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# Condition and productivity of marginal oak and beech plantations in the southern part of the Right Bank Forest Steppe of Ukraine

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## Abstract

The condition and productivity of marginal oak-beech plantations in the conditions of fresh hornbeam grove of the southern part of the Right Bank Forest Steppe of Ukraine, outside the natural habitat of European beech have been studied. It was found that with the observance of agricultural techniques and timely silvicultural care and felling of plantations at the age of 19–20 productive crops are formed with an average height of beech trees 9.2–10.4 m, diameter 11.8–12.7 cm, preservation of 352–386 pieces·ha$^{-1}$, which grow according to I$^{b}$ class of quality. In the studied oak-beech crops of European beech trees lag behind in growth from common oak trees, but according to taxonomic indicators, hornbeam, sharp-leaved maple, birch and heart-leaved linden trees predominate. The prospects of growing of beech in non-range conditions have been established, as it can compete with aboriginal forest species.

**Key words:** average diameter, average heights, crop productivity, European beech, planting composition.

## Introduction

As indicated by Krynytskyy et al. (2017), European beech is one of the main forest-forming species of the Ukrainian Roztochchia. In the forest fund of the region, beech is spread over an area of 12,810 ha (28.4 %). Productivity of beech stands reaches the I quality class, and some of them have I$^{a}$–I$^{b}$ quality. In general, here beech stands are characterized by significant forest-typological potential and biotic resistance, achieve high productivity and are capable of self-reproduction.

According to Myklush and Myklush (2017), European beech forms forest stands mainly in barren forest types (over 85.6 % of the area of lowland beech forest stands), of which 48.8 % of areas are concentrated in the type of forest vegetation

conditions $D_2$ and 39.8 % – in $D_3$. Under conditions of fresh beech, both pure and mixed beech stands are formed, in which 2–4 species are mainly involved, where the participation of beech is three or more units. Under conditions $D_2$, pure and mixed beech forests are characterized by $I^b$–III quality classes.

According to Belous (1962), the condition of beech plantations indicates that in Vinnytsia and Khmelnytskyi regions beech grows successfully in plantation and is not inferior to oak in productivity. Plantation outside the eastern border of the natural range are characterized by good growth and development.

The southern limit of the natural range of forest or European beech (*Fagus sylvatica* L.) is located in the Mediterranean mountain belt to the limit of forest distribution (Cullotta et al. 2016). As indicated by Köcher et al. (2009) and Zang et al. (2014), the species *Fagus sylvatica* is more sensitive to drought than *Quercus petraea* (Matt.) Liebl. and *Q. robur* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Tilia cordata* Mill., *Picea abies* (L.) Karst.

Studies by Berry et al. (2002), Attorre et al. (2008) and Garzón et al. (2008), found that climate change, as indicated by Thomas et al. (2004) and Gessler et al. (2007), threaten the existence of European beech plantations on the southern borders of its range. According to the forecast of Kramer et al. (2010), both the southern and northern boundaries of the distribution of this species will shift to the north in the future.

Marginal peripheral populations of beech are threatened with extinction. These plantations are particularly vulnerable and require constant monitoring, conservation and protection. According to Popadynets (2002), the Podilsk variety of European beech is better adapted to the conditions of a drier continental climate, it is characterized by light-loving, xeromorphic leaf structure and a higher level of photosynthesis.

According to folklore, natural beech plantations used to grow in the Uman region in ancient times. Probably the name of the village Buky comes from them. However, due to intensive deforestation, unsatisfactory natural regeneration and without the creation of artificial plantations, beech forests in our region have gradually disappeared.

The urgency of the research is due to the need to study and make scientifically sound adjustments to the functioning of marginal populations of beech in climate warming and reducing the humidity of air and soil, reproduction of peripheral genetically stable resources of beech in the southern part of the Right Bank Forest Steppe of Ukraine.

The subject of research is the regularities of growth and development of forest beech trees of and aboriginal forest species in marginal artificial oak-beech plantations outside the natural range of beech depending on their species composition and mixing schemes.

The purpose of the study is to study condition and productivity of marginal oak and beech plantations in the conditions of fresh hornbeam wood, to establish the characteristics of the growth of beech, oak, ash and other native species with simultaneous growth in marginal plantations on the southeastern border area of European beech. To confirm or refute the hypothesis under these conditions, beech trees are not inferior in terms of biometric indicators to the trees of aboriginal species of forest species and successfully withstand competition with them, and artificial marginal oak-beech plantations are not inferior in terms of productivity to

native oak stands and are promising for creation in the southern part of the Right Bank Forest Steppe.

