achinelli 2006).

Silvicultural practices usually lead to an increase in the growth rate of the trees, which accelerates the development of the stem (Fisher and Binkley 2000). Together with growth trend information, it is also important to know how vegetation management and fertilization influence the quality of the end products, as any change in the growth pattern of the tree could possibly affect wood properties and, consequently, the pulp and paper quality (Da Silva Perez and Fauchon 2003).

The available information on the consequences of weed control on wood quality is limited, with some information for *Pinus* and *Eucalyptus*. Weed control usually leads to an increase in the growth rate of trees. In ring-porous hardwoods, the growth rate can show a low positive correlation with density. Diffuse-porous species, such as poplars, seem to show no relationship between growth rate and density (Zobel and Talbert 1988; Saranpää 2003). Preliminary studies in Salicaceae indicate that the relationship between growth rate and density depends on the clone and the age (Monteoliva and Marlats 2007). As fibre length depends on the rate of transverse division of the initial cambium cells, the final result in fast-growing trees is the possible decrease in the fiber length (Zobel and Talbert 1988). For *Populus*, most of the studies found no relationship between fibre length and growth rate; however, some of them reported a positive correlation between these two variables (DeBell *et al.* 2002; Cisneros *et al.* 2000; Yu 2001; Zhang *et al.* 2003). The chemical composition of poplar wood changes very little with an increasing growth rate, although a reduction in the cellulose content has been reported (Olson *et al.* 1985; Sykes *et al.* 2008).

The literature, which mainly has focused on conifers, indicates that fertilization has a specific effect on wood properties, independent of the growth response. Those studies generally report a decrease in density and in tracheid length, as well as changes in chemical composition, as a result of fertilizer application (Zobel and Talbert 1988; Saranpää 2003). For different species and hybrids of *Populus*, the references indicate that fertilized timbers have lower wood density (Blankenhorn *et al.* 1988, 1992a), whereas fibre length could be longer, shorter, or approximately the same length than that of the controls (Snook *et al.* 1986; Luo *et al.* 2005; Pitre *et al.* 2007). Pitre *et al.* (2007) studied the application of three fertilization treatments with nitrogen on hybrid poplar. After two years, they found differences in the formation, structure, and chemical composition of the fibre walls. Other authors also reported changes in the chemical composition of different poplars in the short term (one to three years), with increases or decreases in various chemical components, according to the applied treatments (Snook *et al.* 1986: Blankenhorn *et al.* 1988, 1992b).

No references were found regarding the effect of forestry practices on the chemi-mechanical pulp (CMP) properties of poplar. The consequences of fertilization have been analysed in the kraft pulps of conifers, *Eucalyptus*, and the NE-388 hybrid poplar (Snook *et al.* 1986; Courchene *et al.* 2000; Miranda *et al.* 2006; Chandrasekhara Pillai *et al.* 2013; Pillai *et al*. 2013). Because CMP pulps behave more like mechanical pulps than as chemical pulps (Monteoliva *et al.* 2008), the comparisons with these citations are inconsistent. The influence of weed control on pulp quality is even less known, and there are no references for *Populus*.

The aim of the present study was to determine the long-term effects of weed control and fertilization practices on the growth parameters of the *Populus deltoides* commercial clone, as well as the basic wood density, the fibre weight, the fibre length, and the chemical composition of the wood, on the chemi-mechanical pulp properties, eight years after planting.

EXPERIMENTAL

Sampling

Eight-year-old trees of *Populus deltoides* Bartr. ex Marsh. `Delta Gold´ (formerly `Stoneville 66´) were cut from an experimental trial planted in Alberti, Buenos Aires, Argentina (34° 50’ S Lat.; 60° 30’ W Long.; 55 m elevation). The mean annual temperature is 15.8 ºC (min. 9.21 ºC; max. 41.6 ºC), with an average annual rainfall of 908 mm. The site soil is classified as Hapludoll typical, loamy textured (50.1% sand, 30% silt, 19.9% clay, 2.5% organic, and pH 7.4). Site quality was determined to be good to very good for cottonwood because of its deep, fertile, and well-drained soil (Lanfranco *et al.* 1999).

The site was disked and 70 cm long cuttings were planted at 3.5 x 2.8 m spacing on a ground free of weed cover. The original trial evaluated 14 treatments, disposed in a randomized complete block design with four replications. From this trial, we analysed four of the original treatments, namely:

- *M*, mechanical weed control: mechanized cross-disking between trees, plus manual hoeing around each tree; treatments were conducted over the first two growing seasons, twice per season.
- *CHM*, chemimechanical control of weeds: winter application of a pre-emergent herbicide (2.75 kg active ingredient/ha of simazine) in 1.3-m-wide bands, complemented with a graminicide application (54 g a.i./ha of quizalofop-P-ethyl) in mid-November and January, plus disking between bands. Treatments were conducted over the first two growing seasons; an additional weed control with 0.75 kg a.i./ha of ammonium glufosinate was performed before the pre-emergent treatment of the second growing season, to reduce weed coverage.
- *CHM-F*, fertilized + chemimechanical control of weeds: same as above, plus a “starting”, localized fertilization treatment with 45 g of nitrogen (N) / plant as urea and 34 g of phosphorous (P) / plant as triple superphosphate. Half of the nitrogen was applied at the beginning of the first growing season, and the remaining N was applied at the beginning of the second growing season.
- *C*, control: no weeding and no fertilization treatment was done after planting.

Four trees were cut from each of the treatments (C, M, CHM, and CHM-F), totalizing 16. From each one, two wood discs were removed at the base (0.20 m) and at breast height (1.30 m); one of them was used to determine wood properties, and the other one was used for the determination of pulp properties. Discs were cut at 1-m increments from the base going to the top of the tree.

