EFFECTS OF FLOOD DURATION AND DEPTH ON GERMINATION OF CHERRYBARK, POST, SOUTHERN RED, WHITE, AND WILLOW OAK ACORNS

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Abstract—Effects of flood duration (0, 10, 20, and 30 days) and depth (10 and 100 centimeters below a water surface) on acorn germination were tested for two bottomland oaks (cherrybark oak [*Quercus pagoda* Raf.] and willow oak [*Q. phellos* L.]) and three upland oaks (post oak [*Q. stellata* Wang.], southern red oak [*Q. falcata* Michx.], and white oak [*Q. alba* L.]). The study was a 4 x 2 factorial with a completely randomized design. Acorns of the five species were collected in November 1995 in Drew County, Arkansas and stored in a refrigerator at 4 degrees Centigrade until stratification. Acorns were stratified for 45 days in plastic germination flats with 20-cubic centimeter cells filled with a silt loam soil and then flooded in a small pond from March 19 to April 18, 1996. After flooding, acorns were germinated for 60 days. Flood depth did not significantly affect germination of any species, but flood duration affected germination of the three upland species. There was no interaction between flood duration and depth for any species. Among the upland species, germination of white oak acorns with 20 days or more of flooding was almost totally prohibited, while germination of southern red oak acorns gradually decreased as flood duration increased. Although germination of post oak was significantly reduced by 20 and 30 days of flooding, more than 65 percent of the acorns germinated. Results of our study indicate that the effects of flooding on the species composition of bottomlands begin with the germination process.

INTRODUCTION

Seasonal flooding frequently occurs in bottomlands and is a principal factor in determining tree species distribution (Hodges and Switzer 1979). Flooding may affect tree growth by displacing soil air and limiting root respiration along with other effects, and extended flooding can kill flood-intolerant trees (Kramer and Kozlowski 1979). Flood tolerance of the major bottomland hardwood species, including many oaks, has been summarized (Hook 1984; Allen and Kennedy 1989), but little is known about the flood tolerance of tree seeds. For instance, some species can develop aerenchymatous tissue to facilitate transport of oxygen to the roots, but this is not possible for seeds (Norton 1986). For the oaks, acorns of some species may be damaged by extended flooding, and damaged acorns may not be able to germinate or produce vigorous seedlings. There is some indication that acorns of the bottomland oaks can tolerate more flooding than upland species. For instance, 15 days of flooding severely reduced acorn germination of white oak (*Quercus alba* L.) (Bell 1975), but acorns of Nuttall oak (*Q. nuttallii* Palmer) were not affected by 34 days of flooding (Briscoe 1961). Guo and others (1998) found that spring flooding significantly reduced epicotyl emergence of black (*Q. velutina* Lam.) and northern red oak (*Q. rubra* L.) acorns but did not affect cherrybark (*Q. pagoda* Raf.) or water oak (*Q. nigra* L.).

Water depth may vary greatly during flooding based on location within the floodplain and intensity of the flood. Water depth may affect aeration, temperature, and pressure, which may influence acorn viability. The effect of flood depth on acorn germination has not been studied. Therefore, the objective of this study was to test the effects of flood duration and depth on acorn germination of five oak species common to the southern United States. The species were two bottomland oaks (cherrybark and willow oak [*Q. phellos* L.]) and three upland oaks (post oak [*Q. stellata* Wang.], southern red oak [*Q. falcata* Michx.], and white oak).

