Book Chapter

Influence of Soil Substrate on Success of Growing of of English Oak (*Quercus robur*, L.) Seedlings: Key Study in Conditions of Forest-Steppe Ukraine

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Abstract

The topical issues for elaboration of new approaches to grow English oak (*Quercus robur, L.)* seedlings with the purpose to establish sustainable plantations in forest-steppe Ukraine. The goal of the research is to elaborate a technology for growing the containerized seedlings of English oak. Oaks are among the most common tree species found throughout the world. Throughout history, oaks have provided humans and wildlife with shelter, and food. However Ukrainian forests face multiple natural and anthropogenic pressures. Climate change generates a particular threat for Ukrainian forests and stability of agroforestry landscapes. This paper considers the impacts of expected climate change on vulnerability of Ukrainian forests, especially for oaks. In response to forest depletion, stricter forest management practices emerged to replant, protect, and maintain forest cover and the multi-functionality of forests in terms of wood production. Even though oaks have wide ecological amplitudes of suitable growing conditions, Ukrainian forests dominated by oaks often fail to regenerate naturally. In this regard, it is necessary to increase the cultivation of crops in containers. Field germination of oak seedlings in containers with different substrate composition was identified in the case study in the conditions of Ukrainian Left-bank Forest-Steppe. The height and diameter values of the seedlings were investigated and summarized including the influence of the root ball substrate composition. We tested different compositions of the substrate containing low-land peat, which is rich in nutrients and mixtures with different ratios of soil, humus, and sawdust. The advantage over the control in germination ability, survival and condition has been experimentally proved for variants with the use of peat in the substrate and, to a large extent, for the variant with the use of soil, humus, and sawdust. Among tested substrates, the peat-containing variant with equal portions of dark gray wooded middle loamy soil and peat (peat:soil = 1:1) and the variant of the three-component mixture soil:humus:sawdust = 4:2:1 are the most balanced in the basic soil parameters (acidity and nutrient content). At the same time they are the best among the studied ones for the productive growing of English oak seedlings. The use of containerized planting stock allowed foresters not only to significantly extend the terms of forest planting, which is particularly topical for Ukraine, but also to increase the root-taking of planting stock up to nearly 100% in forest-cultivated areas.

Keywords

Ukrainian Forests; Substrate Composition; English Oak; Seedlings in Containers

Introduction

Forests are biologically diverse ecosystems that provide habitat for a multiplicity of plants, animals, and micro-organism. Forest is the largest terrestrial ecosystem in the European Union covering around 40% of the territory and is home to much of the continent’s biodiversity. Forest ecosystems are considered primarily as the main component of the biosphere, capable of stabilizing and restoring its natural balance. Forests of Ukraine are the most powerful factors that stabilize the functional organization of natural ecosystems at a certain level, increase their resistance to human-induced disturbance and climate change [1]. Ukraine belongs to the countries with a relatively low average forest cover, since only 15.9% (9.6 million hectares) of the territory is forested. Ukraine ranks only ninth in Europe by forest area [2]. English oak (*Quercus robur L.*) grows in total on 28% of forest area of Ukraine.

Oaks are among the most common tree species found throughout the world. Throughout history, oaks have provided humans and wildlife with shelter, and food. Growing oak trees on suitable Ukraine sites can provide landowners with soil erosion control, wildlife habitat, and timber. Oaks also take in carbon dioxide and give off oxygen. This process maintains the atmospheric balance so often discussed in conversations about global climatic change. Farkaš and Saniga [3] state that with the increasing frequency of calamities and climatic extremes, the cultivation of oak, which acts as a stabilizer of forest ecosystems, is becoming increasingly important.

Addressing the problems of forest use and reproduction of forests in Ukraine on the principles of sustainable development becomes nationally important.

In the past, the natural habitat for English oak was considerably wider than now. The downward trend in the area of oak stands is observed both in Ukraine and other European countries. The results of the analysis of forest management materials show that during the period of 2000–2010 the area of oak forests of natural seed origin decreased by 20.5 thousand hectares, or by 6% [4] what means 2 thousand hectares per year.

