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# OVEN DRY DENSITY OF SESSILE OAK, TURKEY OAK AND HORNBEAM IN DIFFERENT REGION OF MECSEK MOUNTAIN

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## ABSTRACT

The importance of the renewable and reusable materials is continuously growing from the aspects of environment consciousness and sustainable development. The wood as a raw material is widely used in different fields such as energy and cellulose production to the wood products. One of the most important parameters of the wood is the density. Density is influenced by many factors and there are interactions between them. The present study investigated the wood density of sessile oak (*Quercus petrea* (MATT.) LIEBL.), turkey oak (*Quercus cerris* L.) and hornbeam (*Carpinus betulus* L.) in five regions of Mecsek Mountain. The oaks are showing higher differences than that of the hornbeam between the regions.

KEYWORDS: Wood density, sessile oak, turkey oak, hornbeam.

## INTRODUCTION

The importance of wood density is growing because its market value depends on the dry mass at power stations and different panel or cellulose/wood pulp factories. Therefore it is very important for the practical silviculture to explore the factors that influence density. In Hungary the significance of the issue is stressed because of around 70 % of the lumbered wood is stacked industrial wood and firewood.

The density – the mass of wood per unit volume – has an overriding importance among the physical properties because density is closely connected with the most physical and mechanical properties (Aguiar et al. 2003). Knowing it we can deduce mechanical properties (Alteyrac et al. 2005) and it can define the dry mass production of the tree (Babiak and Molnár 1998).

Density can be seen as an universal material property therefore it would be very important to have information about it many times when qualifying the assortment of logs in the forest. The porous structured natural wood creates a special three-phase solid wood-water-air material structure, so the density can be expressed in several ways. Wood density can be described among others by the density of absolute dry wood, wet or green density, air dry density and basic density (Molnár 2004).

In this work our aim was to define the wet and oven dry density of the three most important wood species in 5 districts of Mecsek region and its statistical analysis separating the juvenile wood, heartwood and sapwood. The Mecsek region located in south-west of Hungary between the Northern latitude of 45.50 and 46.20; Eastern longitude of 17.40 and 18.30 with the highest peak of 602 meter and with the lowest fields around 100 meter above sea level.

The wood of sessile oak (*Quercus petraea* (MATT.) LIEBL.), turkey oak (*Quercus cerris* L.) and hornbeam (*Carpinus betulus* L.) were examined in this research. A great number of researches were done on these species. Guilley et al. (1999) examined the density of sessile oak and found that the habitat and the effects of silviculture describe a little part of the whole diversity. Vavrcik et al. (2010) examined the density differences between the pedunculate oak and the sessile oak. They found that in the case of the same width of the annual ring the sessile oak has a bigger proportion of latewood and has a bigger density, and also established that the density does not only depend on the proportion of latewood but on its quality too. Berges et al. (2000) investigated the effect of the ecological factors on the width of the annual ring of the sessile oak and its density. Also Berges et al. (2000) did a long term research examining the width of the annual ring and the density of sessile oak plotted against the increasing carbon-dioxide content of the atmosphere. Zhang (1997) examined the relation between the density inside the annual ring and the climatic conditions on sessile and pedunculate oak. He found that there is less close connection between the width of the annual ring and the climatic parameters than between the width of the latewood and the density of latewood and the climate.

## Factors influencing wood density

Density is influenced by several factors which are also in correlation with each other. Without the intention to be exhaustive on the surveying of technical literature these are the following:

*Species*

Density, as well heritable property of species, shows characteristic values of each species (Park et al. 2009, Pliura et al. 2007, Aguiar et al. 2003, Rozenberg et al. 2002, Babiak and Molnár 1998, MacDonald et al. 1997, Beaudoin et al. 1992, Singh 1987).

*Moisture content*

It influences most properties of the wood as well as density. Filling up the intermicellar cavities of the cell wall and the lumen of the cells with water increases the density of porous wood.

