Assessment of Silvicultural Practices to Improve Survival and Growth of Pioneer and Mid-Successional Hardwoods on Old Field Restoration Sites.

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ASSESSMENT OF SILVICULTURAL PRACTICES TO IMPROVE SURVIVAL AND GROWTH OF PIONEER AND MID-SUCCESSIONAL HARDWOODS ON OLD FIELD RESTORATION SITES

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ABSTRACT

Survival and growth of planted trees are common indices used to evaluate success of wetland restoration efforts used to compensate for wetland losses. Restoration efforts on marginal agricultural lands typically result in less than satisfactory survival and growth of desired tree species. This study evaluated seed source ecotype, greenhouse preconditioning and combinations of five mechanical site preparation techniques (mound, bed, rip, disk, pit), four levels of planting stock (gallon, tubeling, bare root, and direct seed), and three planting aids (mat, tube, none) on the survival and growth of American sycamore (*Platanus occidentalis* L.) and willow oak (*Quercus phellos* L.) planted on an old field riparian area in the Virginia Piedmont. American sycamore seedlings subjected to greenhouse flood preconditioning had 25% greater height and willow oak seedlings grown under normal greenhouse conditions had 18% greater diameter, but these greenhouse adaptations did not confer greater survivability or growth after field planting. American sycamore seeds sourced from dry ecotypes were 14% taller than wet ecotype seeds, and willow oak acorns sourced from wet ecotypes were 11% taller than dry ecotype acorns, indicating that parental ecotype may influence survivability and growth. The combination of mounding site preparation and gallon planting stock increased mean survival to 100% and aboveground dry biomass (5.44 Mg/ha/yr) in American sycamore. Willow oak had 45% greater woody stem volume with mounding site preparation 80% greater woody stem volume with gallon and bare root planting stock. Tubeling planting stock provided significant benefit relative to the low planting stock cost for American sycamore, while bare root seedlings were shown to be an effective planting stock for willow oak. The use of appropriate ecotype seed sources, use of mounding mechanical site preparation techniques and planting of species appropriate planting stock increased survival and growth of common early and mid-successional Piedmont tree species on marginal agricultural lands. Treatments that appear to be economically viable for restoration and mitigation efforts could potentially offer other economic incentives such as short rotation woody crops and timber value, which might induce additional private landowners to attempt restoration efforts in marginal old field riparian areas.

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GENERAL AUDIENCE ABSTRACT

In order to offset the loss of wetlands due to development, strategies are needed to create wetlands in areas along streams that are unfarmed. Survival and growth of planted trees are commonly used to evaluate the success of these new wetland areas. The goal of this research is to provide alternative methods to increase survival and growth of two common trees planted in the Piedmont of Virginia. The results show that creating mounds of soil before planting trees and planting larger trees will increase tree survival and growth in these wetland areas. Landowners and land managers can use these methods to increase the value of unfarmed land along streams while also increasing water quality and providing habitat animals that use the streams and wetlands.

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DEDICATION

To my family, without your patience, love, support and understanding this would have never been possible. And for Gene and Duane, your sacrifice always pushes me forward.

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1.0 ASSESSMENT OF SILVICULTURAL PRACTICES TO IMPROVE SURVIVAL AND GROWTH OF PIONEER AND MID-SUCCESSIONAL HARDWOODS ON OLD FIELD RESTORATION SITES.

1.1 Introduction

Wetland and stream ecosystems provide a suite of valuable ecosystem services to humans including water quality protection (Osborne and Kovacic, 1993), storage of flood stage waters (Hey and Philippi, 1995), detention and retention of sediment and nutrients (Baker and Lockaby, 2001; Sheridan et al., 1999), wildlife habitat and travel corridors (Fischer and Fischenich, 2000; Tarr et al., 2017), and economic services (Brown and Lant, 1999; Sather and Smith, 1984). Conversion of riparian forests and wetlands to agricultural lands and subsequently to predominantly impervious urban landscapes has resulted in the degradation of these ecosystems, many of which eventually became regulated by federal and state agencies (Tweedy and Evans, 2001). The promulgation of the Clean Water Act in 1972 led to regulatory agency mandates to reduce or eliminate the loss of wetlands, and the 1988 Presidential "No Net Loss" legislation resulted in the requirement of compensatory mitigation to offset impacts to wetlands and streams (Brown and Lant, 1999; Morgan and Roberts, 2003). The emphasis on the replacement of wetland impacts authorized under the Clean Water Act was further reinforced by the 2008 Compensatory Mitigation Rule, which codified a hierarchical approach to the replacement of permanently impacted wetland areas. Under the 2008 Rule, compensatory wetland credits, which are calculated based upon a regulatory ratio by wetland type, could be provided by commercial wetland mitigation banks, purchased from state managed in-lieu fee programs, or by constructing as-needed compensatory wetland areas as permittee-responsible mitigation projects (Hough and Harrington, 2019; Van den Bosch and Matthews, 2017). Wetland creation and wetland restoration are often combined into a global term of "wetland restoration" when referenced in the context of compensatory mitigation, however, wetland creation typically occurs in areas that do not have any regulatory parameters that define wetlands, while wetland restoration typically has at least one regulatory wetland parameter (Cowardin and Golet, 1995). Wetland regulatory parameters are defined in 33 CFR 328.3 and 40 CFR 230.3 as areas that meet diagnostic criteria for the presence of hydrophytic vegetation, wetland hydrology and hydric soils (U.S. Army Corps of Engineers, 1987). Wetland creation and restoration mitigation sites are often constructed in old field agricultural areas and other lower productivity crop areas that are often along the margins of managed agricultural areas (Wiens et al., 2011). These areas are often characterized by high soil compaction, low nutrient and organic matter content and saturated soil conditions during the typical growing season (Stanturf et al., 1998). Conversion or restoration of these areas to functioning wetland and riparian areas can increase soil organic matter, create areas for nutrient deposition and cycling, increase vegetative biodiversity and provide wildlife habitat and travel corridors (Dale et al., 2011; Tarr et al., 2017). Wetland restoration or creation on these types of sites usually relies upon the establishment of wetland herbaceous cover, woody stock, and rapid biomass accumulation to meet long-term site success goals. While the concept of wetland mitigation is defined clearly by Federal and State regulatory policy, the implementation of wetland mitigation site design and the success of these sites is fraught with issues. Many compensatory mitigation projects encounter substantial issues with hydrologic regimes, abrupt wetland and upland transition areas, and survival of planted wetland species (Gutrich and Hitzhusen, 2004; Matthews and Endress, 2008; Zedler and Callaway, 1999). The low rate of replacement in compensatory mitigation sites was addressed by the 2008 Mitigation Rule, which prioritized the use of commercial mitigation banks as the primary method to mitigate for wetland impacts, followed by in-lieu fee credit purchases and finally permittee-responsible mitigation sites. Commercial mitigation sites are required to demonstrate success by establishing wetland criteria prior to the release of wetland mitigation credits and as such are more likely to replace the functions and values of impacted wetlands at a more consistent rate than other mitigation options (Salzman et al., 2009).

The 2008 Mitigation Rule prioritized the use of commercial mitigation banking as the method to mitigate for permanent wetland impacts. Commercial mitigation banks were initially developed in the early 1990s as a partnership between public and private entities to fulfill the no-net loss requirement for wetlands, and have become a method to commodify wetland ecosystem services. (Robertson, 2004). Commercial compensatory mitigation banking has become a multi-billion-dollar industry, with commercial banks occurring in a variety of forms throughout the United States (Bendor, 2009). Given the monetary value assigned by commercial mitigation banks to forested wetlands and the ecosystem value determined by regulatory agencies that in part drives the monetary value, a greater emphasis has been placed on the survival and growth of woody species in these sites, as this is typically one of the primary factors limiting the delivery of desired long-term ecosystem services. Success is usually based on a combination of survival and growth of woody species. Silvicultural operations used for plantation establishments have been successful in wetland areas such as wet mineral flats and bottomland hardwood areas of the southeastern United States (Aust et al., 2019). The use of established silvicultural techniques, including mechanical site preparation, selection of planting stock based upon prevailing site conditions, and the use of planting aides are gaining momentum and support from the regulatory bodies overseeing the wetland mitigation implementation programs. These techniques are not widely used by wetland design and construction groups within the current compensatory mitigation market (McLaughlin et al., 2000; Sun et al., 2001).

Mechanical site preparation is characterized by the use of heavy equipment to manipulate site soils to optimize site conditions for the establishment of woody species. Site preparation in wetlands is potentially beneficial, as many created forested wetlands fail due to incorrect hydroperiods and soil compaction (Morris and Lowery, 1988). Forestry operations have used mechanical site preparation for decades to prepare harvested sites and to ameliorate the impacts of timber harvesting (Aust and Blinn, 2004; Löf et al., 2012; McLaughlin et al., 2000). The reduction of soil compaction, creation of site microtopography and competition control from undesirable species are the primary benefits of mechanical site preparation in forested wetlands (Bruland and Richardson, 2005). The method of site preparation varies depending upon the location, site conditions, and available machinery. Some of the primary mechanical site preparation methods most often used in areas that have limitations to tree establishment due to hydrologic fluctuations and soil compaction include mounding, bedding, ripping and disking (Bruland and Richardson, 2005; Löf et al., 2012; Londo and Mroz, 2001; Miwa et al., 2004).

The success of constructed forested wetlands and riparian forest buffers are often dependent upon the survival and growth of early and mid-successional hardwood species that are tolerant to periods of groundwater drawdown and re-flooding. The availability and flood tolerance of seedlings are often deciding criteria for inclusion in wetland and riparian restoration plantings; however, the success of these restoration efforts often results in less than satisfactory survival and growth of the desired tree species (Roquemore et al., 2014). Due to the importance placed upon height growth during the mitigation evaluations, early successional species, such as

American sycamore (*Platanus occidentalis* L.), are commonly planted in the Piedmont have adapted to variability in groundwater levels and re-flooding events by germinating during groundwater drawdown periods and developing adventitious roots during seedling establishment. Wildlife habitat restoration often favors mid-successional Piedmont hardwood species, such as willow oak (*Quercus phellos* L.), which are well adapted to these site conditions. Red and white oaks are ring porous species that have large diameter early wood vessels and more narrow late wood vessels that allow for more efficient use of water during periods of inundation and drawdown, and develop deep early roots as seedlings (Abrams, 1996; McKnight et al., 1981). Both American sycamore and willow oak seedling establishment could potentially be improved with source selection and pre-conditioning efforts.

Environmental conditioning of seedlings and collection of seeds from disparate geographic settings have also been identified as areas that may reduce the survival and growth of planted stock. Previous research has indicated that using locally collected seeds from superior individual trees or well performing stands in similar landscape positions will increase survival growth on marginal sites (Dey et al., 2008). Seed source provenance research has been ongoing since the 1930s and continues as climate variability increases, making resistance to drought and flooding a more desirable seedling trait (Friedman and Lee, 2002; Matías et al., 2012). Regional sourcing of seeds may increase adaptation to biotic and abiotic factors and increase the potential for ecosystem restoration, but evidence of a parental genotypic link to climate resilience has not been as widely investigated as seedling edaphic adaptations (Baughman et al., 2019; Bucharova et al., 2019). Nursery seedling adaptations are most commonly induced by preconditioning the seedlings that have sprouted but have not matured to the size required for site planting. Preconditioning treatments, including methods to manipulate hydrologic regime, seedling root adaptation and reducing seedling leaf area, are conducted to increase post-planting stress resistance and improve seedling survival and growth. Preconditioning can increase resilience to drought conditions by impacting root growth, shoot to root ratio, rate of photosynthesis, osmotic potential and water-use efficiency (Hook and Brown, 1973; Kozlowski and Pallardy, 2002; Seiler and Johnson, 1988, 1985). Seedlings collected from floodplain locations may be more adaptable to changes in surface and subsurface hydrology compared to upland seedlings (Havens, 2004), which suggests that these species may be better suited for wetland and riparian restoration plantings.

The type of planting stock is also an important factor in the success of wetland mitigation sites. Silvicultural operations use a variety of planting stock optimized for the specific site conditions. These options typically include direct seeding, bare root seedlings, tubelings, and containerized seedlings (Stanturf et al., 2014). Each of the planting techniques have costs/benefits associated with it, and a combination of these techniques can be used during the construction and planting of wetland sites (Gardiner et al., 2004). However, traditional site planning utilizes the most economical planting stock due to the anticipated need to re-plant to meet regulatory planting density requirements. This planting stock is used based on the immediate economics of purchasing the planting stock, and often ignores the cost to replant or plant different stock of plant survival densities are not achieved at the site (Gardiner et al., 2000; Kruse and Groninger, 2003).

Tree tubes and planting mats, two commonly used planting aids, are often utilized to promote survival of seedlings by limiting competition and herbivory with early successional herbaceous and woody species. These aids reduce the use of herbicides, which are often restricted to a subset rated for use in aquatic sites, and the mechanical damage associated with trimmers and mowers (Allen, 1997). Planting tubes have been shown to effectively prevent tree girdling and browsing by herbivores (Correll, 2005). Mats can effective in controlling herbaceous competition, and are typically installed after significant earth moving activities (Zedler, 2000). However, the effects of matting are limited when installed in upland areas where competition from herbaceous species is strong (Bruland and Richardson, 2005).

Previous research has indicated that use of seed sourced from mesic areas and application of nursery preconditioning may increase survival and growth of riparian tree species, and the use of mechanical site preparation, planting stock type, and planting aids may be beneficial to survival and growth of woody species planted in marginal old field settings. The overall goals of this research were to quantify the recovery and restoration of marginal agricultural sites from the initial stages of nursery establishment to the near-term effectiveness of these treatments on survival and growth, and to assess the effectiveness of mechanical site preparation, planting stock type and planting aids on the survival and growth of early and mid-successional hardwoods in a marginal old field restoration site in the Virginia Piedmont. These results are anticipated to be of interest to personnel involved in wetland creation and planning, agency personnel involved in wetland oversite and inspections, and landowners interested in riparian wetland restoration.

1.2 Objectives and Organization

This dissertation is organized into five chapters that describe the thematic similarities and implications of wetland mitigation site preparation methods for mitigation managers and policymakers. Chapter one introduces the challenges inherent to the restoration of marginal agricultural areas and describes the subsequent chapter organization and overall research objectives. Chapters two through four provide the basis for a collection of stand-alone, thematically linked essays that evaluate select mitigation site preparation methods. Chapter five summarizes the overall findings from this dissertation and discusses the applicability and implications for restoration designers, managers, and policy. Additional details regarding the three manuscript chapters are provided below.

Specifically, the second chapter presents the results of an assessment of the impact of seed source and greenhouse preconditioning on the survival and growth of American sycamore and willow oak in an old field restoration experiment. The objectives of this chapter were to determine if parental seed source ecotype, regional location and seedling greenhouse preconditioning could potentially enhance the survival and growth of commonly planted early and mid-successional restoration species.

The third chapter describes the results from a field experiment to assess the effectiveness of bottomland hardwood silvicultural applications on the survival and growth of early successional hardwoods. The study evaluated the combinations of five mechanical site preparation techniques (mound, bed, rip, disk, pit), four levels of planting stock (gallon, tubeling, bare root, and direct seed), and three planting aids (mat, tube, none) on the four-year survival and growth of American sycamore planted on an old field riparian area in the Piedmont of Virginia. The data from this study were presented at the Society of Ecological Restoration Southeast Chapter 2019 Symposium.

The fourth chapter presents the results from a field experiment to assess the effectiveness of bottomland hardwood silvicultural applications on the survival and growth of mid-successional hardwoods. The study evaluated the combinations of five mechanical site preparation techniques (mound, bed, rip, disk, pit), four levels of planting stock (gallon, tubeling, bare root, and direct seed), and three planting aids (mat, tube, none) on the four-year survival and growth of willow oak planted on an old field riparian area in the Piedmont of Virginia.

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2.0 SEED SOURCE AND GREENHOUSE PRECONDITIONING EFFECTS ON SURVIVAL AND GROWTH OF PIONEER (AMERICAN SYCAMORE) AND MID-SUCCESSIONAL (WILLOW OAK) BOTTOMLAND SPECIES IN A PIEDMONT OLD FIELD RIPARIAN RESTORATION.