However Ukrainian forests face multiple natural and anthropogenic pressures [4]. Starting from the second half of the 20th century, climate change has brought new threats caused by hotter droughts of historically unprecedented severity, acceleration of natural disturbances, and worsening environment conditions due to air pollution, soil and water contamination [5]. In response to forest depletion, stricter forest management practices emerged to replant, protect, and maintain forest cover and the multi-functionality of forests in terms of wood production. Even though oaks have wide ecological amplitudes of suitable growing conditions, Ukrainian forests dominated by oaks often fail to regenerate naturally.

One of the main problems of reforestation in the context of sustainable development of the forestry is the deficiency of forest planting capacity and quality reforestation. The reproduction, especially artificial, even despite excessive regulation, does not always provide quality regeneration the renewal of biologically stable forest ecosystems, which better approximate the composition and form of the stands of primary forest types [5].

The containerized planting stock production replaces the traditional technology of planting stock production in open ground with a traumatized root system almost everywhere as more technologically sophisticated. The use of containerized planting stock allowed foresters not only to significantly extend the terms of forest planting, which is particularly topical for Ukraine (especially for Steppe and Forest-Steppe zones with short optimal terms for spring planting), but also to increase the root-taking of planting stock up to nearly 100% in forest-cultivated areas [6, 7]. The benefits of containerized planting stock cultivating have been repeatedly proved in numerous publications by domestic and foreign researchers [7-11].

Climate change significantly affects the condition and development of oak stands. A moderate continental climate dominates Ukraine. In the west and northwest, the climate is mild with excessive humidity and mild temperature conditions. The east and southeast are characterized by a lack of precipitation and slightly elevated temperatures. Climate models show that air temperature will increase, and precipitation will change unpredictably throughout the year. Such a development can influence the shift of climatic seasons but also the change in the length of the growing season, shortening the duration of stable snow cover, which has a direct impact on the state and development of forest ecosystems. Ongoing climate change is bringing extremely unpredictable weather events. In the last 30 years, 1355 cases of heavy rains have been recorded in Ukraine. Although their frequency may change from year to year depending on synoptic processes, their number has increased significantly [12]. The occurrence of such meteorological phenomena as dense fog, heavy snowstorms, large hail, stormy winds, showers, and extreme heat is also increasing [5]. Research results show that in Ukraine, the temperature and other meteorological parameters differ more and more from the long-term climate norm. Compared to the years 1961-1990, according to Balabuh [13], the average annual air temperature increased by 0.8 °C in the years 1991-2018 (Figure 1). Changes in maximum and minimum air temperatures were also recorded. The total amount of precipitation does not show such significant changes. However, precipitation decreases in winter, while in autumn it increases slightly [13]. This increases the risk of natural expansion and renewal of oaks. Maintaining its oak appearance is possible by increasing the cultivation of seedlings in containers. The question is what substrates are suitable for this form of cultivation.

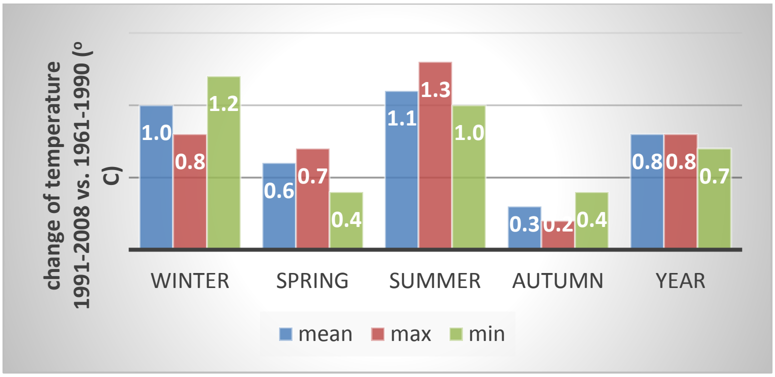

Figure 1: The changes of temperatures (°C) in 1991−2018 years compared to the 1961−1990 (prepared using Balabuh data [13]).

It is well-known that the internal energy of an oak seed, namely the growing power of the germ and enough nutrients in the endosperm, ensures its germination but for the further growth is equally important also the nutritional value of the substrate and its moisture content. Therefore, the aim of our tests was to determine the degree of influence of the container substrate composition on the seed's germination indices and on the qualitative survivability of seedlings during their growing in containers until they are used.

