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BIOMETRIC CHARACTERISTICS AND HEALTH STATE OF ENGLISH OAK (*QUERCUS ROBUR* L.) STANDS ESTABLISHED USING VARIOUS STOCK TYPES

SUMMARY

Planting methods and stock quality significantly influence productivity and resilience of future stands. However, there is no consensus on planting practices and stock types to grow resistant English oak (*Quercus robur* L.) stands in various site conditions. In the study, we investigated English oak forest stands established in 2010. The study area is situated in forest-steppe zone (Kharkiv region, Ukraine). The stands were established on a non-uprooted felling site using different methods and stock types: planting bare-root and containerized seedlings and direct sowing of acorns. The highest average height and diameter were registered in 11-year-old oak stand established with container seedlings. The differences in height and diameter were statistically insignificant compared with the stand established by sowing and bare-root seedlings. The best health condition was identified for the direct-seeded stand. The oak height increment intensity in the direct-seeded stand, estimated from the average current height increment, was 2.8% and 5.5% higher than in the stands grown from container and bare-root seedlings, respectively. Direct sowing should be preferred for artificial establishment of oak stands in fresh rich forest sites within the forest-steppe zone in the case sufficient crop of acorns is available no threatened with rodents or wild boars damage. This method is inexpensive and best suited to forest nature. Planting bare-root and containerized seedlings is also relevant in the absence of a sufficient number of germinative acorns for sowing.

Keywords: acorn sowing; bare-root seedlings; container seedlings; current height increment; young stands

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INTRODUCTION

English oak (*Quercus robur* L.) is one of the most common tree species in Ukrainian forests. Oak stands occupy 28% of the total forest area of the country (2.7 million hectares) (Tkach *et al.*, 2019). Oak forest management aims at the cultivation of resilient, highly-productive and long-lived stands.

In Ukrainian forests, oak regeneration occurs both naturally and artificially. The latter way has an advantage due to the periodicity of fruiting of English oak, which is an average of five years (Majboroda, 2010; Prévosto *et al.*, 2015). Artificial regeneration of oak stands is done in two ways, by sowing acorns and planting bare-root or containerized seedlings. Both methods have pros and cons (Thadani, 2008; Zadworny *et al.*, 2014; Prévosto *et al.*, 2015; Löf *et al.*, 2019; Yavorovskiy and Segeda, 2019).

The method of establishing oak stands as well as the stock type and quality influence the productivity, health and resistance of future forests to the adverse impacts of various biotic and abiotic factors.

In Central Europe, due to more favourable climatic conditions, forest management is focused on the regeneration of oak stands by natural seeding or by sowing acorns. At the same time, many studies (Arosa *et al.*, 2015*; Ivetić et al.*, 2016; Stojanović *et al.*, 2017; Grossnickle and MacDonald, 2018) are devoted to the issue of sustainable forest management, which emphasize the need to follow all the prescribed technological processes and operations during artificial reforestation, which are strictly regulated by terms and quality.

Currently, there is no consensus among researchers regarding the methods of establishing artificial oak stands and stock type. Some (Madsen and Löf, 2005; Thadani, 2008; Zadworny *et al.*, 2014; Prévosto *et al.*, 2015; Ostapchuk *et al.*, 2018; Löf *et al.*, 2019) give preference to sowing acorns as a simple, inexpensive and most natural way of regeneration, while others (Hahn, 1982; Bondar and Hordiienko, 2006; Dey *et al.*, 2007; Tarnopilsky *et al.*, 2019; Yavorovskiy and Segeda, 2019) prioritize planting bare-root or containerized seedlings.

This issue is extremely relevant to countries whose oak forests occupy large areas. Proof of that is the study of a research team including scientists from many European countries (Leverkus *et al.*, 2021). In the study, the specificities of oak forests regeneration using various methods have been investigated throughout the European continent, including sowing acorns and planting seedlings.

The aim of the study was to compare biometric characteristics (diameter and height) and the health condition of English oak stands established using different methods and stock types: container and bare-root seedlings and direct sowing of acorns.

