EFFECTS OF RADICLE CLIPPING AND SEEDBED DENSITY ON SOME MORPHOLOGICAL CHARACTERISTICS OF *QUERCUS PETRAEA* (MATT.) LIEBL. SEEDLINGS

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Abstract. Production of high-quality seedling and successful reforestation is the main objective of foresters. Seedbed density and radicle clipping are some of the main factors, which are affecting oak seedling morphology and quality. Sessile oak (*Quercus petraea* (Matt.) Liebl.) seedlings which were radicle clipped and unclipped, were sown at five different spacings (3-6-9-12-15 cm) by using randomized split parcels design. Radicle clipping had a significant effect on seedling diameter, dry shoot weight, Dixon's quality index, shoot to root ratio, number of fine roots and number of main roots. Decrease of seedbed density had a significant effect on shoot height, Dixon's quality index, root collar diameter, fresh shoot weight, dry shoot weight, dry root weight, seedling diameter, number of fine roots, sturdiness quotient. Both radicle clipping and seedling spacing together had a significant effect on shoot height, dry root weight, Dixon's quality index, number of fine roots, dry and fresh shoot weight, sturdiness quotient and root collar diameter. If radicle clipping is applied, 9 cm seedbed density can be used, without radicle clipping, 12 cm seedbed density is advised. This study was carried out in Igneada forest nursery Kırklareli Turkey.
Keywords: *sessile oak, seedling quality, seedling spacing, bare-root seedling, root collar diameter, seedling height*

Introduction

Marmara Region is the most densely populated and intensely industrialized geographic region in Turkey. As a result of rapid population growth, social activities and developments such as immigration, industrialization, urbanization and agriculture, natural forests of the region suffer significant losses in terms of area and productivity. On the other hand, these social developments increase the demand for forest products and services. Furthermore, the society has varying interests and expectations about forest goods and services (Sahin et al., 2021).

The science of growing tree seedlings for reforestation, however, really began to develop in the early 20th century; the objective was to ensure that outplanted seedlings achieve high survival rates and good growth (Dumroese et al., 2016). Stock quality is a "fitness for purpose" of seedlings' as it relates to achieving specific silvicultural objectives (Lavender et al., 1980). The concept of a target seedling has been defined as "targeting specific physiological and morphological characteristics that can be linked with reforestation success" (Rose and Haase, 1995). Nursery managers and researchers grew more interested in seedling quality and acknowledged that a quality seedling is made up of both morphological and physiological characteristics. Many States and/or regional organizations have established hardwood seedling specifications for their geographic area (Starkey, 2019).

One of the aims of the foresters is to obtain the highest quality and amount of seedlings from the nursery. There are different factors affecting quality. It is known that the density of seedlings on seedbed is one of the important factors, affecting the diameter and height growth and thus the quality of the seedlings (Brissette and Carlson, 1987; Boyer and South, 1988). However average seedling height was not affected by spacing (South et al., 1990). Growing seedlings in high density reduces the quality of seedlings, as well as growing on the low density has negative effect (i.e. getting low number of seedlings). Since the seedling quality directly affects the survival and development of the seedlings in the field, it is seen as an important problem to know the ideal growing density (amount of seed to be sown per unit area) in the nursery. Specifications for sessile oak seedling production has not been established for any region such as Marmara in Turkey. Conventionally, acorns are sown on drills by hand, approximately 3 or 4 cm intervals. There is no regionally standardized optimum sowing density for sessile oak seedling production on forest nurseries.

Despite greater performance for morphologically improved seedlings, some foresters do not rely on economic analyses and instead recommend that landowners plant standard seedlings for loblolly pine. They recommend standard stock because seedlings with 4-mm root collar diameter (RCD) are cheaper to purchase and are easier to plant by hand than morphologically improved seedlings (Blake and South, 1991). Survival rates with standard seedlings are often lower under adverse conditions, however, these foresters often recommend outplanting more than 1000 per ha (400/ac). This combination (high outplanting rate and standard seedlings) often increases the overall cost of reforestation while reducing the production of large-diameter sawlogs (South et al., 2005). It has been estimated that outplanting morphologically improved seedlings (with 6-mm RCD) can sometimes result in a 1-year “age-shift” when compared to standard seedlings with 4-mm RCD (South et al., 2005).