Materials and Methods

In our experiments, we used a rigid container (“ball” type) 160 mm high, 80 mm in average top diameter, with the effective volume of 600 cm^3 (Figure 2). The bottom of each container is perforated with a hole of 4–5 mm in the diameter to remove excessive moisture from atmospheric precipitation. A characteristic feature is that the containerized seedlings were in open test sites with adjusted irrigation three times a week throughout the time of growing.

Figure 2: Individual variants of experiment (a) and a detailed view of containers with oak seedlings (b)

During the cultivation of English oak seedlings in containers in the nurseries of the state forest enterprises of the Kharkiv Regional Department of Forestry and Hunting of the State Forestry Agency of Ukraine, we tested different compositions of the substrate containing low-land peat (Peat), which is rich in nutrients and mixtures with different ratios of soil (S), humus (H) and softwood sawdust (SD). The following variants were tested: 1. Soil (control); 2. Peat:S = 1:1; 3. Peat:S = 1:2; 4. Peat:S = 2:1; 5. Peat:S = 3:1; 6. S:H:SD = 1:1:1; 7. S:H:SD = 2:1:1; 8. S:H:SD = 3:2:1; 9. S:H:SD = 4:2:1.

The Scandinavian technology is taken as a basis for growing the containerized seedlings of English oak. The technology includes automation of all the activities with a view to intensify the process. However, it is obligatory to know the growth characteristics of the containerized seedlings of English oak as well as the development of root system in the limited volume of a cell to use the considered technology. It particularly concerns the sector for elaboration of a sowing device. For the experiment, the acorns were collected in the territory of Chuguevo-Babchan Forest. Average weight of acorn was 5.7 g, length – 29.5 mm, width– 17.3 mm.

Regular method of seeding supposes that an acorn to be planted with a pointed end down or chaotically which is of no high significance for sowing the acorns in the soil of a nursery or on a site. Seeding of the acorns in a container by said method is a different story. In this case, there is no uniform allocation of roots throughout the substrate. Hence, extracting the seedlings out from the container results in the loss of a top of the substrate. It happens because a root collar is located lower the upper part of the container and the plant roots do not hold this part of the substrate (Figure 3a). We developed a new method of acorn planting. It is suggested that the acorns to be planted in a container with the pointed end up and to be embedded at a depth of 1.0 cm from the top of the container (Figure 3b). It makes it possible to form physiologically active roots of the second and third orders from the top to the bottom of the container, to enhance the stability of rootball, and to improve the establishment of plants after replanting them on a site.

The germination (in %) and survival rate (in %) of English oak seeds were evaluated during two-years period (2019-2020). The survival rate was determined in the spring of the year following after sowing. The survival of seedlings in containers was estimated at the end of the 3rd decade of April as the share of survived plants expressed as a percentage of the total number of young seedlings in given variants. The results of testing have been analyzed in accordance with modern research methods [14] and are presented in tables in Result section (Table 1 and 2).

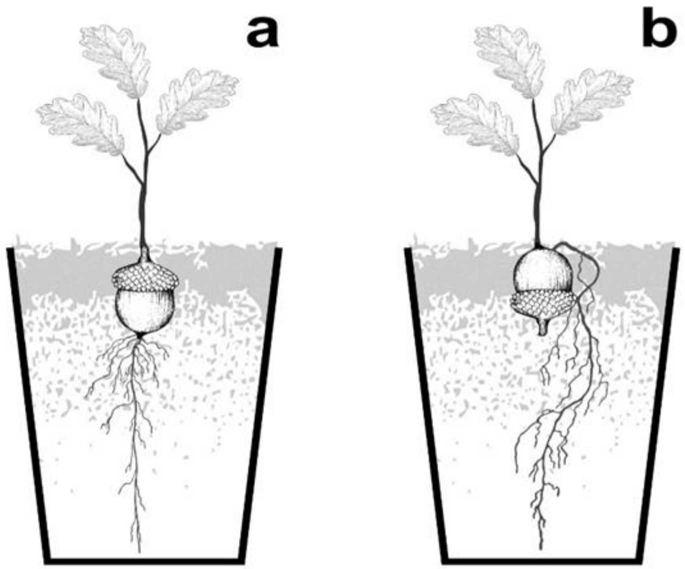

Figure 3: Regular (a) and offered (b) methods of acorn planting

The specimens were determined: the granulometric composition by the pipette method [14]; Humus content according to Tyurin [15]; The content of the general forms of N, P, K (in concentrated sulfuric acid extraction by the Ginzburg method) [16]; The level of acidity is potentiometrically [17].