Methods

Growth parameters

Volume (m^3): the diameter (including bark) of the discs at each sampled height was obtained as an average of two crossed measurements made on the cross section of each disc. The real volume of each tree was calculated using the Smalian formula (1):

$$V = L * \frac{(D_1^2 * \pi / 4) + (D_2^2 * \pi / 4)}{2} \tag{1}$$

where V is volume, D_1 and D_2 are the diameters of the upper and lower slices, according to their position in the stem segment, and L is the length of the stem segment.

Total height (m): Individual tree height was calculated by adding up the stem segments lengths (L), including the top one.

Diameter at breast height - DBH (m): DBH was obtained as an average of two cross measurements made on the transverse section of discs taken at a height of 1.30 m.

Wood properties

Basic density (kg/m^3): six discs per tree (at heights of 0.20, 1.30, 4, 8, 12, and 16 m) were debarked and cut into quarters. Three of these quarters were used for wood basic density determination following TAPPI Standard T 258 om-94. The average density value of each disc was used to calculate the arithmetic mean per tree and per treatment (72 determinations per treatment).

Fibre Weight (kg): basic wood density multiplied by stem volume was calculated as average values for each tree, as an index of stem dry fibre yield. This parameter has been demonstrated to constitute an excellent strategy selection for genetic improvement in *Populus* (Zhang *et al.* 2003).

Fibre length (mm): samples from 5 or 6 discs (at heights of 0.20, 1, 5, 9, 13 and 17 m) from two radial positions (of 25% and 75% from the pith) were chipped and macerated to determine fibre length (Franklin 1945). Twenty-five fibers from each radial position were measured using image analysis software (ImagePro Plus, v6.3, MediaCybernetics, MD, USA). The arithmetic means per tree and treatment were calculated (total of 1000 to 1200 fibers per treatment).

Chemical analysis: the remaining quarter of each disc used for the basic density determination was totally chipped with hand tools (hammer and chisel). All the chips of the trees sampled for each treatment were combined to compose a single sample. The chips were ground in a Wiley mill (Thomas Scientific, model No. 4) until 85% of the sample passed through a 40-mesh screen.

Chemical analysis determinations included the following: alcohol-benzene extractives (TAPPI T 204 cm-07), soluble material in hot and cold water (TAPPI T207 cm-08), acid-insoluble lignin (TAPPI T 222 om-06), acid-soluble lignin (TAPPI UM 250), ash determination at 525 ºC ignition (TAPPI T 211 om-07), cellulose (Seifert 1956), and hemicelluloses (by difference).

Pulping procedure

One half of each of the discs obtained at heights of 0.20, 1.30, 2, 6, and 10 m were hand chipped, while avoiding the rotting parts or knots. Chips were cut to approximately

2.5 cm long x 1.5 cm wide x 0.3 cm thick. The chips from the four trees of each treatment were mixed thoroughly and a representative sample for analysis was taken using the quartering procedure. The samples were then subjected to chemi-mechanical pulping. The chips were soaked with demineralised water until saturation, and afterwards atmospherically steamed for 20 min. The chemical impregnation treatment was carried out in a 7-L laboratory digester (M/K System Inc., Model M/K 409) under the following conditions: liquor-to-wood ratio = 5.5/1, Na_2SO_3 and NaOH = 2.6% on the basis of oven dry wood, cooking temperature = 80 ºC, and time at maximal temperature = 40 min.

Impregnated chips were defibrated in a 5-HP atmospheric refiner (Bauer Co.) with 8-inch-diameter discs. The resulting pulp fibers were drained on a 270-mesh screen. The obtained pulp was screened with a Sommerville fractionator to remove shives (TAPPI T 275 sp-07) in a closed water circuit with the recirculation of fines. It was then refined in a PFI mill according to TAPPI T 248 sp-08. Two or three refining stages were required to attain the targeted 44-46º SR drainage. Test handsheets were manufactured according to TAPPI T 205 sp-06 and ISO 3688-1977 (optical properties), with water recirculation to avoid the loss of fines.

Pulp properties

The following methods used for pulp characterisation:

- Refining degree, with a Schopper Riegler drainage tester (ºSR, ISO 5267-1: 1979).
- Water retention value (WRV) according to SCAN-C 62:00 (centrifuge force 3,000 ± 50 g; room temperature; 15 min ± 30 s).
- Physical and mechanical properties (bulk, burst, tear, tensile, air resistance), according to TAPPI test methods.
- Optical properties, according to ISO 3688-1977 and ISO 2471-1977 standards. The measurements were made with a Technidyne ISO spectrophotometer (Color Touch Model), which uses diffuse illumination (d/0°), with QTH source, illuminant D65, and 10° observer. Four sheets of each pulp were analysed, measuring brightness, L^*, a^*, b^*, opacity, absorption coefficient (k) and scattering coefficient (s) on both sides.
- Pulp component fractions, according to TAPPI T 233-cm-06, using a Bauer-McNett fibre classifier with 5 screens: R30, R50, R100, R150, and R270. The Forgacs (1963) L-factor (R30+R50) and R50+R100 sums were also calculated.

Statistical analysis

To determine the main effects of weed and fertilization treatment on all variables, a one-way ANOVA was carried out, with the type of treatment (C, M, CHM, and CHM-F) as the source of variability. Means were compared using Tukey's test. Differences between parameter means were considered significant when the P-value of the ANOVA F-test was less than 0.05. The following variables were not statistically analysed because only one value per treatment was available: refining degree, k and s coefficients, and fibre fractions. The relationships between variables were tested by correlation analysis. Statistical analyses were carried out using Statistica 7.0 software (StatSoft, Tulsa, Oklahoma, U.S.A.).