## Object and Methods

Object of the study is marginal beech plantations in Synytsia forestry of Uman Forestry State Enterprise. Its geographic coordinates are 48°41′45″ N, 30°4′15″ E.

Uman Forestry State Enterprise is located in the Southern Forest-Steppe Region of the Dnipro Upland on the border with the Northern Steppe. According to long-term observations of Uman meteorological station, the average annual air temperature is 7.6 ºC, the absolute maximum is 36.8 ºC, and the absolute minimum is minus 32.9 ºC. The average rainfall is 508 mm per year, of which 50 % falls during the growing season. Relative humidity is 67 % with a climate coefficient of 0.6–0.7, which indicates an area of insufficient humidity. The growing season is 216 days. Gray forest loam soils predominate.

The research methodology involves the study of hardwood forests and is generally accepted for silvicultural and taxonomic research using general scientific methods of comparison, component analysis and synthesis of data to determine the status and productivity of European beech plantations. Forestry and assessment indicators of 18–19-year-old oak and beech crops were studied on temporary test plots of Synytske Forestry of the state enterprise 'Uman Forestry', which were established in accordance with normative and methodological materials 'Test areas are forested. Method of laying: SOU 02.02-37-476:2006' (Ministry of Agrarian … 2009). In sector 2 of block 93 (Object 1) and sector 1 of block 78 (Object 2), three trial areas were laid out. The researched plantings were created artificially. Rows of beech trees are planted with one-year-old saplings of the Podil variety of the European beech tree. The rows of oak trees are also planted with one-year-old saplings, trees of other types of trees of natural seed and shoot origin. The initial purpose of planting these plantations was to obtain a round forest. However, later, when it turned out that beech plantations are very rare in the research region, their research function was also added. The height of the trees was measured with an eclimemeter-altimeter EV1U1. Measurements of the tree DBH were performed by a measuring fork. Taxation indicators of plantations were determined according to assortment tables. The average diameter was calculated by the sum of the cross-sectional areas of the trunks, the average height of the trees – by the 'height curve'. The quality class was determined by the average age and average height of the forest element in accordance with the quality scale by Orlov (1931).

Statistical processing of research results was performed on a personal computer by the method of analysis of variance according to Dospekhov (1985).

Studies of the condition, composition and productivity of marginal artificial oak and beech plantations were conducted in Object 1 and Object 2 of Synytske Forestry in the conditions of fresh hornbeam grove. The height and diameter of trees of common oak, beech, ash and other species of aboriginal forest tree species were measured on the temporary test plots included in these species, and the stock of plantations was determined. The research was carried out during 2017–2019 in the third decade of April under favourable weather conditions and soil moisture, when the blooming of leaves on tree branches began and shoots began to grow.

## Results

Forest crops in Object 1 were established in 2000 (Fig. 1). Type of forest vegetation conditions – fresh oak ($D_2$). The soil is gray forest and loamy. According to the FAO classification of soil types, they belong to the Podzol group. The category of forest area is a fresh felling. Soil preparation for forestry included lowering stumps on 1.8–2.0 m wide strips to provide proper conditions for tractor operation, removal of cutting residues and branches, autumn tillage and spring cultivation on these strips by KLB-1.7 cultivator.

The method of creating forest crops is mechanized planting. The scheme of planting – 6 × 0.7 m. The scheme of mixing wood species – 3 rows of common oak and 1 row of European beech. Black elderberry (*Sambucus nigra* L.), warty cowberry (*Euonymus verrucosus* Scop.), and hazel (*Corylus avellana* L.) were found in the undergrowth. Undergrowth up to 2.0 m is dense, placed on the square curtains. The living above-ground cover included: violet (*Viola sylvestris* Lam.), European ungulate (*Asarum europaeum* L.), medicinal bush (*Polygonatum officinale* All.), common primrose (*Aegopodium podagraria* L.). It is evenly distributed over the area, liquid. Survey data obtained in 2017 are shown in Table 1.

