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EMPIRICAL USE OF THREE OAK SPECIES IN AFFORESTATION: LESSONS FROM SOWING AND TRANSPLANTING EXPERIMENTS

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Abstract: The effects of different factors on the growth in height and diameter of oak saplings in comparative cultures were estimated: progeny from autumn and spring sowing of acorns (1); growing conditions of pedunculate oak (*Quercus robur* L.) mother plants (2); the initial planting density of sessile oak (Q. *petraea* Liebl.) (3); natural lightening level of downy oak (*Q. pubescens* Willd.) mother plants (4). The pedunculate oak seedlings obtained after spring sowing were characterized by faster growth compared with those obtained from the autumn sowing. The lower growth rate observed in seedlings sown in autumn was due to the prolonged frosty weather during winter, which led to a decrease in acorn viability and progeny vigour. Due to the higher genetic diversity of the progeny obtained from the free-pollinated pedunculate oaks, it is possible that their growth was more intense and stable in comparison to those of saplings obtained from the acorns of isolated trees. The planting under the forest canopy had a clear influence on the growth in height of saplings. At low density levels (1.0 x 1.0 m), the sessile oak saplings benefited from larger availability of soil nutrients and displayed the highest growth, contrasting with those planted at high density (0.5 x 0.5 m). The deep and moderate shading caused a substantial reduction in the growth of downy oak saplings. Therefore, when planting, it is recommended to avoid using fast-growing species, which, due to asymmetric competition, could drastically reduce the growth in height of the downy oak saplings. Prolonged regeneration of the pruned root system following the transplantation process of sessile and downy oak seedlings determined their very slow growth in the first years of life.

Key words: sowing, growth, height, diameter, sapling plantation, shading, *Q. robur*, *Q. petraea*, *Q. pubescens*.

Introduction

The regeneration of the pedunculate oak by seed is made more problematic due to the high periodicity of fruiting, parasitic acorns, the slow growth rate of the seedlings and periods of drought [5, 21, 39, 45]. Foresters plant oak saplings or sow acorns directly to complete the natural regeneration. The latter procedure is simpler, cheaper, and the developed seedlings have a deeper pivoting root, which determines a higher rate of survival in the first year and greater drought resistance over time [24, 48, 54].

The improvement of the cultivation procedures in nursery crops has allowed the development of high quality oak seedlings [22, 50]. When carrying out afforestation and reforestation, the use of oak seedlings grown in a nursery and then transplanted, leads to high rates of disruption of their root systems and to very slow growth in height in the first years of life [16, 17, 27, 46].

The survival of oak seedlings depends on their access to ground water during the summer, which can be only achieved by strong and deep roots [49]. Therefore, the root growth rate in the first months of life (spring-summer) can have a decisive influence on the survival of seedlings

during the dry season [31]. As deep rooting is one of the main strategies for the survival of oak seedlings in their early growth phase, direct acorn sowing represents a good alternative method of regeneration, with the added advantage of having a low cost [19].

There are several factors which often contribute to poor pedunculate and sessile oak regeneration when using direct seeding, two of them being more important. The first is rodents, which unearth and consume the sown acorns [7]. The second is the weeds that reduce the growth of seedlings through asymmetric competition. This prolongs the period in which the seedlings are most sensitive to weeds. Both factors need to be controlled if direct sowing is to become a viable alternative to planting [35, 48, 53].

When carrying out afforestation works, it is important to consider choosing the correct sowing period for pedunculate oak acorns. This necessity is fundamental since, in whichever season the sowing is executed (autumn or spring), a specific influence of some unfavourable natural factors is possible, which could cause damage to the acorns embedded in the soil or to seedlings [32]. Autumn sowing may incur losses in winters with severe frost if the plantation is not protected by litter or snow cover. The acorns may freeze if they are directly exposed to temperatures below −6°C. At the same time, there is a high risk that rodents and wild boars will use acorns as food in long winters [3, 8, 24, 45]. Spring sowing can too be affected by late frosts and spring drought [43, 45].

Even though the performed sowing is successful, considering the percentage of the germinated seedlings, it is important, from a practical standpoint, that the oak seedlings have a rapid growth and high vitality starting from their first years of life. The growth rate of the pedunculate oak seedlings derived from different trees is subject to obvious variations. There can be multiple causes of the unequal growth of oak seedlings in forestry crops. The influence of the acorn size on the vigour and growth rate of seedlings can last up to the age of 15–18 years [33]. The sowing period also influences the growth rate of oak seedlings [12, 13, 15, 34], but the hereditary traits of the seeded trees have the most important role in the progeny growth processes [4, 14, 25, 36]. More than that, the influence of the hereditary factor, which is expressed in terms of growth energy, acts gradually in the course of the ontogenetic development [15, 28].

