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Short note

The effects of stock type and radicle pruning on blue oak morphology and field performance

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Summary — Blue oak (*Quercus douglasii* Hook & Arn) acorns were germinated and divided into three groups or stock types. The first group was directly sown in the field; the second was sown into containers and grown for 4 months before outplanting; and the third was grown for a year before outplanting. In addition, each of these groups was further divided into three radicle pruning treatments: i) radicles left intact; ii) 2–3 mm cut from radicle tip; and iii) radicles pruned back to 1 cm. Results indicated that radicle pruning dramatically altered the morphology of container seedlings, but had almost no effect on field performance. Stock type, however, dramatically influenced field growth and survival, with the directly sown acorns and the 4-month-old seedlings growing far faster than the 1-year-old seedlings.

blue oak / radicle pruning / regeneration / seedling production / California

Résumé — Les effets de la qualité des plants et du cernage racinaire sur la morphologie et la croissance de *Quercus douglasii*. *Des glands de* Quercus douglasii *ont été mis à germer et répartis en trois groupes ou types de plants. Le premier a été semé directement au champ, le second a été élevé en conteneurs pendant 4 mois, et le troisième pendant un an avant transplantation. De plus, chacun de ces groupes a été subdivisé en trois traitements de cernage racinaire : i) racines intactes, ii) ablation de 2–3 mm à l'apex, iii) cernage à 1 cm. Les résultats indiquent que le cernage a fortement modifié la morphologie des semis en conteneurs, mais n'avait pratiquement aucun effet sur les performances de croissance après transplantation. En revanche, le type de plants a fortement affecté la croissance et la survie au champ, les semis directs et les plants de 4 mois présentant de bien meilleures croissances que les plants d'un an après transplantation.*

cernage de racines / *Quercus douglasii* / production de plants / Californie

INTRODUCTION

Blue oak (*Quercus douglasii* Hook & Arn) is one of three species of native California oaks that is reported to be regenerating poorly in portions of the state (Bolsinger, 1988; Muick and Bartolome, 1987). It is a white oak, endemic to California, which grows primarily in the foothills surrounding the state's Central Valley. Blue oak

woodlands are the most extensive hardwood type in the state, comprising over a million hectares (Bolsinger, 1988), and are vital habitats to a wide range of wildlife species. These woodlands are also extremely important to water quality and yield – a subject of increasing public scrutiny and concern – since a large percent of the state's water originates at high elevations and flows through the oak woodlands before being diverted for agriculture, domestic uses, or flowing to the ocean. Oak woodlands are also very important aesthetically, since the tree-covered hillsides provide a distinctive character to the state's landscape. In the minds of many, oaks and oak woodlands are emblematic of California's appearance.

To assist in developing successful artificial regeneration techniques for blue oak, the following study was undertaken. It was designed to help evaluate and compare different stock types, including directly sown acorns, 4-month-old seedlings and 1-year-old seedlings. This project also examined the effects of trimming the radicles of germinated acorns on seedling morphology and field performance.

MATERIALS AND METHODS

Acorn collection and planting

Acorns for this study were collected in early October 1989, from a single blue oak tree located 3 km from the planting site, and placed in cold storage (2–5 °C). In late November, the acorns were removed and examined. Those that had begun to germinate, and had radicles at least 1.5 cm long, were returned to cold storage. Those that had not yet germinated, or had short radicles, were removed and placed on their sides in flats containing moist vermiculite to stimulate germination. These flats were kept on a laboratory bench and checked daily. When an acorn's radicle was 1.5 cm or longer, that acorn was removed and put into cold storage.

In early December, when approximately 800 acorns had radicles in the desired range (1.5–3 cm), the acorns were divided into three equal groups and assigned to different stock-type treatments. Stock type 1 were acorns to be directly sown into the field planting site. Stock type 2 were to be grown for 4 months in containers and then transplanted to the field. Stock type 3 were to be grown for a full year in containers before transplanting. Each of these groups were further divided into the following three treatments:

Treatment 1: control, radicles left intact;

Treatment 2: 2–3 mm of the radicle pruned from the tip;

Treatment 3: radicles pruned back to 1 cm.

