EFFECT OF ACORN MOISTURE CONTENT AT SOWING ON GERMINATION AND SEEDLING GROWTH OF WHITE OAK AND NORTHERN RED OAK

Shi-Jean Susana Sung, Paul P. Kormanik, Catharine D. Cook, Stanley J. Zarnoch, and Taryn L. Kormanik[1]

Abstract—White oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) acorns were collected locally or from seed orchards in October 2002. Mean acorn moisture content (MC) was 48 percent for white oak and 39 percent for northern red oak. These acorns were air dried to different MCs before being sown into nursery beds in early December 2002. Acorn MC at sowing had a great impact on germination percentage, especially for white oak. White oak acorns with 48, 40, 30, and 20 percent MC had 70, 53, 12, and 3 percent germination, respectively. Northern red oak acorns with 39, 35, 25, and 15 percent MC had 84, 80, 68, and 46 percent germination, respectively. However, acorn MC at sowing did not affect first-year seedling growth or grading for either species. In November 2003, another study of white oak acorn MC was implemented. Germination was 90, 57, and 22 percent for acorns with 49, 33, and 25 percent MC, respectively. In this experiment, as in the first one, acorn MC at sowing did not affect growth of white oak seedlings.

INTRODUCTION

There are six major steps in the process of artificial oak regeneration on high-quality mesic sites: acorn collection and handling, nursery protocol, seedling grading, site preparation, seedling outplanting, and stand maintenance. The success of each step is critical to the success of the next step, and early production of acorns by planted stands is essential to complete the cycle. Kormanik and others (1998, 2000, 2004) have demonstrated successful establishment of white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) stands using graded, high-quality 1-0 seedling stocks on high-quality mesic sites in Georgia and North Carolina. They also reported that vegetation control on these sites is essential for the continued growth of oak plantings. Northern red oak trees in this type of extensive management have produced acorns in < 8 years after outplanting (Kormanik and others 2004). Characteristically, this species is reported to start acorn bearing at age 40 to 50 years (Sander 1990).

Using an improved nursery protocol, Kormanik and others (1994) were able to consistently grow and grade seedlings to a minimum standard of 70 cm in height, 8 mm in root-collar diameter (RCD), and five first-order lateral roots (FOLRs) for many red oak species. However, growth of white oak seedlings with this specific nursery protocol has not been consistent among progeny from different mother trees. White oak acorn germination can be sporadic for progeny of some mother trees and > 80 percent for others (Kormanik and others 1997; Sung and others 2002, 2004). Negative effects of desiccation on acorn germination have been reported in various oak species, especially species in the white oak group (Connor and Sowa 2003, Farmer 1975, Finch-Savage and others 1996, Gosling 1989, Schroeder and Walker 1987). In almost all of these studies, however, the acorns were germinated in containers and under a controlled environment; thus, subsequent seedling growth was not followed. Here we tested the hypotheses that acorn MC at sowing is critical for germination and for subsequent seedling growth under field conditions for both white oak and northern red oak.

MATERIALS AND METHODS

Experiment 1

Open-pollinated white oak acorns were collected from seven mother trees in Athens, GA, and from three mother trees at the Georgia Forestry Commission's Arrowhead Seed Orchard (Milledgeville, GA) in October 2002. Open-pollinated northern red oak acorns were collected from eight mother trees in Athens, GA, and from two mother trees at the Georgia Forestry Commission's Flint River Nursery Seed Orchard (Montezuma, GA) in October, 2002. Immediately after collection, acorns were floated for 10 minutes. Only those that sank and did not have any holes, cracks, or discolored cap scars were used in the study. All acorns were stored in plastic bags at 4 °C until air-drying treatments were imposed in mid-November 2002.

