EVALUATING THE FLOOD TOLERANCE OF BOTTOMLAND HARDWOOD ARTIFICIAL REPRODUCTION

John M. Kabrick, Daniel C. Dey, and Jonathan R. Motsinger[1]

Abstract—We experimentally compared the survival and growth after flooding of six bottomland species: eastern cottonwood (cuttings) (*Populus deltoides* Bartr. Ex Marsh.), pin oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), bur oak (*Q. macrocarpa* Michx.), black walnut (*Juglans nigra* L.), and pecan [*Carya illinoensis* (Wangenh.) K. Koch]. Flood treatments (5-week flowing, 5-week stagnant, 3-week flowing, and control) were initiated in May, 2004, and plants were evaluated in September. Cottonwood maintained high survival and growth but had a significant basal diameter growth reduction with increased flood duration. Swamp white oak and pin oak each had greater survival than cottonwood, exceeding 95 percent regardless of treatment. Swamp white oak maintained high growth, regardless of treatment. Although not significant, pin oak and pecan had high survival but reduced growth and bur oak and black walnut had both reduced survival and growth with increased flood duration.

INTRODUCTION

Throughout the Central Hardwood Region, there is increasing interest in establishing bottomland hardwood seedlings. Collectively, thousands of acres in floodplains are being planted on both private and public land driven by bottomland restoration efforts (Shaw and others 2003, Kabrick and others 2005), the Wetland Reserve Program (Stanturf and others 2001), and efforts to establish riparian buffers in intensively-managed agricultural fields (Dey and others 2004, Schultz and others 2000).

Ensuring successful hardwood tree establishment requires carefully matching the ecological requirements and tolerances of the species to the environmental conditions of the planting site (Allen and others 2001). In bottomlands, it is particularly important that the planted seedlings are tolerant of the flood regime of the site.

Several factors influence the flood tolerance of bottomland seedlings. In addition to differences among species, other factors include the plant size and age, the timing and duration of flooding, and the flood water quality (Kozlowski and Pallardy 1997). In general reproduction is more vulnerable to flooding than are older trees. Floods during the growing season are more damaging than those during dormant periods because they restrict oxygen to roots when both root and shoot growth are most active. Additionally, stagnant flood water contains less oxygen than flowing water and thus is more damaging to plants (Kozlowski and Pallardy 1997).

Although much is known about the factors that influence flood tolerance, flood tolerance ratings remain largely qualitative. Flood tolerance often is expressed with vaguely-defined terms such as “moderately tolerant” or “somewhat tolerant” (Kabrick and Dey 2001). Even when explicitly defined, flood tolerance often has been determined observationally, based on case histories rather than experimentally from controlled studies where confounding influences were reduced or eliminated.

The wide-spread tree planting in bottomlands throughout the Central Hardwood Region has prompted us to more carefully examine the flood tolerance of bottomland hardwood reproduction. Our objectives were to compare survival, recovery, and growth after flooding of commercially-available hardwood planting stock and to compare our results to published tolerance ratings for the species we examined. Our findings are important for guiding species selection for hardwood plantings on both private and public land.

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METHODS

We tested six commonly-planted bottomland species in a state-of-the-art outdoor flood tolerance laboratory located at the Horticulture and Agroforestry Research Center in New Franklin, MO. This facility comprises twelve 20-foot wide x 600-foot long channels constructed on the floodplain of Sulfur Creek, a perennial stream that flows into the Missouri River. Water pumped from an adjacent retention pond can be regulated to control flood depth, duration, timing, and flow rate in each channel. Detailed information about the soil conditions at the flood tolerance laboratory is described by Van Sambeek and others (2007).

Species tested in this experiment included eastern cottonwood (*Populus deltoides* Bartr. Ex Marsh.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.), bur oak (*Q. macrocarpa* Michx.), black walnut (*Juglans nigra* L.), and pecan [*Carya illinoensis* (Wangenh.) K. Koch]. We established cuttings for cottonwood and planted 1-0 bareroot stock for the other species (table 1). All stock was purchased from the George O. White State Forest Nursery located near Licking, MO. These species and stock types were selected because foresters and wildlife managers often plant them and collectively their published flood tolerances range from intolerant to very tolerant. For each species, there is some inconsistency in the reported flood tolerance (table 2).

