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Original Research Article

Influence of Initial Seedling Size and Root Pruning Intensity on Growth of Transplanting Seedling of *Quercus acutissma*

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Abstract - The objective of this study was to examine the effect of root pruning intensity in combination with different initial seedling size on the growth of transplanting seedlings of *Quercus acutissima*. One-year-old seedlings were divided into three groups depending on their height, i.e. small (< 15 cm), medium (25-35 cm) and large size (35 cm <). Root of seedlings was pruned by three intensity such as, leaving 5 cm (severe), 10 cm (medium) and 15 cm (light) of taproot from the root-collar. After one year, we investigated survival rate, height and root-collar diameter (RCD) increment and final shoot dry weight. Also we measured characteristics of newly developed lateral roots such as number, total length, dry weight and diameter. Severe root pruning showed the lowest survival rate in all seedling size. Height increment, RCD increment and shoot dry weight were decreased with increasing intensity of root pruning. Seedlings of medium and light root pruning showed similar above-ground growth and dry weight of lateral roots. More large seedlings showed good survival rate, height increment and final shoot dry mass in all root pruning intensity. Therefore, one-year-old seedlings of *Q. acutissima* should be pruned taproot by 10 cm and transplanted to obtain excellent performance and increase the efficiency of transplanting work. Based on the findings of this study, it is important that applying to different root pruning intensity depending on initial seedling size for producing 2-year-old seedlings with excellent growth and high quality.

Key words - Initial seedling size, Lateral roots, *Quercus acutissima*, Root pruning intensity, Transplanting performance

Introduction

Quercus acutissima is most widely distributed oak tree species in Korea and has high adaptability and viability even on poor site. The timber of *Q. acutissima* has been used for structure wood, tool handle, mine timber, furniture, charcoal and medium for mushroom culture (Korea Forest Research Institute, 2007).

For successful outplanting, high quality seedlings with excellent survival and growth should be required (Duryea, 1985; Mattsson, 1997). High quality seedlings secured enough productivity included in affordable cost (Davis and Jacobs, 2005). Seedling quality is directly related to genetic composition, size, vigor, and nursery conditions, and is also affected by the management after gathering such as seedling storage (Davis and Jacobs, 2005).

Generally, root pruning was applied to tree seedlings in the nursery to ease transplanting and induce branching of the root (Andersen *et al*., 2000). It is well known that root pruning can stimulates new root growth (Castle, 1983) and rapidly producing new roots in response to root pruning (Farmer and Pezeshki, 2004). Also, root fibrosity and root growth potential were increased by root pruning (Ritchie and Dunlap, 1980). According to species, however, the effects of root pruning were varied (Brantley and Conner, 1997).

Traditionally, root of oak seedlings was pruned to 15 cm or 20 cm length (Allen and Kennedy, 1989; Schultz and Thompson, 1996). However, there were some reports that root pruning effect was various depending on the pruning intensity (Sterling and Lane, 1975; Yang *et al*., 2010).

Seedling size (height and/or diameter) are greatly different even in the seedlings of same age. If we applied fixed length in root pruning to various size of seedlings, the root pruning rate may be different (Farmer and Pezeshki, 2004). Thus, without consideration of seedling size, applying fixed length in root pruning may inhibit the production of high quality seedlings and planting success. There were many studies on

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the influence of seedling size or root pruning on seedling quality. However, the researches on the effect combined with two factors together were inadequate.

Well-developed and well-structured root systems with numerous laterals roots are one of the most essential attributes of high quality seedlings (Aldhus, 1994). Moreover, the form of root development of seedlings largely affects the plantation performance (Sutton, 1980; Burdett *et al*., 1983). Thus, investigation on root characteristics (root mass and volume, number of first order lateral root, root length and area index) is very important in assessing seedling quality and predicting field success (Rose *et al*., 1997; Jacobs and Seifert 2004).

The objective of this study was 1) to examine the influence of initial seedling size and root pruning intensity on above-ground growth and root development of *Q. acutissima* seedling after transplanting and 2) to determine the optimal intensity of root pruning in combination with different seedling size for successful establishment and excellent growth of seedlings.

Materials and Methods

Materials

One-year-old bareroot seedlings of *Q. acutissima* were used in this study, which were produced from mixed seed of seed orchard established by Korea Forest Research Institute and grown at 144 seedlings per m^2.

