European Journal of Forest Research (2020) 139:459–472
https://doi.org/10.1007/s10342-020-01259-7

ORIGINAL PAPER

Comparison of growth and wood quality of Norway spruce and European larch: effect of previous land use

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Received: 20 October 2019 / Revised: 17 December 2019 / Accepted: 23 January 2020 / Published online: 1 February 2020

Abstract

Afforested farmland is a phenomenon of Central Europe. In this study, we evaluate the radial growth of Norway spruce [*Picea abies* (L.) Karst.] and European larch (*Larix decidua* Mill.) in forest stands established on abandoned agricultural land compared to forest stands on standard forest soils. As the quality of wood from such sites is often challenged, we also focused on wood quality of those species. The following characteristics of wood were evaluated: wood density, bending strength, impact bending strength, modulus of elasticity and radial growth in relation to climatic factors. The radial growth of both tree species showed higher radial increment to tree age of 19–23 years on former agricultural land compared to forest land. Norway spruce growing on forest land was significantly ($p<0.05$) more sensitive to climatic factors than on agricultural land (7 significant moths vs. 3 months), while there were low differences in larch. Spruce produced wood with significantly higher density on agricultural land (399 kg m^{-3}), while larch had higher density on forest land (583 kg m^{-3}). In other characteristics, significant differences were found only in the case of larch. Higher values were detected for impact bending strength (4.5 J cm^{-2}) and bending strength (87 MPa) on forest land. The detected differences between wood characteristic were not important for industrial purposes and final usage of the wood. Therefore, afforested agricultural lands provide wood of similar quality and also showed higher resistance in relation to climatic change compared to permanent forest lands.

Keywords Afforestation · Production · Wood density · Bending strength · Climatic factors · Central Europe

Introduction

In the past, the European continent undergone a major transformation of land use (Ellis et al. 2013). The first intensive human-induced changes were due to soil use (Hopcroft 1999; Panagos et al. 2016). In the previous millennia, these changes were particularly evident in terms of considerable deforestation due to the acquisition of agricultural land, pastures, or wood, which was used as a building material or fuel (Williams 2000; Kaplan et al. 2009, 2017). Further growth in human activity and following transformation of natural ecosystems into intensively used agricultural and urbanized land continued over the previous centuries (Ramankutty and Foley 1999; Antrop 2005). A major expansion and intensification of land use in Europe occurred in the last 150 years (Rudel et al. 2009; Jepsen et al. 2015). One of the main reasons was undoubtedly the growing dietary demands of the human population (Goldewijk 2001; Lambin and Meyfroidt 2011). However, in the course of the twentieth century, the opposite trend gradually begun to emerge as well: leaving less profitable agricultural areas (Meyer and Turner 1992). Thus reforestation, especially of mountain or sub-mountain areas, repeatedly became an importance in Europe. The most frequently mentioned reasons for afforestation were the de-intensification of agriculture, possibly due to the complete abandonment of agricultural production and the decline in land use for grazing (Fuchs et al. 2015; Houet et al. 2017).

In Central Europe, the afforestation of abandoned agricultural land has been the largest, whether due to the targeted afforestation or retention of spontaneous succession, after World War II (Kolecka et al. 2017), especially in Slovakia (Bezák and Mitchley 2014; Špulerová et al. 2017), Poland

Communicated by Martina Meincken.

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(Szwagrzyk 2004; Orczewska and Fernes 2011; Kolecka et al. 2017) Romania (Müller et al. 2013), Ukraine (Baumann et al. 2011) and in the Czech Republic (Špulák and Kacálek 2011; Kotecký 2015). The increase in afforestation of former agricultural land as a result of the socio-economic transformation of rural areas in the European Union has continued in recent years. Between 1995 and 2015, 12.9 million hectares of abandoned farmland became afforested, with 1.5 million hectares intentionally afforested (Forest Europe 2015).

Currently, 12–16 million hectares of agricultural production are destined for further afforestation in Europe (Campbell et al. 2008), 385–472 million hectares of abandoned farmland are suitable for afforestation or plantation of fast-growing trees worldwide (FAO 2008; Campbell et al. 2008). Land suitable for afforestation is also located in the Czech Republic. Podrázský et al. (2011) reports that the suitable area for afforestation is ranging from 50,000 to 500,000 hectares. More specific data refer to 350,000 hectares of unused land that could be removed from the agricultural production and afforested (Jarský and Pulkrab 2013). In the case of Czech Republic and in Central Europe in general, abandoned agricultural land was mostly afforested with Norway Spruce [*Picea abies* (L.) Karst.] (Hytönen and Jylhä 2008; Špulák and Kacálek 2011; Irbe et al. 2015; Kotecký 2015) and other tree species like European larch (*Larix decidua* Mill.), black alder [*Alnus glutinosa* (L.) Gaertn.], European ash (*Fraxinus excelsior* L.) and Scots pine (*Pinus sylvestris* L.) (Johansson 2014; Vacek et al. 2016; Hytönen et al. 2017).

Compared to the standard forest land, the afforested agricultural land and forests that were established on agricultural land (especially the first generation of the forest) have considerable specifics. Previously conducted studies of the effects of afforestation of agricultural land focused mainly on soil chemistry, surface humus and production (rapid growth) of newly established crops, or reduction in soil erosion (Hagen-Thorn et al. 2004; von Oheimb et al. 2008; Podrázský et al. 2009; Hatlapatková and Podrázský 2011; Kacálek et al. 2011; Houet et al. 2017). Another aspect of the increase in forest area in Europe is the change in soil carbon stock in recent years, which is strongly influenced by land use (Olofsson et al. 2011; Holubík et al. 2014; Kuemmerle et al. 2015; Cukor et al. 2017; Kaplan et al. 2017). However, sufficient attention has not yet been paid to the quality of wood mass grown on former agricultural land, which may be different due to rapid growth compared to standard forest land.

