DEVELOPING A FIELD FACILITY FOR EVALUATING FLOOD TOLERANCE OF HARDWOOD SEEDLINGS AND UNDERSTORY GROUND COVERS

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Abstract—Information about the flood tolerance of most plants has been obtained from either observations following natural floods or pot studies with amended soils. To better evaluate and compare flood tolerance among hardwood seedlings and ground covers for use in riparian buffer and bottomland plantings, a large outdoor facility with natural floodplain soils is needed where flood timing, depth, flow, and duration can be controlled and replicated. In 1999, the University of Missouri Center for Agroforestry constructed a field facility at the Horticulture and Agroforestry Research Center on the floodplain adjacent to Sulphur Creek. Using soil excavated to create a retention pond, 6-m wide by 2-m high berms were constructed on the original floodplain soil with minimal disturbance to soils within twelve parallel 6-m wide x 180-m long channels. Water from the retention pond can be pumped independently into each channel to control timing, depth, and duration of either standing or flowing water. First year survival of spring planted seedlings of black walnut (*Juglans nigra* L.) in the control channels has continued to increase each year with annual modifications to lower the high water table caused by seepage and improved post-flood draining of channels. On-going studies include evaluating genotypic variation in response to flooding within hardwood species and seedling flood tolerance among hardwood species and forage crops.

INTRODUCTION

Installation of riparian buffers and afforestation of bottomland sites that are subject to period flooding requires species specific information as to plant tolerances to saturated soils (Allen and others 2001, Schultz and others 2000). Published information on flood tolerance is based largely on observations following natural flooding for many of the hardwood species in the Central Hardwood region (Allen and others 2001, Hook 1984, Hosner 1960, Kabrick and Dey 2001, Loucks 1987). Differences in the testing regimes and time of the year has resulted in conflicting information for some hardwoods, i.e., reported flood tolerance of bur oak (*Quercus macrocarpa* L.) and black walnut (*Juglans nigra* L.) ranges from intolerant to tolerant (Bell and Johnson 1974, Catlin and Olsson 1986, Kabrick and Dey 2001, Loucks 1987).

Stanturf and others (2004) indicated that lack of detailed knowledge of a species flood tolerance is a major cause of regeneration failures when the wrong species are planted in flood prone areas. In the past, species have been placed in broad categories ranging from intolerant to very tolerant based primarily on observations made following natural flooding during the growing season (Bell and Johnson 1974, Hook 1984, Loucks 1987, Melichar and others 1983). For a number of hardwoods including black walnut (*J. nigra* L.), more detailed information has been obtained from replicated pot studies (Catlin and Olsson 1986, Frye and Grosse 1992, Kaelke and Dawson 2003, Pezeshki and others 1999, Smith and Bourne 1989). Extrapolating results from pot studies can be problematic as most studies have been done with highly disturbed soil frequently amended with sand or other bulking agents to improve drainage and reduce bulk density. These soils may be quite different from actual floodplain soils characterized by a relatively shallow rooting zone due to poor aeration, high clay contents, and high bulk densities.

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Information is also needed on flood tolerance of potential ground cover vegetation when establishing riparian buffer strips or implementing agroforestry practices such as alley-cropping on bottomland or floodplain sites subject to period flooding (Garrett and others 2000, Van Sambeek and Garrett 2005). Flood tolerance of herbaceous species, especially native forbs, appears to be less well documented than for woody plants. Partially, this is a consequence of greater susceptibility to inundation and changing flood tolerance during different growth stages of forage crops (Brady 1974).

Our objective for this paper is to describe our experiences in designing, constructing, and modifying a field facility using native bottomland soils to be used to evaluate flood tolerance of hardwood seedlings and ground covers to flooding of controllable timing, flow, depth, and duration. In addition, we will highlight some of the information that can be found in other papers as to observed variability in annual survival of black walnut seedlings in response to different flood treatments (Coggeshall and others 2007, Kabrick and others 2007).

MATERIALS AND METHODS

Initial construction of a field facility for evaluating flood tolerance of forage species began in 1999 at the Horticulture and Agroforestry Research Center in New Franklin, Missouri on a wide first terrace floodplain between Sulphur Creek and a limestone-covered county road (fig. 1). Soil types are a mix of moderately well drained Nodaway silt loam (fine-silty, mixed, nonacid, mesic, Mollic Udifluvents) and poorly drained Carlow silty clay (fine, montmorillonitic, mesic, Vertic Endoaqualls) (Grogger and Landtiser 1978). Soil excavated for a retention pond was used to build parallel 2-m-high berms that resulted in twelve 6 m wide by 180 m long channels. Slope within each channel averages less than a 15 cm drop from inlet to outlet. Two 1,600 L/hour electric pumps move water from the retention pond to adjustable butterfly valves located at the inlet end of each channel. Once all channels were flooded, flow rates within channels with flowing water were adjusted to exchange the water once each day (120 L/minute). Adjustable flood leveling gates at the outlet end control the depth of water between 0 and 0.5 m for flowing water flood treatments.