METHODS

In November 1995, acorns from an individual tree of the five oak species were collected in Drew County, AR. After conducting a float test, acorns were air dried overnight and stored in polyethylene bags at 4 degrees Centigrade. A silt loam soil (Typic Ochraquults) was collected in Drew County, AR. The soil was air dried and hand-processed to pass a 5-millimeter sieve. Plastic germination flats with sixty 20-cubic centimeter cells per flat were filled with soil, and twelve acorns of each of the five species were buried 1 centimeter below the soil surface with one acorn per cell. Acorns were buried in soil because small mammals commonly bury acorns and survival of acorns on the forest floor is generally low (Bowersox 1993). After sowing, the soil was saturated with distilled water, and flats were

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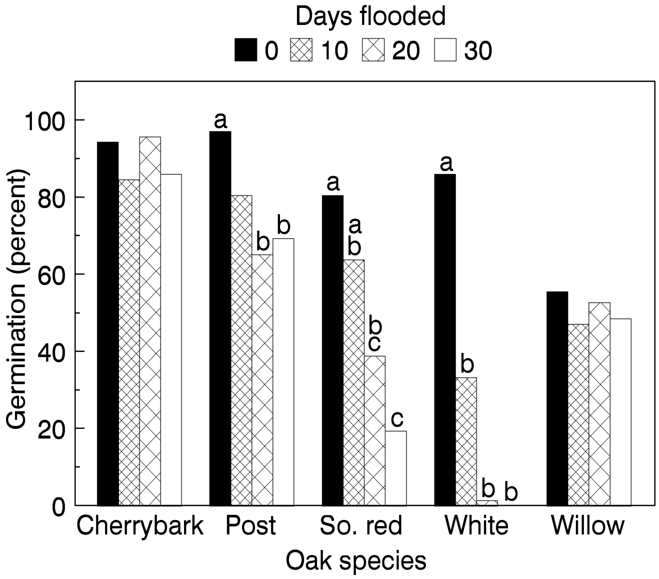

Figure 1—Effects of flood duration on germination of cherrybark, post, southern red, white, and willow oak acorns. Bars of a cluster with different letters differ at α =0.05.

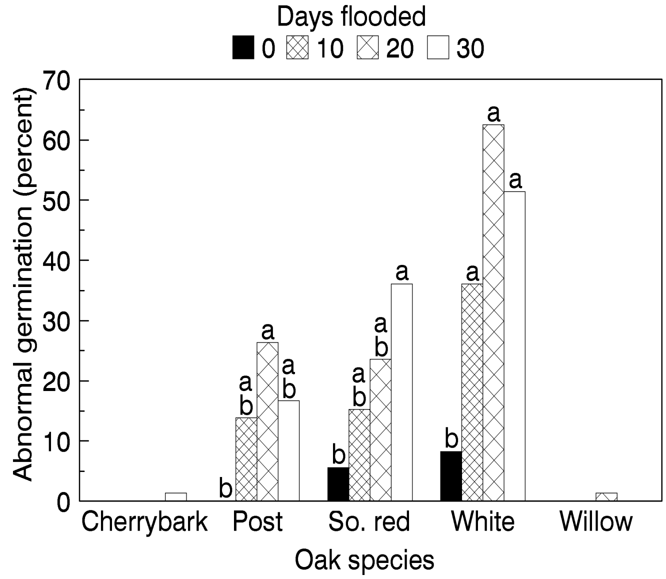

Figure 2—Effects of flood duration on the abnormal germination (a radicle or roots produced with no accompanying epicotyl or shoot) of cherrybark, post, southern red, white, and willow oak acorns. Bars of a cluster with different letters differ at α =0.05.

stored for 45 days at 4 degrees Centigrade to stratify acorns, assuring a uniform state of dormancy.

The study design was a 4 x 2 factorial with a completely randomized layout with treatments of flood duration and depth. There were four flood durations: 0 (control), 10, 20, and 30 days, and two flood depths: 10 and 100 centimeters below a water surface. Each treatment combination was replicated three times with 12 acorns per replicate. Flooding was conducted in a 0.2-ha pond in Drew County, AR from March 19 to April 18, 1996. Plastic germination flats with the 10-centimeter depth were protected with a wire screen (1.2-centimeter mesh) to keep out seed-consuming animals. A maximum-minimum thermometer was submerged with germination flats, and water temperature was recorded every 10 days. Flooding of replicates of the 10- and 20-day treatments was staggered in time so that environmental gradients occurring over the 30-day period could affect all treatment levels. Plastic germination flats awaiting flooding and those with completed flooding treatments were drained and stored at 4 degrees Centigrade until day 30 when all germination flats were collected. Minimum water temperatures for the 10-centimeter depth were 10.1, 11.0, and 14.6 degrees Centigrade, respectfully, for the three 10-day flooding periods, and maximum temperatures were 17.4, 19.3, and 22.3 degrees Centigrade. Corresponding minimum temperatures for the 100-centimeter depth were 10.6, 11.9, and 14.6 degrees Centigrade, and maximum temperatures were 14.4, 16.8, and 18.2 degrees Centigrade.