Before the air-drying treatments were applied, 50 acorns from each family were randomly sampled and analyzed for the day zero MC (based on percent fresh weight). Acorns of each family of each species were randomly separated into four treatment groups. Fresh weight of each treatment group was recorded. Acorns in the air drying treatment groups were placed in glass trays on a lab bench. Room temperature was approximately 21 °C. Subgroups of five acorns each were marked and their fresh weight recorded on day zero. On various days throughout the air-drying process, these subgroups of acorns were removed for the determination of actual residual MC. The estimated residual MC on day X (MCx) for each treatment group was calculated as:

$$MCx\ (\%) = [(FWx - DW_0)/ FWx]*100\%$$

[1] Research Plant Physiologist, USDA Forest Service, Southern Research Station, Pineville, LA 71360; Principal Silviculturist and Biological Technician, respectively, USDA Forest Service, Southern Research Station, Athens, GA 30602; Research Mathematical Statistician, USDA Forest Service, Southern Research Station, Asheville, NC 28802; and Graduate Student, School of Forest Resources, University of Georgia, Athens, GA 30602.

Citation for proceedings: Connor, Kristina F., ed. 2006. Proceedings of the 13th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 640 p.

where FWx is acorn fresh weight on day X and DW_0 is acorn dry weight on day zero.

White oak acorns were air dried to 40 (40MC), 30 (30MC), or 20 percent MC (20MC). Acorns that were not air dried served as the control (C) and were stored at 4 °C throughout the drying treatment. Northern red oak acorns were dried to 35 (35MC), 25 (25MC), or 15 percent MC (15MC), or were not dried (C). When a group of acorns reached targeted MC, this group of acorns was stored at 4 °C until sowing. The stored acorns did not lose more MC during this short period of storage. A radicle protruded from about 40 percent of acorns in some white oak families during drying treatment or in storage at 4 °C. No radicle protrusion was observed with the northern red oak acorns.

Acorns were sown at the Whitehall Experimental Nursery (Athens, GA) in early December 2002. There were six replications for each species. In each replication, 10 families were randomly planted with 4 treatments randomly assigned within each family. There were 13 acorns per treatment per family per replication. Seedlings were grown according to the oak nursery protocol developed by Kormanik and others (1994). Germination was assessed in mid-April 2003. In January 2004, all seedlings were lifted and growth parameters recorded. The growth parameters assessed included seedling height (HT), RCD, number of FOLRs, lateral root fibrosity, and taproot forking. Only roots that originated from the taproot, had diameter > 1 mm, and had sturdy structure were counted as FOLRs. An arbitrary ranking system was used for lateral root fibrosity: 0 for absence of fine (< 1 mm in diameter) lateral roots on taproots; 1 for few fine lateral roots on taproots; 2 for intermediate number of fine lateral roots on taproots; and 3 for many fine lateral roots on taproots. Taproot forking was recorded as yes or no.

Experiment 2

Open-pollinated white oak acorns were collected from five mother trees in Athens, GA, and from three mother trees at the Arrowhead Seed Orchard (near Cockran, GA) in October 2003. Acorns from four of these trees were also collected for use in experiment 1. Only sunk and sound acorns (without any hole, crack, or discolored cap scar) were used in this experiment. Air-drying treatments were imposed on these acorns much as in experiment 1. In addition to the C treatment, acorns were air dried to 33 (33MC) and 25 percent MC (25MC). Two days before sowing, half of the acorns from each of the 33MC, 25MC, and C groups were soaked in water for 2 days and designated as 33S, 25S, and CS, respectively. Fewer than 2 percent of acorns in experiment 2 had radicle protrusion at sowing. Acorns were sown in late November 2003. There were four replications for each species. In each replication, eight families were planted randomly, and six treatments, namely C, CS, 33MC, 33S, 25MC, and 25S, were randomly assigned within each family. There were 13 acorns per treatment per family per replication. Seedlings were grown using the same protocol as in experiment 1. Germination was recorded in mid-April 2004. In late December 2004, all seedlings were lifted and growth parameters recorded.