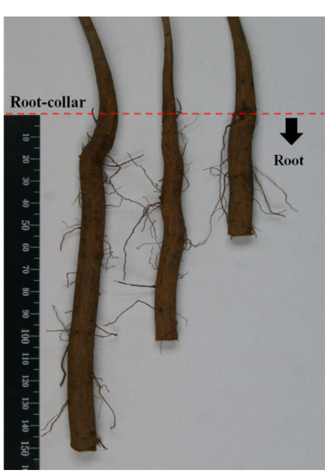

Fig. 1. Photograph of root pruning: left was cut 15 cm from the boundary of root and stem (red-dotted line); middle was cut 10 cm from the red-dotted line; light was cut 5 cm from the red-dotted line.

The seedlings were divided into three groups based on their height, i.e. small (< 15 cm), medium (25-35 cm) and large size (35 cm <). Root-collar diameter (RCD) was not considered in determining of seedling size group. All seedlings have single taproot with a few fine roots. Root of seedlings was pruned by three intensity such as leaving 5 cm (severe), 10 cm (medium) and 15 cm length of taproot (light) from the root-collar (Fig. 1).

Change of pruned taproot

As seedlings were being pruned, the taproot weight and removed rate were measured depending on the level of root pruning (Table 1). Dry weight of unimpaired taproot indicated 9.0 g in large seedlings, 8.1 g in medium seedlings, and 6.3 g in small seedlings, respectively. Removed rate in large seedling obtained 26.5% in 15 cm pruned, 50.6% in 10 cm pruned, and 77.0% in 5 cm pruned, and those of 15 cm, 10 cm and 5 cm in medium was 29.2%, 52.7%, and 78.3%, respectively. In small seedling, removed rate of was 15 cm, 10 cm and 5 cm was 32.4%, 55.3%, and 79.5%, respectively. As a result, the smaller seedlings got the less root weight. Also remove rate was increased as smaller seedling in same pruning intensity. In spite of the same intensity of root pruning, rate of removed taproot was different by seedling size.

Nursery phase

The seedlings were outplanted at nursery in April, 2011.

Table 1. Root dry weight and removed rate of root at different initial seedling size and root pruning intensity before transplanting

Seedling size	n	Root pruning	Root weight (g)	% Removed
Large (Over 35 cm)	101	unimpaired	9.0 ± 0.3	0
		15 cm	6.5 ± 0.2	26.5 ± 0.8
		10 cm	4.3 ± 0.1	50.6 ± 0.7
		5 cm	2.0 ± 0.1	77.0 ± 0.4
Medium (25~35 cm)	98	unimpaired	8.1 ± 0.3	0
		15 cm	5.6 ± 0.1	29.2 ± 1.1
		10 cm	3.7 ± 0.1	52.7 ± 0.9
		5 cm	1.7 ± 0.0	78.3 ± 0.5
Small (below 25 cm)	55	unimpaired	6.3 ± 0.3	0
		15 cm	4.1 ± 0.2	32.4 ± 1.5
		10 cm	2.7 ± 0.1	55.3 ± 1.1
		5 cm	1.2 ± 0.1	79.5 ± 0.7

The trial was laid out as a complete randomized block design with three replications. Total 648 seedlings included in these trials (3 seedling size × 3 root pruning × 3 replications × 24 seedlings). The planting density was 64 seedlings per m^2. After transplanting of seedlings in nursery, height and RCD were measured in all treatments.

Analysis

After one growing season, in April 2012, all seedlings were carefully lifted by hand. And then, we investigated survival rate, height and RCD, final shoot dry weight, and taproot and first-order lateral roots (FOLR) characteristics of all seedlings. Height and RCD were assessed two times 1) at the right after planting and 2) at the end of the growth period, respectively to calculation increment.

For biomass measurements the seedlings were divided into shoot and two parts of root (taproot + FOLR). Both shoot and two root parts were oven-dried at 70℃ for 48 h and weighted.

Using these data, we calculated seedling characteristics such as height to diameter ratio (HD ratio), shoot to root ratio (SR ratio), and seedling quality index (SQI, Dickson *et al.*, 1960). Also, the root to shoot ratio (RS ratio) was calculated by the root and shoot dry weights.

$$\text{SQI} = \text{Seedling dry weight (g)} / (\text{HD ratio} + \text{SR ratio})$$

Where, HD ratio = shoot height (cm) / root-collar diameter (mm), SR ratio = shoot dry weight (g) / total root dry weight (g).

