Stemwood Density in Young Grey Alder (*Alnus incana* (L.) Moench) and Hybrid Alder (*Alnus hybrida* A. Br.) Stands Growing on Abandoned Agricultural Land

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Abstract

The aim of the study was to determine the density of oven dry stemwood (moisture content 0%) of two fast-growing tree species, grey alder (*Alnus incana* (L.) Moench) and hybrid alder (*Alnus hybrida* A. Br.), growing on abandoned agricultural land. The study is based on two 16-year-old experimental stands located in Southern Estonia (N 58°32 E 27°12). The average stemwood density of grey and hybrid alder was 396±32 kg m^{-3} (average ± st. error) and 427±29 kg m^{-3}, respectively.

For grey alder, the impact of stem height section on stemwood density was significant in all cases ($p<0.005$); it was higher in the upper stem sections. A similar trend was revealed for hybrid alder.

There was no correlation between breast height diameter and average stemwood density either for grey alder or for hybrid alder.

Key words: grey alder, hybrid alder, stemwood density, abandoned agricultural land

Introduction

Considering the limited reserves of fossil fuels but also the need to reduce CO_2 emissions, more extensive utilization of biofuels, among them wood, has been discussed worldwide. In the conditions of continuously rising prices of fossil fuels, energy forestry and renewable energy will gain more importance in the nearest future. The long-term development plan of the Estonian energy industry foresees a reduction in the use of fossil fuels (primarily oil shale) and an increase in the share of biofuels.

In connection with the more intensive use of woody biomass, the issues of biomass production and short-rotation forestry have been added to the agenda. In recent time several research projects have been carried out and new data about the biomass production of different tree species have been reported. Among them several studies demonstrate that grey alder (*A. incana* (L.) Moench) is a promising fast-growing tree species for short-rotation forestry in the Nordic and Baltic countries (Granhall and Verwjist 1994, Saarsalmi 1995, Rytter 1996, Telenius 1999, Miezite 2008, Uri et al. 2002, 2009). According to several research results this species is highly productive both on mineral and organic soils (Granhall and Verwjist 1994, Saarsalmi 1995, Lõhmus et al. 1996, Rytter 1996, Tullus et al. 1998, Telenius 1999, Uri et al. 2009).

However, in scientific publications the values of biomass production are usually expressed in weight units (t ha^{-1}; kg ha^{-1}) while in practical forestry stem volume units (m^3 ha^{-1}) are applied. For converting data from mass units to volume units, or conversely, determination of an appropriate wood density value is essential.

Data on grey alder wood densities are highly variable; the values reported by Nordic authors are quite low (Hakkila 1970, Björklund and Ferm 1982, Johansson 2005) compared with those reported from the Baltic countries (mainly Latvia) (Table 3). The empirical values of grey alder wood density from Estonia are practically missing with the exception of only a few preliminary results (Keedus and Uri 1997). Thus there is a need for empirically substantiated values of grey alder stemwood density which is inherent in the local region.

While grey alder and black alder (*A. glutinosa*) are widespread tree species in the northern hemisphere, hybrid alder (*Alnus incana x Alnus glutinosa*) is rather rare in the nature in Estonia as well as in the other Baltic countries with only a few reported habitats (Hainla 1971, 1979, Pirag 1962, Kundzins 1969). Data on the growth and yield of hybrid alder are also quite scarce in the literature. However, some results show that its growth in natural conditions can be more rapid than the growth of grey alder or black alder (Pirag 1962, Kundzins 1969). Granhall (1982) suggests that hybrid alder can be considered a promising species in short-rotation forestry. Hybrid alder might also be potentially interesting for timber industry, as the quality of its wood is intermediate between that of grey alder and black alder, while the increment of the wood is larger compared with that of black alder (Pirag 1962). In the last decade some experimental plantations of hybrid alder were established in Estonia, on the basis of which the growth dynamics and biomass production of this tree species have been described (Uri and Tullus 1999, Uri et al. 2003). Regarding stemwood density, only a few results have been reported about hybrid alder until recent time (Pirag 1962) and this issue has not been studied earlier in Estonia.