Field data processing was performed by the method of mathematical statistics using Statistika 6 and Excel 2010. Average values of measured parameters (x), variation (S_x) and degree of significance (t) were evaluated.

Results

It was found that the best significant values of the seed germination percentage, namely 93%, were obtained in the substrate variant with the use of peat. The specified value significantly exceeded the value of the germination ability of the control by 25%.

From the proposed peat-containing variants, the highest germination ability of seeds at the level of 94% was found in the variant Peat:S = 2:1. The value did not differ significantly from the previous variant but distinctly (by 17.4%) and significantly (Peat < 0.01) exceeded the control value.

The lowest germination percentage of oak seeds in both years (69.9% and 71.6 respectively) was identified in the variant of equal parts of soil, humus, and sawdust (S:H:SD = 1:1:1). The most statistically significant degree of significance (t) was demonstrated by variants using peat.

Table 1: Germination of English oak seeds in containers with different substrate composition (in %) - statistical data included.

Variant	Year of study			
	1st		2nd	
	$x \pm S_x$	t	$x \pm S_x$	t
1. Soil (control)	78.1 ± 2.2	-	77.9 ± 2.2	-
2. Peat : S = 1 : 1	85.1 ± 2.1	1.9	92.4 ± 2.3	3.6
3. Peat : S = 1 : 2	82.3 ± 2.3	1.0	84.6 ± 2.1	1.6
4. Peat : S = 2 : 1	92.4 ± 2.3	4.6	93.5 ± 2.2	4.3
5. Peat : S = 3 : 1	91.8 ± 2.2	4.4	97.6 ± 2.4	5.9
6. S : H : SD = 1 : 1 : 1	69.9 ± 2.0	1.8	71.6 ± 1.9	1.6
7. S : H : SD = 2 : 1 : 1	77.9 ± 2.5	0.4	74.6 ± 1.2	0.9
8. S : H : SD = 3 : 2 : 1	81.1 ± 1.9	1.2	80.1 ± 2.3	0.4
9. S : H : SD = 4 : 2 : 1	80.5 ± 2.4	0.8	79.7 ± 2.0	0.3

Notes: t 0.001 = 2.9; t 0.01 = 3.2; t 0.05 = 3.0; t 0.1 = 2.3.
S – soil; H – humus; SD – sawdust.

In all variants, the average value of oak seed germination was 81-83% according to research years, generally confirming the usability of the substrates and the chosen technology.

A comparison of the two-year average data on the oak seed germination in the substrate variants shows that germination percentage was 87% for using substrates containing peat and while it was 74% for the substrates with contents of such constituents as soil – humus – sawdust (Figure 4).

The germination percentage for oak seeds in the variant of H:S = 1:1 was significantly higher than in the variant where the peat was one-third of the substrate mass (83 and 80%, respectively). A further increase of the peat content in the substrate (up to two-thirds) has resulted in an increase in the seeds germination. This index was 94%, that is, it had the highest value of all variants, with the exception of the 5 variants. Due to the high cost of peat, if added in the specified amount, this variant is not economically lucrative.

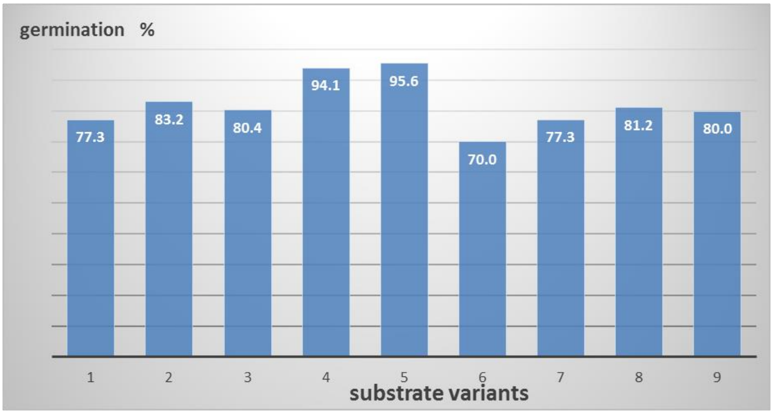

Figure 4: Average germination percentage of English oak seeds in containers with different substrate composition Variants: 1. Soil (control); 2. Peat:S = 1:1; 3. Peat:S = 1:2; 4. Peat:S = 2:1; 5. Peat:S = 3:1; 6. S:H:SD = 1:1:1; 7. S:H:SD = 2:1: 1; 8. S:H:SD = 3:2:1; 9. S:H:SD = 4:2:1 (P – peat; S – soil; H – humus; SD – sawdust).