Wood density, strength and stiffness characteristics are the important indicators of wood quality in terms of the final usage. Very little attention has been paid to this issue in the Czech Republic and neighbouring regions. Sporadic studies on wood quality are available dealing with spruce (Bartoš et al. 2010) or non-native Douglas fir (Zeidler et al. 2017). From Central European region, Polish works on wood quality of trees cultivated on former agricultural land were published in the last few years (Tomczak and Jelonek 2013; Jelonek et al. 2019). However, the studies that would deal with wood quality of larch from afforested agricultural land are missing.

The aim of this work was in general to evaluate the growth and wood quality of Norway spruce, which was the most used species for afforestation of abandoned agricultural land in the area of Sudeten mountains in the 1950s and 1960s (Novák et al. 2009). Established stands were planted as monocultures, possibly with the addition of other tree species such as European larch, which was also evaluated. These stands established on agricultural land after the Second World War are now reaching the rotation age and therefore the knowledge of the wood quality is highly needed not only in the Czech Republic but also in other European countries. The partial aims were to describe the wood density, impact bending strength, bending strength and modulus of elasticity in detail. Part of the research was dedicated to radial growth in relation to climatic factors (temperature, precipitation) due to ongoing global climatic change and subsequent extensive disturbances of coniferous forest stands in Central Europe (Van Der Maaten-Theunissen et al. 2013; Seidl et al. 2017; Vacek et al. 2019b, c).

Materials and methods

Study site

The wood quality and growth samples were taken from forest stands in the northeastern part of the Czech Republic in the Orlické hory Mts. Protected Landscape Area, Natural forest area 25—Orlické hory Mts. These samples were taken from dendromass of Norway spruce and European larch on four permanent research plots (PRPs). Two PRPs are historically typical forest stands and two PRPs represent forest stands on former agricultural lands (one PRP for different historically land use and different tree species) that were afforested after World War II (Fig. 1).

The basic characteristics of the individual PRPs are given in Table 1. The forest site type corresponds to the Czech forest ecosystem classification system (Viewegh et al. 2003). The average annual temperature in the wider area of interest is approximately 6 °C and the annual rainfall ranges from 900 to 1100 mm yr^{-1} with a maximum in August (120 mm). Snow depths range from 30 to 40 cm. The average length of the growing season varies from 120 to 130 days with an average rainfall of about 550 mm and an average temperature of about 11 °C. The area of interest lies in the humid continental climate with hot and humid summers and cold winters

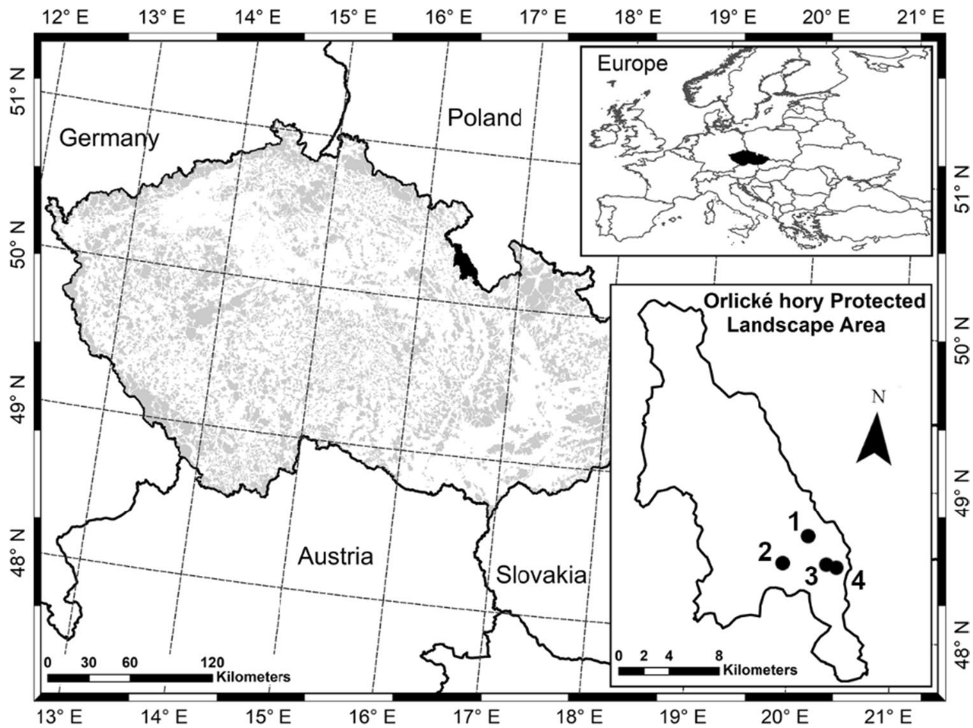

Fig. 1 Location of permanent research plots 1–4 in Orlické hory Mts. Protected Landscape Area

Table 1 Basic characteristics of each forest stands on permanent research plots according to Forest Management Plan

ID	Tree species	Altitude (m a.s.l.)	Age (y)	Land use	Forest site type	Average height (m)	DBH (cm)
1FL	*Larix decidua*	720	68	Forest land	Nutrient-medium Fir-Beech (*Abieto-Fagetum mesotrophicum*)	26	29
2FL	*Norway spruce*	730	67	Forest land	Nutrient-medium Spruce-Beech (*Picceto-Fagetum mesotrophicum*)	23	26
3AL	*Larix decidua*	640	68	Agricultural land	Nutrient-medium Spruce-Beech (*Picceto-Fagetum mesotrophicum*)	29	32
4AL	*Norway spruce*	630	68	Agricultural land	Nutrient-medium Spruce-Beech (*Picceto-Fagetum mesotrophicum*)	27	31

DBH diameter at breast height

(Cfb) according to the Köppen climate classification (Köppen 1936). The prevailing soil type is modal Cryptopodzol and the bedrock is composed mostly of muscovite schists.

Data collection

We cut off a section (100 cm) from trunks of spruce and larch sample trees. The lower part of the section was cut at 20 cm above the ground level. Four dominant individuals of Norway spruce were selected on standard forest site and four on afforested agricultural land. The same methodology was used for European larch. The central board was cut from each section. These boards were used for production of rectangular testing samples 20 × 20 × 300 mm (tangential × radial × longitudinal) for individual test (Fig. 2). The testing samples were conditioned at 20 °C and 65% air humidity to obtain 12% moisture content of wood. From the physical properties, the wood density was tested according to the national standard (ČSN 1993).

