BLACK WILLOW CUTTING SURVIVAL IN STREAMBANK PLANTINGS, SOUTHEASTERN UNITED STATES[1]

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ABSTRACT: Field studies were conducted on black willow (*Salix nigra*) cuttings planted for riparian zone restoration along Harland Creek, Twentymile Creek, and Little Topashaw Creek in Mississippi, USA. Planted cuttings were 2.5 to 3 m long and had base diameters of 2.5 to 7.5 cm. Streams were unstable, deeply incised sand bed channels with eroding banks 1 to 6 m high. Soil texture, redox potential (Eh), depth to water table, and willow survival were monitored for two to three years after planting. While many factors influence willow cuttings at restoration sites, soil texture and moisture are key to plant success. In these studies, plant survival and growth were best for cuttings planted in soils with less than 40 percent silt-clay content and a water table 0.5 m to 1.0 m below the soil surface during the growing season. These conditions produced soil Eh greater than approximately 200 mV and were most often observed 1 to 2 m higher than the bank toe. These findings suggest criteria useful for preplanting site evaluations. Additional evidence suggests that preplanting soaking enhances performance of black willow cuttings. Additional factors (channel erosion, herbivory by beaver, and competition from exotics) may control performance over periods longer than two to three years.
(KEY TERMS: riverbank; restoration; incised channel; willow post; streambank erosion; riparian zones.)

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INTRODUCTION

In the southeastern United States, riverbanks and stream corridors are often subject to erosion that degrades water quality and degrades associated habitats. However, there are opportunities for riverbank restoration using techniques that help control erosion while improving habitat conditions. These techniques include planting vegetation, particularly woody species, on eroding banks. Willow cuttings, otherwise known as posts, originated from *Salix* spp., have been extensively used for such projects (Roseboom, 1993; Shields *et al.,* 1995a,b; Watson *et al.,* 1997; Federal Interagency Stream Restoration Working Group, 1998). Large diameter (more than 7.5 cm at base) willow cuttings with lengths up to 4 m are sometimes used in efforts to stabilize eroding banks. These posts are planted 1 to 3 m deep, thus providing mechanical control of erosion during the period of initial growth and establishment. The establishment of transplanted willow posts is intended to ensure a relatively stable bank, thus modifying riparian habitats and fostering natural succession to a diverse riparian plant community. Despite the reported success of such approaches on many restoration sites, low survival rates also have been reported. For example, survival rates of less than 40 percent by the end of the first growing season have been reported for northern Mississippi (Shields *et al.,* 1995a). Planting failure has been attributed to many factors, including post location on the bank, flooding, drought, and soil texture (Shields *et al.,* 1998; Schaff *et al.,* 2003). Experimental evidence on adverse extreme soil moisture effects have come primarily from greenhouse studies conducted on black willow (*Salix nigra*) cuttings and have shown that flooding and drought have significant adverse effects on physiological functioning, growth, and biomass production (Pezeshki *et al.,*1998).

In addition to the greenhouse research, field observations also suggested the importance of soil moisture on the growth of willow cuttings. Willow posts planted on steep banks 1 to 4 m high along incising streams in

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Mississippi did better in middle elevations as compared to those planted close to the bank toe or at higher elevations (Watson *et al.,* 1997; Shields *et al.,* 1998). At these elevational extremes relative to the base flow, varying conditions affect willow cuttings. At high elevations, periodic soil drought may impose severe water stress, while at low elevations close to the permanent water table, willows are likely to be subjected to frequent root inundation due to soil flooding. In such conditions, plants could suffer from root oxygen deficiency as well as soil chemical changes that result from flooding, that is, soil reduction (Pezeshki, 1994, 2001; DeLaune *et al.,* 1998). The effects of soil oxidation reduction conditions (redox potential, Eh) could be significant because reducing soil conditions (low soil Eh) may impose substantial stress even on flood tolerant plants such as willow (Hook, 1984). Depending on the level of soil reduction in the root zone, significant decrease in root growth may occur in many flood tolerant woody species (Pezeshki, 1991, 2001). Substantial alterations in normal root metabolic activities may also occur, leading to the disruption of various root processes that are critical to plant survival and functioning. These processes include water and nutrient uptake, production of metabolites, and oxidation of rhizosphere (Pezeshki, 1994; DeLaune *et al.,* 1998). Partial or complete death of roots may occur, leading to insufficient masses of functional roots, and this may create root/shoot imbalances. Such imbalances may initiate a chain of events leading to shoot water deficits and massive root and shoot death (Kozlowski, 1982, 1997; Pezeshki, 1991, 2001).