RESULTS AND DISCUSSION

Growth Parameters and Wood Properties

Treatment means and Tukey's test results for tree growth and wood properties are shown in Table 1.

There was no significant long term influence of the different weeding and fertilization treatments on tree growth. Nevertheless, the control showed lower values for volume (0.12 m^3), tree height (16.80 m), diameter (0.14 m), and fibre weight (39.9 kg) when compared with the silvicultural experimental treatments, such as chemical-mechanical treatment (CHM): 0.22 m^3, 19.64 m, 0.19 m, and 73.5 kg, respectively.

An increased growth rate during the early stages of development will necessarily modify wood in areas close to the pith. These changes alter the quality of stems, particularly in short rotation species (DeBell *et al.* 1998; Efhami *et al.* 2012). Although short-term responses are important during the establishment phase of a plantation, the main interest of forest managers regarding cropping practices involve long-term responses. Four different types of response to silvicultural treatments have been defined (Nilsson and Allen 2003; South *et al*. 2006).

In some cases the effects of a silvicultural treatment on productivity can be observed only after many years (named "type-A" response), although it can also happen that its effects are maintained even though rotation is shortened ("type-B" response). In other cases certain important short-term gains in growth have been lost by the end of rotation ("type-C" response). Finally, it may happen that growth of treated stands show inferior performance relative to the control ("type-D" response). Trees of this work have shown a type-C response in some growth parameters, *e.g.*, basal area, because treatments produced significant differences in the early years, but these differences vanished starting from the fifth year (data not shown, Achinelli 2007).

Results of this work confirm this classification, because the application of treatments M, CHM, and CHM-F produced initial gains, but they were gradually lost as harvest age approached. Silvicultural treatments did not significantly affect the basic wood density. These results differ from those reported by Blankenhorn *et al.* (1988, 1992a) for poplar hybrids; these authors found a reduction in wood density with fertilized timbers. The absence of variation of the basic density and fibre length suggested that the yield and some pulp properties would not be affected by silvicultural treatments.

The relationship between growth rate and density has been extensively studied for hardwoods, but the reported results are often controversial. Bilodeau-Gauthier *et al.* (2011) claimed that the use of weed control treatments for *Populus* typically led to an increase in the growth rate of the trees and consequently to possible modifications of wood quality. In Argentina, Monteoliva and Senisterra (2008) analysed 12 poplar clones (10-year-old Delta Gold) grown in the same location of this study; the authors found positive correlations between growth parameters and density. In the case of other *Populus* hybrids, there are also reports that density increased with growth parameters (Yanchuk *et al.* 1983; Cortizo *et al.* 2005). Nevertheless, most references indicated that with diffuse-porous species, there is no relationship between growth rate and wood density (DeBell *et al.* 2002; Zhang *et al.* 2003; Pliura *et al.* 2005), which agrees with the results of this work.

Table 1. Growth Parameters and Wood Properties of `Delta Gold´ *Populus* Clone under Different Treatments of Weed Control and Fertilization. Mean (±Standard Deviation)

	F(df,value) *P* [b]	C	M[a]	CHM	CHM-F
Wood Volume (m^3)	F (3, 3.15)	0.12 a[c]	0.18 a	0.22 a	0.24 a
	ns	(±0.05)	(±0.07)	(±0.04)	(±0.05)
Total height (m)	F (3, 2.82)	16.80 a	19.16 a	19.64 a	18.60 a
	ns	(±2.00)	(±1.28)	(±1.28)	(±0.17)
Diameter at breast height (m)	F (3, 3.25)	0.14 a	0.17 a	0.19 a	0.20 a
	ns	(±0.02)	(±0.03)	(±0.02)	(±0.02)
Wood Density (Kg/m^3)	F (3, 2.72)	336 a	341 a	341 a	347 a
	ns	(±1.64)	(±6.24)	(±4.37)	(±2.19)
Fibrous weight (Kg)	F (3, 3.44)	39.91 a	60.64 a	73.49 a	83.00 a
	ns	(±15.38)	(±22.56)	(±14.80)	(±19.21)
Fiber length (mm)	F (3, 0.25)	0.88 a	0.86 a	0.86 a	0.86 a
	ns	(±0.01)	(±0.02)	(±0.02)	(±0.07)
Alcohol-benzene extractives (%)	F (3, 8.69)	1.62 ab	1.42 a	1.52 ab	1.64 b
	**	(±0.08)	(±0.02)	(±0.05)	(±0.00)
Hot water soluble materials (%)	F (3, 22.19)	1.44 ab	1.34 a	1.78 c	1.68 bc
	**	(±0.04)	(±0.01)	(±0.11)	(±0.02)
Cold water soluble materials (%)	F (3, 5.35)	1.00 a	0.87 a	1.02 a	1.08 a
	ns	(±0.04)	(±0.03)	(±0.09)	(±0.03)
Acid-insoluble lignin (%)	F (3, 11.86)	22.3 ab	22.0 a	21.7 a	23.1 b
	**	(±0.24)	(±0.20)	(±0.19)	(±0.36)
Acid-soluble lignin (%)	F (3, 2.34)	2.36 a	2.33 a	2.22 a	2.26 a
	ns	(±0.06)	(±0.04)	(±0.01)	(±0.09)
Cellulose (%)	F (3, 3.00)	41.9 a	42.5 a	42.2 a	42.8 a
	ns	(±0.04)	(±0.47)	(±0.33)	(±0.21)
Hemicelluloses (%)	F (3, 27.38)	29.8 b	29.8 b	30.0 b	28.0 a
	**	(±0.27)	(±0.31)	(±0.19)	(±0.23)
Ashes (%)	F (3, 33.62)	0.52 a	0.54 a	0.62 b	0.50 a
	**	(±0.01)	(±0.02)	(±0.00)	(±0.01)

[a] **M**: mechanical weed control; **CHM**: chemimechanical control of weeds; **CHM-F**: fertilized + chemimechanical control of weeds; and **C**: no treatment
[b] P value: ** <0.05, ns not significant
[c] Letters are to be read horizontally. Similar letters imply the absence of significant differences (Tukey's test).