From strength and stiffness characteristics, we tested the bending strength, the impact bending strength and modulus of elasticity (MOE) in accordance with following standards (ČSN 1979, 1980, 1982). The number of tested samples according to tree species and previous land use is described in Table 2.

Data for radial growth analysis was obtained by taking 25 cores (including trees used for wood characteristic analysis) per each tree species and land use variant at tree diameter at

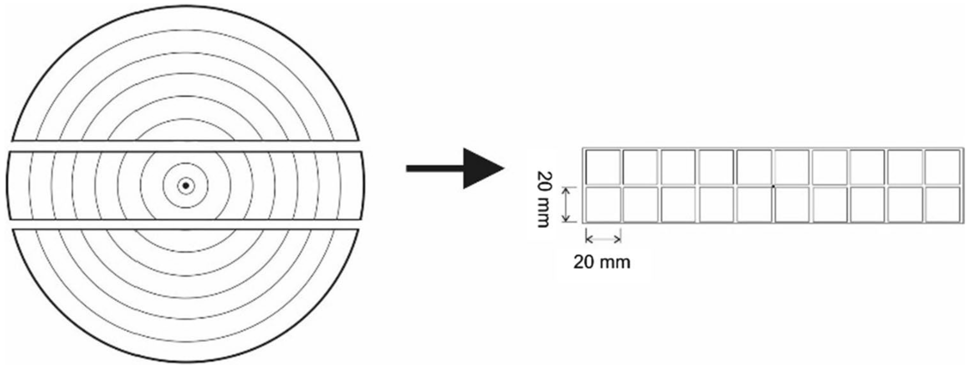

Fig. 2 Schematic diagram for the position of testing samples cut from the centre board

Table 2 The number of tested samples according to tree species and previous land use

Measured characteristics	Norway spruce (N)		European Larch (N)	
	Forest land	Agricultural land	Forest land	Agricultural land
Wood density	348	200	251	226
Bending strength	172	100	125	114
Modulus of elasticity	172	100	125	114
Impact bending strength	175	100	126	112

the breast height (1.3 m) by a Pressler borer (Mora Sweden) from live dominant and co-dominant trees. The core samples were randomly (RNG function in Excel) taken from trees on PRPs in upslope/downslope direction. Annual ring widths were measured with an accuracy to 0.01 mm by an Olympus binocular microscope on the LINTAB measuring table (Rinntech) and recorded with TsapWin software (Registograph).

Data analyses

Tree-ring increment series were individually cross-dated (removal of errors connected with the occurrence of missing tree-rings) using statistical *t* tests in the PAST4 software (Knibbe 2007) and, subsequently, visually checked according to Yamaguchi method (Yamaguchi 1991). Particular curves for PRPs were age detrended and a mean tree-ring series were created in the ARSTAN programme using a 30-year smoothing spline (Grissino-Mayer et al. 1992). The analysis of negative pointer years was conducted according to Schweingruber (Schweingruber et al. 1990). For each tree, the pointer year was tested as an extremely narrow tree-ring that did not reach 40% of the average of increments from four preceding years. The occurrence of a negative year was proved if such a strong increment reduction occurred at least in 20% of trees on the plot. For the modelling of diameter increment in relation to climate characteristics (monthly precipitation and temperature) the DendroClim software was used (Biondi and Waikul 2004). Climate data (1961–2017) were obtained from the meteorological station Deštné v Orlických horách (656 m a.s.l.; GPS 50°18′24″ N, 16°21′07″ E). Climatic data was provided by the Czech Hydrometeorological Institute (CHMI 2017).

Statistical analyses were processed in Statistica 13 (Del Inc., Tulsa). Differences in wood parameters and among tree species and variant of land use were tested by one-way analysis of variance (ANOVA) and significant differences were consequently tested by post hoc comparison Tukey's HSD tests. Significance of statistics was noted as follows: $p > 0.05$, $p < 0.05$, $p < 0.01$ and $p < 0.001$. Situational map was created in ArcGIS 10 (Esri).

Results

Wood density

The previous use of sites proved to have an influence on wood density. There was a significant difference ($p < 0.001$) in wood density between afforested agricultural land and permanent forest land in the case of both tested species. For European larch, the highest value of wood density was obtained for the forest land (583 kg $m^{-3} \pm 63$ SD), for Norway spruce, on the contrary, the afforested agricultural land produced wood of higher density (399 kg $m^{-3} \pm 40$ SD, see Fig. 3). Although the differences in values of wood density between the sites were not so striking and non-important for industrial purposes, the difference between the tested species (irrespective the site) are noticeable.

Bending strength

The origin of site did not have an unambiguous effect on bending strength. There was a significant difference ($p < 0.001$) for the bending strength between the afforested agricultural land and the permanent forest land just for the