Establishment of plantations of fast-growing tree species for biomass production, preferably on abandoned agricultural land, will be the prospect of the nearest future. Thus studies focusing on grey alder stands growing on abandoned farmland represent innovative research.

The main aims of the present study were:

– to estimate knot free stemwood density in young grey alder and hybrid alder stands growing on former agricultural land;

– to analyse the effect of tree height section and breast height diameter on stemwood density of grey alder and hybrid alder.

Material and methods

Stem samples of grey alder and hybrid alder were collected from two plantations established in 1995 and 1996, respectively. Both stands are growing on fertile former agricultural land (Table 1) and the results about their biomass production have been published earlier (Uri et al. 2002, 2009). When the expression "stemwood density" is used in current paper, oven dry (moisture content 0%) stemwood density is considered.

Table 1. Description of the study sites (average ± st. deviation)

Species	Location	Area, ha	Age, y	Stand density, ha^{-1}	Soil	$D_{1,3}$, cm	Height, m	Basal area, m^2 ha^{-1}
Grey alder	58°3' 27°1'	0.1	16	5400	Eutric Podzoluvisol	9.3±2.9	13.9±2.1	35.2
Hybrid alder		0.2		3600		9.4±3.1	13.1±0.7	24.8

Estimation of wood density

The stem diameter at breast height ($D_{1.3}$) of all trees was measured in both stands in the September of 2009. The trees were divided into five classes on the basis of $D_{1.3}$ and a model tree was selected randomly from each class. An additional tree was felled from two classes with a larger number of trees in order to have a more representative sample and valid data. Altogether seven model trees were felled from both stands. The stems of the model trees were divided into five sections: the fifth section at a height of 0 to 1.3 m, the fourth section from a height of 1.3 m up to the living crown. The living crown was divided into three layers of equal length; the sections were numbered from three to one, as the third section being the lowermost. For estimating wood densities of different stem sections, subsamples with a length of 50 cm were sawn from the middle part of stem sections 5, 4 and 3. The height of the third section was dependent on the beginning of the living crown. It was slightly higher for grey alder than for hybrid alder, varying from 7.9 to 10.0 m and from 7.0 to 9.2 m, respectively. The stem samples were sawn into board in a wood processing laboratory and dried at room temperature until the moisture content equilibrium of the indoor air which was detected by the successive weightings until reaching the constant mass. After the samples were planed and calibrated, as many knot- and bark-free test pieces (3x2x2 cm) as possible from each test subsample were sawn in accordance with ISO 3129-1975 (E), ISO 3131-1975 (E). All test pieces were identified with a number, then dried in the oven at 102°C until constant dry mass. The test pieces were measured with an electronic caliper to 0.01 mm and weighed to 0.01 g. The volume (1) and density (2) of each oven dry test piece was calculated as follows:

$$V=abc, \quad (1)$$

where *a, b* and *c* are the dimensions of test pieces (mm),

$$\rho=V/m, \quad (2)$$

where *V* is the volume of the test pieces (cm^3) and *m* is the mass of test pieces (g).

Statistical methods

Normality of data was tested with the Lilliefors and Shapiro-Wilk tests. Repeated Measures Analysis of Variance was used for checking the impact of stem section on stemwood densities. The assumptions of ANOVA were full filled in all cases. The Tukey HSD test in the case of unequal samples size and Ficher's LSD test were used for multiple comparison of means. Linear and allometric models were employed for estimating relationships between tree dimensions ($D_{1.3}$) and wood densities. The software STATISTICA 7.1 was employed and the significance level a=0.05 was accepted in all cases.

Results

Average stemwood density and effect of tree height section

The average stemwood densities of hybrid alder were significantly higher than the respective values of grey alder ($p<0.05$; Unequal N HSD test).

The stemwood density of grey alder and hybrid alder was 396±32 kg m^{-3} and 427±29 kg m^{-3}, respectively. Average difference between the stemwood densities of the two species was 7.3%.