Figure 1—Aerial photograph taken July 3, 2004, of the flood tolerance facility at the Horticulture and Agroforestry Research Center in New Franklin, MO. Sulphur Creek is in the upper left corner, the county road in the lower right corner, and the pump house sits adjacent to graveled berm behind the retention pond in lower left corner.

Adjustable float valves were installed on the inlet end to control flooding depth for standing water flood treatments. Excess water in all channels flows back into the retention pond through outlet pipes installed 15 cm lower than the surface of each channel.

Several improvements have been made to the flood tolerance facility since initial construction. In spring 2000 we installed flapper check valves to the outlet drain pipes to prevent backwater from flowing into channels during flash flooding along Sulphur Creek. In 2001, we had 30 m^2 depressions excavated approximately 20 cm deep at the outlet end of each channel to collect post-flooding water and allow the use of self priming water pumps (930 L/minute) to rapidly drain each channel when flooding was terminated. In spring 2003, we cut 20-cm-deep circular ditches with a field digger along both sides of each channel to increase post-flooding flow of water from the channel and to intercept water seeping under berms into the control channels. After the entire facility flooded in 2002 and 2003, we raised the height of the berms surrounding the facility an additional 50 cm in summer 2004 so that it exceeds the 500-year flooding depth. In winter 2005, we further improved the capacity to remove flood water by laying a supplemental drain pipe across all channels beneath the outlet depressions. During flooding, open grid caps are replaced with removable stand pipes.

To characterize the variation in soils within the facility, 0 to 20 cm soil cores were taken from each channel following flooding in 2003. Composite samples were dried and analyzed for soil pH, electrical conductivity (1:2 soil ratio with water), and major macro- and micro-nutrients following Mehlich 3 extraction (1:7 ratio) and inductively coupled plasma atomic emission spectrometric determination. Gravimetric water content and soil temperature were monitored during and after flooding in spring 2004. Water content was measured weekly with Watermark Sensors (Irrometer Cc., Inc.) and temperature was recorded hourly with Stowaway temperature dataloggers (Onset Computer Corp, Bourne, MA). In spring 2005, we installed electronic sensors connected to CR23X microloggers (Campbell Scientific, Logan, UT) in each channel to monitor soil temperature and soil water at 5 and 15 cm depths, soil pH and redox potential at 5 cm, oxygen at the water/soil interface, air temperature, and daily rainfall during flooding and post-flooding recovery. In addition, twice a week we monitored soil pH, redox potential, dissolved oxygen, and temperature at 5 cm with portable Oakton 300 series meters and 90 cm long submersible electrodes (Cole-Parmer, Vernon Hills, IL).

Four adjacent channels were grouped into three blocks from the road to the creek. Within each block, one of four flood treatments was randomly assigned to each channel. Flooding treatments each spring (May and June) from 2002 through 2005 were (1) a no flood control, (2) five weeks of 15 cm deep stagnant water, (3) five weeks of 15 cm deep flowing water, and (4) three weeks of 15 cm deep flowing water (2004 and 2005 only). For evaluating shrubs and herbaceous species in 2003 through 2005, individual plants of fifteen grasses and ten legumes were established on a 1-m x 1-m spacing in five pseudo-replications in each channel the summer before spring flooding. When evaluating flood tolerance of recently planted seedlings, nursery stock of five to seven species was purchased from the George O. White Nursery and each species planted in 25-tree plot on a 0.75-m x 1.0-m spacing (Kabrick and others, 2007). When evaluating genotypic variation for flood tolerance among oak seedlings from single-tree collections, 1-0 bareroot seedlings grown at the George O. White Nursery or container-grown seedlings grown at the Horticulture and Agroforestry Research Center were planted on a 0.75-m x 1.0-m spacing with a completely random arrangement within each channel (Coggeshall and others, 2007).