*The position of the analyzed wood within the tree*

The changes of the size features and chemical composition of tissue elements result in the special changes along the cross section and length of the trunk (Park et al. 2009, Alteyrac et al. 2005, Via et al. 2005, Igartúa et al. 2003, Raymond and Muneri 2001, Kucera 1994, Beaudoin et al. 1992, Yanchuk et al. 1983). The average density continuously grows from the pith outwards in the juvenile period, then it reaches the maximum level in the mature wood (Knapic et al. 2007, Parolin 2002). In trees with definite colored heartwood, the density of the sapwood is lower with 5-15 % than that of the heartwood. Along the trunk the change of density is connected with the shape of the crown and the mechanical functions of the trunk (Molnár 2004). The position inside the forest, the diameter of the trunk, the height of the tree and the size of the crown also influence the density of the wood. Therefore, for example in the ring-porous wood species the individuals that have a larger diameter and reach the prevailing height are 5-7 % denser in average than the thinner or lower ones (Molnár 1988).

*The effects of ecological and silvicultural factors*

According to more researches, the density of wood is the highest in about the middle of the geographic area of the species, in the climatic optimum. In fully stocked stands where the trees that are grown under careful silvicultural activities wood usually have higher density in average (Park et al. 2009, Bouffier et al. 2003, Eguiluz-Piedra and Zobel 1986).

On the basis of surveying the technical literature above it can be ascertain that inside a trunk depending on the species the variety of density is 15-20 %, within a stand there can be significant differences between the average density of trunks, the relative deviation reaches 20-30 %. There is no significant difference (5-10 %) between the density of different wood stands if they are from the same species, originate from the same area and have similar age. Among wood stands having larger geographic and topographic differences can be significant differences (10-20 %) in wood density and in this case genetic effects should also be considered.

## MATERIAL AND METHODS

The density of the samples from the five regions of Mecsek (Árpádtető, Sellye, Szigetvár, Pécsvárad, Sásd) was examined, 12-12 samples from 5-5 parts of forests from each district. This means 300 samples per species (turkey oak, sessile oak, hornbeam). The place of origin of the samples was chosen carefully to represent the tree stand of the region the best. Because of the comparison we also made an effort to choose the samples from the inside parts of the stands not from the edges of them.

The samples are from the top part of the first log namely from 3.5-4.0 meter height. Sample discs were cut in the field than carried to the place of examination in hermetically sealed bags. The size of the specimen was 20 x 20 x 25 mm; the 25 mm was directed to the grain. From each discs, three specimens were cut: one from the juvenile part, one from the heartwood and one from the sapwood. The size and weight data of the specimen were immediately recorded. The quantity determination of the moisture content was made by drying to constant weight. The density of the specimen was calculated by determining the sample volume in wet and oven dry condition.

## RESULTS AND DISCUSSION

### Comparison of species

The most important data describing some mass of facts are the average, maximum and minimum values and deriving from this the overall range and the standard deviation (SD). Instead of the average the median could be used, but in the following the average is needed and in this case the medians do not differ basically from the average.

*Tab. 1: The average, maximum and minimum value and the standard deviation (SD) of wet and oven dry density (kg.m$^{-3}$).*

| | Turkey oak | | Sessile oak | | Hornbeam | |
|---|---|---|---|---|---|---|
| | Wet | Oven dry | Wet | Oven dry | Wet | Oven dry |
| Average | 1030.81 | 753.07 | 938.65 | 679.59 | 920.55 | 677.88 |
| Maximum | 1357.18 | 933.15 | 1190.43 | 895.68 | 1118.34 | 871.88 |
| Minimum | 767.53 | 583.36 | 590.83 | 442.86 | 720.83 | 505.89 |
| SD | 78.42 | 55.50 | 107.04 | 76.79 | 67.86 | 54.81 |

The average density (Tab. 1) of the turkey oak is inside the range given by literature (Molnár and Bariska 2006) in wet (1000-1100 kg.m$^{-3}$) and oven dry conditions (570-850 kg.m$^{-3}$) though they are at the top of the range. In the case of sessile oak the oven dry values are in harmony with the literature values (690 kg.m$^{-3}$) but the wet density falls behind the literary values (1100 kg.m$^{-3}$). In the case of the hornbeam the averages of the wet density are in the middle of the ranges, but the oven dry density is lower than the European average. Although the measured value is very close to the data of Požgaj et al. (1997). In the cases of both the turkey oak and the sessile oak the highest recorded wet value exceeds the literary values.