Two of the groups were taken to the California Department of Forestry and Fire Protection Nursery at Davis, CA, for planting into containers, while the third was directly sown in the field during the following week.

The radicle pruning was done using a razor blade or sharp knife. After treatment, the acorns taken to the nursery were planted individually in open-ended paper containers, 5 cm square and 20 cm tall, using a potting mix containing peat moss, fir bark and vermiculite. They were then placed in an unheated shadehouse where they were regularly watered and fertilized.

Field planting and maintenance

The field planting site was located at the Sierra Foothill Research and Extension Center (SFREC), 30 km northeast of Marysville, at an elevation of approximately 200 m. Directly sown acorns were placed on their sides and positioned such that the radicles were pointing down. They were covered with 1–2 cm of soil.

The field plot consisted of 360 planting spots, on 1.2 m centers, within a deer and cattle exclosure. The plot layout contained four blocks. Within each block were ten rows of nine seedlings each. Each row contained one randomly positioned seedling from each of the nine treatment combinations (three stock types x three pruning treatments).

In November 1989, prior to planting, each planting spot was augured to a depth of 60 cm using a tractor mounted 15 cm diameter auger. Afterwards, the soil was placed back in the holes and several liters of water were added to help

settle the soil before planting. A 21 g slow release fertilizer tablet (20-10-5 NPK) was also placed in each hole at a depth of 20–30 cm. These tablets were placed in the ground in winter 1989 for the direct seeded acorns and 4-month-old seedlings, and in fall 1990 for the 1-year-old stock.

The 4-month-old seedlings were brought to the research center and planted in the field plot in early April 1990. At the time of planting, it had not rained for some time so the soil was quite dry and crumbly. We were concerned that the seedlings might not survive so we decided to provide 2 L of water to each seedling as they were planted. No further irrigation was provided to these, or to seedlings from the other stock types, during the remainder of the study. The 1-year-old seedlings were kept at the nursery until December 1990, when they were brought to the research center and planted.

The plot was kept moderately weed-free during the course of the study using a combination of herbicides and mowing. Glyphosate was sprayed on the plot before the study began, and again in the early spring of each year before the seedlings had commenced leaf-out. However, there was generally also a crop of late-season weeds which were removed mechanically.

Seedling morphology

At the time of field planting, 15 seedlings from each radicle pruning treatment for both the 4-month and 1-year-old seedlings were destructively harvested and a variety of morphological traits measured. The potting mix was carefully removed from the roots using both water and tweezers. The height, basal diameter and number of tap roots (main roots originating at the radicle trim point) were measured and recorded. Seedlings were then cut at the cotyledon scars, and the shoots and roots dried at 70 °C for 2 days. These were then weighed and the total seedling weights and shoot root ratios calculated.

Field measurements

The emergence date of the directly sown acorns was recorded in spring 1990. The plot was evaluated twice a week and the date when the shoot was first visible at the soil surface was noted. At the end of each growing season (usually late fall), when all late season flushing had ceased, the year-end height and basal diameter of each seedling planted in the field was recorded. The height was the distance from the ground to the tip of the longest branch. The diameter was the stem diameter approximately 2 cm above the ground. Average height, diameter and emergence date were calculated for surviving seedlings only. Since it was difficult to accurately assess the seedling mortality in the fall, year-end survival for a given year was considered to be the number of seedlings that leafed-out the following spring.

Statistical analysis

For the field plot, the average emergence date (direct seeded acorns in 1990 only), year-end height, diameter and survival for each of the nine treatment combinations (three stock types x three pruning treatments) were calculated for each block. Each variable was then analyzed using analysis of variance for a randomized block design. When significant differences were found for main effects (stock types or radicle pruning treatments), a least significant difference (LSD) test at $P = 0.05$ was performed to determine which treatments were significantly different from one another.