The wood density of hybrid alder can be considered vertically more homogeneous compared to grey alder. The intersectional variance of hybrid alder stemwood densities is roughly half as big as for the same values of grey alder (Table 2). The breast height diameter of sample trees had no effect on wood densities for either species.

For grey alder, the effect of stem section was significant ($p<0.0001$). The analysis also indicated that effect of repetitions is not significant ($p>0.9$), i.e. there are no differences between repeated measurements within one section.

Table 2. Stemwood densities of grey alder and hybrid alder in different height sections. Section V - 0 to 1.3 m; Section IV - 1.3 to the living crown; Section III - the lowermost third of the living crown

Species	Stem section	N
	III	
Grey alder	464 a* ± 9	24
Hybrid alder	460 a ± 16	23
	IV	
Grey alder	405 b ± 19	83
Hybrid alder	429 a ± 25	89
	V	
Grey alder	376 c ± 19	117
Hybrid alder	415 b ± 26	108

*- Letters indicate significant difference ($p<0.05$)

According to the Tukey HSD test average stemwood densities differ significantly between the sections. The highest wood densities were determined in the highest measured section (section no. 3) of the stem and the lowest densities were found in the lowermost part of the stem (Table 2). All differences between the wood densities of different sections of grey alder are significant ($p<0.05$).

Stem section did not affect wood densities of hybrid alder ($p=0.07$). Wood density was only significantly different between section 3 and section 5 ($p<0.05$; Fisher's LSD test) (Figure 1). Differences between the sections in percentages are approximately twice smaller for hybrid alder than for grey alder.

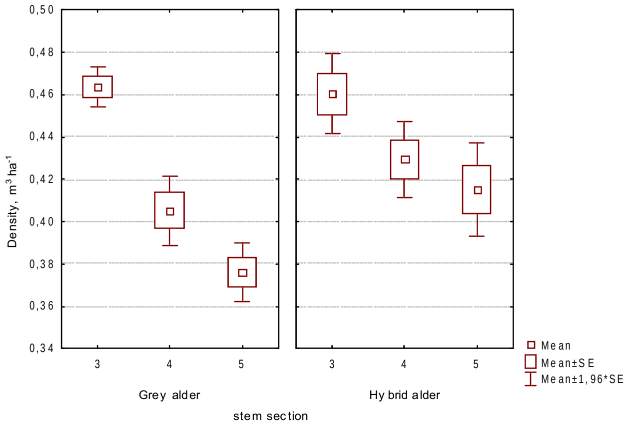

Figure 1. Average stemwood density of grey alder and hybrid alder in different stem sections (section 3 is the highest and section 5 is the lowest)

Effect of tree dimensions

Linear regression analysis was applied to study the effect of tree breast height diameter on stemwood densities. The breast height diameter did not affect stemwood density. The study failed to demonstrate any evident trend in stemwood densities for trees belonging to different diameter classes (Figure 2).

Discussions

The average stemwood densities of grey alder found in this study are in good accordance with earlier results reported in the literature (Table 3). Wiemann and Williamson (2002) suggested that the mean wood specific gravity of angiosperms gradually increases with decreasing latitude. Average wood densities reported from Nordic countries (Finland, Norway, Sweden) are lower than those reported from more southern countries (Latvia) (Table 3), which is most probably related to higher mean annual temperature and the longer vegetation period.

Data about the stemwood density of grey alder are relevant for biomass research. In recent time, several studies on the biomass productivity of grey alder have been carried out in Estonia. However, as a rule, all scientific estimates in these studies are expressed in mass-based units (t ha^{-1} or kg ha^{-1}). For comparing the obtained biomass estimates with the data of the

