PHENOTYPIC CORRELATIONS AMONG WOOD PROPERTIES AND GROWTH IN WILD CHERRY PLANTATIONS

Michela Nocetti,[a,]* Michele Brunetti,[a] Fulvio Ducci,[b] Manuela Romagnoli,[c] Philippe Rozenberg,[d] and Frédérique Santi [d]

Italy is one of the major users of cherry wood (*Prunus avium* L.), and its cultivation has been increasing since the early nineties, together with studies aimed at improving genotypes, with a selection usually based on growth, stem form, vigor, and tree adaptation. Here, the phenotypic correlations between growth rate and the physical and mechanical properties of wood are investigated in two wild cherry plantations. X-ray microdensitometry was also applied to analyze the age-age correlations of wood density. It was shown that growth rate did not affect wood properties, and density was confirmed to be the trait that best represents the main properties of wood. The absence of relationships between wood density and growth rate was confirmed by densitometric analysis, although an increase of wood density with an increase of ring width was detected for very narrow rings (less than 3 mm wide). The average density at age 7 to 8 was observed to be highly correlated (r > 0.90) to the average density of a 19-year-old tree, allowing reliable estimation of the wood properties of older trees by early investigation of young trees.

Keywords: Prunus avium; Clone; Wood density; X-ray microdensitometry; Wood quality

Contact information: a: CNR – IVALSA, Istituto per la Valorizzazione del Legno e delle Specie Arboree, Via Madonna del Piano 10, 50019 Sesto Fiorentino (FI), Italy; b: CRA – SEL, Centro di Ricerca per la Selvicoltura, Viale Santa Margherita 80, 52100 Arezzo, Italy; c: DAF – Università degli Studi della Tuscia, Via S. Camillo de Lellis, 01100 Viterbo, Italy; d: INRA Orléans, Unité Amélioration Génétique et Physiologie Forestières, 2163 Avenue de la Pomme de Pin, BP 20619 Ardon, 45166 Olivet Cedex, France
** Corresponding author: nocetti@ivalsa.cnr.it*

INTRODUCTION

Italy is one of the major European users of cherry wood (*Prunus avium* L.), which is highly appreciated and mainly used for furniture, both as solid wood or veneer, for cabinet making, turnery, and flooring. Currently, the high timber demand is partly satisfied by the import of black cherry from North America, although wild cherry cultivation has been expanded since the early nineties, thanks to the public incentives. The positive carbon-sink functions and the wide geographical range that make it a native species in most of the European countries are among the several benefits of wild cherry cultivation, together with the production of valuable timber, which can be used for lasting product manufacture.

Therefore, studies aimed to select and improve genotypes for arboriculture purposes, and numerous breeding programs for wild cherry have been increased in Italy, as well as in many other European countries (Muranty *et al.* 1998; Santi *et al.* 1998; Martinsson 2001; Kobliha 2002; Curnel *et al.* 2003). Up until now, the selection of superior genotypes has been mostly based on growth, stem form, adaptation, and survival traits. But, because the timber production is the final goal, the knowledge of the relationship between growth and wood traits is a fundamentally important issue (Rozenberg and Cahalan 1997; Raymond 2002; Zhang *et al.* 2003; Bouffier *et al.* 2008).

Compared to softwoods, the influence of the growth rate on the physical and mechanical properties of hardwoods seems reasonably lower. For diffuse-porous hardwoods, no relationship between growth rate and wood density has been found in previously studies (Fukazawa 1984; Zobel and van Buijtenen 1989; Zhang 1995). The same conclusion was drawn in particular for black cherry (*Prunus serotina*, Koch 1967) and birch (*Betula pendula*, Nepveu and Velling 1983). For poplar (*Populus* spp.) the results have been more controversial: some authors reported the absence of correlation between density and growth rate (Mátyás and Peszlen 1997; DeBell *et al.* 2002; Zhang *et al.* 2003), while others described a weak negative relationship (Beaudoin *et al.* 1992; Hernández *et al.* 1998; Pliura *et al.* 2006, 2007). Little research has been done on the influence of growth rate on shrinkage and mechanical properties of hardwoods. For diffuse-porous hardwoods, a number of studies did not detect any such correlation in poplar (Zhang 1995; Mátyás and Peszlen 1997; Koubaa *et al.* 1998; De Boever *et al.* 2007) and birch (*Betula platyphylla* and *Betula utilis*, Zhang 1995), while few reported a negative correlation again in birch (Nepveu and Velling 1983) and poplar (Hernández *et al.* 1998). So far, no specific studies have been carried out on wild cherry.

In the same way, the relationships in the wood properties of valuable hardwoods still remain an open question. For example, wood density is generally considered the most representative trait of wood properties and it is used to describe overall wood quality, both as concerns mechanical timber properties, as well as workability, shrinkages, and dimensional stability, although most studies have focused on softwoods, on *Populus*, and *Eucalyptus* genera (Zobel and van Buijtenen 1989; Zhang 1997; Hernández *et al.* 1998; Koubaa *et al.* 1998; De Boever *et al.* 2007). Density is also an easily measurable trait that can be useful for extensive studies. Here, the importance of knowing the correlations among traits arises from two main aspects: firstly, the demands of the future industry sometimes are difficult to foresee properly. Also, because of the very long time needed in forest tree improvement programs, it seems worthwhile to acquire as much information (*i.e*. several traits) as possible on the wood characterization of previously selected clones. At the same time, the use of a large number of traits during breeding programs would increase costs and time requirements, leading, moreover, to a loss in the effectiveness of selection; therefore attention should be focused on a few wood properties, while being aware of the correlations with the other traits.

