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Comparison of native woody species for use as live stakes in streambank stabilization in the southeastern United States

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Abstract: Live stakes are cuttings taken from dormant woody plant species used to establish riparian vegetation. Although many species may be suitable, black willow (*Salix nigra*) is the species of choice in streambank stabilization projects in the southeastern United States. Studies were conducted on four species native to the southeastern United States that have potential for success as live stakes. Black willow, silky willow (*Salix sericea*), silky dogwood (*Cornus amomum*), and Virginia sweetspire (*Itea virginica*) were evaluated for biomass differences among species, effect of soaking stakes in tap water for 48 hours prior to installation, and differences in survival attributed to season of harvest. The experiment was conducted at the Paterson Horticulture Greenhouse Complex, Auburn University, Alabama. Each species was established from live stakes and had 100% survival when harvested during the dormant season. Total biomass of soaked and nonsoaked live stakes of silky dogwood was greater than soaked and nonsoaked black willow live stakes at nine months. This was driven by belowground biomass. At nine months, silky dogwood belowground biomass for nonsoaked stakes was greater than belowground biomass for black willow, silky willow, and Virginia sweetspire. Belowground biomass of soaked silky dogwood stakes was similar to belowground biomass of silky willow and greater than belowground biomass of black willow. Soaking live stakes collected in the dormant season for 48 hours resulted in only one significant total biomass difference between soaked and nonsoaked in the species silky dogwood at six months. After nine months of growth, there were no differences between soaked and nonsoaked live stake biomass. Virginia sweetspire, a shrub, consistently had less biomass, diameter, and height than the other species. However, the nine month root:shoot ratio of Virginia sweetspire was greater than both willow species and similar to silky dogwood. There was 0% survival of black willow, silky willow, and silky dogwood after six months when live stakes were harvested during the growing season irrespective of soaking treatment. Live stakes of Virginia sweetspire harvested in the growing season had a survival rate of 80% for soaked stakes and 67% for nonsoaked stakes. The four native species evaluated in this study became established and survived as live stakes. These species are candidates for use in riparian enhancement and restoration projects, which will assist with increasing riparian plant diversity.

Key words: bioengineering—live stake—restoration—riparian buffer

Vegetation enhancement and restoration projects that assist in reclaiming the benefits of riparian ecosystems are well documented and accepted as an important natural mechanism to mitigate water pollution (Lowrance et al. 1985; Lee et al. 2000; Lee et al. 2003; Polyakov et al. 2005). Riparian vegetation plays an essential role in stream health and watershed function (Lowrance et al. 1984; Dosskey et al. 2010), providing food and habitat for terrestrial animals; allochthonous food source for aquatic animals; shade resulting in a more constant temperature regime that is less stressful for in-stream biota; and increased levels of dissolved oxygen (O_2), biogeochemical cycling, and streambank stabilization.

Riparian plants minimize pollutants entering a stream by physically slowing water and allowing solutes to settle (Gray and Sotir 1996) and by assisting transformation of those pollutants into less harmful and in some cases beneficial byproducts (Licht and Isebrands 2005). For example, inorganic forms of nitrogen (N) and phosphorus (P) may be assimilated by microbes or plants and converted into less mobile organic forms (Lockaby and Walbridge 1998) instead of being transported to a stream where they may promote eutrophication (Wells 2002).

Native plant species are recommended for riparian buffer plantings to restore or enhance a stable, natural stream and floodplain system. Native plants have traits that make them well adapted to local climate, soil conditions, and interactions with other local species. Specifically, native plants in riparian areas are resistant to stress associated with periodic flood and drought episodes, and thus are preferred for rapid establishment (Correl 2005; DuBois et al. 2009).

Riparian planting efforts often call for use of live stakes. Live stake plants are fast-growing deciduous hardwood cuttings of dormant branches installed along streambanks that are typically 0.5 to 1 m (1.6 to 3.3 ft) in length and 1 cm to 10 cm (0.4 to 4 in) in diameter (Bir et al. 2002; DesCamp 2004; Logar and Scianna 2005; Greer et al. 2006; Li et al. 2006; Pezeshki and Shields 2006). Hoag (2009) noted that planting unrooted cuttings, such as live stakes, is the most common way to establish riparian woody species. Live stakes become established quicker than seeds and are less likely to wash away (Oklahoma Water Resource Board 2006). These characteristics make use of live stakes a cost-effective alternative to other bioengineering practices (Sotir and Fischenich 2003).