For germination tests, the plastic germination flats were placed in a laboratory with a bay of south-facing windows, exposing flats to diffuse sunlight. The germination flats were periodically irrigated with distilled water to keep the soil moist. Temperature in the laboratory was maintained at 20 degrees Centigrade. Epicotyl emergence of each acorn was recorded weekly over an 8-week period when length exceeded 2 centimeters. Seedlings were allowed to continue development in the germination flats after acorns were recorded as germinated. To assess possible germination activity at the time of flooding, subsamples of acorns were established that were identical to the unflooded control, except that they were removed from soil and examined at the beginning of the germination test; the four activity classes were none, acorn split, radicle $\leq$ 5 millimeters, and radicle >5 millimeters. At the end of the germination test, all ungerminated acorns were examined for decay and abnormal germination (a radicle or roots exceeding 2 centimeters but no corresponding shoot).

Germination results were analyzed by GLM of SAS (SAS Institute Inc. 1986). Significance was accepted at α = 0.05. Means were separated by the Ryan-Einot-Gabriel-Welsch multiple range test at α = 0.05.

RESULTS

Flood duration significantly affected germination of post (P = 0.03), southern red (P < 0.01), and white (P < 0.01) oak acorns, but did not affect cherrybark (P = 0.12) and willow (P = 0.89) oak acorns. Flood depth did not significantly affect germination of any species, and there was also no significant interaction between flood duration and depth. Temperatures averaged 15.8 degrees Centigrade for the 10-centimeter depth and 14.4 degrees Centigrade for the 100-centimeter depth, but the slight lowering of average temperature with increasing water depth was apparently not enough to affect flood damage.

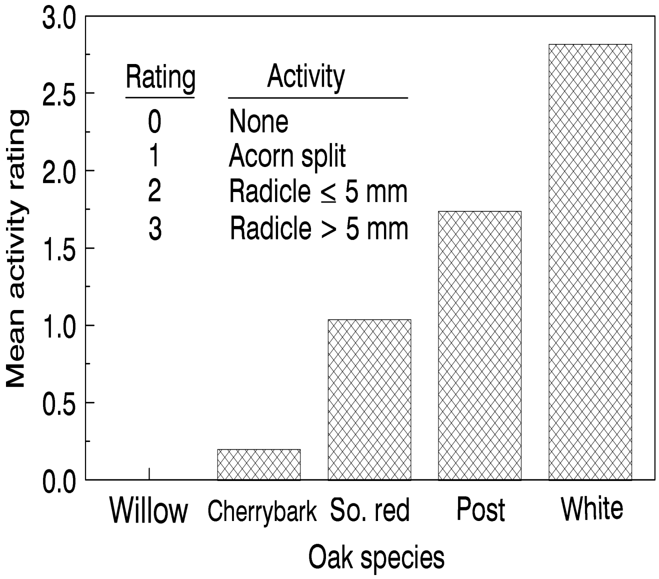

Figure 3—Activity rating of unflooded acorns of cherrybark, post, southern red, white, and willow oaks determined after 75 days of stratification which coincided with the end of the flooding treatments.