2.1 Abstract

Planting stock for compensatory wetland creation and restoration projects often have limited availability and some restoration practitioners have opted to generate their own planting stock by collecting seeds and establishing seedlings. Flood tolerance and growth rate of seedlings are often deciding criteria for inclusion in wetland and riparian restoration plantings; however, success of these restoration efforts often produces inadequate survival and growth of planted tree species. In an attempt to determine if parental seed source ecotype and seedling greenhouse preconditioning could potentially enhance survival and growth of common early and mid-successional restoration species, seeds from American sycamore (*Platanus occidentalis* L.) and willow oak (*Quercus phellos* L.) were collected from upland and floodplain sites in the Piedmont and Ridge and Valley regions of Virginia and were subjected to three greenhouse preconditioning techniques (control, flooding, drought) prior to outplanting. American sycamore seedlings that were subjected to flood preconditioning had more than 25% greater height that drought preconditioned seedlings, and willow oak seedlings that were grown under normal greenhouse conditions had 18% greater root collar diameter than flood or drought conditioned seedlings. Greenhouse preconditioning did not have any significant effects on survival and growth following outplanting. After three years, American sycamore seeds sourced from dry

ecotypes were 14% taller than seeds sourced from dry ecotypes while willow oak acorns sourced from wet ecotypes were 11% taller than dry ecotype acorns. Use of seedlings from dry ecotype parents for American sycamore and acorns from wet ecotype parents may increase survival and growth of these species on marginal Piedmont agricultural sites. Adaptations observed after greenhouse preconditioning do not appear to increase survivability or growth after outplanting compared to planting stock grown under proper nursery conditions. Selection of seed sources from trees that exhibit good growth and vigor in landscape settings similar to the restoration area may increase the likelihood of meeting restoration goals and objectives.

2.2 Introduction

The success of forested wetlands and riparian forest buffers often depend upon the survival and growth of early and mid-successional hardwood species that are tolerant to periods of groundwater drawdown and re-flooding. Many compensatory wetland creation and restoration mitigation sites and riparian restoration projects fail due to mortality of planted wetland tree species (Zedler and Callaway, 1999). Given the ecosystem services and monetary value of forested wetland and riparian areas as defined by regulatory agencies and commercial mitigation credit providers, greater emphasis has been placed on the success of planted woody species in these sites. Early successional hardwoods, such as American sycamore (*Platanus occidentalis* L.) are adapted to periods of groundwater drawdowns, site re-flooding, and competition from perennial herbaceous competition by germinating during hydroperiod drawdown and sapling adaptation to flooded conditions. Similarly, mid-successional hardwood species, such as willow oak (*Quercus phellos* L.), have physiological adaptations, including increased seedling root growth and decreased shoot development, that make the species well suited for planting in areas with unpredictable hydrologic regimes (McKnight et al., 1981).

Naturally occurring seed sources of species observed in wetland and riparian areas are typically genetically similar, and all seedlings within these areas undergo similar environmental conditioning during establishment and growth. However, woody plantings in restoration areas are typically sourced from greenhouses and nurseries that are outside of the established seed sources for the restoration area, with undetermined seed source locations and grown in conditions with minimal hydrologic changes prior to planting. While the climatic tolerance of hardwood tree species are well understood (Collins and Battaglia, 2008; Grossnickle, 2012; Hook and Brown, 1973; Jones and Sharitz, 1998; McCurry et al., 2010; McKnight et al., 1981; Self et al., 2010), the impact of parent seed source ecotype and seedling preconditioning on the survival and growth of early and mid-successional hardwoods in wetland and riparian restoration has not been widely documented. Regeneration of oak species are of particular concern, as there are well documented issues with regeneration, including intolerance to drought, slow growth rate and seedling transplant stress (Dey et al., 2008).

Species specific selection of seed sources from differing landscape positions as a method to influence drought and flooding tolerances have been investigated since the 1930s (Meuli and Shirley, 1936) and interests continue as climate variability increases at the local and regional scale. Differences in resistance to drought and flooding may alter the spatial distribution of species in communities, and may also alter growth traits at the individual plant level (Friedman and Lee, 2002; Matías et al., 2012; Merritt et al., 2010). Seeds obtained from xeric environments tend to have greater resilience to drought (Abrams et al., 1990; Ferrell and Woodard, 1966; Meuli and Shirley, 1936); however, there are variable results for seeds obtained from flooded conditions. Previous investigations of mid successional species found that seeds from flooded environments may not increase resilience to inundation in seedlings (Collins and Battaglia, 2008;

Renninger et al., 2019; Will et al., 1995), while early successional species may have higher survival due to the link to the hydrologic regime of the parent seed source (Havens, 2004; Keeley, 1979). Regional sourcing of seeds may increase adaptation to biotic and abiotic factors and increase the potential for ecosystem restoration, but evidence of a parental genotypic link to climate resilience has not been as widely investigated as seedling phenotypic adaptations and responses (Baughman et al., 2019; Bucharova et al., 2019). Seedling acclimations are most commonly induced by preconditioning the seedlings that have sprouted but have not matured to the size required for outplanting.

Seedling acclimations to climatic conditions are heavily influenced by preconditioning treatments during seed establishment and growth. Preconditioning treatments, which include methods to manipulate hydrologic regime, seedling root morphology and reducing seedling leaf area, are conducted to increase post-planting stress resistance and improve seedling survival and growth. Typically these treatments are carried out during the final stage of nursery care before field planting (Vilagrosa et al., 2003). Preconditioning can confer resilience to drought conditions by influencing root growth, shoot to root ratio, rate of photosynthesis, osmotic potential and water-use efficiency (Hook and Brown, 1973; Kozlowski and Pallardy, 2002; Seiler and Johnson, 1988, 1985). Seedling adaptations to flooded conditions can include development of adventitious roots, shorter seedling height, and increased stem diameters from lenticel development (Garssen et al., 2015; Kozlowski, 1997, 1984; Parad et al., 2016). Floodplain seedlings and seedlings collected from moderately flood tolerant species may be more adaptable to groundwater drawdown and reflooding in comparison to seedlings obtained from flood tolerant species (Havens, 2004; Keeley, 1979), which suggests that these species may be better suited for wetland and riparian restoration plantings. Seedlings collected from floodplains may be more adaptable to flooded conditions; however, these adaptations have not been evaluated in conjunction with parental ecotype to investigate whether adaptability to fluctuating hydroperiod is influenced more heavily by parental hydrologic adaptations or by environmental effects on the seedlings after sprouting.

Previous studies indicated that seed source location, ecotype selection and seedling preconditioning may be beneficial to survival and growth of woody species planted in wetland and riparian restoration settings. The objective of this project was to investigate whether seeds sourced from more hydrologically inundated sites have a higher probability of survival compared to seeds sourced from upland sites and if greenhouse preconditioning the seedlings for drought or flooded conditions increase the survival and growth post planting for moderately flood tolerant early and mid-successional hardwood species in wetland and riparian restoration sites.

2.3 Methods

Field research was conducted at the R.J. Reynolds Homestead Forest Resources Research Center, which is located in the Piedmont physiographic province in Patrick County, Virginia (Figure 2-1). The area is dominated by former agricultural fields historically used for tobacco cultivation in the uplands and corn and other crops in the bottomlands. The study site is in the riparian area of a first order perennial unnamed tributary to Mill Creek with a 197-hectare watershed. The watershed is predominantly mixed upland hardwoods and pine, with interspersed managed pine plantations. Common native riparian species include yellow polar (*Lirodendron tulipifera* L.), boxelder (*Acer negundo* L.), and red maple (*A. rubrum* L). The field study area is comprised of two soil types. The primary dominant soil series is French soils, taxonomically classified as fine-loamy over sandy or sandy-skeletal, mixed, active mesic Fluvaquentic Dystrudepts on 0 to 3 percent slopes. The second soil series are Braddock series, taxonomically classified as fine, mixed, semiactive mesic Typic Hapludults on 2 to 8 percent slopes. Soils are moderately to moderately well drained with colluvium and alluvium parent material. Legacy sediment comprised the upper soil layers resulting in buried mineral soil horizons observed throughout the site. Site soils exhibited field hydric soil indicators consistent with wetland soil diagnostic criteria (U.S. Army Corps of Engineers, 1987). Yearly temperatures range from 19.4°C to 7.2°C, with an average annual rainfall of 1,380 mm and 290 mm of snowfall for a total average annual precipitation of 1,670 mm.

American sycamore and willow oak are common riparian species in the Virginia Piedmont and are commonly used in wetland and riparian area restoration plantings. Collection of ripe seeds occurred during November for American sycamore (Bonner, 1979), and between August and December for willow oak (Bonner, 1970). Seed collection area ecotypes were classified as having periods of hydrologic inundation (wet) if hydric soil indicators were present in the upper 30 cm of the soil or dry if hydric soil indicators were absent from the upper 30 cm of the soil (United States Department of Agriculture Natural Resources Conservation Service, 2010). American sycamore seeds were collected using a shotgun to detach seed balls still attached to live stems from three to five parent trees at five locations, with two wet locations in the Piedmont physiographic region: Pittsylvania County (PCW) and Appomattox County (ACW), one wet location in the Valley and Ridge physiographic province: Montgomery County (MCW) and two dry locations in the Valley and Ridge: Montgomery County (MCD) and Botetourt County (BCD). Willow oak acorns were collected during fall acorn drop from four locations in the Piedmont physiographic province, two wet locations in Pittsylvania County Wet (PCW and PCX) and two dry locations, one in Pittsylvania County (PCD) and the other in Nelson County (NCD) (Figure 2-2). Acorns were collected from directly under four to six trees at each site through tarp collection and direct removal from leaf litter. All collected seeds were cold stratified at 4°C for a minimum of one month and acorns were float tested prior to planting to help remove defective seed (Johnson et al., 2013).

Seeds were germinated in shallow flats containing a 1:1 mix of sphagnum peat moss and Promix BX (Premier Horticulture, Inc., Quakertown, Pennsylvania) at the Virginia Tech greenhouses (Blacksburg, Virginia) during January 2011. Emerged seedlings were transplanted into 10 cm^3 Ray-Leach RLC4 Cone-tainer tubes (Stuewe and Sons, Inc., Tangent, Oregon) with the same soil mix and fertilized with 0.8g Osmocote 14-14-14 fertilizer (Scotts-Sierra Horticultural Products, Marysville, Ohio). Seedlings were grown under well-watered conditions until mid-April 2011. Seedlings were then partitioned into three groups for preconditioning treatments: well-watered (Control), pre-flooded (Flood) and water-stressed (Drought). Well-watered seedlings were kept hydrated but well drained at all times. Flood treatment seedlings were submerged in water up to the root collar for five cycles of: a) two days submerged, one day drained; b) three day submerged, one day drained; c) four day submerged, two days drained; and d) five day submerged, two days drained. Drought treatment seedlings were only watered when they showed visible signs of wilting, at which point they were fully rehydrated. Drought seedlings were watered individually to prevent seedlings that were not undergoing visible water stress from accidental hydration.

Seedlings were transplanted at the field research site in early May 2011. Seedlings were planted on a 1.8m x 1.2m grid. American sycamore seedlings were planted in 20 rows with 15 seedlings per row, and willow oak were planted in 15 rows with 12 seedlings per row. Hand plantings were conducted with shovel or dibble bar and were conducted or supervised by professional foresters familiar with these planting techniques. Glyphosate 4+ (41% glyphosate)

(Alligare, LLC, Opelika, Alabama) herbicide was applied once in the first growing season and mowing was conducted between June and September of the first growing season. The weed control was representative of the controls typically employed in wetland and riparian restoration sites. No weed control was conducted after the first year of the study.

Survival data, ground line diameter, diameter at breast height (dbh, as it developed) and height were collected after the end of each growing season starting in January 2012 and ending in January 2014. Survival of seedlings were visually evaluated during each data collection. Ground line diameter and dbh (mm) for each stem were collected to the nearest 0.1 mm using digital calipers. Total height (m) were collected using a height pole to the nearest 2.5 cm. Willow oak seedlings did not reach the height required by year 3 for dbh to be measured; however, for the more rapid growing American sycamore dbh measurements were collected for the year 3 growing season.

The experimental design was a randomized complete block design along the tributary floodplain that was evaluated with a two-way analysis of variance. There were a total of 300 observations for American sycamore and 252 observations for willow oak. Each species was analyzed separately. Statistical analyses were conducted using JMP Pro version 14.2.0 (SAS, n.d.). Means were generated using the standard least squares method, and multiple comparisons among means were calculated using post hoc Tukey's HSD. An alpha level of 0.05 was applied to indicate statistical significance. Only surviving stems were included in diameter, dbh and height calculations.

Prior to planting, five seedlings from each species and treatment were destructively sampled for height (cm), root collar diameter (cm), root length (cm), root diameter (cm) and root surface area (cm^2). Leaves were removed and leaf area was measured with a LI-3100 Area Meter

(Licor Inc., Lincoln, Nebraska). Roots, leaves and stems were then oven dried at 60°C to determine dry weight (g).

2.4 Results

Ecotype did not have a significant pre-planting effect on American sycamore seedling growth indices (Table 2-1). Regional American sycamore seed source location significantly affected seedling height, root collar diameter, stem weight and leaf weight, however, dominant regional seed source locations varied between growth indices. Preconditioning treatments had a significant effect on all American sycamore seedling growth indices except root length and root surface area. The flood preconditioning treatment had significantly greater growth indices than the drought preconditioning for all significant measurements. No statistically significant differences were observed between Flood and Control preconditioning treatments, except seedling height, which was not significantly different between Control and Drought treatments (Table 2-1).

Willow oak wet ecotype seed locations had 20% greater stem weight than dry ecotype (p=0.0267), but ecotype did not have a significant effect on any other growth indices. Regional willow oak seed source location had a significant effect on height, root collar diameter, stem weight and root weight, with the acorns sourced from Pittsylvania County having an average of 20% greater growth than the Nelson County acorns. Preconditioning treatment had a significant effect on willow oak root collar diameter, stem weight and root weight. The control treatment had an average of 25% growth than drought conditioned seedlings, and no significant differences were observed between the flood and drought preconditioning treatments (Table 2-2).

American sycamore seedling year 1 field survival percentages were not different between wet (84.5%) and dry (85.1%) ecotypes (p=0.8935). Regional seed source location had a significant impact on American sycamore survival (p= 0.0125); however, no differences were observed between seed collection locations. No differences were observed for year 1 survival percentages for American sycamore preconditioning treatments (p=0.2267). No differences were observed for year 1 survival percentages between ecotype (p=0.5713), location (p=0.6952), or preconditioning treatment (p=0.4067) for willow oak (Table 2-3).

Average height was greater for dry American sycamore ecotypes for years 1, 2 and 3. The upland BCD location height was significantly greater (2.07 m) than wet locations PCW (1.69 m) and MCW (1.52 m) for year 1, but was only different from MCW for years 2 and 3. The wet location ACW had greater height (1.91 m) than MCW for year 1, with no observed difference between the sites in years 2 and 3. No other height differences were observed between seed source locations in years 1, 2 or 3. American sycamore preconditioning did not have a significant treatment effect on height for year 1 (p=0.2990), year 2 (p=0.4129) or year 3 (p=0.5181). Wet ecotype willow oak height was 20% greater than dry ecotype for years 1, 2 and 3. Willow oak seeds sourced from the wet location PCX had 25% greater height in year 1 and 22% greater height in year 2 than the dry seed source locations PCD and NCD. No other differences were observed between willow oak seed source locations. Willow oak preconditioning did not have an observed treatment effect on height for year 1 (p=0.4265), year 2 (p=0.1341) or year 3 (p=0.5591) (Table 2-4).

Average groundline diameter was not statistically significant for American sycamore ecotype for year 1 (p=0.1080), year 2 (p=0.1126) or year 3 (p=0.1520). The upland BCD seed source location averaged 10% larger groundline diameter than the wet location MCW in all years, but no other differences were observed between seed source locations for American sycamore. American sycamore preconditioning did not have a significant treatment effect on groundline diameter for any year. Willow oak wet ecotype had an average 20% larger average groundline diameter than dry ecotype for all years. Seed source location had a significant effect on willow oak for year 1 and year 2 but was not significant for year 3 (p=0.0666). The wet location PCX had over 20% greater groundline diameter than the dry sites PCD and NCD for year 1 and 2, and the wet site PCW had significantly 20% greater average groundline diameter than the dry site PCD in year 1 and 2. No other significant differences between seed source locations were observed for willow oak. Willow oak preconditioning treatments did not have a significant effect on height for year 1 (p=0.2018), year 2 (p=0.5467) or year 3 (p=0.2757) (Table 2-5).