Installation of live stakes on streambanks has proven effective for repairing eroded banks, adding support to the soil, and minimizing pollutants that enter streams (Sotir and Fischenich 2003). Live stakes minimize erosion through promoting root growth, which stabilizes and controls shallow mass movement of soil by binding particles together and removing moisture from the

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soil (Gray and Sotir 1996). After establishment, live stakes reduce nonpoint source pollution by intercepting sediment and attached pollutants that would otherwise enter the stream (Sotir and Fischenich 2003; Logar and Scianna 2005). However, live stakes must establish roots, stems, and leaves before erosion is slowed (DesCamp 2004). Live stakes can dislodge and be swept downstream if not installed properly or if they have not rooted before a heavy rainfall event (Logar and Scianna 2005).

It is recommended that live stakes be harvested in the dormant season (Gray and Sotir 1996; Sotir and Fischenich 2003; Logar and Scianna 2005). Previous practice indicates that stakes should not dry out before planting, and it is recommended that they be soaked in water for a minimum of 48 hours in a cool place away from direct sunlight before installation (Logar and Scianna 2005; Tilley and Hoag 2008). Soaking live stakes prior to installation has been shown to increase survival and root:shoot ratio of willow species (*Salicaceae*) due to an increase in stem water content (Schaff et al. 2002, Tilley and Hoag 2008). Soaking also decreased mortality of willow live stakes when planted directly after removal from water (Schaff et al. 2002; Sotir and Fischenich 2003; Li et al. 2006; Pezeshki and Shields 2006). Although research has been conducted on willow, there is a lack of data in the literature on differences between survival and biomass of soaked and nonsoaked live stakes of other native species.

Many riparian buffer restoration projects predominantly use willow species live stakes (Greer et al. 2006; Li et al. 2006; Pezeshki and Shields 2006). Although black willow (*Salix nigra*) has the ability to rapidly establish from dormant cuttings (Pezeshki et al. 2005; Greer et al. 2006), it has been noted to have poor root strength, relatively lower roots per unit area than sycamore (*Platanus occidentalis*) and river birch (*Betula nigra*), and shallow roots that are mostly in the upper 20 to 30 cm (8 to 11.8 in) (Simon and Collison 2002). The use of willow species as live stakes has been adopted by several agencies even with a survival rate as low as 40% (Schaff et al. 2003; Greer et. al. 2006; Pezeshki and Shields 2006). The low survival rate has been linked to flooding, drought, vertical location on bank, soil texture, and soil fertility (Pezeshki et al. 1998; Schaff et al. 2003; Greer et al. 2006; Li et al. 2006; Pezeshki and Shields 2006; Tilley and Hoag 2008). Other trees and shrubs that root easily have not been well evaluated and may or may not outperform willow species (Darris 2002). For example, red osier dogwood (*Cornus sericea*) and Douglas spirea (*Spiraea douglasii*) have been identified as acceptable species for soil bioengineering (Darris 2002), but no published research on their establishment and survival could be found. Examples of other recommended live stake species in the Southeast include silky dogwood (*Cornus amomum*), silky willow (*Salix sericea*), Virginia sweetspire (Itea virginica), buttonbush (*Cephalanthus occidentalis*), and elderberry (*Sambucus canadensis*) (Mitchell and Dyck 2000; Bir et al. 2002).

Though several different species of live stakes have been used in practice, combinations of them have rarely been observed in the same experiment. The combination of multiple species of live stakes in one experiment is important because it is likely the conditions will be more similar than repeating an experiment for each individual species. Black willow (*Salix nigra*), silky willow, silky dogwood, and Virginia sweetspire were selected for investigation due to previous experience that indicates their potential to thrive in moist conditions, ability to be planted as live stakes, and potential for long-term viability.

The objective of this study was to determine the effect of 48 hours of soaking in water before stake installation on survival and growth, evaluate and compare survival and growth of four native species of live stakes, and observe differences in survival based on season of installation.

Materials and Methods

Four species were studied: black willow, silky willow, silky dogwood, and Virginia sweetspire. Live stakes were cut using methods described by USDA NRCS (1996) from various locations on and around the Auburn University main campus in Auburn, Alabama, United States. Straight, healthy branches with a diameter of approximately 1 cm (0.4 in) were selected except for the shrub, Virginia sweetspire, from which branches were selected with a smaller diameter (0.5 cm [0.2 in]) due to its smaller branch size. Shears were used to cut selected branches from trees. Smaller branches and leaves were removed from each large branch and cut so all that remained was a straight, smooth stick. Next, branches were cut into live stakes that measured 1.5 m (59.0 in) in length except for Virginia sweetspire, which was cut to a length of 46 cm (18.0 in). Each species was bundled and labeled to avoid confusing similar-looking stakes.