The present study estimated the effects of different factors on the growth in height and diameter of oak seedlings in comparative crops, namely the sowing period and parental specificity of the pedunculate oak (*Quercus robur* L.), the initial planting density of the sessile oak (*Q. petraea* Liebl.), and the amount of light availability of the downy oak (*Q. pubescens* Willd.).

Materials and Methods

In order to determine the influence of the sowing period and of parental specificity on the growth rate of seedlings, comparative experimental crops of pedunculate oak (*Quercus robur* L.) have been created within the scientific reserve “Plaiul Fagului”. The seeded area lies on a gentle slope (5°) exposed to the south-east and is located in the immediate vicinity of the Rădeni stream meadow. The soil is a typical luvisol [29].

The sown acorns were harvested from a forest stand, in the vicinity of the site where the sowing was performed. Autumn (2002) and spring (2003) sowing of acorns, harvested from 64 trees inside the pedunculate oak stand (‘*forest interior*’) and from 5 isolated trees growing at the edge of the forest massive (‘*forest edge*’), were carried out in randomized blocks that included four treatment variants with five repetitions. The experiment took place in 7 m-sided square plots within

which the acorns were sown in 64 nests according to a 1.0 x 1.0 m spacing scheme. The design of the experimental pedunculate oak crops, the method of preserving the acorns and the sowing procedure were described in a previous publication [18].

In order to determine how the planting density influences the growth in height of seedlings, comparative experimental crops of sessile oak (*Q. petraea* Liebl.) under a hornbeam overstorey were established in the spring of 2002. The site conditions can be summarized as follows: elevation (240 m), slope (5°), aspect (north-east) and soil type (luvisol). The hornbeam stand represented the most mature community under which the planting was performed, but the original climax forest vegetation was, however, composed of sessile oak, lime and hornbeam.

The soil was prepared inside some quadrats of 3.0 x 3.0 m using a hoe to a depth of 12–14 cm. The quadrats were chess-shaped with a 4–5 m distance between their centres. The planting inside the quadrats was executed according to three treatments, namely: the first featured a distance of 0.5 x 0.5 m resulting in twenty-five seedlings planted inside a quadrat. The second treatment saw the planting of sixteen sessile oak seedlings in quadrats arranged at 0.7 x 0.7 m. The third treatment, the seedlings were placed in quadrats, nine in each, with a distribution of 1.0 x 1.0 m.

Another experiment was carried on downy oak (*Q. pubescens* Willd.) to estimate to what extent light availability influences the growth in height of seedlings. Comparative experimental crops were established in the spring of 2005 in the nursery area of the Băiuş Forest District. The soil was prepared in the summer of 2004 according to the system of black field. Three rows of downy oak seedlings were planted along the south-western side of the forest (160-m length). The experimental design was comprised of three treatments. The first consisted in planting a row of saplings aligned at 2.5 meters from the edge of the forest. The second included saplings planted in a row along the forest edge, 7.5 m away from the stand. In the third treatment the saplings were planted 10.0 m away from the edge of the forest. The treatments were denoted with Roman figures: I – deep shading; II – moderate shading; and III –poor shading of saplings.

The height and diameter of all oak seedlings were measured with a tape measure (± 0.5 cm accuracy). Student's t-test was used to estimate the significance of differences in mean height and diameter of saplings between treatments [55].

Results

Sowing experiment with pedunculate oaks

The sprouting of the pedunculate oak acorns was relatively constant regardless of the sowing season (average: 70.9% autumn *vs* 69.4% spring), the influence of limiting factors (disturbance induced by biotic factors before and / or after sowing, losses during acorn preservation and / or in soil after sowing) being more or less compensatory (Table 1). The location (forest interior *vs* edge) and the number of parents (64 *vs* 5 trees in the second) did not influence the percentage of acorn sprouting (69.2% within stand *vs* 71.1% at its edge). In spite of the light availability difference, this result is – to some extent – predictable, considering the small distance between the two categories of mother trees from which the seeds were harvested and the similar location in which they developed.

The survival rate of the pedunculate oak seedlings after five seasons was very high (over 90%) in three of the four tested treatments (Table 1). Only the seedlings sown in spring, at the forest edge, had a much lower survival rate (77%), displaying the lower performance since the emergence of seedlings. The seedlings that had the lowest survival rate sprouted from acorns

harvested from a single tree, which might have been determined by local factors (unfavourable environmental factors, high self-pollination, genetic characters, etc.).