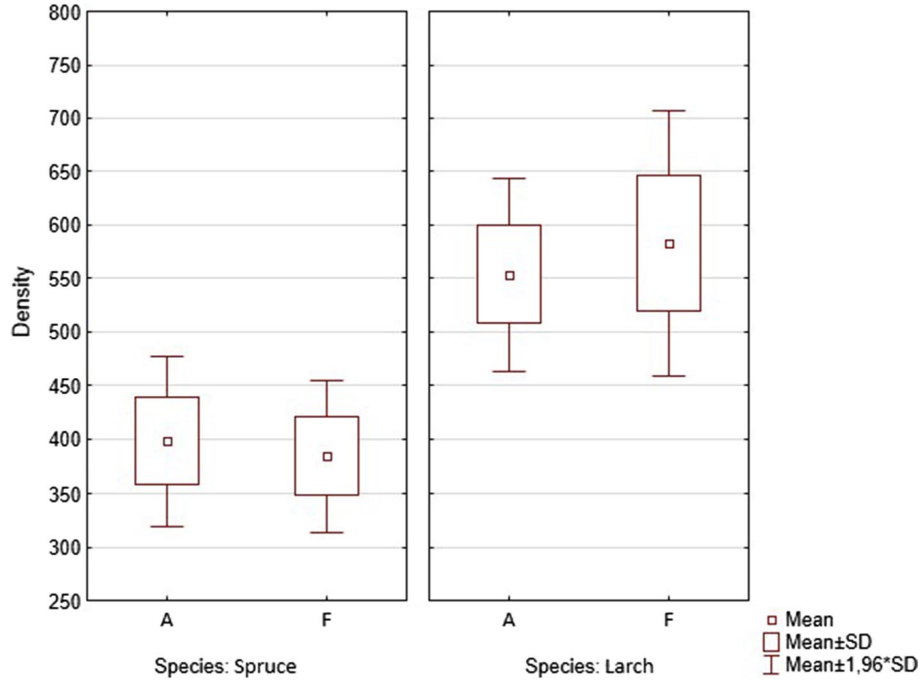

Fig. 3 Influence of site on the density (kg m^{-3}) of spruce and larch wood

larch wood. In the case of Norway spruce, no significant difference was confirmed. For spruce, the highest value of bending strength was obtained for the afforested agricultural land (54 MPa ± 14 SD), for European larch, on the contrary, the forest land produced wood with higher strength (87 MPa ± 21 SD, see Fig. 4). Similarly, as in the case of density, larch provided timber of higher strength compared to spruce regardless the site.

Modulus of elasticity

The origin of site did not play a role in the case of MOE. There was a significant difference ($p < 0.05$) between the species but not between the sites (within the tested species). For spruce, the highest value of MOE was obtained for the afforested agricultural land (6029 MPa ± 1753 SD), for larch, like in the case of the bending strength, the highest value was obtained for the forest land (8418 MPa ± 2562 SD, see

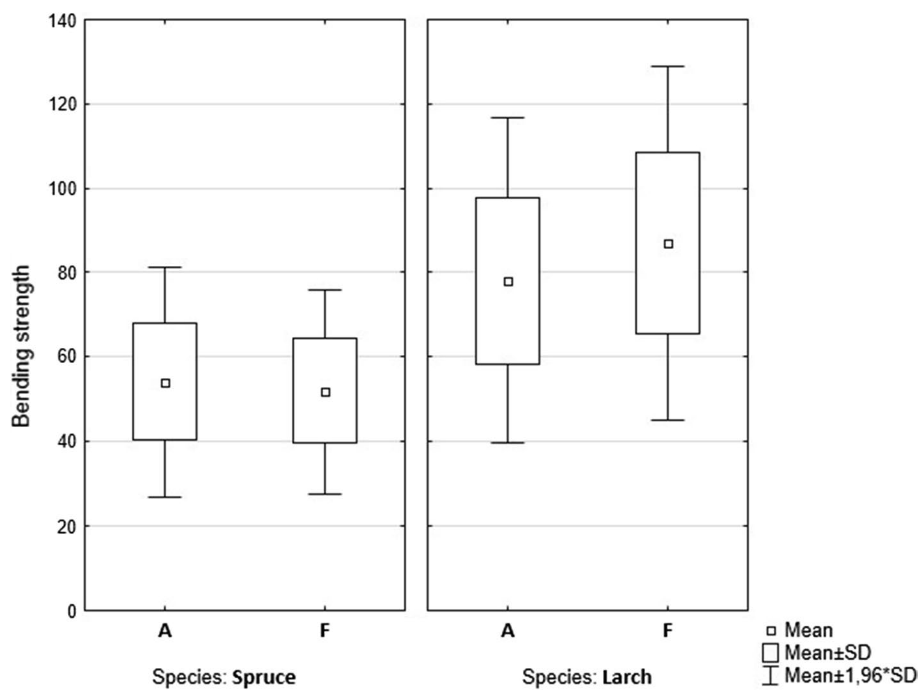

Fig. 4 Influence of site on the bending strength (MPa) of spruce and larch wood

Fig. 5). The reason for such similarity with the bending strength was the close correlation between these strength and stiffness characteristics. Figure 6 shows this dependency between the characteristics in relation to the tested species. The differences between sites were not noticeable. The dependency of the bending strength and MOE on wood density turned out to be less pronounced (spruce $r^2=0.29$ and larch $r^2=0.63$ for the bending strength; spruce $r^2=0.23$ and larch $r^2=0.57$ for MOE) and predictability of those properties, using wood density, is therefore lower. As in the case of density and bending strength, larch wood surpassed spruce wood in stiffness, no matter the origin of the site. It can be also generalized that the correlations between all tested properties were closer in the case of larch wood.

Impact bending strength

The origin of site had an unambiguous effect on the impact bending strength. There was a significant difference ($p<0.05$) for the impact bending strength between the afforested agricultural land and the permanent forest land only for larch wood. Standard forest land provided wood of

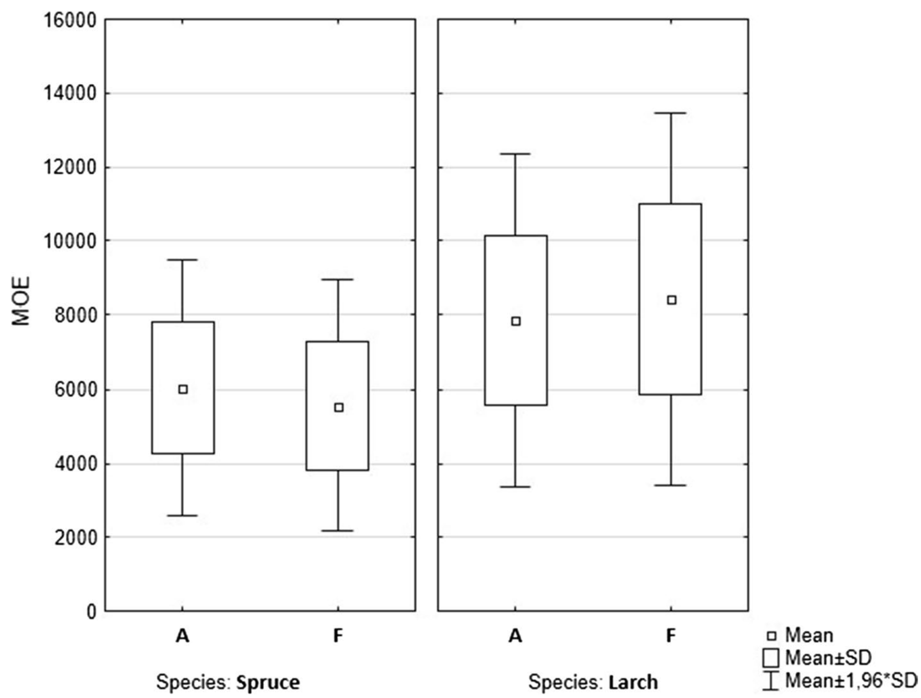

Fig. 5 Influence of site on the modulus of elasticity (MPa) of spruce and larch wood