**Fig. 1. A row of beech trees in Object 1.**

**Table 1. Forest and valuation characteristics of oak and beech crops (2017).**

| Object | Composition of forest stand | Forest | Average height, m | Average diameter, cm | Stock of timber, $m^3 \cdot ha^{-1}$ |
|---|---|---|---|---|---|
| 1 | 48 % oak | oak | 8.4 | 11.6 | 39.1 |
| | 19 % ash | ash | 8.2 | 12.1 | 17.9 |
| | 19 % beech | beech | 7.1 | 11.2 | 13.2 |
| | 9 % maple | maple | 5.1 | 6.6 | 4.8 |
| | less than 5 % (elm, | elm | 6.1 | 9.8 | 4.1 |
| | aspen, | aspen | 5.9 | 7.1 | 3.7 |
| | hornbeam, | hornbeam | 5.5 | 6.7 | 2.9 |
| | little-leaf linden) | little-leaf linden | 4.6 | 7.2 | 0.8 |
| | LSD | | 0.23 | 0.46 | 0.39 |
| 2 | 48 % oak | oak | 9.4 | 11.2 | 31.3 |
| | 19 % beech | beech | 9.0 | 9.4 | 16.7 |
| | 19 % hornbeam | hornbeam | 5.7 | 6.6 | 10.6 |
| | 9 % maple | maple | 6.2 | 6.9 | 3.8 |
| | less than 5 % (ash, | ash | 6.1 | 8.4 | 3.6 |
| | little-leaf linden) | little-leaf linden | 6.1 | 7.2 | 2.1 |
| | LSD | | 0.27 | 0.23 | 0.34 |

Note: LSD – least significant difference.

As it can be seen from Table 1, the average height of common oak trees in Object 1 is 8.4, common ash – 8.2 and beech – 7.1 m. According to analysis of variance,

this indicates a significant advantage and more intensive growth of trees of these two species in compared with beech. However, beech trees have a significantly higher average height than trees of related species: maple, birch, linden, aspen and hornbeam. In terms of average diameter, European beech plants significantly outnumber plants of these species, but have a smaller diameter than plants of common oak and common ash. Moreover, the advantage of ash trees over oak and beech trees is significant, and oak trees over beech trees is not significant.

Composition of plantation is 48 % of common oak, 19 % common ash, 19 % European beech, 9 % Norway maple and less than 5 % of others, such as elm, aspen, common hornbeam, and linden. Relative completeness 0.94 with a tent closure of 1.0. Average increase 5.1 $m^3 \cdot ha^{-1}$, stock 87 $m^3 \cdot ha^{-1}$, including beech – 13.2 $m^3 \cdot ha^{-1}$. The plantation is highly productive, it grows according to $I^b$ class of quality, and currently requires of maintenance felling. Due to the late spring frosts in mid May 2000, some beech seedlings died (supplement made in the spring of 2001 with annual beech seedlings), but today there are 386 $ha^{-1}$ (10.9 % of the plantation) (Fig. 2).

Preservation of trees of the main species – common oak (*Quercus robur*) is satisfactory and is 1034 pieces·$ha^{-1}$ (30 % of plantation).

Sufficient natural seed and vegetative regeneration of ash (*Fraxinus excelsior*), maple (*Acer platanoides* L.), hornbeam (*Carpinus betulus*), linden (*Tilia cordata*), birch (*Ulmus minor* Mill.) and aspen (*Populus tremula* L.) grows in the plantation. On the forest outskirts and near the inter-quarter roads, there are trees of wild fruit species, among which white mulberry (*Morus alba* L.), cherry (*Cerasus avium* (L.) Moench) and plum (*Prunus cerasifera* Ehrh.) predominate. Young 2–3-year-old white mulberry seedlings from these plantations are used by researchers (Vitenko et al. 2019) as rootstocks for growing seedlings of ornamental forms.

The growth of oak, beech and other aboriginal trees can be traced on the graph of the ratio of average height and diameter of trees (Fig. 3).