Table 1: Statistics of seedling rate sprouting and survival in each of the two treatments

Site of seed collection	Sowing period	Sprouting (%) – 2002	Survival (%) – 2006
		$\overline{X}$ ± SD	$\overline{X}$ ± SD
Forest interior	Autumn	67.0 ± 1.49	0.91 ± 0.03
	Spring	71.3 ± 1.76	0.93 ± 0.03
Forest edge	Autumn	74.7 ± 1.51	0.93 ± 0.01
	Spring	67.5 ± 1.93	0.77 ± 0.07

The spring sowing resulted in faster growth of pedunculate oaks, both in height and diameter, during the first 10 years of life, compared to autumn sowing (Fig. 1). In the first two years of life, the growth rate of oak trees sown in autumn and spring was similar. Between the second to the end of the 5th season of vegetation, there was an obvious acceleration of growth in the spring sowing seedlings compared to those obtained by autumn sowing. Thus, after the fourth year of life, the spring saplings were 15.4% higher compared to those obtained from the autumn sowing. These seedlings also grew in diameter significantly faster (by 11.4%) than those sown in autumn sowing. In the sixth year of life, the differences between the progeny originated from seeds sown in different seasons increased and then remained practically constant. At the age of eight, the seedlings sown in spring were 1.2 times taller compared to those of the autumn sowing (Fig. 1a).

Due to the growth characteristics of seedlings obtained through spring sowing, in the middle of the fourth vegetation season, the crowns of several oak saplings closed, casting shadow over the underlying vegetation. The low availability of light inhibited the development of weeds and gradually caused change in the composition of ground species. Many weeds that had invaded the oak seedlings, such as couch grass (*Elymus repens*), gradually disappeared. The decrease in the adventive vegetation cover due to the conjoining of sapling oak crowns had two positive consequences. First, it caused a relaxation of competition for mineral nutrients between seedlings and weeds and reduced the non-productive loss of soil moisture. Second, this change led to a decrease in the sapling care work. No canopy closure was observed among the autumn sowing saplings, during the 4th year. Consequently, the time of the sowing had practical importance since it led to the rise in the efficiency of the care work on seedlings during the early period of pedunculate oak cultivation.

The growth rate in height and diameter of the pedunculate oak seedlings was affected differently, depending on the origin of harvested acorns (‘forest interior’ *vs* ‘forest edge’) and the number of parents (64 *vs* 5 trees).

The spring-sown progeny of the pedunculate oak, originated from within-stand trees, showed a tendency to faster growth in height, compared to those originated from forest edge (Figure 2). With aging of oak saplings, the difference in growth rate between the progeny of interior and edge trees has increased. It is interesting to note that in the first two years of life the seedlings from different treatments were characterized by similar increases in height. In the years that followed, the progeny of interior trees showed a faster growth, thus outgrowing in height those originated from edge oaks. For example, after the third year of life, the average height of saplings from the ‘forest interior’ was 9.6% higher compared to that of their counterparts from the ‘forest edge’ (Table 2). The seedlings originated from trees of ‘forest interior’ displayed an obvious

tendency also to rapid growth in diameter. Thus, the seedlings obtained from the trees of 'forest interior' had a 6.4% higher diameter increase, compared to saplings originated from trees of the 'forest edge', which is a significant difference. After the seventh season of vegetation, the seedlings resulted from forest interior trees exceeded by 13.8% the height of their counterparts (Table 2).

