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QUALITY OF BEECH, BIRCH AND OAK WOOD FROM STANDS GROWING ON POST-AGRICULTURAL LANDS

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ABSTRACT

This study assessed the quality of birch, beech, and oak for timber production on former agricultural land. All sample plots for the selected species had the same forest habitat type. All measured trees had already reached the age of felling. Thus, beech was over 120 years old, birch was over 70 years old, and oak was over 140 years old. On each plot, the same morphological features were measured for all trees: diameter at breast height, tree height, height of the first dead branch, height of the first live branch, and crown base. Based on collected data the length and percentage of the trunk suitable for industrial purposes were calculated. In general birch and beech trees from former agricultural land were higher, but had thinner trunks, when in oak reverse observation were noticed. Tree trunks from former agricultural lands have app. 7% shorter knots-free trunk section. The bigger different between forest and former agricultural land was noticed in case of the oak – 14%, then beech – 5% and birch – 1%. Considering the morphological characteristics of the trees and quality indicators, we showed that all species could be used for the afforestation of former agricultural lands to produce high-quality wood for future industrial purposes. However, it should be noticed, that in general calculated standing volume was lower on former agricultural land.

KEYWORDS:Farmland, agricultural land, wood quality, *Fagus sylvatica*, *Betula pendula*, *Quercus* spp., wood production.

INTRODUCTION

Given the upward trend in demand for wood raw materials, according to FAO (2000, 2022) global wood production increased by about 24%, measures should be taken to increase the production of quality wood. One such measure is the afforestation of former agricultural land (Cukor et al. 2020a, b, Kozakiewicz et al. 2020, Tomczak and Jelonek 2013, Tomczak et al. 2022). Additionally, afforestation of former agricultural lands may be one of the essential solutions to mitigate climate change (Cukor et al. 2022), increase environmental biodiversity

(Rey Benayas and Bullock 2012), increase a country's forest cover (Kaliszewski 2016), and improve the visual qualities of the landscape.

Intensive afforestation on former agricultural land has been observed, especially in the countries of Eastern and Central Europe. In Latvia, forest cover increased from 27% to 50% between 1935 and 2008, mainly through the natural afforestation of former farmland and afforestation of collective farms (Ruskule et al. 2012). In the Czech Republic, forest area has increased from 24% to 34% since the 18th century, with the most extensive afforestation coming after World War II (Holubík et al. 2014, Kozak et al. 2007, Skaloš et al. 2012).

In high-income countries, much farmland has been taken out of use for socio-economic reasons (Tomaz et al. 2013). In 2008 it was estimated (Campbell et al. 2008) that across the whole of Europe approximately 12–13 million hectares of former agricultural land was ready for afforestation. At the beginning of the 21st century, afforestation programmes on former agricultural land were established in many European countries (EC, Directorate-General for Agriculture 2003), including Portugal (Jones et al. 2011, Tomaz et al. 2013), Greece (Arabatzis 2005), Latvia (Nikodemus et al. 2020), Spain (Quinto et al. 2021, Vadell et al. 2016), Czech Republic (Kotecký 2015), Slovakia (Špulerová et al. 2017) and Poland (Szwagrzyk 2004). In Poland from 1945 to 2021 around 1496 thousands ha of agricultural lands not suitable for agricultural production and wasteland were afforested.

Former agricultural land can be afforested using both conifers and hardwoods (Löf et al. 2004, Mosquera-Losada et al. 2018, Vacek et al. 2018). However, the tree species selected for afforestation should have undergone testing in different conditions and exhibit high survival rates (Cogliastro et al. 2003). Compared with conifers, hardwood trees grown on post-agricultural land require greater financial outlays on cultivation and care, mainly because of their stricter habitat requirements (von Althen 1991). For these reasons, former agricultural land is often afforested with fast-growing species, both native (Fahlvik et al. 2021, Hynynen et al. 2010, Lutter et al. 2015, Rytter 2016) and foreign (Jones et al. 2011, Soliño et al. 2018).