Most studies describing the effects of weed control and fertilization on wood quality only include short-term effects, for periods lasting from several months to 2 years (Wilkins and Horne 1991; Little *et al*. 2003). In the very short term, important structural changes in wood cells that form under different fertilizer concentrations usually occur (Luo *et al.* 2005; Pitre *et al.* 2007). Koubaa *et al*. (1998) found an increase in fibre length in 6- to 8-year-old fertilized hybrid poplars. Luo *et al*. (2005) reported that fertilized *Populus nigra* trees had longer fibers than the control, but the opposite behavior was observed for *Populus x euramericana*. Other authors also found fiber shortening with fertilization in *P. trichocarpa x P. deltoides* (Pitre *et al*. 2007). Results of the present study show that there was no change in fiber length as the tree diameter and volume increased. These findings are coincident with those of Snook *et al.* (1986). Thus, the increase in growth generated by weed control and fertilization does not necessarily result in a decrease in wood quality as reported by other authors (Little *et al*. 2003; Efhami *et al*. 2012). These findings are coincident with those of Snook *et al*. (1986). There was no evidence of tension wood in the analyzed radial positions for fiber length. Differences with other studies are possibly due to variations caused by the genotype and the specific conditions used (dose, concentration, *etc*.).

The chemical composition of wood changed slightly with the applied treatments during the growth period (8 years). Alcohol-benzene extractives, hot water-soluble materials, acid-insoluble lignin, hemicelluloses, and inorganic material significantly varied in comparison to the control (C) and to the mechanical treatment (M). The alcohol-benzene extractives and acid-insoluble lignin increased, whereas the hemicellulose content decreased, for the fertilized trees (CHM-F). The hot water-soluble materials increased slightly for the trees treated with herbicides (CHM and CHM-F), and the ash content increased in the trees subjected to CHM treatment. Ash content is related to the nutritional state (Kauter *et al.* 2003).

Trees treated with herbicides had greater water and light availability, as shown in their growth parameters (Table 1). Biomass growth improvement involves an increase in stem reserves, including ash content and hot water-soluble material. In agreement with these results, Blankenhorn *et al.* (1992b), when analysing the second rotation of plantations, concluded that management strategies had little effect on the chemical composition of trees, except for the extractive content, which increased with fertilization. Snook *et al.* (1986) reported an increase in lignin and ash content for fertilized *Populus* NE-388 hybrid trees.

For the same hybrid, Blankenhorn *et al.* (1988) stated that, in general, cellulose and extractive contents decreased or remained unchanged, while lignin content occasionally increased due to supplementary nutrients. Pitre *et al.* (2007) reported that high doses of nitrogen increased the cellulose content for one-year-old hybrid *Populus* because of the appearance of internal layers in the cell wall, similar to the G layer in tension wood.

Pulping and Pulp Properties

The results of chemi-mechanical pulp properties and Tukey's test are presented in Table 2.

Table 2. Chemi-mechanical Pulps Properties of \`Delta Gold´ *Populus* Clone under Different Treatments of Weed Control and Fertilization. Mean (±Standard Deviation)

	F (df, value) *P* [b]	C	M[a]	CHM	CHM-F
Pulp yield	-	94.0	93.5	93.2	93.9
ºSR[c]	-	46	44	54	37
WRV[c] (%)	F (3, 123.39) **	159 a[d] (±0.53)	170 b (±0.36)	177 c (±0.91)	160 a (±1.89)
Bulk ($cm^3.g^{-1}$)	F (3, 185.07) **	2.75 c (±0.01)	2.68 b (±0.03)	2.73 c (±0.02)	2.56 a (±0.02)
Tear Index ($mNm^2.g^{-1}$)	F (3, 7.59) **	2.89 ab (±0.27)	3.22 bc (±0.41)	3.34 c (±0.25)	2.63 a (±0.11)
Tensile Index ($Nm.g^{-1}$)	F (3, 0.48) ns	21.8 a (±1.61)	22.1 a (±1.54)	21.8 a (±1.40)	22.4 a (±0.92)
Elongation (%)	F (3, 5.31) **	1.14 b (±0.13)	1.01 a (±0.08)	1.17 b (±0.10)	1.08 ab (±0.06)
TEA Index ($J.g^{-1}$)	F (3, 1.43) ns	0.14 a (±0.03)	0.12 a (±0.02)	0.14 a (±0.03)	0.13 a (±0.02)
Burst Index ($kPam^2.g^{-1}$)	F (3, 1.75) ns	0.91 a (±0.04)	0.88 a (±0.03)	0.87 a (±0.03)	0.88 a (±0.06)
Air resistance (s)	F (3, 3.28) **	6.44 ab (±0.84)	6.05 ab (±0.91)	5.55 a (±0.58)	6.49 b (±0.65)
Brightness (%)	F (3, 270.44) **	60.8 c (±0.09)	59.4 b (±0.20)	58.2 a (±0.19)	61.2 d (±0.16)
Opacity (%)	F (3, 63.64) **	90.3 b (±0.44)	89.5 a (±0.19)	91.5 c (±0.30)	90.0 b (±0.30)
k[c] ($m^2.kg^{-1}$)	-	1.95	2.05	2.25	2.05
s[c] ($m^2.kg^{-1}$)	-	41.3	41.1	41.9	40.8
L*	F (3, 314.74) **	89.6 c (±0.05)	89.4 b (±0.08)	88.7 a (±0.04)	90.1 d (±0.08)
a*	F (3, 88.83) **	1.30 b (±0.03)	1.39 c (±0.03)	1.54 d (±0.01)	1.18 a (±0.05)
b*	F (3, 136.92) **	13.8 a (±0.07)	14.8 c (±0.06)	14.8 c (±0.13)	14.3 b (±0.04)
R30[c] (%)	-	26.36	24.19	28.33	21.53
R50 (%)	-	30.99	28.82	29.69	33.51
R100 (%)	-	16.24	15.35	22.07	14.15
R150 (%)	-	9.51	9.64	5.66	11.90
R270 (%)	-	6.56	6.41	7.83	6.29
P270[c] (%)	-	10.34	15.59	6.42	12.62
L[c] factor (R30+R50) (%)	-	57.35	53.01	58.02	55.04
R50+R100 (%)	-	47.23	44.17	51.76	47.66