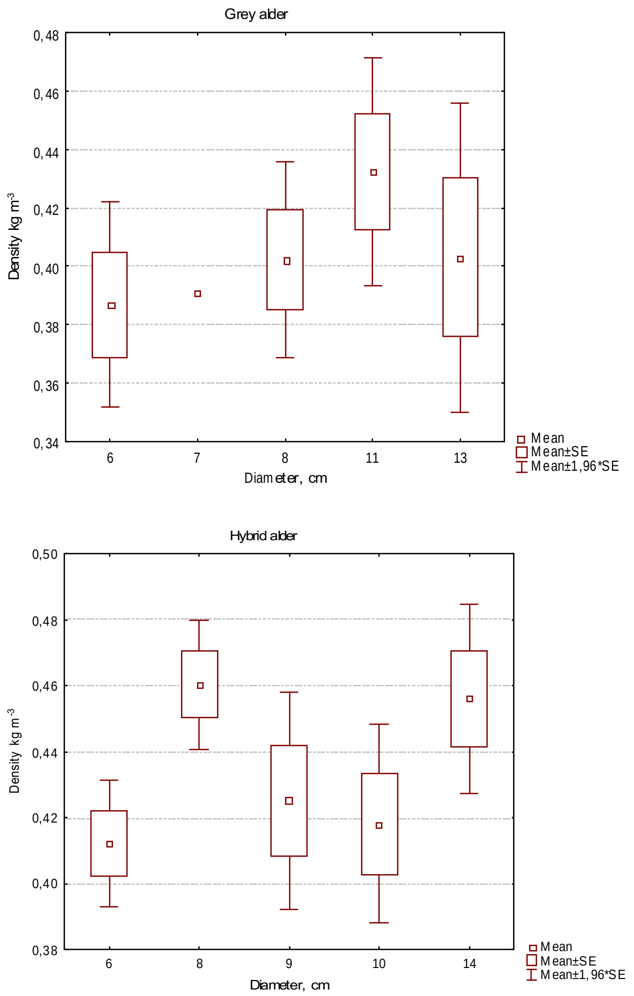

Figure 2. Average stemwood density of grey alder and hybrid alder trees with a different breast height diameter

Table 3. Average stemwood densities of grey alder on the basis of different literature sources

Country	Density kg m^{-3}	Author
Norway	369	Stemsrud (1964)
	365	Nagoda (1966)
	340 (324...358)	Vadla (1999)
Sweden	359 (230...440)	Johansson (2005)
Finland	361	Hakkila (1970)
	353	Björklund & Ferm (1982)
Estonia	384	Keedus, Uri (1997)
Latvia	432...574	Vanins (1950)
	420	Pirag, 1962
	420...630	Draudiņš, Bekeris (1979)
	432...458	Klevinska, Bikova (1999)
	447 (388...506)	Miezite (2008)

average increment of Estonian grey alder stands, or with the data of yield tables, an appropriate stemwood density value is required. Already quite slight variability in the density value used affects the obtained result considerably. For example, the annual current production (CAI) of stem mass in a 15-year-old grey alder stand studied by us was 14.2 t DM ha^{-1} yr^{-1}. When converting this result to volume units and using the oven dry stemwood density value obtained in this study (396 kg m^{-3}), the annual stand stemwood increment will be 35.8m^3 ha^{-1}. However, when using the wood density value reported from Sweden (359 kg m^{-3}), CAI would be 39.5 m^3 ha^{-1}, and basing on oven dry grey alder wood density data from Latvia (Miezite and Dreimanis 2006) CAI would be 30.9 m^3 ha^{-1}.

In published literature, the data about oven dry wood density are scarce; mostly the data of basic density are reported. Still, results of oven dry wood density of common alder, silver birch and European aspen, reported in the Estonian wood science handbook (Puiduteadus 2006) are 490, 600 and 470 kg m^{-3}, respectively.

Current study reports the results about the wood densities of grey- and hybrid alder which are estimated on the basis of one stand per species. Both stands are thoroughly investigated and the results have been published throughout the years (Uri and Tullus 1999, Uri 2000, Uri et al. 2002, Uri et al. 2003ab, Aosaar and Uri 2008, Uri et al. 2009). However, no studies about wood properties have been carried out. In the case of hybrid alder only few planted stands are growing in Estonia at all. Due to the restraint of single sample area per species, the present results are applicable mainly on a regional level. While previous data for grey- and hybrid alder wood density for Estonia are practically missing, the results are valuable both for practical and scientific aspects.