In addition to soil moisture regime, soil texture is critical because soil pore space, moisture holding capacity, and oxidation reduction profile are closely correlated with texture. For instance, poor performance of willow posts planted on streambanks composed of fine soils have been reported under field conditions (Abt *et al.,* 1996; Schaff *et al.,* 2003). Posts also are likely to experience severe drought in coarse soils (sand gravel) on steep banks during low precipitation periods because of the low moisture holding capacity of coarse soils. Therefore, texture and soil moisture regime are interrelated and play critical roles in governing the success of willow cuttings planted on a streambank.

Clearly, the overall performance of willow posts at a given riparian restoration site is governed by a complex and often interacting group of environmental factors. The environmental conditions and the associated plant responses change substantially over the course of a typical growing season in dynamic riverbank systems. Therefore, in this paper the results obtained from three field study sites (Shields *et al.,* 1998; Schaff *et al.,* 2003) over a seven-year period are revisited and, for the first time, synthesized. The main focus of this paper is to define the relationships of soil texture, moisture regime, and other edaphic factors to the survival of willow posts under a wide range of soil conditions. The first objective of this effort is to develop criteria useful for preplanting site evaluations to reduce uncertainty in restoration outcomes. The second objective is to examine the effect on the early survival and establishment of black willow cuttings of the preplanting treatment of soaking them in water.

MATERIALS AND METHODS

Study Sites

Fieldwork was conducted on black willow (*Salix nigra* Marsh.) posts planted for streambank restoration at three restoration sites in northern Mississippi – at Harland Creek (HC), at Twentymile Creek (TC), and at Little Topashaw Creek (LTC) (Figure 1 and Table 1). All three sites are located in the hilly terrain of northern Mississippi, which receives about 1,500 mm of precipitation annually. Watersheds had forested hillslopes and bottomlands in pasture or under cultivation. Channels lacked geologic controls and experienced rapid incision in response to channelization within the studied reaches or downstream during the period 1960 to 1990. Details regarding the sites and methodologies can be found in Shields *et al.* (1998), Pezeshki *et al.* (2002), and Schaff *et al.* (2003).

Harland Creek

The HC project (Figure 1) has been described by Abt *et al.* (1996), Derrick (1997), and Watson *et al.* (1997). In February 1994, during the dormant season, 9,383 willow posts were harvested from local populations and planted within 48 hours. The posts were 3 to 4 m in length and at least 7.5 cm in diameter at the base. Posts were placed in holes 2.4 m deep created by a 20 cm diameter hydraulic auger, and no more than 1.2 m of each post remained above ground. Willow posts were planted in four rows parallel to the stream on 0.9 m centers. The first row of posts was placed 30 cm from the water's edge at the time of planting. About 80 percent of the posts survived for four months, but only 42 percent survived for eight months. In June 1996 a total of 13 surviving posts were selected along an elevational gradient extending from the farthest upstream post and ending at the last downstream post and at various distances from

Figure 1. Locations of the Harland Creek, Twentymile Creek, and Little Topashaw Creek Restoration Sites.

TABLE 1. Description of Study Sites.

Site	Estimated Two-Year Discharge (m^3/s)	Watershed Area (km^2)	Bank Height (m)	Bed Material
Harland Creek	110	80	1.6 to 12	Sand to Medium Gravel
Twentymile Creek	300	340	5 to 10	Fine Sand
Little Topashaw Creek	75	37	3 to 6	Medium Sand

the creek. In July 1996 polyvinyl chloride (PVC) piezometers 3.1 cm in diameter were established near each post where soil Eh also was monitored. Water level, soil, and plant measurements were continued through the end of the 1996 growing season (November).