MATERIAL AND METHODS

The research was conducted in the oak forest site in north-eastern part of Ukraine (Kharkiv region), within the forest-steppe zone. In the region, deciduous forests predominate, with English oak as the most common forest-forming species. The area of oak-dominated forests is more than 84% of the total forest area. The climate of the study region is temperate continental. The average air temperature varies from + 21 °C in the summer to -7 °C in the winter. The growing season is on average 190 ± 5 days. The average annual rainfall is 492 mm, of which 280 mm falls in the growth season. The height of the snow cover is 18–28 cm (Ecological passport of Kharkiv region, 2021).

Soils are mainly light-textured loam and clay chernozems (Ecological passport of Kharkiv region 2021).

Geographical coordinates of the study site were the following: 50°03′54.0″ N; 36°06′09.0″ E. Growth specificities of planted oaks were studied in three plots with an area of 0.3 hectares each. Acorns were sown in the autumn of 2009; the stands were established in the spring of 2010, after a strip-gradual regeneration felling with 25 m wide felled strips. In the Plot 1 (Acorn treatment), two or three acorns were sown in each seed spot, at spacing of 4.0 × 0.7 m. In the experiment, acorns harvested in the study region were used for planting. Plot 2 (Container treatment) was established by planting one-year-old containerized seedlings with powered hole borer at 4.0 × 1.0 m spacing. In the Plot 3 (Bare-root treatment), oaks were established by planting one-year-old bare-root seedlings using Kolesov's planting iron, at 4.0 × 0.7 m spacing. In all plots, soil was treated in strips with a plough. Weed removal in rows was carried out three times during the first year after the stand establishing, three times in the second year, two times in the third year and once in the fourth year. Shrubs and secondary tree species were removed in space between the rows at the age of three; at the age of seven, a liberation felling with a Stihl brush cutter was made in the stands. The felling was carried out equally and simultaneously in all three plots, so this factor did not have a significant impact on the oak condition. During the liberation felling at the age of seven, one best oak plant was left in each seed spot in Acorn treatment.

Oak trees were surveyed in rows on each plot. In each row, the survey was conducted for 20 linear meters along the diagonal of the plot. The total length of the surveyed rows was 100 m where 100–120 oak trees were measured. The height of the oaks was measured with an accuracy of 1 cm with a special telescopic levelling stuff. Tree diameter was measured with an accuracy of 0.1 cm at a height of 1.3 m using Intertool MT-3015 calliper. The survival of oaks was estimated as the percentage of living oak trees from the number of planted ones.

The current height increment Z (cm) was determined by the formula (1):

$$Z = H_A - H_{A-1} \quad (1)$$

where:

H_A = the stand height in the study year (cm);

H_{A-1} = the stand height in the previous year (cm).

To be able to assess and compare height increment intensity of the stands having different initial parameters (age and average height), we calculated the average current height increment Z_{AVE} (cm) for the relevant observation period by the formula (2):

$$Z_{AVE} = \frac{Z_1+Z_2+\cdots+Z_n}{A} \quad (2)$$

where:

Z_n = current height increment of the relevant year (cm);

A = age of the stand (years).

The height increment intensity was defined as the relative difference in the current height increments between treatments, expressed as a percentage.

We assessed health condition of the trees using six categories (Table 1).

Table 1. Scale used to assess the stand health (Voron *et al*., 2011).

Health condition index range	Stand damage degree	Health status of the stand	Average health condition category
1.00−1.50	None	Healthy trees	1
1.51−2.50	Light	Weakened trees	2
2.51−3.50	Moderate	Severely weakened trees	3
3.51−4.50	Severe	Dying trees	4
4.51−5.00	Very severe	Standing dead trees died over the current year	5
5.01−6.00	Very severe	Standing dead trees died over recent years	6

Stand health condition was described by the health condition index I_c that can be obtained by the formula (3) (Voron *et al*., 2011):

$$I_c = \frac{K_1 n_1 + K_2 n_2 + \cdots \ldots . + K_6 n_6}{N} \quad (3)$$

where:

$K_1 \ldots K_6$ = the category of the health condition of the trees (from 1 to 6);

$n_1 \ldots n_6$ = the number of trees of the given health condition category;

N = the total number of the recorded trees in the sample plot.

Normality tests, one-way analysis of variance (ANOVA), Tukey HSD test with a significance level of $p < 0.05$ were performed for data analyses.