The basal end of all stakes were cut at a 45 degree angle to facilitate easier planting, while tops were cut flat. This eliminated confusion as to the correct end of the stake to soak and install. Immediately after being harvested, exactly one-half of each species (51 stakes) were placed in a bucket with basal ends submerged in 20 cm (7.8 in) of tap water. Buckets containing the soaked stakes were placed in a cooler at 4°C (39°F) for 48 hours before installation. Nonsoaked stakes were immediately installed by hand into microcosms that were under an outdoor 60% woven shade cloth structure at the Paterson Horticulture Greenhouse Complex, Auburn, Alabama. The top of the structure was 3.4 m (11 ft) tall, sloping to 1.8 m (6 ft) along the short side, and a rain barrier of double layer 6 mL (0.4 in^3) clear polyethylene plastic was present.

Microcosms were constructed using plastic tubs (Sterilite Corp., Townsend, Massachusetts) with dimensions of 48 cm (18 in) height, 86 cm (34 in) length, and 48 cm (18 in) width. Microcosms were filled with a mixture of 85% by volume sand (124 L [33 gal]), 10% topsoil (15 L [4 gal]), and 5% organic matter (aged pine bark mulch) (9 L [2 gal]) substrate. Ten drainage holes were equally spaced along the sides, 0.1 m (4 in) from the bottom of the tub, with two each on the shorter sides and three each on the longer sides.

Plastic flagging tape was tied around each stake at the point where root collar diameter measurements were taken at the substrate surface to improve consistency of measurement. Plants were watered triweekly and 13-13-13 fertilizer (PeaFowl fertilizer, Piedmont Fertilizer Inc., Opelika, Alabama) was added biweekly at a concentration of 50 mg L^{-1} to ensure proper plant nutrition. Plants were irrigated until the point that water flowed freely from the drainage holes. Weeds were removed, and the stakes were monitored closely for problems such as weather damage or insect effects.

Dormant Season Planting. Trial 1 was conducted from March of 2010 to December of 2010, and trial 2 was conducted from February of 2011 to November of 2011. In both trials, live stakes were cut and installed in the dormant season before bud break. Stakes were installed into the media of each microcosm until only half of the stake was exposed aboveground: 22.8 cm (9 in) for Virginia sweetspire and 30.5 cm (12 in) for the remaining species. Six stakes were installed in each microcosm in trial 1. Given the high survival rate observed in trial 1, only four stakes were installed per microcosm in trial 2. A digital caliper (VWR LabShop, Batavia, Illinois) was used to measure the initial root collar diameter.

Destructive biomass harvests occurred at three, six, and nine months after stake installation. At each harvest date, 20 stakes (10 soaked and 10 nonsoaked) were collected for each species. Only living stakes were harvested. Height and diameter were measured for harvested stakes. Measurements were taken from the point of stake contact with the substrate (marked with flagging tape) to the tallest terminal bud. If a stake was no longer living, it was recorded as dead. The stakes were collected from the media with as many roots as possible intact and rinsed gently with water to remove soil. Stakes were separated into stem, leaf, and root components and placed in labeled paper bags. The labeled bags were dried at 70°C (158°F) for 48 hours. After 48 hours, or until a constant weight was achieved, the samples were weighed and the results recorded. Aboveground biomass was recorded as stems plus leaves from above the initial point of stake contact with the substrate, and belowground biomass was all biomass below the initial point of stake contact with the substrate, including roots. Root:shoot ratio was calculated using belowground biomass and aboveground biomass.

Growing Season Planting. Live stakes were cut in July of 2011 during the growing season. The same methods for live stake selection and soaking were used as in the dormant season experiment. Height, diameter at root collar, and survival were determined at three and six months for every stake (Schaff et al. 2003; Pezeshki and Shields 2006).

Data Analysis. The experiment was a split plot design with species as main plots and soaking treatment as subplots. Microsoft Excel was used to consolidate the data. The statistical program SAS 9.2 was used to compare and analyze the data (SAS Institute Incorporated 2008). The Proc Univariate procedure was used to test for normality. The PROC GLM-factorial procedure was used to compare main interaction effects, observe differences between soaking treatments within species, and detect differences among species. The level of significance was α = 0.05 using the Tukey-Kramer adjustment.

Results and Discussion

Influence of Soaking Live Stakes for 48 Hours in Water before Installation, Dormant Season Collection and Planting. There was no significant main effects interaction of the independent variables soaking and species for biomass or diameter at the three, six, and nine month harvests. There was a significant species-soaking interaction for height at three months ($p < 0.01$, $F = 3.51$), but this interaction was not significant at the six or nine month harvests. Results below compare the soaked to nonsoaked live stakes within species.

