WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.5.718730
e-ISSN 2729-8906
67(5): 2022 718-730 pp.

WOOD DENSITY AND ANNUAL RING WIDTH OF PEDUNCULATE OAK FROM STANDS GROWN ON FORMER AGRICULTURAL LAND

KAROL TOMCZAK, PRZEMYSŁAW MANIA, ARKADIUSZ TOMCZAK
POZNAŃ UNIVERSITY OF LIFE SCIENCES
POLAND

(RECEIVED MARCH 2022)

ABSTRACT

The main aim of this study was to determine differences in basic density and average annual ring width of pendulate oak wood collected from trees grown on former agricultural land and on forest land, using a dimensional method. The experiment was carried out in the western part of Poland, near to Poznan, which is in the central part of the European range of pedunculate oak. In our study the average basic density was 0.528 $g \cdot cm^{-3}$, and the value for former agricultural land was lower by 0.026 $g \cdot cm^{-3}$ than that for forest land. Differences in basic density values between these two land types were statistically significant. The average annual ring width in samples collected from forest land in our study was 2.48 mm, samples from former agricultural land were characterized by wider average annual rings. The results suggest that there are significant differences in quality of wood from former agricultural land and from forest. However, from view of wood quality and applications the difference is not important.

KEYWORDS: Basic density, former farmland, *Quercus robur*, annual ring, wood physical properties.

INTRODUCTION

From the point of view of forest management, the conditions of tree growth and development are of exceptional importance for the formation of wood tissue and for the quality of the wood raw material (Brüchert et al. 2000, Přemyslovská et al. 2008, Tomczak et al. 2013). Some of the most important external factors that affect the conditions of tree growth and development are forest habitat type, biosocial position of the tree, management treatments, and progressive climate change (Wiemann and Williamson 2002, Mäkinen and Isomäki 2004, Muñoz et al. 2008). Trees grown on former agricultural land are particularly vulnerable to a range of environmental stresses. The main factor that differentiates forest stands and post-agricultural stands is the soil. The soil of former agricultural land is modified as a result of afforestation

(Meyer 1978, Alriksson and Olsson 1995, Ritter et al. 2003, Hagen-Thorn et al. 2004). Changes are observed first of all in soil properties such as pH, content of basic elements, and porosity (Olszewska and Smal 2008, Smal and Olszewska 2008). According to Jug et al. (1999) and Post and Kwon (2000) it can be assumed that the cessation of agricultural cultivation, and consequently the application of high doses of fertilizers, weeding, etc., can contribute to the improvement of soil water quality and lead to the accumulation of organic matter in the soil. The establishment of forest ecosystems on former agricultural land is important not only for environmental, but above all for economic reasons (Rosenqvist 2007). Considering the expected increase in demand for wood raw material (FAO 2000, 2020), measures should be taken to increase the production of high quality wood from sources other than forest land. This objective is being pursued globally through the establishment of fast-growing tree plantations, and in Europe through the afforestation of unused (abandoned) agricultural land. Since World War II there has been growth in the use of former agricultural land to increase forest cover in many countries worldwide, using both native species and fast-growing tree plantations. The largest trend toward the afforestation of unused agricultural land is observed in central Europe, for example in Poland (Szwagrzyk 2004, Orczewska and Fernes 2011, Kolecka et al. 2017), Slovakia (Špulerová et al. 2017), the Czech Republic (Kotecký 2015) and Ukraine (Baumann et al. 2011), as well as in the Scandinavian countries (Rytter 2016, Rytter and Lutter 2019). Rytter (2016) showed that approx. 1.8–2.6 million ha of former agricultural land in the Baltic and Nordic countries could be used for afforestation. In Poland, as part of the national programme to increase forest cover modified in 2003, it was agreed that 680,000 ha of former agricultural land would be afforested between 2004 and 2020, with the aim of increasing the country's forest cover to 30%. Between 1995 and 2014, a total of 274,300 ha were afforested (Kaliszewski 2016). Currently, there are approximately 12–16 million hectares of agricultural land available for afforestation across Europe (Campbell et al. 2008), while globally there are approximately 385–472 million hectares of such land (FAO 2008, Campbell et al. 2008).