Twentymile Creek

The TC site (Figure 1) was planted with about 12,000 black willow posts in February 1998. Planting methods were similar to those used for HC except that the area planted extended from the water's edge to half of the bank height, usually allowing for eight to ten rows of posts running parallel to the stream. Along the creek, four transects, each 10 to15 m long, were established in areas with varying slope and soil conditions. Each transect was placed perpendicular to the creek and extended from the toe of the creek to the top edge of the planting zone, approximately halfway up the bank. Three plots were located within each transect – one at each of the elevational extremes and one in the middle elevation. Piezometers were installed in the middle of each plot. Each plot consisted of 12 posts planted in a grid on 0.9 m centers. Water level, soil, and plant measurements were initiated in the spring of 1998 and continued through the end of 1999 growing season.

Little Topashaw Creek

The LTC site (Figure 1) was planted with about 4,000 black willow cuttings in January 2001. Posts were approximately 2.5 cm in diameter and 2.5 m in length and were planted using a water jetting technique (Drake and Langel, 1998). Of the 20 plots, 10 were established on sandbars and 10 on eroding banks. Each study plot was planted in four rows of four posts on 0.9 m centers. Measurements at each piezometer monitored soil Eh. Water level, soil, and plant measurements were initiated in the spring of 2001 and continued through the end of the 2002 growing season.

Methodologies

The monthly total precipitation for each site was obtained from the closest active weather station, for Twentymile and Harland Creeks, Baldwyn and Lexington 2 NNW stations, respectively (National Climatic Data Center, 2006) and for Little Topashaw Creek data from the USDA National Sedimentation Laboratory (unpublished). The frequency and duration of flooding at each site was analyzed using stage data collected at 15-minute intervals from nearby U.S. Geological Survey (USGS) gaging stations (Michael Runner, USGS, Jackson, Mississippi, personal communication, June 2, 1997, for Harland Creek Site and March 2, 2000, for Twentymile Creek Site) or from a water stage recorder installed for this study (Little Topashaw). The TC transects were about 0.4 to 1.7 km downstream from the gage, the HC site was about 6.3 km upstream from the gage, and the LTC plots were 0.1 to 1.0 km downstream from the gage. The applicability of the HC gage data to the study site was verified by comparing the signal from the USGS gage with a temporary gage located about 1 km upstream (Steve Sutton, U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi, personal communication, September 2, 1997). Stages were transformed into height above base flow elevation by subtracting the mean base flow stage from each record for assessing impacts at each site.

Soil samples were collected during piezometer installation at each site from various depths below the soil surface (15, 30, 60, and 90 cm except LTC, where soil sampling was not done at 90 cm), These samples were used to characterize the soil texture for each post location using standard methods (Brady, 1974). For HC, the percentage of sand, silt, and clay were approximate as determined by the “feel method,” For TC and LTC, soil particle size distribution was determined by the “feel method” and by analyzing nine replicate portions of each sample using a laser-scattering particle size distribution analyzer (Horiba, Model LA-910, Horiba Instruments, Inc., Irvine, California). Soil texture data presented are the mean for various depths at each study site.

Soil redox potential (Eh) at each site was measured at a distance of 15 cm from each piezometer at various depths (15, 30, 60, and 90 cm except LTC, where soil sampling was not done at 90 cm) below the soil surface using platinum tipped redox electrodes, a millivoltmeter (Orion, Model 250A, Thermo Orion Inc., Beverly, Massachusetts), and a calomel reference electrode (Corning, Model 476350, Corning, Inc., Corning, New York) according to the method described in detail by Patrick and DeLaune (1977). Measurements were recorded after the redox probes had been in the ground at least for two hours to allow for equilibration of the electrodes. Measurements of Eh were conducted on a biweekly schedule and were replicated (two measurements at each depth) per sampling location per sampling date. Measurements of Eh were conducted during the following periods at the study sites: July through October 1996 at HC (total of 320 measurements); May through October 1998 and 1999 at TC (total of 1,440 measurements); and May through October 2001 and 2002 at LTC (total of 1,872 measurements). Soil Eh data provided in the tables below represent the means for various depths at each location at a given study site over the study period. Water level at each monitoring well was quantified using a measuring tape during each site visit. Water level data presented below represent the mean for each site over the course of study.

Biomass accumulation at HC was quantified by biomass sampling of seven posts at the end of the 1996 growing season. Posts were destructively sampled, brought to the laboratory, and dried to a constant weight, and dry weight of biomass components were determined (Shields *et al.,* 1998). Growth of posts at TC was determined by measurement of height of study posts at the end of the study. No destructive samples were conducted on these posts since the posts were to be utilized in a longer study. At the LTC site, plant growth response could not be evaluated due to sporadic herbivory; however, survival data were recoded for the duration of the study over two growing seasons following transplanting.