Ecotype may have affected American sycamore dbh in year 3 (p=0.0641). No significant relationships were observed between American sycamore seed source location and dbh for year 3 (p=0.0961). American sycamore preconditioning did not have a significant treatment effect on dbh for Year 3 (p=0.4325) (Table 2-6). No significant interactions between seed source location and preconditioning treatment were found for any measured growth indices in any year for American sycamore (Table 2-7) or willow oak (Table 2-8).

2.5 Discussion

The high woody stem mortality often associated with the restoration of old field riparian areas has often been attributed to improper species selection (Kozlowski, 1997; Matthews and Endress, 2008; Zedler and Callaway, 1999). The observed high survival and growth in this study indicated that the proper species selection can have significant positive impact on survival and growth in old field and marginal agricultural sites in the Piedmont. Based upon evaluation of the site using the Baker and Broadfoot site index model (Baker and Broadfoot, 1979), site indices (base age fifty) were approximately 70 to 75 feet (21 to 23 m) for American sycamore and 65 to

70 feet (20 to 21 m) for willow oak, which indicated that these species were suitable for the observed site conditions. Furthermore, mature sycamore were also observed immediately downstream from the research property within existing woody riparian and wetland areas in the watershed.

Previous studies indicated that seeds sourced from mesic locations more readily adapt to preconditioning treatments (Abrams et al., 1990; Keeley, 1979). The observed results indicated that American sycamore seeds sourced from upland locations, particularly the BCD location, had high growth response for root collar diameter and leaf area than seeds sourced from wet locations. However, the dry classification of the site was dependent upon the absence of hydric soil indicators, which does not indicate that the site location would be classified as xeric. The observed willow oak results were similar to previous studies in that no differences were observed between wet and dry locations for red maple grown in flooded conditions (Will et al., 1995). The observed differential preconditioning growth responses may indicate that ecotype location is more dependent upon the ability of the species to adapt to site specific variation rather than the seed source ecotype, which is similar to previously investigations, particularly for oak regeneration (Dey et al., 2008).

American sycamore response to flood preconditioning contradicted previous studies that indicated that drought conditioning elicited greater growth responses in seedlings (Gomes and Kozlowski, 1980; Kozlowski and Pallardy, 2002; Parad et al., 2016). American sycamore adaptations to wet conditions include development of adventitious roots, which may have attributed to the greater root weight compared to drought conditioning. Similarly, the control preconditioning treatment had the largest growth indices in willow oak, which may indicate that traditional nursery and greenhouse methods are better applications for developing willow oak seedlings. The lack of willow oak post-planting response in the preconditioning treatments further supports traditional greenhouse practices for willow oak.

According to the U.S. Drought Monitor, which uses data from the Palmer Drought Severity Index, CPC Soil Moisture Model, USGS Weekly Streamflow, Standardized Precipitation Index and local observations to create a classification of state and regional drought conditions, Patrick County was under Moderate Drought conditions starting in January 2011 through May 2011, and under Abnormally Dry to Moderate Drought Conditions in August and September 2011 ((NDMC) et al., n.d.). Despite the dry soil conditions, the survival rates of American sycamore were much higher than many previous studies, which ranged from 59% to as low as 45% (Matthews and Endress, 2008; Roquemore et al., 2014). The high survival rates of the American sycamore seedlings contradicts previous studies, which found that sycamore seedlings are more resilient to inundation during establishment than other bottomland hardwood species but are more susceptible to dry hydrologic conditions (McKnight et al., 1981; Will et al., 2013). However, many of the previous evaluations were based on bare root seedlings, whereas the seedlings used in the study would be classified as a tubeling or container stock type. Use of tubelings and other container stock have been previously observed to reduce transplant shock by increasing root to shoot ratio and increasing soil transfer, which may help seedlings adjust to marginal soil conditions (South et al., 2005; Stanturf et al., 2004). The survival rates observed were consistent with tubeling survival rates observed at the study location for other American sycamore survival and growth investigations (Steele, 2020). These adaptive traits and more mature planting stock type may account for the high survival rates and growth indices observed during the year 1 drought conditions.

The willow oak survival rates observed in this study were similar to previous studies of oak afforestation survival, which characterized year 1 survival between 84% and 100% (Duplissis et al., 2000; Löf et al., 2012; Rathfon et al., 1995; Self et al., 2011). However, previous studies used bare root planting stock while this study utilized tubeling planting stock. The high survival rates of the willow oak tubelings are also contrary to previous studies, which found that willow oak tubeling planting stock typically had higher rates of mortality and lower growth indices than the traditionally used bare root stock in the first years after outplanting (Roquemore et al., 2014). Other studies conducted at the study location had low survival results for willow oak tubeling stock (37.5%); however, the tubeling stock were sourced from outside of the geographic area of the study (Steele, 2020). The tubeling planting stock that was grown from regionally located seed sources may have been more resilient to the abnormally dry and moderate drought conditions at the study location, which may account for the differences in survival and growth observed during the study.

Oak afforestation has been historically difficult due to fluctuating hydrology, competition for available light and improperly applied planting practices. The results of this study indicate that parental site conditions do not have as significant of an impact on survival and growth in comparison to the location of seed sources. The willow oak seeds collected from locations that were in closer regional proximity to the study site had higher growth indices, which corresponds to previous studies that found seedlings sourced from local floodplain areas had better growth and survival on sites with fluctuating hydroperiods (Havens, 2004; Keeley, 1979). Choosing local seed sources from trees that have good health and vigor may increase the probability of survival and growth on marginal agricultural sites. Selection of species that are ecologically appropriate for the site type is equally important and the incorporation of site index models and species distribution at the watershed level will further complement the use local seed sources (Stanturf et al., 2014). Appropriate seedling care, including cold stratification of seed, proper handling of planting stock prior to planting to reduce thermal and wind moisture losses, and planting during proper temperature and moisture conditions may further improve planting stock survival and growth. Proper planting technique can reduce the cost of afforestation by decreasing seedling mortality and reduce the need for additional nursery applications to prepare seedlings for outplanting.

Seedling preconditioning had no effect on the survival and growth of American sycamore or willow oak during the period evaluated in this study. These results contradict previous studies, which found that flood conditioned seedlings typically had lower growth indices (Keeley, 1979; Will et al., 1995). Based on the observed survival and subsequent growth in years 2 and 3, no preconditioning is necessary for American sycamore or willow oak when these species are planted on wetland and riparian restoration sites that meet minimum site index criteria or in watershed that already support the selected species.

2.6 Conclusion

Use of seedlings from dry ecotype parents for American sycamore and acorns from wet ecotype parents may influence survival and growth of these species on marginal Piedmont agricultural sites. The findings suggest that the adaptability of these species may have been the primary influence on parent tree location rather than the parental genetics. Finding seeds from parental stock that are in good health and vigor, which increases the probability of good genetics, is the best option for improving the survival and growth of these species. Preconditioning treatments did not increase survival or growth in this study, and do not appear to be warranted if seedlings are grown in proper nursery conditions and planted according to forestry best practices.

Overall, use of tubelings or other containerized planting stock appears to provide a potential opportunity to improve survival on similar restoration sites. Further large-scale investigation is warranted to determine if regional ecotype variations have significant impact on long term growth of these species on wetland and riparian restoration sites.

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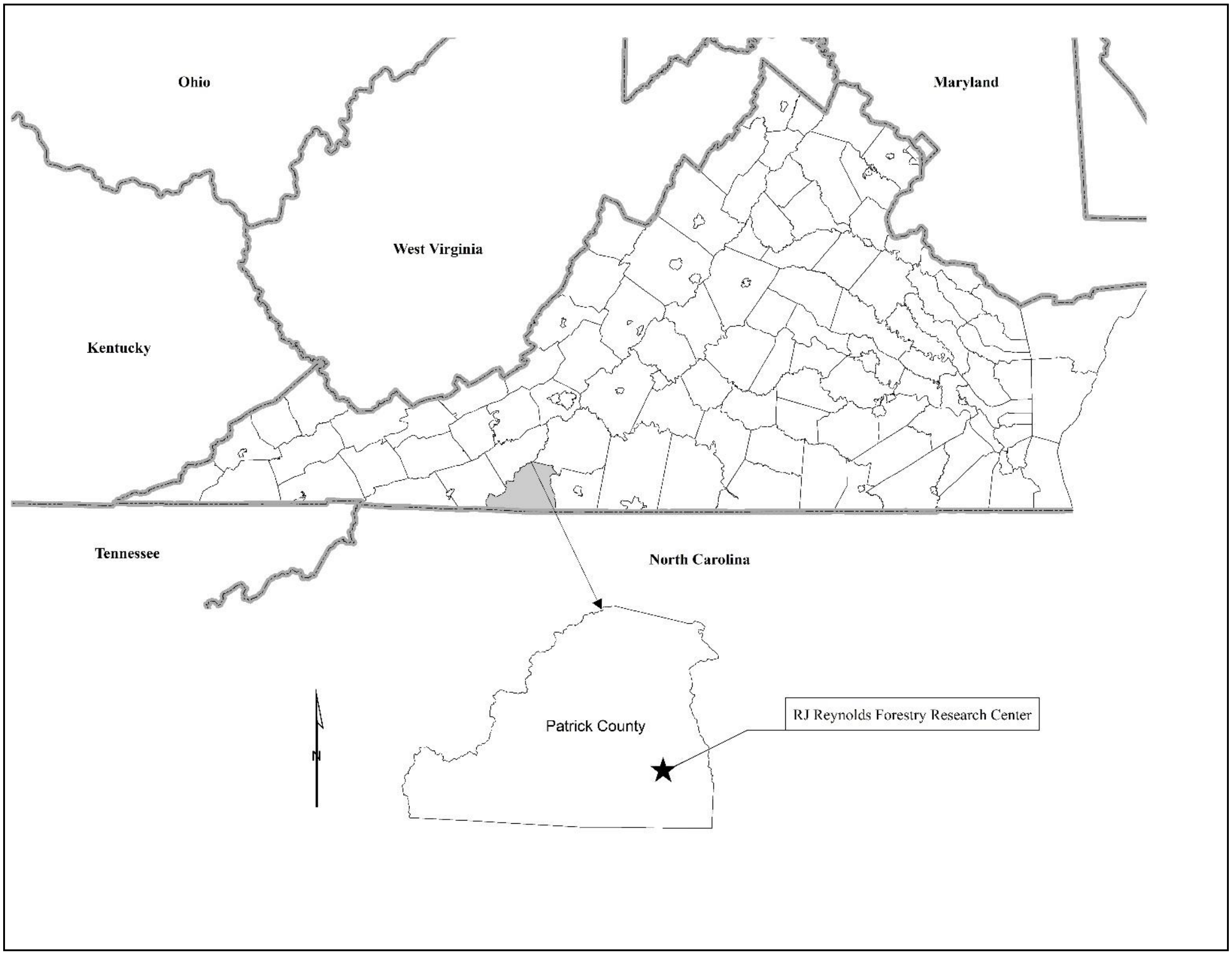

Figure 2-1. Location of the Virginia Tech RJ Reynolds Forestry Research Extension Center, Critz, Virginia.

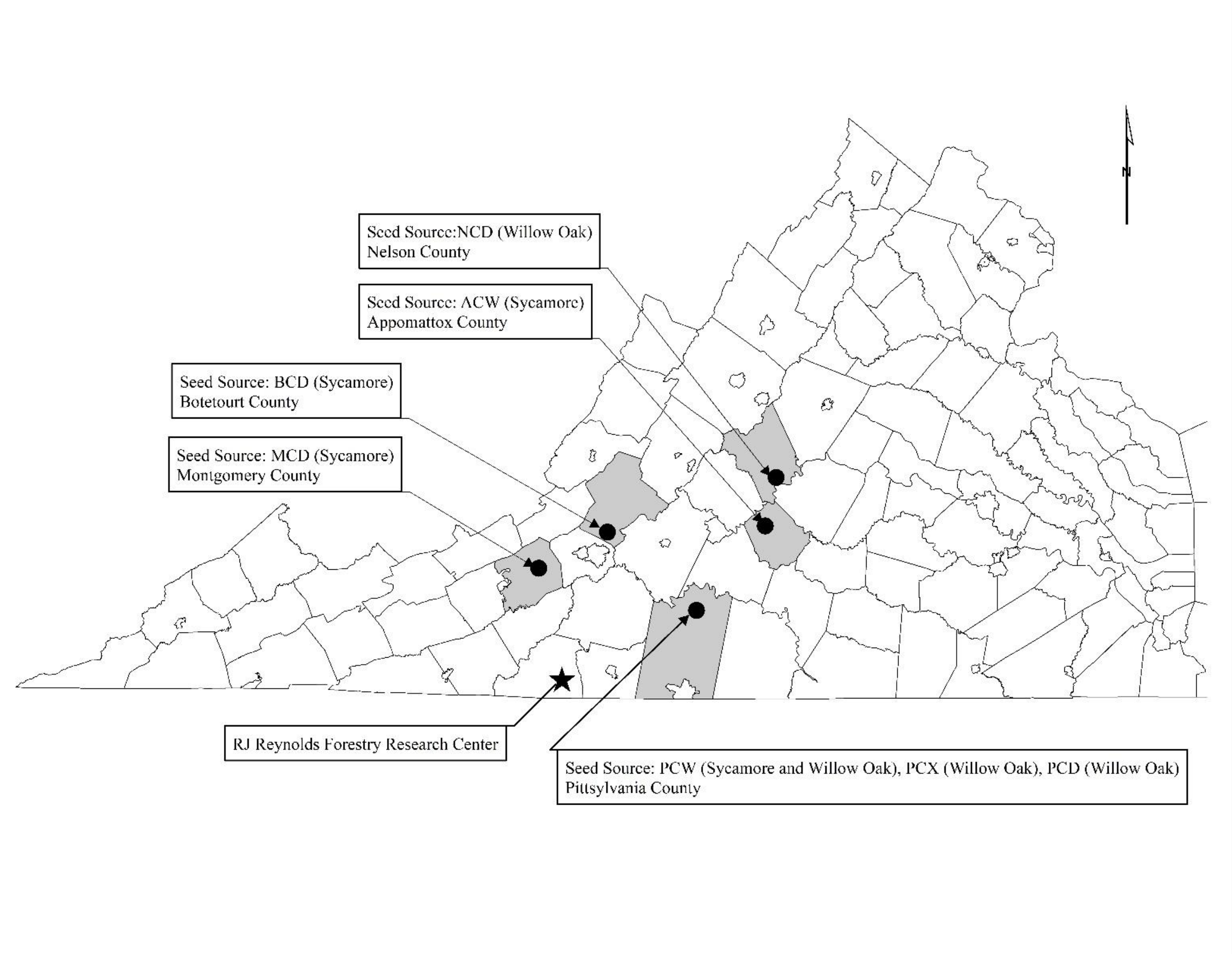

Figure 2-2. Location of seed sources for American sycamore and willow oak.