The density of wood is considered to be the most important parameter determining its mechanical and physical properties, regardless of the species of tree or type of wood. It also determines the quality and use of the wood i.e.: wood with a higher density will have higher strength and therefore be more suitable for use in construction. Scientific works distinguish several types of wood density (Glass et al. 2010, Tomczak et al. 2018, Jakubowski and Dobroczyński 2021); the most fundamental include green density, determined on the basis of the mass and volume of wood in fresh state, oven-dry density, determined using dry weight and volume, and basic density (BD), determined using dry weight and volume of wood at maximum fibre saturation. To date, several methods of determining wood density, both non-destructive and destructive, have been developed (Gao et al. 2017). Previous investigations of the density and other properties of wood from former agricultural land have mainly concerned coniferous wood (Jelonek et al. 2008, 2019, Irbe et al. 2015, Miezite et al. 2017, Zeidler et al. 2017, Cukor et al. 2020, Kozakiewicz et al. 2020). Among deciduous species, such studies have been carried out on the wood density of silver birch (Přemyslovská et al. 2008, Liepiņš and Rieksts-Riekstiņš 2013, Miezite et al. 2017) and grey alder and its hybrid (Aosaar et al. 2011). No other work has been found concerning the wood properties of deciduous trees grown under the conditions of former agricultural land.

The main aim of this study was to determine differences in the density of wood collected from trees grown on former agricultural land and on forest land, using a dimensional method with samples collected using a Pressler drill. It was hypothesized that the wood from trees grown on former agricultural land would exhibit a higher wood density (H1) and a larger average width of annual rings (ARW) (H2). Furthermore, it was hypothesized that the density distribution across the stem cross-section would be similar for both land types and that there would be no statistically significant differences between them (H3). By determining and comparing the density distribution on the stem cross-section, it was planned to test for variation in wood quality throughout the growth period, and to determine whether oak wood from former agricultural land is of poorer quality, defined by wood tissue properties, and thus less suitable for industrial use, for example in construction.

MATERIAL AND METHODS

Study design and site selection

The study was carried out in November 2021 in the western part of Poland (N 51° 51' 13.631"; E 16° 26' 8.844"), which is in the central part of the European range of pedunculate oak. Model trees were located on two different plots. The first plot was classified as former agricultural land, and the second as permanent forest land. Trees from both stands were of similar age, between 90 and 110 years, and grew in the same forest habitat type (mixed fresh forest). For all pedunculate oak (*Quercus robur* L.) trees located in the sample plots, the height (H) and diameter at breast height (DBH) were measured. Model trees were then selected in each plot. Tests were carried out on 18 model trees: 9 from former agricultural land, and 9 from forest land.

Specifying of wood properties using dimensional method

After the model trees had been chosen, samples were collected from each tree at breast height using a Pressler drill. Next, each increment core was divided into samples containing 10 annual rings (10 years of growth) and labelled according to the scheme illustrated (Fig. 1).

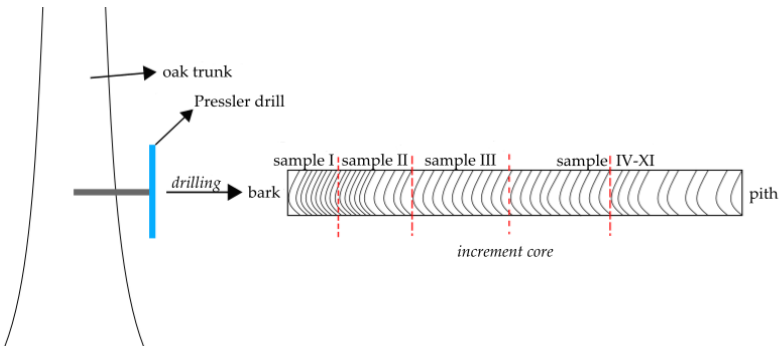

Fig. 1: Increment cores drilling process by Pressler drill at the breast height of oak model trees. Dividing increment cores on the samples with 10 annual rings each.

Immediately after sampling and division, the length of each sample was measured to the nearest 0.01 mm using a certified Vogel calliper (Vogel Germany GmbH & Co. KG, Kevelaer, Germany). The diameter (D) of each sample was specified, according to the manufacturer's instructions, as 5.15 mm. Then, based on the methodology suggested by Pérez-Harguindeguy et al. (2017), the volume of the samples was calculated using Eq. 1:

$$V = \pi x \left(0.5D\right) 2 x L \qquad \left[cm^3\right] \qquad (1)$$

where: V – volume; D – diameter of the sample = 5.15 mm; L – length of sample.

Additionally based on length of samples average width of rings was calculated using Eq. 2:

$$AW = L / AR \qquad (2)$$

where: L – length of samples, AR – number of rings in each sample.