For the HC site, study posts were grouped into four categories based on soil characteristics and relative elevation from the creek data as shown in Table 2. The general linear models (GLM) procedure of the Statistical Analysis System (SAS, 1994) was used to test for differences in depth to water table, soil Eh, root dry mass, and shoot dry mass among different groups of posts planted at various elevations relative to the creek. For the TC data, regression analysis between percent fine particles (silt and clay at 15 and 30 cm depths), and survival and height growth was performed using SAS (1994). For TC and LTC data, the GLM procedure was used to test the differences in means of depth to water table, soil Eh, and survival. For all sites, Tukey’s Studentized Range Tests were used to identify differences at the 0.05 level.

TABLE 2. Post Location, Soil Texture, Depth to Water Table, Soil Eh, Root Dry Mass, and Shoot Dry Mass for Posts Studied at Harland Creek Restoration Site in Mississippi in the Third Growing Season After Transplanting.

	Post Location on the Streambank			
Variable	**Lower Bank Group IV**	**Medium Group III**	**Medium Group II**	**Upper Bank Group I**
Soil Texture	Sand-Gravel	Sand-Silt-Clay	Sand-Silt	Sand-Gravel
Water Table Depth (m)	0.33 (0.0) c	0.58 (0.05) b	0.54 (0.03) b	1.13 (0.05) a
Soil Eh (mV)	+202 (29) b	+107 (21) b	+172 (10) b	+384 (13) a
Root Dry Mass (g)	100 (0)	29 (8) b	192 (17) a	NA
Shoot Dry Mass (g)	24 (0)	173 (62) b	1029 (96) a	NA
Survival (percent)	NA	NA	NA	NA

Notes: Dry mass values are from seven posts, and values represent the mean dry mass per post. Different letters within each row indicate statistically significant differences ($p < 0.05$) across post locations. Standard error is shown following the mean in parentheses. Values of depth to water table and soil Eh are the means for biweekly measurements conducted over the study period. Value for soil Eh is the mean for measurements conducted at 15, 30, 60, and 90 cm depths. See text for details. NA indicates missing data (from Pezeshki *et al.,* 2002).

RESULTS

Harland Creek

At HC rainfall and runoff patterns during the period 1994 through 1996 were within the range typical of the period of record but were slightly above average. Growing season (March through October) precipitation was 1,152 mm, 980 mm, and 965 mm in 1994, 1995, and 1996, respectively, which compares with a 30-year average of 864 mm for this season of the year. Cumulative total precipitation for the period March 1994 through October 1996 was 236 mm above normal. Observations of the willows at this site were confined to the 1996 growing season, when total precipitation was 101 mm above normal. The monthly totals for March, July, and October 1996 were 43 mm, 11 mm, and 27 mm below normal, respectively. During the study, inundation of the posts was brief and infrequent. The median duration of flooding ranged from about 26 hours for posts located at low elevation to 15 hours for the posts located at high elevation. Median times between flooding ranged from more than eight days to more than 13 days, depending on elevation. Study posts were grouped into four categories (Table 2).

The HC soils were different from those at the other two study sites due to the presence of small to medium gravel (generally less than 30 mm in diameter; Tables 1 and 2). Posts in the upper part of the bank where soil texture was sandy gravel experienced little or no soil saturation, as was evidenced by soil Eh data (greater than 350 mV). However, due to location and soil texture, the posts were likely to have endured drought episodes. The two medium-elevation groups showed a mean (root and shoot) biomass per post significantly greater in Group II than in Group III (Table 2), a response that was attributed to the difference in a more favorable soil texture for Group II (less cohesive, higher Eh) than for Group III (more cohesive, lower Eh). Posts located at low elevations in sandy gravel soil experienced reducing soil conditions. However, Eh was not significantly lower than the middle-bank groups due to the sandy gravel soil texture, which had little capacity for intense reduction. Overall, conditions for growth of willow posts at HC were best at moderate elevations characterized by sandy silt soil texture and water levels that fluctuated close to the soil surface, allowing for adequate soil moisture but frequent drainage. In contrast, posts located at higher elevations relative to the base flow stage suffered from soil moisture deficits, while posts located at the bank toe were hampered by flooded soils and low soil Eh conditions. Long term performance data for the HC willow plantings are not available.