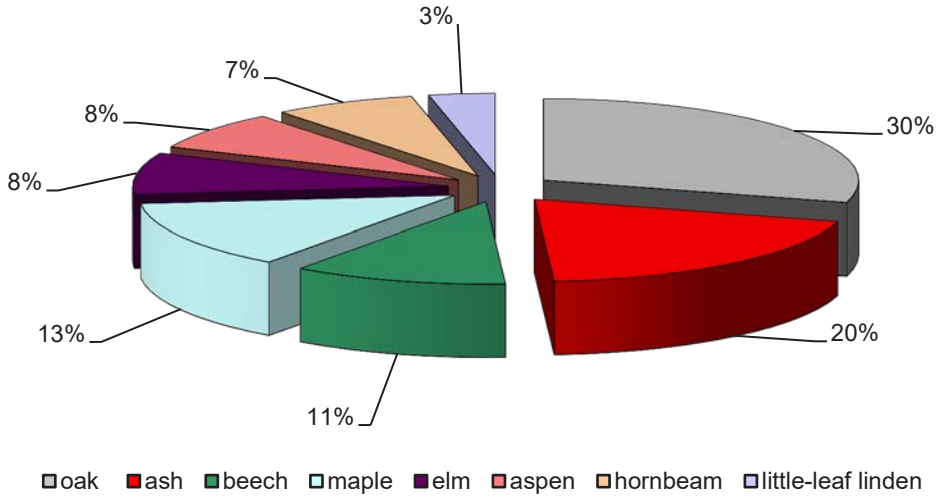


**Fig. 2. The composition of plantation in Object 1.**

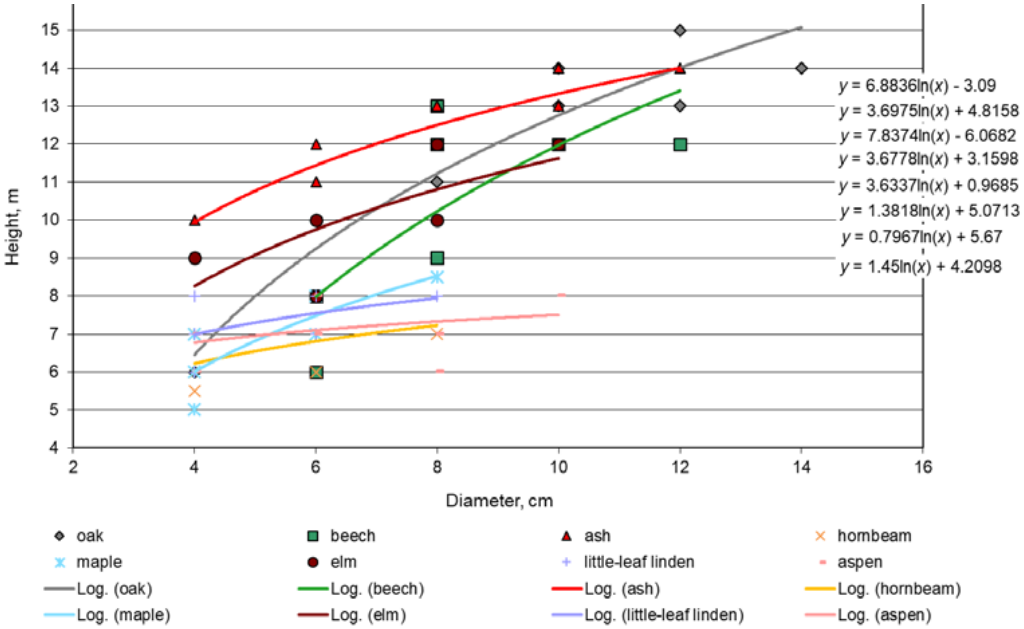


**Fig. 3. The ratio of average height and diameter of trees in Object 1.**

Analyzing the graph of the ratio of average height and diameter of trees, which is shown in Figure 3, it can be concluded that beech trees have a lower growth rate than oak and ash trees, but they are dominated by trees of other aboriginal forest species.

Oak and beech plantations in Object 2 were established in 1999 by planting annual seedlings of common oak and beech according to the mixing scheme – 1 row of common oak and 1 row of European beech. The type of forest vegetation conditions, soils, soil preparation technology on this forest area are the same as on the previous area. As of 2017, it was a highly productive plantation with a 48 % common oak, 19 % European beech, 19 % common hornbeam, 9 % Norway maple and less than 5 % (common ash, linden) with a total stock of 68 $m^3 \cdot ha^{-1}$ and an average increase of 3.8 $m^3 \cdot ha^{-1}$ (Fig. 4). Quality class – $I^a$, relative completeness – 0.77.