Although commercial suppliers have suggested a 48-hour soaking period and previous research recommends some period of soaking (Phipps et al. 1983; Schaff et al. 2002; Balch 2008), it did not result in significant improvement in live stake survival or biomass increase for silky willow, black willow, or Virginia sweetspire live stakes cut in the dormant season. Silky dogwood soaked stakes had significantly greater total biomass (76.7 g [0.17 lb]) compared with the nonsoaked stakes (58.2 g [0.13 lb]) at six months ($p < 0.04$, $F = 4.53$) (figure 1). This difference was driven primarily by the difference between belowground biomass of soaked (38.3 g [0.08 lb]) and nonsoaked (25.6 g [0.06 lb]) stakes ($p < 0.04$, $F = 4.77$). By nine months, there was no difference in total biomass between soaked and nonsoaked live stakes for any of the species evaluated.

Nonsoaked stakes in this study received adequate water immediately after collection and installation, which may have had the same effect as soaking for 48 hours. Ensuring live stakes do not dry out before installation is a common recommendation (USDA NRCS 1996; Logar and Scianna 2005). Soaking may not be required if live stakes are immediately installed at or below bankfull where they are in contact with water. Increasing the number of days that live stakes are soaked in water may influence biomass and survival. For example, Tilley and Hoag (2009) noted significantly greater root production after 70 days in peachleaf willow (*Salix amygdaloides*) cuttings that had been soaked for 14 days compared with nonsoaked cuttings. With only one exception, survival of peachleaf willow live stakes soaked for 14 days was better than nonsoaked stakes (Tilley and Hoag 2008).

Comparison of Live Stake Biomass among Species, Dormant Season Collection and Planting. All four species became established and had 100% survival when live stakes were cut in the dormant season. Results are presented as a comparison among species within the same soaking treatment.

There were significant differences among live stake species at three, six, and nine months in height, diameter, aboveground, belowground, and total biomass (tables 1, 2, and 3). Nonsoaked and soaked stakes of black willow, silky willow, and silky dogwood had greater aboveground, belowground, and total biomass than Virginia sweetspire at the three-month harvest (table 1). Black willow below- and aboveground biomasses at three months were similar to findings by Greer et al. (2006) for control stakes (well watered, well drained) with diameter sizes of 1 and 5 cm (0.4 and 2 in).

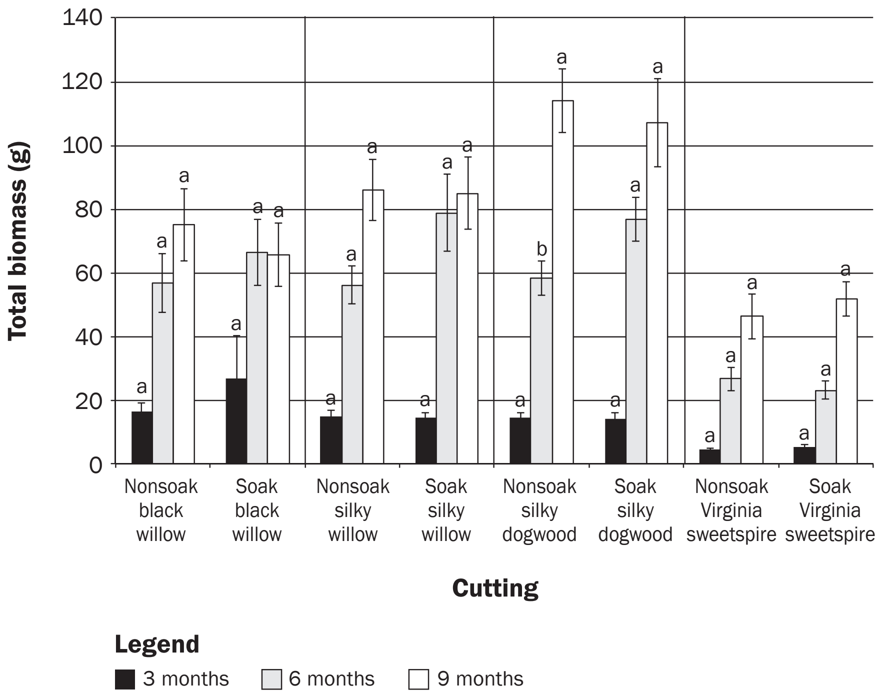
At six months, nonsoaked and soaked stakes of Virginia sweetspire had less aboveground biomass than black willow, silky willow, and silky dogwood (table 2). Correspondingly, the six month total biomass of nonsoaked and soaked Virginia sweetspire live stakes were less than black willow, silky willow, and silky dogwood. Black willow belowground biomass was similar to Virginia sweetspire in both the nonsoaked and soaked treatments at the six month harvest.