Radicle pruning, clipping radicle from the distal end of the sprouted acorns before sowing, is another potential technique to improve taproot development for seedlings. Radicle pruning proposed by Carpenter and Guard (1954) induced the formation of multiple tap roots originating at the radicle trim point. It aimed to avert drastic loss of roots from lifting oak bareroot seedlings by forming relatively shallow taproots at the expense of shortening the single taproot which can reach a depth of 45 cm (Lyford, 1980; Barden and Bowersox, 1989). In addition, radicle pruning does not seem to inhibit shoot development (Bonner, 1982; McCreary, 1996), but enhances root surface area during the nursery stage (Ertas, 2002) and root growth capacity after transplanting in pots (Barden and Bowersox, 1989). These results imply that radicle clipping might be used to form a multiple-taprooted root system.

Reforestation of degraded forests is among the most important forestry activities in the Marmara region. In the reforestations which were carried out in the previous years in the region, exotic coniferous species have been prioritized. However, the natural forests of the region generally consist of broad-leaved species (i.e. oak species, beach, hornbeam). Coniferous plantations have been subjected to fire, insects and similar natural disasters. Urbanization has forced the forests for recreation, water production and aesthetic functions. Native broad-leaved species has been broadly used in reforestations.

One of the most important factors in the success of afforestation is the usages of high-quality seedlings with superior genetic qualities for the appropriate species and province. The task of forest nurseries is to produce high quality seedlings. Healthy seedlings with an appropriate diameter, height and stem/root ratio are main characteristics for high quality seedlings. Standardization of broad-leaved and

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coniferous seedlings, which are suitable for using in reforestation in European Union member countries is given great importance. In Italy, the nurseries producing non-standard quality seedlings were closed and instead of these, it is aimed to establish modern nurseries which are produced large quantities of high-quality seedlings. Thus, it was made possible to use high quality, healthy, high survival and field performance seedlings in all plantations. Oak species have an important proportion in plantations in Turkey (Urgenc, 1986). Oak seedling production has increased recent years.

High-quality seedlings are needed to ensure a high rate of survival and acceptable growth. Oak species in general are known for their high degree of variation in morphology and growth rates (Dey and Parker, 1997). Nursery cultural practices and regeneration decisions will not guarantee outplanting success, because field performance is also dictated by site conditions. Planting seedlings with quality root systems can improve chances for successful field establishment (Grossnickle and Ivetic, 2022). Artificial regeneration technology strives to minimize regeneration costs and maximize seedling performance and regeneration efficiency. The dilemma of unsatisfactory oak regeneration is a result of the failure to balance the competing objectives of cost and performance. The challenge for today’s forester is to improve the one without compromising the other. Using high quality seedling will decrease plantation cost and it will not necessitate complementary planting.

Reforestation programs should be supported by adequate nursery techniques. These selections of the type and quality of seedlings will determine the success of reforestation (Budiman et al., 2015). Long and Carrier (1993) showed that initial diameter and root mass of Douglas fir 2 + 0 seedlings were evaluated at five sites in Oregon and they were positively related to field performance in 3-5 years after planting.

Seedling morphology does not always predict field performance because the morphology does not indicate vitality or vigor of seedlings. South (1993) pointed out that “While it is certainly true that seedling morphology is not a perfect predictor of field survival, it is wrong to imply that seedling morphology is a poor indicator of growth potential. In fact, for an individual seedling prior to planting, seedling morphology is the best tool we have to predict the relative potential for growth. Although knowing the genotype usually does not help predict field survival, this does not mean genetically improved seedlings should not be used to improve the growth potential of a plantation. Likewise, just because seedling morphology is not a perfect predictor of field survival, this does not mean we should not use morphologically improved seedlings to improve the growth potential of our plantations. Morphological grading could improve seedling field survival under dry Mediterranean conditions (Tsakaldimi et al., 2013).

Evaluation of the effect of the seedbed density and radicle clipping on sessile oak seedling’s morphological characteristics is aimed in this research in case of Igneada forest nursery.

Materials and methods

Material

The study was conducted in Igneada Forest Nursery, located between 41°48’30”-41°49’20” North latitudes and 27°56’40”- 27°57’30” East longitudes in Demirköy in Kırklareli in Turkey. Igneada has a warm and temperate climate. During the vegetation season, there is enough amount of rainfall. According to the data of Igneada

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Meteorological Station, the average annual temperature is 12.6 °C, the mean annual precipitation is 699.6 mm. According to Thornthwaite, the water deficit is 226.4 mm and is mostly seen in July-August.

In the study, the seeds, obtained from sessile oak stand in Çakmaktepe subdistrict of Demirkoy Forest District Directorate were used. Firstly, the seeds were collected in second half of October, 2015 and acorns were floated in order to separate empty seeds in the nursery. Then, half of the seeds were sown without any process, and the remainder was stored in moist sand media for pre-germination (radicle reaching 2 cm) for 15-20 days at room temperature. The soil properties of the seed bed and seed covering material were given in *Table 1*.

