SURVIVAL AND GROWTH OF RESTORED PIEDMONT RIPARIAN FORESTS AS AFFECTED BY SITE PREPARATION, PLANTING STOCK, AND PLANTING AIDS

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Abstract--Forest mitigation sites may have poor survival and growth of planted trees due to poor drainage, compacted soils, and lack of microtopography. The effects of five replications of five forestry mechanical site preparation techniques (Flat, Rip, Bed, Pit, and Mound), four regeneration sources (Direct seed, Bare root, Tubelings, and Gallon), and three planting aids (None, Mat, Tubes) on American sycamore (*Platanus occidentalis* L.) and willow oak (*Quercus phellos* L.) were examined for 2 years following establishment in order to evaluate the treatment potential for enhancing survival and growth. After 2 years, Mounding and Gallon seedlings were found to be the most beneficial treatments for American sycamore survival and growth. Bedding also proved beneficial. For willow oak, Mound and Bed were also beneficial, particularly with Bare root seedlings Gallons. The positive responses of the species to mounding and bedding were due to treatment effects on elevation on poorly drained sites, reduction of competition, and reduction of compaction.

INTRODUCTION

The Federal Water Pollution Control Act of 1972 and subsequent amendments and interpretations have resulted in policies which require wetland restoration or creation to offset wetland losses caused by activities such as urbanization (Stolt and others 2000). Wetland creation projects have a relatively poor track record for success, thus it is common to have wetland mitigation ratios of 2:1 or 3:1 (Brown and Lant 1999). The relatively poor success rates are caused by a variety of problems, including: poor recognition of site conditions which results in poor species selection; sites with compacted soil conditions, which inhibit soil water movement and root penetration; excessively wet sites that may kill or suppress growth of desired tree species; and lack of topography which may limit the survival and growth of planted tree species (Bailey and others 2007).

Forest managers have been facing similar regeneration problems on such sites. Harvested sites are commonly compacted and poorly drained, yet silviculturalists have overcome these limitations with a variety of mechanical site preparation techniques (Aust and others 1998). For example, both mounding and bedding have been widely used across the eastern United States since the 1950s and 1960s to overcome lack of relief and soil compaction on wet sites (Lof and others 2012, Miwa and others 2004). Similarly, riparian restoration efforts often have site limitations that are overcome by using alternative planting sources or planting aids. Interestingly, there has been little technical transfer between forest managers and the wetland restoration community.

The literature indicates that wetland restoration efforts could be enhanced with increased use of silvicultural tools. Therefore, the objective of this research project is to quantify the effects of mechanical site preparation, regeneration source, and planting aids on the survival and growth of two species commonly used on mitigation sites: the early successional species American sycamore (*Platanus occidentalis* L.) and the later successional species willow oak (*Quercus phellos* L.).

MATERIALS AND METHODS

Study Site

The study site is located in the Piedmont physiographic province on the Virginia Tech R.J. Reynolds Homestead Forest Research Extension Center near Critz, VA. Much of this 280-ha area was converted to tobacco plantations during the 1800s, and the specific riparian area was subjected to agriculture and excessive compaction by a recent soil compaction research project. Thus the area has compacted soils, lack of relief, and is excessively wet during winter and spring. Soil series in the study include Augusta (fine-loamy, mixed semiactive, thermic Aeric Endoaquults), French (fine loamy over sandy, mixed, active

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mesic Fluvaquentic Dystrudepts), and Roanoke (fine, mixed, semiactive thermic Typic Endoaquults). The site is located in the floodplain of a first-order perennial stream with a 500-ha watershed. Flooding to a depth of approximately 25 cm occurs during most spring seasons.

Treatments

Five site preparation treatments were established (Flat, Rip, Bed, Pit, Mound). The Flat treatment consisted of surface tillage with a disk harrow to reduce herbaceous competition. The Rip treatment consisted of subsoiling with a 30-cm ripping shank underneath the planting zones. The Bed treatments were made with the blade on a bulldozer. The Pit and Mound treatments were created in the same area: a tractor-mounted backhoe was used to excavate pit material (approximately 40 cm) to create an adjacent mound of approximate 40 cm. Four regeneration sources (Seed, Bare root, Tubeling, Gallon) were superimposed across all site preparation treatments. For the Seed treatment, three acorns or a finger pinch of American sycamore seeds were planted. The seeds were collected from piedmont seed sources approximately 3 months prior to planting. The bare-root seedlings were purchased from commercial nurseries and planted with dibble bars. Tubeling and Gallon containers were purchased from a commercial nursery and planted with spades. Three levels of planting aids were applied to all combinations of site preparation and regeneration sources (None, Tubes, and Mats). Tubes consisted of 1-m planting tubes, and mats were 50- by 50-cm geotextile fabric. Seeds and seedlings were planted in May 2011, and planting aids were installed in June 2012. Minimal herbaceous control was conducted during summer 2011 and 2012.