Statistical Analysis

Both experiments were analyzed as split-plot designs with replication by means of blocks in the nursery beds. The whole-plot factor was family, which was assigned at random within each block. Experiment 1 had six blocks, and experiment 2 had four blocks. The subplot factor was acorn MC, which was assigned at random within each whole plot. Each subplot had 13 acorns that were assessed for germination and subsequently for HT, RCD, and FOLR number. Percent germination was computed as the percentage of the 13 acorns originally sown. The seedlings per subplot were considered subsamples. Nongermination of some acorns or early seedling mortality resulted in unequal numbers, and this was taken into account in the analysis. In addition, measures of lateral root fibrosity and taproot forking were recorded for white oak in both experiments. The analysis for family, MC, and the family*MC interaction was performed, least square means were computed, and Tukey-Kramer pairwise comparisons were obtained. PROC MIXED (SAS Institute 2004) was used for all analyses at the 0.05 significance level. Because some observations were missing, least squares means were nonestimable for various families, and not all 10 families were used in the analysis. Most analyses for northern red oak in experiment 1 were for eight families. Most analyses for white oak in experiment 1 were for five families, and most analyses for white oak in experiment 2 were for seven families. The exception was the analysis of percent germination, where all families were used.

RESULTS AND DISCUSSION

Experiment 1

Figure 1 shows some typical patterns in acorn MC change during air-drying treatment for white oak acorns (fig. 1A) and northern red oak acorns (fig. 1B). Mean acorn MC at day zero was 48 percent for white oak and 39 percent northern red oak. Between 3 and 5 percent of MC was lost during the first day of air drying. Throughout the air-drying period, estimated acorn MC was within 3 percent of actual MC obtained from subgroups of acorns for each species. Mean numbers of days required to dry white oak acorns to 40, 30, and 20 percent MC were 1.9, 4.3, and 7.0 days, respectively. Mean numbers of days required to dry northern red oak acorns to 35, 25, and 15 percent MC were 1.5, 4.7, and 9.3 days, respectively. The drying rates reported here probably represent the maximum MC loss rate for fallen acorns in field. This rate of MC loss is slower if the fallen acorns are covered by fallen leaves or if it rains often in late fall or winter. Nevertheless, the quickness of acorn MC loss warrants frequent and timely acorn collection for artificial regeneration purposes.

There were significant treatment differences in germination percentage for white oak acorns (table 1). Both the 30MC and 20MC treatments proved detrimental to white oak acorns. Connor and Sowa (2003) reported a sharp decrease, from 90 percent to 10 percent, in germination of white oak acorns when their MC dropped below 30 percent. After just a short period of drying (< 2 days), germination of the 40MC acorns was 17 percent lower than that of the C acorns (table 1). Finch-Savage and others (1996) and Gosling (1989) reported that MC levels < 40 percent were associated with dessication damage in *Q. robur* acorns. Özbingöl and O'Reilly (2005) reported that drying soaked *Q. robur* acorns from an MC of 46 percent to 37 percent decreased germination from 68 to 8 percent after 2 months of freezing storage. Although the current study did not test the effects of cold storage of acorns, sowing acorns in early December and scoring germination in April would make this study comparable to the study design