**Fig. 4. A row of beech trees in Object 2.**

Undergrowth is almost absent. As shown in Table 1, oak trees have an average height of 9.4 m, beech – 9.0 m, which is significantly (0.4 m) less than the average height of oak trees. The average diameter of beech trees is 9.4 cm, which according to the analysis of variance is significantly smaller (1.8 cm or 16.1 %) than the average diameter of oak trees, which is 11.2 cm. The average diameters of trees of other related species are significantly smaller than oak and beech trees and are 6.6–8.4 cm.

In the undergrowth warty elderberry, black elderberry, blood-red swine (*Swida sanguinea* L.) grow. It is dense, evenly distributed over an area up to 2.0 m high. In the living above-ground cover there are European ungulate, *Corydalis solida* L., medicinal tussock, *Stellaria holostea* L., *Betonica officinalis* L., *Anemone ranunculoides* L.

In Object 2 there are an average of 2546 pieces·ha$^{-1}$ trees, including: oak – 703 and beech – 352 pieces·ha$^{-1}$. From natural regeneration, seed and undergrowth plants of hornbeam – 872, maple – 256, ash – 228 and linden – 135 pieces·ha$^{-1}$ (Fig. 5) were found.

Analyzing the graph of the ratio of average height and diameter of trees (Fig. 6), we can conclude that beech trees have a lower growth rate than oak trees.

Thus, in Object 2 the average height and diameter of beech trees is smaller than that of oak trees, but larger than other species of aboriginal related species: hornbeam, maple, linden and ash. The decrease in the height of trees of related species was due to the maintenance fellings carried out in 2016.

During 2018–2019, similar to 2017, the growth processes of trees of the studied species were observed (Table 2). However, it should be noted that the average height and, especially, the diameter of the beech tree, began to approach oak and ash trees in Object 1 and the oak trees in Object 2. Thus, the first area of beech trees in 2018 on average reached a height of 8.2 m, while oak trees – 9.2 m, ash – 9.1 m. According to analysis of variance, the advantage in height of oak and ash trees over beech trees was significant, and