To support the difference between the average values a statistical test were performed. The comparison of more expected values (average) can be done with analysis of variance. The examined question is an analysis of variance problem for three species, five regions and three position inside the disc, where there are three factors (wood species, region, wood part) their effects and interactions can be examined applying them to the dependent variable (density). So the question is if the average value of the examined variable (wet and oven dry density) differs in the case of different factors or factor combinations. Certainly there can be combinations whose examination makes no sense. A theoretical premise of using this method is that the analyzed variable has standard deviation. In nature a lot of analyzed variables have standard deviation such as the density of wood.

According to the analysis of variance there is a significant difference between the factors (species), so we are curious to know between which pairs we can find a difference namely we made comparisons in pairs with more methods. On the one hand we calculated the least significant difference (LSD) that considers those samples different where there is a higher difference between their average values. The disadvantage of the method that it can find an unjustified difference, therefore we made calculations with another, less sensitive method, the Tukey test. We made the tests both on the wet and oven dry densities. In the case of wet density there is a significant difference between the average density of the three species as expected by both tests. However in the case of the oven dry density, the density of the turkey oak significantly differs from the oven dry density of the sessile oak and hornbeam but the latter ones do not differ from each other.

## Density difference between wood parts

Within the species we can analyze the average values connected with the places and the parts of the wood and the standard deviation too. It is senseless to handle all data of juvenile wood, heartwood and sapwood together of the tree species because the genetic and biological differences are significant. Furthermore we demonstrated above the differences between the species so most likely there is a difference also between their parts (Tab. 2).

*Tab. 2: Density of each investigated wood parts (kg.m⁻³).*

| | Turkey oak | | Sessile oak | | Hornbeam | |
|---|---|---|---|---|---|---|
| | Wet | Oven dry | Wet | Oven dry | Wet | Oven dry |
| Juvenile wood | 1059.73 | 768.97 | 980.41 | 718.91 | 906.11 | 644.99 |
| Heartwood | 1062.45 | 777.11 | 958.21 | 707.41 | 928.39 | 687.43 |
| Sapwood | 980.32 | 725.82 | 873.01 | 613.57 | 925.85 | 701.71 |

## Turkey oak

Analyzing the differences between the parts of the wood we also used LSD and Tukey test. We calculated if there is a difference at 0.05 significance level and we also gave the exact significance level (Tab. 3).

*Tab. 3: Significance test of turkey oak.*

| | | | Wet | | Oven dry | |
|---|---|---|---|---|---|---|
| | | | Significance level | Average difference | Significance level | Average difference |
| Tukey | Juvenile wood | heartwood | -0.6998 | 0.991 | -5.1257 | 0.422 |
| | | sapwood | 84.1723* | 0.000 | 48.7016* | 0.000 |
| | Heartwood | sapwood | 84.8720* | 0.000 | 53.8273* | 0.000 |
| LSD | Juvenile wood | heartwood | -0.6998 | 0.899 | -5.1257 | 0.422 |
| | | sapwood | 84.1723* | 0.000 | 48.7016* | 0.000 |
| | Heartwood | sapwood | 84.8720* | 0.000 | 53.8273* | 0.000 |

* The difference between average values is significant at a level of 0.05

Significant difference cannot be shown between the juvenile wood and heartwood but the sapwood has a significant difference both in the cases of the wet and the oven dry density. It can derive from that the juvenile wood of the pith does not separate from the heartwood in all cases.

## Sessile oak

In the case of the sessile oak we found a significant difference on both densities between the parts of wood (Tab. 4).

*Tab. 4: Significance test of sessile oak.*

| | | | Wet | | Oven dry | |
|---|---|---|---|---|---|---|
| | | | Significance level | Average difference | Significance level | Average difference |
| Tukey | Juvenile wood | heartwood | 22.7321* | 0.001 | 11.7220* | 0.032 |
| | | sapwood | 107.2729* | 0.000 | 104.1003* | 0.000 |
| | Heartwood | sapwood | 84.5408* | 0.000 | 92.3783* | 0.000 |
| LSD | Juvenile wood | heartwood | 22.7321* | 0.000 | 11.7220* | 0.012 |
| | | sapwood | 107.2729* | 0.000 | 104.1003* | 0.000 |
| | Heartwood | sapwood | 84.5408* | 0.000 | 92.3783* | 0.000 |

* The difference between average values is significant in 0.05 level

## Hornbeam

In the case of the hornbeam significant difference between the wet heartwood and sapwood could not be demonstrated but in the other cases differences are apparent (Tab. 5).