The morphological data were analyzed separately for 4-month-old and 1-year-old seedlings. Each of the variables was analyzed using a one-way analysis of variance to determine if there were significant differences ($P = 0.05$) among the pruning treatments.

RESULTS

Emergence date

Seedlings emerged over a 12-week interval beginning in early March. There were no significant differences in average emergence date among pruning treatments, although there was a general trend for seedlings from acorns with the most severe pruning to emerge slightly later.

Survival

Survival was nearly 100% for the outplanted 4-month-old seedlings at the end of their 1993 growing season (table I). Only two of the 120 seedlings originally planted died, apparently from the clipping of roots by gophers during the third field season. Survival of the 1-year-old seedlings was less (90%), but not significantly different. However, survival for the direct seeded acorns (76%) was significantly less than for either container type. The reduced survival of the acorns appeared mainly due to acorn losses within the first few weeks after sowing. Most of this appeared to result from the augured holes sinking after the first heavy rains (in spite of our efforts to water them in), causing exposure of the acorns, which were then discovered and removed by rodents.

For the 1-year-old seedlings, almost all of the mortality occurred during the first year, and appeared to be due to the poor physiological quality of the planting stock. Many seedlings turned partially brown and bent over and appeared to be suffering from transplant shock. This is also supported by the fact that height growth of the surviving 1-year-old seedlings during the first year was extremely small.

Survival of the three radicle pruning treatments, on the other hand, was almost identical. In 1993, survival of the three treatments, averaged over stock types, varied by 1% or less (table II).

Table I. Field performance of different stock types in 1993.

Stock type	*Survival (%)*	*Height (cm)*	*Diameter (mm)*	*Height increment (cm)*	*Diameter increment (mm)*
Acorns	76[b]	141.4[a]	23.8[a]	43.5[a]	8.0[a]
4-month-old seedlings	99[a]	148.5[a]	24.8[a]	44.0[a]	8.3[a]
1-year-old seedlings	90[a]	90.8[b]	15.6[b]	36.5[b]	5.5[b]

In each column, values not followed by the same letter are significantly different ($P \leq 0.05$) by a Fisher's protected LSD test.

Table II. Field performance of seedlings from different radicle pruning treatments in 1993.

Radicle pruning treatment	*Survival (%)*	*Height (cm)*	*Diameter (mm)*	*Height increment (cm)*	*Diameter increment (mm)*
Control (radicle intact)	88	131.3	21.8	40.3	7.3
3 mm cut off radicle tip	89	125.7	21.6	41.8	7.5
1 cm of radicle left	88	123.8	20.8	41.9	7.0

There were no significant differences ($P \leq 0.05$) among radicle pruning treatments using analysis of variance.

Height growth

There was a consistent pattern in total height among stock types over the 4 years of the study, with direct seeded acorns and 4-month-old seedlings growing significantly more than 1-year-old seedlings. By the end of 1993, average height of seedlings from these first two treatments was more than 50% greater than that of seedlings from the 1-year-old stock type (table I). However there were no significant differences among radicle pruning treatments for height or height increment during any of the years of the study, including 1993 (table II).

Diameter growth

Diameter growth followed a similar pattern to height growth, with the 1-year-old stock type growing much less than the other two types in. At the end of 1993, the average diameters of acorns and 4-month-old seedlings were well over 50% greater than that of the 1-year-old seedlings (table I).

As with height, differences among radicle pruning treatments were slight, with no significant differences in 1993 (table II).