By nine months, silky dogwood and silky willow live stakes had greater belowground and total biomass compared to black willow and Virginia sweetspire (table 3). Silky dogwood total biomass was greater than all other species, and this difference was significant for the nonsoaked treatment. Belowground biomass was the primary driver of total biomass differences among species at nine months in contrast to the three and six month results where aboveground biomass was the main influence.

Differences in aboveground, belowground, and total biomass were detected among species, and silky dogwood and silky willow appear to be the species of choice following nine months of establishment. Considering that most bioengineering associated with stream restoration occurs in the

Figure 1

Mean (± standard error) total biomass (g) of soaked and nonsoaked live stake cuttings at three, six, and nine months of four live stake species harvested and planted during the dormant season. Significant differences in biomass due to soaking, indicated by different letters, are within species harvested at the same time. The Tukey-Kramer adjustment was used to determine significance at α = 0.05.



dormant season, greater belowground biomass at nine months of silky dogwood and silky willow may prove beneficial for stream stabilization at a critical time when projects face increased fall and winter stream flows. Roots in a streambank provide increased soil strength and resistance to erosion (Barrett et al. 2006), and selecting live stake species that have greater belowground biomass may assist in stabilizing streambanks more rapidly than those with less belowground biomass. Additionally, long-term survival may be enhanced by greater belowground biomass that provides resistance to drought stress through improved ability to intersect water tables.

Root:Shoot Ratio No differences among species were observed for root:shoot ratios at three months regardless of soaking treatment (table 4). Black willow root:shoot ratios at three months were similar to findings by Greer et al. (2006) for control stakes (well watered, well drained) with diameter sizes of 1 and 5 cm (0.4 and 2 in). Silky willow's root:shoot ratio was greater than black willow and less than silky dogwood and Virginia sweetspire, but these differences were not significant at six months. At six and nine months, the root:shoot ratios of Virginia sweetspire and silky dogwood were greater than black willow for both soaked and nonsoaked stakes. Developing root:-shoot ratio relationships for live stake species may assist in determining root production for field studies where destructive harvesting of belowground biomass may be difficult or undesirable (Monk 1966).

The establishment and survival of willow and dogwood species was expected based on prior experience and research. Numerous field and greenhouse studies with black willow suggest it is a good option for use as live stakes (Greer et al. 2006; Li et. al. 2006; Pezeshki and Shields 2006). Barrett et al. (2006) noted dogwood and willow species that had been planted as live stakes or poles (larger dormant cuttings) were the only species that survived five years after the implementation of a bioengineering project

Table 1

Means of leaf, stem, aboveground (leaf + stem), belowground, and total (aboveground + belowground) biomass; diameter; and height of four live stake species three months following dormant season collection and planting in microcosms.

Treatment and species	Leaf biomass (g)	Stem biomass (g)	Aboveground biomass (g)	Belowground biomass (g)	Total biomass (g)	Diameter (mm)	Height (cm)
Nonsoaked stakes							
Black willow	2.5a	6.4a	8.9a	7.3a	16.2a	7.5a	67.7a
Silky willow	2.3a	5.4a	7.7a	7.0a	14.7a	6.8ab	58.5ab
Silky dogwood	2.3a	4.3ab	6.7a	7.8a	14.5a	6.8ab	51.9b
Virginia sweetspire	0.6b	1.5b	2.1b	2.3b	4.4b	4.7b	27.4c
Soaked stakes							
Black willow	1.8bc	4.2a	6.0a	7.2a	13.3a	7.2a	58.3b
Silky willow	2.9a	4.8a	7.6a	6.7a	14.4a	6.5a	77.9a
Silky dogwood	2.0ab	4.0a	6.0a	8.0a	13.9a	7.2a	49.2b
Virginia sweetspire	0.95c	1.7b	2.6b	2.8b	5.4b	5.4a	27.3c

Note: Values within the same column within the same soaking treatment followed by different letters are significantly different by Tukey-Kramer adjustment at α = 0.05.

Table 2
Means of leaf, stem, aboveground (leaf + stem), belowground, and total (aboveground + belowground) biomass; diameter; and height of four live stake species at six months following dormant season collection and planting in microcosms.