Twentymile Creek

At TC the rainfall and runoff patterns during study period were typical but showed the potential for drought periods. Growing season (March through October) precipitation was 810 mm in 1998 and 642 mm in 1999, compared to a 30-year average of 882 mm in this season of the year. However, cumulative total precipitation for the study period (March 1998 through October 1999) was 366 mm below normal. In 1998 the distribution of rainfall during the growing season showed low precipitation in June (40 mm), while in 1999 there was a period of low precipitation in August through September (12 mm). Low elevation plots were flooded frequently due to proximity to the creek, which rose whenever light to moderate rains fell. The middle plots flooded at a moderate frequency but required moderate to heavy rainfall throughout the watershed, while the high elevation plots at the top of the planting zone were never flooded. Plots located 0.3 m above base flow were flooded about 10 percent of the time, while those at intermediate elevations (more than 1.0 to 1.5 m above base stage) were flooded only about 1 percent of the time. Flooding episodes lasted two to 39 hours, and median times between flooding ranged from eight to 26 days, depending on elevation.

Sediment texture and moisture availability differed across elevation. Soil in the low-elevation and middle-elevation plots was 60 percent sand, while plots located at the upper part of the bank had 79 percent sand (Table 3). Low-elevation plots were closest to the water table (0.5 m), resulting in reduced sediment Eh conditions (+ 183 mV; Table 3). The middle-elevation and high-elevation plots were farther from the base flow (1.3 and 2.1 m, respectively) and had sediment Eh values indicative of aerated soils (+ 385 and + 407 mV, respectively).

At TC, willow height growth was 53 percent in middle plots, compared to 37 percent in high-elevation plots (Table 3). Poor initial growth occurred on plots with high amounts of silt and clay in sediment, and this trend of poor growth held throughout the duration of the study.

During the 1998 growing season, survival rates were 67 percent, 50 percent, and 46 percent for high-, middle-, and low-elevation plots, respectively. Interestingly, posts that survived the first growing season also survived through the end of the study (Table 3), even though there were some indications of periodic drought, particularly in high-elevation plots during the second year. Willow posts planted in fine grained sediments had lower survival rates (31 percent) by the end of the first growing season compared to posts planted in coarse sediments (78 percent). However, all of the trees that survived the first growing season were alive at the end of the study, indicating less sensitivity of willow posts to edaphic factors once the posts became established on the bank. Visual inspection of the TC project at the end of the third growing season indicated good survival and growth for most of the planted areas.

TC data confirmed the significance of soil texture on willow performance. For example, soil texture had a substantial impact on height growth and survival, as they were both significantly greater in coarse sandy soils than in fine silt and clay soils. Regression analysis indicated a significant negative correlation ($r = -0.68$, $p = 0.0438$) between percent fine particles (silt and clay at 15 and 30 cm depths) and survival. Height growth was also significantly correlated ($r = -0.69$, $p = 0.0412$) to the average percent fine particles (at 15 and 30 cm depths), showing lower growth

TABLE 3. Field Data of Post Location, Soil Texture, Depth to Water Table, Soil Eh, Height Growth, and Survival for Willow Posts Studied at the Twentymile Creek and Little Topashaw Creek Restoration Sites in Mississippi at the End of the Second Growing Season After Transplanting.

	Post Location on the Streambank		
Study Site	**Lower Bank**	**Medium**	**Upper Bank**
Twentymile Creek			
Soil Texture (percent coarse)	60 (7)	60 (10)	79 (13)
Water Table Depth (m)	0.5 (0.03) c	1.3 (0.05) b	2.1 (0.06) a
Soil Eh (mV)	+ 183 (13) b	+ 385 (10) a	+ 407 (7) a
Height Growth (cm)	290.9 (43) ab	345.8 (53) a	225.8 (37) b
Survival (percent)	46 (10)a	50 (10) a	67 (10) a
Little Topashaw Creek			
Soil Texture (percent coarse)	79 (4.7)	82 (2.7)	75 (8.1)
Water Table Depth (m)	0.5 (0.03) b	0.86 (0.09) b	1.94 (0.19) a
Soil Eh (mV)	420 (29) c	577 (45) a	579 (25) a
Survival (percent)	47 (5.6) a	81 (9.1) a	52 (8.6) a

Notes: Means in each row followed by the same letter are not significantly different across groups at the $p = 0.05$ level (Twentymile Creek data from Schaff *et al.,* 2003). Standard error is shown following the mean in parentheses. Values of depth to water table and soil Eh are the means for biweekly measurements conducted over the study period. Value for soil Eh is the mean for measurements conducted at 15, 30, 60, and 90 cm depths. See text for details.

where soils contained a high percentage of fine particles (silt and clay).