In both grey alder and hybrid alder, stemwood densities increased in the upper stem sections. However, the difference in densities between the stem sections was statistically significant for grey alder but not for hybrid alder. The highest densities occurred in the upper part of the stem, which is in good accordance with the results of other studies (Nagoda 1968, Björklund and Ferm 1982, Miezite 2008). One possible reason for this may be the gradual change in the proportions of late- and earlywood. In younger age the width of the annual rings was large due to rapid tree growth and the relative proportion of less dense earlywood was big compared to the proportion of denser latewood. Later on, when the rate of tree growth started to decelerate, the share of latewood in the annual rings increased and also wood density started to gradually increase.

Data about the wood properties of hybrid alder in the literature are scarce (Pirag 1962). Earlier studies have pointed out that the wood properties, including wood density, of this tree species are intermediate between the parental species (grey alder and black alder) (Pirag 1962). According to Pirag (1962), stemwood density was 420 kg m^{-3} for grey alder and 520…540 kg m^{-3} for black alder; the density of hybrid alder wood was 500 kg m^{-3}.

In hybrid alder, the distribution of wood densities is vertically less variable than in grey alder. A statistically significant difference was only revealed between the third and the fifth sections, i.e. the lowest and the highest trunk sections studied. The growth strategy of hybrid alder differs from that of grey alder. Hybrid alder achieves its maximum stemwood increment later than grey alder, hence, changes in the proportions of early- and latewood are not so drastic. This could explain the more homogeneous vertical wood density distribution in hybrid alder.

In the present study no correlation was found between average stemwood densities and breast height diameter for either studied tree species. Also, the same average density values would be appropriate both for small and large trees, which would simplify the practical use of average wood density value.

Conclusions

Average stemwood density of hybrid alder is significantly higher than that of grey alder's. Stemwood densities determined of grey alder increase gradually from the stump towards the crown, but not that of hybrid alder. The wood of hybrid alder is vertically more homogeneous than the wood of grey alder. There is no correlation between breast height diameter of tree and stemwood densities. For Estonian forestry practice, the recommended oven dry stemwood density would be 396 kg m^{-3} for grey alder and 427 kg m^{-3} for hybrid alder.

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ПЛОТНОСТЬ СТВОЛОВОЙ ДРЕВЕСИНЫ В МОЛОДЫХ ДРЕВОСТОЯХ СЕРОЙ (*ALNUS INCANA* (L.) MOENCH) И ГИБРИДНОЙ ОЛЬХИ (*ALNUS HYBRIDA* A. BR.), РАСТУЩИХ НА ЗАБРОШЕННЫХ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЛЯХ

И. Аосаар, М. Варик, К. Леохмус, К. и В. Ури

Резюме

Основной целью исследования было определить плотность абсолютно сухой стволовой древесины (влажность 0%) двух быстрорастущих древесных пород, серой ольхи (*Alnus incana* (L.) Moench) и гибридной ольхи (*Alnus hybrida* A. Br.), растущих на заброшенных сельскохозяйственных земелях. Исследование проводилось в двух 16-летних экспериментальных древостоях, расположенных в Южной Эстонии (N 58° 3' E 27° 1'). Средняя плотность абсолютно сухой стволовой древесины серой ольхи была 396 ± 32 кг $м^{-3}$ Средняя плотность стволовой древесины гибридной ольхи превысила соответствующее значение серой ольхи. Средняя плотность абсолютно сухой гибридной ольхи была 427±29 кг $м^{-3}$.

У серой ольхи плотность стволовой древесины была больше в верхних частях ствола. Статистически значимая зависимость плотности древесины от расположения секции ствола наблюдалась во всех случаях ($p <0,005$). Аналогичная тенденция была выявлена для гибридной ольхи, однако статистические различия между разными секциями ствола не подтвердились.

Величина диаметра на высоте груди не имела существенного влияния на плотность древесины во всех случаях. Корреляции между диаметром на высоте груди и средней плотностью древесины ни у серой и ни у гибридной ольхи не обнаружено.

Ключевые слова: серая ольха, гибридная ольха, плотность стволавой древесины, заброшенная сельскохозяйственная земля