Seedling morphology

Both 4-month-old and 1-year-old seedlings exhibited similar morphological responses to the radicle pruning treatments (tables III and IV). For both stock types, cutting off part of the radicle prior to planting caused the formation of significantly more main tap roots, but resulted in significantly less root weight and total seedling weight. The average number of main tap roots resulting from either radicle trimming was close to three for both stock types. The average number for the control 4-month-old seedlings was almost exactly one, while it was 1.7 for the 1-year-old seedlings. However, the only difference in the other morphological variables was for shoot root ratio for the 4-month-old seedlings, where the ratio for the control seedlings was less than that for the most severely pruned. For both seedling types, there were no significant differences between the two treatments that removed part of the radicle.

Not surprisingly, at the time of destructive sampling for morphological characteristics, the 1-year-old seedlings were much larger than the 4-month-old seedlings, because of their additional 8 months of growth. Their average dry weight was approximately ten

Table III. Morphology of 4-month-old seedlings from different radicle pruning treatments.

Radicle pruning treatment	*Shoot height (cm)*	*Shoot diameter (mm)*	*Shoot weight (g)*	*Root weight (g)*	*Number of main tap roots*	*Shoot root ratio*	*Total seedling weight (g)*
Control (radicle intact)	7.2	2.1	0.36	0.70[a]	1.0[a]	0.54[a]	1.06[a]
3 mm cut off radicle tip	8.3	2.3	0.33	0.52[b]	2.9[b]	0.67[ab]	0.86[b]
1 cm of radicle left	7.7	2.2	0.33	0.47[b]	3.1[b]	0.70[b]	0.80[b]

In each column, means not followed by the same letter are significantly different ($P \leq 0.05$) by a Fisher's protected LSD test.

Table IV. Morphology of 1-year-old seedlings from different radicle pruning treatments.

Radicle pruning treatment	*Shoot height (cm)*	*Shoot diameter (mm)*	*Shoot weight (g)*	*Root weight (g)*	*Number of main tap roots*	*Shoot/ root ratio*	*Total seedling weight (g)*
Control (radicle intact)	36.1	5.4	3.5	7.7[a]	1.7[a]	0.47	11.2[a]
3 mm cut off radicle tip	35.1	4.8	2.9	5.0[b]	2.8[b]	0.58	7.9[b]
1 cm of radicle left	27.2	5.0	2.6	6.2[ab]	3.0[b]	0.44	8.8[b]

In each column, values not followed by the same letter are significantly different ($P \leq 0.05$) by a Fisher's protected LSD test.

times as great, and their shoot height about four times as great.

DISCUSSION

As a member of the white oak group, blue oaks do not have embryo dormancy. As a result, they begin to germinate rapidly (even in cold storage) and in general cannot be stored for more than 4–6 months (Bonner and Vozzo, 1987). This early germination can cause viability problems, since the fleshy radicles are vulnerable to pathogenic fungi and can be severely damaged. Also, once the radicles grow over several centimeters long, they are difficult to plant either in containers or in bareroot nurseries without injury. However, this may not be a serious problem since Bonner (1982) reported that the breaking of radicles prior to sowing for Shumard (*Q shumardii* Buckl) and cherrybark oak (*Q falcata* var *pagodaefolia* Ell) did not adversely affect seedling production.

Some nursery operators intentionally clip off part of the radicles of germinated acorns prior to sowing. Schettler and Smith (1980) reported that tip-pinching of radicles was used to induce root branching. This practice generally inhibits the development of a main carrot-type tap root, and causes the formation of several tap roots and a more fibrous root system. It is thought that such a root system may confer an advantage to seedlings, by providing a greater root surface area for the absorption of moisture and nutrients. However, to date, there has been relatively little research on this subject. Harmer (1990) reported that without any modification of the radicles, northern red oak (*Q rubra* L) seedlings produced single tap roots that had little or no branching in the top 5 cm. 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.

This is the first study that we are aware of that examines the effects of radicle clipping on a California oak species. 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. This is somewhat surprising since root morphology of both red and white oaks has been closely tied to field performance, with seedlings having greater numbers of first order lateral roots more successful and competitive after outplanting (Schultz and Thompson, 1992).