The Box-Cox transformation was used to transform the data to the normal distribution, stabilize group variances and meet the homoscedasticity condition (Hammer *et al*., 2001). The Tukey's pairwise ANOVA (Hammer *et al*., 2001; Delacre *et al*., 2019) was used to find statistically significant differences between the statistical samples of height (Table 2), diameter (Table 3) and current height increment (Table 4) measurements.

RESULTS

Average height of 11-year-old oak stands in different treatments varied within 464–479 cm (Table 2). The height of the stand established with bare-root seedlings was 2% and 3% lower than those established by direct sowing of acorns and using container seedlings, respectively**.**

Table 2. Average height (cm) of oak seedlings for different age and growth conditions.

Treatments	Age (years)						
	1	2	3	6	7	9	11
Acorn	$13.37±0.57^a$	$42.21±0.43^a$	$62.74±2.72^a$	$219.89±5.11^a$	$269.38±6.35^a$	$363.18±8.69^a$	$474.21±6.42^a$
Container	$26.48±0.86^b$	$50.07±0.78^b$	$69.16±2.22^b$	$224.38±4.91^a$	$274.38±8.28^a$	$371.05±8.84^a$	$478.97±5.95^a$
Bare-root (control)	$21.84±0.58^c$	$44.83±0.56^c$	$60.70±2.52^a$	$214.11±2.92^a$	$264.38±5.72^a$	$359.02±8.27^a$	$464.12±7.95^a$
F	97.39	39.47	3.52	1.76	0.52	0.50	1.12
p	< 0.01	< 0.01	0.03	0.18	0.60	0.61	0.33

Values show the mean +/- standard deviation. Different letters in the columns (a, b, c) indicate significant difference between treatments ($p < 0.05$, Tukey's pairwise ANOVA).

The height dynamics in the investigated stands during 11 years of observations are noticeable when estimating their heights in relative values (Table 3). In the first year, direct-seeded oaks were significantly lower in height compared with those in the Bare-root (control) and Container treatments: by 41% and 50%, respectively. For the second year, the difference decreased considerably, to 7% and 16%, respectively, being statistically significant. As the root systems of trees established by sowing acorns had not been damaged during transplanting, the height difference gradually levelled off. Therefore, Table 3 shows that the height increment intensity for oaks in the Acorn treatment is higher than that in the Bare-root and Container treatments. The difference in average heights between the treatments and control decreases with age.

Table 3. English oak stand height in different treatments as a percentage from the control height (Bare-root).

Treatment	Age of stand (years)										
	1	2	3	4	5	6	7	8	9	10	11
Bare-root (control)	100	100	100	100	100	100	100	100	100	100	100
Acorn	59	93	103	103	103	103	102	101	101	101	102
Container	118	111	113	107	105	105	104	104	103	103	103

The oak stand established by sowing acorns had the smallest average diameter (Table 4). The stand established with bare-root seedlings had 5% larger diameter. The stand established with container seedlings had the largest average diameter of 9% greater than that of direct-seeded stand.

The significance of the differences between the average diameters in the Acorn and Container treatments as well as in the Acorn and Bare-root treatments up to the age of nine is explained by the fact that the stand established by sowing acorns was dense before the liberation felling at the age of eight due to the presence of one to three oaks in the same seed spot.

Improvement felling and removal of inferior oak trees promoted intensive tree diameter growth. As a result, in 9–11-year-old stands, the differences between the average diameters in the Acorn and Container treatments and Acorn and Bare-root treatments decreased and became statistically insignificant.

Table 4. Average diameter (cm) of oak seedlings for different age and growth conditions.

Treatments	Age (years)			
	6	7	9	11
Acorn	0.98±0.04[a]	1.46±0.07[a]	2.72±0.12[a]	3.90±1.22[a]
Container	1.43±0.08[b]	2.06±0.10[b]	3.13±0.10[b]	4.28±0.10[b]
Bare-root (control)	1.43±0.05[b]	1.96±0.07[b]	3.03±0.12[a.b]	4.14±0.10[a.b]
F	25.55	18.15	3.57	2.94
p	< 0.01	< 0.01	0.03	0.05

Values show the mean +/- standard deviation. Different letters in the columns (a, b, c) indicate significant difference between treatments ($p < 0.05$, Tukey's pairwise ANOVA).