RESULTS AND DISCUSSION

The site for the flood tolerance laboratory was originally chosen in 1999 because the area was large enough to construct twelve nearly level channels with minimal disturbance to the existing floodplain soils. Post-construction evaluation of the field facility indicated experimental designs for conducting flood tolerance studies would require blocking because the soil type gradually changed from a Nodaway silt loam adjacent to the creek to Carlow silty clay adjacent to a county road (table 1). Subsequent soil nutrient analyses revealed nutrient gradients also exist across the channels for pH, calcium, and zinc (table 1), but not for electrical conductivity (84 umhos/cm), phosphorus (82 kg/ha), potassium (530 kg/ha), magnesium

Table 1—Soil properties within top 20 to 25 cm across three replications of four channels each within the flood tolerance facility at the Horticulture and Agroforestry Research Center in New Franklin, MO

Variable	Block I[a]	Block II	Block III
Dominant soil type[b]	Carlow and Nodaway	Nodaway and Carlow	Nodaway
Estimated percent silt content[b]	58	63	68
Estimated percent clay content[b]	34	28	23
Estimated water content (cm) at field capacity[b]	4.5	5.1	5.6
Soil pH			
Post flooding in 2003	7.4	6.9	6.5
When flooded in 2005	6.9	6.8	6.6
Post flooding in 2005	6.6	6.6	6.5
Soil redox potential (mV)			
Post flood 2005 recovery	357	394	422
Soil nutrients in 2003			
Ca (kg ha^{-1})	6100	5200	4900
Zn (kg ha^{-1})	5.6	5.9	6.6

CA = calcium; ZN = zinc.
[a] Block I includes the northern four channels adjacent to the gravel road and block III includes the southern four channels adjacent to Sulphur Creek.
[b] Values as reported by Grogger and Landtiser (1978).

(790 kg/ha), sulfur (26 kg/ha), iron (400 kg/ha), manganese (195 kg/ha), copper (4.5 kg/ha), and boron (1.5 kg/ha). We hypothesize the pH and calcium gradients are in response to limestone dust from the adjacent graveled county road rather than past cropping activity on the floodplain.

Flood tolerance trials with forage crops in 2002 indicated and subsequent soil water monitoring in 2004 confirmed that lateral movement of water under the berms from flooded channels raised the water table within a few centimeters of the soil surface in the non-flooded control channels. Fortuitously, newly planted seedlings of black walnut have been included in flood tolerance each year since 2003. As expected, newly planted seedlings of black walnut exhibit little tolerance to 3 or 5 weeks of flooding by flowing or stagnant water (table 2). Catlin and Olsson (1986) also reported that few walnut seedlings survived partial inundation for three weeks. We also had high mortality of black walnut seedlings in the non-flooded control channels. Because black walnut seedlings, even when subjected to improper lifting at the nursery or handling before planting, typically show high first year survival (Rietveld and Van Sambeek 1989, von Althen and Webb 1982, Williams 1974), we hypothesize that seedling mortality is a consequence of creating a high water table and saturated soils due to lateral movement of water from adjacent flooded channels.

Reductions in the redox potential occurred under all four flood treatments including the non-flooded control channels (fig. 2). With flowing or stagnant flood water, redox potentials declined from between 500 and 550 mV to less than 200 mV during the first week of flooding. This was followed by a slight recovery the second week and subsequent decline to less than 100 mV with continued flooding. Ponnamperuma (1984) describes similar changes in his review on effects of flooding on soils. The redox potential in the control channels rapidly declined during a 6-day period when we received over 150 mm of precipitation producing saturated soils over a high water table. With the cessation of rainfall or flooding, soil redox potentials rapidly recovered to pre-flooding values over a two week period.

Table 2—First-year survival of bare-root black walnut seedlings exposed to four flooding regimes within the field flood tolerance laboratory from 2003 through 2005

Year	Control	3-week flowing	5-week flowing	5-week stagnant
	- - - - - - - -	- - - - - - - *percent*	- - - - - - - -	- - - - - - -
2003	34	nd	1	1
2004	64	16	9	4
2005	55	24	12	29

nd = treatment not tested in 2003.