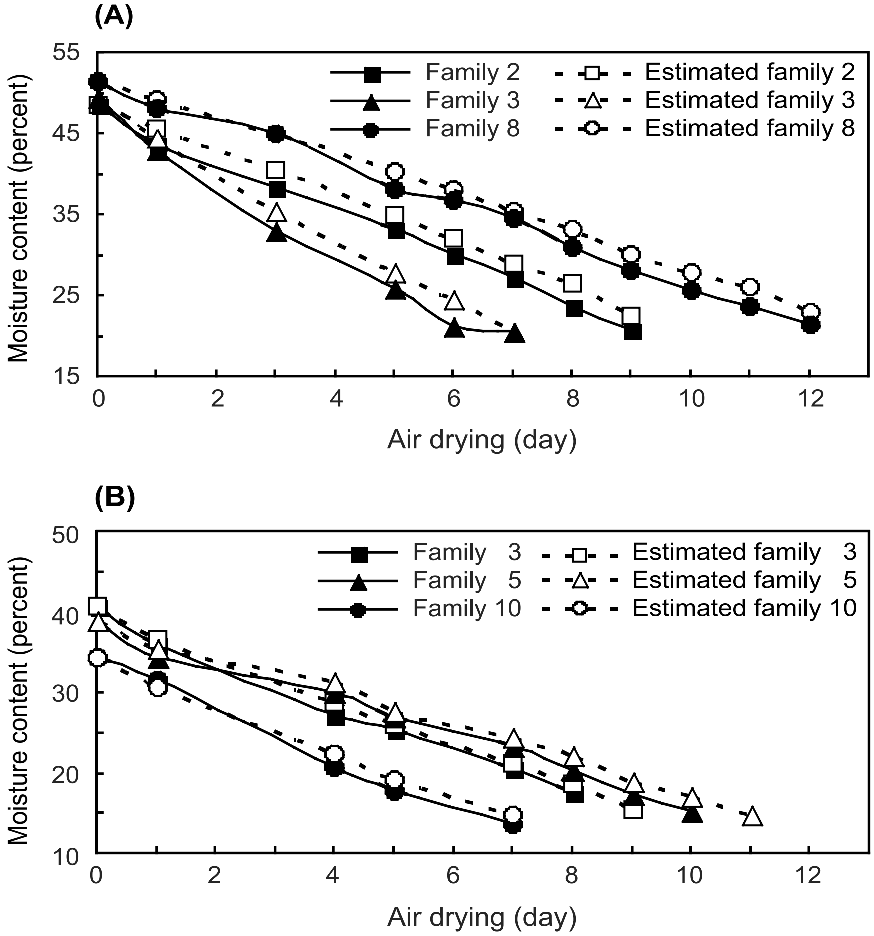

Figure 1—Acorn moisture content (MC) changes during air drying of acorns. Solid symbols represent actual MC, and open symbols represent estimated MC. (A) White oak acorns from families 2, 3, and 8, dried to about 20 percent MC. (B) Northern red oak acorns from families 3, 5, and 10, dried to about 15 percent MC.

Table 1—Effects of white oak acorn moisture content at sowing on germination and first-year seedling growth in 2003

Treatment	Germ[a]	HT[b]	RCD	FOLR	Lateral root fibrosity ranking[c]	Seedlings with forked taproot
Percent MC	*%*	*cm*	*mm*	*no.*		*percent*
C (48MC)	70d	39a	8.2a	3.3a	0.80a	10a
40MC	53c	40a	8.3a	3.3a	0.72a	28b
30MC	12b	41a	8.3a	2.8a	0.72a	14a
20MC[d]	3a	—[d]	—[d]	—[d]	—[d]	—[d]

Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.

Means in a column followed by the same letter are not significantly different at the 0.05 level.

[a] All 10 families were included in the statistical analysis.

[b] Five families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.

[c] Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

[d] Because the germination percentage for this treatment was very low, no values of growth parameters are presented.

of Özbingöl and O'Reilly (2005). Here we showed the sensitivity of white oak germination to acorn MC at sowing.

Germination percentages also differed significantly from family to family for white oak acorns (data not shown). No significant treatment*family interaction was observed, however. Generally, acorns collected at the Arrowhead Seed Orchard had much higher germination in all treatments than acorns collected from the field. In the C treatment, five families had > 80 percent germination, and three of these families were from the seed orchard. The other five families had germination ranging from 47 to 62 percent. In the C group, families that had the lowest (47 percent) and highest (89 percent) germination had, respectively, 50.7 and 49.4 percent acorn MC. The family that had the lowest MC (44.9 percent) had 81 percent germination. It is possible that besides MC, other factors, which are not readily apparent in this study, may contribute to low germination in some white oak families.

Because the germination percentage was extremely low for the 20MC treatment, differences in growth parameters were analyzed for the other three treatments (table 1). No treatment differences were observed for growth parameters such as HT, RCD, number of FOLR, or lateral root fibrosity. The percentage of seedlings with a forked taproot was higher for the 40MC treatment than for the C or 30MC treatments. Although this experiment was not designed to test the effect of taproot forking on subsequent survival and growth of transplanted seedlings, seedlings with forked taproots are usually harder to plant.