The lowest current height increment was observed in the oak stands established with seedlings (Container and Bare-root treatments) in the first year, in the so-called root-taking phase, which lasts one or two years. Instead, this variable in the Acorn treatment was significantly higher than in the Container and Bare-root treatments, by 38% and 54%, respectively, because the root systems of the direct-seeded trees were not damaged. A significant decrease in current increment occurred in 3-year-old stands in the dry growing season in 2012 (Table 5).

Table 5. Current height increment (cm) of oak seedlings for different age and growth conditions.

Treatments	Age (years)					
	1	2	3	4	5	6
Acorn	13.37±0.57[a]	28.77±0.72[a]	20.64±0.80[a]	50.00±1.93[a]	67.35±3.31[a]	40.10±1.93[a]
Container	7.65±0.32[b]	25.53±0.62[b]	18.60±0.66[a.b]	48.68±1.75[a]	65.10±3.37[a]	41.30±2.97[a]
Bare-root (control)	6.12±0.35[c]	23.78±1.07[b]	16.00±0.91[b]	48.99±2.00[a]	64.92±2.49[a]	39.23±2.14[a]
F	58.91	9.25	7.32	0.13	0.19	0.16
p	< 0.01	< 0.01	< 0.01	0.87	0.83	0.85

Values show the mean +/- standard deviation. Different letters in the columns (a, b, c) indicate significant difference between treatments ($p < 0.05$, Tukey's pairwise ANOVA).

The highest current growth was observed in 2014 in 5-year-old stands in all experimental treatments, with the maximum in the Acorn treatment (67 cm). In this year, 318 mm of precipitation fell during April–August at a standard amount of 260 mm, i.e. the rainfall was 22% over the normal.

To assess and compare the height increment intensity for the stands with different initial values of age and height, the average current height increment over 11 years of observations was calculated. It was the largest in the Acorn treatment, amounting to 42.8 cm. The value was 2.8% above the Container treatment (41.6 cm) and 5.5% above the Bare-root treatment (40.5 cm).

The health condition of oaks from 2 to 11 years of age was assessed as healthy in all treatments (I_c was between 1.1 and 1.4). The stand condition in the Container and Bare-root treatments was rated as weakened (I_c was 1.6 and 1.7, respectively) only in the first year of establishment due to transplantation and adaptation of seedlings to new growing conditions in the regeneration site. Instead, the condition of the first-year direct-seeded stand was assessed as healthy. The best value of the average health condition index was noted in the Acorn treatment. The indicators were slightly worse in the Container and Bare-root treatments (Figure 1).

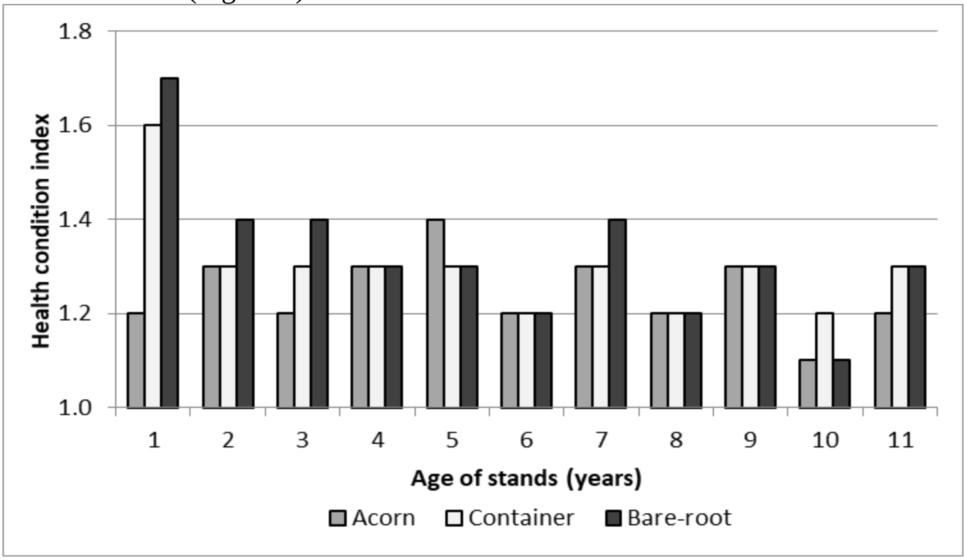

Figure 1. Health condition index of English oak stands.