Treatment and species	Leaf biomass (g)	Stem biomass (g)	Aboveground biomass (g)	Belowground biomass (g)	Total biomass (g)	Diameter (mm)	Height (cm)
Nonsoaked stakes							
Black willow	13.5a	27.5a	41.0a	15.8ab	56.7a	12.6a	135.6a
Silky willow	12.3ab	22.2a	34.8a	21.3a	56.1a	11.2ab	127.3a
Silky dogwood	12.6a	18.4ab	32.6a	25.6a	58.2a	10.6ab	109.9a
Virginia sweetspire	8.0b	7.8b	15.8b	10.8b	26.6b	9.3b	57.5b
Soaked stakes							
Black willow	16.4a	33.4a	49.8a	16.6bc	66.4a	11.3a	139.1a
Silky willow	15.2a	27.3a	41.7a	28.6ab	70.3a	11.2a	137.2a
Silky dogwood	14.0a	26.5a	38.4a	38.3a	76.7a	16.6a	116.0a
Virginia sweetspire	7.5b	6.3b	13.9b	9.2c	23.1b	9.1a	58.3b

Note: Values within the same column within the same soaking treatment followed by different letters are significantly different by Tukey-Kramer adjustment at $\alpha = 0.05$.

Table 3
Means of leaf, stem, aboveground (leaf + stem), belowground, and total (aboveground + belowground) biomass; diameter; and height of four live stake species at nine months following dormant season collection and planting in microcosms.

Treatment and species	Leaf biomass (g)	Stem biomass (g)	Aboveground biomass (g)	Belowground biomass (g)	Total biomass (g)	Diameter (mm)	Height (cm)
Nonsoaked stakes							
Black willow	3.7b	45.1a	48.8a	26.3b	75.1bc	16.6a	161.7a
Silky willow	3.4b	37.3a	40.7a	45.4b	86.0b	11.6a	136.6a
Silky dogwood	10.0a	27.6ab	37.6ab	76.4a	114.0a	18.6a	108.7b
Virginia sweetspire	6.2ab	13.0b	19.1b	27.0b	46.2c	9.7a	67.0c
Soaked stakes							
Black willow	3.2ab	33.5a	37.8a	27.1b	65.5b	13.1a	146.7a
Silky willow	2.2b	30.2a	32.3ab	51.8ab	84.8ab	12.7a	140.3a
Silky dogwood	5.7ab	27.1a	37.9a	73.2a	107.1a	12.3a	106.8b
Virginia sweetspire	6.8a	11.1b	17.9b	33.9b	51.8b	10.3a	66.1c

Note: Values within the same column within the same soaking treatment followed by different letters are significantly different by Tukey-Kramer adjustment at $\alpha = 0.05$.

in Ohio. Black willow consistently had less biomass than the other species evaluated, except for Virginia sweetspire, and the root:shoot ratio of black willow was less than that of other species evaluated and significantly less than silky dogwood for both soaked and nonsoaked treatments (table 4). Visual inspections at times of harvest supported observations by others that black willow had fewer roots per unit area than the other species evaluated in this project and these small diameter roots were generally found in the top 20 to 30 cm of soil (Simon and Collison 2002) (figure 2).

Virginia sweetspire performed well as a live stake, although it had less total biomass, significantly less height, and smaller diameter than the other species at three, six, and nine months (tables 1, 2, and 3). This difference in biomass, height, and diameter is expected as Virginia sweetspire's growth habit is a medium shrub and the other species are considered either large shrubs (silky dogwood) or trees (willow species) (Dirr 1998; Lady Bird Johnson Wildlife Center 2012). At nine months, belowground biomass of Virginia sweetspire was significantly less than silky dogwood and similar to the willow species (table 3).

The excellent survival and growth of the four species observed supports incorporating a combination of these species for riparian restoration efforts in the Southeast rather than relying on one species, such as black willow. A diversity of species provides benefits including varied types of root systems that may improve soil stability by occupying the soil at different angles and depths (Kutschera and Lichtenegger 1997; Stokes et al. 2009). Species diversity of riparian vegetation has been noted to increase water quality, terrestrial wildlife, and biodiversity (Kauffman and Krueger 1984; Bjornn and Reiser 2008). By using riparian vegetation plantings that have a wide range of shade, habitat, and pollutant control capabilities, stream degradation can be slowed (Correll 2005; Bir and Conner 2010).

Harvest Timing. Cutting and planting live stakes in the dormant season resulted in 100% survival for all for species evaluated in the experiment (data not shown). Survival rates, height, and diameter of live stakes cut in the growing season were lower than stakes cut in the dormant season regardless

Table 4
Live stake comparison of root:shoot ratio among species at three, six, and nine months following collection and installation in microcosms during the dormant season.