Table 2-1. Pre-planting average height, stem weight, leaf area, leaf weight, root collar diameter, root weight, root length and root surface area (SE) for American sycamore by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

Treatment	**Height (cm)**		**Root Collar Diameter (cm)**		**Stem Weight (g)**		**Leaf Area (cm^2)**	
Ecotype	*p=0.0960*		*p=0.2713*		*p=0.9052*		*p=0.5652*	
Wet	25.0 (0.95)		0.36 (0.01)		0.50 (0.04)		315.0 (15.7)	
Dry	22.5 (1.17)		0.39 (0.01)		0.50 (0.05)		329.4 (19.3)	
Location	*p=0.0258*		*p=0.0015*		*p=0.0326*		*p=0.0269*	
PCW	22.7 (1.44)	ab	0.32 (0.02)	c	0.38 (0.06)	b	273.5 (24.6)	b
ACW	26.9 (1.44)	ab	0.38 (0.02)	abc	0.57 (0.06)	ab	324.8 (24.6)	ab
MCW	25.6 (1.44)	ab	0.40 (0.02)	ab	0.52 (0.06)	ab	346.8 (24.6)	ab
MCD	20.5 (1.44)	b	0.35 (0.02)	bc	0.38 (0.06)	b	284.5 (24.6)	b
BCD	24.5 (1.44)	ab	0.42 (0.02)	a	0.59 (0.06)	ab	374.3 (24.6)	a
Preconditioning	*p=0.0001*		*p<0.0001*		*p=0.0003*		*p=0.0051*	
Control	23.7 (1.1)	b	0.40 (0.01)	a	0.51 (0.05)	a	319.1 (19.0)	ab
Flood	27.8 (1.1)	a	0.41 (0.01)	a	0.62 (0.05)	a	367.3 (19.0)	a
Drought	20.6 (1.1)	b	0.31 (0.01)	b	0.34 (0.05)	b	276.1 (19.0)	b

Treatment	**Leaf Weight (g)**		**Root Weight (g)**		**Root Length (cm)**	**Root Surface Area (cm^2)**
Ecotype	*p=0.2042*		*p=0.4395*		*p=0.9568*	*p=0.7904*
Wet	1.0 (0.07)		0.50 (0.05)		2,287.7 (200.1)	280.8 (24.9)
Dry	1.1 (0.08)		0.60 (0.06)		2,304.95 (245.1)	291.3 (30.5)
Location	*p=0.0746*		*p=0.1126*		*p=0.7301*	*p=0.8159*
PCW	0.89 (0.11)		0.43 (0.08)		2,135.2 (353.2)	263.9 (43.9)
ACW	1.1 (0.11)		0.57 (0.08)		2,036.7 (353.2)	254.9 (43.9)
MCW	1.1 (0.11)		0.5 (0.08)		2,691.3 (353.2)	323.5 (43.9)
MCD	0.97 (0.11)		0.43 (0.08)		2,349.1 (353.2)	297.8 (43.9)
BCD	1.3 (0.11)		0.69 (0.08)		2,260.8 (353.2)	284.8 (43.9)
Preconditioning	*p=0.0077*		*p=0.0389*		*p=0.6408*	*p=0.4610*
Control	1.16 (0.09)	a	0.62 (0.06)	a	2,151.3 (273.6)	256.0 (34.0)
Flood	1.21 (0.09)	ab	0.55 (0.06)	ab	2,501.0 (273.6)	316.1 (34.0)
Drought	0.84 (0.09)	b	0.40 (0.06)	b	2,231.7 (273.6)	282.8 (34.0)

Table 2-2. Pre-planting average height, stem weight, leaf area, leaf weight, root collar diameter, root weight, root length and root surface area (SE) for willow oak by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

Treatment	**Height (cm)**		**Root Collar Diameter (cm)**		**Stem Weight (g)**		**Leaf Area (cm^2)**
Ecotype	*p=0.0655*		*p=0.1348*		*p=0.0267*		*p=0.5652*
Wet	20.6 (0.10)		0.33 (0.01)		0.31 (0.02)	a	122.7 (7.8)
Dry	18.0 (0.10)		0.30 (0.01)		0.23 (0.02)	b	109.2 (7.8)
Location	*p=0.0121*		*p=0.0151*		*p=0.0107*		*p=0.5431*
PCW	20.9 (1.3)	a	0.32 (0.01)	a	0.30 (0.03)	a	127.9 (11.6)
PCX	20.3 (1.3)	a	0.33 (0.01)	a	0.32 (0.03)	a	117.6 (11.6)
PCD	20.5 (1.3)	a	0.33 (0.01)	a	0.28 (0.03)	ab	114.4 (11.6)
NCD	15.5 (1.3)	b	0.27 (0.01)	b	0.19 (0.03)	b	104.0 (11.6)
Preconditioning	*p=0.1274*		*p=0.0027*		*p=0.0036*		*p=0.2524*
Control	21.1 (1.1)		0.34 (0.01)	a	0.33 (0.02)	a	128.0 (10.0)
Flood	18.8 (1.1)		0.31 (0.01)	ab	0.27 (0.02)	ab	115.8 (10.0)
Drought	17.9 (1.1)		0.28 (0.01)	b	0.21 (0.02)	b	104.1 (10.0)

Treatment	**Leaf Weight (g)**	**Root Weight (g)**		**Root Length (cm)**	**Root Surface Area (cm^2)**
Ecotype	*p=0.0679*	*p=0.4503*		*p=0.7874*	*p=0.8949*
Wet	0.58 (0.03)	0.39 (0.03)		923.4 (67.4)	88.0 (6.1)
Dry	0.50 (0.03)	0.36 (0.03)		949.2 (67.4)	89.1 (6.0)
Location	*p=0.2287*	*p=0.0078*		*p=0.7444*	*p=0.9785*
PCW	0.57 (0.04)	0.39 (0.04)	ab	903.4 (86.5)	86.5 (8.7)
PCX	0.60 (0.04)	0.40 (0.04)	a	343.2 (86.5)	89.4 (8.7)
PCD	0.52 (0.04)	0.45 (0.04)	a	903.5 (86.5)	87.0 (8.7)
NCD	0.48 (0.04)	0.27 (0.04)	b	1,011.8 (86.5)	91.2 (8.7)
Preconditioning	*p=0.0969*	*p=0.0028*		*p=0.7454*	*p=0.9602*
Control	0.61 (0.04)	0.47 (0.03)	a	954.0 (74.9)	90.3 (7.6)
Flood	0.53 (0.04)	0.32 (0.03)	b	956.3 (74.9)	87.5 (7.6)
Drought	0.49 (0.04)	0.35 (0.03)	b	889 (74.9)	87.8 (7.6)

Table 2-3. Year 1 average survival (SE) for American sycamore and willow oak by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

	Average Survival (%)		
Treatment	**American Sycamore**	**Treatment**	**Willow Oak**
Ecotype	*p=0.8935*	***Ecotype***	*p=0.5713*
Wet	84.5 (2.8)	*Wet*	90.3 (2.5)
Dry	85.1 (3.3)	*Dry*	87.9 (3.3)
Location	*p=0.0125*	***Location***	*p=0.6952*
PCW	93.3 (3.1) a	*PCW*	91.1 (3.1)
ACW	81.7 (3.8) a	*PCX*	89.4 (4.0)
MCW	78.1 (6.0) a	*PCD*	90.9 (4.6)
MCD	76.3 (5.9) a	*NCD*	84.8 (4.8)
BCD	93.3 (3.1) a		
Preconditioning	*p=0.2267*	***Preconditioning***	*p=0.4067*
Control	89.7 (2.4)	*Control*	86.0 (4.3)
Flood	83.0 (3.3)	*Flood*	88.4 (3.9)
Drought	83.0 (3.6)	*Drought*	92.8 (2.4)

Table 2-4. Average height (SE) (m) for American sycamore and willow oak by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

	American Sycamore		
Treatment	**Year 1**	**Year 2**	**Year 3**
Ecotype	*p=0.0078*	*p=0.0099*	*p=0.0268*
Wet	1.72 (0.06)	2.98 (0.08)	4.14 (0.11)
Dry	1.95 (0.07)	3.33 (0.10)	4.81 (0.14)
Location	*p=0.0007*	*p=0.0112*	*p=0.0089*
PCW	1.69 (0.09) bc	2.97 (0.14) ab	4.49 (0.18) ab
ACW	1.91 (0.09) ab	3.18 (0.14) ab	4.65 (0.19) ab
MCW	1.52 (0.10) c	2.77 (0.16) b	4.04 (0.21) b
MCD	1.79 (0.10) abc	3.13 (0.16) ab	4.50 (0.21) ab
BCD	2.07 (0.09) a	3.47 (0.13) a	5.04 (0.18) a
Preconditioning	*p=0.2990*	*p=0.4129*	*p=0.5181*
Control	1.83 (0.07)	3.25 (0.11)	4.69 (0.13)
Flood	1.87 (0.08)	3.16 (0.12)	4.59 (0.16)
Drought	1.72 (0.08)	3.00 (0.11)	4.44 (0.16)

	Willow Oak		
Treatment	**Year 1**	**Year 2**	**Year 3**
Ecotype	*p=0.0002*	*p=0.0005*	*p=0.0369*
Wet	0.66 (0.02)	1.07 (0.04)	1.49 (0.06)
Dry	0.53 (0.02)	0.86 (0.04)	1.32 (0.06)
Location	*p=0.0013*	*p=0.0014*	*p=0.1715*
PCW	0.63 (0.03)	1.00 (005)	1.45 (0.08)
PCX	0.69 (0.03)	1.13 (0.06)	1.53 (0.08)
PCD	0.56 (0.03)	0.89 (0.06)	1.34 (0.08)
NCD	0.52 (0.03)	0.84 (0.06)	1.29 (0.09)
Preconditioning	*p=0.4265*	*p=0.1341*	*p=0.5591*
Control	0.61 (0.03)	1.04 (0.05)	1.46 (0.08)
Flood	0.62 (0.03)	0.98 (0.05)	1.41 (0.07)
Drought	0.57 (0.03)	0.89 (0.05)	1.35 (0.06)

Table 2-5. Average groundline diameter (SE) (cm) for American sycamore and willow oak by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

	American Sycamore		
Treatment	**Year 1**	**Year 2**	**Year 3**
Ecotype	*p=0.1080*	*p=0.1126*	*p=0.1520*
Wet	2.56 (0.09)	3.94 (0.15)	5.56 (0.20)
Dry	2.81 (0.11)	4.31 (0.18)	6.02 (0.24)
Location	*p=0.0501*	*p=0.0500*	*p=0.0443*
PCW	2.61 (0.15)	4.04 (0.24) ab	5.73 (0.33) ab
ACW	2.71 (0.16)	4.13 (0.25) ab	5.73 (0.34) ab
MCW	2.36 (0.17)	3.60 (0.27) b	5.13 (0.38) b
MCD	2.52 (0.18)	3.86 (0.27) ab	5.31 (0.38) ab
BCD	3.02 (0.15)	4.65 (0.23) a	6.53 (0.32) a
Preconditioning	*p=0.8067*	*p=0.4897*	*p=0.3956*
Control	2.72 (0.12)	4.27 (0.18)	5.99 (0.24)
Flood	2.66 (0.12)	4.08 (0.21)	5.78 (0.30)
Drought	2.61 (0.13)	3.93 (0.20)	5.47 (0.27)

	Willow Oak		
Treatment	**Year 1**	**Year 2**	**Year 3**
Ecotype	*p<0.0001*	*p=0.0001*	*p=0.0107*
Wet	0.80 (0.02)	1.13 (0.04)	1.65 (0.07)
Dry	0.63 (0.02)	0.92 (0.04)	1.39 (0.07)
Location	*p<0.0001*	*p=0.0012*	*p=0.0666*
PCW	0.78 (0.03) a	1.11 (0.05) ab	1.60 (0.10)
PCX	0.82 (0.03) a	1.16 (0.05) a	1.71 (0.10)
PCD	0.63 (0.03) b	0.90 (0.05) c	1.37 (0.10)
NCD	0.63 (0.03) b	0.95 (0.06) bc	1.43 (0.11)
Preconditioning	*p=0.2018*	*p=0.5467*	*p=0.2757*
Control	0.73 (0.03)	1.04 (0.06)	1.57 (0.11)
Flood	0.75 (0.03)	1.06 (0.05)	1.60 (0.09)
Drought	0.68 (0.03)	0.99 (0.04)	1.42 (0.07)

Table 2-6. Average diameter at breast height (SE) (cm) for year 3 American sycamore by ecotype, location, and preconditioning treatments. Averages with different letters are significantly different.

	American Sycamore
Treatment	**Year 3**
Ecotype	*p=0.0641*
Wet	1.83 (0.09)
Dry	2.10 (0.11)
Location	*p=0.0961*
PCW	2.95 (0.22)
ACW	2.95 (0.24)
MCW	2.47 (0.26)
MCD	2.95 (0.25)
BCD	3.41 (0.22)
Preconditioning	*p=0.4325*
Control	3.07 (0.17)
Flood	3.07 (0.20)
Drought	2.78 (0.18)

Table 2-7. Average growth indices (SE) for American sycamore by location and preconditioning interaction for year 1 through 3 growing seasons.

	Average Height (m)			**Average Groundline Diameter (cm)**			**Average dbh (cm)**
Treatment	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**	**Year 3**
	p=0.7576	*p=0.6949*	*p=0.4807*	*p=0.8864*	*p=0.5490*	*p=0.5459*	*p=0.4399*
PCW x Control	1.70 (0.15)	2.97 (0.23)	4.66 (0.31)	2.72 (0.26)	4.37 (0.41)	6.19 (0.56)	3.37 (0.38)
PCW x Flood	1.81 (0.16)	3.21 (0.24)	4.75 (0.32)	2.66 (0.27)	4.06 (0.42)	5.90 (0.58)	3.18 (0.39)
PCW x Drought	1.57 (0.16)	2.76 (0.23)	4.07 (0.31)	2.44 (0.27)	3.68 (0.41)	5.11 (0.56)	2.32 (0.38)
ACW x Control	1.90 (0.15)	3.22 (0.23)	4.61 (0.31)	2.67 (0.26)	3.98 (0.41)	5.66 (0.56)	2.92 (0.38)
ACW x Flood	1.99 (0.17)	3.13 (0.26)	4.56 (0.34)	2.68 (0.29)	4.26 (0.45)	5.89 (0.61)	2.85 (0.42)
ACW x Drought	1.84 (0.17)	3.18 (0.26)	4.79 (0.34)	2.80 (0.29)	4.21 (0.45)	5.68 (0.61)	3.09 (0.41)
MCW x Control	1.52 (0.18)	2.87 (0.29)	4.23 (0.38)	2.44 (0.30)	4.07 (0.50)	5.77 (0.69)	2.38 (0.47)
MCW x Flood	1.37 (0.18)	2.48 (0.27)	3.54 (0.35)	2.06 (0.30)	2.92 (0.46)	4.19 (0.64)	2.16 (0.43)
MCW x Drought	1.68 (0.18)	2.96 (0.27)	4.35 (0.35)	2.57 (0.30)	3.86 (0.46)	5.50 (0.64)	2.83 (0.43)
MCD x Control	1.85 (0.18)	3.32 (0.28)	4.64 (0.37)	2.64 (0.30)	4.24 (0.48)	5.75 (0.66)	3.12 (0.43)
MCD x Flood	1.89 (0.17)	3.22 (0.26)	4.72 (0.34)	2.58 90.29)	3.92 (0.45)	5.53 (0.61)	3.01 (0.40)
MCD x Drought	1.60 (0.19)	2.83 (0.29)	4.07 (0.38)	2.30 (0.33)	3.38 (0.50)	4.61 90.69)	2.72 (0.47)
BCD x Control	2.11 (0.15)	3.52 (0.22)	5.10 (0.30)	3.03 (0.25)	4.58 (0.39)	6.38 (0.53)	3.33 (0.36)
BCD x Flood	2.24 (0.16)	3.69 (0.25)	5.24 (0.33)	3.22 (0.27)	5.11 (0.43)	7.17 (0.59)	4.01 (0.40)
BCD x Drought	1.87 (0.15)	3.23 (0.23)	4.80 (0.30)	2.83 (0.26)	4.33 (0.40)	6.15 (0.55)	2.98 (0.37)

Table 2-8. Average growth indices (SE) for American sycamore by location and preconditioning interaction for year 1 through 3 growing seasons.