After collecting all the data necessary to determine the volume of the samples, the samples were transported to the laboratory, where they were dried in an electric dryer. Drying took place at 105°C for 24 hours. After reaching 0% water content and constant weight, the samples were placed in a desiccator until cooled. The samples were then weighed to the nearest 0.001 g using a Steinberg laboratory balance (Steinberg Systems SBS-LW-200A, Germany). The basic density was calculated according to the standard ISO 13061-2:2014/AMD 1:2017

Statistical analyses

In the first step, the Shapiro–Wilk test was performed to verify the normal distribution of data. The test assumes that a statistically significant result permits rejection of the hypothesis of the normal distribution of data. To compare the parametric T-student test was performed, to compare non-parametric Test Manna-Whitney'a was performed. To compare data between samples on cross-section of the trunk ANOVA test was performed. After significant differences were proved post-hoc test HSD Tukey was performed. Statistical inference was performed at significance level $\alpha = 0.05$. The program RStudio and the R package (R Core Team 2021) were used for the calculations.

RESULTS AND DISCUSSION

Basic density

The mean value of basic density from all studied samples was 0.528 $g \cdot cm^{-3}$. A greater average value of basic density (0.539 $g \cdot cm^{-3}$) was observed in samples from forest land. The BD of wood from former agricultural land was lower by 0.026 $g \cdot cm^{-3}$. Differences in BD values between these two land types were statistically significant (Tab. 1). Our results are quite similar to those of Jakubowski et al. (2021), who determined the basic density of *Q. robur* on forest land.

Tab. 1: Descriptive statistics of basic density (g cm^{-3}).

	Mean	N	Std. dev	Var	Coef. var	Min	Max	Median	t-student test result
Forest land	0.539	89	0.06	0.003	0.1	0.404	0.699	0.538	0.00
Former agricultural land	0.513	65	0.05	0.002	0.1	0.430	0.644	0.518	
Mean	0.528	154	0.05	0.003	0.1	0.404	0.699	0.527	

N – number of samples; Std. dev – standard deviation; Var – variation; Coef. var - coefficient of variation; Min – minimum; Max – maximum.

As regards the radial distribution of basic density, the largest values were observed close to the pith, between 10 and 50 years of growth, and then a decrease towards the bark (Fig. 2). The same phenomenon was also observed by other authors studying the radial distribution of density in ring-porous wood species (Lei et al. 1996, Vavrčík and Gryc 2012, Bahmani et al. 2018, Tomczak et al. 2018). According to the results of Tukey's HSD test, there were not statistically significant differences on the cross-section between the wood samples from former agricultural land. In case of radial variation of BD on the cross-section of the trees from forest land statistically significant differences were found (Tab. 2). The obtained results shows that history of land use may significantly effect on the oak wood density. However, from view of wood quality and applications the difference is not important, which confirmed results presented by Kozakiewicz et al. (2020) on Scots pine wood.

Tab. 2: Results of basic density HSD Tukey test between samples from forest land by every 10 years.

	FL-I										
FL-I	x	FL-II									
FL-II		x	FL-III								
FL-III			x	FL-IV							
FL-IV				x	FL-V						
FL-V					x	FL-VI					
FL-VI						x	FL-VII				
FL-VII							x	FL-VIII			
FL-VIII	0.01							x	FL-IX		
FL-IX	0.00	0.01			0.01	0.01			x	FL-X	
FL-X	0.00	0.000	0.02	0.00	0.00	0.00				x	FL-XI
FL-XI											x