Treatment and species	Months 3	6	9
Nonsoaked stakes			
Black willow	1.03a	0.46b	0.56b
Silky willow	1.03a	0.60ab	1.37b
Silky dogwood	1.45a	0.81a	2.90a
Virginia sweetspire	1.28a	0.84a	2.06a
Soaked stakes			
Black willow	1.30a	0.35b	0.67b
Silky willow	0.89a	0.66ab	1.69ab
Silky dogwood	1.38a	0.99a	2.40a
Virginia sweetspire	1.18a	0.83a	2.12a

Note: Root:shoot ratio is defined as the belowground (root) biomass divided by aboveground (leaves and stem) biomass. Values within the same column within the same soaking treatment followed by different letters are significantly different by Tukey-Kramer adjustment at α = 0.05.

of soaking treatment (table 5). These results confirm previous research on timing of live stake installation in the dormant season to maximize establishment and survival (Darris 2002; Shafer and Lee 2003; Sotir and Fischenich 2003; Logar and Scianna 2005; Balch 2008.). Virginia sweetspire had the highest survival rate after three months and was the only species that survived to six months. This may be related to its ability to perform well in a drought environment (Dylewski et al. 2012; Baily 2009).

Because of the high levels of mortality in black willow, silky willow, and silky dogwood, a growing season harvest is not recommended for the installation of live stakes. If a growing season harvest cannot be avoided, the use of Virginia sweetspire may

Figure 2
Belowground biomass of (a) black willow, (b) silky willow, (c) silky dogwood, and (d) Virginia sweetspire, which were soaked prior to installation.

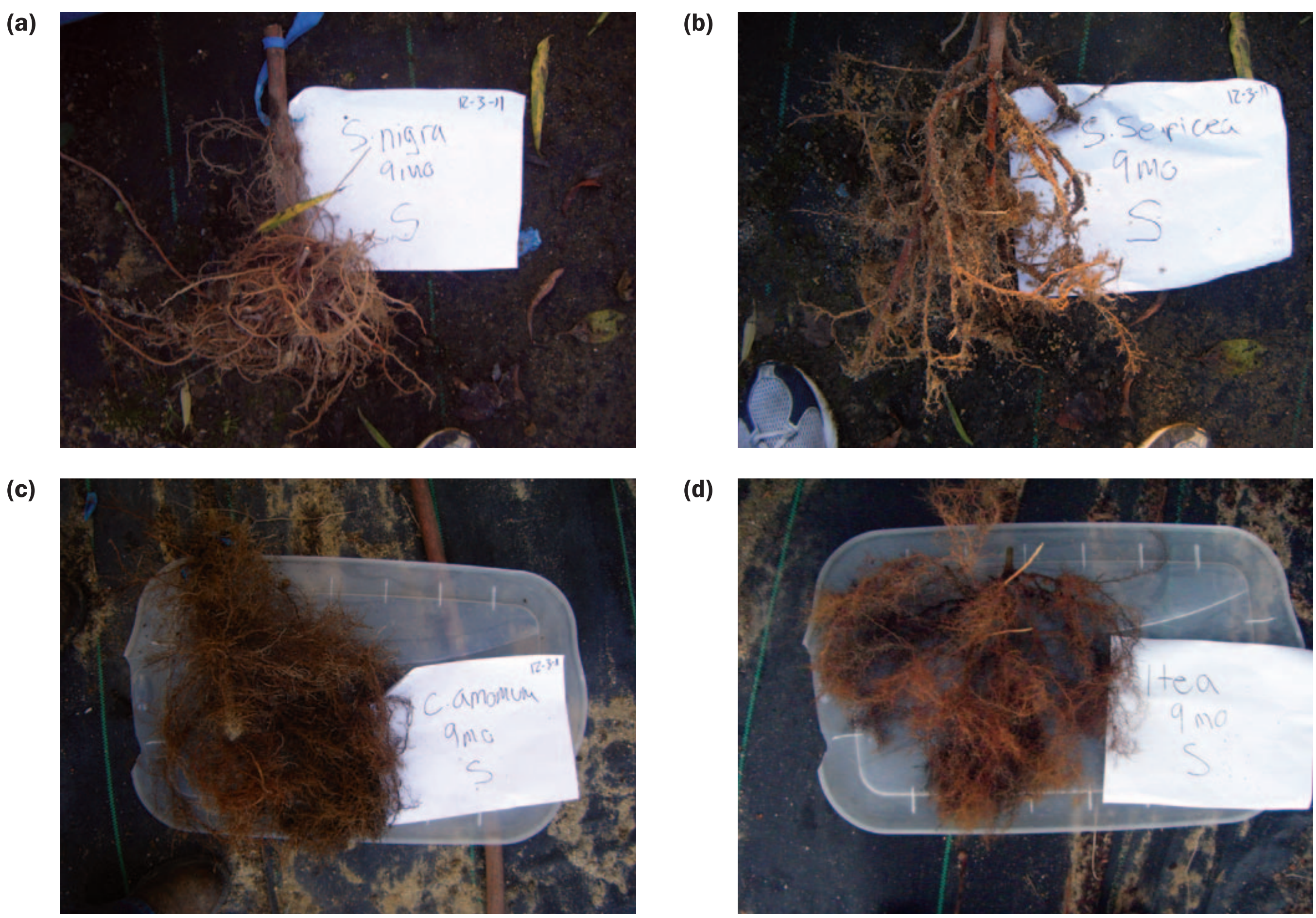


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Table 5
Growing season harvest survival of four soaked and nonsoaked live stake species at three and six months after planting. Results presented as number alive, number dead, and percentage alive.