At the age of seven years, before the liberation felling, the vitality of oaks was the highest (96%) in the treatment established with containerized seedlings. The value was slightly lower (85%) in the stand established with bare-root seedlings and the lowest (81%) in direct-seeded stand.

DISCUSSION

The reforestation technique and the stock type and quality influence the productivity and resistance of future forests to diseases and pests. At the same time, there are different approaches on the establishment of English oak stands in various forest site conditions (Tovstukha *et al.,* 2017; Ostapchuk *et al.,* 2018; Yavorovskiy and Segeda, 2019).

According to Hordiienko *et al.* (2005) and Ostapchuk *et al.* (2018), direct sowing of acorns should be preferred for establishing oak stands in fresh and moist fertile sites. This reforestation method is simple and inexpensive; it is most consistent with the nature of a forest. The cost of sowing acorns is one third lower than the cost of planting seedlings. Such forest stands adapt better to environmental conditions. The root system of oak trees arisen from seeded acorns is not damaged, as there is no need for the transplanting (Hordiienko *et al.,* 2005; Thadani, 2008; Zadworny *et al.,* 2014; Prévosto *et al.,* 2015). Sown oak stands tolerate drought better than those established with seedlings (Zadworny *et al.,* 2014) due to the naturally developed taproot.

Seedlings provides some advantages over acorn sowing, among them evenly spaced seedlings. The seedlings are less suppressed by grass vegetation and undergrowth of other woody plants. The number of necessary interventions decreases and the crowns close faster in such stands established from seedlings (Bondar and Hordiienko, 2006).

Forest stands established with seedlings are less resistant to pests and diseases than those established by direct sowing of acorns because taproots were often damaged during transplantation from a nursery. Such trees are not good in self-pruning, which is then reflected in the technical quality of wood (Rudnev and Rybachok, 1975; Hensiruk, 2002).

One of the ways to increase forest regeneration efficiency is the establishment of forest stands using container-grown stock. This stock type has some advantages, among them the shorter root-taking time, more intense growth and development of plants after replanting on a regeneration site, high survival percentage as a result of minor damage to the roots during transplanting, and ability to plant trees during the entire growing season (Maurer, 2011; Tovstukha *et al.,* 2017; Tarnopilsky *et al.,* 2019; Yavorovskiy and Segeda, 2019).

Among the shortcomings for the cultivation of containerized oak seedlings are additional costs required for the container purchasing and the soil mixture preparing. Furthermore, the roots are often damaged when planting seedlings in the soil, thus weakening plants (Tarnopilskiy *et al.,* 2016; Yavorovskiy and Segeda, 2016). Lyalin (2013) investigating the economic efficiency of container and bare-root English oak seedlings cultivation, has found that containerized seedling growing is 40% more expensive.

Our data are consistent with the findings of Yavorovskiy and Segeda (2019) in Ukrainian Right-Bank Forest-Steppe. They have found that the average height and diameter of 8-year-old oak stands established with containerized seedlings exceeded those of stands established with bare-root seedlings and by sowing acorns. However, the increase for the containerized seedlings was more significant (23 and 43% in height and 20 and 44% in diameter, respectively) than in our study. Survival of container-grown seedlings at the end of the growing season was 98%, bare-root seedlings – 86% and by sowing acorns – 80%.

Instead, in our experiment, 11-year-old English oak stand in the Container treatment had slightly increased average height and diameter as compared with the Bare-root and Acorn treatments; the differences were only 3% and 1% over Bare-root treatment and 5% and 9% over the Acorn treatment, respectively.

Similar results were obtained during the study of forest stands established with container and bare-root stock at different planting densities in another permanent research object within Ukrainian Left-Bank Forest-Steppe (Tarnopilska and Korotych, 2018).

The study showed that 8-year-old oak stands established with container stock were higher than those of the same age established with bare-root seedlings in almost all treatments, regardless of density. The height difference was within 4–26% and the difference in average diameter at breast height was 17–33% (Tarnopilska and Korotych, 2018).