Weeding, application of fertilizers, and other agrotechnical treatments can improve soil water quality and lead to the accumulation of organic matter in the soil (Post and Kwon 2000, Smal and Olszewska 2008). The soil history of former agricultural land may impact tree growth, reflected in parameters such as tree height, diameter, and wood volume and quality (Jelonek et al. 2012,2019, Tomczak et al. 2009, Tomczak and Jelonek 2013). Analyses have been made of wood quality and properties, especially in conifers such as Scots pine (*Pinus sylvestris* L.) (Jelonek et al. 2019, Kozakiewicz et al. 2020, Tomczak and Jelonek 2013), Norway spruce (*Piceaabies*(L.) H. Karst.)(Bartoš et al. 2010, Cukor et al., 2020a, Irbe et al. 2015, Zeidler et al. 2017), Douglas fir (*Pseudotsugamenziesii* (Mirb.) Franco) (Cukor et al. 2020b, Zeidler et al. 2017) and European larch (*Larix decidua* Mill.) (Cukor et al. 2020a). Studies of the wood properties of hardwood trees grown on former agricultural land have been made in relation to silver birch (*Betula pendula* Roth.) (Liepiņš and Rieksts-Riekstiņš 2013, Miezite et al. 2017), oak (*Quercuss spp.*) (Tomczak et al. 2022), and grey alder (*Alnus incana* (L.) Moench.) and its hybrid (Aosaar et al. 2011). In forestry practice, morphological features of trunks and crowns are also indicators of wood quality (Malinowski and Wieruszewski 2017). Published data on morphological characteristics primarily concern the height and breast height diameter of conifer model trees. In studies on the quality of conifer wood, more significant differences in growth between trees from former agricultural and forest lands have been observed with respect to diameter, while trees from forest land are characterised by greater height (Bartoš et al. 2010, Cukor et al. 2020a, Jelonek et al. 2019, Tomczak and Jelonek 2013). Cukor et al. (2022) additionally studied the length of trunk without branches, form factor and trunk volume in a mixed stand 14 years after the afforestation of abandoned agricultural land. Characteristics of a young birch stand growing on former agricultural land were measured by Liepinš and Rieksts-Riekstinš (2013). However, those authors did not compare their results with those from similar stands established on permanent forest land.

Knowledge of the characteristics of mature stands that have already reached the age of felling will make it possible to determine appropriate economic indications in the context of maturing stands on former agricultural land. As research to date has mainly focused on coniferous species, we aim to establish whether beech, birch and oak are species suitable for producing high-quality wood on former agricultural lands by checking the hypothesis: *(1)* Agricultural history of land use has an influence on wood quality of growing trees; *(2)* Trees from forest land will characterised by greater diameter, height and trunk length; and *(3)* Trees which grow on former agricultural land characterised by lower wood quality established based on visible trunk defects.

MATERIAL AND METHODS

Site description

The study was carried out in the north-western part of Poland in areas managed by the National State Forests (Tab. 1, Fig. 1).The feature that differentiates the selected areas is their history of use: the selected stands grew on former farmland and on permanent forest land. All sample plots for the selected species had the same forest habitat type, according to Polish classification. All measured trees had already reached the age of felling. Therefore, beech was over 120, birch was over 70 and oak was over 140 years old.

Tab. 1: Localisation of study plots.

Forest district	Species	GPS Coordinates	Forest-site type
Polanów	*Silver birch* Roth.	N 54° 7’ 36.895”,S 16° 40’ 29.871”	fresh mixed coniferous
Bobolice	*Fagus sylvatica* L.	N 53° 57’ 26.61”,S 16° 36’ 0.791”	fresh deciduous
Dobrzany		N 53° 21’ 34.085”, S 15° 25’ 38.308”	
Lipka		N 53° 28’ 53.551”, S 17° 15’ 21.956”	
Pniewy	*Quercus spp.*	N 52° 30’ 21.435”, S 16° 15’ 8.304”	fresh mixed
Oborniki		N 52° 40’ 39.12”, S 16° 47’ 33.084”	

Fig. 1: Location of study plots on the map.