Among variants with humus and sawdust in the substrate composition, the seed germination percentage was the lowest (in both observed years 58.3% and 62.4% respectively) in the variant of S:H:SD = 1:1:1. This value has insignificantly been smaller than that for the control (soil) and for the three-component mixture S:H:SD = 2:1:1. The most statistically significant degree of significance (t) was demonstrated by variants using peat and soil:humus:sawdust.

The results of survival rate of English oak seedling and its statistical data are presented in Table 2.

Table 2: Survival rate of English oak seedlings in containers with different substrate composition (in %) – statistical data included.

Variant	**Year of study**			
	1st		**2nd**	
	$x \pm S_x$	*t*	$x \pm S_x$	*t*
1. Soil (control)	78.3 ± 7.1	-	81.6 ± 7.8	-
2. Peat : S = 1 : 1	68.6 ± 5.9	2.2	70.2 ± 6.7	2.7
3. Peat : S = 1 : 2	72.5 ± 6.2	1.3	77.6 ± 6.9	1.0
4. Peat : S = 2 : 1	59.2 ± 5.0	4.1	61.6 ± 6.0	4.4
5. Peat : S = 3 : 1	79.1 ± 6.7	0.2	80.7 ± 7.6	0.2
6. S : H : SD = 1 : 1 : 1	58.3 ± 4.2	4.3	62.4 ± 5.6	4.3
7. S : H : SD = 2 : 1 : 1	59.4 ± 4.8	4.1	62.6 ± 6.8	4.2
8. S : H : SD = 3 : 2 : 1	66.8 ± 7.0	2.6	75.6 ± 7.5	1.5
9. S : H : SD = 4 : 2 : 1	71.3 ± 6.9	1.6	73.8 ± 6.7	1.9

Notes: t 0.001 = 2.9; t 0.01 = 3.2; t 0.05 = 3.0; t 0.1 = 2.3.
S – soil; H – humus; SD – sawdust.

The survival rate of seedlings during the growing in containers was 58-68% on average in the years of research, respectively. The increase in the value over the years has been also noted in the control and in all variants of the experiment and could be explained by specific experience gained in the growing of seedlings in containers.

In all years of the experiments, the highest seedling survival rate (on average 80.2%) was obtained when using a grey forest middle loamy soil as a substrate (the control). Both in some years and on average, the values of seedling survival in control insignificantly exceeded the values in the 5 variants (an average of 81.1%).
The average value of the survival rate was 66% in the peat variants (70%, considering the 5 variants) and 64% in variants using humus and sawdust.

Among peat in a mixture with soil variants, the highest survival rate of seedlings (74.5%) was found for Peat:S = 1:2 ratio of the mixture components. Increasing the peat proportion in the mixture up to 65% (Peat:S = 2:1) resulted in the seedling survival rate being even 17.6% less than that in variant using

Peat:S = 1:1 mixture, where this value was 6.3% lower than in the previous variant (Peat:S = 1:2) (Figure 5).

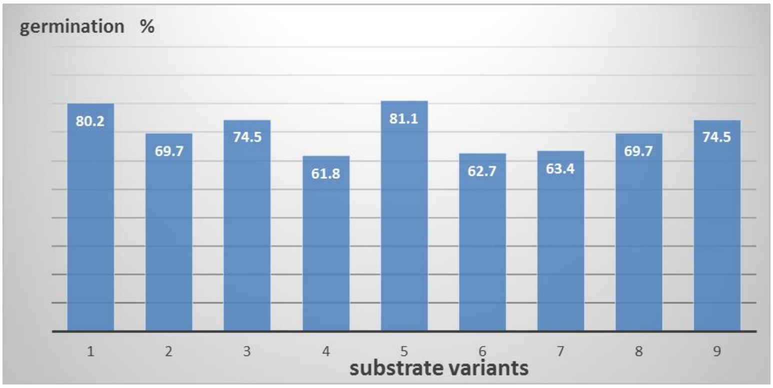

Figure 5: Average survival rate of English oak seedlings in containers with different substrate composition Variant: 1. Soil (control); 2. Peat:S = 1:1; 3. Peat:S = 1:2; 4. Peat:S = 2:1; 5. Peat:S = 3:1; 6. S:H:SD = 1:1:1; 7. S:H:SD = 2:1:1; 8. S:H:SD = 3:2:1; 9. S:H:SD = 4:2:1 (P – peat; S – soil; H – humus; SD – sawdust).