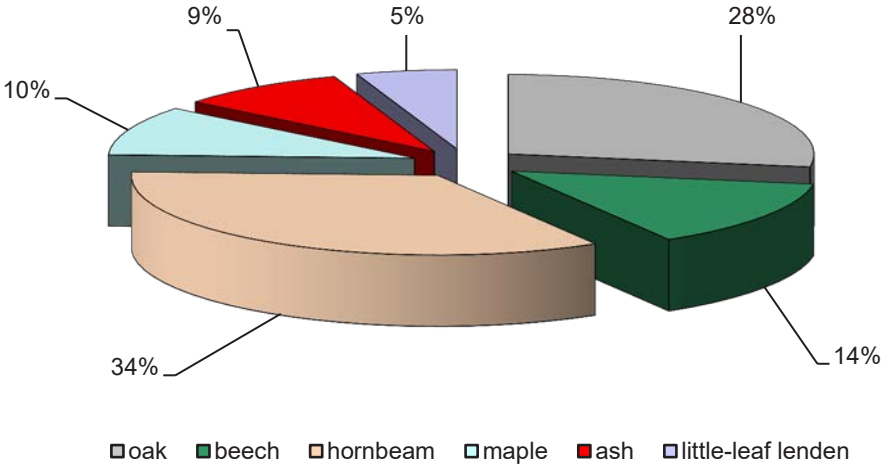


**Fig. 5. The composition of plantation in Object 2.**

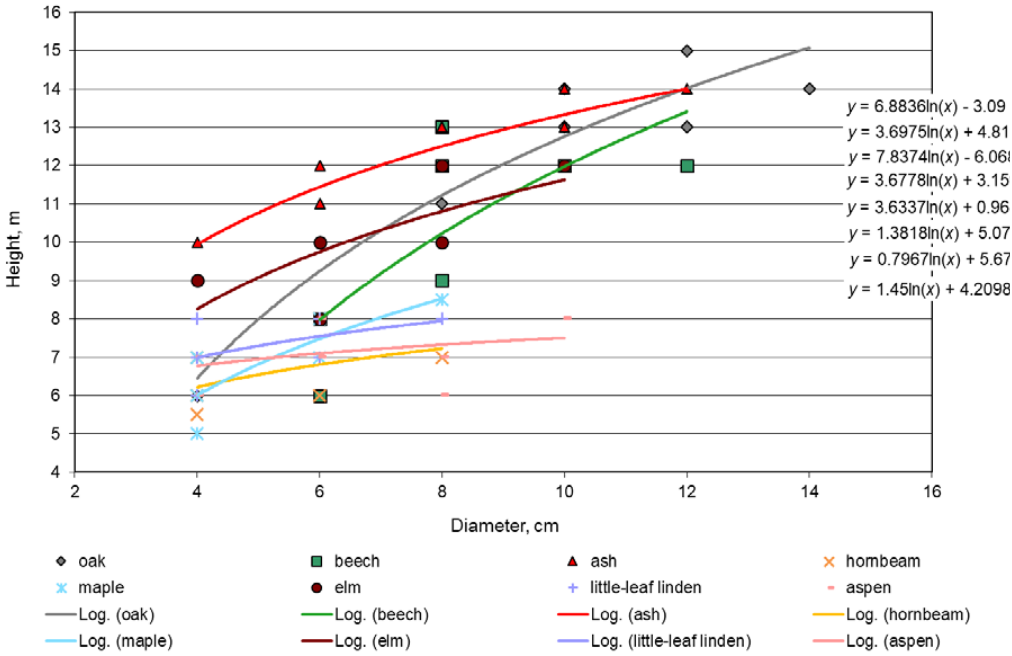


**Fig. 6. The ratio of the average height and diameter of trees in Object 2.**

**Table 2. Average height and diameter of trees in oak and beech crops.**

| Object | Forest | Average height, m | | Average diameter, cm | |
|---|---|---|---|---|---|
| | | 2018 | 2019 | 2018 | 2019 |
| 1 | oak | 9.2 | 10.1 | 12.2 | 12.9 |
| | ash | 9.1 | 9.9 | 12.5 | 13.0 |
| | beech | 8.2 | 9.2 | 11.8 | 12.7 |
| | maple | 6.4 | 7.6 | 7.0 | 7.8 |
| | elm | 6.6 | 7.5 | 10.1 | 10.6 |
| | aspen | 6.6 | 8.0 | 7.7 | 8.7 |
| | hornbeam | 6.5 | 7.7 | 7.5 | 8.1 |
| | little-leaf linden | 5.5 | 6.5 | 8.0 | 8.6 |
| | LSD | 0.24 | 0.25 | 0.19 | 0.21 |
| 2 | oak | 10.0 | 10.8 | 11.9 | 13.1 |
| | beech | 9.5 | 10.4 | 10.2 | 11.8 |
| | hornbeam | 6.4 | 7.4 | 7.1 | 8.5 |
| | maple | 6.7 | 7.7 | 7.4 | 8.7 |
| | ash | 6.6 | 7.9 | 8.8 | 10.2 |
| | little-leaf linden | 6.5 | 7.2 | 7.6 | 8.7 |
| | LSD | 0.09 | 0.21 | 0.14 | 0.23 |

oak trees over ash trees – insignificant, since it was less than LSD (0.24). In 2019, the average height of oak trees was 10.1 m, ash – 9.9 m and significantly exceeded the height of beech trees (9.2 m). The largest average diameter of 12.5 cm in 2018 was in ash trees and significantly exceeded 0.3 cm of oak and 0.7 cm of beech. In 2019, only ash trees significantly outperformed beech trees, and the predominance of oak trees over beech and ash trees over oak was insignificant, as it was less than LSD (0.21). According to the analysis of variance, oak, ash and beech trees had significantly higher trunk height and diameter com-

pared to trees of other forest species in this area.

As it can be seen from Table 2, on the second area of beech trees in 2018 on average reached a height of 9.5 m, which was significantly less than the height of oak trees 10.0 m, but significantly exceeded the average height of trees of other species. The average height of beech tree in 2019 reached 10.4 m and was significantly lower by 0.4 m than the height of oak trees. The results of analysis of variance show that the trees of these two species significantly outperformed the trees of other forest species in Object 2. On average, the largest indicators in 2018 were oak trees – 11.9 cm, which significantly outperformed beech trees (1.7 cm) and other studied species. In 2019, oak trees continued to significantly outperform beech trees (1.3 cm). In addition, the trees of these two species had a significant advantage over the trees of other forest species in this area.

In our opinion, it is impractical to compare the average stock due to the different number of trees of the studied species in the composition of plantations in these species.