The majority of the main physical and mechanical characteristics of wood were analysed previously in order to provide information on the variability of the cherry wood properties both within the tree, within and among clones, and between sites (Nocetti *et al.* 2010). The results showed significant clone effect for all the studied traits; for growth traits the most important source of variation was the site, while for wood properties the highest variability was detected within the tree. In this paper, the correlations among all these traits are investigated.

Finally, wood properties fluctuate with tree age, and the evaluation of wood traits carried out on very young trees can lead to unexpected performances of older plants.

Therefore, age-age correlations and the determination of minimum age at which traits can be assessed in order to obtain a reliable estimation of the same properties at later ages is of crucial importance to favor the early investigations and, consequently, to shorten the studies on wood properties (Vargas-Hernandez and Adams 1992; Rozenberg and Cahalan 1997; Koubaa *et al.* 2000; Raymond 2002). Hence, a microdensitometry technique was applied to wild cherry trees in order to calculate the age-age correlations for the wood density and the results are presented. Hence, the aims of the work are to:

- Examine the relationships between growth rate and wood properties;
- Investigate the correlations between physical and mechanical properties of wood and verify density as the best trade-off trait of overall wood characteristics for cherry as well;
- Analyze the age-age correlations for wood density.

MATERIALS AND METHODS

Sampling and Laboratory Measurements

In total, 71 cherry trees were collected in two twenty-year-old clonal trials located at two sites, Marani farm and Forestello, in the north and in the centre of Italy, respectively. The clones were micro-propagated from selected phenotypes located in the central Apennines, between 44°31’20” lat. N and 43°23’00” at different altitudes (between 150 and 1000 m a.s.l.) and planted in 1986. At the Marani farm the initial spacing was 3 x 3 m and a systematic thinning was carried out in 1995; at Forestello the plantation was mixed with *Alnus cordata*, and the spacing was 3 x 3 between trees and 6 x 6 m between wild cherry trees.

Six clones, with four clones common to both sites, and four-eight ramets per clone, were felled and processed in 2006 and 2007 in order to undergo laboratory tests and measurements. The characteristics of the sites, the specimen preparation, and the laboratory tests have been described in detail in a previous paper (Nocetti *et al.* 2010).

After harvesting, diameter at breast height and total tree height were measured, and a 1-m-long log was collected 50 cm above ground level from each tree, transported to the laboratory, and immediately processed. The percentage of heartwood area in the cross section and the number of sapwood rings were measured in a 2 cm thick disc; specimens were scanned and processed with an image analyzer software.

Wood density, linear and volumetric shrinkages, shape factor (ratio of tangential to radial shrinkage), and the main mechanical properties were determined in defect-free specimens cut from the four radial planks of the log and numbered in sequence from the pith to the bark. The heartwood / sapwood position were recorded accordingly.

For the physical determinations the specimens were first measured in the green state, conditioned at 65% RH and 20°C, measured again, and finally oven-dried. Wood density was calculated as the ratio of weight to volume at 12% of wood moisture content (conditioned state, ISO 3131); radial, tangential, and volumetric shrinkages were calculated as the percentage of oven-dried to green measures (ISO 4469 and ISO 4858).

For mechanical tests the specimens were cut and conditioned before testing. The dynamic modulus of elasticity was measured by means of the BING software (http://www.xylo-metry.org/en/softwares.html) (Brancheriau and Baillères 2002). After that, the specimens were subjected to the static bending test to determine the modulus of rupture (ISO 3133). The maximum compression strength parallel to grain and the maximum shear strength were calculated as the load at failure divided by the cross specimen area measured at the testing time (ISO 3787 and ISO 3347, respectively). Finally, wood hardness was determined by means of the Brinell method (EN 1534). Samples for physical and mechanical properties determinations were collected both from heartwood and sapwood zones (Table 1).

Table 1. Symbols and Number of Specimens per Site and Heartwood (h) / Sapwood (s) Area

Trait	Symbol	Marani		Forestello		TOT
		h	s	h	s	
Growth Traits						
diameter at breast height	DBH	48		23		71
height	H	48		23		71
stem volume	VOL	48		23		71
mean ring width	RW	48		23		1270
Heartwood/Sapwood content						
percentage of heartwood area	HW%	48		23		71
number of sapwood rings	SR	48		23		71
Wood Traits						
wood density	D_{12}	279	127	192	152	750
radial shrinkage	RS	279	127	192	152	750
tangential shrinkage	TS	279	127	192	152	750
volumetric shrinkage	VS	279	127	192	152	750
shape factor	T/R	279	127	192	152	750
modulus of elasticity	MOE	110	82	80	88	360
modulus of rupture	MOR	129	90	89	90	398
max compression strength	MCS	131	90	90	91	402
max shear strength	MSS	131	90	89	91	401
hardness	HB	93	66	46	46	251

In addition, microdensitometric analysis was performed in order to describe the density variation along the radius and to investigate its relationship with growth at ring level: microdensitometry allows a decomposition of the relationships in wood density, its intra-ring components (minimum and maximum ring density), and growth rate (ring width). The measurements so achieved were also used for calculation of the age-age correlations for wood density.