Table 2 shows the percentage of white oak seedlings in each treatment group that satisfied a set of seedling grading standards based on those developed by Kormanik and others (1994, 1997) but with some modifications. A shorter standard for HT (45 cm vs. 70 cm) was used here. Seedlings that met minimum HT and RCD standards and had > 0 lateral root fibrosity were considered meeting the grading standards even if they had fewer than five FOLR. Treatment effects did not change the percentage of seedlings meeting grading criteria (table 2), nor did they affect growth parameter means. Fewer than 30 percent of seedlings in any of the treatment groups met the grading standards. The percentage of seedlings that met the standards was lower for seedlings having a forked taproot than for those that did not have a forked taproot.

As with white oak MC, northern red oak acorn MC at sowing affected germination but not subsequent seedling growth (table 3). However, northern red oak acorns were less sensitive to drying than were white oak acorns. Germination percentages for the C and 35MC treatments did not differ. And, acorns with MC as low as 15 percent still had 46 percent germination (table 3). Although family affected germination percentages significantly, no correlation was found between day zero MC (which ranged from 34.4 to 42.9 percent) and germination percentage (which ranged from 71 to 97 percent) of the C group acorns.

Less than 0.5 percent of northern red oak seedlings had forked taproots in any treatment group (data not shown). Between 37 and 45 percent of northern red oak seedlings in each treatment met the grading standards (data not shown). Treatment means for northern red oak seedlings that met the standards were 89 to 99 cm for HT, 12.2 to 12.6 mm for RCD, and 9.3 to 9.6 for FOLR number. Treatment means for seedlings that did not meet the standards were 44 to 47 cm for HT, 7.8 to 8.4 mm for RCD, and 1.7 to 2.8 for FOLR number.

Experiment 2

In experiment 1, a high percentage of white oak acorns in some families started radicle protrusion during air-drying treatment or in cold storage. Therefore, experiment 2 was implemented within 2 weeks of acorn collection so that the effect of radicle damage would not be confounded with the effects of acorn MC on germination and growth. As in experiment 1, drying treatment in experiment 2 decreased germination but not subsequent seedling growth. Furthermore, soaking the 25MC acorns only increased their germination

Table 2—Effects of white oak acorn moisture content at sowing on first-year (2003) seedling grading results

Treatment	Meet grading standard[a]	Seedlings	HT	RCD	FOLR	Lateral root fibrosity ranking[b]	Seedlings with forked taproot
Percent MC		*%*	*cm*	*mm*	*no.*		*percent*
C (48MC)	Yes	23	65	11.0	7.9	1.24	17
	No	77	28	7.2	1.5	0.52	31
40MC	Yes	28	71	11.1	8.3	1.31	26
	No	72	28	7.3	1.1	0.47	40
30MC	Yes	23	74	11.6	9.8	0.91	4
	No	76	26	6.9	1.2	0.45	25
20MC	Yes	20	69	12.0	12.5	1.25	0
	No	80	26	6.8	2.3	0.69	13

HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.
[a] All 10 families were included in grading. Grading standards were 45 cm HT, 8 mm RCD, and 5 FOLR or presence of fibrous roots.
[b] Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

Table 3—Effect of northern red oak acorn moisture content at sowing on germination and first-year seedling growth in 2003

Treatment	Germ[a]	HT[b]	RCD	FOLR
% MC	*%*	*cm*	*mm*	*no.*
C (39MC)	84c	68a	10.0a	5.7a
35MC	80c	67a	10.0a	5.4a
25MC	68b	66a	9.8a	5.3a
15MC	46a	66a	9.9a	5.2a

Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots; MC = moisture content.
Means in a column followed by the same letter are not significantly different at the 0.05 level.
[a] All 10 families were included in the statistical analysis.
[b] Eight families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.

percentage to half that of the C acorns, although their MC was increased to a level similar to that of the C acorns (table 4). Even the 33S acorns did not have germination percentage as high as that of the C or CS acorns. Since the MC of these soaked acorns almost reached the MC of the C acorns, some irreversible damage must have occurred in some 25S and 33S acorns and rendered them not viable.