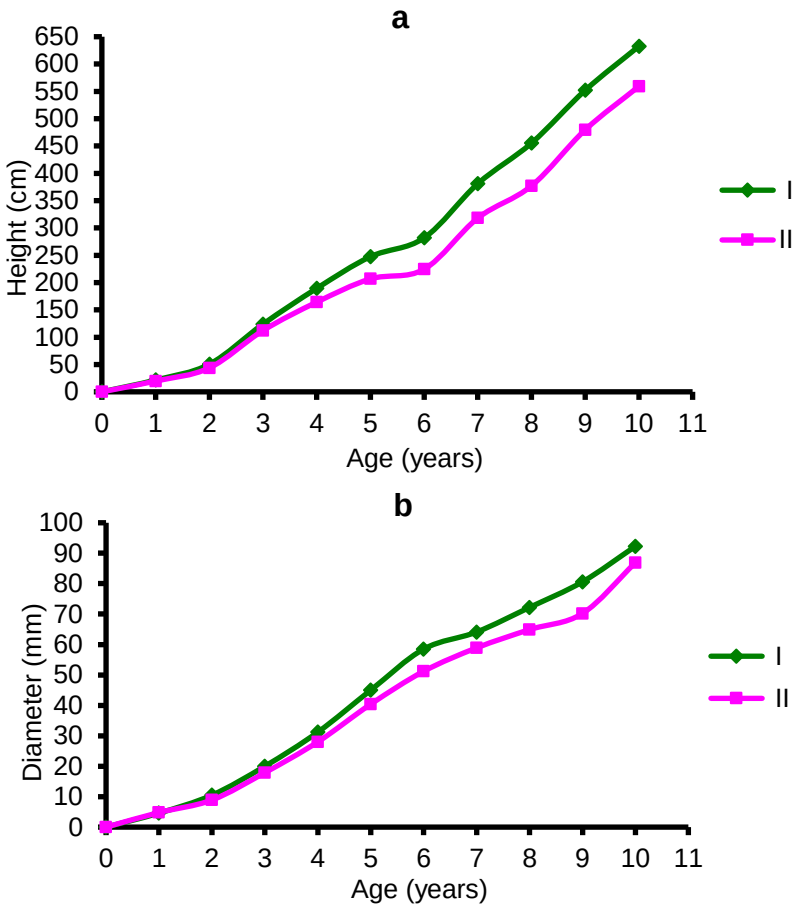


Fig. 1: Dynamics of growth in height (a) and diameter (b) of pedunculate oak seedlings from spring (treatment I) and autumn (treatment II) sowing

Table 2: Significance of the differences in height between the pedunculate oak seedlings depending on site of acorn collection

Site of seed collection	Average height (cm)	Student *t* criterion
		Forest interior
	After 3 years of life	
Forest interior	123.9	-
Forest edge	113.0	3.356***
	After 4 years of life	
Forest interior	189.3	-
Forest edge	173.7	3.939***
	After 5 years of life	
Forest interior	247.4	-
Forest edge	222.7	5.054***
	After 6 years of life	
Forest interior	281.7	-
Forest edge	247.6	6.262***
	After 7 years of life	
Forest interior	381.0	-
Forest edge	334.8	7.577***

Statistical significance: * 1% < p < 5%; ** 0.1% < p < 1%; *** p < 0.1%

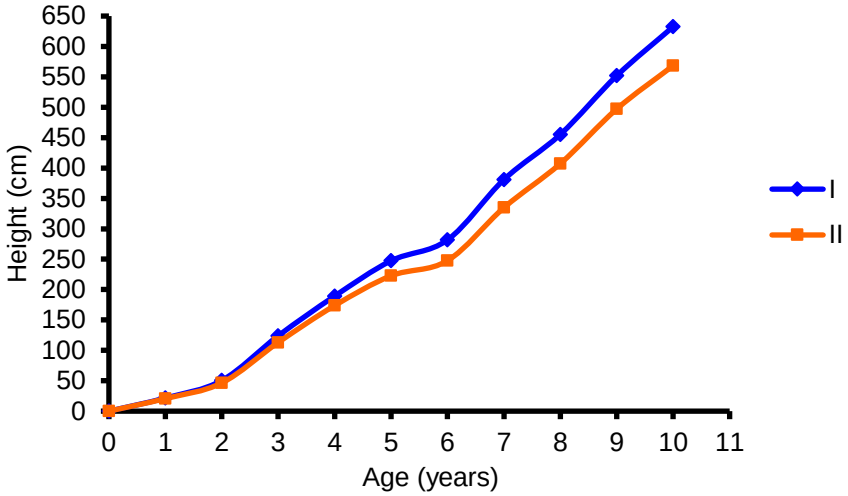


Fig. 2: The dynamics of the height increase in the pedunculate oak seedlings originated from parent trees located at the forest interior (treatment I) and edge (treatment II)

The growth of the progeny from the pedunculate oak trees located at the 'forest interior' and that from the 'forest edge', sown in autumn, were similar. Apparently, the specificity of the oak progeny growth was determined by the fact that the trees located at the 'forest edge' were characterized by a lower degree of heterozygosity, which affected the growth rate of the progeny. Probably, due to the different degree of heterozygosity of each individual parental tree from the 'forest edge' their progeny was characterized by specific growth rate. It was expected that the difference in the growth rate of progeny from different parental trees from the 'forest edge' will be directly proportional to their degree of heterozygosity. In reality, some oak seedlings, progeny from the 'forest edge' trees, showed a rapid increase in height, while others displayed a slow growth, with the lower average height value of all progeny.