Tree measurements and assessment of wood quality

On each study plot, the same morphological features were measured for all trees. First, the north direction was marked with paint on the trunk of each tree. Tree diameter at breast height ($D_{1.3}$) was measured to an accuracy of 1 cm by the cross-over method, using a Haglöf calliper (Haglöf Sweden AB, Sweden) in the directions north–south ($D_{N\text{-}S}$) and east–west ($D_{E\text{-}W}$), and tree height (H) was measured to an accuracy of 0.5 m using a Suunto PM-5 clinometer (Suunto, Finland).The following trunk and crown characteristics were measured: height of the first dead branch (H_{DB}), height of the first live branch (H_{LB}), and crown base (C_B). Mean diameter at breast height ($D_{1.3}$) was calculated according to Eq. 1 and crown length (C_L) according to Eq. 2:

$$D_{1.3} = (D_{N\text{-}S}+D_{E\text{-}W})/2 \quad [\text{cm}] \quad (1)$$

$$CL= H - C_B \quad [\text{m}] \quad (2)$$

Length and percentage of trunk without branches

Based on the location of the crown base and the height of the lower located branch (F_B), the length (L_w/O_B) and percentage (P_w/O_B) of the trunk suitable for industrial purposes (such as roundwood or pulpwood) were calculated from Eqs. 3 and 4:

$$L_w/O_{\mathbf{B}} = C_B - F_B \quad [\text{m}] \quad (3)$$

$$P_w/O_B. = (L_w/O_B. \times 100)/C_B \quad [\%] \quad (4)$$

Standing volume

The standing volume [m^3/ha] was established based on data collected from the Forest Data Bank (FDB) of Poland (www.bdl.lasy.gov.pl). We generate a stand description for each study plot, and then the selected data about the standing volume and share of each species were collected. The share of each species could be different on different plots, therefore the final volume of examined species was calculated according to Eqs. 5:

$$V_{sv}= (SV_{FBD} \times 100\%)/S_{FDB} \quad [\text{m}^3/\text{ha}] \quad (5)$$

where: V_{sv} – final standing volume, SV_{FDB}- standing volume from FDB, S_{FDB} – share from FDB.

Statistical analysis

To verify the distribution of the data, the Shapiro–Wilk test was performed. The data for all measured morphological characteristics (from 453 trees) and calculated variables led to rejection of the normal distribution hypothesis. To compare non-parametric data, the Mann–Whitney test was performed. Statistical inference was performed at the significance level $\alpha = 0.05$. The RStudio program and R package 4.2.1 (R Core Team 2022, Vienna, Austria) were used to visualize the calculations and data.

RESULTS AND DISCUSSION

Morphological characteristics of trees

In this study, based on selected characteristics, we have compared groups of the three most common hardwood tree species in Poland, growing on permanent forest land and on former agricultural land, to determine whether the history of soil use influenced the final wood quality, and whether these species are suitable to produce high-quality timber on former agricultural land. According to studies by other authors, former agricultural land can be successfully afforested with hardwood tree species, including sycamore maple (*Acer pseudoplatanus* L.) (Vacek et al. 2018), red oak (*Quercus rubra* L.) (Cogliastro et al. 2003), birch (*Betula* spp.) (Mosquera-Losada et al. 2018), European beech (*Fagus sylvatica* L.) (Cukor et al. 2022), European oak (*Quercus robur* L.) (Tomczak et al. 2022) and others. However, most of the cited authors focused on survival rate, stand productivity, tree growth and diameter, or soil transformation on former agricultural land. The trunk quality of trees on former agricultural land was studied only by Cukor et al. (2022), who analysed the shape of the trunk (straight monopodial, curved, deformed) and relative length of the trunk without branches in a 14yearold stand containing both conifer and hardwood species. In our study, the morphological characteristics and quality of mature hardwood stands between 70 and 160 years old were analysed.

Beech trees which grew on former agricultural land were characterised by trunks with smaller diameters at breast height (–2.31 cm), but were slightly taller than trees on FL. The height of the first living branch was very similar on both types of land, while the first dead branch was much higher in trees from forest land (+2.08 m). Around 50% of trees on FA and 70% of trees on FL had no dead branches. Crown bases were lower on FA, and the crowns were longer. Statistically significant differences were observed only in the case of crown length.

Birch trees growing on former agricultural land had smaller diameters (–1.6 cm) and greater heights (+1.8 m) than trees on forest land. The first live branches of trees from FA were located higher on the trunk (+2.98 m) than in the case of trees from FL. The same pattern was observed in the case of the first dead branch. The percentage of birch trees with no dead branches was 10% on former agricultural land and around 8% on forest land. The crown was higher in the case of trees from FA (+1.9 m), but crown lengths were similar on both types of land. Large statistically significant differences in the morphological characteristics of trees from the two types of land were observed in the case of height, the height of the first dead branch, and crown base.