Table 1—Postplanting basal diameter and shoot length prior to flooding of the bare-root seedlings used in the study[a]

	Treatment			
Species[b]	Control	Three-week flood, flowing	Five-week flood, flowing	Five-week flood, stagnant
	inches			
Basal diameter				
Black walnut	0.22	0.22	0.21	0.21
Pecan	0.16	0.17	0.17	0.17
Bur oak	0.19	0.22	0.21	0.19
Pin oak	0.20	0.18	0.19	0.18
Swamp white oak	0.22	0.24	0.23	0.24
Cottonwood	—	—	—	—
	feet			
Shoot length				
Black walnut	1.7	1.8	1.8	1.9
Pecan	0.7	0.7	0.7	0.7
Bur oak	1.0	1.1	1.2	1.2
Pin oak	1.2	1.1	1.2	1.1
Swamp white oak	1.0	0.9	0.9	0.9
Cottonwood	—	—	—	—

[a] Basal diameter is the average of two measurements made in orthogonal directions. No pretreatment measurements were made on the cottonwood cuttings. For each species, there were no significant pretreatment differences in basal diameter or shoot length.
[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.).

Table 2—Published flood tolerances for the tree species evaluated in this study illustrating the range in flood tolerance among and within each species[a]

Species[b]	Flood tolerance[a]: Teskey and Hinckley 1977[c]	Whitlow and Harris 1979[d]	Allen and others 2001, Haynes and others 1988[e]
Black walnut	Intolerant	Intolerant	Weakly tolerant
Pecan	Intermediately tolerant	Tolerant to very tolerant	Weakly tolerant
Bur oak	Tolerant	Somewhat tolerant	Intolerant
Pin oak	Intermediately tolerant	Tolerant	Moderately tolerant
Swamp white oak	Tolerant	Somewhat tolerant	Moderately tolerant
Eastern cottonwood	Very tolerant	Tolerant	Weakly tolerant to moderately tolerant

[a] Note that tolerance definitions differ slightly among authors.
[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (Populus deltoides Bartr. ex Marsh.).
[c] Very tolerant: withstands flooding for two or more growing seasons; tolerant: withstands flooding for most of one growing season; intermediately tolerant: survives flooding for 1 to 3 months during the growing season; intolerant: cannot withstand flooding during the growing season.
[d] Very tolerant: survives prolonged flooding for more than 1 year; tolerant: survives flooding for one growing season; somewhat tolerant: survives flooding or saturated soil for 30 consecutive days during the growing season; intolerant: unable to survive more than a few days of flooding during the growing season.
[e] Tolerant: survives saturated or flooded soil for long periods during the growing season; moderately tolerant: survives saturated or flooded soil for several months during the growing season; weakly tolerant: survives saturated or flooded soil for a few days or weeks during the growing season; intolerant: unable to survive short periods of saturated or flooded soil during the growing season.

We used a split plot design with three blocks, each comprising four adjacent channels. Within blocks, a single treatment (main effect) was randomly assigned to each channel: 5-week flowing, 5-week stagnant, 3-week flowing, or control. Twenty-five, 1-0 bareroot seedlings or cuttings (cottonwood) of each species were planted per channel (subplot effect) (75 seedlings per species per treatment and 1800 seedlings total).

Flood treatments were initiated on May 15, 2004, approximately one month after seedling planting. In the flooded channels, the water depth was maintained at 8 to 10 inches. The timing and depth of the flood treatments were selected to simulate late spring floods that commonly occur throughout the Central Hardwood Region. Also, floods during the growing season generally cause greater seedling mortality than do dormant season floods.

During the growing season at times when the channels were not flooded, weedy competition was controlled by mowing and applying a 2 percent glyphosate solution around the experimental trees.

At the end of the growing season, seedlings were evaluated for survival and shoot growth or dieback. We also rated the foliage condition of all living seedlings noting whether the foliage appeared green and healthy or chlorotic, browsed by deer or rabbits, or partially or fully defoliated by insects.

We used analysis of variance to determine treatment effects (error = treatment x block interaction) and differences among species (error = residual error for the experiment) on measured variables. For significant effects ($\alpha = 0.05$), we conducted multiple comparison tests using a procedure of Milliken and Johnson (1984).

RESULTS AND DISCUSSION

Overall, flooding significantly decreased the survival (P = 0.03) and diameter growth (P < 0.01) of the plants (table 3; figs. 1 and 2). Generally, the greatest differences were between the five-week flood treatment and the controls. For the five-week flood treatment, we found few differences in survival or diameter growth between seedlings in stagnant and flowing water. We anticipated that seedlings would suffer more dieback or greater mortality in the stagnant treatment because of the greater potential to develop anoxic soil conditions. However, we did not measure soil oxygen levels and we cannot be sure that it was lower in the stagnant treatment than in the flowing treatment. The flood treatments did not significantly decrease seedling shoot growth (P = 0.08) or significantly decrease the proportion of seedlings with healthy, green foliage (P = 0.10).