## Discussion

Vakulyuk and Samoplavskyi (2006) found that in extra-areal conditions beech can be marked by intensive growth, predominantly aboriginal species. In 104-year-old crops created in fresh oaks of Dzhurynske Forestry of Vinnytsia region, European beech trees had an average height of 30.2 m and an average diameter of 43.4 cm, oak trees – 29.9 m and 42.7 cm, respectively, ash trees – 32.3 m and 43.4 cm. Since the trees of all three species in fresh oak crops in mature age reached approximately the same size, we can conclude that the successful growth of beech in fresh oak outside its natural range.

As established by Myklush and Myklush (2017), the intensity of growth in height of beech stands at different ages is not the same. By the age of 25–30, plain beech stands are mainly characterized by I, less often by II and III quality classes. After 30 years, the intensity of their growth increases and in the age range of 30–80 years, areas where beech is characterized by $I^a$ and higher grades of quality prevail. Pure and mixed young and medieval stands are characterized by similar trends in height, so the average values of quality classes in them are very similar. Up to 40 years, the studied pure and mixed stands are characterized by a similar growth trend in height to normal stands and their average heights do not differ significantly. Not the same intensity of growth in height of beech stands in different age periods also affects their growth in diameter. It is established that the most intensive increase in diameter is observed up to 60 years, when the average increase in diameter of the studied stands reaches 0.52 cm.

According to Gordienko and Gordienko (2005), poor growth of European beech in the first years of life is a widespread phenomenon. The most intensive growth of beech trees in height in natural and artificial plantations of fresh oaks is manifested in the period from 10 to 45 years. In the plains of Ukraine beech shows high biological stability and intensive growth.

According to our research, at a young age (up to 20 years) in artificial plantations created on felling in the conditions of fresh hornbeam grove in the southern part of the Right Bank Forest Steppe of Ukraine, beech trees lag behind in growth from oak and ash, as they suffer from excessive lighting in the first years of life in the open,

but ahead of hornbeam, maple, birch, aspen and linden. Therefore, the results of our research confirm the data on the lower intensity of growth of beech trees under 25–30 years of age under the growth in pure and mixed plantations, previously obtained by Gordienko and Gordienko (2005), Myklush and Myklush (2017) in the conditions of fresh beech both within and outside the natural range of the European beech.

Unfortunately, no mature beech forest stands have been found in the studied area, but in Pashkevych V. V. Arboretum of Sofiyivka National Dendrological Park three mighty trees of ornamental garden forms of beech over 120-years-old grow, which are not inferior to aboriginal forest trees species growing in the same plantation (figs 7 and 8).

All this confirms the hypothesis that in the conditions of fresh hornbeam oak in the southern part of the Right Bank Forest Steppe of Ukraine beech trees are not inferior in average diameter and height to trees of aboriginal varieties of forest species.

**Fig. 7. Three age-old trees of decorative garden forms of beech.**


**Fig. 8. Purple beech tree.**

## Conclusions

Studies have shown that European beech trees successfully grow and develop in artificial marginal plantations in the conditions of fresh hornbeam grove in the southern part of the Right Bank Forest Steppe of Ukraine and compete with oak and other native species.

It was found that with the observance of agricultural techniques and timely silvicultural care and felling of plantations at the age of 17–18, productive oak-beech crops are formed with an average height

of beech trees 7.1–9.0 m, diameter 9.4–11.2 cm, preserved 352–386 pieces·ha$^{-1}$, which grow according to I$^{b}$ class of quality. At the age of 19–20, the average height of beech trees reaches 9.2–10.4 m, diameter 11.8–12.7 cm, the preservation (number) of trees in the plantation does not change, as maintenance felling is not carried out at this time, and natural waste has already ended.

Thus, according to taxonomic indicators in oak-beech plantations, European beech trees lag behind in growth from trees of oak and ash in Object 1 and common oak in Object 2, but are dominated by hornbeam, maple, birch, aspens and lindens. Given the continued sufficient preservation of trees, it can be predicted that the productivity of artificial marginal oak-beech plantations in the studied extra-areal conditions will not be inferior to native oak stands, and beech trees in height and diameter – trees of aboriginal forest species. Therefore, the cultivation of European beech in industrial plantations to obtain round assortments of wood has real prospects, but requires further study as the age of the plantations increases.

A positive solution to this problem will provide an increase in the number of European beech trees not only in arboreta, but also in artificial marginal plantations, which will contribute to the preservation of the beech gene pool and the expansion of biodiversity in the southern part of the Right Bank Forest Steppe of Ukraine.

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