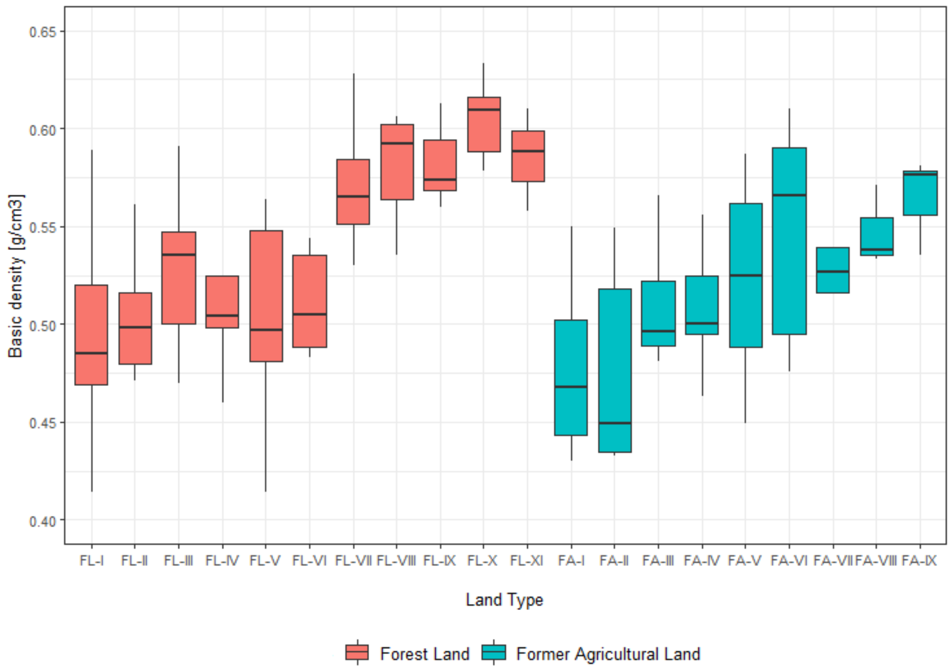

Fig. 2: Basic density (g cm^{-3}) changes on the cross-section by every 10 years from bark (FL -I/ FA-I) to the pith (FL– XI/FA – IX).

Average annual ring width

Mean value of ARW was 3.06 mm. The increment cores collected from trees from former agricultural land had wider average annual rings than the samples from forest land. The average difference between the two land types was approx. 1.4 mm, and was statistically significant (Tab. 3).

Tab. 3: Descriptive statistics of average ring width.

Type of land	Mean (mm)	N	Std. dev	Var	Coef. var	Min (mm)	Max (mm)	Median (mm)	M-W test result
Forest	2.48	89	1.13	1.29	0.46	0.92	6.17	2.16	0.00
Former agricultural land	3.87	65	1.50	2.56	0.41	1.54	8.13	3.45	
Mean	3.06	154	1.51	2.28	0.49	0.92	8.13	2.7	

N – number of samples; Std. dev – standard deviation; Var – variation; Coef. var - coefficient of variation; Min – minimum; Max – maximum.

The average annual ring width in samples collected from forest land in our study was 2.48 mm, similar to the result of 2.1 mm for the annual ring width of pedunculate oak reported by Vavrčík et al. (2012), although Zeidler et al. (2016) reported a value of around 4.0 mm. In the case of samples from former agricultural land in our study, the average width was quite similar to the latter result (3.87 mm). Comparing different parts of the cross-section of the trunk, the widest annual rings were observed in the central part (close to the pith), and the narrowest close to the bark (Fig. 4).

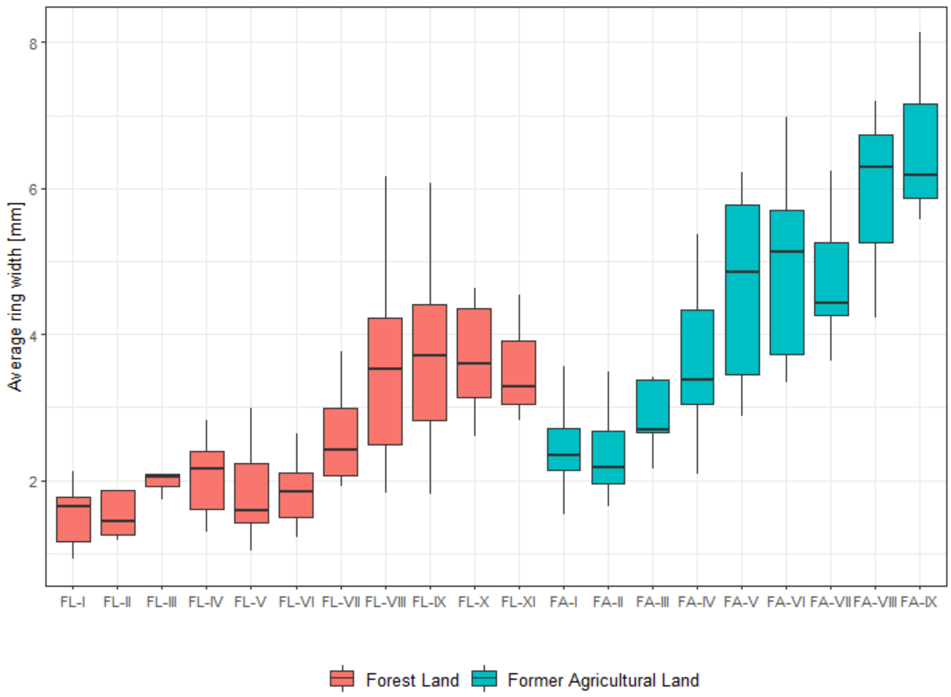

Fig. 4: Average ring width (mm) changes on the cross-section by every 10 years from bark (FL-I/FA -I) to the pith (FL – XI/FA – IX).