For treatments C, CS, 33MC, 33S, 25MC, and 25S, the percentages of white oak seedlings that met the grading standards were 20, 19, 19, 21, 12, and 16, respectively. Mean treatment growth parameters in experiment 2 (data not shown) were similar to those of white oak seedlings in experiment 1.

The cause of taproot forking observed with white oak seedlings in this study is not known. Table 5 presents the results of our efforts to identify any correlation between taproot forking and seedling growth. To avoid the confounding effect of the air-drying treatment, only the control groups in experiments 1 and 2 were analyzed. Also, all 10 families in experiment 1 and all 8 families in experiment 2 were included. Growth means for seedlings with forked taproots did not differ meaningfully from those for seedlings without forked taproots in either experiment. The percentage of white oak seedlings with forked taproots was higher in experiment 1, in which many acorns had radicle protrusion before sowing, than in experiment 2 (table 5). Furthermore, only 6 percent of seedlings with forked taproots met the grading standards in both experiments, whereas about 20 percent of seedlings with nonforked taproots met the grading standards. Barden and Bowersox (1991) showed that cutting off 50 percent of each protruding radicle before sowing increased northern red oak first-year seedling growth but not the first-year growth after transplanting. They did not report any taproot forking in their study. A more detailed study is needed of the effects of various kinds of damage to the protruding radicle before sowing on white oak germination and subsequent seedling growth, including taproot forking.

CONCLUSIONS

Germination of white oak acorns was very sensitive to acorn MC at sowing. Air drying of white oak acorns to 30 percent or lower MC resulted in < 25 percent germination. Soaking of the air-dried acorns helped increase germination to some extent. Air drying of northern red oak acorns to 15 percent MC decreased germination to about half that of the control acorns. First-year seedling growth in the nursery was not affected by acorn MC at sowing for either oak species. To achieve successful artificial oak regeneration, the first step is to collect acorns before they start to dry in the field. Soaking should help germination if the acorns have not lost too much moisture.

Table 4—Effects of white oak acorn moisture content (MC) at sowing on germination and first-year seedling growth in 2004. Acorns were air dried to the target MC and half of them were then soaked for 48 hours before sowing

Treatment	MC at sowing	Germ[a]	HT[b]	RCD	FOLR	Lateral root fibrosity ranking[c]	Seedling with forked taproot
	- - - - *percent* - - -		*cm*	*mm*	*no.*		*percent*
C	49	90e	34a	7.5a	3.6a	0.45a	12a
C+soak	49	88e	34a	7.5a	3.9a	0.42a	14a
33MC	33	57c	34a	7.7a	4.4a	0.43a	19a
33MC+soak	48	73d	33a	7.7a	3.9a	0.48a	19a
25MC	25	22a	31a	7.0a	3.2a	0.30a	12a
25MC+soak	46	42b	32a	7.5a	3.6a	0.53a	14a

MC = moisture content; Germ = germination; HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots.
Means in a column followed by the same letter are not significantly different at the 0.05 level.
[a] All eight families were included in the statistical analysis.
[b] Seven families that had seedlings in every treatment were included in the statistical analysis for all growth parameters.
[c] Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.