Statistical analysis

Statistical comparisons were conducted using PROC GLM of the Statistical Analysis System (SAS Institute Inc., 1999). When F-values for treatment effects were significant (< 0.05 level), means were compared using Duncan's multiple range test. Data were compared at two levels; 1) between different root pruning intensity for each seedling size, 2) between different seedling sizes for root pruning intensity.

Results

Seedling survival

Root pruning influenced survival rate of pruned seedlings (Table 2). Survival rate of seedlings was significantly decreased when taproot had been pruned more severely (Fig. 2). In large size group of seedlings, the highest survival rate was observed in medium root pruning (pruned by 10 cm) and survival rate of light root pruning (pruned by 15 cm) was higher than that of severe (pruned by 5 cm) root pruning (P < 0.0031). In medium and small size groups of seedlings, the highest survival rate was found in light root pruning, while the lowest survival rate was found in severe root pruning at both seedling size (medium size: P < 0.0005; small size: P < 0.0001).

Seedling size at the time of transplanting influenced survival of seedling (Table 2). Large size group of seedling gave an excellent survival in all root pruning intensities. In other words, taller seedlings had lower mortality than smaller

Table 2. Analysis of variance of seedling size, root pruning and interaction on above-ground growth

	Root pruning	Seedling size	Interaction
DF	2	2	4
Survival rate	< 0.0001[y]	< 0.0001[*]	< 0.0001
Height increment	0.0041	< 0.0001	0.3557
RCD[z] increment	0.0113	0.0198	0.9171
Final shoot dry mass	< 0.0001	< 0.0001	0.3853

[z]Root-collar diameter.
[y]Probability.

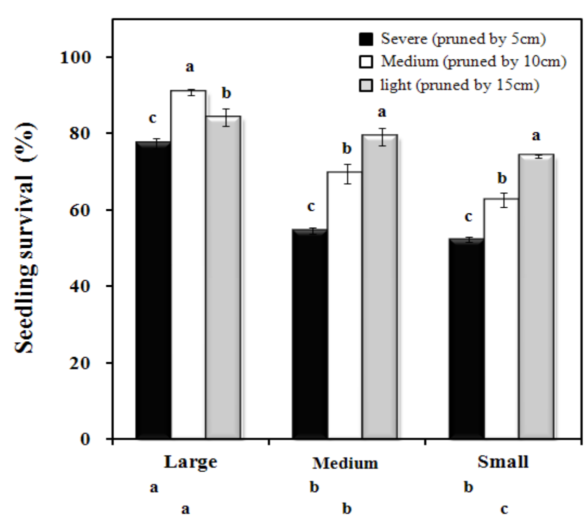

Fig. 2. Seedling survival by seedling size and root pruning intensity. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test.

seedlings (Fig. 2).

Above-ground growth

Seedling size influenced on the height growth, while RCD growth was not affected by seedling size (Table 2). Height and RCD increment was only significantly different in small group of seedling (Fig. 3). Generally, height increment of medium and light root pruning were higher than that of severe root pruning. On the other hand, RCD increment of medium root pruning was largest in all pruning intensity, although it was only significant in small size group of seedling. Large size in height increment was taller than medium and small size group of seedlings except for severe root pruning (Fig. 3).

Shoot dry weight was affected by both root pruning and seedling size (Table 2). Dry weight of final shoot was significantly reduced when root had been pruned severely in all seedling size. The heaviest dry weight of shoot was observed in light and medium root pruning in all seedling size (Fig. 4). Dry weight of large size group of seedlings was heavier than that of medium and small size group of seedlings in all root pruning intensities. However, there was no significant difference in dry weight between medium and small size group of seedling in all root pruning intensity.

Taproot regrowth

Pruning of the taproot and seedling size before transplanting had effect on the regrowth of taproot (Table 3). The highest and lowest regrowth of taproot was observed in light root pruning and severe root pruning all seedling size, respectively. Hence, although same root pruning intensity, taller seedling at the time of planting showed was more on regrowth of taproot (Fig. 5).