	Average Height (m)			Average Groundline Diameter (cm)		
Treatment	**Year 1**	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
	p=0.7672	*p=0.5839*	*p=0.5326*	*p=0.2630*	*p=0.4030*	*p=0.5933*
PCW x Control	0.60 (0.06)	0.98 (0.10)	1.38 (0.14)	0.73 (0.06)	1.06 (0.09)	1.51 (0.17)
PCW x Flood	0.70 (0.06)	1.11 (0.10)	1.59 (0.14)	0.84 (0.06)	1.23 (0.09)	1.80 (0.17)
PCW x Drought	0.61 (0.06)	0.90 (0.09)	1.38 (0.14)	0.76 (0.06)	1.02 (0.09)	1.50 (0.17)
PCX x Control	0.74 (0.06)	1.28 (0.10)	1.68 (0.14)	0.86 (0.06)	1.24 (0.09)	1.93 (0.17)
PCX x Flood	0.66 (0.06)	1.09 (0.10)	1.54 (0.15)	0.82 (0.06)	1.12 (0.09)	1.72 (0.18)
PCX x Drought	0.67 (0.06)	1.03 (0.10)	1.36 (0.14)	0.78 (0.06)	1.10 (0.09)	1.46 (0.17)
PCD x Control	0.56 (0.05)	0.94 (0.10)	1.32 (0.14)	0.59 (0.05)	0.81 (0.09)	1.27 (0.17)
PCD x Flood	0.55 (0.06)	0.83 (0.10)	1.27 (0.15)	0.69 (0.06)	0.94 (0.09)	1.45 (0.18)
PCD x Drought	0.55 (0.06)	0.91 (0.10)	1.44 (0.14)	0.63 (0.05)	0.94 (0.09)	1.38 (0.17)
NCD x Control	0.56 (0.06)	0.91 (0.11)	1.45 (0.16)	0.75 (0.06)	1.06 (0.10)	1.57 (0.19)
NCD x Flood	0.54 (0.05)	0.86 (0.10)	1.23 (0.15)	0.64 (0.06)	0.92 (0.09)	1.41 (0.18)
NCD x Drought	0.47 (0.06)	0.73 (0.10)	1.19 (0.15)	0.54 (0.06)	0.89 (0.10)	1.30 (0.18)

3.0 FOUR-YEAR EFFECTS OF MECHANICAL SITE PREPARATION, PLANTING STOCK, AND PLANTING AIDS ON THE SURVIVAL AND GROWTH OF AMERICAN SYCAMORE (*Platanus occidentalis* L.) IN AN OLD FIELD RIPARIAN RESTORATION.

3.1 Abstract

Survival and growth of planted tree species are common indices used to evaluate success of wetland restoration efforts used to compensate for wetland losses. Unfortunately, restoration efforts on marginal agricultural lands have typically resulted in less than satisfactory survival and growth of desired tree species. In an attempt to determine the effects of bottomland hardwood silvicultural methods on the survival and growth of pioneer tree species, this study evaluated combinations of five mechanical site preparation techniques (mound, bed, rip, disk, pit), four levels of planting stock (gallon, tubeling, bare root, and direct seed), and three planting aids (mat, tube, none) on the four-year survival and growth of American sycamore (*Platanus occidentalis* L.) planted on an old field riparian area in the Piedmont of Virginia. After four growing seasons, results indicate that a combination of mounding during site preparation and gallon (3.8 L) planting stock provided the most positive influences on mean survival (100%), height (4.72 m) and groundline diameter (9.52 cm), and resulted in the greatest aboveground dry biomass accumulation (5.44 Mg/ha/yr). These treatments may be economically viable for restoration and mitigations efforts and could potentially offer other economic alternatives such as short rotation woody crops that might make restoration efforts in marginal old field areas more attractive to private landowners.

3.2 Introduction

Wetlands are a valued resource for water quality, wildlife use, and food/fiber production, yet an estimated 50% of wetlands in the United States have been converted to non-wetlands (Davidson, 2014). The promulgation of the Clean Water Act in 1972 (33 U.S.C. 1251 et seq. §1972) led to regulatory agency mandates to reduce or eliminate the loss of wetlands, often referred to as the "No Net Loss" legislation (Brown and Lant, 1999), and the 2008 Compensatory Mitigation Rule created a framework for replacing wetland losses through commercial wetland banks, in-lieu fee programs or by permittee-responsible mitigation projects. An emphasis was placed on establishing wetland viability prior to release of compensatory wetland credits, making commercial mitigation banks the primary method to fulfill wetland mitigation requirements (Hough and Harrington, 2019). However, the actual implementation of compensatory wetland and mitigation site design is oftentimes not successful in replacing the functions and values of the permanently impacted wetland. Wetland restoration sites have historically failed due to the mortality of planted wetland tree species (Matthews and Endress, 2008). Establishing pioneer tree species on mitigation sites may accelerate the restoration of these wetland functions and values and increase compliance with wetland mitigation regulations. Greater emphasis has been placed on the success of planted woody species in these sites, as tree survival and growth are typically limiting factors for long term site success. Incongruously, commercial forestry operations have been successful in harvesting and planting in wetland areas, such as wet mineral flats and bottomland hardwood areas of the southeastern United States (Aust et al., 2019). These techniques are not widely used by wetland design and construction groups within the current compensatory mitigation market (McLaughlin et al., 2000; Sun et al., 2001).

Pioneer tree species such as American sycamore (*Platanus occidentalis* L.) have rapid growth rates which favor their stature development over competing species. Pioneer species are adapted to periods of groundwater drawdown, site re-flooding, and competition from perennial herbaceous species by germinating during hydroperiod drawdown and sapling adaptation to flooded conditions. Typically, pioneer species will achieve closed canopy conditions without significant re-planting efforts, if species mortality, most often associated with initial planting stress, are minimized during site planting. Thus, commonly planted pioneer tree species, such as black willow (*Salix nigra* Marshall), sweetgum (*Liquidambar styraciflua* L.), boxelder (*Acer negundo* L.) and river birch (*Betula nigra* L.) are critical for the long-term success of Piedmont forested compensatory mitigation sites.

Commercial silvicultural techniques may create a less stressful environment that allows for pioneer tree species to become established and rapidly accrue biomass in an environment that would otherwise be dominated by perennial herbaceous species resulting in herbaceous autogenic dominance (DeBerry and Perry, 2012; Noon, 1996). Incorporation of pioneer tree species in lieu of late successional woody species, such as *Quercus spp.*, has been reported to facilitate woody volunteers and lead to changes in long-term woody species composition and complexity in compensatory wetland sites in the southeastern Piedmont and Coastal Plain (DeBerry and Perry, 2012). Furthermore, establishment of pioneer species facilitates slower growing late successional species, allowing them to mature in environments that would otherwise result in low long term late successional woody species density and survival.

American sycamore is a resilient, native hardwood species that grows well in old field agricultural areas and other marginal crop areas typically used for mitigation and fiber production (Brinks et al., 2011). Furthermore, American sycamore have been planted as part of short rotation woody crop (SRWC) plantations throughout the southeast, particularly in old field areas of the Piedmont ecoregion that are often characterized by high soil compaction, low nutrient content and wet soil conditions (Dickmann, 2006; Torreano and Frederick, 1988). Such areas are often along margins of managed agricultural areas and are frequently unsuitable for crops (Wiens et al., 2011). Planting trees on these areas may improve soil health by increasing soil organic matter, create areas for nutrient cycling, increase biodiversity through additional vegetative cover, and provide additional wildlife habitat (Dale et al., 2011; Tarr et al., 2017).

American sycamore has periodically been used for rapid biomass production for silage and co-fired power plants since the 1970’s (Davis and Trettin, 2006). However, use of rapid growing species, such as American sycamore, for biomass and bioenergy applications has been recently revisited in the United States and Europe, resulting in a need to quantify the effects of site preparation, planting stock and planting aids on tree growth response (Zalesny et al., 2019). Marginal old field areas have historically been used for both compensatory mitigation sites and bioenergy production, and both uses rely upon the establishment of woody stock and rapid biomass accumulation for long-term success and meeting site utilization goals.

3.2.1 Mechanical Site Preparation

Mechanical site preparation typically requires the use of heavy equipment to manipulate site soils to optimize site conditions for the establishment of woody species (Aust et al., 2019). Site preparation in wetlands is potentially beneficial, as many created forested wetlands fail due to incorrect hydroperiods and soil compaction (Morris and Lowery, 1988). Commercial forestry operations have used mechanical site preparation for decades to prepare harvested sites and to ameliorate the impacts of timber harvesting (Aust and Blinn, 2004; Löf et al., 2012; McLaughlin et al., 2000). The reduction of soil compaction, creation of site microtopography and competition control from undesirable species are the primary benefits of mechanical site preparation in forested wetlands (Bruland and Richardson, 2005). The method of site preparation varies depending upon the location, site conditions, and available machinery. Some of the primary mechanical site preparation methods most often used in areas that have limitations to tree establishment due to hydrologic fluctuations and soil compaction include mounding, bedding, disking (Bruland and Richardson, 2005; Löf et al., 2012; Londo and Mroz, 2001; Miwa et al., 2004).

Mounding is a commonly recommended mechanical site preparation method in bottomland hardwood sites that are generally comprised of poorly drained soils and high groundwater levels (Conner, 1994; Kolka et al., 2000). Mounding is generally accompanied by adjacent pits, creating a microtopographic gradient that allows for seedling establishment in high water table areas and habitat increased habitat diversity in pit areas (Collins and Battaglia, 2008; Ott et al., 2020). Mounds are integral for sites that are planted with late-successional species, such as oak (*Quercus spp.*) (Löf et al., 2012; Londo and Mroz, 2001), although the long-term impacts of pit and mounding are not well documented in available literature. Pit and mound site preparation techniques are commonly used in compensatory wetland mitigation sites to approximate the undulating microtopography of naturally occurring wetlands. This technique requires digging pits and placing the excavated soil material nearby to create a mound. These mounds are similar to naturally produced hummocks and root tip up mounds resulting with flooding and wind storms (Löf et al., 2012; Londo and Mroz, 2001) and the ridges and sloughs associated with meandering stream patterns (Hodges 1997). Pits and mounds incorporate soil organic matter, decrease compaction, expose mineral soil and decrease or increase depth of the water table, which allows for simultaneous establishment of hydrophytic and upland species.

Seedling survival has been shown to be greater in mound topography, due in large part to the amelioration of hydroperiod impacts outside of the growing season and during flood events. The use of pit and mound site preparation may be more advantageous in compensatory mitigation sites, where a wider range of flood tolerant species establishment is desired, where hydroperiod is less predictable, and where increased microtopography is desired for other reasons, such as diversity of wildlife habitat. Similarly, pit and mound site preparation techniques are preferable on marginal sites that have saturated soil conditions, where survival and growth are increased with lower herbaceous and woody competition.

Bedding creates a linear and uniform raised area that incorporates organic matter and increases the aerable soil volume immediately underneath planted seedlings on wet sites (Miwa et al., 2004). This method is widely used on commercial pine (*Pinus* spp.) plantations in the southeast for seedling establishment (Jones et al., 2010). The long-term effect on site productivity is limited as mature trees often outgrow the prepared bedding area (Eisenbies et al., 2005; Miwa et al., 2004). While bedding can also be used as a remedy for compacted site soils, the method is best implemented on sites with high water tables and moderate available organic matter (Carter et al., 2006; Löf et al., 2012).

Disking involves the direct mechanical manipulation of compacted site soils by breaking though large clods and soil clumps (Moser et al., 2009). Species diversity increases in areas that were disked prior to planting, and impact of hydrologic variation is buffered in wetlands that were subjected to disking during site construction (Ahn and Dee, 2011; Moser et al., 2009). Disking does not impact depth to groundwater, and may have limited utility in areas with high water table or large fluctuations in hydrology (Löf et al., 2012; Morris and Lowery, 1988).

Ripping, also known as subsoiling, improves site conditions by increasing root depth by fracturing the traffic pan and increasing aeration, increasing infiltration capacity, and increasing soil water availability to seedlings (Duplissis et al., 2000; Löf et al., 2012). Ripping has similar application method as disking, except it utilizes a chisel plow or ripping shank to rip soil at a depth up to 0.5 m below ground surface. Ripping and disking are commonly used in forest restoration sites due to the low relative cost in proportion to the increase in seedling survival and growth (Espelta et al., 2003).

Previous research suggests that mechanical site preparation may increase seedling resilience to unpredictable hydrologic cycles, increase the biodiversity of restoration areas, decrease competition, and decrease overall restoration cost per acre. However, there are many site conditions that require additional measures, including planting of more mature planting stock, to meet land management goals. Planting of seedlings or broadcast of seed is typically the next phase of the mitigation plan for old field marginal area restoration.

3.2.2 Planting Stock

The type of planting stock is an important factor in the success of mitigation sites that utilize marginal old field areas. Commercial forestry operations traditionally use a variety of planting stock optimized for the specific site conditions. These options typically include direct seeding, bare root seedlings, tubelings, and containerized seedlings (Stanturf et al., 2014). Each of the planting techniques have a cost/benefit associated with it, and a combination of these techniques can be used during the construction and planting of wetland sites (Gardiner et al., 2004). However, compensatory site planning often utilizes the most economical planting stock due to the anticipated need to re-plant to meet regulatory planting density requirements. Planting stock is used based on the immediate economics of purchasing planting stock, and often ignores the cost to replant or plant different stock of plant survival densities are not achieved at the site (Gardiner et al., 2000; Kruse and Groninger, 2003).

Direct seeding is the simplest method of planting, with a less restrictive planting window and low overall cost in comparison to other popular planting methods. However, direct seeding success requires more intensive mechanical site preparation and is susceptible to rodent damage (Allen, 1997; Bullard et al., 1992). Survival of direct seeded sycamore is generally low compared to bare root and container planting, potentially making direct seeding less economical from a labor and management perspective (Stanturf et al., 2014).

Bare root seedlings are a method that is often employed on sites that have been mechanically prepared by bedding, pits and mounds, or other means. Survival rates are higher amount bare root seedlings than direct seedlings (Williams and Craft, 1998). Planting is generally limited to geographically specific planting periods and are susceptible to changes in hydrology (Self et al., 2010). Bare root seedlings are the most common planting stock for bioenergy sites, which emphasize high density planting regimes to meet site productivity goals (Domec et al., 2017).

Containerized seedlings, most commonly tubelings and gallon (3.8 L) pots, are often utilized in wetland plantings due to the lower likelihood of failure in comparison to direct seed and bare root seedlings (Stanturf et al., 2014). Overall costs are generally higher than other seedling types, and containerized seedlings are susceptible to inundation and temperature stress prior to becoming established on the site. Survival is typically greater with containerized seedlings when directly compared to other planting types, making these plants a more economical option for planting on marginal sites with poor soil conditions (Self et al., 2010; Williams and Craft, 1998).

3.2.3 Planting Aids

Planting aids, such as tree tubes and planting mats, have been utilized to promote survival of seedlings by limiting competition with early successional herbaceous and woody species. These aids may reduce the need for herbicides, which are often prohibited or strictly controlled in wetlands, and the mechanical damage associated with trimmers and mowers (Allen, 1997). Mechanical and chemical control of herbaceous competition are common for mitigation and bioenergy sites and are often required for multiple years until woody stock has become established. Options for planting aids include planting tubes and mats, which are cost effective for installation and maintenance. Planting tubes have been shown to effectively prevent tree girdling and browsing by herbivores (Correll, 2005). Mats can be effective in controlling herbaceous competition, and are typically installed after significant earth moving activities (Zedler, 2000). However, the effects of matting are limited when installed in upland buffer areas where competition from perennial herbaceous species is strong (Bruland and Richardson, 2005).

3.3 Study Objectives

Previous studies indicate that mechanical site preparation, type of planting sock, and use of planting aids may be beneficial to survival and growth of woody species planted in marginal old field settings. Therefore, the goal of this study was to evaluate the effects and interactions of five silvicultural mechanical site preparations, four common planting stock types, and three planting aids with the overall goal of improving survival and growth of American sycamore in Piedmont old field riparian areas that are suitable for mitigation and fiber/bioenergy sites.

3.4 Methods

Field research was conducted at the R.J. Reynolds Homestead Forest Resources Research Center, which is located in the Piedmont physiographic province near Critz, Virginia (Figure 3-1). The area is dominated by former agricultural fields historically used for tobacco cultivation. The study site is in the riparian area of a first order perennial unnamed tributary to Mill Creek with a 197-hectare watershed. The watershed is predominantly mixed upland hardwoods and pine, with interspersed managed pine plantations. Common riparian species include yellow poplar (*Lirodendron tulipifera* L.), American boxelder (*Acer negundo* L.), and red maple (*A. rubrum* L.). The field study area is comprised of two soil types. The primary dominant soil series is French soils, taxonomically classified as fine-loamy over sandy or sandy-skeletal, mixed, active mesic Fluvaquentic Dystrudepts on 0 to 3 percent slopes. The second soil series are Braddock series, taxonomically classified as fine, mixed, semiactive mesic Typic Hapludults on 2 to 8 percent slopes. Soils are moderately to moderately well drained with colluvium and alluvium parent material. Legacy sediment comprised the upper soil layers resulting in buried mineral soil horizons observed throughout the site. Site soils exhibited field hydric soil indicators consistent with wetland soil diagnostic criteria (U.S. Army Corps of Engineers, 1987). Annual average temperatures range from 19.4°C to 7.2°C, with an average annual rainfall of 1,380 mm and 290 mm of snowfall for a total average annual precipitation of 1,670 mm.