Statistically significant differences were observed in the case of both types of land (Tabs. 4 and 5), and also in the case of similar samples located closest to the pith from forest and former agricultural land. In a direct comparison of the same growth decades of samples from both stand types, statistically significant differences in average ring width were found for the first, fifth and sixth growth decades. These significant differences may be caused by dynamic growth in the initial growth phase. Jelonek et al. (2009) observed a similar phenomenon of dynamic growth in the first three decades of growth of Scots pine on former agricultural land.

Tab. 4: Results of average annual ring width HSD Tukey test between samples from forest land by every 10 years.

	FL-I										
FL-I	x	FL-II									
FL-II		x	FL-III								
FL-III			x	FL-IV							
FL-IV				x	FL-V						
FL-V					x	FL-VI					
FL-VI						x	FL-VII				
FL-VII							x	FL-VIII			
FL-VIII	0.03	0.03			0.03	0.04		x	FL-IX		
FL-IX	0.00	0.01		0.04	0.00	0.01			x	FL-X	
FL-X	0.01	0.02			0.02	0.02				x	FL-XI
FL-XI											x

Tab. 5: Results of average annual ring HSD Tukey test between samples from former agricultural land by every 10 years.

	FA-I	FA-II	FA-III	FA-IV	FA-V	FA-VI	FA-VII	FA-VIII	FA-IX	FA-X
FA-I	x									
FA-II		x								
FA-III			x							
FA-IV				x						
FA-V	0.00	0.00			x					
FA-VI	0.00	0.00	0.01			x				
FA-VII	0.00	0.00					x			
FA-VIII	0.00	0.00	0.00	0.04				x		
FA-IX	0.00	0.00	0.00	0.00					x	
FA-X										x

Spearman correlation of examined properties

Spearman correlation was used to determine the correlation between basic density and average annual ring width. The results show a strong positive correlation between these two properties (0.51). The correlation between BD and ARW for samples from former agricultural land (0.75) was stronger than in the case of forest land (0.71). The density was found to increase in direct proportion to the width of the annual rings (Fig. 5).

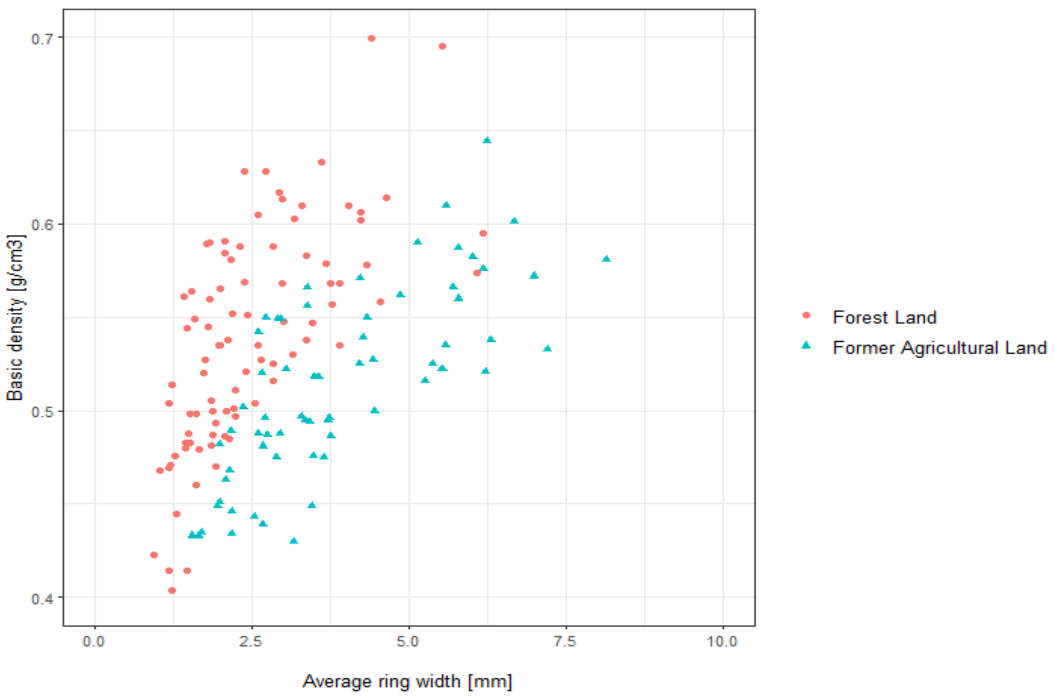

Fig. 5: Variation of basic density and average ring width for all model trees.