Survival and Growth Parameters

Survival and growth indices were measured after one and two growing seasons (2011, 2012) simply recording if the individual had survived. Growth parameters included average ground line diameter based on caliper measurements from two directions and total tree height measured to the nearest 1 cm with a height poles. For trees taller than 1.3 m, diameter at breast height (d.b.h., cm) was also recorded. The diameter and height measures were subsequently converted to a biomass index in cm^3 based on d^2h geometry.

Statistical Design and Analysis

The study is arranged as a split-split plot within a Randomized Complete Block Design. Five blocks were established for each of the two species. The main effects are five site preparation treatments (Flat, Rip, Bed, Pit, and Mound). The Pit and Mound treatments were established together but were analyzed as two treatments. The split plot was comprised of the four regeneration sources. The second split consisted of the three planting aids. For each experimental unit, four units (seed or seedling) were established. Thus, for both American sycamore and willow oak , approximately 1,200 trees or seeds were planted (5 blocks x 5 site preparation treatments x 4 regeneration sources x 3 planting aids x 4 trees per seeds = 1,200). Survival and growth parameters were analyzed via analysis of variance (ANOVA) and statistically different means were separated with a Tukeys HSD test.

RESULTS AND DISCUSSION

American sycamore survival was consistently between 62 and 66 percent across the site preparation treatments during years 1 and 2 with the exception of the Pit treatment, which had significantly lower survival (table 1). American sycamore's biomass index was significantly reduced by the Pit treatment during both years and was significantly increased by the Mound site preparation treatment (table 1). Not unexpectedly, American sycamore survival percentages were favored by the Tubeling and Gallon regeneration sources and were very low for direct seeding (table 2). Biomass values followed the same general trends: lowest for Direct seeding, followed by Bare root and Tubeling, and greatest in the Gallon regeneration sources (table 2). Examination of the effects of planting aids on American sycamore survival and growth indicated that the

Table 1--Effects of site preparation on survival and biomass indices for American sycamore on a Piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10

Site preparation treatment	--------Survival--------		---Biomass index---	
	Year 1	Year 2	Year 1	Year 2
	--------*percent*---------		-----------*cm*^{3}------------	
Flat	68b	68b	496b	1487b
Rip	68b	68b	549b	1900b
Bed	66b	66b	649b	2497b
Pit	62a	59a	333a	1232a
Mound	68b	68b	913c	3811c
p	≤0.0001	≤0.0561	≤0.0001	≤0.0001

Table 2--Effects of regeneration sources on survival and biomass indices for American sycamore on a piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10

Regeneration source treatment	--------Survival-------		---Biomass index---	
	Year 1	Year 2	Year 1	Year 2
	--------*percent*--------		----------*cm*^{3}------------	
Direct seed	36a	16a	10a	10a
Bare root	72b	58b	196a	933b
Tubling	85c	85c	445b	1896c
Gallon	88c	88c	1023c	3728d
p	≤0.0001	≤0.0001	≤0.0001	≤0.0001

planting Mats and Tubes slightly increase survival, and the Mat increased biomass (table 3).

Willow oak survival was also reduced by the Pit treatment (table 4). Mound treatment positively increased biomass for willow oak during year 1. During year 2, the pattern continued, but the differences were not significant. Bare root and Gallon both provided good survival for willow oak (table 5), and the Direct seeding survivals were lower. However, survival of the relatively larger-seeded willow oak was better with direct seeding than for American sycamore. During year 1, the gallon regeneration source offered the best biomass growth for willow oak, but by year 2, regeneration sources effects on willow oak biomass were not significant (table 5). The Mat planting aid provided both enhanced survival and biomass for willow oak (table 6).