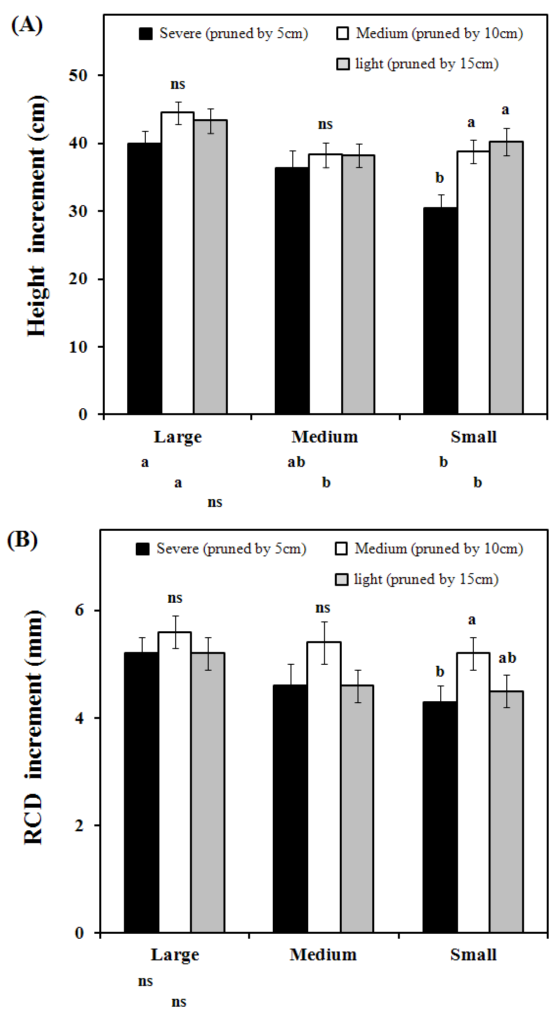

Fig. 3. Increment of seedling height (A) and root-collar diameter (B) by different initial seedling size and root pruning intensity. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test. ns; non-significant.

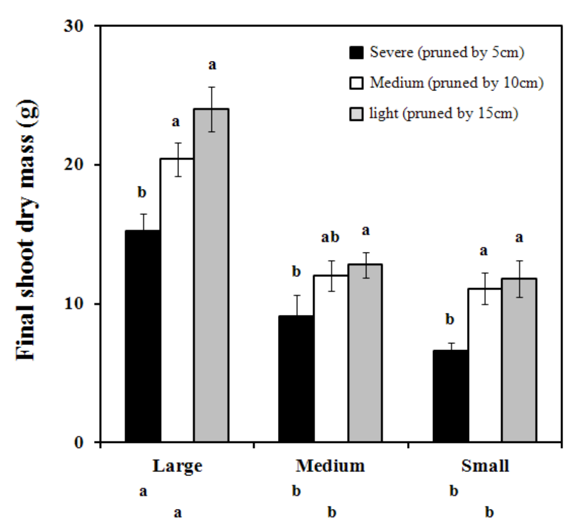

Fig. 4. Final shoot dry weight by different initial seedling size and root pruning intensity. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test.

Table 3. Analysis of variance of seedling size, root pruning and interaction on below-ground growth and seedling quality

	DF	Taproot weight	First order lateral root				R/S ratio[z]	SQI[y]
			Number	Length	Weight	Diameter		
Seedling size	2	< 0.001[x]	0.0412	< 0.001	0.0313	0.0082	< 0.0001	0.0023
Root pruning	2	< 0.001	0.0001	0.6008	0.0175	0.0002	< 0.0001	< 0.0001
Interaction	4	0.0092	0.0346	0.5371	0.5878	0.5792	< 0.0001	0.4067

[y]seedling quality index.
[x]Probability.
[z]root to shoot ratio.

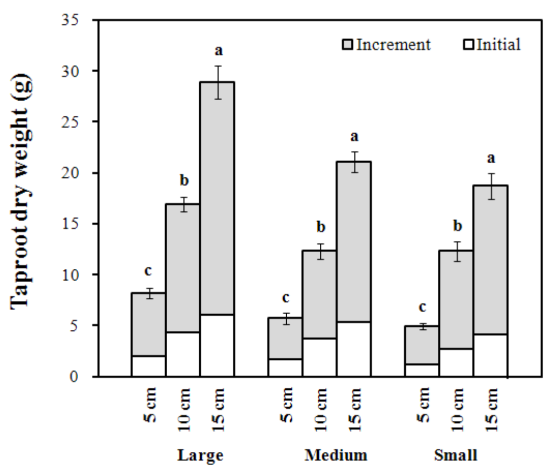

Fig. 5. Taproot dry weight by different initial seedling size and root pruning intensity at the time of transplanting. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test.