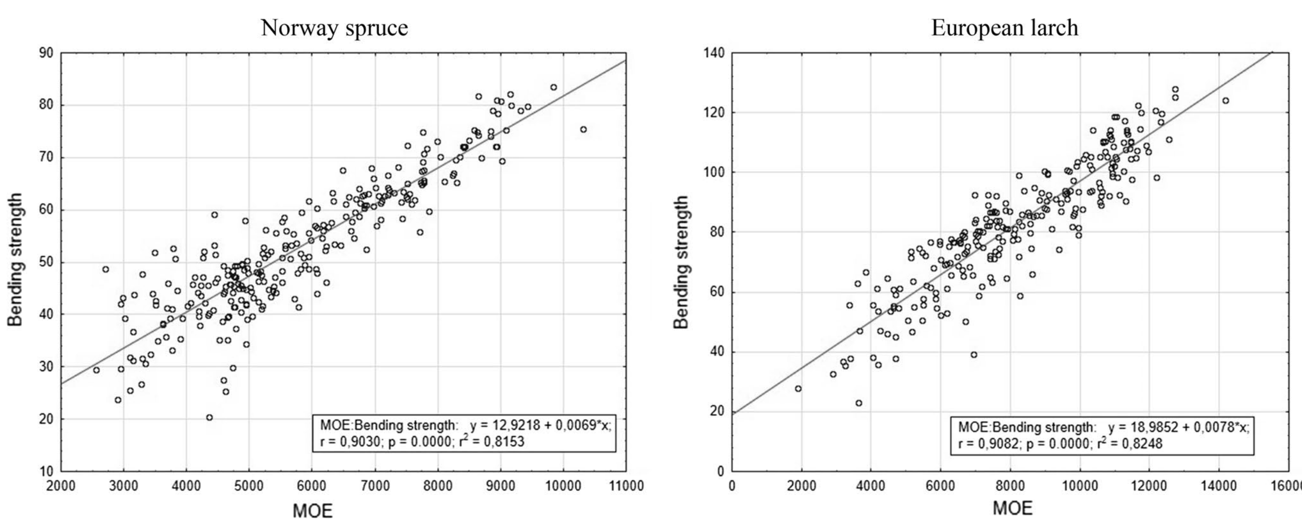

Fig. 6 Correlation between MOE (MPa) and bending strength (MPa) of spruce and larch wood

higher strength in the case of larch (4.5 J $cm^{-2} \pm 1.5$ SD, see Fig. 7). Analogously to the previous properties, larch provided timber of higher strength compared to spruce regardless the site (forest land 2.4 J $cm^{-2} \pm 0.9$ SD, agricultural land 2.4 J $cm^{-2} \pm 1.1$ SD).

Distribution of the tested properties within a stem in direction along stem radius, from the pith to the cambium, was similar for both species. The wood density (Fig. 8) was growing from the centre of the stem (pith) to the outer part (bark). This trend was obvious especially in the case of larch and it was the same for both sites. For spruce, a decrease in wood density was visible for both agricultural and forest land followed by an increase.

Radial growth and impact of climatic factors

The dynamics of radial growth of both tree species showed higher diameter increment to tree age of 19–23 years on

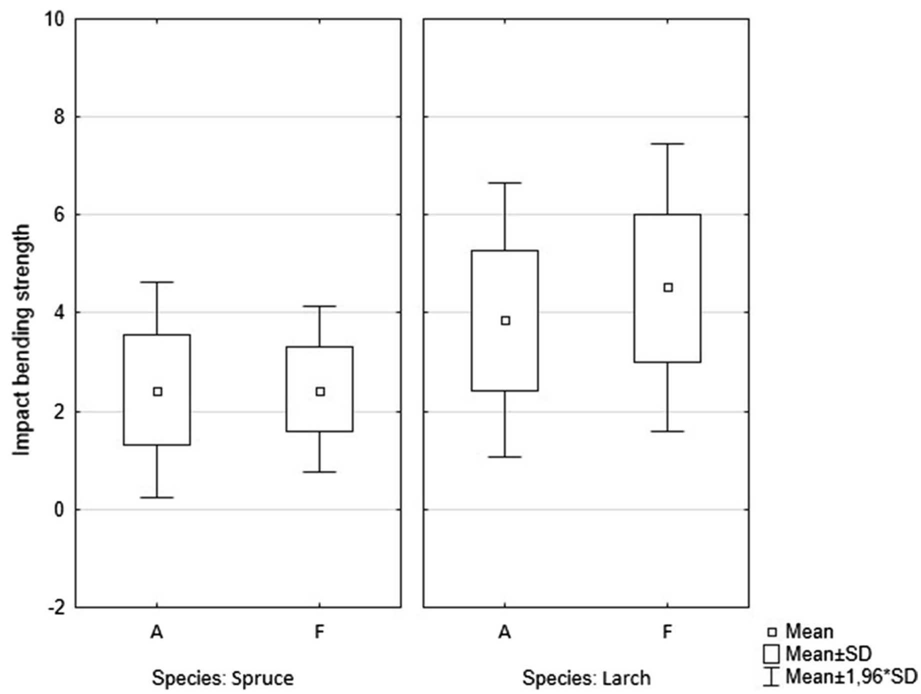

Fig. 7 Influence of site on the impact bending strength (J cm^{-2}) of spruce and larch wood