Little Topashaw Creek

Total precipitation during the 2001 growing season (1,308 mm) was 194 mm below the 30-year average (1,502 mm). The early growing season was especially dry, with no rainfall accumulation for 14 days (February 1 through 15) after the cuttings were planted. March was also a dry month, with no rainfall for 22 consecutive days. April and July also had below-average precipitation. In contrast, conditions during the second growing season were not as dry. Total precipitation during the 2002 growing season (1,793 mm) was above the 30-year mean. This above average rainfall, however, occurred in four of seven months during the growing season, while for April through June rainfall was below average. Therefore, there were brief drought periods in sandy plots at high elevation during April through June 2002. During both growing seasons, the low-elevation, medium-elevation, and high-elevation plots were flooded only about 3 percent, 1 percent, and 0.2 percent of the time, respectively, with flooding episodes lasting from about 0.5 to 50 hours.

Survival rates at study plots during the second growing season remained within 15 percent of the first-year survival rates, indicating that the first-year conditions were most critical to willow survival. Contributing factors to low mortality during the second growing season probably included higher precipitation levels and well developed root systems compared to the first growing season. Plots located close to the creek, with low slopes and low elevations above creek base flow, were more likely to be grazed by beaver. Herbivory affected 26 percent of willow cuttings during the first year. Heights of eaten plants were reduced from an average of 1.2 m to 0.6 to 0.8 m. However, posts showed a capacity for compensation of shoot height growth eaten by beaver during the first growing season. Nevertheless, height growth was negatively affected by herbivory in the second growing season.

As noted above for the other study sites, soil texture and elevation were also important factors influencing the survival of posts at LTC (Table 3). The highest survival rates were found in plots located at intermediate elevations above base flow (0.6 m to 1.1 m), particularly those with moderate sand content (54 percent to 73 percent). High-elevation plots with moderate sand content (66 percent) had higher survival rates than high-elevation plots with high sand content (86 percent sand), likely due to the quick draining nature of the sandier soils. Mild reductions in soil Eh were found at low-elevation plots, but survival was not negatively affected.

Overall survival of willows in LTC study plots was about 60 percent at the end of three growing seasons, but overall survival of all project posts was estimated to be only approximately 10 percent following four growing seasons. Soil conditions, erosion, sediment deposition, herbivory by beaver, and competition from exotics were possible factors.

DISCUSSION

Studies at the three restoration sites provided the opportunity to examine willow post survival and growth in response to the predominant environmental factors. Results indicated the complexity of soil plant interactions in highly dynamic creek banks. These riparian systems are characterized by steep slopes, a wide range of soil moisture conditions, and various soil textures that reflect past and ongoing erosion and deposition processes. Willow cuttings displayed a great level of sensitivity to soil moisture conditions. For instance, at HC, soil Eh for posts in Group I was above + 350 mV, thus, in the aerated range, suggesting that these posts were not exposed to flooding or soil saturation during any of the measurement days (Table 2). Nevertheless, this group experienced periodic drought based on precipitation patterns and elevation as well as the poor water-holding capacity of the soil (sand gravel). In contrast, posts in Group IV were at the lowest elevations to the creek relative to other groups. Here, water levels were high (close to the soil surface), creating reducing soil conditions indicated by low Eh values (less than + 202 mV). Root biomass data indicated that reductions in soil Eh had a negative impact on root growth. Root development is slowed in areas of low soil Eh conditions because of the lack of adequate oxygen needed for roots to carry out normal respiration. In a greenhouse study, little or no root growth was found for black willow cuttings at locations that remained subjected to continuous flooding and soil Eh around -200 mV (Pezeshki *et al.,* 1998). This absence of roots indicated that willow cuttings either failed to initiate roots or that such roots, if initiated, died in response to the continued, intense soil-reducing conditions. Other studies have shown that root biomass in black willow was significantly decreased as flooding depth and duration increased (Donovan *et al.,* 1988).