[a] **M**: mechanical weed control; **CHM**: chemimechanical control of weeds; **CHM-F**: fertilized + chemimechanical control of weeds; and **C**: no treatment

[b] P value: ** <0.05, ns not significant

[c] ºSR: Shopper Riegler degrees, WRV: water retention value, *k*: light absorption coefficient, *s*: light scattering coefficient, R: fiber fraction retained in 30 (50, 100…) mesh screen, P: fiber fraction passing through 270 mesh screen, *L*: Forgacs (1963) *L* factor.

[d] Letters are to be read horizontally. Similar letters imply the absence of significant differences (Tukey's test).

Pulping yields were similar between the treatments (93 to 94%). Water retention value, bulk, air resistance, tear strength, elongation, opacity, brightness, and colour parameters (*i.e.*, *L* *, *a**, and *b**) varied significantly for pulps obtained from trees that underwent different silvicultural treatments, whereas tensile strength, burst strength, and TEA index did not differ significantly (Table 2 and Fig. 1).

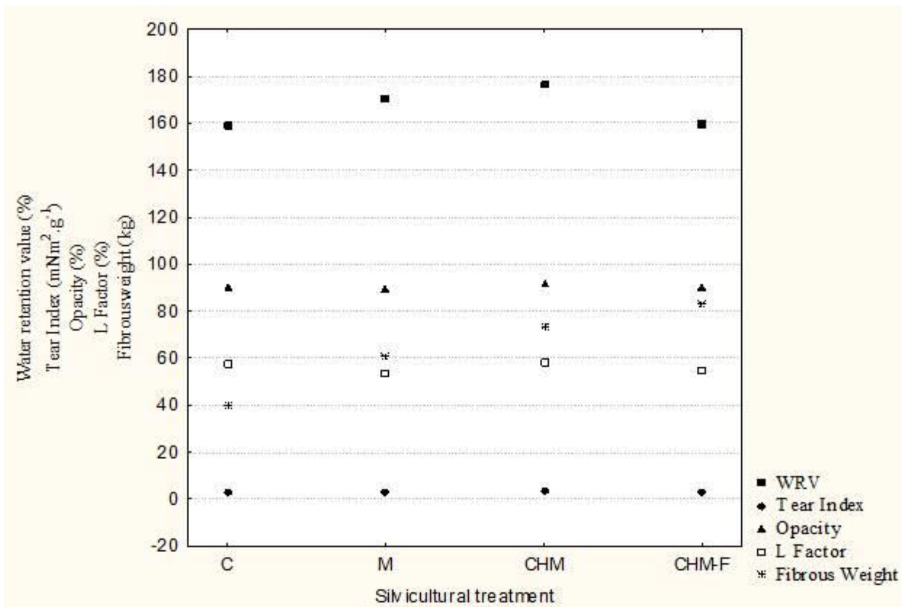

Fig. 1. Water retention value, tear index, opacity, Forgacs *L* factor and fibrous weight, arranged by treatment (arithmetic means). Chemimechanical treatment (CHM) had the best performance relative to WRV, opacity, tear index, and *L* factor, while fibre yield was as higher from one of the fertilized trees (CHM-F).

The pulp made from the control (C) trees was statistically different than pulp made from trees submitted to other treatments with respect to the water retention value, bulk, tear strength, elongation, and optical properties. It was the bulkiest pulp (CHM had a similar behavior) and had the lowest WRV (similar to CHM-F). The pulp from treatment C showed lower tear strength than that from CHM and higher elongation than that from M. The tear strength values were generally very low, but the pulp from CHM had 25% higher tear strength than the pulp from trees with CHM-F treatment. These behaviours correlated with the hemicellulose content (r = 0.73). The water retention values (WRV) and strengths were within the range reported by other authors for CMP pulps from poplars and willows (Zanuttini and Marzocchi 2000; Monteoliva *et al.* 2007).

Brightness and *L** followed similar trends; CHM-F had the highest values, followed by C, M, and CHM. These results indicated that, except for the chemi-mechanical fertilized treatment, all remaining silvicultural treatments darkened the resulting pulp by 1 or 2%. CHM had the highest opacity, absorption, and scattering coefficients, whereas the control and CHM-F showed lower values. The parameters *a** and *b** positioned the pulps in the red-yellow quadrant in the CIE *L***a***b** system (*i.e.*, all positive values).