Pedunculate oak is classified as a ring-porous species. In this type of wood, increases in annual ring growth cause a proportional increase in the width of late wood. Therefore, in contrast to conifers, when the annual rings are wide, the density of the wood is high (Kollmann 1968). In our study we observed unusual phenomenon - the density from forest land is higher but the annual ring width is smaller, than in case of wood samples from former agricultural land. This phenomenon may be caused, by higher proportion of juvenile wood in samples from former agricultural land. In oak wood juvenile wood zone may cover even 30 growth rings (Raczkowska-Helińska 1994). Nevertheless, this hypothesis need to be confirmed in further studies covering not only average width of annual rings, but also their anatomy.

CONCLUSIONS

Wood density can be regarded as a universal property that supplies very important information enabling the classification of harvested wood and determination of its potential uses. Therefore, it is important to know the properties of the wood of trees growing in different locations and under different growth conditions. Our study rejected the first hypothesis (H1) – wood collected from trees grown on former agricultural land was characterized by lower density; however, despite significant differences, from a biological perspective the differences in basic density were not great, amounting to only 0.026 $g \cdot cm^{-3}$. Average annual ring width was approximately 1.4 mm larger in wood from former agricultural land, which confirmed our second hypothesis (H2). The third hypothesis was also confirmed, because we did not find any statistically significant differences in the basic density distribution on the cross-section of the trunk between samples from study plots with different historical use. Despite the absence of statistically significant differences between the densities of wood in the same decade, the initial growth of pedunculate oak on former agricultural land was significantly more rapid.

ACKNOWLEDGMENTS

The authors would like to acknowledge anonymous reviewers for commenting and improving scientific quality of this paper.

REFERENCES

1. Alriksson, A., Olsson, M.T., 1995: Soil changes in different age classes of Norway spruce (*Picea abies* (L.) H. Karst.) on afforested farmland. Plant Soil 168–169: 103–110.
2. Aosaar, J., Varik, M., Lõhmus, K., Uri, V., 2011: Stemwood density in young grey alder (*Alnus incana* (L.) Moench) and hybrid alder (*Alnus hybrida* A. Braun) stands growing on abandoned agricultural land. Baltic Forestry 17: 89–94.
3. Bahmani, M., Saeedi, S., Humar, M., Kool, F., 2018: Effect of tree diameter classes on the properties of Persian oak (*Quercus brantii* Lindl.) wood. Wood Research 63: 755–762.
4. Baumann, M., Kuemmerle, T., Elbakidze, M., Ozdogan, M., Radeloff, V.C., Keuler, N.S., Prishchepov, A.V., Kruhlov, I., Hostert, P., 2011: Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. Land Use Policy 28: 552–562.
5. Brüchert, F., Becker, G., Speck, T., 2000: The mechanics of Norway spruce (*Picea abies* (L.) H. Karst): Mechanical properties of standing trees from different thinning regimes. Forest Ecology and Management 135: 45–62.

6. Campbell, J.E., Lobell, D.B., Genova, R.C., Field, C.B., 2008: The global potential of bioenergy on abandoned agriculture lands. Environmental Science & Technology 42: 5791–5794.
7. Cukor, J., Zeidler, A., Vacek, Z., Vacek, S., Šimůnek, V., Gallo, J., 2020: Comparison of growth and wood quality of Norway spruce and European larch: effect of previous land use. European Journal of Forest Research 39: 459–472.
8. Gao, S., Wang, X., Wiemann, M.C., Brashaw, B.K., Ross,. R.J., Wang, L., 2017: A critical analysis of methods for rapid and nondestructive determination of wood density in standing trees. Annals of Forest Science 74: 1–13.
9. Glass, S.V., Zelinka, S.L., 2010: Wood handbook, Chapter 04: Moisture relations and physical properties of wood.
10. Hagen-Thorn, A., Callesen, I., Armolaitis, K., Nihlgård, B., 2004: The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. Forest Ecology and Management 195: 373–384.
11. Helińska-Raczkowska, L., 1994: Variation of vessel lumen diameter in radial direction as an indication of the juvenile wood growth in oak (*Quercus petraea* Liebl). Annals of Forest Science 51: 283-290.
12. Irbe, I., Sable, I., Noldt, G., Grinfelds, U., Jansons, A., Treimanis, A., Koch, G., 2015: Wood and tracheid properties of norway spruce (*Picea abies* (L.) H. Karst.) Clones Grown on Former Agricultural Land in Latvia. Baltic Forestry 21: 114–123.
13. ISO 13061-2, 2014: Physical and mechanical properties of wood. Test methods for small clear wood specimens. Part 2: Determination of density for physical and mechanical tests.
14. Jakubowski, M., Dobroczyński, M., 2021: Allocation of wood density in European oak (*Quercus robur* L.) trees grown under a canopy of scots pine. Forests 12(6): 712.
15. Jelonek, T., Arasimowicz-Jelonek, M., Gzyl, J., Tomczak, A., Łakomy, P., Grzywiński, W., Remlein, A., Klimek, K., Kopaczyk, J., Jaszczak, R., Kuźmiński, R., 2019: Influence of former farmland on the characteristics and properties of scots pine (*Pinus sylvestris* L.) tree tissue. BioResources 14: 3247–3265.
16. Jelonek, T., Pazdrowski, W., Tomczak, A., 2008: Biometric traits of wood and quality of timber produced in former farmland. Baltic Forestry 14(2): 138 – 148.
17. Jelonek, T., Pazdrowski, W., Tomczak, A., 2009: Selected properties of wood in Scots pine (*Pinus sylvestris* L.) growing on post-agricultural land in northern Poland. Forest Research Papers 70: 277–286.
18. Jug, A., Makeschin, F., Rehfuess, K.E., Hofmann-Schielle, C., 1999: Short-rotation plantations of balsam poplars, aspen and willows on former arable land in the Federal Republic of Germany. III. Soil ecological effects. Forest Ecology and Management 121: 85–99.
19. Kaliszewski, A., 2016: National programme for increasing forest cover - status and difficulties in implementation implementation from a local perspective (In Polish). Studia i Materiały CEPL w Rogowie R.18 (48B/5/2016).