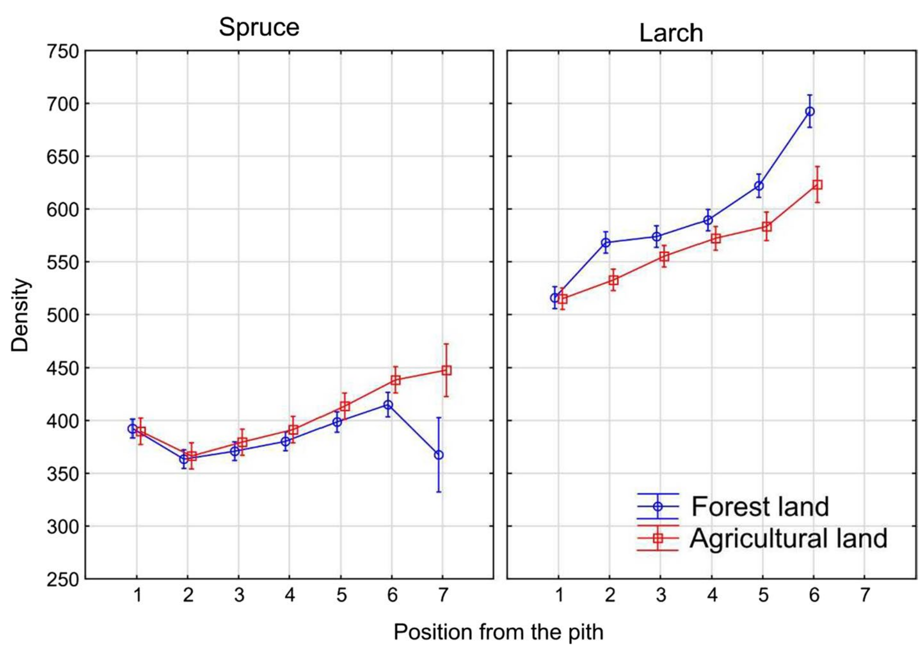

Fig. 8 Distribution of the wood density (kg m^{-3}) in radial direction in the stem of spruce and larch

former agricultural land compared to forest land (Fig. 9). In the next age period, radial growth was relatively balanced or higher on forest land. After initial high diameter increment in the tree growth, fast decrease was observed (5–15 years), especially for larch on forest land. Radial growth of spruce was more balanced compared to larch. In terms of site differences, higher growth variability was observed on forest land (SD ± 0.21 mm) compared to agricultural land in spruce (SD ± 0.14 mm), while similarity in growth variability of larch was observed between sites (forest land SD ± 0.22 mm, agricultural land SD ± 0.24 mm).

The radial dynamics of Norway spruce and European larch showed several significant decreases caused by climatic extremes in 1961–2017, especially in spruce on forest land. Significantly negative year with low radial increment for spruce and larch on forest land was 1988 due to the driest first part of growing season in study period (from April to June sum of precipitation 149 mm, long-term mean 284 mm). Moreover, next significantly negative years were 1976 and 2016 in spruce again on forest land. Year 1976 was characterized by extremely dry growing season (432 mm, long-term mean 624 mm) and year 2016 was the driest year to 2017 (820 mm, long-term mean 1153 mm). On the other hand, no significant years in spruce on agricultural land was observed. In larch on agricultural land, significantly negative year was 2007, when the warmest non-growing season was observed (temperature 3.3 °C, long-term mean − 0.3 °C). Year 2017 for negative year for all variants because of synergism of extreme dry and hot weather.

The climatic factors in 1961–2017 showed significant effect on diameter increment (Fig. 10). The prevailing factor influencing the diameter increment of spruce in study area was temperature. Monthly mean temperature had significantly higher effect on radial growth of spruce compared to the sum of precipitation, while trees growing on forest land were significantly more sensitive to climatic factors

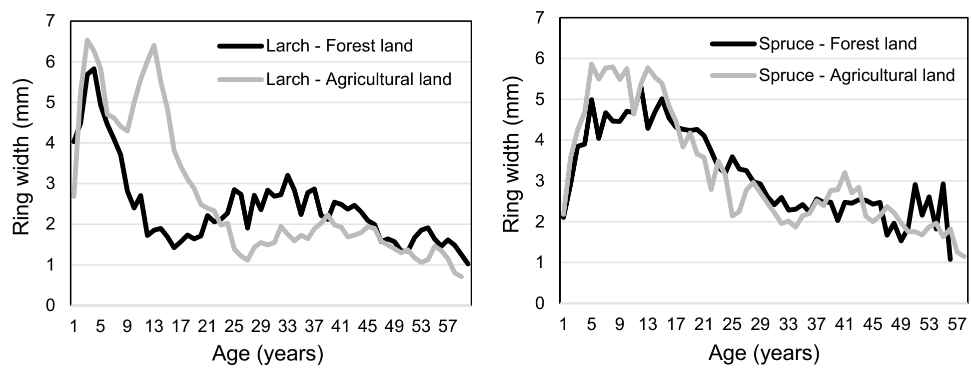

Fig. 9 Annual rings width (mm) of European larch (left) and Norway spruce (right) in relation to historically land use