The humus, which is formed from the decomposition of the litter accumulated in the lower and toe slopes the oak stands near by the nursery, was used as a seed covering material.

Table 1. *The soil properties of the seed bed and seed covering material*

Properties	Sand (%)	Silt (%)	Clay (%)	Soil texture	pH (H_2O)	EC (mS/cm^2)	$CaCO_3$ (%)
Seedbed soil	88	6	6	Loamy sand	6.55	72.70	0.08
Seed covering material	86	6	8	Loamy sand	5.82	22.50	0.10

Method

Plots were installed in a randomized parcels design with four replications on two adjacent seed beds. The whole plot treatment was radicle clipping (clipped and unclipped (radicles left intact)). Pre-germinated acorns, approximately 2 cm long radicles, were broken by hand from the tipping point. The subplot treatment was seedling density (five levels). There was a 35 cm isolation zone between subplots (experimental units). Seedbeds were standard 1.2 m wide and oriented in the north–south direction in the nursery. Sowing was made on 5 sowing drills (20 cm between drills) in fall 2015 for 1 + 0 seedlings, but seedlings in the middle 3 lines were used for measurements. Seeds were sown by hand, placing the three seeds each hole (distal ends pointing middle of the hole) and boards were used to establish correct spacing. Seeds were sown at each spot at 2 cm depth to ensure germination for proper density. Acorns were covered by seed covering material and additional fertilization did not applied. In the control plots, existing sowing density in the nursery (400-450 g/m² or 3 cm spacing) was used. Approximately one month after the emergence of the seedlings (5 cm seedling height), 6-9-12-15 cm spacing between the seedlings for each subplot was created respectively. Weak developed seedlings were cut from the soil surface for remaining one healthy seedling for each spot at the subplots. After the experimental design was applied in the nursery, routine weeding and irrigation activities were carried out (*Fig. 1*). Seedling roots were cut at 20 cm depth from the soil surface by using root cutting blade in the mid of September (*Fig. 2*). Seedlings were lifted by shovel from the seedbed at the end of November of 2016. Thus, seedlings were grown at 5 different seedbed densities with controls (*Table 2*).

40 seedlings for each treatment (10 seedlings × 4 replications) were randomly chosen without grading (total 400 seedlings). Some morphological seedling traits (shoot height, root collar diameter, seedling diameter, number of main or tap roots, number of lateral

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coarse roots, number of fine roots, fresh shoot and root weights, dry shoot and root weights, were determined in the laboratory (*Figs. 3-4*). Average seedling root length was the 20 cm because of the root cutting in the nurserybed. After careful washing, seedlings were separated into stems and roots by cutting from root collar. Dry weights were determined after samples were dried at 105 °C for 24 h in oven.

Figure 1. *Weeding on the seedbeds*

Figure 2. *Root cutting of seedlings below from 20 cm seedbed surface*

Table 2. *Spacing and average number of seedlings on 1 m²*

Applied spacing (cm)	Mean number of seedlings
3 (Control)	138
6	90
9	45
12	35
15	28

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Figure 3. *Measuring the shoot height*

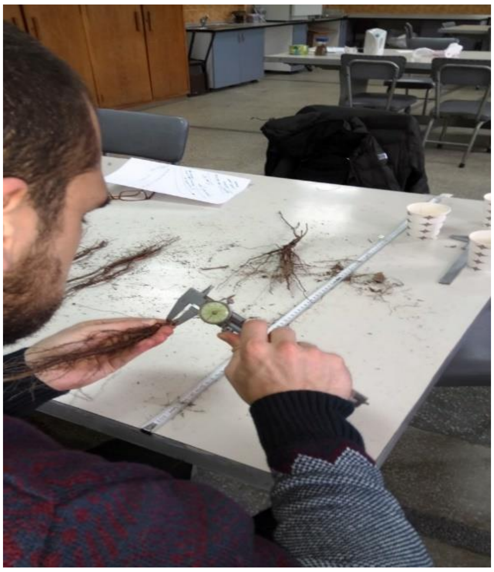

Figure 4. *Measuring the root collar diameter*

Morphological features were measured in seedlings, listed below:
Shoot height (SH) (cm): The distance from the root collar to the tip of the terminal leader.
Root collar diameter (RCD) (mm): The diameter value of the different colored and slightly raised place where the root system starts.
Seedling diameter (SD) (mm): Diameter at 2 cm above from the root collar.
Number of main Roots (MRN): The number of root alike tap roots (number) that make up the root system (pcs).
Number of lateral coarse roots (CRN, diameter ≥ 2 mm).
Number of fine roots (FRN, diameter < 2 mm and longer than 5 cm).
Fresh shoot weight (FSw): Weight of above ground parts of seedlings (gr).