To the purpose, a disc was cut (1.3 m high from ground level) from each tree log, and a radius was chosen to be free of defects and to be representative of the whole disc. From the radius, a thin section (1 cm in size on the tangential direction and 1.2 mm thick on the longitudinal direction) was cut and then seasoned at 20°C and 65% R.H. before undergoing X-ray analysis according to the procedure developed by Polge (1978). Briefly, the specimens were perpendicularly irradiated by X-rays (distance from the source 1.6 m) at the voltage of 9 kV and current flow of 10 mA for 12-15 minutes. The resulting X-ray films were scanned at a 1,000 dpi resolution with 8 bits per pixel and the digital images were then processed with the WinDENDRO software (Guay *et al.* 1992), obtaining a spatial resolution of 25 μm. Together with the specimens, a wedge of wellknown density was irradiated, such as to convert the X-ray absorption (resulting in a grayscale) in density. The microdensitometric measurements were analyzed using a computer routine written in R language (R Development Core Team 2010).

For each ring of the microdensity profiles, ring width (**rw**), mean, minimum, and maximum ring density (**m**, **mi**, **ma**, respectively) were computed. After that, the mean ring width was calculated at the tree level both for the whole radius, in the heartwood, and the sapwood area.

Data Analysis

The statistical analysis was performed separately for the two sites. At first the assumptions of the normality of each data series distribution and the homogeneity of variance were verified by Wilk-Shapiro and Levene test respectively. Afterwards, because of the significant clone effect and the high variation between heartwood/ sapwood areas previously observed (Nocetti *et al.* 2010), an ANOVA model was performed for each trait including clone and (for the wood traits) sampling position (heartwood/sapwood) as fixed effects (Model 1).

$$Y_{ij} = \mu + \beta_i + \gamma_j + (\beta\gamma)_{ij} + \varepsilon_{ij} \quad (1)$$

In Eq. 1, Y_{ij} is the observed value at tree level of the sampling position j of the clone i, μ is the overall mean, β_i is the effect due to the ith clone, γ_j is the effect due to the jth sampling position, $(\beta\gamma)_{ij}$ is the interaction between the ith clone and the jth sampling position, and ε_{ijk} is the random error.

Models were checked for significance and distribution of residuals: as expected, most of the variables showed significant clone and sampling position effect, while the interaction between the factors was not always significant. When a lack of significance was detected, a new model was recalculated, excluding the not significant parameter. The correlation analysis was then achieved by the calculation of Pearson correlation coefficients on the bases of the residuals from the model: these residuals do not contain the variance due to the fixed effects and can be interpreted to a larger extent as phenotypic correlations (no clone effect).

The correlation analysis was divided into three phases: firstly, correlation coefficients at tree level were calculated between all pairs of growth traits, heartwood content, and wood traits (trait-trait correlations).

Secondly, phenotypic correlations at ring level were calculated between all pairs of microdensity variables, in order to fully analyze the relationship between tree growth and wood density, and to eliminate the cambial age effect. Correlations between ring width and density variables were calculated for each year-ring indexed by cambial age.

Finally, cumulated weighted means of wood density at different ages (d_n) were calculated based on the mean density of each ring (m_i) and ring area (ra_i):

$$d_n = \frac{\sum_{i=1}^{n} ra_i \cdot m_i}{\sum_{i=1}^{n} ra_i} \quad (2)$$

Age-age correlations for wood density were then computed.

In the case of the microdensity analysis, the correlations were calculated on the residuals of the models where only the clone effect was included.

RESULTS

Trait-Trait Correlations

The correlation coefficients between all possible pairs of growth traits and heartwood/sapwood content traits are shown in Table 2 for both sites. In Table 3 the correlation coefficients are reported for ring width and wood properties.

Growth traits were positively correlated with each other. As expected, the diameter and the ring width showed high correlation coefficients with each other and with the tree volume; on the contrary the tree height did not display any significant correlation neither with diameter nor with ring width (only in Marani a weak correlation was detected), but only a moderate and positive correlation with the tree volume.

The percentage of heartwood area displayed a positive and moderate correlation with growth traits (except for ring width), but only in Forestello. On the contrary, the number of sapwood rings (on average 10 rings, quite constant over sites, clones, and trees) did not show any significant correlation with the other characters, but a negative correlation with the percentage of heartwood area in Marani.

Generally, growth traits, the percentage of heartwood, and the number of sapwood rings were not significantly correlated with wood traits. Moreover, the correlations between growth traits and shrinkages did not define any clear trends (data not shown).

The absence of any relationship between growth rate and wood properties was confirmed by the lack of significant correlations found out between mean ring width and wood traits (Table 3).

As far as wood traits are concerned only (Table 3), the linear and volumetric shrinkages were significantly positively and strongly correlated with each other; the correlations between shrinkages and mechanical properties were mostly not significant.