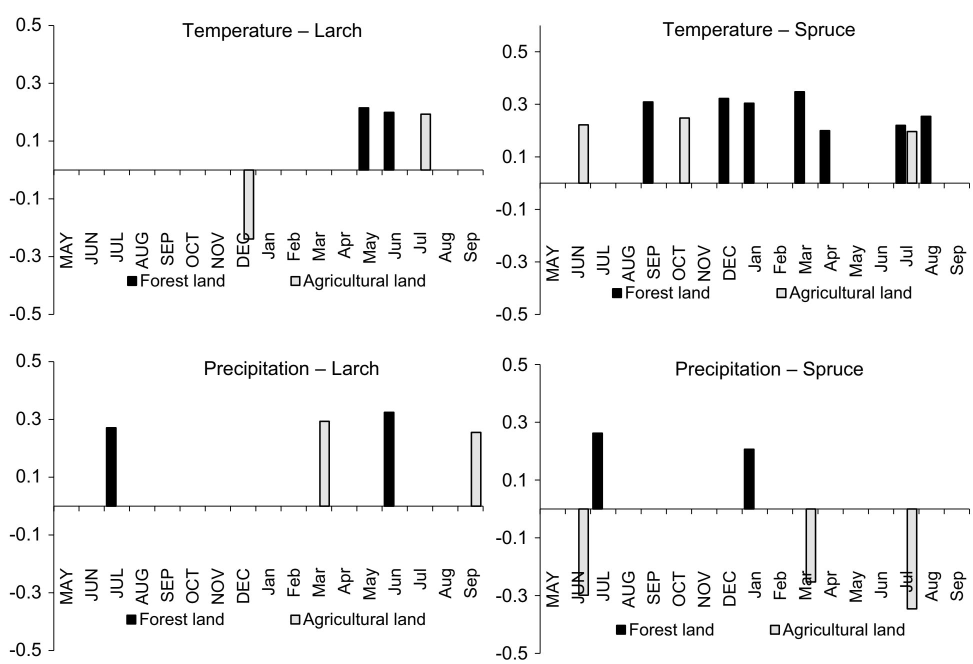

Fig. 10 Correlation coefficients of the regional residual tree-ring index chronology of European larch (left) and Norway spruce (right) with the monthly temperature and precipitation from April to December of the preceding years (capitals) and from January to September of the current year (lower case) on forest land (black colour) and former agricultural land (grey colour) in 1961–2017

($\alpha = 0.05$) than on agricultural land (7 significant moths vs. 3 months). Temperature in March of current year had the highest positive effect on radial increment of spruce on forest land ($r = 0.35$). Temperature in July had positive effect in case of spruce on both sites ($r = 0.20$–0.22). On the contrary in larch, there were no observed differences between sites in relation to effect of climatic factors on radial growth. The temperature from May to June had the prevailing positive effect on radial growth of larch ($r = 0.19$–0.22). Generally, effect of temperature was significantly higher in spruce compared to larch.

Precipitation had low effect on diameter increment compared to temperature in both tree species. The positive effect of precipitation on radial growth of larch was observed in growing season on both sites, especially in June of current year ($r = 0.32$). Conversely in terms of spruce, temperature had the negative effect on radial growth on agricultural land, while low temperature was a limiting factor on forest land. The maximum effect of precipitation on radial growth of spruce was observed in July of current year ($r = -0.35$) and June of previous year ($r = -0.30$).

Discussion

Afforested former agricultural land is often believed to produce timber of lower quality, with low density and strength properties. This idea is supported by several studies (Johansson 1999; Tomczak and Jelonek 2013; Jelonek et al. 2019). This opinion is based on the fact, that former farmland usually contains more nutrition (compared to permanent forest land) because of the previous land use with extensive fertilization of fields. Higher accessible nutrient content is resulting in a vigorous growth of trees used for afforestation, producing wider annual rings and consequently, just in the case of softwoods, lower wood density and related properties of wood. It is a kind of effect very similar to forest stands fertilization (Jaakkola et al. 2006; Cao et al. 2008; Vacek et al. 2019a). However, that bias against wood quality from such sites should not be a rule. There are some studies from Central European region that confirmed comparable quality of wood of different softwoods from former afforested farmlands (Bartoš et al. 2010; Zeidler et al. 2017) for softwoods. The wood from such localities can be of the same quality as the wood from permanent forest land, as was also confirmed by our research conclusions. It is necessary to avoid simplifications since a study of Jelonek et al. (2005) even confirmed higher wood density of timber in the case of Scots pine from former agricultural land.

The values of wood density and bending strength obtained for Norway spruce from afforested farmland were similar to those reported by Bartoš et al. (2010). Research showed that wood density of spruce was higher on afforested area, while for larch it was higher on forest land. Larch is a very shade-intolerant tree species that requires suitable light conditions for growth prosperity (Boratyński 1986; Øyen 2002), and then creates a high proportion of spring wood (Boratyński 1986; Carrer and Urbinati 2006). If a larch is shaded, it slows down its radial growth and creates a higher proportion of late wood (Novák et al. 2011; Wilczyński and Kulej 2013; Vitas 2015), which is denser than spring wood (Boratyński 1986). On the other hand, due to the higher nutrient content in the soil, spruce had a higher production on former agricultural land than on forest land (Cukor et al. 2017). In both cases, the spruces were planted in the same spacing and, due to the higher growth rate, spruce stands on former agricultural land were denser than on forest land (Vacek et al. 2009). The larger canopy thus led to higher wood density (Białobok 1977; Boratyński et al. 1998; Tjoelker et al. 2007).

The trend of distribution of the wood density in radial direction in the stem of spruce and larch was similar for both species. However, in the initial growth phase of spruce, there was a decrease in density, then a gradual increase compared to constant density increase in larch. The highest difference was observed in a significant decrease in wood density of spruce on forest land in last section due to the high nutrient consumption and growth in a relatively dense canopy. There was still a higher proportion of late wood formation on the former agricultural land in the adult growth phase compared to previous growth phases (Białobok 1977; Boratyński et al. 1998) and there was a large amount of nutrients (especially potassium) (Vacek et al. 2009; Hatlapatková and Podrázský 2011; Vopravil et al. 2014), which maintained the ongoing trend of increasing the density of wood compared to forest soils.

The bending strength and stiffness properties were related to density. A high correlation is to be expected and the density is often regarded as a good predictor of mechanical properties (Barnett and Jeronimidis 2003; Dinwoodie 2000). That was the reason why similar distribution was confirmed for the tested mechanical properties in our study. The remaining tested properties were not available for spruce from former agricultural land. Compared to the general literature, they can be regarded as lower. For larch, there are no studies on wood quality available from afforested farmland. When compared to general properties of larch wood, the tested properties were lower in comparison with the literature (Wagenführ 2007).