The efficacy of any given treatment will be due to a combination of the treatment effects on both survival and growth. Therefore, we created a unitless performance index which is the product of survival and biomass for both American sycamore (table 7) and willow oak (table 8). We then examined the top 25 percent of all treatments to select the “best” treatments. For American sycamore, the Mound treatment followed by the Bed site preparation treatment combined with large Gallon containerized seedlings clearly performed the best. There was no clear pattern with planting aids for American sycamore. For willow oak the Mound and Bed treatments worked well for the Gallon containers, but the Bare root seedlings also performed well. For both species, the Mound and Bed treatments elevated the seedlings in the poorly drained soils and favored tree survival. The Mound and Bed treatments also alleviated soil compaction. The Mound treatment

Table 3--Effects of planting aids on survival, diameters, heights, and biomass indices for American sycamore on a piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10. Year 1 biomass indices were not significantly different

Planting aid treatment	-------Survival------- Year 1	Year 2	--Biomass index-- Year 1	Year 2
	------*percent*--------		----------*cm*^{3}----------	
None	71a	63a	600	2230ab
Tube	76b	66ab	533	1694a
Mat	77b	70b	649	2632b
p	≤0.006	≤0.0001	≤0.6370	≤0.0144

Table 4--Effects of site preparation on survival and biomass indices for willow oak on a piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10. Year 2 biomass indices were not significantly different

Site preparation treatment	-------Survival------- Year 1	Year 2	---Biomass index--- Year 1	Year 2
	--------*percent*-------		--------*cm*^{3}------------	
Flat	77b	56b	53a	2193
Rip	79b	60b	67b	1471
Bed	80b	80b	69b	1435
Pit	67a	67a	70b	440
Mound	83b	83b	84c	2001
p	≤0.0001	≤0.0001	≤0.0001	≤0.1507

Table 5--Effects of regeneration sources on survival and biomass indices for willow oak on a piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10. Year 2 biomass indices were not significantly different

Regeneration source treatment	--------Survival------- Year 1	Year 2	---Biomass index--- Year 1	Year 2
	----------*percent*----------		------------*cm*^{3}------------	
Direct seed	61a	31a	0.5a	1240
Bare root	86c	86c	65c	2278
Tubling	74b	65b	5b	1435
Gallon	84c	84c	127d	1104
p	≤0.0001	≤0.0001	≤0.0001	≤0.2038

Table 6--Effects of planting aids on survival, diameters, heights, and biomass indices for willow oak on a piedmont forest restoration site during years 1 and 2. Mean values within a column followed by a different letter are significantly different at α ≤ 0.10. Year 1 biomass indices were not significantly different

Planting aid treatment	-------Survival------- Year 1	Year 2	--Biomass index-- Year 1	Year 2
	------*percent*-------		---------*cm*^{3}----------	
None	74a	51a	67	718a
Tube	78ab	60ab	67	1620b
Mat	82b	69b	67	2154c
p	≤0.0001	≤0.0001	≤0.3323	≤0.0011

Table 7--American sycamore performance index (biomass x survival) at 2 years. Numbers with asterisk represent the top 25 percent of all treatment combinations for performance

Regeneration source	Planting aid	-----------------Site preparation treatment------------- Flat	Rip	Bed	Pit	Mound
Direct seed	None	1	156	17	1	337
	Tube	1	438	112	76	76
	Mat	2	3	25	7	11
Bare root	None	557	550	670	138	2023*
	Tube	426	530	770	257	1370
	Mat	402	451	250	92	852
Tubling	None	645	1523	2238*	382	2234*
	Tube	721	831	1084	443	874
	Mat	893	1616	1799	875	3119*
Gallon	None	2193*	2208*	1923*	1803	3113*
	Tube	1684	2038*	2735*	1393	3456*
	Mat	1592	1905*	3532*	2042*	6234*

Table 8--Willow oak performance index (biomass x survival) at 2 years. Numbers with asterisk represent the top 25 percent of all treatment combinations for performance

Regeneration source	Planting aid	-----------------Site preparation treatment------------- Flat	Rip	Bed	Pit	Mound
Direct seed	None	111	4	4	1	5
	Tube	20	86	10	1	31
	Mat	1	10	15	1	39
Bare root	None	398	748	1541*	145	1624*
	Tube	2173*	516	1015*	76	1025*
	Mat	669	674	787	237	1424*
Tubling	None	52	127	33	1	153
	Tube	101	108	38	45	118
	Mat	116	53	13	8	390
Gallon	None	727	1067*	987*	287	1480*
	Tube	676	985*	1157*	518	1354*
	Mat	888	972*	1168*	446	1201*

provided some competition control by burying the seeds of competitors deeper than they could survive. Currently, the use of large seedlings is common practice on mitigation sites, but these data indicate that Mound and Bed also offer significant potential for improving wetland mitigation. The wetland mitigation community typically has close working ties with equipment contractors, thus locating excavator operators should be relatively straightforward. The use of Mounds offers significant potential to overcome the typical problems encountered on Piedmont mitigation sites.

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