Planting experiment with sessile oaks

In the first three years after transplanting, the seedlings of sessile oak had similar but slow growth (Fig. 3). A large number of seedlings did not grow in height during the year of planting. Another group of seedlings grew very little in height, up to 1.0–2.5 cm. The leaves appeared about one month later compared to mature trees and, therefore, they remained small. As one can see, transplantation was a forestry intervention that significantly influenced the condition and viability of the seedlings. They had different levels of reserves to maintain and speed up the root system regeneration and to ensure their consolidation in the soil.

In our case, the adaptation phase of the sessile oak seedlings was long and lasted an entire vegetation season after their planting. As a result of the difficult regeneration of the root system, the growth of the seedlings' aerial part was slow during this period; therefore, the plants were in leaf mainly on the account on their reserve substances. The seedlings also grew slowly in the second year after their planting (i.e., the third year of life) (Fig. 3).

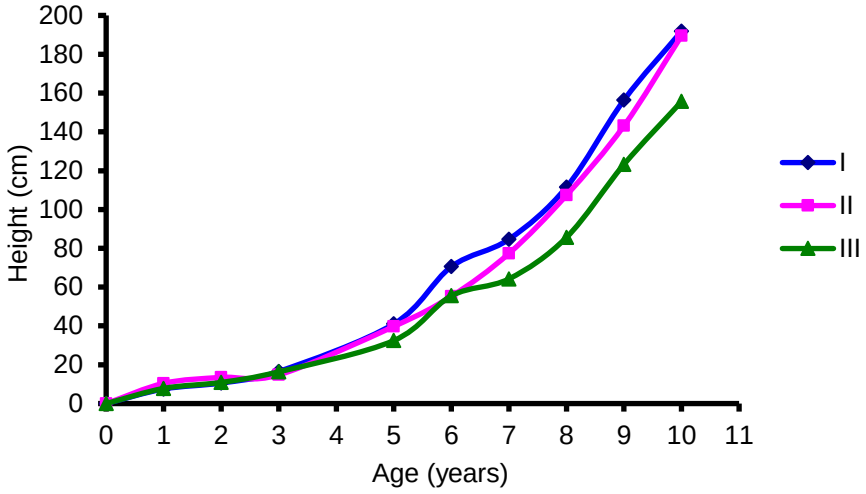


Fig. 3: Height dynamics in sessile oak seedlings planted at different densities (I: 1x1 m; II: 0.7x0.7 m; III: 0.5x0.5 m) under the forest canopy

A tendency to uneven increase in height of different sessile oak treatments was only observed after the fifth year of life. In the fifth year the fastest growth was observed in seedlings planted 1 m apart. The average height of the sessile oaks in this treatment was 41.0 cm, which is 3.2% higher than those planted 0.7 m apart and 26.2% higher than those planted 0.5 m apart (Figure 3). There is evidence that the sessile oaks planted at the largest distance from one another displayed a faster increase in height.

In the following years, the rapid growth in height of the sessile oaks could still be observed in the treatment with the 1.0 x 1.0 m planting scheme, compared to that based on the 0.5 x 0.5 m design. A longer planting distance ensures sufficient availability of mineral elements for the sessile oak (appropriate to their stage of development), which increases their rate of growth.

Planting experiment with downy oaks

During the first five years of life, the downy oaks were characterized by slow and similar growth (Fig. 4). Starting with the fifth year of life, the growth rate of the seedlings in all treatments increased significantly. Moreover, as they grew older, the differences in the growth rate of the seedlings in the investigated treatments were observed, indicating that the gradient of shading substantially influenced the growth process of the seedlings. During the first seven years, the treatments where the seedlings had poor and moderate shading showed a similar rate of growth in height. In the years that followed, the growth rate of the seedlings with poor shading increased compared to the growth of the seedlings that were moderately shaded. Slow growth was typical of the seedlings with increased shading.

The downy oak seedlings that were little shaded showed the fastest growth during the first ten years of life. After eight seasons of vegetation, the average height of these seedlings exceeded the treatment with seedlings that were exposed to increased shade by 40.4%. The differences between treatments were highly significant (Table 3). In the years that followed, the tendency to rapid growth in height of the little shaded saplings was maintained. Thus, in the tenth year of life, the seedlings from the treatment with poor shading achieved an average height of 102.1 cm, which exceeded the height obtained in the moderate shading treatment by 30.0% and the height of the increased shading seedlings – by 46.2% (Table 3).