The effects of the flood treatment and survival and diameter growth differed significantly among species (P < 0.01). Black walnut suffered the greatest mortality and diameter growth reduction in flooded channels (table 3; figs. 1 and 2). This was expected because black walnut is considered very sensitive to

Table 3—Postflood treatment survival and proportion of seedlings having healthy foliage at the end of the first growing season[a]

	Treatment				
Species[b]	Control	Three-week flood, flowing	Five-week flood, flowing	Five-week flood, stagnant	All
	percent				
Survival					
Black walnut	61 A a	16 B a	9 B a	4 B a	23 a
Pecan	95 A b	99 A b	87 A bc	63 B b	86 b
Bur oak	96 A b	75 B b	76 B bc	67 B b	79 b
Pin oak	97 A b	95 A b	95 A bc	99 A c	97 b
Swamp white oak	99 A b	100 A b	99 A bc	97 A c	99 b
Cottonwood	89 A b	83 A b	73 A c	65 A b	78 b
All	89 A	78 AB	73 AB	66 B	
Healthy foliage condition[c]					
Black walnut	28 a	13 a	3 a	0 a	11 a
Pecan	81 bc	87 b	73 b	51 b	73 b
Bur oak	59 c	48 c	45 c	53 b	51 c
Pin oak	84 bc	81 b	60 c	79 b	76 b
Swamp white oak	95 c	96 b	96 b	96 c	96 b
Cottonwood	89 c	83 b	73 b	65 b	78 b
All	73	68	58	57	

[a] Flood treatments were initiated on May 15, 2004, 1 month after planting. For survival, there were significant differences among treatments ($p = 0.03$) and species within treatments ($p < 0.01$). For the proportion of seedlings having healthy foliage, there were no treatment effects ($p = 0.09$), but there were significant species differences ($p < 0.01$). Differences within rows are indicated with uppercase letters; differences within columns are indicated with lowercase letters.

[b] Black walnut (*Juglans nigra* L.); pecan [*Carya illinoensis* (Wangenh.) K. Koch]; bur oak (*Quercus macrocarpa* Michx.); pin oak (*Quercus palustris* Muenchh.); swamp white oak (*Quercus bicolor* Willd.); eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.).

[c] Healthy foliage condition is the proportion of seedlings having green foliage and lacking obvious symptoms of chlorosis or browning leaves.