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Fresh root weight (FRw): Weight of subsoil parts of seedlings (gr).
Seedling fresh weight (SFw): Total weight of seedling's stem and root.
Dry shoot weight (DSw): Seedling's stem (shoot) weight of oven dried at 105 °C for 24 h.
Dry root weight (DRw): Seedling's root weight of oven dried at 105 °C for 24 h.
Seedling dry weight (SDw): Total dry weight of seedling's shoot and root.
Dry root percentage (DRP): Dry root weight / Dry seedling weight (DRw + DSw).
Shoot / root ratio (SRR): Dry shoot weight / Dry root weight (DSw/DRw).
Sturdiness quotient (1) (SQ1): Shoot height (cm) / root collar diameter (mm).
Sturdiness quotient (2) (SQ2): Shoot height (cm) / seedling diameter (mm).
Dickson quality index (1) (DQI 1): Seedling dry weight / (SQ 1 + SRR).
Dickson quality index (2) (DQI 2): Seedling dry weight / (SQ 2 + SRR).

After the morphological measured values of the seedlings were transferred to the computer, the normality test was performed and then analyses of variance (ANOVA) were used to evaluate the radicle clipping and seed bed density effect by using the SAS package program. Significant differences between variable means were determined by Duncan test ($P < 0.05$).

Results

The means of the seedling morphological variables for radicle clipping and seedbed density are shown in *Tables 3, 4, 5* and *6*. According to the analysis of variance, radicle clipping had a significant effect on seedling diameter (SD), dry shoot weight (DSw), Dixon's quality index (2) (DQI (2)) 5%, shoot to root ratio (SRR) 1%, number of main roots (FRN) 0.1% alpha level (*Table 3*).

Decrease of seedbed density (increase of spacing) had a significant effect on shoot height (SH), Dixon's quality index 1 (DQI (1)) 5%, root collar diameter (RCD), fresh shoot weight (FSw), dry root weight (DRw), Dixon's quality index (2) (DQI (2)) 1%, seedling diameter (SD), number of fine roots (FRN), dry shoot weight (DSw), sturdiness quotient 1 and 2 (SQ (1-2)) 0.1% alpha level (*Table 3*).

Both radicle clipping and seedling spacing together had a significant effect on SH, DRw, DQI (1) 5% FRN, DSw, FSw, SQ (2) 1%, RCD, SD, SQ (1) 0.1% alpha level (*Table 3*).

Table 3. *Analysis of variance of one year old sessile oak seedlings*

Source	fd	SH	RCD	SD	FRN	FSw	DSw	DRw
Block	3	0.0158	0.764	0.1578	0.1758	0.3139	0.1678	0.2978
Radicle clipping	1	0.4916ns	0.1586ns	0.0444*	0.0512ns	0.0858ns	0.0248*	0.1039ns
Spacing	4	0.0011*	0.0027**	<.0001	<.0001	0.0033**	<.0001	0.0041**
Spacing × radicle clipping	4	0.0019*	<.0001	<.0001	0.0003**	0.0002**	0.0002**	0.0328*
Source	fd	MRN	SRR	SQ(1)	SQ(2)	DQI(1)	DQI(2)	
Block	3	0.9707	0.8801	0.1402	0.0144	0.949	0.472	
Radicle clipping	1	<.0001	0.0046**	0.6540ns	0.5940ns	0.1256ns	0.0452*	
Spacing	4	0.7672ns	0.9468ns	<.0001	<.0001	0.0332*	0.0053**	
Spacing × radicle clipping	4	0.1751ns	0.6753ns	<.0001	0.0044**	0.014*	0.0087**	
Error	27							

SH: Shoot height, RCD: Root Collar Diameter, SD: Seedling height, FRN: Number of fine roots, FSw: Fresh shoot weight, DSw: Dry shoot weight, DRw: Dry root weight, MRN: Number of main roots, SRR: Shoot to root ratio,SQ(1): Sturdiness quotient (1), SQ(2): Sturdiness quotient (2), DQI (1): Dickson quality index (1), DQI (2): Dickson quality index (2)

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Seedlings that were grown on 15 cm spacing (28 seedlings grown in 1 m²) and radicle clipped had a significant effect on SH, SD, FSw, DSw, DRw, MRN, DQI(2) 1%; DQI(1) 5% alpha level. Seedlings that were grown on 12 cm spacing (35 seedlings grown in 1 m²) and radicle clipped had a significant effect on MRN and SQ(1) 1%; SQ(2)5%, and radicle unclipped had a significant effect on RCD, SD, FSw, DSw 1%; DQI(1 and 2) 5% alpha level. Seedlings that were grown on 9 cm spacing (45 seedlings grown in 1 m²) and radicle clipped had a significant effect on RCD, SD, FSw, DSw 1%; QI(2). Seedlings that were grown on 6 cm spacing (90 seedlings grown in 1 m²) and radicle clipped had a significant effect on SRR 5%. Control (3 cm spacing) and radicle clipped had a significant effect on RCD and MRN 1%; radicle unclipped had an effect on FRN 0.1% and SQ(1) 1% level (*Table 4*).