Oak trees on former agricultural land had greater diameters (+5.78 cm) and were slightly taller than trees from forest land. The first live and first dead branches were located higher on trees from FL, respectively at 3.15 m and 2.50 m. We observed dead branches in the case of all measured oaks on FA and on almost 98% of trees from FL. Crowns of trees from former agricultural land were located lower on the trunk (–1.28 m) and were longer (+1.56) than in the case of trees from forest land. Statistically significant differences were observed for all measured variables except tree height (Tab. 1, Figs. 2a-f). A similar finding was reported in the case of an 80–100-year-old pine stand by Tomczak et al. (2009). Jelonek et al. (2019)

observed that old pine trees were thicker and taller in a stand growing on former agricultural land. In the case of oak, the trees on FA were thinner and taller.

Tab. 1: Mean values of measured trees' morphological variables.

Species	Type of land	Diameter [cm]	N	Height [m]	N	H 1st live branch [m]	N	H 1st dead branch [m]	N	Crown base [m]	N	Crown length [m]	N
Beech	FA	55.78	77	28.56	77	7.24	77	6.01	39	13.82	77	14.40	77
Beech	FL	58.09	70	28.30	70	6.84	70	8.10	21	14.46	70	13.64	70
p-value		NS		NS		NS		NS		NS		0.02*	
Birch	FA	28.63	70	25.32	70	14.91	70	11.29	63	16.72	68	8.60	68
Birch	FL	30.24	60	23.52	60	11.93	60	9.50	55	14.83	60	8.69	60
p-value		NS		0.00*		NS		0.00*		NS		0.00*	
Oak	FA	68.98	90	29.14	90	7.17	90	4.56	90	13.14	90	16.00	90
Oak	FL	63.21	86	28.87	86	10.33	86	7.07	84	14.42	86	14.44	86
p-value		0.00*		NS		0.00*		0.00*		0.00*		0.00*	

Note: FA – former agricultural land; FL – forest land; NS – no statistically significant difference; * – statistically significant difference; N- number of measured trees.