An important factor is not only the above-mentioned quality of wood, but also the sustainability of wood production, especially in the time of global climate change and forest disturbances (Keenan et al. 2015; Seidl et al. 2017; Marchi et al. 2018). The dynamics of radial growth showed differences between studied tree species and sites. For trees up to approximately 25 years of age, diameter increment was higher on former agricultural land compared to forest land. Similarly, the initially faster growth of spruce on agricultural land was observed in Orlické hory Mts. (Cukor et al. 2019a). Spruce showed two times higher variability in radial growth on forest land compared to agricultural land in time period with ongoing climatic change (calculated for the last 15 years), while only marginal differences were observed between sites with European larch. The initial faster growth and consequently lower growth variability on agricultural land can be explained by the better initial light conditions, higher nutrient availability, favourable physical properties of the topsoil and microbial conditions (Kacálek et al. 2009; Vopravil et al. 2014). Regarding tree species, larch was more fast-growing in initial youth stage compared to spruce, as larch had probably better light conditions in this period on agricultural land than on forest land. In spruce, however, the onset of radial growth at the youngest age was slower and lasted longer and its subsequent decline was not as sharp as in case of larch. These radial growth tendencies (larch and spruce) are influenced by many factors, such as air pollution (Hauck et al. 2012; Král et al. 2015; Vacek et al. 2017), biological properties in terms of intolerance or tolerance to shade, nutrition on forest and agricultural soils in close relation to the root systems, silvicultural management (Remeš et al. 2015; Štefančík et al. 2018), game damage (Gill 1992; Cukor et al. 2019b), insect (Vejpustková and Holuša 2006; Vacek et al. 2015) and by the effect of climate (Białobok 1977; Boratyński et al. 1998; Tjoelker et al. 2007; Bosela et al. 2019; Vacek et al. 2019c).

Specifically, significant effect of climate (temperature, precipitation) on the diameter increment of larch and spruce is in accordance with the results of correlation analyses of numerous other researches (Friedrichs et al. 2009; Králíček et al. 2017; Kukarskih et al. 2018; Guo et al. 2019; Putalová et al. 2019). In our study, Norway spruce showed higher sensitivity to climatic factors and extremes compared to European larch. Moreover, mixing of tree species in the forest stands play important role (Pretzsch et al. 2014; Mina et al. 2018). Vacek et al. (2019c) reported lower growth sensitivity of Norway spruce to climatic factors and air pollution in mixed stands compared to monocultures, similarly to other works documenting stand mixing as positive (Toïgo et al. 2015; Sharma et al. 2017; Vitali et al. 2017).

Dendrochronological analyses also showed several significant decreases in radial growth caused by climatic extremes in 1961–2017 in our study, especially for Norway spruce on forest land. Significantly negative years with low radial increment were observed in spruce 4 times and in larch 3 times. Spruce was sensitive to extreme drought, especially during the growing season. Similarly, negative effect of great lack of precipitation in the growing season and consequently bark beetle feeding enhanced by extreme and more frequent droughts was confirmed in Germany (Van Der Maaten-Theunissen et al. 2013), Poland (Bijak 2011), Russia (Aakala and Kuuluvainen 2011) and also in another Czech Mountain range—e.g. Krkonoše Mts. (Král et al. 2015; Putalová et al. 2019) and Jizerské hory Mts. (Vacek et al. 2019c). European larch on study site was negatively influenced by extremely warm years, especially in non-growing season connected with winter desiccation. Moreover, temperature in March and July had main significant effect on radial growth of larch. Similarly, lack of moisture in winter and spring negatively affected the larch growth in other part of Czech Republic (Vejpustková and Holuša 2006). In the Polar Urals, the most affecting radial growth of larch were temperatures in June and July (Kukarskih et al. 2018). A positive effect of temperatures in these 2 months (as a main indicators of radial growth) was documented for spruce in many other mountains (Büntgen et al. 2007; Rybníček et al. 2010; Treml et al. 2012), such as in our study. It can be explained by the conditions in the period when a great part of radial increment was produced (Putalová et al. 2019). Radial growth of spruce was also positively affected by temperature from December of previous year to April of current year. Generally, spruce was more sensitive to climatic factors and climatic extremes compared to larch, especially on forest land. Spruce can be recommended for afforestation of farmland due to relatively low effect of climatic factors under suitable site conditions (mountains, high-altitude areas). Larch showed only small differences between radial growth on former agricultural land and forest land. However, ongoing global climatic change with warming, more frequent and severe summer droughts, tree growth and vitality will be at risk, especially for spruce with the interaction of bark beetle outbreak (Van Der Maaten-Theunissen et al. 2013; Vacek et al. 2019c).

Conclusions

Afforested former agricultural lands provide wood of similar quality compared to permanent forests lands. In case of Norway spruce wood, there was no difference between the sites in the case of all tested mechanical properties and sites differed just in the case of wood density. For industrial purposes and wood utilization, the differences were negligible, even in the case of wood density. For larch wood, statistically significant differences were confirmed for all tested properties, except for MOE. From this point of view, the standard forest land produces timber of higher quality. It is necessary to say that for industrial purposes and final usage, the differences between values were not important even for the larch wood. In contrast to small differences between sites, the species must be considered. In all of the tested properties, the larch wood obtained higher values and exceeds the most important commercial species in the country—Norway spruce. In case of wood density, the value was almost by 200 kg m^{-3} higher. Moreover, spruce showed higher sensitivity to climate compared to larch, especially on the forest lands. Spruce showed higher resistance to climatic extremes on former agricultural land compared to forest soils. The main limiting factors of growth of spruce was extreme droughts and low temperature in the studied mountain area. Larch showed higher resistance to climatic extremes. In relation to silvicultural management and timber productivity, effect of climatic factors on growth must be considered, especially in the time of ongoing global climate change and disturbances of spruce stands not only in the Czech Republic, but in whole Central Europe.

Acknowledgements This study was supported by the Czech University of Life Sciences in Prague, Faculty of Forestry and Wood Sciences (Excellent Output 2019 and Internal Grant Agency, Project No. B 19/05) and Ministry of Agriculture of the Czech Republic (Project No. QK1910232).

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