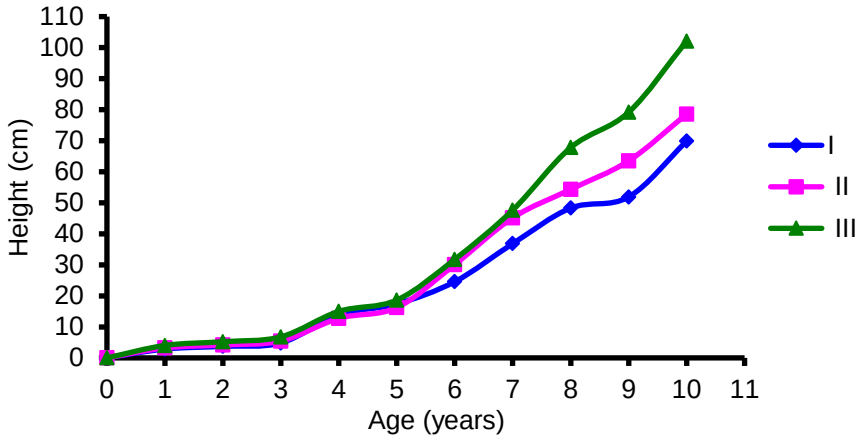


Fig. 4: Height dynamics of downy oak seedlings by shading treatment (I: deep shading; II: moderate shading; III: low shading)

Table 3: Significance of the differences in height between the downy oak saplings grown at different levels of shading

Shading treatment	Average height (cm)	Student *t* criterion	
		Low shading	Moderate shading
After 7 years of life			
Low shading	47.6	-	-
Moderate shading	45.2	1.582	-
Deep shading	36.8	2.620*	0.424
After 8 years of life			
Low shading	67.8	-	-
Moderate shading	54.3	1.033	-
Deep shading	48.3	3.385**	1.927
After 9 years of life			
Low shading	79.2	-	-
Moderate shading	63.5	2.358*	-
Deep shading	51.9	3.726***	2.189*
After 10 years of life			
Low shading	102.1	-	-
Moderate shading	78.6	1.189	-
Deep shading	69.9	3.533***	2.432*

Statistical significance: * 1% < p < 5%; ** 0.1% < p < 1%; *** p < 0.1%

Discussion

Our results indicate that the origin of harvested acorns did not influence the percentage of sprung acorns in any way, during the emergence phase of the pedunculate oak seedlings. Our investigations did not confirm the hypothesis according to which the proportion of sprouted acorns from parental trees, which benefit from better fruiting conditions in the forest edge, should be higher compared to those originated from the row of trees (forest interior) [51]. Different genotypes develop naturally over large distances (and low densities), which ensures isolation and prevents cross-pollination from other genotypes, or at least under different habitat conditions that favor the development of different ecotypes [26, 41]. Such an outcome may be due to the hybridization from natural stands, containing several species of oak, as well as artificial plantations of oaks of various provenence and species, perhaps bringing together different genotypes in small areas, which can change the natural distribution of oak genotypes [2, 11].

The growth and development rate were different among the pedunculate oaks sown in autumn and spring. Even though, during the first two years of life, the growth rate of the seedlings of autumn and spring sowing was similar, as they grew older, gradually, the seedlings of the pedunculate oak of spring sowing showed a significantly faster increase in height and diameter compared to those obtained from autumn sowing. Probably, the weather conditions in winter weakened the vitality of the autumn sown acorns and the germinating embryos, which led to the decrease in the growth rate of these progeny compared to those obtained from the spring sowing. The seeds prepared for sowing by stratification (respecting the humidity and temperature conditions) and incorporated into the soil in very early spring displayed a higher seedling growth potential compared to those harvested several days before and sown in autumn.

Our results are consistent with those obtained by P. Madsen and M. Löf (2005), who demonstrated that spring and clear-cut seedlings performed generally better than autumn and shelterwood seeding respectively. The present study suggests that direct seeding of pedunculate oaks may potentially become an effective regeneration and reforestation method, which can be used for restoration purposes.

In addition, the number of parent genotypes had a positive effect on the growth rate of pedunculate oak seedlings sown in spring. This fact suggests that introducing numerous genotypes into the composition of experimental cultures ensures better performance of the seedlings in terms of ecological stability and growth rate. The presumed higher genetic diversity of the progeny originated from trees from the forest interior determined their better performance in terms their faster growth in comparison to the seedlings obtained from the trees located at the edge of the forest. These results are consistent with the unanimous view, according to which, genetically diversified forest crops compared to monocultures have the advantage of high biomass production and protection against perturbing natural factors [30, 42, 56].