The mechanical properties, however, were significantly positively but moderately correlated with each other (although correlations were sometimes weaker for hardness and modulus of elasticity).

Table 2. Correlation Coefficients Between Growth Traits and Heartwood/Sapwood Content by Sites. Marani Above the Diagonal and Forestello below (Symbols Explained in Table 1)

	DBH	H	VOL	RW	HW%	SR
DBH		ns	0.76***	0.69***	ns	ns
H	ns		0.41**	0.32*	ns	ns
VOL	0.85***	0.44***		0.61***	ns	ns
RW	0.80***	ns	0.78***		ns	ns
HW%	0.44*	0.46*	0.46*	ns		-0.60***
SR	ns	ns	ns	ns	ns	

*** significant at α = 0.001; ns = not significant

Table 3. Correlation Coefficients by Site (Marani Above the Diagonal and Forestello Below) between all Possible Pairs of Wood Traits and Ring Width (Symbols Explained in Table 1)

	RW	D_{12}	RS	TS	VS	T/R	MOEd	MOR	MCS	MSS	HB
RW		0.24*	ns	ns	ns	-0.25*	ns	ns	ns	ns	ns
D_{12}	ns		0.35***	0.45***	0.52***	ns	ns	ns	0.39***	0.61***	0.63***
RS	-0.30*	0.67***		0.36***	0.71***	-0.76***	ns	ns	ns	ns	ns
TS	ns	0.45**	0.46**		0.88***	ns	ns	ns	ns	ns	ns
VS	ns	0.64***	0.75***	0.90***		ns	ns	ns	ns	ns	ns
T/R	ns	-0.35*	-0.74***	ns	-0.30*		ns	ns	ns	ns	ns
MOEd	ns	ns	ns	ns	ns	ns		0.50***	0.45***	ns	ns
MOR	ns	0.60***	ns	ns	ns	ns	0.33*		0.44***	ns	0.22*
MCS	ns	0.52***	0.48***	ns	ns	-0.47**	ns	0.30*		0.44***	0.39***
MSS	ns	0.38***	ns	ns	ns	ns	0.30*	0.50***	ns		0.58***
HB	ns	0.34***	ns	ns	ns	ns	ns	ns	0.38**	ns	

*significant at α = 0.05; ** significant at α = 0.01; *** significant at α = 0.001; ns = not significant

Wood density was significantly correlated with the physical and mechanical wood properties. Correlations were high and positive except with the shape factor and the dynamic modulus of elasticity.

Microdensitometric Analysis: Correlation between Growth Rate and Wood Density

Mean ring density was positively and highly correlated both with the minimum ($r=0.88$; $p<0.001$ and $r=0.81$; $p<0.001$ in Marani and Forestello, respectively) and maximum ring density ($r=0.82$; $p<0.001$ and 0.86; $p<0.001$), while minimum and maximum ring density showed a positive and highly significant relationship between each other, but lower values of the correlation coefficients ($r=0.60$; $p<0.001$ and 0.57; $p<0.001$).

In Fig. 1, the radial variations of ring width and mean ring density for each site are illustrated. After an increase at the beginning (mainly in Forestello), a steep decline in the growth rate could be measured starting at cambial age 4 to 5. The mean ring density was quite constant along the radius in Marani and was slightly decreasing in Forestello. These led, at site level, to a weak and positive relationship between ring width and mean ring density ($r=0.29$; $p<0.05$).

If calculated based on cambial age, this relationship was somewhat different (Table 4). In Marani samples a positive correlation was detected between ring width, and mean and maximum density in the outer rings (very narrow rings, less than 3 mm wide), while no correlation was found with minimum density. In Forestello no significant correlations between ring width and microdensity variables were observed, with the exception of a positive correlation with the mean and maximum density in few external and narrow rings.

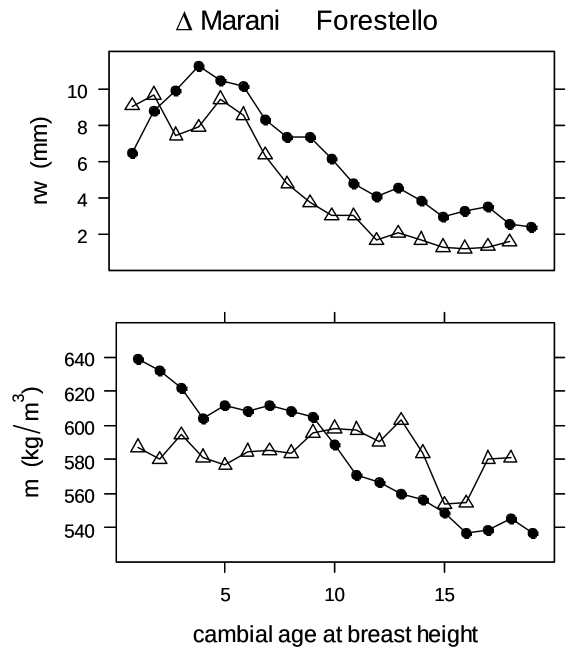


Fig. 1. Radial variation of ring width (rw) and mean ring density (m) for Marani and Forestello sites