*Tab. 5: Significance test of hornbeam.*

| | | | Wet | | Oven dry | |
|---|---|---|---|---|---|---|
| | | | Significance level | Average difference | Significance level | Average difference |
| Tukey | Juvenile wood | heartwood | -22.9680* | 0.000 | -42.4270* | 0.000 |
| | | sapwood | -20.3089* | 0.000 | -56.7794* | 0.000 |
| | Heartwood | sapwood | 2.6591 | 0.871 | -14.3525* | 0.001 |
| LSD | Juvenile wood | heartwood | -22.9680* | 0.000 | -42.4270* | 0.000 |
| | | sapwood | -20.3089* | 0.000 | -56.7794* | 0.000 |
| | Heartwood | sapwood | 2.6591 | 0.871 | -14.3525* | 0.000 |

* The difference between average values is significant in 0.05 level

## Comparison between regions

The analysis of the five regions did not provide enough bases to analyze the habitat effects (soil, rainfall, temperature, hydrological conditions) separately. According to this our aim was to find what differences can occur between the regions of origin which are in 10-50 km distance and there is several hundreds of meters difference in altitude (Tab. 6).

*Tab. 6: Comparison between regions, average density (kg.m$^{-3}$).*

| Region | Turkey oak | | Sessile oak | | Hornbeam | |
|---|---|---|---|---|---|---|
| | Wet | Oven dry | Wet | Oven dry | Wet | Oven dry |
| Szigetvár | 1049.77 | 761.75 | 958.10 | 659.69 | 946.37 | 671.06 |
| Pécsvárad | 1038.64 | 755.21 | 945.09 | 697.89 | 941.32 | 666.29 |
| Sásd | 1036.06 | 741.24 | 928.16 | 681.97 | 900.63 | 687.39 |
| Sellye | 1052.02 | 788.41 | 954.89 | 662.35 | 921.27 | 680.14 |
| Árpádtető | 994.32 | 739.87 | 899.79 | 697.90 | 890.98 | 685.33 |

In the case of the average values describing the regions the wet density values of the samples from Árpádtető are uncommonly low in turns with all species. This can be explained with lower starting moisture content. For the statistical comparison of the regions we also used an analysis of variance.

### *Turkey oak*

In the case of wet density, significant difference cannot be shown between the regions except of Árpádtető which place is significantly different from all the other regions. However in the case of the oven dry density it is Sellye which is significantly different from the other regions, Pécsvárad forms a group with Szigetvár, they are not significantly different from each other; and Árpádtető with Sásd. Although it is hard to prove in the background there can be geological reasons and genetic differences can arise from it (Fig. 1).

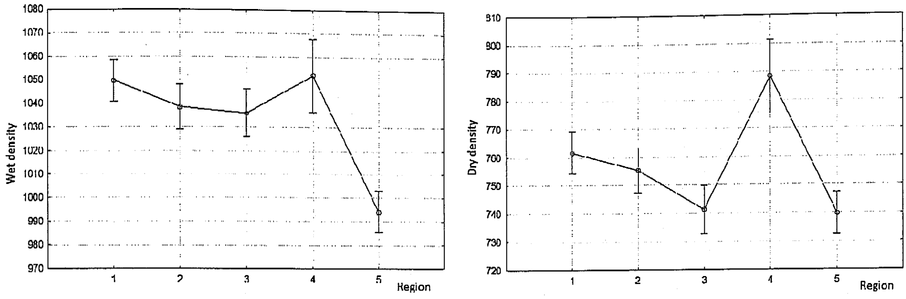


*Fig. 1: Wet (left) and dry (right) wood density of Turkey oak in different regions (1: Szigetvár; 2: Pécsvárad; 3: Sásd; 4: Sellye; 5: Árpádtető) Vertical bars show the 0.95 confidence intervals.*

### *Sessile oak*

Árpádtető is different in the case of wet density from the other regions but there are other groups in the case of the sessile oak, Szigetvár, Pécsvárad and Sellye are in one group but Sásd forms a separate group. In the case of the oven dry density Árpádtető does not differ from Pécsvárad and Szigetvár forms a group with Sellye and Sásd stays in a separate group (Fig. 2).