The data obtained can be explained by the higher (almost 11 times) water retention capacity of peat, which contributes to the higher moisture content in the root ball and leads in time, during winter storage, to frost killing of root systems of ball-rooted seedlings which are kept in open areas during the winter. Table 3 presents physical and agrochemical parameters of substrates used measured in first year of experiment.

Table 3: Results of physical and agrochemical analyses of the components of substrates used in growing English oak seedlings in containers.

Sample	pH		Water retention capacity, %
	Water extract	Salt extract	
Soil	7.1	6.0	45.0
Humus	8.6	8.2	135.0
Softwood sawdust	4.3	4.1	295.0
Peat	8.1	8.0	454.0

Among variants using mixture of soil, humus and sawdust, the lowest value of the survival rate (59.1%) was found in the variant with the highest content of sawdust (S:H:Peat = 1:1:1) while the highest value (72.0%) was in the variant with the greatest share of soil (S:H:Peat = 4:2:1). Over 40% increase in the humus proportion resulted in yellowing of the needles of seedlings and formation of alkaline conditions, which suppressed the growth of English oak seedlings to a certain extent.
The condition of oak seedlings, on a scale of 1–5 taken for its assessment, was the best in all peat-containing variants compared to the control (Table 4).

Table 4: Condition of one-year oak seedlings in containers.

Variant	Condition, points	**t**	% of the control
1. Soil (control)	5.2 ± 0.1	-	100.0
2. Peat : S = 1 : 1	6.0 ± 0.1	1.9	115.4
3. Peat : S = 1 : 2	5.8 ± 0.1	2.8	111.5
4. Peat : S = 2 : 1	5.5 ± 0.1	1.7	105.8
5. Peat : S = 3 : 1	5.3 ± 0.1	0.9	101.9
6. S : H : SD = 1 : 1 : 1	5.4 ± 0.7	1.7	103.8
7. S : H : SD = 2 : 1 : 1	5.2 ± 0.3	3.3	100.0
8. S : H : SD = 3 : 2 : 1	5.5 ± 0.1	2.0	105.7
9. S : H : SD = 4 : 2 : 1	5.8 ± 0.1	2.6	111.5

Notes: t 0.001 = 2.9; t 0.01 = 3.2; t 0.05 = 3.0; t 0.1 = 2.3.
S – soil; H – humus; SD – sawdust.

With the highest significance, the control values were 15% exceeded by the seedlings grown in the substrate mixture Peat:S = 1:2. The variant with the largest content of peat was significantly the least effective; it had 3% excess of the control.

In the substrate variants using soil, humus and sawdust, the best seedlings condition (5.8) was found in S:H:SD = 4:2:1 variant, which the most significantly exceeded the control by 14%.

Discussion

By studying the optimal substrate composition for growing containerized English oak several scientists were engaged [7,11]. Similar to our study, the growth and vitality of oak seedlings grown in containers were monitored. The vitality of forest plantations created using these seedlings was also monitored. Similar to our case, the technology of growing oak seedlings in containers was developed (type of container, composition of the substrate, dates and length of cultivation). Our results and recommendations confirm the effectiveness of growing seedlings in containers, they correspond with experiments known so far and, moreover, they specify the most suitable substrate for growing seedlings.

The results of the study to determine the optimal substrate composition for growing containerized English oak planting stock showed that the best germination ability traits and biometric indices of oak seedlings were found in variants using peat, which were used appropriately in containers.