Table 4. Correlation Coefficients at Ring Level Between Ring Width (rw) and Density Variables (m = Mean Ring Density; mi = Minimum Ring Density; ma = Maximum Ring Density) for Each Cambial Age (ca) (years)

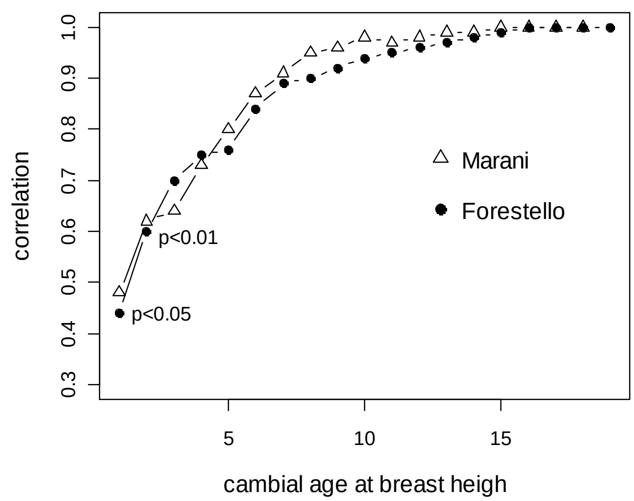
	Marani			Forestello		
ca	m	mi	ma	m	mi	ma
1	-0.33*	ns	-0.49***	ns	ns	ns
2	-0.48***	-0.33*	ns	ns	ns	ns
3	ns	ns	ns	ns	ns	ns
4	-0.39**	-0.33*	-0.30*	ns	ns	ns
5	ns	ns	ns	ns	ns	ns
6	ns	ns	ns	ns	ns	ns
7	ns	-0.33*	ns	ns	ns	ns
8	ns	ns	ns	ns	ns	ns
9	ns	ns	ns	ns	ns	ns
10	ns	ns	ns	0.58**	0.47*	ns
11	ns	ns	0.37**	ns	ns	0.54**
12	ns	ns	0.31*	0.42*	ns	ns
13	ns	ns	ns	ns	ns	ns
14	0.55***	ns	0.59***	0.42*	ns	ns
15	0.39**	ns	0.46***	0.47*	ns	0.48*
16	0.51***	ns	0.51***	ns	ns	0.52*
17	0.53***	ns	0.68***	ns	ns	0.57**
18	-	-	-	0.50*	ns	0.65**

*significant at $\alpha = 0.05$; ** significant at $\alpha = 0.01$; *** significant at $\alpha = 0.001$; ns = not significant

Age-Age Correlations

The densitometric data have been used to investigate the relationship between tree density at different cambial ages (from 1 to 19 years) and whole tree density at age 19 (Fig. 2).

As a consequence of the lack of density variation observed along the radius in Marani (Fig. 1), the early years average density was highly correlated with that of the older tree; in Forestello the correlation coefficients at early ages (age 1 to 3) were quite a bit lower, but they rapidly increased. In both sites, the correlations were enhanced with cambial age and reached a value of 0.99 at year 13 in Marani and year 15 in Forestello, but exceeded the value of 0.90 at year 7 in Marani and year 8 in Forestello.



Where not explicitly indicated, the correlation coefficient significance was p<0.001; ns = not significant.

Fig. 2. Correlations between the density at different ages (cumulative average from the pith to age n) and at the mature age (cumulative average of the whole radius) in Marani and Forestello sites

DISCUSSION

The study was conducted in two clonal trials located in different sites. The site, as well as the clone factor and the variation inside the tree were shown to have a significant effect over the growth traits (site and clone) and the wood properties (site, clone and radial position of the specimens, Nocetti *et al.* 2010). All these sources of variation were taken into account in order to remove their influence over the determination of the correlations. In particular, the two sites were kept separate in the analysis, while the clone and the sampling position effects were eliminated by analyzing the residual of the ANOVA model which included the two factors. This enables the calculation of phenotypic correlations: in the sampled plantations included in the study the number of clones was not sufficiently high to permit the calculation of genetic correlations, therefore only phenotypic correlations were determined.

In addition, as strictly concerns the wood properties determination, the sampling was done keeping in mind the necessity to minimize costs and effort, but, at the same time, aiming to achieve representative results. To the purpose, the bottom of the tree was avoided, because the wood property variation in that part of the trunk has been found to be higher than in the other parts (Zobel and van Buijtenen 1989). At the same time the sampling was done at the breast height because it was considered in the past satisfactory in predicting the whole tree (mainly as concerns the wood density, Zobel and van Buijtenen 1989). However, it has to be noticed that the sampling sufficiently considered the radial variation of the wood properties, but not the variation that might occur along the stem.

Therefore, the following discussions and conclusions have to be read keeping in mind the sampling limitations set out.

Trait-Trait Correlations

Growth traits were positively correlated among each other, similarly to what was described in other studies on wild cherry (Muranty *et al.* 1998; Curnel *et al.* 2003) and many other species. By contrast, the tree height showed a lack of correlation with diameter.