According to the analysis of variance, SH, DSw, MRN, SRR and DQI (2) were significantly different on radicle clipped seedlings. Two groups according to the radicle treatment were revealed by Duncan's test. Means of the radicle clipped seedlings had the highest values comparing the unclipped seedlings (*Table 5*).

According to the analysis of variance, SH, RCD, SD, FRN, FSw, DSw, DRw, SQ (1-2) and DQI (1-2) were significantly different on seedlings which were grown on different spacings. Mean values were calculated over the radicle treatment (clipped and unclipped). Two groups were revealed by Duncan's test according to seedling height, control (3 cm) and 9 cm spacings group had the lowest means. Two groups were revealed by Duncan's test according to root collar diameter, control, 9 cm, 12 cm and 15 cm spacings group had the highest means. Four groups were revealed by Duncan's test according to seedling diameter, 12 cm spacing group had the highest mean, they were followed 9 cm and 15 cm spacings group. Five groups were revealed by Duncan's test according to dry shoot weight, control (3 cm) spacing group had the lowest mean (0.79 g), followed by 9 cm spacing group (0.83 g). Four groups were revealed by Duncan's test according to dry root weight, 12 cm spacing group had the highest mean. Four groups were revealed by Duncan's test according to sturdiness quotient (1-2), 9 cm spacing group had the lowest mean. Three groups were revealed by Duncan's test according to Dickson quality index (1) 12 cm spacings group had the highest mean, followed by 9 cm and 15 cm spacing group. Three groups were revealed by Duncan's test according to Dickson quality index (2), 12 cm spacings group had the highest mean (*Table 6*).

Discussion

Each year, millions of seedlings are sent to the forest for outplanting. However, many of those do not survive or grow well. Often, mortality and poor field performance are attributed to poor seedling stock quality. Each year's crop quality can vary due to several factors (Haase, 2007). The assessment focused on morphological attributes, which collectively give sufficient information on the quality of seedlings and their likelihood of survival upon outplanting. Although height, root collar diameter and their ratio are the easiest parameters for assessing tree seedling quality, they alone are inadequate to assess the seedling condition fully as they miss the root system (Haase, 2008).

Pre sowing radicle clipping and seedbed density effected some morphological traits of the 1 + 0 bare root sessile oak seedlings. Radicle clipping had a significant effect on seedling diameter (SD), dry shoot weight (DSw), Dixon's quality index 2 (DQI(2)),

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shoot to root ratio (SRR), dry root percentage (DRP), number of fine roots (FRN) and number of main roots (MRN).

Radicle clipping has raised seedling diameter. Seedling stem diameter is correlated with most morphological characteristics because it seems to integrate the entire seedling's morphological response to the environment. Certainly, diameter is correlated with height. Diameter is equally well correlated with shoot and root weight as well as total seedling weight (Mexal and Landis, 1990). Diameter is also related to root characteristics including root weight and root morphology, when seedlings are carefully lifted. At harvest, large diameter seedlings have more primary laterals (Rowan, 1987). While it is possible that large diameter seedlings inherently have a more fibrous root system, it is more likely that smaller seedlings have thinner primary lateral roots that are more easily stripped during the lifting operation. The improved field performance ascribed to larger diameter may, partially, be the result of decreased root stripping. Even though stem diameter is strongly correlated to both root and shoot weight, the relationship between diameter and R:S ratio is less clear (Mexal and Landis, 1990).