Table 5—Comparisons of white oak seedling growth of the controls in experiments I and II. Many acorns in experiment 1 had radicle protrusion at sowing and very few had radicle protrusion in experiment 2

	Experiment 1[a]		Experiment 2[b]	
Item	Forked	Nonforked	Forked	Nonforked
Seedlings (%)	28	72	13	87
HT (cm)	32	39	30	34
RCD (mm)	7.9	8.2	7.2	7.6
FOLR (no.)	1.4	3.5	2.5	3.7
Lateral root fibrosity[c]	0.79	0.65	0.52	0.43
Meeting grading standard (%)[d]	6	21	6	19

HT = height; RCD = root-collar diameter; FOLR = first-order lateral roots.
[a] All 10 families were included.
[b] All eight families were included.
[c] Ranking of lateral root fibrosity was: 0 = absence of fine (<0.5 mm in diameter) lateral roots on taproots; 1 = few fine lateral roots on taproots; 2 = intermediate number of fine lateral roots on taproots; and 3 = many fine lateral roots on taproots.
[d] Grading standards were 45 cm HT, 8 mm RCD, and 5 FOLR or presence of fibrous roots.

LITERATURE CITED

Barden, C.J.; Bowersox, T.W. 1991. Effects of radicle clipping on subsequent growth of red oak seedlings in high and low moisture environments. In: Coleman, S.S.; Neary D.G., eds. Proceedings of the sixth biennial southern silvicultural research conference. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 131-137.

Connor, K.F.; Sowa, S. 2003. Effects of desiccation on the physiology and biochemistry of *Quercus alba* acorns. Tree Physiology. 23: 1147-1152.

Farmer, F.T., Jr. 1975. Long term storage of northern red and scarlet oak seed. The Plant Propagator. 21: 11-14.

Finch-Savage, W.E.; Blake, P.S.; Clay, H.A. 1996. Desiccation stress in recalcitrant *Quercus robur* L. seeds results in lipid peroxidation and increased synthesis of jasmonates and abscisic acids. Journal of Experimental Botany. 47: 661-667.

Gosling, P.G. 1989. The effect of drying *Quercus robur* acorns to different moisture contents, followed by storage, either with or without imbibition. Forestry. 62: 41-50.

Kormanik, P.P.; Sung, S.S.; Kass, D.J. [and others]. 1998. Effect of seedling size and first-order lateral roots on early development of northern red oak on mesic sites. In: Waldrop, T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-20. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 247-252.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. 1994. Toward a single nursery protocol for oak seedlings. In: Proceedings of the 22nd southern forest tree improvement conference. Publication No. 44. [Place of publication unknown]: Southern Forest Tree Improvement Center: 114-123.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 1997. Heritability of first-order lateral roots in five *Quercus*: effect on 1-0 seedling quality evaluation. In: Steiner, K.C., ed. Diversity and adaptation in oak species. Proceedings of the second meeting of IUFRO working party 2.08.05, Genetics of *Quercus*. University Park, PA: Pennsylvania State University: 194-200.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 2000. Heritability of first-order lateral root number in *Quercus*: implication for artificial regeneration of stands. In: Stokes, A., ed. Supporting roots of trees and woody plants: form, function and physiology. The Netherlands: Kluwer Academic Publishers. Developments in Plant and Soil Sciences. 87: 171-178.

Kormanik, P.P.; Sung, S.S.; Kormanik, T.L. [and others]. 2004. Northern red oak from acorns to acorns in 8 years or less. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 555-558.

Özbingöl, N.; O'Reilly, C. 2005. Increasing acorn moisture content followed by freezing-storage enhances germination in pedunculate oak. Forestry. 78: 73-81

Sander, I.L. 1990. Northern red oak (*Quercus rubra* L.). In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America: 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 727-733.

SAS Institute. 2004. SAS/STAT user's guide. Version 9.1. Cary, NC: SAS Institute. 5121 p.

Schroeder, W.R.; Walker, D.S. 1987. Effects of moisture content and storage temperatures on germination of *Quercus macrocarpa* acorns. Journal of Environmental Horticulture. 5: 22-24.

Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 2002. Growth and development of first-year nursery-grown white oak seedlings of individual mother trees. In: Outcalt, K.W., ed. Proceedings of the 11th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 346-351.

Sung, S.S.; Kormanik, P.P.; Zarnoch, S.J. 2004. Flush development dynamics in first-year nursery-grown seedlings of eight oak species. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 542-546.