High germination values were obtained also in variants using three-component mixtures with humus, sawdust, and dark gray wooded middle loamy soil, which was taken as the basis of the substrates. In Ukraine, dark gray wooded middle loamy soils are among the most fertile ones at the level of potential fertility. They were formed under sufficiently sparse broad-leaved forests with a well-developed herbaceous cover on heavy-loam carbonate loess. The combination of such soil formation factors as the presence of a significant amount of eutrophic organic sediments as well as parent rock saturated with calcium and clay particles provides dark gray wooded soils with high nutrient-supplying capacity. Soil conditions are very important even in seasonally dry environments [18]. On the other hand, English oak seeds and seedlings are also tolerant to floods [19].

Thus, in comparison with other substrates used in the mixtures for growing seedlings, the forest soil has the highest potassium and phosphorus contents. The only exception is the humus, in which the phosphorus content is higher than that in the forest soil, but its acidity (pH 8.6), as compared with the soil (pH 7.1), is not sufficiently favorable for the growth of the planting stock of most tree species. It is common knowledge that the range of soil acidity for hardwood species, at which they reach a high level of productivity, ranges from slightly acidic to neutral. It is this level of acidity that forest soil manifests (see Table 3). Similar research results were obtained by other researchers [1,7,11]. Similar research in Poland [20] shows that oak thrives best on sandy soils and clay-sand substrates. The high clay content had an adverse effect on the growth of trees.

In accordance with works of a similar focus, it was confirmed that the current policy in the management and use of forests must accept ongoing climate changes. It requires considering many natural and social factors and implementing the latest scientific research at various levels. It is obvious that when creating forestry plans, it is necessary to consider procedures that respond flexibly to climate changes.

Rumiantsev et al. [4] stated that one of the important aspects of the management in oak forests during their regeneration, both in Ukraine and in other European countries, is the use of natural reproduction of oak. Our results show that oak growing can be effective also in suitable substrate in containers.

According to Tkach et al. [2] the absence of young oak forests of natural origin (about 1%) is a result of unsatisfactory regeneration of oak forests in the last 40–50 years. In accordance with this author, we believe that the restoration of oak forests can also be done in a container way. In our study, we looked for the composition of a suitable substrate for this form of planting.
Experiments carried out by us also confirm that the success of germination and the survival rate of seedlings, in addition to measurable parameters, also depends on improving the quality of substrate preparation in containers, substrate density in containers and mulching of seeds and care before and after the emergence of seedlings.

Realization of the planned works requires the proper financial and material support. In the first place, there is a need to introduce modern approaches and technologies for providing forest cultivation work with high-quality seeds and standards-compliant planting stock, as this determines not only the success of forest plantations growth in the early stages of their development but also to a large extent the productivity and biological stability of future stands.

Conclusions

Taking into consideration the periodicity of English oak fruiting, the necessity for conservation of its best genotypes, and for growing the planting material with the improved hereditary characters, industrial technology of growing the containerized seedlings is possible and perspective.

A way of acorn sowing in the containers has a significant impact on the growth of plants. Distribution of an acorn in a cell with a pointed end up makes it possible to form physiologically active roots of the second and third orders from a top of a container cell, to fix a rootball and to raise the survival ability of plants on sites.

Among tested substrates for a container volume of 600 cm3, the peat-containing variant with equal portions of dark gray wooded middle loamy soil and peat (peat:soil = 1:1) and the variant of the three-component mixture soil:humus:sawdust = 4:2:1 are the most balanced in the basic soil parameters (acidity and nutrient content) and are the best among the studied ones for the productive growing of English oak seedlings.

Poorer germination percentage of the oak on substrates with sawdust may be explained by the fact that nutrients content in the mixture is lower in comparison with soil itself and also with soil:humus mixture, but these have to be more studied in the future.

To conserve and reproduce high yield and sustainable oak forests, it is desirable to restore forests using the containerized planting material with the improved selective and genetic properties grown according to the industrial technology. To elaborate and implement this technology, it is necessary: 1) to elaborate the modes of storage and preparation of acorns for planting, providing no less than 90% germinating capacity and maximum efficiency of utilization of containers; 2) to adapt the existing devices or elaborate principally new sowing machines for acorns planting in automatic mode, as implemented for growing the containerized seedlings of coniferous species; 3) to save and propagate the best genotypes of oak, resistant to deceases, anthropogenic burden, and unfavorable climatic factors, it is advisable to create a seed bank with an extended storage period and develop an effective technology for microclonal propagation in vitro.

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