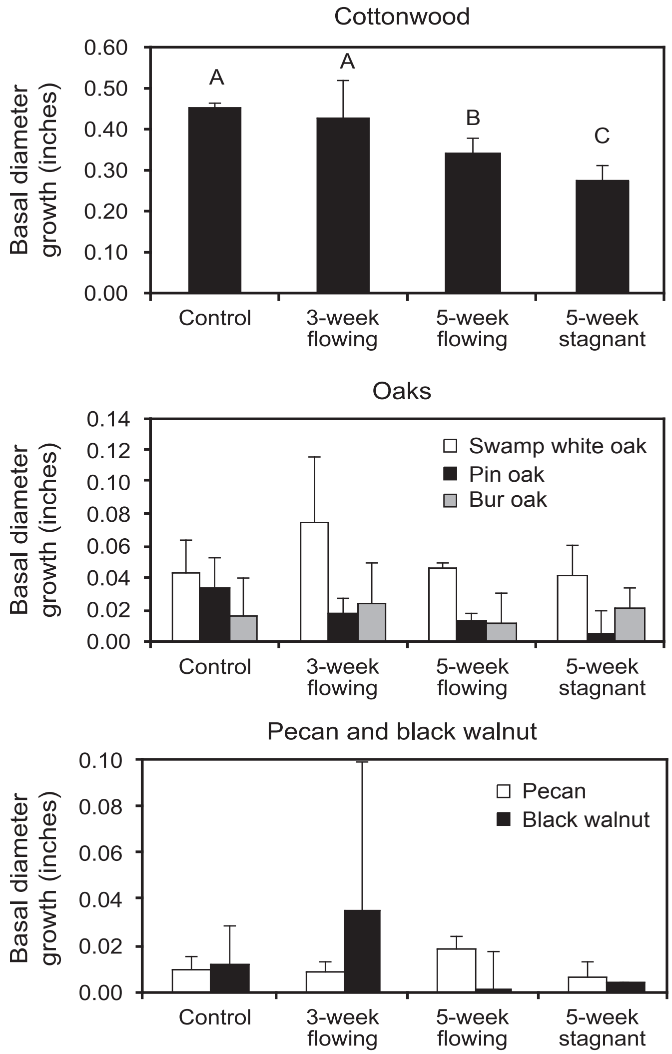

Figure 1—Basal diameter growth of the six species by flood treatment determined at the end of the growing season. Species were arranged by significant differences ($P < 0.01$) in growth increment: cottonwood (*Populus deltoides* Bartr. ex Marsh.) > oaks [bur oak (*Quercus macrocarpa* Michx.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.)] > pecan [*Carya illinoensis* (Wangenh.) K. Koch] and black walnut (*Juglans nigra* L.). Flood treatments were initiated May 15, 2004, 1 month after planting. Cuttings were planted for cottonwood and 1-0 bare-root stock was planted for the other species. All stock was from the George O. White State Forest Nursery located near Licking, MO. Error bars are + one standard deviation. Significant treatment effects ($P = 0.01$) are indicated with different uppercase letters.

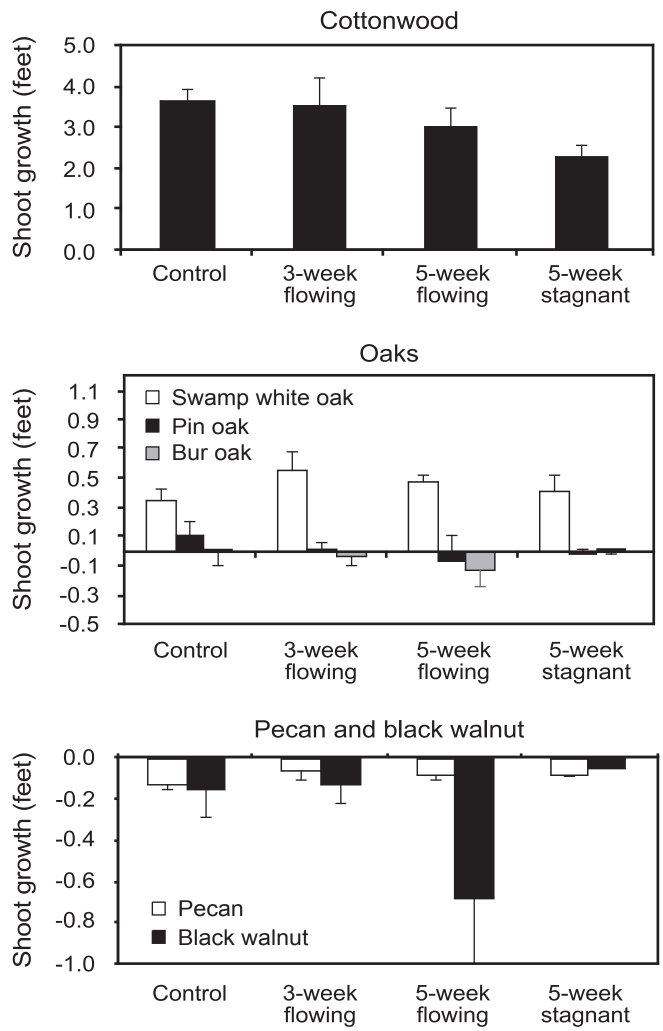

Figure 2—Shoot growth of the six species by flood treatment determined at the end of the growing season. Species were arranged by significant differences ($P < 0.01$) in growth increment: cottonwood (*Populus deltoides* Bartr. ex Marsh.) > oaks [bur oak (*Quercus macrocarpa* Michx.), pin oak (*Q. palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.)] > pecan [*Carya illinoensis* (Wangenh.) K. Koch] and black walnut (*Juglans nigra* L.). Flood treatments were initiated May 15, 2004, 1 month after planting. Cuttings were planted for cottonwood and 1-0 bare-root stock was planted for the other species. All stock was from the George O. White State Forest Nursery located near Licking, MO. Error bars are + (or −) one standard deviation. There were no significant differences in shoot growth among treatments ($P = 0.08$).

site conditions and intolerant of flooding (Williams 1990) and was included in our study to serve as a sensitive indicator of flood-induced stress. We also found that black walnut in controls had relatively low survival and a chlorotic appearance. This most likely occurred because the soils of the control channels remained nearly saturated when adjacent channels were flooded because of seepage (Van Sambeek and others 2007).

Eastern cottonwood, which is commonly classed as moderately tolerant to very flood tolerant (Teskey and Hinckley 1977, Allen and others 2001), maintained high survival and had the greatest diameter and shoot growth even though cuttings were completely inundated in the flooded channels early in the growing season (table 3; figs. 1 and 2). However, cottonwood showed a significant reduction in diameter growth with increased flood duration. Despite growth reductions in flooded channels, cottonwood maintained healthy and green foliage in all treatments.