Tovstukha *et al.* (2017) studied the growth of English oak stands aged 6–9 established with various stock types at 10 research plots in Ukrainian Left Bank Forest-Steppe (Sumy region). Oak stands were established on felling sites in fresh rich forest conditions. The study also showed that English oak stands established with container seedlings had a higher vitality (76–87%) compared with those established with bare-root seedlings (56–70%) or direct-seeded. Their crowns closed faster, and they moved to the next phase of stand development earlier. The stands established by sowing acorns had higher growth rate than that of the stands planted with bare-root and container seedlings. We obtained similar results in our study, but with a slightly higher vitality percentage.

In Ukrainian Right-Bank Forest-Steppe, starting from the age of 10, the average height of direct-seeded oak stands was 6–9% higher than that of the stands planted with seedlings (Ostapchuk *et al.*, 2018). The difference in the heights increased over time and varied from 11% to 19% at the age of 68. The productivity of oak stands established by sowing acorns was found to be higher by an average of 17%. The trees in oak stands established by sowing acorns self-prune better; accordingly, they have a better technical quality of wood and are also more resistant to forest diseases (Ostapchuk *et al.*, 2018).

Wilson *et al.* (2007) also indicated higher survival of container red oak seedlings compared to bare-root ones in Ontario (Canada) – 100% vs 75%. In addition, container seedlings reached a greater height during the first growing season. Container-grown seedlings were less stressed during transplanting to the forest area than bare-root ones. This was primarily due to the uninjured root system of seedlings in containers and their greater mass, which contributed to the intensive growth immediately after transplanting. Similar results were obtained by Woolery and Jacobs (2014) in the eastern United States for the growth intensity of containerized and bare-root red oak seedlings and their survival in the first year after transplanting.

The poor man-made oak reforestation by sowing acorns and planting container seedlings was emphasized by Schweitzer and Stanturf (1997) and Dey *et al.* (2006) in the Mississippi River Floodplain for pin oak (*Quercus palustris*

Muenchh.) and swamp white oak (*Quercus bicolor* Willd.). Only 9% of the area was successfully regenerated by these ways (Dey *et al.*, 2006).

The success of oak regeneration in such conditions can be partially improved by planting large seedlings, especially those with well-developed roots. Such criteria are met, in particular, by seedlings grown in containers (Schultz and Thompson, 1997; Kormanik *et al.*, 1998; Stanturf *et al.*, 1998; Gardiner *et al.*, 2002; Johnson *et al.*, 2002).

A comparison of survival rates of 3-year-old stands of *Quercus palustris* Muenchh. and *Quercus bicolor* Willd., established by container and bare-root seedlings, showed that container seedling survival for both oak species was 94% while for bare-root seedlings it was 76% for *Quercus palustris* Muenchh. and 54% for *Quercus bicolor* Willd. In addition, container seedlings of both oak species had higher biometric characteristics (height and root collar diameter) compared to bare-root seedlings (Dey *et al.*, 2006).

However, man-made reforestation using container seedlings is noted to be much more expensive than that with bare-root seedlings or direct seeding of acorns. Also, it requires a longer observation period before it can be recommended as a primary reforestation method in the Mississippi River Floodplain (Dey *et al.* 2006).

CONCLUSIONS

The article considers the growth dynamics (in height, diameter, current height increment and health condition) of oak stands within 11 years after their establishment by sowing acorns and planting bare-root and container-grown stock.

The highest values of height and diameter were recorded in 11-year-old oak stand established with container seedlings as compared with the direct-seeded stand and the stand established with bare-root seedlings.

The height increment intensity for the direct-seeded oak stand, calculated by an average current height increment, was higher than that for the stands established with container and bare-root seedlings.

The health condition index for the English oak stand established by sowing acorns was slightly higher for all the years of observations as compared with the stands established with container and bare-root seedlings.

The revealed features of oak tree growth in forest stands planted using various stock types indicate that direct oak sowing should be preferred for establishing artificial oak stands in fresh rich sites within forest-steppe zone, provided that a sufficient number of acorns is available and there is no threat of damage to acorns from rodents or wild boars. This method is inexpensive and best from biology point of view. Seeding provides high productivity and biological stability of future stands. Planting bare-root and containerized seedlings is also relevant in the absence of a sufficient number of germinative acorns for sowing.

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