3.4.1 Study Layout

Five treatment blocks were established within the old field riparian area to maximize use of the stream floodplain (Figure 3-2). Blocks were 25.6 m x 29.3 m (0.075 ha) and were established using staff compass and surveyor tape. Corners were marked with rebar and surveyed with a total station. Each site preparation area measured 7.3 m in width, with each block having a width of 29.3 m. Five mechanical site preparations were established within each of the five blocks: disking, ripping, bedding, pit, and mound. Pit and mound were applied together with the pits situated directly adjacent to the mound. Mound heights and pit depths were approximately 90 cm with an approximate width of 0.5 m, while bed heights were approximately 50 cm. Combinations of four planting stock types: direct seed, bare root, tubeling, gallon, and three planting aids: control, tube, mat, were installed within the mechanical site preparation plots. Four stock types were planted within each of the 12 combinations of seedling type and planting aid (Figure 2-23-3). The study layout allowed for 1,200 trees a planting density of 3,200 stems/ha. Planting density was considerably higher than typical riparian plantings within compensatory mitigation sites but is an acceptable density for bioenergy sites. Planting of the combination of planting stock and planting aids were installed in factorial combination for a total of 48 stems per block.

Mechanical site preparation was conducted in April 2011 and all planting was completed by May 2011. Plantings were conducted by hand, shovel or dibble bar and were conducted or supervised by professional foresters familiar with these planting techniques. Glyphosate 4+ (41% glyphosate) (Alligare, LLC, Opelika, Alabama) herbicide was applied once in June of the first growing season and mowing was conducted between June and September of the first growing season. The weed control was representative of the controls typically employed in wetland and riparian restoration sites. No weed control was conducted after the first year of the study. The weed control was representative of the controls typically employed in bioenergy and mitigation sites. No weed control was conducted after the first year of the study.

3.4.2 Planting Stock

American sycamore seeds were sourced from counties located in both the Piedmont and the Valley and Ridge physiographic provinces of Virginia and were collected by mechanical removal of the seeds from the tree. Bare root seedlings were obtained from the Virginia Department of Forestry (Crimora, Virginia) and were transported to the site in March 2011. Seeds and bare root seedlings were kept refrigerated until planting. Gallon containerized plants and tubelings were ordered from Wetland Studies and Solutions, Inc (Gainesville, Virginia). Tubelings and gallon stock seedlings were stored outside in the open and watered daily until planting.

3.4.3 Planting Aids

Mats were 1 m^2 VisPore mats (Landscape Supply, Inc., Roanoke, Virginia) and were installed with steel landscape staples. Tubes were 1 m Tubex Standard Tree Shelters (Tubex USA, Old Hickory, Tennessee) and were installed using a 1 m wooden support stake. Planting aids were installed in June 2011 after planting and before weed control measures were initiated.

3.4.4 Data Collection and Analysis

Survival data, ground line diameter, diameter at breast height (dbh) and height were collected at the end of each growing season starting in January 2012. Successful germination of seeds or survival of seedlings were visually evaluated during each data collection. Ground line diameter and dbh (mm) for each stem were collected to the nearest 0.1 mm using digital calipers. Total height (m) were collected using a height pole to the nearest 2.5 cm. Stem volume was calculated based on the volume of a simple cylinder, where volume (cm^3) = diameter^2 (cm) * height (cm). Dry weight biomass for the total stem above stump height (10 cm) were calculated for year 3 and year 4 based upon (Belanger, 1973) to determine whole tree dry mass at the plot level (kg/m^2) and scaled to Mg/ha. Aboveground net primary production (ANPPwood in Mg/ha/yr) was calculated from the difference in aboveground biomass between years 3 and 4.

The experimental design was a split plot within a randomized complete block design (Box and Jones, 1992) to evaluate the treatment and interaction effects on survival and growth. The mechanical site preparation techniques constituted the main effects, while the combinations of plant stock type and planting aids provided the split treatment. All treatment combinations were applied during the study, but shortages in planting stock due to low gallon stock availability and low availability of the Visipore matting and Tubex tree shelters during planting aid installation compromised the original design and resulted in a planted n = 960. Statistical analysis was conducted using JMP Pro version 14.2.0 (SAS, n.d.). Least square means were generated using the REML analysis, and multiple comparisons among means were calculated using post hoc Tukey’s HSD. An alpha level of 0.05 was applied to indicate statistical significance. The assumption that data were normally distributed with constant variance were tested using studentized residuals comparison to predicted values to test for constant variance and normal quantile plots to test for normal data distribution. Data were determined to have constant variance and normal distribution. Only surviving stems were included in diameter, height, and biomass calculations.

3.5 Results

3.5.1 Site Preparation Treatments

In general, mounding resulted in best survival and growth performance. Year 1 survival was greatest in mound (69.2%) and disk (69.2%) and lowest in the pit (59.2%) treatment (p=0.0172), but site preparation did not have a significant impact on survival in the remaining years (Table 3-1). Mounding had the largest growth indices across all years, followed by bedding. The pit treatment had the lowest growth indices across all measures. Mounding produced 20% greater height than bedding and 25% greater height than pit (Table 3-2), almost 30% greater groundline diameter than bedding and 40% greater groundline diameter than pit (Table 3-3), and more than 25% greater dbh than ripping and 40% greater dbh than pit(Table 3-4). Total dry stem biomass (Table 3-5) was 40% greater in the mound treatment than ripping, which had the next largest average biomass. Mounding was 80% greater than disking, which had the lowest average dry stem biomass accumulation. The rip treatment groundline diameter, dbh and biomass growth indices steadily increased after year 1 and were statistically similar to the mound treatment by year 4. Mound ANPPwood (2.62 Mg/ha/yr) was significantly greater than the bed (1.43 Mg/ha/yr), disk (0.92 Mg/ha/yr) and pit (1.13 Mg/ha/yr) treatments with no difference observed between mound and rip (1.68 Mg/ha/yr) treatments (Table 3-5).

3.5.2 Planting Stock

Year 1 average survival were greatest in gallon (99.7%) and tubeling (93.0%), and lowest in direct seed (14.5%) (p<0.0001) (Table 3-1). Average tree height showed a strong significant relationship with planting stock in all years (p<0.0001). Gallon planting stock was 75% taller than direct seed, 30% taller than bare root and 20% taller than tubeling stock in years 1, 2, and 3.

The wide height discrepancy was maintained between gallon stock and bare root in year 4, but was reduced to 20% taller than bare root and within 10% of tubeling height. Tubeling heights were also significantly greater than bare root and direct seed in all years (Table 3-2). Average groundline diameters were significantly different across all years ($p<0.0001$), with gallon and tubeling planting stock over double the average diameter of bare root (Table 3-3). Planting stock had a significant effect on average dbh across all years ($p<0.0001$), with gallon and tubeling planting stock dbh significantly greater than bare root and direct seed across (Table 3-4). Gallon planting stock showed significantly greater year 4 biomass (6.02 Mg/ha) than all other planting stock ($p<0.0001$). ANPPwood was significantly greater with gallon planting stock (3.19 Mg/ha/yr) than all other planting stocks (Table 3-5).

3.5.3 Planting Aids

The effects of planting aids on survival were not significantly different ($p=0.2089$) (Table 3-1). Planting aids did not significantly affect tree height in any for any year (Table 3-2). Planting aids had a significant relationship with average groundline diameter in year 1 and 2, with matting having significantly greater diameter than tree tubes. No significant difference was observed between no planting aid and matting (Table 3-3). No significant effect was observed for dbh for any year (Table 3-4). No significant effects were observed for biomass or ANPPwood from matting, tree tubes or no treatment applications (Table 3-5).

3.5.4 Interaction Effects

A significant interaction effect in all years was observed between site preparation and planting stock for survival. Gallon and tubeling planting stock combined with the mound site preparation had survival rates ranging from 97% (tubeling) to 100% (gallon) for all four years

(Table 3-6). No significant interactions were observed for average height (Table 3-7), average groundline diameter (Table 3-8), average dbh (Table 3-9), average biomass or ANPPwood (Table 3-10).

3.6 Discussion

The high woody stem mortality often associated with compensatory mitigation sites can often be traced to marginal existing site conditions and improper species selection of planting stock (Matthews and Endress, 2008; Zedler, 2000). The observed survival and biomass results of this study indicated that the appropriate species selection, application of site preparation techniques, and use of appropriate planting stock type can increase survival and growth within old field and marginal agricultural sites in the Piedmont of Virginia. Based upon evaluation of the site using the Baker and Broadfoot site index model (Baker and Broadfoot, 1979), the site was considered marginal for most hardwood species due to the cumulative impacts of high intensity agriculture at the site. Site index (base age fifty) was approximately 70 to 75 feet (21 to 23 m) for American sycamore, which indicated that these species were suitable for the observed site conditions. Selection of American sycamore for the site was further validated as mature sycamore were also observed immediately downstream from the research property within existing woody riparian and wetland areas in the watershed.

The survival rates observed in this study for both site preparation and planting stock are much higher than previous studies of sycamore survival in compensatory mitigation sites, which ranged from 59% to 45% after 4 years (Matthews and Endress, 2008; Roquemore et al., 2014). Overall, mortality was greatest during year 1, with no significant differences in survival observed between the remaining years of the study. This trend is similar to previously observed mortality rates, which were greatest in the first three years after planting (Jones and Sharitz, 1998;

Roquemore et al., 2014). The high survival rates of gallon and tubeling stock have historically been attributed to greater groundline diameter, root development and hydrologic resilience (Stanturf et al., 2004). Site preparation such as mounding, bedding and ripping reduced soil compaction inherent in marginal agricultural field settings and increased survival (Löf et al., 2012; Londo and Mroz, 2001). The combined effect of site preparation and stock type, specifically mounding, bedding and gallon or tubeling stock types, favored very high survival and biomass accumulation rate. Higher survival rates could be attributed to mounding and bedding reducing inundation related mortality and increased root volume, resulting in greater soil moisture availability during periods of low precipitation. American sycamore seedlings are more resilient to inundation during establishment than other bottomland hardwood species, but are more susceptible to dry hydrologic conditions (McKnight et al., 1981; Will et al., 2013). Gallon and tubeling stock types increased resilience likely by increasing root growth potential and reduced transplant shock (South et al., 2005; Stanturf et al., 2004).

Tree growth indices, as measured by average height, groundline diameter and dbh, were highest in the lowest mortality treatments. Mounding site preparation was significantly greater than all other site preparation techniques through year 4, and directly supports greater hydrologic resilience for planted stock in marginal agricultural areas. Gallon and tubeling stock were consistently greater in all areas of tree growth and met regulatory success criteria for tree height and canopy closure prior to year 3 of the study. Planting aids, which are commonly used in marginal land restoration programs such as the Conservation Reserve Enhancement Program, did not provide any significant benefit beyond year 3, which is consistent with previous research (West et al., 1999). The observed results support use of site preparation, particularly mounding and bedding, in combination with gallon and tubeling planting stock, to expedite tree growth to meet site success criteria. Ripping may also be a viable site preparation technique for meeting longer timeline success criteria. Economically, the use of site preparation techniques and planting stock accelerate meeting site success criteria, increasing the availability of wetland and buffer credits, which are typically available starting in year 3 after planting on sites that meet regulatory success criteria. Typical costs for site preparation range from $182 to $286 per acre ($358 to $623/hectare) in 2018, with mounding having a higher cost than bedding or ripping due to the lower equipment efficiency and the amount of earthwork required (Maggard and Barlow, 2018). Planting costs vary widely, with gallon plants typically an order of magnitude more expensive than bare root plants (Roquemore et al., 2014). However, American sycamore tubeling planting stock are similarly priced to bare root planting stock, and the cost of handplanting ranged from $60 to $112 per acre ($136 to $178/ha) in 2018 at an average of 580 seedlings per acre (Callaghan et al., 2019; Maggard and Barlow, 2018). Comparatively, the price range for compensatory wetland and buffer credits range from $52,000 to $100,000 per acre ($128,000 to $247,000/ha) for in-lieu fee advanced Piedmont wetland credits in Virginia and North Carolina (Conservancy, 2018; Department of Mitigation, North Carolina Department of Mitigation, N. C. (n.d.). Statewide Stream, Wetland and Riparian Buffer Rates. Retrieved January 1, 2020, n.d.). Commercial wetland credits are typically more expensive than in lieu fee credits, with value fluctuating with market demand. These credits are often produced in regions that do not have in-lieu fee advanced credits available, and typically wetland mitigation credits are required to encompass more area than the credit value, which increases commercial wetland credit cost as land values increase (Stephenson and Tutko, 2018)

Under current regulatory conditions, wetland and buffer credits are released for sale if site conditions meet success criteria, which generally include stem density and growth indices requirements by the third and fifth years after planting. Based upon our study results, implementation of site preparation techniques and planting gallon or tubeling stock could potentially increase the likelihood of attaining required stem density success criteria. Traditionally, bare root planting stock has been the preferred planting stock due to the low cost of stock and planting in comparison to more mature planting stock. However, the results of this study indicated that bare root planting stock generally do not meet regulatory thresholds for success for stem density or growth, and due to the lower survival rates observed, require greater investment in re-planting, which will delay the credit release schedule and reduce the financial incentive to create wetland areas in compensatory mitigation sites. Limited compensatory credit supply has the potential to increase costs per wetland credit, which may stress the current regulatory "no-net loss" goals and may reduce both economic returns and ecological benefits.

Our results demonstrated that dry stem biomass values from using mounding combined with gallon and tubeling planting stock produced between 3.3 and 5.4 Mg/ha/yr on Piedmont old field marginal agricultural sites, at a planting density of 3,200 stems/ha, without the use of irrigation, fertilizers, or other silvicultural inputs after establishment (Table 3-5). These values were within the range of previous studies that did not conduct mechanical site preparation, utilized higher planting densities of 5,000 to 10,000 trees/ha (Domec et al., 2017). The dry stem biomass values observed were most likely underestimated since the biomass of leaves and branches were not included in our study (Domec et al., 2017; Fischer et al., 2017; Ghezehei et al., 2015; Roquemore et al., 2014). This study is unique in assessing site preparation and planting stock in lieu of high inputs (irrigation, fertilizer, chemical applications) and increased planting density. Typically high inputs are used to decrease the growth period of planted stock in order increase the economic viability of marginal land SRWC plots, where it is estimated that a biomass production of 8 to 10 Mg/ha is required for economic viability (Boone, 2017).

Tubeling and gallon planting stock returned biomass values greater of three times the bare root dry biomass, and when site preparation and planting stock treatments were combined, all combinations of site preparation and gallon or tubeling stock outperformed bare root stock. Traditionally, bare root planting stock are the predominant planting method, which are coupled with high input silvicultural management methods, including fertilizer and irrigation. The results of this study indicate that use of larger planting stock and any site preparation method except pitting will increase dry biomass and increase the economic viability of marginal lands for bioenergy production.

3.7 Conclusion

Marginal agricultural lands in the Piedmont are typically less suitable for row crop agriculture and are of restricted ecological and economic benefits to landowners or the environment if they remain as marginal agricultural lands. The low agricultural productivity of these areas is typically limited due wet soil conditions, soil compaction, low soil fertility and excessive site wetness. Use of silvicultural site preparation techniques, specifically mounding and bedding, increases the potential utility of these sites for sycamore growth. Use of gallon or tubeling planting stock provides an even greater biomass return in sycamore, and the combination of site preparation and planting stock increased productivity of American sycamore on these sites at levels typically observed with high input management practices. Using larger planting stock and implementing site preparation techniques decrease the negative effects of soil compaction, excessive soil wetness, and unpredictable precipitation and increase early root establishment, which increases biomass production. The biomass increases observed at relatively low planting density illustrate the viability of these silvicultural applications.