Development of FOLR

The length growth of first order lateral roots (FOLR) was affected by initial seedling size, while number and diameter of FOLR was influenced by root pruning. Interaction of initial seedling size and root pruning has no effect on taproot and FOLR growth (Table 3).

The number of FOLR per seedling was 3.0-5.2 in root pruned seedlings. Numbers of newly developed FOLR tend to be more abundant when roots had been pruned severely. Regardless of root pruning intensity, the smallest number of newly developed FOLR was observed in small size group of seedlings (Fig. 6A).

Length of FOLR was not shown a significant difference between root pruning intensity all seedling size. However, the lengths of newly developed FOLR tend to be longer in taller and more root pruned seedlings (Fig. 6B).

Dry weight and diameter of FOLR in medium and light root pruning was heavier and thick than those of severe root pruning, respectively. Weight and diameter of FOLR of seedlings pruned by medium was shown similarly those pruned by light. There was no notable difference among seedling size on dry weight and diameter of newly developed FOLR (Fig. 6C and 6D).

Seedling quality

Seedling size and root pruning strongly affected RS ratio and SQI (Table 3). In all seedling size, the highest RS ratio was found in light root pruning and those of the medium and severe root pruning was similar. RS ratio was higher in small seedlings and lower in large seedlings. The effect of root pruning on RS ratio was similar to the effect on SQI. But, there were no significant differences among seedling size except for light root pruning (Fig. 7).

Discussion

One-year seedlings of *Q. acutissima* were root pruned before transplanting in order to estimate the pruning intensity of the best root pruning in combination with different initial seedling size. Severe root pruning (leaving 5 cm of taproot) had a pronounced effect on survival of the seedlings at all seedlings size. Height growth was reduced by severe root pruning in all seedling size. RCD increment was only significantly reduced in small size group of seedlings. In large and medium size group of seedlings, there were no significant differences in RCD increment (Fig. 3). Final dry weight of shoot was significantly reduced when taproot was more removed before planting (Fig. 4). Pruning of the taproot