Germination rate of the control for post oak acorns was 97 percent, which did not differ from the 10-day flooding (81 percent) but was significantly greater than the 69 and 65 percent of the 20- and 30-day flooding treatments (figure 1). No difference was found among the three flood duration treatments. For southern red oak acorns, germination rate of the control was 81 percent. That was not different from the 10-day flood treatment at 64 percent but was significantly different from the 20- and 30-day treatments (39 and 19 percent). There were no differences between the 10- and 20-day treatments and between 20- and 30-day treatments. Compared to post and southern red oak, acorns of white oak were more severely affected by flooding. Germination rate of the control was 86 percent. With 10-day flooding, germination was reduced to 33 percent, which was significantly different from the control. Almost no germination occurred with the 20- and 30-day durations.

Cherrybark oak germination varied from 95 to 85 percent with the greatest germination rate occurring with 20-day flooding. Willow oak acorns varied within a narrow range (47-55 percent), but the germination rate was much lower than that of cherrybark oak.

Germination failures of post, southern red, and white oaks were mostly accounted for by abnormal germination, where radicles or roots developed without accompanying epicotyls or shoots (figure 2). Abnormal germination generally increased for these species with increasing flood duration. In contrast, abnormal germination was nearly nil for cherrybark and willow oak. For willow oak, most of the acorns that did not germinate were classified as being decayed, averaging 42 percent across all durations with no significant treatment effects.

The activity of unflooded acorns at the end of 75 days of stratification was considerably less for bottomland species than for upland species (figure 3). Willow and cherrybark oak acorns showed almost no activity. Most of the southern red oak acorns were split, but no radicles had emerged. In contrast, most post oak acorns had radicles less than 5 millimeters long, while most radicles of white oak were longer than 5 millimeters.

DISCUSSION

Among the five tested species, post, southern red, and white oaks are upland species, while cherrybark and willow oaks are bottomland species. However, cherrybark oak is seldom abundant on wet or swampy soils, and it grows best on loamy sites on the first bottom ridges (Krinard 1990). Willow oak is found on ridges and high flats of first bottoms of major streams, and on ridges, flats, and sloughs on second bottoms, but it grows best on clay loam ridges of new alluvium (Schlaegel 1990).

Cherrybark oak acorns are tolerant to flooding at least up to 30 days (Guo and others 1998). This study further shows that flooding in deep water in spring does not affect acorn germination of the species. Germination rates of the acorns were high, ranging from 81 to 97 percent across the treatments. In contrast, germination of willow oak acorns was only around 50 percent, including the control. It is not clear why the willow oak acorns had such low germination rates. Bonner (1974) found different germination rates for willow oak acorns collected at different dates; acorns collected on October 6 had a germination rate of 59 percent, compared to 86 percent on October 18, and 96 percent on November 1. Although our acorns were collected in November, they could have possibly fallen to the ground earlier.

For the three species affected by flooding, post oak showed considerable tolerance to flood damage. Even after 30 days of flooding, more than 65 percent of the post oak acorns germinated normally. Thus, flooding damage to acorns is probably not a significant factor limiting the distribution of post oak. Southern red oak also showed some tolerance to short-term flooding; the germination rate was more than 50 percent for 10 days of flooding. Thus, a short flooding period about 10 days is not likely to substantially reduce southern red oak acorn establishment. Compared to post and southern red oak, however, white oak acorns are very sensitive to flooding. Ten days of flooding reduced germination appreciably, and 20 days of flooding almost eliminated any possibility of germination. Bell (1975) also found that acorn germination of white oak was severely limited by 15 days of flooding. This sensitivity may be caused by the characteristic that white oak acorns germinate soon after they fall to ground. In this study, most acorns germinated during stratification. Increased metabolism within the acorns apparently made them susceptible to flooding. Martin and others (1991) pointed out that increased anaerobic metabolism can damage seeds through the buildup of toxic materials.