Time after planting	Species	Treatment	Alive (n)	Dead (n)	Alive (%)	Average diameter (mm)	Average height (cm)
3 month	Black willow	Soaked	6	9	40	10.8	47.8
		Nonsoaked	4	11	27	11.1	49.3
	Silky willow	Soaked	10	7	59	10.4	36.8
		Nonsoaked	12	5	71	9.2	37.4
	Silky dogwood	Soaked	4	12	25	6.4	37.5
		Nonsoaked	1	14	14	6.3	37
	Virginia sweetspire	Soaked	12	3	80	6.46	27.4
		Nonsoaked	14	4	78	5.86	27.5
6 month	Black willow	Soaked	0	15	0	—	—
		Nonsoaked	0	15	0	—	—
	Silky willow	Soaked	0	17	0	—	—
		Nonsoaked	0	17	0	—	—
	Silky dogwood	Soaked	0	16	0	—	—
		Nonsoaked	0	15	0	—	—
	Virginia sweetspire	Soaked	12	3	80	6.9	29.6
		Nonsoaked	14	4	67	6.7	29.4

assist with establishing vegetation until the following dormant season with the understanding that the stakes must intersect stream baseflow so that they do not dry out after installation. A longer soaking period may also result in increased survival of live stakes cut in the growing season. A seven-day soaking period for nondormant cuttings that are well watered, but not inundated, enhanced survival and early development (bud flush) (Pezeshki et al. 2005).

Summary and Conclusion

This study evaluated the growth and survival of black willow, silky willow, silky dogwood, and Virginia sweetspire live stakes that are native plants commonly found in riparian corridors in the southeastern United States. Results indicate that soaking live stakes in water for 48 hours may not be required for survival and establishment as long as stakes do not dry out prior to establishment and are installed below bankfull where there is adequate soil moisture. Significant differences in biomass and root:shoot ratio among the species were observed, and the season of live stake harvest is critical for live stake survival.

When live stakes were harvested in the dormant season, there was no difference between soaked and nonsoaked survival or total biomass at the three, six, and nine-month harvest for all four species with one exception. Soaked live stakes of silky dogwood were significantly greater in total biomass than nonsoaked live stakes at six months. By nine months, however, there was no difference between the live stakes in each soaking treatment. All live stakes harvested in the dormant season had 100% survival regardless of soaking treatment.

Silky dogwood and silky willow had greater belowground and total biomass after nine months than black willow and Virginia sweetspire. Greater belowground biomass may improve the ability of these species to provide streambank soil stabilization and increase ability of a live stake to survive droughty conditions through a healthy root system that may access lower water tables. Silky dogwood and Virginia sweetspire had greater root:shoot ratios than the willow species. Virginia sweetspire had the least biomass compared with the other species, which is expected as it is a medium shrub. The smaller aboveground biomass and high root:shoot ratio of Virginia sweetspire makes it an attractive live stake species for stream restoration projects that may desire lower-growing vegetation, such as public parks and golf courses.

A dormant season collection and installation is recommended for these live stake species based on low survival rates during growing season installation. If a growing season harvest of live stakes is necessary, Virginia sweetspire was the only species that survived to six months, and soaked live stakes had an 80% survival rate.

Possible factors to be investigated in future research may include variable time of soaking stakes, use of rooting hormone, and whether or not those factors affect growing season harvest results. Future studies may also incorporate other native live stake species, such as elderberry, buttonbush, river birch, sycamore, and ninebark (*Physocarpus opulifolius*).

Every restoration project is unique and requires its own analysis before implementation. Therefore, recommendations on live stake species should be determined by site-specific needs, such as shade tolerance or aesthetics. A mixture of black willow, silky willow, silky dogwood, and Virginia sweetspire live stakes may be used to achieve an aesthetically appealing riparian corridor and to increase biodiversity along streams. Results from this study and future studies will provide landowners and resource managers with recommendations for low-cost and effective alternatives for stream and river riparian vegetation plantings.

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