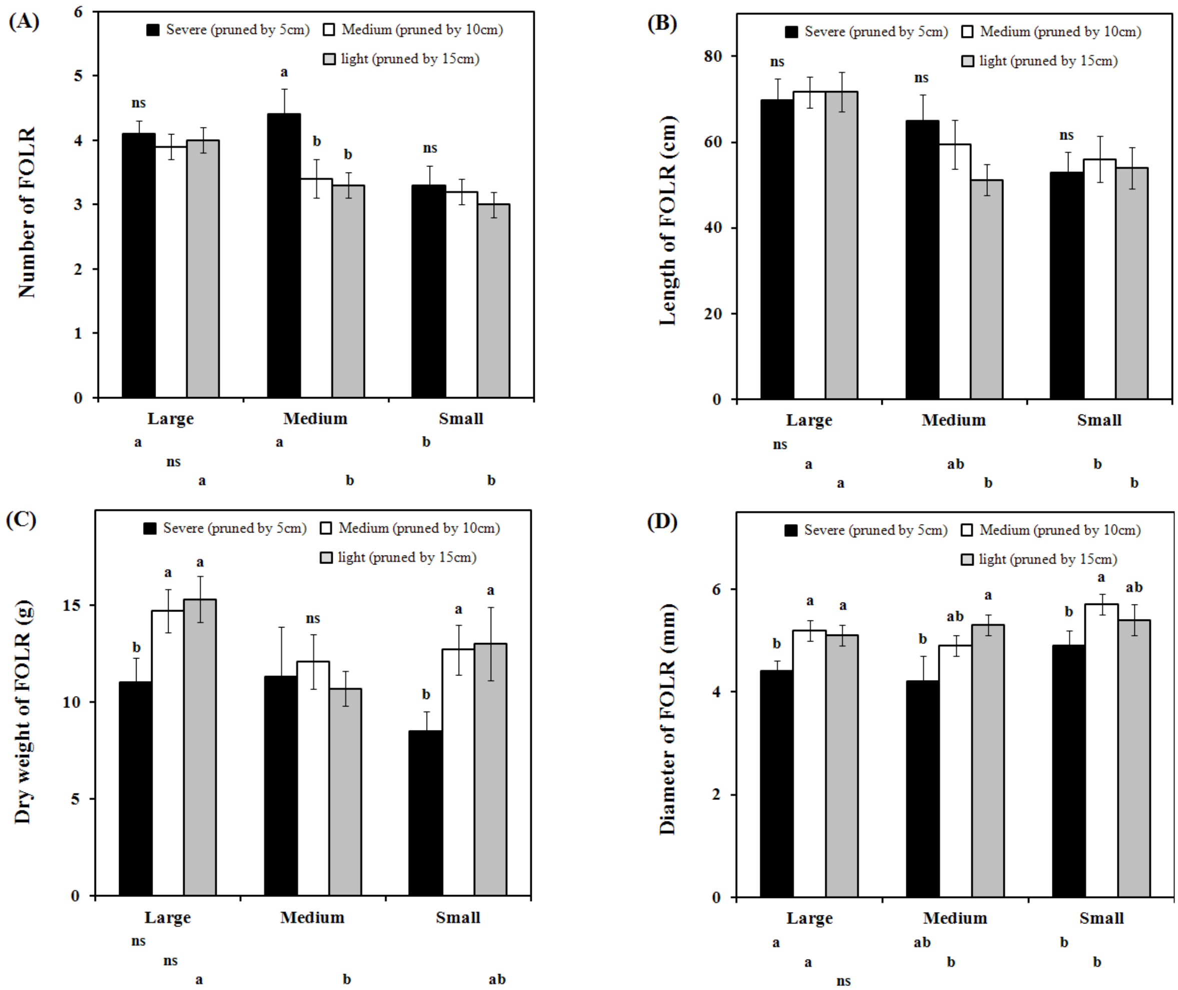

Fig. 6. Growth characteristics of FOLR by different initial seedling size and root pruning intensity at the time of transplanting. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test. ns; non-significant.

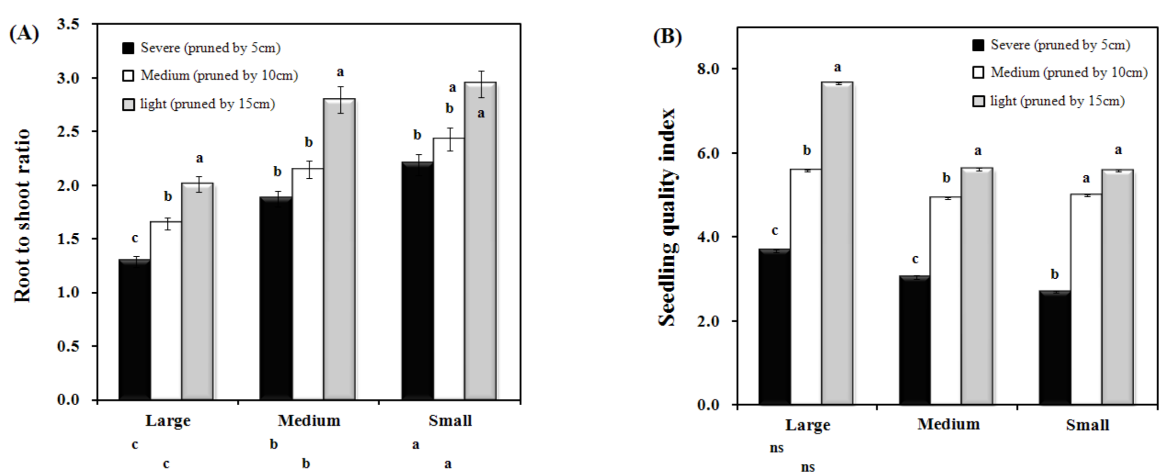

Fig. 7. Root to shoot ratio (A) and seedling quality index (B) by different initial seedling size and root pruning intensity. Different letters on the columns indicate statistical differences at the 5% levels by Duncan's multiple range test.

significantly decrease taproot regrowth in accordance with the severity of pruning (Fig. 5).