Although germination of southern red oak acorns was reduced significantly after 20 days of flooding in this study, different results were reported by Larsen (1963) who tested the effects of water soaking for up to 8 weeks on acorn germination of southern red oak, willow oak, laurel oak (*Q. laurifolia* Michx.), and overcup oak (*Q. lyrata* Walt.). Flooding did not affect germination of southern red and willow oak acorns, and both species had germination rates between 40 and 45 percent. The response of willow oak acorns to flooding is similar to that found in this study. However, the germination of southern red oak acorns without flooding in Larsen's study was much lower than that in our study, which may indicate considerable variation among the seed lots.

For upland species, the embryo axes of acorns were most severely damaged by flooding. Guo and others (1998) found similar damage for black and northern red oak acorns. However, radicles or roots often developed from the connective tissue between the embryo axis and the cotyledons, especially for white oak acorns. Some of the radicles and roots were still alive after 30 days of flooding and the 60-day germination test even though the embryo axes were apparently dead. However, no seedlings developed from the flood-damaged acorns because of the dead embryo axes.

One factor that affects distribution of species is flooding on alluvial sites. Tree seeds must be able to withstand flooding before seedlings can occupy alluvial sites. Cherrybark and willow oaks apparently have no problem becoming established on sites with spring flooding of up to 30 days. They may withstand additional flooding but further research is needed to confirm this. An interesting finding of our study is the tolerance of the post oak acorns to flooding. Post oak typically grows on dry sites on upper slopes (Stransky 1990), yet its acorns showed a fairly high tolerance to flooding. It is likely that the exclusion of this species on alluvial sites is due to some other factor than damage of acorns by flooding.

REFERENCES

Allen, J.A.; Kennedy, H.E., Jr. 1989. Bottomland hardwood reforestation in the lower Mississippi valley. Slidell, LA: U.S. Department of Interior, Fish and Wildlife Service, National Wetland Research Center; and Stoneville, MS: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 28 p.

Bell, D.T. 1975. Germination of *Quercus alba* L. following flood conditions. For. Res. Rep. 75-2. Urbana-Champaign, IL: University of Illinois, Department of Forestry. 4 p.

Bonner, F.T. 1974. Maturation of acorns of cherrybark, water, and willow oaks. Forest Science. 20: 238-242.

Bonner, F.T. 1996. Responses to drying of recalcitrant seeds of *Quercus nigra* L. Annals of Botany. 78: 181-187.

Briscoe, C.B. 1961. Germination of cherrybark and Nuttall oak acorns following flooding. Ecology. 42: 430-431.

Guo, Y.; Shelton, M.G.; Lockhart, B.R. 1998. Effects of flood duration and season on germination of black, cherrybark, northern red, and water oak acorns. New Forest. 15: 69-76.

Hodges, J.D.; Switzer, G.L. 1979. Some aspects of the ecology of southern bottomland hardwoods. In: North America's forests: gateway to opportunity. Joint Convention of the Society of American Foresters and the Canadian Institute of Forestry. 1978 October 22-26. St. Louis, MO: Washington, DC: Society of American Foresters: 360-365.

Hook, D.D. 1984. Waterlogging tolerance of lowland tree species of the South. Southern Journal of Applied Forestry. 8: 136-149.

Kramer, P.J.; Kozlowski, T.T. 1979. Physiology of woody plants. New York, NY: Academic Press. 811 p.

Krinard, R.M. 1990. Cherrybark oak. In: Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 644-649.

Larsen, H.S. 1963. Effects of soaking in water on acorn germination of four southern oaks. Forest Science. 9: 236-241.

Martin, B.A.; Cerwick, S.F.; Reding, L.D. 1991. Physiological basis for inhibition of maize seed germination by flooding. Crop Science. 31: 1052-1057.

Norton, C.R. 1986. Germination under flooding: metabolic implications and alleviation of injury. HortScience. 21: 1123-1125.

SAS Institute Inc. 1986. SAS user's guide: statistics. 5th edition. Cary, NC. 956 p.

Schlaegel, B. E. 1990. Willow oak. In: Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 715-720.

Stransky, J.J. 1990. Post oak. In: Burns R.M.; Honkala B.H. (eds.). Silvics of North America. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture: 738-743.