Black willow is a flood tolerant species, and it possesses physiological and morphological adaptations allowing oxygen transport to the root zone. However, as soil Eh decreases, the chemical and biological demands for oxygen within the soil rise. Thus, the oxygen delivery system may be overwhelmed by this increasing demand that is concomitant with increased internal demand for oxygen (DeLaune *et al.,* 1990; Pezeshki, 2001). Other studies also reported changes in vigor and survival of willow cuttings due to elevation. For instance, cuttings located close to the creek and exposed to prolonged, frequent flooding had mortality rates of 80 percent (Abt *et al.,* 1996). At the other elevation extreme, periodic soil drought may pose a threat to survival (Pezeshki *et al.,* 2002). The posts at the highest elevations and greatest distances from the creek, which were likely to experience drought, had mortality rates of about 91 percent. However, higher survival rates, of 39 to 58 percent, were associated with the posts located in the area between these zones (Abt *et al.,* 1996).

Preplanting Techniques for Improving Success

As mentioned above, laboratory and field studies have identified many factors that govern survival of willow cuttings in the field. However, the physiological status of cuttings prior to planting (actively growing versus dormant) and preplanting treatments such as soaking in water may also be crucial in determining the success of transplanted cuttings. In general, production and extension of a substantial root mass is critical to the establishment of cuttings at a restoration site. Thus, a preplanting treatment that enhances tissue water content may promote root initiation, development, and early survival of willow cuttings. For instance, previous reports have indicated that a brief period of soaking in water prior to planting significantly enhanced shoot and root growth for many woody species (Petersen and Phipps, 1976; Phipps *et al.,* 1983; Schaff *et al.,* 2002). These positive responses have been attributed to root and shoot initiation during the soaking period as well as improved water content of the cuttings.

Studies of the effects of soaking on black willow cuttings demonstrated that soaking dormant black willow cuttings for 10 days prior to planting enhanced root and shoot production, while three days of soaking had no detectable effects (Schaff *et al.,* 2002). Positive effects on root and shoot growth were enhanced if soaking water was saturated with dissolved oxygen (Martin *et al.,* 2004). In contrast, 15 days of preplanting soaking proved to be harmful for actively growing (nondormant) black willow cuttings irrespective of the soil moisture regime during the post-transplanting period (Pezeshki *et al.,* 2005). Soaking for 15 days followed by transplanting cuttings into flooded or drained soil led to reductions in growth and survival, while soaking for seven days enhanced performance, although the beneficial effects were limited to nonflooded (control) plants.

Rapid root initiation and extension is clearly an important factor affecting performance of transplanted cuttings. Previous studies reported increases in the number and dry weight of roots when cuttings were subjected to a soaking treatment (Schaff *et al.,* 2002). Dormant black willow cuttings soaked for 10 days produced more roots and more root biomass than did cuttings that were not soaked. However, nondormant cuttings did not display similar responses (Pezeshki *et al.,* 2005). In the latter study, there was no apparent benefit from soaking on root dry weight in the group soaked for seven days, and significant decreases were noted in root production in the group soaked for 15 days. The results highlighted the differences in response of cuttings based on their initial physiological status,that is, dormant versus actively growing, as well as the duration of soaking.

The differences noted in shoot and root responses to soaking between the dormant cuttings used in Schaff *et al.* (2002) and the actively growing cuttings used by Pezeshki *et al.* (2005) highlight the importance of the physiological status of black willow cuttings in governing subsequent root and shoot development. Differences in responses were likely due to a number of factors, including the variation in growth regulator concentrations and/or ratios and the availability of carbohydrates. Roots initiated on cuttings are known as "adventitious roots." Adventitious rooting phenomenon has been primarily attributed to auxin, a root-inducing hormone, although other plant hormones such as ethylene have been implicated as well (Haissig and Davis, 1994). Adventitious root initiation is governed by a balance of internal substances such as hormones, carbohydrates, and nitrogenous compounds and many cofactors (Friend *et al.,* 1994; Haissig and Davis, 1994; Houle and Babeux, 1998).