Table 4. *Comparison of radicle treatment effect on some morphological differences of one-year old sessile oak seedlings grown at different sowing densities*

Morphological attributes	Radicle treatment	Sowing densities					
		Control	6 cm	9 cm	12 cm	15 cm	Mean
Shoot height (cm)	Radicle clipped	13.53ns	14.39ns	14.89ns	15.77ns	16.92**	15.1
	Unclipped	14.49ns	15.97ns	13.44ns	16.00ns	14.50ns	14.88
Root collar diameter (mm)	Radicle clipped	5.89**	4.55ns	5.94**	5.10ns	5.81ns	5.46
	Unclipped	4.70ns	5.00ns	5.09ns	6.12**	5.40ns	5.26
Seedling diameter (mm)	Radicle clipped	3.88ns	3.45ns	4.19**	3.95ns	4.16**	3.92
	Unclipped	3.55ns	3.64ns	3.59ns	4.47**	3.67ns	3.78
Number of coarse roots	Radicle clipped	0.79ns	1.22ns	0.96ns	1.11ns	1.28ns	1.07
	Unclipped	0.68ns	0.57ns	0.66ns	0.93ns	1.36ns	0.84
Number of fine roots	Radicle clipped	12.54ns	13.77ns	12.3ns	11.52ns	12.18ns	12.46
	Unclipped	20.14***	13.72ns	12.96ns	11.95ns	9.76ns	13.71
Fresh shoot weight (gr)	Radicle clipped	1.42ns	1.32ns	1.81**	1.52ns	1.83**	1.58
	Unclipped	1.5ns	1.29ns	1.28ns	1.91**	1.37ns	1.47
Dry shoot weight (gr)	Radicle clipped	0.77ns	0.98ns	0.97**	0.99ns	1.21**	0.98
	Unclipped	0.8ns	0.89ns	0.69ns	1.24**	0.86ns	0.9
Fresh root weight (gr)	Radicle clipped	4.97ns	4.34ns	5.82ns	5.23ns	5.89ns	5.25
	Unclipped	5.47ns	4.96ns	4.97ns	6.35ns	4.88ns	5.33
Dry root weight (gr)	Radicle clipped	2.55ns	2.92ns	2.99ns	3.2ns	3.66**	3.06
	Unclipped	2.61ns	2.88ns	2.46ns	3.55ns	2.71ns	2.84
Number of main roots	Radicle clipped	1.83**	1.53ns	1.51ns	1.77**	1.75**	1.68
	Unclipped	1.29ns	1.32ns	1.34ns	1.16ns	1.18ns	1.26
Dry shoot/dry root	Radicle clipped	0.34ns	0.36*	0.35ns	0.34ns	0.35ns	0.35
	Unclipped	0.32ns	0.31ns	0.31ns	0.34ns	0.32ns	0.32
Sturdiness quotient (1)	Radicle clipped	2.36ns	3.29ns	2.58ns	3.19**	2.93ns	2.87
	Unclipped	3.15**	3.28ns	2.7ns	2.64ns	2.73ns	2.9
Sturdiness quotient (2)	Radicle clipped	3.56ns	4.45ns	3.62ns	4.06*	4.09ns	3.96
	Unclipped	4.12ns	4.45ns	3.87ns	3.56ns	4.00ns	4
Dickson quality index (1)	Radicle clipped	1.32ns	1.15ns	1.39ns	1.27ns	1.5*	1.33
	Unclipped	1.04ns	1.12ns	1.13ns	1.63*	1.2ns	1.22
Dickson quality index (2)	Radicle clipped	0.91ns	0.89ns	1.03*	1.00ns	1.13**	0.99
	Unclipped	0.8ns	0.83ns	0.8ns	1.23*	0.83ns	0.9

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Table 5. *Effect of radicle clipping on some morphological attributes*

Treatment	Seedling diameter (mm)	Dry shoot weight (g)	Number of main roots (n)	Shoot to root ratio	Dickson quality index (2)
Radicle clipped	39.25a	0.99a	1.68a	0.35a	0.99a
Radicle unclipped	37.84b	0.90b	1.26b	0.32b	0.90b

Means in the same column followed by the same lowercase are significantly different than the others according to Duncan's post-hoc test (P < 0.05). Mean values were calculated over the five sowing densities

Table 6. *Effect of sowing densities on some morphological attributes*

Sowing density (cm)	Seedling height (cm)	Root collar diameter (mm)	Seedling diameter (mm)	Number of fine roots	Fresh shoot weight (g)	Dry shoot weight (g)	Dry root weight (g)	Sturdiness quotient (1)	Sturdiness quotient (2)	Dickson quality index (1)	Dickson quality index (2)
Control	14.01b	5.29a	3.71bc	16.34a	1.46bc	0.79d	2.58c	2.76bc	3.84bc	1.18b	0.86b
6 cm	15.18a	4.78b	3.54c	13.75b	1.20c	0.94bc	2.90bc	3.28a	4.45a	1.14b	0.86b
9 cm	14.17b	5.51a	3.89b	12.63bc	1.55ab	0.83dc	2.73c	2.64c	3.74c	1.26ab	0.91b
12 cm	15.89a	5.61a	4.21a	11.74bc	1.72a	1.11a	3.38a	2.91b	3.81bc	1.45a	1.12a
15 cm	15.72a	5.60a	3.92b	10.97c	1.60ab	1.03ab	3.18ab	2.83bc	4.05b	1.35ab	0.98ab