Root pruning stimulates new root growth (Castle, 1983), whereas others have found no effect on root growth (Geisler and Ferree, 1984), but a pronounced decrease in shoot growth with increasing severity of root pruning (Andersen *et al*., 2000; Brantley and Conner 1997; Geisler and Ferree, 1984; Solfjeld and Hansenf, 2004; Yang *et al*., 2010). The seedlings with heavier strength of root pruning were unable to uptake adequate water and nutrient due to the decreased root-soil contact and root surface area from root pruning (Farmer and Pezeshki, 2004). Therefore, It is essential that root pruned seedling was rapid root growth than what is needed (Burdett *et al*., 1984; Nambiar and Sands, 1993) because root pruned seedlings suffer water stress (Geisler and Ferree, 1984; Toliver *et al*., 1980). New root growth helps to alleviate this problem. Farmer and Pezeshki (2004) were presented that rapid new root growth in root pruned seedling needed to overcome an imbalance in the root to shoot ration in order to provide adequate water and nutrient absorption to support future growth and development.

In this study, seedlings of large size had higher survival rate, taller height, greater shoot weight, and longer lateral roots than medium and small size seedling (Fig. 2-4, 6). Large seedlings produced better survival and growth than small seedlings (Burns and Brendemuehl, 1971, Dierauf and Garner, 1996; McNabb and Vanderschaaf, 2005; Mexal and Landis, 1990). Large red oak seedlings effectively compete against severe competition from newly germinated seedlings and other herbaceous vegetation (Kormanik *et al*., 1998), and the seedling size at planting has been found to be critical with regards to vegetation competition (Karlsson, 2002). Therefore, taller seedling was expected excellent early survival and growth in outplanting. But proper shoot to root ratio was also important consideration factor in outplanting.

Proper root to shoot balance and high seedling quality is critical for successful seedling establishment. Taller seedlings suffer more transplanting stress attributable to water stress caused by poor root-soil contact and limited amount of roots than shorter seedlings (Burdett 1990; Grossnickle and Heikurinen 1989). Also poor root-soil contact can occur after planting (Sands, 1984). Therefore, proper root and shoot balance may contribute to overcoming transplanting stress. Adequate shoot to root balance is an important because it is an assessment of seedling water uptake capability at the time of planting and those have the best potential for avoiding planting stress (Ritchie, 1984; Burdett, 1990; Mexal and Landis, 1990; Grossnickle, 2000).

Considering the results on number and length of newly developed FOLR in root pruned seedling, it was suggested that higher strength of root pruning gave better seedling growth (Fig. 6). In other words, the severe pruned seedlings made greater efforts to overcome the lack of absorbance of water and nutrients. However, dry weight and diameter growth of FOLR was reduced by severe root pruning.

Root growth is critical to the establishment of planted seedlings. Especially, well-developed FOLR closely related to capability of water and nutrient absorption can induce to increasing root surface, decreasing transplanting stress and increasing survival and growth after outplanting (Davis and Jacobs, 2005; Dey and Parker, 1997; Grossnickle, 2005; Noland *et al*., 2001; Ponder, 2000; Ward *et al*., 2000; Thompson and Schultz, 1995). Therefore, the number of FOLR may be an important factor determining seedling survival and growth (Kormanik 1986; Kormanik *et al*., 1995; Schultz and Thompson 1990; 1996). Longer FOLR length was associated with higher leaf gas exchange rates (Gazal and Kubiske, 2004), and was provided sites for initiation of new higher-order roots (Thompson and Schultz, 1995).

Other studies have found positive relationships between field performance and the number of FOLR (Kormanik, 1986; Thompson and Schultz, 1995; Dey and Parker, 1997; Ponder, 2000; Ward *et al*., 2000; Noland *et al*., 2001). Therefore, FOLR of seedling is very important to the growth of seedlings in transplanting.

For various reasons such as transplant shock (Struve and Joly, 1992), competing vegetation (Crow, 1988), lack of soil nutrient (Oak *et al*., 1991) and poor seedling quality (Clark *et al*., 2000; Ward *et al*., 2000), many transplants of hardwood species fail to survive and/or grow satisfactorily (Dixon *et al*., 1984; Jacobs *et al*., 2004). Seedling establishment is also depended on the environmental condition of planting site and seedling quality at the time of planting (Burdett, 1990). Therefore, seedlings used for transplant should have taller initial height and ability to develop excellent lateral roots after transplanting.

In other to produce high quality seedling for outplanting, different root pruning rate should be applied depending on the initial seedling size. If we do that, we would produce high quality seedlings with excellent growth and well-developed and well-structured root system.

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