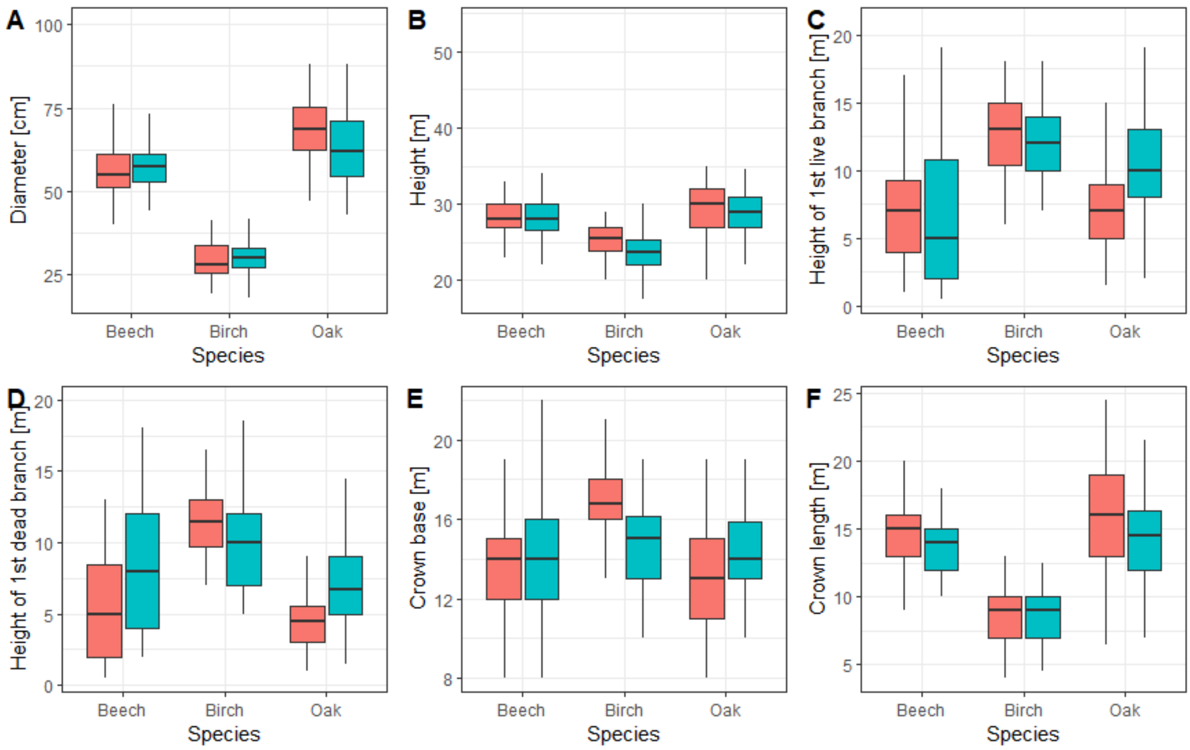

Fig. 2:Descriptive statistics of morphological variables for trees on former agricultural land (red) and forest land (blue). A – diameter; B – height; C – height of first live branch; D – height of first dead branch; E – crown base; F – crown length. Whiskers correspond to minimum and maximum values, boxes represent the 1st and 3rd quartile values, midlines indicate the median.

Length and percentage of trunk without branches and standing volume

According tothe technical documentation for wood classification, the quality class of a single living tree is assigned to the quality of the first few metres of the trunk, where the most important trunk characteristic (in the Polish wood quality classification) is the length of the defect-free section (Order No. 51/2019 of the DG of the State Forests dated 30 Sept 2019 on the Introduction of technical conditions in the turnover of wood raw material in the State forests in Poland (Mark: ZM.800.8.2019). Knots are among the most frequent wood defects, especially in conifer species, affecting the quality of the raw wood and of resulting products or semi-finished products such as sawn timber and veneer (Duchateau et al. 2013, Frayssinhes et al. 2020). Knots cause stress concentrations, and therefore impair the mechanical properties of timber such as MOR or MOE, and reduce wood quality (Baño et al. 2013, Krutul et al. 2013, Rocha et al. 2018, Vek et al. 2014). From a mechanical point of view, the knot's location is also crucial for wood quality. Betts et al. (2010) found that knots located in the compression zone caused a smaller decrease in strength than those located in the tension zone. Based on measured morphological characteristics, the trunk length is free from all types of open knots, which result from the removal of dead and living branches either during tree growth or after logging.

The length of the trunk without branches was shorter for trees from former agricultural land for beech and oak. The difference was more significant for oak (2.45 m) than for beech (1.45 m). Trees on former agricultural land, only about 34% of the length of oak trunks had no branches, compared with approximately 42% for beech. On forest land, oak trunks lacked branches on approximately 48% of their length, compared with around 47% for beech. A longer section of the trunk without branches of birch was observed on former farmland, being greater by 1.02 m than on forest land. However, the percentage of the birch trunk without branches was very similar. Statistically significant differences in the length of the trunk without branches between FA and FL were observed for birch and oak, while in the case of the percentageof the trunk without branches, statistically significant differences were observed only for oak (Tab. 2).

Tab. 2: Descriptive statistics of length and percentage of trunk without branches for trees growing on former agricultural land and forest land.

Length of trunk without branches [m]								
Species	Type	Mean	SD	Min	Max	Q_{25}	Median	Q_{75}
Beech	FA	5.78	3.44	0.50	17.00	2.75	6.00	8.00
Beech	FL	7.22	5.60	0.50	33.00	2.00	6.25	11.00
p-value	NS							
Birch	FA	10.57	2.39	6.00	16.50	8.50	10.50	12.00
Birch	FL	9.55	2.95	5.00	18.00	7.00	10.00	12.00
p-value	0.04*							
Oak	FA	4.39	2.26	1.00	13.00	3.00	4.00	5.00
Oak	FL	6.84	2.98	1.50	14.50	5.00	6.25	9.00
p-value	0.00*							
Percentage of trunk without branches [%]								
Species	Type	Mean	SD	Min	Max	Q25	Median	Q75
Beech	FA	42.39	24.96	4.00	100.00	20.50	43.00	58.50
Beech	FL	47.31	69.00	4.00	100.00	17.00	32.02	39.00
p-value	0.35							
Birch	FA	63.43	13.21	37.00	94.00	53.00	66.00	71.50
Birch	FL	64.47	16.81	26.00	100.00	51.00	67.00	78.50
p-value	0.53							
Oak	FA	33.84	16.01	8.00	87.00	21.00	33.00	42.00
Oak	FL	47.92	20.37	11.00	93.00	33.00	46.50	64.00
p-value	0.00*							

Note: FA – former agricultural land; FL – forest land; NS – no statistically significant difference; * – statistically significant difference; Q_{25} - 1st quartile, Q_{75} 3rd quartile.