Means in the same column followed by the same lowercase are significantly different than the others to Duncan's post- hoc. test (P < 0.05). Mean values were calculated over both clipped and unclipped samples

When the radicle is pruned, multiple taproots are induced (Lyford, 1980; Barden and Bowersox, 1989; Tilki and Alptekin, 2006; Devine et al., 2009; Caliskan, 2014). The multiple taproots originated where the radicle had been clipped. Barden and Bowersox (1990) found that radicle clipping of northern red oak resulted in greater height increment. But they also found that the response to the treatments varied greatly by family, with several families producing more new roots following clipping, while others showing no change.

While clipping tended to produce a more branched root system for blue oak seedlings grown in containers, it had no discernible effect on field performance of these seedlings, or of directly sown acorns (McCreary, 1996). On harsh sites where early root-soil contact influences survival, however, the potentially greater root surface area resulting from multiple taproots may increase establishment success (Devine et al., 2009). In this study, radicle clipping has promoted the number of taproots and fine roots. Same result was found for Chinese cork oak (Liu et al., 2016). Radicle clipping raised root to shoot ratio. The ratio of root to shoot dry mass represents the balance between the transpiration area and the water absorbing area of seedling. Seedlings with higher R/S ratios have a competitive advantage in drought tolerance (Grossnicle, 2005a; South,1993).

Radicle clipping has raised Dickson's quality index. It would provide a superior measure of nursery stock quality. However, it does provide an objective basis for comparing the results of nursery management practices and may be useful to practicing foresters and nurserymen in assessing the relative quality of the nursery harvest in any given year (Dickson et al., 1960).

Seedbed density had a significant effect on seedling height (SH), root collar diameter (RCD), seedling diameter (SD), fresh and dry weights of shoot (FSw and DSw), dry root weight (DRw), number of fine roots (FRN), sturdiness quotient 1 and 2 (SQ1-2), Dickson's quality index 1 and 2 (DQI 1-2).

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Decreasing seedbed density (increasing the growing space) had positively affected shoot height and root collar diameter (Brissette and Carlson, 1987; Cicek et al., 2007; South et al., 2016). Contrary to these findings, shoot height increased by increasing seedbed density for northern red oak (Thomlinson et al., 1996) and no response was observed for white oak (Wichman and Coggeshall, 1983). Tall seedlings are difficult to plant, out of balance (poor shoot: root ratio) and susceptible to wind rock (Ritchie, 1984). Tall seedlings may, however, be genetically superior. Rather than culling these seedlings, top moving or clipping has been instituted in the nursery to reduce height and make these seedlings plantable (Duryea, 1984).

At higher growing densities, height growth should be restricted through water stress and undercutting. These practices tend to shift the allocation of photosynthesis into diameter and root growth (Mexal and Landis, 1990). But shoot height has not been consistently correlated with survival (Mullin and Svaton, 1972; Pinchot et al., 2018). The greater the height of a seedling, the greater the leaf area available for photosynthesis and transpiration and the greater the seedling’s weight and bulk. Greater weight and bulk, of course, decrease the number of seedlings that can be carried by an individual during planting. Height affects the shoot/root ratio of seedlings. Diameter has often been considered the best single predictor of field survival and growth. A quality seedling with respect to height is one that is as tall as possible while still possessing an acceptable level of survival potential for the designated site (Thompson, 1985). Tall seedlings are exposed to greater water stress than smaller seedlings under harsh conditions (Grossnickle, 2005b) because root systems cannot supply enough water to transpiring foliage to maintain a proper water balance (Grossnickle, 2005a). Thus, shorter seedlings can have an advantage on stressful sites (Mexal and Landis, 1990).