Use of marginal agricultural areas for compensatory mitigation or SRWC production may increase the environmental and economic viability of the sites and may also increase the willingness of landowners to partition historically low productivity lands for applications that increase the net ecological landscape benefit. Further investigation into increased planting density and long-term sustainability of marginal lands for sycamore biomass production are needed to determine most suitable management practices for optimization of ecological and economic services for marginal lands. Increasing the economic viability may provide more opportunity to utilize these areas for a net positive ecological gain by increasing landscape ecosystem services. Sycamore has a high tolerance for environmental stressors and use of site preparation and larger planting stock to further increase establishment will increase productivity at a potentially acceptable relatively minimal cost for the economic return to landowners and bioenergy producers.

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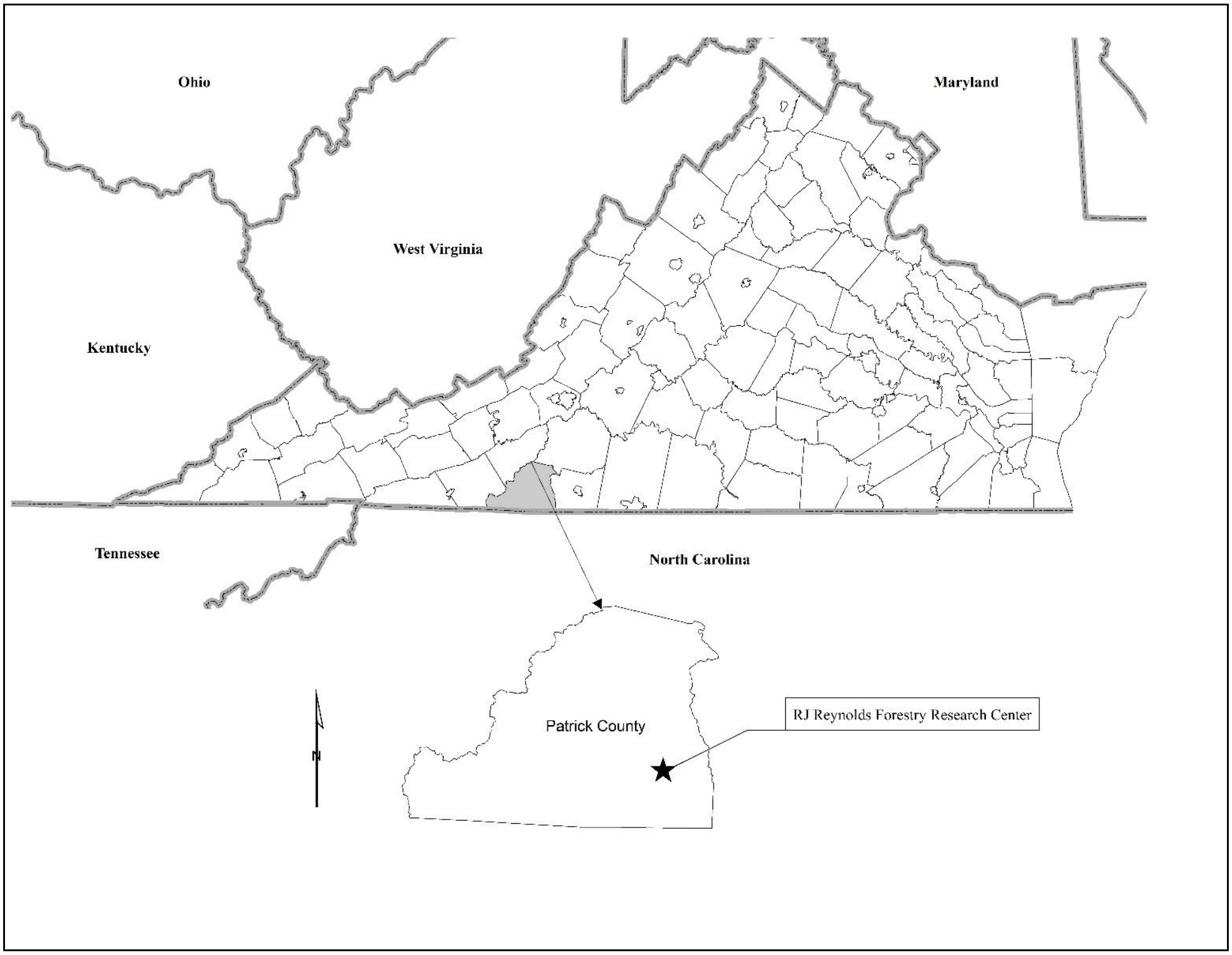
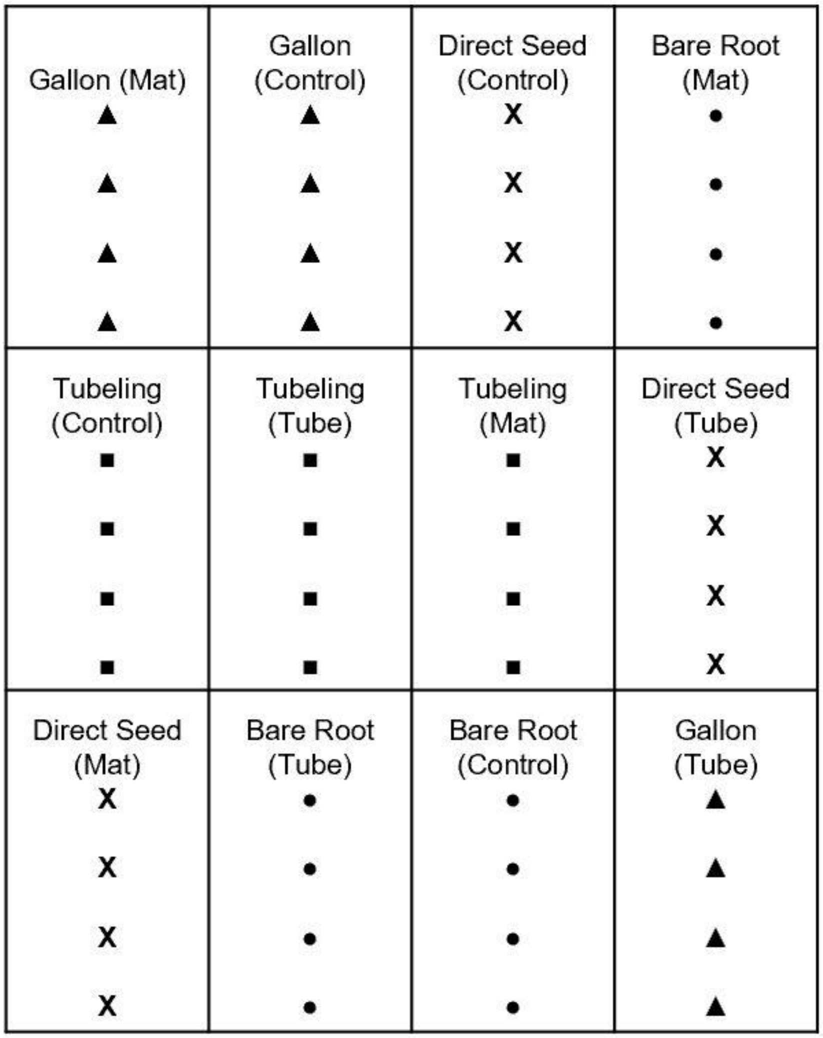


Figure 3-1. Location of the RJ Reynolds Forestry Research Extension Center, Critz, Virginia.

Figure 3-2. Layout of American sycamore treatment blocks (0.075 ha) along the floodplain of an unnamed tributary to Mill Creek, Patrick County, Virginia.



Gallon (Mat) ▲ ▲ ▲ ▲	Gallon (Control) ▲ ▲ ▲ ▲	Direct Seed (Control) X X X X	Bare Root (Mat) ● ● ● ●
Tubeling (Control) ■ ■ ■ ■	Tubeling (Tube) ■ ■ ■ ■	Tubeling (Mat) ■ ■ ■ ■	Direct Seed (Tube) X X X X
Direct Seed (Mat) X X X X	Bare Root (Tube) ● ● ● ●	Bare Root (Control) ● ● ● ●	Gallon (Tube) ▲ ▲ ▲ ▲

Figure 3-3. An example block field layout with each large block representing one site preparation technique, and each internal block representing one experimental unit consisting of the planting stock and planting aid treatments.

Table 3-1. Average percent survival (SE) for American sycamore on the Virginia Piedmont by site preparation, planting stock type and planting aid. Averages within a column with different letters are significantly different.

	Average Survival (%)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p=0.0172*		*p=0.3351*		*p=0.3937*		*p=0.0378*	
Mound	69.2 (10.1)	a	68.3 (10.4)		68.3 (10.4)		68.3 (10.1)	a
Disk	69.2 (10.8)	a	67.5 (11.6)		66.7 (11.8)		66.7 (11.8)	ab
Bed	65.4 (9.5)	ab	65.0 (9.5)		65.4 (9.6)		65.0 (9.8)	ab
Rip	68.1 (10.1)	ab	67.7 (10.3)		67.1 (10.3)		67.5 (10.1)	ab
Pit	59.2 (12.3)	ab	60.8 (10.3)		60.8 (12.3)		60.0 (12.1)	b
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Gallon	99.7 (0.3)	a	99.7 (0.3)	a	99.3 (0.4)	a	99.3 (0.4)	a
Tubeling	93.0 (1.4)	a	93.7 (1.5)	a	94.0 (1.3)	a	93.3 (1.3)	a
Bare Root	57.7 (4.7)	b	58.0 (4.4)	b	57.7 (4.3)	b	57.7 (4.3)	b
Direct Seed	14.5 (2.2)	c	12.2 (2.2)	c	11.7 (2.4)	c	11.7 (2.2)	c
Planting Aid	*p=0.2089*		*p=0.1874*		*p=0.2676*		*p=0.3480*	
Tube	68.5 (8.3)		68.2 (8.4)		67.5 (8.4)		67.2 (8.4)	
Mat	66.0 (7.8)		66.7 (7.8)		66.7 (7.8)		66.2 (7.7)	
None	64.1 (8.2)		62.6 (8.6)		62.7 (8.7)		63.0 (8.6)	

Table 3-2. Average height (SE) for American sycamore on the Virginia Piedmont by site preparation, planting stock type and planting aid. Averages within a column with different letters are significantly different.

	Average Height (m)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p=0.0017*		*p<0.0001*		*p=0.0044*		*p=0.0002*	
Mound	2.16 (0.12)	a	2.87 (0.14)	a	3.65 (0.19)	a	5.10 (0.25)	a
Bed	1.73 (0.12)	b	2.22 (0.14)	b	2.89 (0.18)	b	4.00 (0.27)	b
Rip	1.75 (0.11)	b	2.31 (0.14)	b	3.26 (0.20)	b	4.27 (0.28)	b
Disk	1.62 (0.11)	b	1.99 (0.16)	b	2.51 (0.22)	b	3.56 (0.27)	b
Pit	1.75 (0.10)	b	2.08 (0.16)	b	2.79 (0.22)	b	4.24 (0.30)	b
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Gallon	2.30 (0.08)	a	3.15 (0.12)	a	3.97 (0.17)	a	5.05 (0.21)	a
Tubeling	1.88 (0.08)	b	2.70 (0.12)	b	3.26 (0.16)	b	4.43 (0.21)	b
Bare Root	1.57 (0.08)	c	2.25 (0.13)	c	2.91 (0.17)	c	3.80 (0.22)	c
Direct Seed	0.69 (0.11)	d	1.19 (0.19)	d	1.68 (0.26)	d	2.39 (0.36)	d
Planting Aid	*p=0.1788*		*p=0.1131*		*p=0.1226*		*p=0.1677*	
Tube	1.79 (0.08)		2.49 (0.12)		3.19 (0.17)		4.16 (0.22)	
Mat	1.87 (0.10)		2.70 (0.13)		3.47 (0.16)		4.47 (0.21)	
None	1.74 (0.10)		2.48 (0.14)		3.17 (0.18)		4.08 (0.22)	

Table 3-3. Average groundline diameter (SE) for American sycamore on the Virginia Piedmont by site preparation, planting stock type and planting aid. Averages within a column with different letters are significantly different.

	Average Groundline Diameter (cm)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p<0.0001*		*p=0.0002*		*p=0.0003*		*p=0.0002*	
Mound	3.22 (0.21)	a	4.56 (0.26)	a	5.94 (0.32)	a	7.48 (0.42)	a
Bed	2.47 (0.20)	b	3.36 (0.29)	b	4.37 (0.36)	b	5.35 (0.45)	b
Rip	2.42 (0.16)	b	3.29 (0.25)	b	4.50 (0.33)	b	5.61 (0.41)	ab
Disk	2.22 (0.15)	b	2.99 (0.220	b	3.85 (0.27)	b	4.60 (0.34)	b
Pit	2.13 (0.17)	b	2.77 (0.23)	b	3.75 (0.33)	b	4.43 (0.42)	b
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Gallon	3.46 (0.13)	a	4.52 (0.20)	a	5.76 (0.22)	a	7.02 (0.36)	a
Tubeling	2.56 (0.12)	b	3.45 (0.19)	b	4.58 (0.25)	b	5.69 (0.32)	b
Bare Root	1.95 (0.11)	c	2.78 (0.17)	c	3.69 (0.22)	c	4.48 (0.29)	c
Direct Seed	0.89 (0.12)	d	1.43 (0.24)	d	2.19 (0.31)	d	2.78 (0.39)	d
Planting Aid	*p=0.0014*		*p=0.0158*		*p=0.0594*		*p=0.2007*	
Tube	2.17 (0.13)	b	3.06 (0.20)	b	4.12 (0.27)		5.22 (0.36)	
Mat	2.76 (0.15)	a	3.73 (0.21)	a	4.84 (0.27)		5.84 (0.33)	
None	2.58 (0.15)	ab	3.43 (0.20)	ab	4.55 (0.25)		5.53 (0.32)	

Table 3-4. Average dbh (SE) for American sycamore on the Virginia Piedmont by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average dbh (cm)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p=0.0040*		*p=0.0027*		*p=0.0024*		*p=0.0007*	
Mound	1.21 (0.11)	a	2.40 (0.21)	a	3.18 (0.21)	a	4.31 (0.25)	a
Bed	0.77 (0.10)	b	1.46 90.17)	b	2.12 (0.22)	b	2.87 (0.27)	b
Rip	0.81 (0.09)	ab	1.19 (0.16)	ab	2.28 (0.22)	ab	3.15 (0.27)	ab
Disk	0.72 (0.09)	ab	1.37 (0.15)	b	1.87 (0.19)	b	2.49 (0.23)	b
Pit	0.64 (0.09)	b	1.39 (0.17)	b	1.96 (0.22)	b	2.68 (0.30)	b
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Gallon	1.22 (0.08)	a	2.21 (0.14)	a	2.97 (0.18)	a	3.93 (0.22)	a
Tubeling	0.85 (0.07)	b	1.73 (0.15)	b	2.36 (0.16)	b	3.23 (0.21)	ab
Bare Root	0.61 (0.07)	b	1.28 (0.16)	bc	1.90 (0.16)	b	2.59 (0.20)	bc
Direct Seed	0.10 (0.06)	c	0.43 (0.15)	c	0.82 (0.22)	c	1.36 (0.27)	c
Planting Aid	*p=0.6563*		*p=0.3868*		*p=0.3695*		*p=0.3720*	
Tube	0.81 (0.08)		1.56 (0.13)		2.18 (0.18)		3.01 (0.23)	
Mat	0.87 (0.08)		1.76 (0.16)		2.41 (0.18)		3.26 (0.22)	
None	0.83 (0.08)		1.62 (0.13)		2.28 (0.16)		3.06 (0.20)	

Table 3-5. Average (SE) dry weight biomass and ANPPwood for American sycamore on the Virginia Piedmont by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average Biomass (Mg/ha)				**ANPPwood (Mg/ha/yr)**	
Treatment	**Year 3**		**Year 4**			
Site Preparation	$p=0.0117$		$p=0.0011$		$p=0.0002$	
Mound	2.01 (0.33)	a	4.62 (0.72)	a	2.62 (0.41)	a
Bed	1.36 (0.36)	ab	2.79 (0.68)	ab	1.43 (0.33)	b
Rip	1.33 (0.25)	ab	3.01 (0.54)	ab	1.68 (0.29)	ab
Disk	0.91 (0.26)	b	1.84 (0.48)	b	0.92 (0.23)	b
Pit	0.84 (0.24)	b	1.97 (0.52)	b	1.13 (0.29)	b
Planting Stock	$p<0.0001$		$p<0.0001$		$p<0.0001$	
Gallon	2.83 (0.38)	a	6.02 (0.75)	a	3.19 (0.38)	a
Tubeling	1.60 (0.22)	b	3.70 (0.48)	b	2.10 (0.28)	b
Bare Root	0.55 (0.09)	c	1.28 (0.23)	c	0.72 (0.14)	c
Direct Seed	0.03 (0.02)	c	0.09 (0.03)	c	0.06 (0.02)	c
Planting Aid	$p=0.3695$		$p=0.3629$		$p=0.2926$	
Tube	1.36 (0.27)		3.14 (0.56)		1.78 (0.30)	
Mat	1.46 (0.24)		3.13 (0.49)		1.67 (0.26)	
None	1.06 (0.17)		2.33 (0.35)		1.24 (0.19)	

Table 3-6. American sycamore average (SE) survival on the Virginia Piedmont for treatment combinations. Averages within a column followed by different letters are significantly different.