The brightness values of the pulps from all treatments were around 60% ISO, exceeding by 10 to 12% the brightness of willow pulps obtained by the same CMP process (Monteoliva *et al.* 2007). Opacity, absorption coefficient (*k*), and light scattering (*s*) of these poplar pulps were lower, whereas the luminosity L^* was higher and the parameters a^*, b^* and the scattering coefficients were very similar, compared to those of willow pulps.

All pulps showed similar Bauer McNett fractions: 28.82 to 33.51% R50 fraction (unbroken fibers and long fragments); 21.53 to 28.33% R30 fraction (fiber bundles and slightly damaged fibers), and 14.15 to 22.07% R100 fraction (short fiber fragments, some of them ribbon-like). The three finest fractions, R150, R270 and P270, showed values between 5 and 15%.

Significant correlations ($p < 0.05$) were detected between the following: fraction R30 and ºSR (r = 0.98), R30 and tensile index (r = -0.96), R30 and s (r = 0.96), R100 and s (r = 0.98), R150 and ºSR (r = -0.99), R150 and s (r = 0.99), R270 and s (r= 0.95), P270 and elongation (r= -0.966), P270 and TEA (r = -0.95), and P270 and opacity (r = -0.98). Forgacs's L factor (R30+R50 fractions) correlated with elongation (r = 0.99) and TEA (r = 0.99), whereas R50+R100 (entire and fragmented fibers) correlated with opacity (r = 0.99).

Comparing only the mechanical weeding (M) with the control (C), it is evident that weeding produced an increase in the percentage of P270 fines and WRV and a decrease in bulk, elongation, brightness, opacity, and *L* factor.

The pulp from trees treated with simazine, quizalofop-P-ethyl, and ammonium glufosinate (CHM) had higher WRV, opacity, light absorption coefficient, bulk, elongation, R100, and *L* factor, but lower brightness and P270, than those treated only mechanically (M).

Comparing the treatments CHM and CHM-F, which differ only by the addition of nitrogen and phosphorus to the second, there was an absence of important changes in pulp performance due to fertilization, which coincides with what was found for the NE-388 poplar hybrid kraft pulp (Snook *et al.* 1986). These authors suggested that the yield of biomass per hectare would be greater in fertilized poplar trees, resulting in higher pulp yield in tons/ha, thereby minimizing wood cost while not affecting the wood's pulp properties. In any case, no references showing the effect of silvicultural treatments on the properties of hardwood chemi-mechanical pulps were found, as the literature has focused on conifers or *Eucalyptus* chemical pulps. High yield CMP pulps behaviour is very different from chemical pulps, which makes any comparison misleading.

CHM-F generated a pulp with lower WRV, bulk, opacity, tear resistance, and absorption and scattering coefficients, but higher air resistance and brightness (3% more), than those from trees treated by CHM.

Although no data were found for CMP pulps, tear strength dropped in the fertilized treatment, and this behaviour agreed with what was found by other authors working with kraft pulps (Clark *et al.* 1999; Jett and Zobel 1975). In contrast, it was reported (Clark *et al.* 1999) that for kraft pulps from fertilized *Eucalyptus*, the brightness decreased, whereas the light scattering coefficient increased, which was in contrast to the findings of the present work. In chemical pulps, the fibers usually maintain their anatomical characteristics but became flexible. Consequently a good network is achieved by influencing the physical properties of pulp sheets. However, this direct relationship between original fiber characteristics and physical properties is not apparent in the high-yield pulps. This is because in addition to being rigid, the fibers exhibit morphological changes due to mechanical treatment. In high yield pulps, bonding is related mostly to shortening, wall cleavage, external fibrillation, and amount and quality of fines (Monteoliva *et al*. 2008, Cobas *et al.* 2013). The situation is even worse when dealing with short hardwood fibers. For this reason, it is important to note that results are difficult to generalize.

CONCLUSIONS

1. Silvicultural treatments applied to 8-year-old *Populus deltoides* \`Delta Gold´ clones had little effect on wood properties, except for some modifications in the chemical composition, whereas chemi-mechanical pulp characteristics were affected by the silvicultural treatments under the operating conditions of this research work.
2. Mechanical weed control resulted in a pulp with higher water retention value and P270 fines and in handsheets, with low bulk, elongation, opacity, and brightness. Chemimechanical control of weeds (herbicide application) resulted in an increase of hot water solubles and inorganic material in wood, whereas the effects on the pulp were higher for water retention value, bulk, R100, and L factor, and number of P270 fines. This resulted in handsheets with higher elongation, opacity, and light absorption coefficient, but lower brightness, as compared with trees treated only mechanically. Fertilization with nitrogen and phosphorus produced wood with more acid-insoluble lignin and lower hemicellulose and ash contents than those from trees not fertilized. The effect of fertilization on pulp was a decrease of the Forgacs L factor, water retention value, bulk, tear resistance, opacity, and scattering and absorption coefficients of sheets, and an increase in air resistance and brightness (3%).
3. Wood basic density, fibre length, cold water solubles, acid-soluble lignin and cellulose contents, pulping yields, and burst, tensile, and TEA indices of the sheets were not affected by the treatments.
4. In the context of this study, silvicultural treatments can be applied to this clone to increase productivity (volume and fibrous output) without detrimental consequences on wood and pulp properties, except for a slight reduction in brightness.

ACKNOWLEDGMENTS

Dr. Enrique Portiansky is acknowledged for his valuable comments on the manuscript and his technical assistance with the image analysis. The authors are grateful for the support of Papel Prensa S.A., who provided wood samples from their plantations, and of Fundación YPF, who financed the research.