20. Kolecka, N., Kozak, J., Kaim, D., Dobosz, M., Ostafin, K., Ostapowicz, K., Wężyk, P., Price, B., 2017: Understanding farmland abandonment in the Polish Carpathians. Applied Geography 88: 62–72.
21. Kollmann, F.F.P., 1968: Physics of wood. Wood Science and Technology 160-291.
22. Kotecký, V., 2015: Contribution of afforestation subsidies policy to climate change adaptation in the Czech Republic. Land Use Policy 47: 112–120.
23. Kozakiewicz, P., Jankowska, A., Mamiński, M., Marciszewska, K., Ciurzycki, W., Tulik, M., 2020: The wood of scots pine (*Pinus sylvestris* L.) from post-agricultural lands has suitable properties for the timber industry. Forests 11: 1–10.
24. Lei, H., Milota, M.R., Gartner, B.L., 1996: Between- and within-tree variation in the anatomy and specific gravity of wood in Oregon white oak (*Quercus garryana* Dougl.). IAWA Journal 17: 445–461.
25. Liepiņš, K., Rieksts-Riekstiņš, J., 2013: Stemwood density of juvenile silver birch trees (*Betula pendula* Roth) from plantations on former farmlands. Baltic Forestry 19: 179–186.
26. Mäkinen, H., Isomäki, A., 2004: Thinning intensity and growth of Scots pine stands in Finland. Forest Ecology and Management 291: 311–325.
27. Meyer, F., 1978: Distribution of ectomycorrhizae in native and man-made forests. Marks G.C., Kozlowski T.T. Ectomycorrhizae. Their ecology and physiology. Pp 79-105, New York, NY. Academic Press.
28. Miezite, O., Dubrovskis, E., Ruba, J., 2017: Tree stem quality and sanitary condition of *Pinus sylvestris* L., *Picea abies* (L.) H. Karst. and *Betula pendula* Roth on afforested agricultural areas. Pp 999-1006, International Multidisciplinary Scientific GeoConference. SGEM, Sofia.
29. Olszewska, M., Smal, H., 2008: The effect of afforestation with Scots pine (*Pinus sylvestris* L.) of sandy post-arable soils on their selected properties. I. Physical and sorptive properties. Plant Soil 305: 157–169.
30. Orczewska, A., Fernes, M., 2011: Migration of herb layer species into the poorest post-agricultural pine woods adjacent to ancient pine forests. Polish Journal of Ecology 59: 75–85
31. Pérez-Harguindeguy, N., Díaz, S., Garnier, E., Lavorel, S., Poorter, H., Jaureguiberry, P., Bret-Harte, M.S., Cornwell, W.K., Craine, J.M., Gurvich, D.E., Urcelay, C., Veneklaas, E.J., Reich, P.B., Poorter, L., Wright, I.J., Ray, P., Enrico, L., Pausas, J.G., De Vos, A.C., Buchmann, N., Funes, G., Quétier, F., Hodgson, J.G., Thompson, K., Morgan, H.D., Ter Steege, H., Van Der Heijden, M.G.A., Sack, L., Blonder, B., Poschlod, P., Vaieretti, M.V., Conti, G., Staver, A.C., Aquino, S., Cornelissen, J.H.C., 2013: New handbook for standardised measurement of plant functional traits worldwide. Australian Journal of Botany 61: 167–234.
32. Post, W.M., Kwon, K.C., 2000: Soil carbon sequestration and land-use change: processes and potential. Global Change Biology 6: 317–327.
33. Přemyslovská, E., Šlezingerová, J., Gandelová, L., 2008: Tree ring width and basic density of wood in different forest types. Pp 140-145, Tree Rings in Archaeology, Climatology and Ecology. Proceedings of the Dendrosymposium 2007, Riga, Latvia.