We observed a correlation whereby trees with a lower location of the crown base had a shorter knot-free trunk section. We also observed that trunks of beech trees had a lower frequency of dead branches, on both types of land, than the other tree species. This finding is significant for the future use of the wood. A consequence of dead branches is rotten knots. Such knots significantly impact timber quality, causing the weakening of the raw wood material.

The standing volume of selected species on former agricultural and forest was calculated based on forest inventory data from the Forest Data Bank of Poland, FL stands were characterised by higher standing volume in the case of birch and oak species. When it comes to beech the standing volume was higher on FA (Tab. 3). Standing volume is a very important factor in terms of planning forest management, especially wood harvest and future timber trade.

Tab. 3: Comparison of mean standing volume according to Forest Data Bank of Poland [m^3/ha].

	Former agricultural land	Forest land
Birch	226	260
Beech	422	248
Oak	318	468

In this study, the quality of the timber was determined based on morphological characteristics of the tree trunk. This kind of quality estimation in forestry should be confirmed after logging. However, based on the lower location of knots on former agricultural land (beech and oak trees), it can be expected that the quality of wood from this part of the trunk may be lower than that of wood from the trunk of trees growing on forest land. This hypothesis needs to be confirmed in a future study on the structure and properties of hardwood from former agricultural land. In the case of Scots pine wood, Kozakiewicz et al. (2020) showed that the history of land use may significantly impact wood properties, but it is not important from the point of view of the wood industry or for wood quality. According to Tomczak et al. (2022), who examined the quality of oak wood from FA and FL using increment cores drilled out at breast height, similar results should be expected in the case of other hardwood species.

In general, new forests established on former agricultural land are more unstable in comparison to forest lands (Cukor et al. 2019). It caused them more susceptible on rots or wind damages (Cukor et al. 2017, Łakomy and Cieślak 2008). Often rotten wood is located on the trunk, where damages conducted by the game have been already made (Jelonek et al. 2022, Vacek et al. 2022, 2020). Especially in the case of thin bark species such as spruce (Cukor et al. 2020) or beech (Jelonek et al. 2022). Moreover, future climate changes can increase the occurrence of extreme atmospheric phenomena, such as droughts or hurricanes. These factors can lead to insect gradation (Pretzsch et al. 2018, Bílá 2016). All these threats lead to reduced forest productivity in both forested areas and afforested former farmland, which is particularly vulnerable in the first generation.

This study has aimed to evaluate quality (production) effects based on the morphological characteristics of trees and wood quality indicators. The growth conditions of trees on post-agricultural lands affect the physical and mechanical properties of the wood (Tomczak et al. 2022, Kozakiewicz et al. 2020, Tomczak and Jelonek 2013). Since these properties are the best indication of the quality of wood, more experiments concerning such properties are planned in the future. Combined with the present results, this will make it possible to formulate guidelines for sustainable forest management, which final product is high-quality wood for future industry purposes.

CONCLUSIONS

Knowledge of the characteristics of mature stands that have reached the age of felling will make it possible to determine appropriate economic indications in the context of maturing stands on former agricultural land. While research to date has mainly focused on coniferous species, we have shown that beech, birch, and oak are also species suitable for producing high-quality timber on former agricultural land. The quality of the timber was determined based on morphological characteristics of the tree trunk.

This study has evaluated the effects of the agricultural history of the land on quality of birch, beech, and oak wood. In case of productivity in all examined species, trees form former agricultural land were higher, but thinner, than on forest land, except oak trees which were characterised by greater both – diameter and height. Based on the measurements trunk characteristics it can be statement, that beech and oak trunks have better wood quality for future industrial purpose, when birch on former agricultural land is characterised by better quality trunks. However, considering the morphological characteristics of trees and quality indicators, we have shown that all the studied species can be used for afforestation on agricultural land to produce high-quality wood for the wood industry. Examined species require different silvicultural treatments and have different degrees of suitability for the afforestation of agricultural lands. Therefore, future studies included on different habitats and testing mechanical and physical wood properties are needed.

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