REFERENCES CITED

Achinelli, F. G. (2006). "Silvicultura de álamos y sauces en la pampa húmeda,"*Jornadas de Salicáceas,* Buenos Aires, Argentina, September 2006, *Proceedings,* 21-36.

Achinelli, F. G. (2007). "Bases para el desarrollo de un sistema integrado de control de malezas en el establecimiento de plantaciones de *Populus* spp. del centro-norte de la Provincia de Buenos Aires, Argentina," MSci. Thesis, Universidad Nacional de La Plata, Argentina [In Spanish], 184 pp. http://163.10.34.134/ARG-UNLP-TPG-0000000764/10202.pdf, Accessed December 10, 2013.

Bilodeau-Gauthier, S., Paré, D., Messier, C., and Belanger, N. (2011). "Juvenile growth of hybrid poplars on acidic boreal soil determined by environmental effects of soil preparation, vegetation control and fertilization," *Forest Ecology and Management* 261(2011), 620-629.

Blankenhorn, P. R., Bowersox, T. W., Strauss, C. H., Stimely, G. L., Stover, L. R., and DiCola, M. L. (1988). "Effects of management strategy and site on selected properties of first rotation *Populus* hybrid NE-388," *Wood Fiber Sci.* 20(1), 74-81.

Blankenhorn, P. R., Bowersox, T. W., Strauss, C. H., Kessler, K. R., Stover, L. R., Kilmer, W. R., and DiCola, M. L. (1992a). "Effects of management strategy and site on specific gravity of a *Populus* hybrid clone," *Wood Fiber Sci.* 24(3), 274-279.

Blankenhorn, P. R., Bowersox, T. W., Strauss, C. H., Kessler, K. R., Stover, L. R., and DiCola, M. (1992b). "Chemical composition of second rotation *Populus* hybrid NE-388," *Wood Fiber Sci.* 24(3), 280-286.

Chandrasekhara Pillai, P. K., Pandalai, R. C., Dhamodaran, T. K. and Sankaran, K. V. (2013). "Effect of silvicultural practices on fibre properties of *Eucalyptus* wood from short-rotation plantations," *New Forests* 44(4), 521-532.

Cisneros, H. A., Belanger, L., Gee, W. E., Watson, P. A., and Hatton, J. V. (2000). "Wood and fiber properties of hybrid poplars from Southern British Columbia," *TAPPI J.* 83(7), 60-60.

Clark, N. B., Read, S. M., and Vinden, P. (1999). "Effects of drought and salinity on wood and kraft pulps from young plantation eucalypts," *Appita J.* 52(2), 93-97.

Cobas, A. C., Felissia, F. E., Monteoliva, S., and Area, M. C. (2013). "Optimization of the properties of poplar and willow chemimechanical pulps by a mixture design of juvenile and mature wood," *BioResources* 8(2), 1646-1656.

Cortizo, S., Merna, V., and Pathauer, P. (2005). "Evaluación de clones de álamo en el Delta del Paraná," *11ª Jornadas Técnicas Forestales y Ambientales, FCF, UNaM-EEA Montecarlo INTA. Actas,* 5 pp.

Courchene, C. E., Clark III, A., Belli, M. L., Cooper, W. J., and Shiver, B. D. (2000). "Effects of intensive silvicultural treatments on Kraft pulp quality of loblolly and slash pine," *TAPPI Pulping/Process and Product Quality Conference,* TAPPI Press, Atlanta, GA, Conf. CD, 9 pp.

Da Silva Perez, D., and Fauchon, T. (2003). "Wood quality for pulp and paper," in: *Wood Quality and its Biological Basis,* Barnett and Jeronimidis (eds.), Blackwell Publ. Ltd., U.K., pp. 157-186.

DeBell, J. D., Gartner, B. L., and DeBell, D. S. (1998). "Fiber length in young hybrid *Populus* stems grown at extremely different rates," *Can. J. For. Res.* 28, 603-608.

DeBell, D. S., Singleton, R., Harrington, C. A., and Gartner, B. L. (2002). "Wood density and fiber length in young *Populus* stem: Relation to clone, age, growth rate, and pruning," *Wood and Fiber Sci.* 34(4), 529-539.

Efhami Sisi, D., Karimi, A. N., Pouthamasi, K., and Taghiyari, H. R. (2012). "The effects of agroforestry practices on fiber attributes in *Populus nigra* var.*betulifolia*," *Trees* 26, 435-441.

Fisher, R. F., and Binkley, D. (2000). *Ecology and Management of Forest Soils.* Wiley, New York.

Forgacs, O. L. (1963). "The characterization of mechanical pulps," *Pulp Paper Mag. Can.*, 64(Convention Issue), T89-T118.

Franklin, G. L. (1945). "Preparation of thin sections of synthetic resins and wood-resin composites, and a new macerating method for wood," *Nature* 155(3924), 51.

Jett, J. B., and Zobel, B. J. (1975). "Wood and pulping properties of young hardwoods," *TAPPI J.* 58(1), 92-96.

Kauter, D., Lewandowsky, I., and Claupein, W. (2003). "Quantity and quality of harvestable biomass from *Populus* short rotation coppice for solid fuel use - A review of the physiological basis and management influences," *Biomass Bioenerg.* 24(6), 411-427.

Koubaa, A., Hernández, R. E., Beaudoin, M., and Poliquin, J. (1998). "Interclonal, intraclonal, and within-tree variation in fiber length of poplar hybrid clones," *Wood and Fiber Science* 30(1), 40-47.