The presumed genetic heterogeneity in the ‘modelled’ population does not only display high adaptability, due to the diversity of its genetic background [30, 47], but also rapid and stable growth of the pedunculate oak juveniles. Different studies reported that one of the main mechanisms of maintaining the genetic heterogeneity of populations is the high viability of heterozygotes as compared to homozygotes [23, 38]. In the case of the pedunculate oak, this pattern can be linked to the anemophilous pollination [10], and the populations resulting through panmictic reproduction have an advanced degree of heterozygosity [44]. In our case, the oak trees located at the forest edge, from which the acorns were harvested, hybridize accidentally. The number of pollen donor trees at the forest edge is, however, lower compared to that expected within the forest stand. Under outskirt conditions, oak trees may hybridize with other related trees. This peculiarity in the interbreeding of the forest edge trees or open woodland ones, makes the seedlings obtained from their seeds withstand the influence of ‘inbreeding depression’ to a greater or lesser extent. It is presumed that the segregation of heterozygotes and the accumulation of harmful recessive genes in the polygenes, which control the growth of seedlings originated from seeds of forest edge trees, may affect the growth rate of seedlings adversely. Although the single influence of some harmful genes is insignificant, their cumulative influence may have a considerable effect on the growth of pedunculate oak seedlings. Harmful genes do not slow down the growth of progeny under the conditions of free pollination because interbreeding happens by chance. In the forest interior, each tree crosses with a less related one, which does not contain the same recessive genes [52]. The weak growth performance of the seedlings originated from the tree located at the

'forest edge' is probably due to this phenomenon.

Unlike sowing, planting is a technological process that substantially affects the growth of oak species in the first years after transplanting. A good example is the described comparative crops of sessile oak, installed by transplanting the seedlings from an adjacent stand that grows under similar environmental conditions. The possible cause of the poor seedling performance might reside in the insufficient light reaching the soil in the case of the sessile oak seedlings planted within the forest interior. The amount of light is the most important abiotic factor for plants but, during the early development phases, does not exert a decisive influence on the growth rate of the seedlings. The assertion is based on the results of the published research, demonstrating that the sessile oak seedlings resist and are able to grow 3-4 years in the forest understory, but only grow well in clearings with sufficient light [37]. The availability of light reaching the understory forest is important for the sessile oak in later stages of development, whereas their survival rate is essential in the early ontogenetic development [1].

Consistent with other studies [20], a slow growth rate of sessile oak and downy oak seedlings was observed following their transplantation, which may be attributable to damage to the root system after seedling transplantation [27, 46]. Thus, the analysis of the growth rate of the seedlings of the different species of oak installed by direct seeding and by planting showed, that after 3 years of life, the average height of the pedunculate oak seedlings obtained by sowing in the nests exceeded 11.2 times that of the downy oak seedlings planted in open land and 7.5 times – that of the sessile oak seedlings planted under the forest massive. As for the downy oak, the progeny obtained by sowing had, after 3 years of life, an average height 2.7 times higher compared to that of the transplanted seedlings [17]. Similar results have been reported for other species, that is an increased growth in depth of the root system following considerable pruning while digging seedlings, to the detriment of the growth of aerial parts of seedlings [40].

It is known that the response of seedlings to root pruning is to develop a dense and extensive root system, a compensatory mechanism that allows them to absorb enough water and nutrients [6]. As a result of root cutting, the root:stem size ratio as well as the nutrient supply in seedlings may change dramatically [9]. Our observations show that the long regeneration of the pruned root system following seedling transplantation causes depressed growth of sessile oak and downy oak seedlings. Probably the slower growth rate of seedlings in the first periods after root pruning is determined by their lower ability to assimilate water and nutrients from the soil. The results obtained suggest that in reforestation works, oak species must be introduced by direct seeding, without root pruning, a fact that will ensure the rapid growth of the seedlings and will substantially reduce the financial expenses necessary for care.

The height increase of the sessile oak seedlings was also influenced by planting density. In early developmental stages, the seedlings benefited from sufficient soil nutrients, which resulted in similar growths of the sessile oaks in different experimental treatments. As seedlings become saplings, they require a higher amount of nutrient uptake from the underlying soil. As a consequence of their faster growth, the sessile oak saplings developed larger crowns. Because of the intraspecific competition for soil nutrients, the sessile oak saplings grown at low density have benefited from the larger availability of soil nutrients since the fifth year of their life. This generated a boost in their growth compared to the slower growth of saplings that developed under conditions of higher population density. Therefore, the planting density plays an important role in the sustained and vigorous growth of the sessile oak saplings.