Stock type, however, greatly influenced field performance. The most striking result

was the poor growth of the 1-year-old container seedlings compared to either directly sown acorns or 4-month-old seedlings. The poor growth was obvious the first field growing season, and continued into the fourth year. This may have resulted from the fact that these seedlings had outgrown their containers during the year they spent in them, and consequently, became 'pot-bound'. As a result, they had difficulty adapting to their new environment after outplanting, and grew slowly or died.

The extremely high survival and rapid growth of the 4-month-old seedlings was also surprising, since almost all container oaks produced in California are grown for a year or longer before outplanting. By 1993, this stock type had significantly greater height, diameter, and height and diameter increments than the 1-year-old seedlings. These results suggest that this type of planting material may be very desirable for regenerating blue oaks in California. This is encouraging since 4-month-old seedlings are much cheaper to produce than 1-year-old seedlings. With such a short rearing interval, it may also be possible for a container nursery to raise more than one crop of seedlings in a single year.

It is more difficult to compare the 4-month-old seedlings with the directly sown acorns. While the height, diameter and height and diameter increments of the 4-month-old seedlings were generally greater than those of the acorns, none of these differences were significant during any year of the study. The acorns did have significantly less overall survival (76 versus 99% in 1993), but the mortalities appeared mainly due to rodents, and this might not be a problem at planting sites where rodents are not present, or populations are low. Needless to say, acorns would be far cheaper to plant than 4-month-old seedlings.

Finally, the field results suggest that if a seedling survives through the first year after field planting, there is a high likelihood that it will remain alive. The average survival in 1993 was only slightly less than that in 1990.

CONCLUSION

This study indicates that trimming off part of the radicle of germinated blue oak acorns prior to planting has little or no influence on field performance of either directly sown acorns or container seedlings, and is therefore not recommended. The type of planting material used, on the other hand, can have a large influence on field performance. Both 4-month-old seedlings and directly sown acorns can perform well in the field, with average height growth in excess of 30 cm annually, even though blue oak is considered one of the slower growing species of California oaks. If large numbers of acorn-eating rodents are present at the planting site, seedlings should be used. Otherwise, acorns should be planted.

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REFERENCES

Barden CJ, Bowersox TW (1990) Genotype and radicle clipping influence northern red oak root growth capacity. In: *Abstracts, Fourth Workshop on Seedling Physiology and Growth Problems in Oak Plantings*

(JW van Sambeck, MM Larson, eds), USDA For Ser Gen Tech Rep NC-139, 2

Bolsinger CL (1988) The hardwoods of California's timberlands, woodlands and savannahs. USDA For Ser Res Bul PNW RB-148, Portland, OR, 148 p

Bonner FT (1982) The effect of damaged radicles of presprouted red oak acorns on seedling production. *Tree Planters' Notes* 33, 13-15

Bonner FT, Vozzo JA (1987) Seed biology and technology of *Quercus.* USDA For Ser Res Gen Tech Rep SO-66, New Orleans, LA, 26 p

Harmer R (1990) Relation of shoot growth phases in seedling oak to development of the tap root, lateral roots and fine root tips. *New Phytology* 115, 23-27

Muick PC, Bartolome JW (1987) Factors associated with oak regeneration in California. In: *Proceedings, Symposium on Multiple-Use Management of California's Hardwood Resources, 12–14 November, 1986 San Luis Obispo, CA* (TR Plumb, NH Pillsbury, eds), USDA For Ser Gen Tech Rep PSW-100, 86-91

Schettler S, Smith MN (1980) Nursery propagation of California oaks. In: *Proceedings, Symposium on Ecology, Management and Utilization of California Oaks* (TR Plumb, tech coord), USDA For Ser Gen Tech Rep PSW-44, 143-148

Schultz RC, Thompson JR (1992) Hardwood seedling root morphology and nursery practices. In: *Southern Forest Nursery Association Conference Proceedings,* 31-53