In the same way the heartwood content was widely reported to be positively correlated with growth traits (tree diameter or height), when analysed in the form of heartwood area, volume, and width (Bamber and Fukazawa 1985; Rink 1987; Woeste 2002), but contrasting results can be found on sapwood/heartwood ratio or area percentage: a negative or lack of significant correlation between the percentage of heartwood area and growth rate (height or diameter) was reported in two studies on 10 year-old black walnut (*Juglans nigra*, Rink 1987; Rink and Phelps 1989), while a positive relationship was found out on 35-year-old trees of the same species (Woeste 2002). Similarly, our results were contradictory at two sites, showing no significant relationship between heartwood area percentage and growth traits in one plantation, and positive or not significant in the other, and thus could not provide any reliable conclusion.

The number of sapwood rings, instead, seems to be much more constant over sites, clones, and trees. The lack of correlation with the growth traits can be evidence of the weak influence over this trait of genetic factors (at least at clonal level), site factors (Nocetti *et al.* 2010), and growth rate. Nelson (1976) found out a positive and weak relationship between the number of sapwood rings and tree diameter in black cherry and black walnut, and a much stronger relationship with tree age. Tree age was found to be the main factor influencing the number of sapwood rings also in poplar, where the two variables were positively correlated (Yang and Hazenberg 1991).

At both sites the wood properties were not correlated with growth traits and, in particular, the mean ring width was found not to influence the wood properties analyzed, as a confirmation of the weak effect of growth rate on the physical and mechanical characteristics of diffuse porous hardwoods (Fukazawa 1984; Zobel and van Buijtenen 1989; Zhang 1995).

In addition, wood density was verified to be the trait that best correlated to a number of important wood basic properties, thus able to describe overall wood characteristics in wild cherry, as widely established for other species (Zobel and van

Buijtenen 1989; Rozenberg and Cahalan 1997). This can be useful when an evaluation of wood properties has to be done and the measurement of many traits can be difficult, time consuming, and expensive. In such cases density can be easily measured and can effectively predict most of the wood characteristics.

As strictly concerns wild cherry and considering the use to which it is usually intended (veneer or, as solid wood, furniture, paneling, and flooring), the appearance of wood is very important, and particularly the color, the absence of knots (obtained by pruning), gum pockets, and green vein. However, other traits (*i.e*. hardness and dimensional stability) have to be considered for a better workability of the raw material. So, a choice based on density could positively contribute to an improvement of the wood quality in clonal cherry plantations.

Microdensitometric Analysis

With the microdensity variables it was possible to analyze the intra-ring characteristics and to investigate the correlations between density and growth rate at ring level and for cambial age.

The radial variation of ring width rapidly decreased from the pith to the bark at both sites. Although a possible effect of the cambial age on the growth rate can be reliably hypothesized, the sharp decrease of ring dimension observed here can be mainly ascribed to the high competition among trees. The little spacing between plants and the lack of correct thinning (Nocetti *et al.* 2010) reduced the growth rate to an extreme extent in the last decade.

Cambial age also can affect the relationship between growth rate (ring width) and wood density; indeed, the weak positive correlation between ring width and density variables detected at site level, when calculated for each cambial age, disappeared. Only for very narrow rings (less than 3 mm wide) could an increase of ring width result in a consequent increase of wood density. Similar findings have been described in the literature: Fukazawa (1984) reported a positive correlation between density and growth rate for rings less than 1 mm wide in Japanese diffuse porous hardwoods. On the contrary, Nepveu (1992) quoted the results of other works on wild cherry, where, for rings between 1.5 and 4.5 mm width, there was a decrease of wood density with increase of ring width, but it is impossible to deduce whether these considerations have been carried out at equal cambial age.

No generalization is possible so far, but a lack of correlation between growth rate and wood properties in wild cherry could be seen as a positive result, if we consider that an increase in growth rate will not result in a modification of wood density and wood characteristics. Very narrow rings, the only attribute related to ring width that appears to affect properties, should not be allowed in any silvicultural practice. Instead, the results recommended for wild cherry production is to choose favorable growth sites and to provide enough thinning and/or large spacing (Balandier and Dupraz 1999; Cutter *et al.* 2004). The spacing must be balanced in such a way to ensure the ability of the tree to grow productively (high growth rate) and correctly (high quality stem, straight form and small branches/knots). This is particularly necessary for wild cherry, which is characterized by a slow natural pruning and by the tendency to develop lateral branches when there is a lack of competition (Seifert *et al.* 2010).

Age-Age Correlations

The densitometric data have been used to investigate the relationship between wood density at different cambial ages (from 1 to 19 years) and whole tree density. The results showed that the wood density at cambial age of 7 to 8 years has a strong correlation with the density of a 19-year-old ($r > 0.90$).

Other studies have shown comparable results. Early selection for wood density was possible at age 2 to 3 (over 6 to 7 year-old trees) in eucalyptus (Greaves *et al.* 1997; Osorio *et al.* 2003) and at age 6 (over 10 year-old trees) in poplar (Pliura *et al.* 2006). The cited studies, however, reported conclusions based on genetic correlations, which are not possible to calculate here due to the limited numbers of clones. Phenotypic correlations have been observed to be generally lower, especially at younger ages, than genetic correlations, both for growth traits (Lambeth 1980; Lambeth *et al.* 1983) and wood density (Vargas-Hernandez and Adams 1992), or equal (Bouffier *et al.* 2008), but a generalization in this sense is impossible. Therefore, a further analysis on genetic correlations is necessary to properly assess the potential of early selection.