Lanfranco, J. W., Carrizo, R., and Gelati, P. (1999). "Clasificación para evaluar la capacidad de uso de los suelos," *XIV Congreso Latinoameriano de las Ciencias del Suelo. Pucón, Chile*, 220 pp.

Little, K. M., Johannes van Staden, G., and Clarke, P. Y. (2003). "The relationship between vegetation management and the wood and pulping properties of a *Eucalyptus* hybrid clone," *Ann. For. Sci.* 60(7), 673-680.

Luo, Z. B., Langenfeld-Heyser, R., Calfapietra, C., and Polle, A. (2005). "Influence of free air CO2 enrichment (EUROFACE) and nitrogen fertilization on the anatomy of juvenile wood of three poplar species after coppicing," *Trees* 19, 109-118.

Miranda, I., Gominho, J., Lourenço, A., and Pereira, H. (2006). "The influence of irrigation and fertilization on heartwood and sapwood contents in 18-year-old *Eucalyptus globulus* trees," *Can. J. For. Res.* 36(10), 2675-2683.

Monteoliva, S. E., and Marlats, R. E. (2007). "Efecto del sitio, clon y edad sobre el crecimiento y la calidad de madera en sauces de corta rotación," *Invest. Agrar. Sist. Recur. For.* 16(1), 15-24.

Monteoliva, S., Area, M. C., and Felissia, F. E. (2007). "CMP pulps of willows for newsprint part 1: Pulps evaluation," *Cellulose Chem. Technol.* 41(4-6), 263-272.

Monteoliva, S., Area, M. C., and Felissia, F. E. (2008). "CMP pulps of willows for newsprint. Part 2: relationships between wood characteristics and pulp properties," *Cellulose Chem. Technol.* 42(1-3), 45-59.

Monteoliva, S. E., and Senisterra, G. (2008). "Efecto del sitio, el origen y el clon sobre el crecimiento y propiedades de la madera de *Populus*," *Invest. Agrar. Sist. Recur. For.* 17(3), 261-270.

Nilsson, U., and Allen, H. L. (2003). "Short and long term effects of site preparation, fertilization and vegetation control on growth and stand development of planted loblolly pine," *For. Ecol. Manage.* 175(1-3), 367-377.

Olson, J. R., Jourdain, C. J., and Rousseau, R. J. (1985). "Selection for cellulose content, specific gravity, and volume in young *Populus deltoides* clones," *Can. J. Forest Res.* 15(2), 393-396.

Pillai, P. K. C, Pandalai, R. C., Dhamodaran, T. K., and Sankaran, K. V. (2013). "Wood density and heartwood proportion in *Eucalyptus* trees from intensively-managed short-rotation plantations in Kerala, India," *Journal of Tropical Forest Science* 25(2), 220-227.

Pitre, F. E., Cooke, J. E. K., and Mackay, J .J. (2007). "Short-term effects of nitrogen availability on wood formation and fibre properties in hybrid poplar," *Trees* 21(2), 249-259.

Pliura, A., Yu, Q., Zhang, S. Y., MacKay, J., Périnet, P., and Bousquet, J. (2005). "Variation in wood density and shrinkage and their relationship to growth of selected young poplar hybrid crosses," *For. Sci.* 51(5), 472-482.

Saranpää, P. (2003). "Wood density and growth," in: *Wood Quality and its Biological Basis*, Barnett and Jeronimidis (eds.), Blackwell Publ. Ltd., U.K., pp. 87-117.

Seifert, K. (1956). "New method for rapid determination of pure cellulose," *Papier* 10(13/14), 301-306.

Snook, S. K., Labosky, Jr., P., Bowersox, T. W., and Blankenhorn, P. R. (1986). "Pulp and papermaking properties of a hybrid poplar clone grown under four management strategies and two soil sites," *Wood and Fiber Sci.* 18(1), 157-167.

South, D. B., Miller, J. H., Kimberley, M. O., and Vanderschaaf, C. L. (2006). "Determining productivity gains from herbaceous vegetation management with 'age-shift' calculations," *Forestry* 79(1), 43-56.

Sykes, R., Kodrzycki, B., Tuskan, G., Foutz, K., and Davis, M. (2008). "Within tree variability of lignin composition in *Populus*," *Wood Sci. Technol.* 42(8), 649-661.

Wilkins, A. P., and Horne, R. (1991). "Wood-density variation of young plantation-grown *Eucalyptus grandis* in response to silvicultural treatments," *Forest Ecology and Management* 40, 39-50.

Yanchuk, A. D., Dancik, B. P., and Micko, M. M. (1983). "Intraclonal variation in wood density of trembling aspen in Alberta," *Wood and Fiber Sci.* 15(4), 387-394.

Yu, Q. (2001). *Selection and Propagation of Hybrid Aspen Clones for Growth and Fibre Quality*," PhD Dissertation, Dept. of Applied Biology, Univ. of Helsinki, Helsinki, Finland, 41 pp.

Zanuttini, M., and Marzocchi, V. (2000). "Pulpa quimimecánica de álamo. Relación entre su estado químico, su hinchamiento y sus propiedades," *I Congreso Iberoamericano de Investigación en Celulosa y Papel (CIADICYP). Puerto Iguazú, Argentina.*

Zhang, S. Y., Yu, Q., Chauret, G., and Koubaa, A. (2003). "Selection for both growth and wood properties in hybrid poplar clones," *For. Sci*. 49(6), 901-908.

Zobel, B. J., and Talbert, J. (1988). *Técnicas de mejoramiento genético de árboles forestales*. Ed. Limusa, México.

Article submitted: August 1, 2013; Peer review completed: December 7, 2013; Revised version received and accepted: December 14, 2013; Published: December 17, 2013.