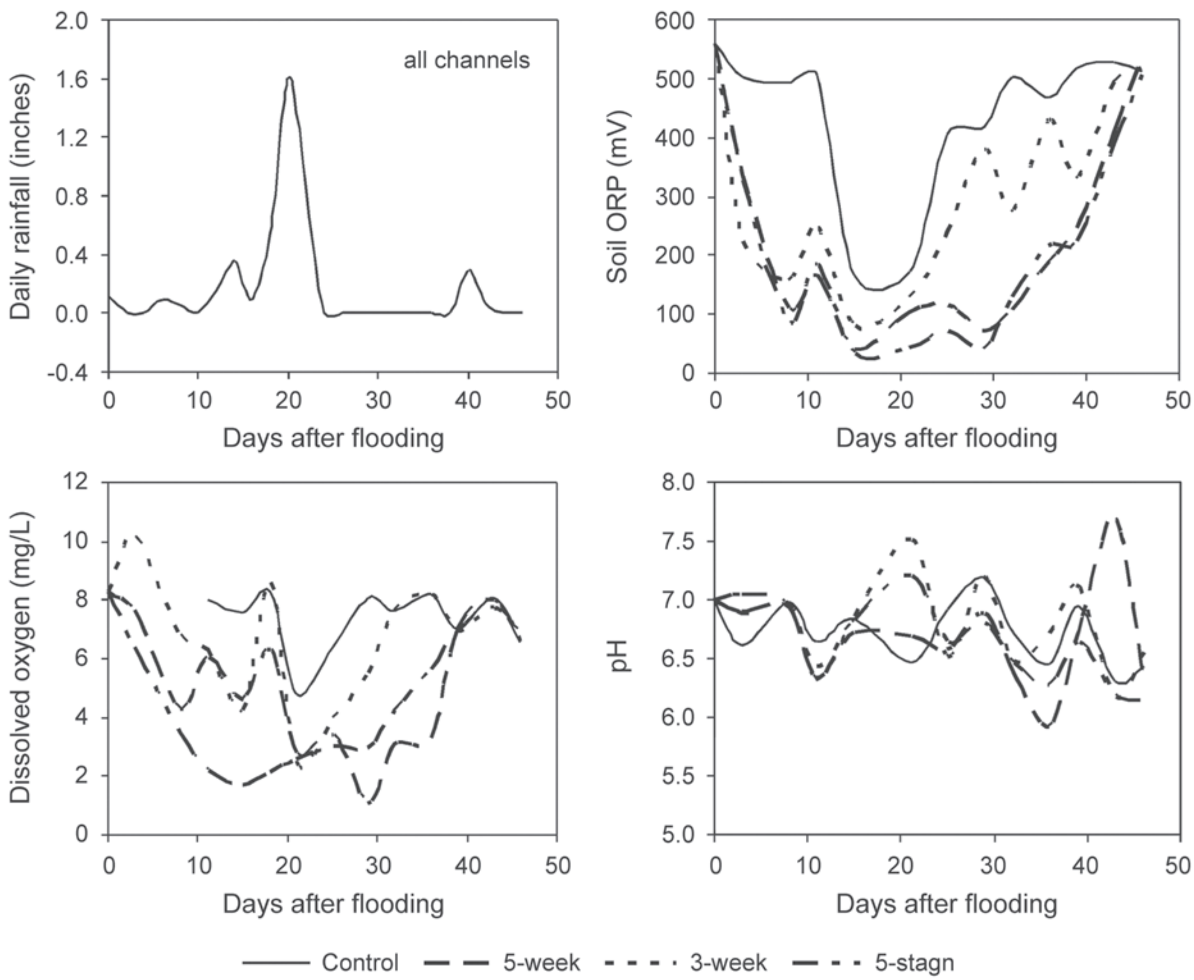

Figure 2—Changes in soil pH, dissolved oxygen, and redox potential (ORP) during and after flooding under four flooding regimes. Flood treatments were initiated on May 23, 2005, (day 0) and terminated on day 21 for 3-week flowing (3-week) and day 35 for 5-week flowing (5-week) and stagnant (5-stagn) treatments.

Dissolved soil oxygen also showed a rapid decline from near equilibrium levels [8.9 mg/L at 20 ˚C (Drew 1990)] to less than 2 mg/L with five weeks of flooding (fig. 2). Spikes in dissolved oxygen were detected in response to oxygen-rich precipitation in the control channels and treatments with flowing water. In contrast to the treatments with flowing water that remained muddy, the soil surface was visible within a week of flooding as suspended soil settled out in treatments with stagnant water. We failed to detect changes in soil water pH or temperature in part because this data was obtained from portable equipment rather than stationary sensors. In addition, because soils were nearly neutral prior to flooding, changes in soil pH are expected to be small (Ponnamperuma 1984).

Although the flood tolerance laboratory is now functional, we are continuing to make modifications to address several concerns. The most significant remains to be the high water table that exists within the control channels when adjacent channels are flooded. Based on observed changes in soil redox potentials and dissolved oxygen, maintaining soil water at or below field capacity can still be problematic especially during periods of extended precipitation. Lastly, having a mix of hardwood seedlings and understory ground covers in each channel has precluded our use of short-term flooding to alleviate moisture stress during summer droughts and has complicated selection of herbicides to control weeds, especially the highly invasive yellow nutsedge (*Cyperus esculentus* L.) and smartweed (*Polygonum* spp.).

In summary, our design for a field facility to evaluate flood tolerance of hardwood seedlings and understory ground covers allows for inexpensively evaluating large numbers of plants on floodplain soils under typical flood conditions. Cost for initial construction and modifications total fewer than 200,000 dollars including 75,000 dollars for micro-meteorological sensors and dataloggers. The current system of pumps, valves, gates, and drainage field allows each channel to be independently controlled for time of flooding, duration, flow, and, to some extend, depth.

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