The soil moisture condition of the media in which black willow cuttings are transplanted may also be an important factor, as was noted in the previous studies (Schaff *et al.,* 2002; Pezeshki *et al.,* 2005). For instance, Schaff *et al.* (2002) reported that black willow cuttings soaked for 10 days and grown across a wide range of soil moisture conditions had improved growth, biomass production, and survival. However, Pezeshki *et al.* (2005) noted that the beneficial effects of seven-day soaking were detectable only if the medium presented a well watered but drained soil moisture regime. Again, there was a profound difference in responses of dormant cuttings of black willow as reported in Schaff *et al.* (2002) and the actively growing cuttings used in Pezeshki *et al.* (2005).

Typically, willow cuttings are transplanted in the spring, but materials are collected while plants are dormant. Thus, soaking induced increases in root initiation and growth noted for dormant materials coupled with favorable soil moisture conditions may enhance root extension into aerated but moist soils (Schaff *et al.,* 2002). Such root expansion creates an additional opportunity for water and nutrient uptake and growth that may lead to improved flood avoidance and drought avoidance capabilities later in the growing season. However, if cuttings were collected later in the spring, when the plants are actively growing (nondormant), the responses are quite different (Pezeshki *et al.,* 2005). Therefore, the use of soaking technique for nondormant black willow cuttings should be considered only if the planting site is likely to present initial conditions of ample but nonflooded soil moisture.

In addition to the laboratory research, field studies indicated that preplanting soaking enhances growth and survival of dormant willow cuttings. After a growing season, cuttings soaked for 14 days prior to planting had 64 percent survival compared to 53 percent survival for unsoaked cuttings (Martin *et al.,* 2005). At higher elevations from the creek, soaked posts had an even higher rate of survival (71 percent) relative to unsoaked posts (43 percent), suggesting that soaked posts had a greater ability to avoid drought stress than unsoaked posts.

Overall, based on the above discussion, the use of soaking technique for enhancing survival of black willow is recommended primarily for dormant cuttings. However, nondormant black willow cuttings should be considered only if the planting site is likely to present initial conditions of ample but nonflooded soil moisture. Since riverbanks have a moderate to steep slope, such moisture conditions are more likely to be found at midbank sites with sandy soils rather than at the top or toe of the bank.

CONCLUSIONS

Willow cuttings are used in many ways to reclaim and revegetate eroding streambanks and failing slopes (Coppin and Richards, 1990; Gray and Sotir, 1996). However, willows are adapted to propagate through natural dispersal of plant fragments during flow events. Since natural deposition of these plant materials usually occurs where sediment deposition occurs and not at erosional locations, it stands to reason that conditions for cuttings at eroding banks tend not to be ideal. Specifically, steep, eroding banks are often composed of silts and clays. If they are sandy, portions of the upper bank are drought prone, while bank toe zones are almost continuously flooded. At all of the restoration sites examined herein, soil texture and moisture regime were important factors affecting survival and growth of willow posts. At these sites, much of the variation in survival and growth was due to soil texture represented by percent fine (silt and clay) or coarse (sand). Under favorable soil moisture conditions, posts performed better in soils characterized by moderate sand content (60 to 80 percent sand) than in finer grained soils. High survival and growth rates of willow posts required ample soil moisture (but nonflooded conditions) and adequate drainage in the upper soil layer, approximately the top 45 to 60 cm of soil. At the three study sites, these conditions were often limited to locations approximately 0.5 m to 1.0 m above stream base flow water surface elevation. Performance of dormant cuttings may be enhanced by soaking the cuttings in water with dissolved oxygen concentrations near saturation (e.g., flowing water) immediately after harvest for more than three and as many as ten days and planting immediately after soaking. Soaking of nondormant cuttings should be considered only if the planting site is likely to present initial conditions of ample but nonflooded soil moisture.

From a restoration perspective, use of willow posts for riverbank planting is intended to stabilize the banks while improving habitat quality. The use of willow posts remains a viable, low cost restoration strategy; however, a proposed planting site must be evaluated prior to undertaking a project, as recommended by basic texts (Coppin and Richards, 1990; Gray and Sotir, 1996). However, the general guidelines for site evaluation provided by these texts should be supplemented by the criteria provided here for soil texture, moisture regime, slope, and distance to the stream edge. Even if sites are ideal with respect to these factors, planting may not succeed over the longer term. Survival of posts for periods exceeding two or three years may reflect additional factors such as channel instability and herbivory.

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