Surprisingly, both swamp white oak and pin oak had equal or greater survival than cottonwood in all treatments, exceeding 95 percent (table 3). Moreover, swamp white oak maintained a high growth rate, second only to cottonwood (figs. 1 and 2). Swamp white oak also maintained healthy and dark green foliage regardless of treatment (table 3). Despite high survival, pin oak had substantial but nominal diameter and shoot growth reductions with increased flooding (figs. 1 and 2). Of the three oak species, bur oak appeared to be the most sensitive to flooding and had nominal reductions in survival and growth in all flood treatments (figs. 1 and 2). A large proportion of bur oak seedlings also appeared to be chlorotic at the end of the growing season, particularly in the 3-week and 5-week flowing treatments. This apparent chlorosis was the primary reason that bur oak seedlings had a lower proportion of healthy seedlings than all others except black walnut.

Pecan had very high survival, but also substantial shoot length reductions due to stem dieback in all treatments (table 3; figs. 1 and 2). This may not have been caused by flooding because the seedlings in the control treatment suffered as much dieback. Others have reported that pecan has a slow juvenile growth rate compared to other bottomland species (Stanturf and others 1998) so that the dieback that we observed may be characteristic for planted seedlings of this species. Despite stem dieback, the foliage of the pecan seedlings generally appeared dark green and healthy in all but the five-week stagnant flood treatment.

Our findings show both consistencies and discrepancies with published flood tolerance ratings for the species that we evaluated (for example, see table 2). There generally is good agreement in the literature that black walnut is intolerant and eastern cottonwood is tolerant to very tolerant of flooding, as our findings confirm. However, the published flood tolerances of the bottomland oaks that we examined ranged from intolerant to tolerant and no single species consistently was rated as more tolerant than the others. Our findings strongly suggest that swamp white oak is more tolerant to flooding than are the other oaks we examined and appeared to tolerate flood treatments better than did eastern cottonwood. This may be partially attributable to the stock used. As noted earlier, cuttings were used for eastern cottonwood and they were completely inundated by the flood treatments. Bareroot stock was used for the other species and most of them were not completely submerged in the flooded channels. Undoubtedly, complete inundation is more stressful than is partial inundation.

Some of the inconsistencies between our findings and those in the literature may be related to how flood tolerance is measured. For example, if seedling survival is the only consideration, then all species except black walnut performed well. However, when shoot growth (or dieback) and overall health relative to controls was considered, some species appeared more tolerant than others. These findings demonstrate that the characteristics used to define flood tolerance must be explicitly described. In addition to survival, measures of flood tolerance should include consideration of seedling growth and vigor relative to these attributes in non-flooded conditions.

We also acknowledge that our findings may have been different if the floods completely inundated the trees or if they were of longer duration. Deeper floods would more severely restrict oxygen diffusion into soil or roots causing increased root damage and associated disease and eventually leading to defoliation or mortality (Kozlowski and Pallardy 1997). The prolonged anoxic conditions caused by floods of longer duration are more likely to inhibit leaf growth, leading to leaf chlorosis, senescence, and abscission (Kozlowski and Pallardy 1997). In addition, our results are of response after one flood event during the establishment year. Flood tolerance may rate differently for larger trees or after a series of flood events.

Flood tolerance may also vary by genotype and ecotype, and stock from individual families or provenances may be more flood tolerant than stock of others. Our objective was to evaluate the stock most commonly available to managers in the Central Hardwood Region. However, future studies will include stock of known genetic origin and ecotype (e.g., upland vs. bottomland) to determine their role in governing flood tolerance.

ACKNOWLEDGMENTS

We thank Dr. Jerry Van Sambeek and Brandon O'Neal (USDA Forest Service), Mark Coggeshall, John Thompson, Ray Glendening, Jimmy Houx, Melissa Niederman, and Dennis Priest (Univ. of Missouri), and all of the technicians who work with the flood facility at the Univ. of Missouri Horticulture and Agroforestry Research Center. We also thank Drs. Mike Gold and Gene Garrett (Univ. of Missouri) for supporting this project. Dr. Michael Wallendorf provided helpful suggestions for analyzing the data. This research was funded through the University of Missouri Center for Agroforestry under cooperative agreements No. 58-6227-1-004 with the USDA ARS Dale Bumpers Small Farms Research Center, Booneville, AR. and C R 826704-01-0 with the US EPA. The results presented are the sole responsibility of the P.I. and/or MU and may not represent the policies or positions of the ARS or EPA.

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