Seedling root-collar diameter (RCD) is a general measure of seedling sturdiness, root system size, and protection against drought and heat damage (Mexal and Landis, 1990). Increasing the growing space for each seedling results in larger stem diameters, increased dry weights, and more uniform crop size for most species. Lowering seedbed density produces seedlings with larger stem diameters and heavier shoots and roots. Furthermore, seedlings grown at lower densities may have an improved ability to regenerate new roots (Duryea, 1984). Seedlings grown at lower densities had more additional first order lateral roots. As bed density increases, roots seem to be more restricted than shoots. Healthy shoots can be produced from deficient root systems in the nursery because ideal conditions of moisture and nutrition are easily supplied. However, seedlings with good shoots but deficient roots respond poorly in the field (Schultz and Thompson, 1997). Field survival of seedlings varies regardless of seedbed density, but height growth of seedlings grown at lower densities most often is superior for several growing seasons after planting. However, all these benefits of growing seedlings at lower densities must in turn be weighed against the costs of using more land to produce the same number of seedlings (Duryea, 1984). Spacing affected root-collar diameters, heights, and percentages of plantable seedlings for 1 + 0 nutall oak and green ash (Kennedy, 1988). Decreased sowing density increased the number of first-order lateral roots, height, and root collar diameter of 1 + 0 northern red oak (Quercus rubra L.) seedlings (Schultz and Thompson, 1992).

The sturdiness quotient is the shoot height (h) in centimeters divided by the stem diameter (d) in millimeters (h/d). It reflects the stocky or spindly nature of the seedlings. Although a good indicator of the ability to withstand physical damage in all stock-types, it is of particular importance in container-grown seedlings where the sturdiness quotient

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can get very high on undesirable spindly stock (Thompson, 1985). Roller (1977) found that black spruce seedlings with sturdiness quotients greater than six were seriously damaged when exposed to wind, drought, and frost. In general, sturdiness quotient should closely parallel diameter in predicting survival and growth in the field (Thompson, 1985).

Dickson et al. (1960) developed the “quality index,” which involves seedling biomass in addition to height and diameter; Quality Index = (Total seedling dry weight / (SQ + SRR)). Seedling-quality assessments involving combinations of morphological characteristics appear to be useful indicators of field performance so long as the physiological condition of different planting stock is the same. In addition, they offer an easy method for quality assessment that can be used throughout the growing season to judge seedling crop development (Johnson and Cline, 1991). Root dry matter was found to have stronger correlation with the Dickson quality index, followed by stem base diameter. In other words, the larger the diameter, the greater the shoot dry matter volume, and the higher the DQI value, indicating better quality (Binnotto et al., 2010).

Conclusion

Considering the radicle clipping and seed bed density; It was determined that 15 cm on SH; 9 cm on RCD; 9 and 15 cm on SD; 6 cm on NSB; 9 and 15 cm on FSw and DSw;15 cm on DRw; control, 12 and 15 cm on MRN; 6 cm on SRR; 12 cm on SQ (1 and 2); 15 cm on DQI (1); and 9 and 15 cm on DQI (2) were effective. Seedbed density was not effective on FRN, CRN, FRw and DRP.

Effect of seedbed density on radicle unclipped seedlings; it was determined that 12 cm on RCD, FRN, FSw, DQI (1-2); 6 and 9 cm on DRP; control on SQ (1-2). Seedbed density has not affected other seedling quality parameters.

Decreasing precipitation and increasing temperature will be the main problem of plantation forestry due to climate change. High quality seedlings are often a critical requirement for successfully implementing forest restoration programs to create healthy, functional and resilient ecosystems (Haase and Davis, 2017). Small seedlings are more robust plants with less sensitivity to wind and drought stress (Ivetic et al., 2016). Among all seedling morphological attributes, root-collar diameter (when categorized in classes) was the best predictor of second-year outplanting survival in all studied species in survival (Tsakaldimi et al., 2013). Total dry matter is often used as an indicator of plant field survival, it represents the net gain in dry matter form and is considered one of the best parameters for indicating plant quality (Manas, 2009). Shoot to root ratio indicates the balance between the transpiration area (the leaves) and the plant roots (water and nutrient absorption regulation) (Mandre, 2003). This indicator is used to determine the growth capacity of plants under adverse conditions (Thompson, 1985). A low sturdiness quotient value is associated with more robust plants with a higher probability of field survival, especially in areas with strong winds, landslides, drought, and salinity (Grossnickle and MacDonald, 2018). A high Dickson quality index value is desirable, as typically found in robust plants with an optimal balance between shoot and root biomass, predicting a high field performance due to high vigor (Manas et al., 2009).

Seedlings which have low height, large root collar diameter, low dry shoot weight, high dry root weight, low shoot to root ratio, low sturdiness quotient and high-quality index, have higher expected chance of survival, especially in windy and dry sites. In light of these findings, for the production of 1 + 0 sessile oak bare root seedlings in

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Igneada forest nursery conditions, where radicle clipping is applied, 9 cm seedbed density can be used, without radicle clipping, 12 cm seedbed density is advised. This conclusion needs to be supported by field performance. Limitation of the present study is that the experiment was conducted in the nursery conditions, but results might be differing in the field due to morphological attributes.

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