The present experimental outcomes indicate that increasing shading has led to a decline in the growth of downy oak seedlings, compared to those that were weakly shaded. That is because the downy oak is a shade-intolerant species [10], which distinguishes it significantly from the sessile and pedunculate oaks, the latter being favoured under partial shading in terms of its fitness and growth [1, 37]. Therefore, great caution should be taken when choosing which species are to be used when designing mixed, downy oak-dominated forest plantations, especially considering the interspecific competition for light. It is recommended to avoid the combinations with fast growing tree species, which could substantially reduce the growth and development of downy oak saplings and even cause their competitive exclusion.

Conclusions

The emergence of saplings from the acorns of pedunculate oak was not significantly influenced by whether the mother tree grew in isolation (at the edge of the forest) or *en masse* (inside the forest). This suggests that in both cases the mother plants belong to the same natural population, with common genetic characteristics. Seedlings obtained from acorns sown in the spring grew faster, compared to those obtained from acorns sown in autumn. Therefore, it is preferable that afforestation works be carried out by sowing acorns in the early spring, with the acorns collected in autumn and kept in moist sawdust at a temperature of 2–5°C. The rapid increase in height is manifested for the saplings the age of which has exceeded 2 years, therefore the risk of their elimination by weeds decreases only after reaching this age. Because the vigour of the descendants obtained from the acorns collected the isolated pedunculate oak trees is relatively low, it is recommended to collect the acorns from the mother trees that grow *en masse*. However, if necessary, the sowing of acorns obtained from solitary trees may be used, provided that in the future only vigorous offspring will be selected and maintained.

Transplanting the seedlings proved to be a technical operation that severely affects the regeneration of the root system of sessile and downy oak, so for afforestation it is recommended to design oak species by direct seeding. As it has been shown the growth inhibition of the saplings of sessile oak the distance between which is <1 m, it is recommended that the distance between the saplings exceeds this distance. Taking into account that deep and moderate shading leads to a substantial decrease in the growth processes of downy oak seedlings, it is necessary to avoid the presence of other, fast-growing species in the afforestation protocols.

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UTILIZAREA EMPIRICĂ A TREI SPECII DE STEJAR ÎN ÎMPĂDURIRE: LECȚII DIN EXPERIMENTELE DE ÎNSĂMÂNȚARE ȘI TRANSPLANTARE

(Rezumat)

Au fost estimate efectele diferiților factori asupra creșterii în înălțime și diametru a puieților de stejar în culturi comparative: descendenți proveniţi din semănăturile de toamnă și primăvară (1); descendenţi proveniţi de la arborii mamă de stejar pedunculat (*Quercus robur* L.) situaţi în masiv şi la lizieră (2); desimea inițială de plantare a puieților de gorun (*Q. petraea* Liebl.) (3); nivelul natural de iluminare a puieților de stejar pufos (*Q. pubescens* Willd.) (4). Puieţii de stejar pedunculat obținuţi din semănăturile de primăvară s-au caracterizat printr-o creștere mai rapidă comparativ cu cei proveniţi din semănăturile de toamnă. Ritmul de creștere mai scăzut observat la puieţii obținuți din semănăturile de toamnă s-a datorat vremii geroase prelungite din timpul iernii, care a dus la scăderea viabilității ghindei și vigorii descendenților. Datorită diversității genetice mai vaste la descendenții obținuți de la arborii de stejar pedunculat din interiorul pădurii, este posibil ca creșterea lor să fie mai rapidă și mai stabilă în comparație cu cea a puieților obținuți din ghindele recoltate de la arborii de pe lizieră. Desimea de plantare a puieților de gorun instalaţi sub masiv de pădure a avut o influență semnificativă asupra creșterii lor în înălțime. În cazul desimii de plantare scăzute (1,0 x 1,0 m), puieții gorunului au beneficiat de o disponibilitate mai mare de substanţe minerale din sol și au demonstrat cele mai performante creșteri, în contrast cu puieţii plantați în desime mare (0,5 x 0,5 m). Umbrirea profundă și moderată a provocat o reducere semnificativă a creșterii puieților de stejar pufos. Prin urmare, la plantare, se recomandă evitarea utilizării speciilor cu creștere rapidă, care, datorită concurenței pentru lumină, ar putea reduce drastic creșterea în înălțime a puieților de stejar pufos. Regenerarea prelungită a sistemului radicular retezat după procesul de transplantare al puieților de stejar pufos și gorun a determinat creșterea lor foarte lentă în primii ani de viață.

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