However, the results reported here can be useful information to effectively investigate the wood properties on young trees, obtaining a reliable estimation of the same properties of older trees.

CONCLUSIONS

In early breeding programs of forest trees for timber production, studies focused mainly on growth, adaptation, form, and disease resistance. The amount of stems and branches has a great impact on wood quality and all of these aspects, therefore, must certainly be considered of primary importance in order to obtain superior genotypes. But it becomes increasingly clearer that there is a need to consider wood traits in order to improve the quality of timber or at least to monitor its evolution when selection is carried out on other genetically correlated traits.

The phenotypic correlations presented in this study can be considered helpful information in order to understand the relationship between growth rate and wood traits. In particular the main achievements of this research can be summarized as follows:

1. Growth traits were positively correlated with each other, but not with wood properties.
2. The wood properties were not affected by the growth rate.
3. Density is confirmed to be the trait that best represents the main properties of wood.
4. The absence of any relationship between wood density and growth rate is confirmed by densitometric analysis, although an increase of wood density with an increase of ring width was detected for very narrow rings (less than 3 mm wide).
5. Average density at age 7 to 8 is highly correlated with the average density of a 19-year-old tree.

ACKNOWLEDGMENTS

Many thanks to Paolo Pestelli and Luciano Scaletti for sample preparation and laboratory tests; to Frédéric Millier for X-Ray scanning.

REFERENCES CITED

Balandier, P., and Dupraz, C. (1999). "Growth of widely spaced trees. A case study from young agroforestry plantations in France," *Agrofor. Syst.* 43(1-3), 151-167.

Bamber, R. K., and Fukazawa, K. (1985). "Sapwood and heartwood: A review," *Forestry Abstr*. 46(9), 567-580.

Beaudoin, M., Hernández, R. E., Koubaa, A., and Poliquin, J. (1992). "Interclonal, intraclonal and within-tree variation in wood density of poplar hybrid clones," *Wood Fiber Sci.* 24(2), 147-153.

Bouffier, L., Charlot, C., Raffin, A., Rozenberg, P., and Kremer, A. (2008). "Can wood density be efficiently selected at early stage in maritime pine (*Pinus pinaster* Ait.)?" *Ann. For. Sci.* 65(1), 106p1-106p8.

Brancheriau, L., and Baillères, H. (2002). "Natural vibration analysis of clear wooden beams: A theoretical review," *Wood Sci. Technol.* 36(4), 347-365.

Curnel, Y., Jacques, D., and Nanson, A. (2003). "First multisite clonal test of wild cherry (*Prunus avium* L.) in Belgium," *Silvae Genet.* 52(2), 45-52.

Cutter, B. E., Coggeshall, M. V., Phelps, J. E., and Stokke, D. D. (2004). "Impacts of forest management activities on selected hardwood wood quality attributes: A review," *Wood Fiber Sci.* 36(1), 84-97.

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

De Boever, L., Vansteenkiste, D., Van Acker, J., and Stevens, M. (2007). "End-use related physical and mechanical properties of selected fast-growing poplar hybrids (*Populus trichocarpa* x *P. deltoides*)," *Ann. For. Sci.* 64(6), 621-630.

Fukazawa, K. (1984). "Juvenile wood of hardwoods judged by density variation," *IAWA Bull*. 5(1), 65-73.

Greaves, B. L., Borralho, N. M. G., Raymond, C. A., Evans, R., and Whiteman, Ph. (1997). "Age-age correlations in, and relationship between basic density and growth in *Eucalyptus nitens*," *Silvae Genet.* 46(5), 264-270.

Guay, R., Gagnon, R., and Morin, H. (1992). "A new automatic and interactive tree ring measurement system based on a line scan camera," *For. Chron*. 68(1), 138-141.

Hernández, R. E., Koubaa, A., Beaudoin, M., and Fortin, Y. (1998). "Selected mechanical properties of fast-growing poplar hybrid clones," *Wood Fiber Sci*. 30(2), 138-147.

Kobliha, J. (2002). "Wild cherry (*Prunus avium* L.) breeding program aimed at the use of this tree in the Czech forestry," *J. For. Sci.* 48(5), 202-218.

Koch, C. B. (1967). "Specific gravity as affected by rate of growth within sprout clumps of black cherry," *J. For.* 65(3), 200-202.

Koubaa, A., Hernández, R.E., and Beaudoin, M. (1998). "Shrinkage of fast-growing hybrid poplar clones," *For. Prod. J.* 48(4), 82-87.

Koubaa, A., Zhang, S. Y., Isabel, N., Beaulieu, J., and Bousquet, J. (2000). "Phenotypic correlations between juvenile – mature wood density and growth in black spruce," *Wood and Fiber Sci.* 32(1), 61-71.

Lambeth, C. C. (1980). "Juvenile – mature correlations in pinaceae and implications for early selection," *For. Sci.* 26(4), 571-580.