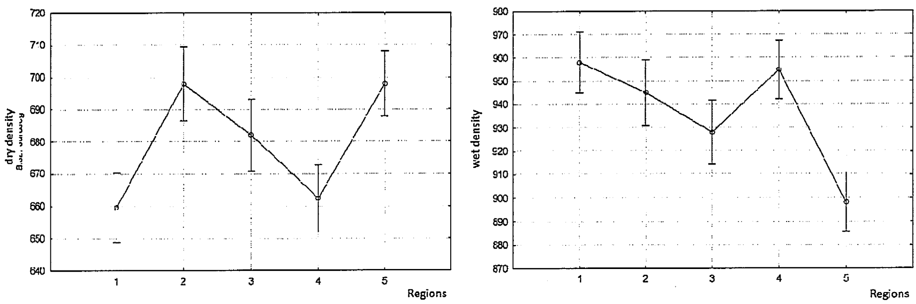


*Fig. 2: Wet (left) and dry (right) wood density of sessile oak in different regions (1: Szigetvár; 2: Pécsvárad; 3: Sásd; 4: Sellye; 5: Árpádtető) Vertical bars show the 0.95 confidence intervals.*

### *Hornbeam*

The analysis of wet density of the hornbeam showed the separation of Pécsvárad and Szigetvár. Another group was formed by Sásd and Árpádtető and Sellye stayed alone (as in the case of the oven dry density of the turkey oak). At the oven dry density on the one hand a Pécsvárad-Szigetvár-Sellye group was formed, on the other hand a Sásd-Árpádtető-Sellye too, namely Sellye is not separated significantly from any of them. Fig. 3.

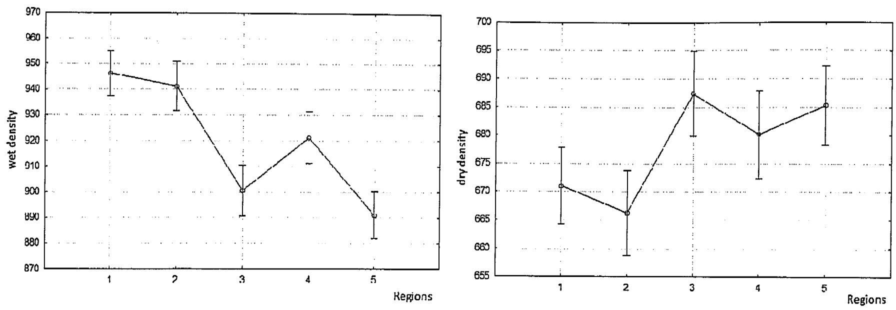


*Fig. 3: Wet (left) and dry (right) wood density of Hornbeam in different regions (1: Szigetvár; 2: Pécsvárad; 3: Sásd; 4: Sellye; 5: Árpádtető) Vertical bars show the 0.95 confidence intervals.*

We can draw a final conclusion that we could demonstrate differences of parts of wood in the case of Turkey oak and sessile oak with colored heartwood and also in the case of the hornbeam with not colored heartwood. In the regions, similarities can be discovered at the oven dry density between the behavior of the Turkey oak and hornbeam, similar groups seems to be formed (Sásd-Árpádtető and Pécsvárad-Szigetvár) which seems to support that the habitat of these groups are similar (climate, soil, exposure) therefore two species support their relation (Figs. 1 and 3).

## CONCLUSIONS

Analysis of density was performed in the five regions of the Mecsek Mountains for 12 trunk trees of three species originated from 5-5 parts of the forest. We took samples from discs of 300 trunk trees of the species separating juvenile wood, heartwood and sapwood.

The results definitely proved the following:

- Density of the sessile oak and Turkey oak species are significantly different among regions. In the case of the hornbeam this deviation is very low.
- The largest difference among oven dry wood densities caused by the origin is 6.6 % for Turkey oak, 5.8 % for sessile oak and 3.2 % for hornbeam.
- During moisture content (absolute dry mass) based delivery of wood material shipments from different regions must be handled separately.
- During moisture content (absolute dry mass) based delivery of Turkey and sessile oak species the sampling must reach the pith because the wet density of the sapwood is significantly different from that of the other wood parts.
- No significant differences were found between the wet density of hornbeam heartwood and sapwood.

The results of the research point out that receiving wood on the basis of the dry mass and wood moisture may cause errors.

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