34. Riesco Munoz, G., Soilán Canas, M., Rodríguez Soalleiro, R., 2008: Physical properties of wood in thinned Scots pines (*Pinus sylvestris* L.) from plantations in northern Spain. Annals of Forest Science 65: 507.
35. Ritter, E., Vesterdal, L., Gundersen, P., 2003: Changes in soil properties after afforestation of former intensively managed soils with oak and Norway spruce. Plant Soil 249: 319–330.
36. Roderick, M.L., Berry, S.L., 2001: Linking wood density with tree growth and environment: a theoretical analysis based on the motion of water. New Phytologist 149: 473–485.
37. Rosenqvist, L., 2007: Afforestation of former arable land in North-Western Europe. PhD dissertation, Uppsala, Sweden.
38. Rytter, L., Lutter, R., 2019: Early growth of different tree species on agricultural land along a latitudinal transect in Sweden. Forestry: An International Journal of Forest Research 93: 376–388.
39. Rytter, R.M. 2016: Afforestation of former agricultural land with *Salicaceae* species - Initial effects on soil organic carbon, mineral nutrients, C: N and pH. Forest Ecology and Management 363: 21–30.
40. Smal, H., Olszewska, M., 2008: The effect of afforestation with Scots pine (*Pinus silvestris* L.) of sandy post-arable soils on their selected properties. II. Reaction, carbon, nitrogen and phosphorus. Plant Soil 305: 171–187.
41. Špulerová, J., Bezák, P., Dobrovodská, M., Lieskovský, J., Štefunková, D., 2017: Traditional agricultural landscapes in Slovakia: why should we preserve them? Landscape Research 42: 891–903.
42. Szwagrzyk, J., 2004: Dynamic and structure of tree stands in Tatra National Park. View project Patterns and drivers of the regeneration processes following catastrophic wind disturbances in forests (In Polish). Sylwan 4: 43–59.
43. Tomczak, A., Jelonek, T., 2013: Radial variation in the wood properties of Scots pine (*Pinus sylvestris* L.) grown on former agricultural soil (In Polish). Leśne Pr Badaw 74: 171–177.
44. Tomczak, A., Tomczak, K., Smarul, N., Rutkowski, K., Wenda, M., Jelonek, T., 2018: The gradient of wood moisture within-stem of sessile oak (*Quercus petraea* (Matt.) Liebl.) in summer. Wood Research 63: 809–820.
45. Vavrčík, H., Gryc, V., 2012: Analysis of the annual ring structure and wood density relations in English oak and sessile oak. Wood Research 57: 573–580.
46. Wiemann, M., Williamson, G., 2002: Geographic variation in wood specific gravity: effects of latitude, temperature, and precipitation. Wood and Fiber Science 34: 96–107.
47. Zeidler, A., Boruvka, V., 2016: Wood density of northern red oak and pedunculate oak grown in former brown coal mine in the Czech Republic. BioResources 11: 9373–9385.
48. Zeidler, A., Borůvka, V., Schönfelder, O., 2017: Comparison of wood quality of Douglas fir and spruce from afforested agricultural land and permanent forest land in the Czech Republic. Forests 9(1): 13.

KAROL TOMCZAK*, ARKADIUSZ TOMCZAK
POZNAŃ UNIVERSITY OF LIFE SCI-ENCES
FACULTY OF FORESTRY AND WOOD TECHNOLOGY
DEPARTMENT OF FOREST UTILIZATION
WOJSKA POLSKIEGO 71A, 60-625 POZNAN
POLAND
*Corresponding author: karol.tomczak@up.poznan.pl

PRZEMYSŁAW MANIA
POZNAŃ UNIVERSITY OF LIFE SCIENCES
FACULTY OF FORESTRY AND WOOD TECHNOLOGY
DEPARTMENT OF WOOD SCIENCE AND THERMAL TECHNICS
WOJSKA POLSKIEGO 38/42, 60-627 POZNAN
POLAND