Lambeth, C. C., van Buijtenen, J. P., Duke, S.D., and McCullough, R. B. (1983). "Early selection is effective in 20-year-old genetic tests of loblolly pine," *Silvae Genet.* 32(5-6), 210-215.

Martinsson, O. (2001). "Wild cherry (*Prunus avium* L.) for timber production: Consequences for early growth from selection of open-pollinated single-tree progenies in Sweden," *Scand. J. For. Res.* 16, 117-126.

Mátyás, C., and Peszlen, I. (1997). "Effect of age on selected wood quality traits of poplar clones," *Silvae Genet*. 46(2-3), 64-72.

Muranty, H., Schermann, N., Santi, F., and Dufour, J. (1998). "Genetic parameters estimated from a wild cherry diallel: Consequences for breeding," *Silvae Genet*. 47 (5-6), 249-257.

Nelson, N. D. (1976). "Gross influences on heartwood formation in black walnut and black cherry trees," USDA Forest Service, Research Paper, FPL 268.

Nepveu, G. (1992). "L'utilisation des bois de frêne et de merisier: Aptitudes technologiques, facteurs de variabilité," *Revue For. Fr*, numér. spec., 42-149.

Nepveu, G., and Velling, P. (1983). "Variabilité génétique individuelle de la qualité di Bois chez *Betula pendula* Roth," *Silvae Genet.* 32(1-2), 37-49.

Nocetti, M., Brunetti, M., Ducci, F., Romagnoli, M., Santi, F. (2010). "Variability of cherry wood properties in two wild cherry clone trials," *Wood Sci. Technol.* 44, 621-637.

Osorio, L. F., White, T. L., and Huber, D. A. (2003). "Age-age and trait-trait correlations for *Eucalyptus grandis* Hill ex Maiden and their implications for optimal selection age and design of clonal trials," *Theor. Appl. Genet*. 106, 735-743.

Pliura, A., Zhang, S. Y., Bousquet, J., and MacKay, J. (2006). "Age trends in genotypic variation of wood density and its intra-ring components in young poplar hybrid crosses," *Ann. For. Sci.* 63(7), 673-685.

Pliura, A., Zhang, S. Y., MacKay, J., and Bousquet, J. (2007). "Genotypic variation in wood density and growth traits of poplar hybrids at four clonal trials," *For. Eco. Manag.* 238, 92-106.

Polge, H. (1978). "Fifteen years of wood radiation densitometry," *Wood Sci. Technol*. 12(3), 187-196.

Raymond, A. (2002). "Genetics of Eucalyptus wood properties," *Ann. For. Sci.* 59, 525-531.

Rink, G. (1987). "Heartwood color and quantity variation in a young black walnut progeny test," *Wood Fiber Sci.* 19(1), 93-100.

Rink, G., and Phelps, J.E. (1989). "Variation in heartwood and sapwood properties among 10-year-old black walnut trees," *Wood Fiber Sci.* 21(2), 177-182.

Rozenberg, P., and Cahalan, C. (1997). "Spruce and wood quality: Genetic aspects (A review)," *Silvae Genet.* 46(5), 270-279.
Santi, F., Muranty, H., Dufour, J., and Paques, L. E. (1998). "Genetic parameters and selection in a multisite wild cherry clonal test," *Silvae Genet*. 47(2-3), 61-67.
Seifert, T., Nickel, M., and Pretzsch, H. (2012). "Analysing the long-term effects of artificial pruning of wild cherry by computer tomography," *Trees* 24(5), 797-808.
Vargas-Hernandez, J., and Adams, W. T. (1992). "Age-age correlations and early selection for wood density in young coastal Douglas fir," *For. Sci.* 38(2), 467-478.
Woeste, K. E. (2002). "Heartwood production in a 35-year-old black walnut progeny test," *Can. J. For. Res.* 32, 177-181.
Yang, K.C., and Hazenberg, G. (1991). "Relationship between tree age and sapwood/heartwood width in *Populus tremuloides* Michx," *Wood Fiber Sci*. 23(2), 247-252.
Zhang, S.Y. (1995). "Effect of growth rate on wood specific gravity and selected mechanical properties in individual species from distinct wood categories," *Wood Sci. Technol.* 29(6), 451-465.
Zhang, S.Y. (1997). "Wood specific gravity – mechanical property relationship at species level," *Wood Sci. Technol*. 31(3), 181-191.
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 van Buijtenen, J. P. (1989). *Wood Variation. Its Causes and Control*, Springer-Verlag, Berlin.

STANDARDS

EN 1534. Wood and parquet flooring - Determination of resistance to indentation (Brinell) - Test method
ISO 3131. Wood - Determination of density for physical and mechanical tests
ISO 3133. Wood - Determination of ultimate strength in static bending
ISO 3347. Wood - Determination of ultimate shearing stress parallel to grain
ISO 3787. Wood - Test methods - Determination of ultimate stress in compression parallel to grain. (1976)
ISO 4469. Wood - Determination of radial and tangential shrinkage
ISO 4858. Wood - Determination of volumetric shrinkage

Article submitted: December 31, 2011; Peer review completed: March 16, 2012; Revised version received and accepted: May 14, 2012; Published: June 4, 2012.