Treatment Interaction		**Average Survival (%)**							
		Year 1		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	***Planting Stock***	*p=0.0024*		*p=0.0004*		*p=0.0004*		*p=0.0005*	
Bed	Gallon	100.0 (4.4)	a	100.0 (4.1)	a	100.0 (4.0)	a	100.0 (3.8)	a
Bed	Tubeling	86.7 (4.4)	abc	86.7 (4.1)	abc	88.3 (4.0)	ab	88.3 (3.8)	ab
Bed	Bare root	55.0 (4.4)	de	53.3 (4.1)	de	53.3 (4.0)	cd	53.3 (3.8)	cd
Bed	Direct seed	20.0 (4.4)	fg	20.0 (4.1)	fg	20.0 (4.0)	ef	18.3 (3.8)	ef
Flat	Gallon	100.0 (4.4)	a	100.0 (4.1)	a	100.0 (4.0)	a	100.0 (3.8)	a
Flat	Tubeling	91.7 (4.4)	ab	91.7 (4.1)	ab	91.7 (4.0)	ab	91.7 (3.8)	ab
Flat	Bare root	75.0 (4.4)	bcd	75.0 (4.1)	bcd	73.3 (4.0)	bc	73.3 (3.8)	bc
Flat	Direct seed	10.0 (4.4)	fg	3.3 (4.1)	g	1.7 (4.0)	f	1.7 (3.8)	f
Mound	Gallon	100.0 (4.4)	a	100.0 (4.1)	a	100.0 (4.0)	a	100.0 (3.8)	a
Mound	Tubeling	96.7 (4.4)	ab	96.7 (4.1)	ab	96.7 (4.0)	a	96.7 (3.8)	a
Mound	Bare root	60.0 (4.4)	d	60.0 (4.1)	d	60.0 (4.0)	c	60.0 (3.8)	c
Mound	Direct seed	20.0 (4.4)	fg	16.7 (4.1)	fg	16.7 (4.0)	ef	16.7 (3.8)	ef
Pit	Gallon	100.0 (4.4)	a	100.0 (4.1)	a	100.0 (4.0)	a	100.0 (3.8)	a
Pit	Tubeling	96.7 (4.4)	ab	100.0 (4.1)	a	100.0 (4.0)	a	96.7 (3.8)	a
Pit	Bare root	33.3 (4.4)	ef	36.7 (4.1)	ef	36.7 (4.0)	de	36.7 (3.8)	de
Pit	Direct seed	6.7 (4.4)	g	6.7 (4.1)	g	6.7 (4.0)	f	6.7 (3.8)	f
Rip	Gallon	98.3 (4.4)	ab	98.3 (4.1)	a	96.7 (4.0)	a	96.7 (3.8)	a
Rip	Tubeling	93.3 (4.4)	ab	93.3 (4.1)	ab	93.3 (4.0)	ab	93.3 (3.8)	ab
Rip	Bare root	65.0 (4.4)	cd	65.0 (4.1)	cd	65.0 (4.0)	c	65.0 (3.8)	c
Rip	Direct seed	15.8 (4.4)	fg	14.2 (4.1)	fg	13.3 (4.0)	f	15.0 (3.8)	f

Table 3-6 (continued). American sycamore average (SE) survival on the Virginia Piedmont for treatment combinations. Averages within a column followed by different letters are significantly different.

		Average Survival (%)			
Treatment Interaction		**Year 1**	**Year 2**	**Year 3**	**Year 4**
Site Preparation	***Planting Aid***	*p=0.5629*	*p=0.4876*	*p=0.6784*	*p=0.4876*
Bed	*Mat*	70.0 (3.8)	70.0 (3.5)	70.0 (3.5)	70.0 (3.3)
Bed	*None*	60.0 (3.8)	60.0 (3.5)	61.3 (3.5)	61.3 (3.3)
Bed	*Tube*	66.3 (3.8)	65.0 (3.5)	65.0 (3.5)	63.8 (3.3)
Flat	*Mat*	71.3 (3.8)	70.0 (3.5)	70.0 (3.5)	70.0 (3.3)
Flat	*None*	66.3 (3.8)	62.5 (3.5)	62.5 (3.5)	62.5 (3.3)
Flat	*Tube*	70.0 (3.8)	70.0 (3.5)	67.5 (3.5)	67.5 (3.3)
Mound	*Mat*	65.0 (3.8)	65.0 (3.5)	65.0 (3.5)	65.0 (3.3)
Mound	*None*	70.0 (3.8)	67.5 (3.5)	67.5 (3.5)	67.5 (3.3)
Mound	*Tube*	72.5 (3.8)	72.5 (3.5)	72.5 (3.5)	72.5 (3.3)
Pit	*Mat*	55.0 (3.8)	60.0 (3.5)	60.0 (3.5)	57.5 (3.3)
Pit	*None*	60.0 (3.8)	60.0 (3.5)	60.0 (3.5)	60.0 (3.3)
Pit	*Tube*	62.5 (3.8)	62.5 (3.5)	62.5 (3.5)	62.5 (3.3)
Rip	*Mat*	68.8 (3.8)	68.8 (3.5)	68.8 (3.5)	68.8 (3.3)
Rip	*None*	64.4 (3.8)	63.1 (3.5)	62.5 (3.5)	63.8 (3.3)
Rip	*Tube*	71.3 (3.8)	71.3 (3.5)	70.0 (3.5)	70.0 (3.3)
Planting Stock	***Planting Aid***	*p=0.1052*	*p=0.0562*	*p=0.1079*	*p=0.0562*
Mat	Bare root	56.0 (3.4)	58.0 (3.1)	58.0 (3.1)	58.0 (3.0)
Mat	Direct seed	18.0 (3.4)	17.0 (3.1)	17.0 (3.1)	17.0 (3.0)
Mat	Gallon	99.0 (3.4)	99.0 (3.1)	99.0 (3.1)	99.0 (3.0)
Mat	Tubeling	91.0 (3.4)	93.0 (3.1)	93.0 (3.1)	91.0 (3.0)
None	Bare root	50.0 (3.4)	50.0 (3.1)	50.0 (3.1)	50.0 (3.0)
None	Direct seed	13.5 (3.4)	7.5 (3.1)	7.0 (3.1)	8.0 (3.0)
None	Gallon	100.0 (3.4)	100.0 (3.1)	100.0 (3.1)	100.0 (3.0)
None	Tubeling	93.0 (3.4)	93.0 (3.1)	94.0 (3.1)	94.0 (3.0)
Tube	Bare root	67.0 (3.4)	66.0 (3.1)	65.0 (3.1)	65.0 (3.0)
Tube	Direct seed	12.0 (3.4)	12.0 (3.1)	11.0 (3.1)	10.0 (3.0)
Tube	Gallon	100.0 (3.4)	100.0 (3.1)	99.0 (3.1)	99.0 (3.0)
Tube	Tubeling	95.0 (3.4)	95.0 (3.1)	95.0 (3.1)	95.0 (3.0)

Table 3-7. American sycamore average (SE) height on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

		Average Height (m)			
Treatment Interaction		**Year 1**	**Year 2**	**Year 3**	**Year 4**
Site Preparation	***Planting Stock***	*p=0.9974*	*p=0.9946*	*p=0.9960*	*p=0.9950*
Bed	*Bare Root*	1.49 (0.18)	2.04 (0.28)	2.69 (0.38)	3.49 (0.50)
Bed	*Direct Seed*	0.61 (0.22)	1.08 (0.36)	1.61 (0.48)	2.42 (0.63)
Bed	*Tubeling*	2.35 (0.16)	3.07 (0.26)	3.81 (0.35)	4.70 (0.46)
Bed	*Gallon*	1.89 (0.16)	2.66 (0.26)	3.47 (0.35)	4.50 (0.46)
Disk	*Bare Root*	1.41 (0.16)	2.03 (0.26)	2.54 (0.35)	3.18 (0.46)
Disk	*Direct Seed*	0.25 (0.36)	0.28 (0.58)	0.38 (0.79)	0.60 (1.03)
Disk	*Gallon*	2.08 (0.16)	2.84 (0.26)	3.53 (0.35)	4.37 (0.46)
Disk	*Tubeling*	1.66 (0.16)	2.40 (0.26)	3.04 (0.35)	3.75 (0.46)
Mound	*Bare Root*	1.96 0.18)	2.82 (0.28)	3.56 (0.38)	4.72 (0.50)
Mound	*Direct Seed*	0.83(0.270	1.43 (0.43)	2.10 (0.57)	2.93 (0.75)
Mound	*Gallon*	2.68 (0.16)	3.75 (0.26)	4.65 (0.35)	6.02 (0.46)
Mound	*Tubeling*	2.35 (0.16)	3.35 (0.26)	4.22 (0.35)	5.42 (0.46)
Pit	*Bare Root*	1.40 (0.24)	2.01 (0.38)	2.68 (0.52)	3.52 (0.68)
Pit	*Direct Seed*	0.75 (0.47)	1.49 (0.74)	1.97 (1.00)	2.70 (1.31)
Pit	*Gallon*	2.19 (0.16)	3.03 (0.26)	3.97 (0.35)	5.07 (0.46)
Pit	*Tubeling*	1.60 (0.16)	2.31 (0.26)	2.99 (0.35)	3.88 (0.46)
Rip	*Bare Root*	1.54 (0.18)	2.25 (0.28)	3.04 (0.38)	4.04 (0.50)
Rip	*Direct Seed*	0.69 (0.25)	1.18 (0.40)	1.48 (0.54)	2.07 (0.71)
Rip	*Gallon*	2.22 (0.16)	3.05 (0.26)	3.87 (0.35)	5.06 (0.46)
Rip	*Tubeling*	1.92 (0.16)	2.79 (0.26)	3.57 (0.35)	4.60 (0.46)

Table 3-7 (continued). American sycamore average (SE) height on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		Average Height (m)			
		Year 1	Year 2	Year 3	Year 4
Site Preparation	***Planting Aid***	*p=0.5629*	*p=0.9091*	*p=0.9642*	*p=0.9560*
Bed	*Mat*	1.80 (0.15)	2.62 (0.24)	3.41 (0.33)	4.39 (0.43)
Bed	*None*	1.40 (0.16)	1.94 (0.26)	2.58 (0.35)	3.38 (0.46)
Bed	*Tube*	1.56 (0.16)	2.07 (0.25)	2.70 (0.33)	3.57 (0.44)
Flat	*Mat*	1.34 (0.18)	1.91 (0.28)	2.47 (0.38)	3.05 (0.50)
Flat	*None*	1.32 (0.18)	1.84 (0.28)	2.31 (0.38)	2.93 (0.50)
Flat	*Tube*	1.39 (0.18)	1.91 (0.28)	2.33 (0.38)	2.94 (0.50)
Mound	*Mat*	2.12 (0.16)	3.20 (0.26)	4.05 (0.35)	5.28 (0.46)
Mound	*None*	1.97 (0.16)	2.75 (0.25)	3.48 (0.33)	4.47 (0.44)
Mound	*Tube*	1.78 (0.17)	2.56 (0.28)	3.36 (0.37)	4.56 (0.49)
Pit	*Mat*	1.61 (0.20)	2.29 (0.32)	3.08 (0.43)	4.06 (0.56)
Pit	*None*	1.38 (0.23)	2.08 (0.37)	2.59 (0.50)	3.33 (0.66)
Pit	*Tube*	1.47 (0.19)	2.25 (0.31)	3.03 (0.41)	3.99 (0.54)
Rip	*Mat*	1.69 (0.15)	2.49 (0.24)	3.27 (0.32)	4.35 (0.42)
Rip	*None*	1.53 (0.16)	2.26 (0.26)	2.95 (0.35)	3.93 (0.46)
Rip	*Tube*	1.56 (0.17)	2.20 (0.28)	2.75 (0.37)	3.55 (0.49)
Planting Stock	***Planting Aid***	*p=0.9486*	*p=0.9710*	*p=9328*	*p=0.9147*
Mat	*Bare root*	1.62 (0.15)	2.41 (0.02)	3.19 (0.31)	4.16 (0.41)
Mat	*Direct seed*	0.86 (0.21)	1.49 (0.01)	2.12 (0.45)	2.96 (0.58)
Mat	*Gallon*	2.36 (0.13)	3.25 (0.03)	4.09 (0.27)	5.18 (0.36)
Mat	*Tubeling*	2.02 (0.13)	2.86 (0.03)	3.61 (0.27)	4.60 (0.36)
None	*Bare root*	1.53 (0.15)	2.17 (0.02)	2.77 (0.32)	3.60 (0.42)
None	*Direct seed*	0.52 (0.25)	0.85 (0.01)	1.12 (0.55)	1.60 (0.72)
None	*Gallon*	2.20 (0.13)	3.02 (0.03)	3.81 (0.27)	4.83 (0.36)
None	*Tubeling*	1.83 (0.13)	2.67 (0.03)	3.44 (0.27)	4.40 (0.36)
Tube	*Bare root*	1.53 (0.14)	2.11 (0.02)	2.74 (0.29)	3.61 (0.38)
Tube	*Direct seed*	0.51 (0.25)	0.93 (0.01)	1.28 (0.54)	1.87 (0.70)
Tube	*Gallon*	2.36 (0.13)	3.17 (0.03)	3.99 (0.27)	5.12 (0.36)
Tube	*Tubeling*	1.81 (0.13)	2.58 (0.03)	3.32 (0.27)	4.29 (0.36)

Table 3-8. American sycamore average (SE) groundline diameter on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		**Average Groundline Diameter (cm)**			
		Year 1	**Year 2**	**Year 3**	**Year 4**
Site Preparation	***Planting Stock***	*p=0.9474*	*p=0.9969*	*p=0.9954*	*p=0.9964*
Bed	*Bare Root*	1.94 (0.26)	2.79 (0.42)	3.68 (0.57)	4.49 (0.73)
Bed	*Direct Seed*	0.72 (0.33)	1.12 (0.51)	1.76 (0.70)	2.36 (0.90)
Bed	*Tubeling*	3.55 (0.24)	4.62 (0.37)	5.65 (0.50)	6.80 (0.65)
Bed	*Gallon*	2.75 (0.24)	3.62 (0.37)	4.91 (0.50)	6.03 (0.65)
Disk	*Bare Root*	1.79 (0.24)	2.37 (0.37)	3.00 (0.50)	3.49 (0.65)
Disk	*Direct Seed*	0.24 (0.53)	0.38 (1.05)	0.78 (2.09)	1.49 (2.70)
Disk	*Gallon*	3.10 (0.24)	3.98 (0.37)	4.92 (0.50)	5.96 (0.65)
Disk	*Tubeling*	2.18 (0.24)	2.98 (0.37)	3.82 (0.50)	4.57 (0.65)
Mound	*Bare Root*	2.79 (0.27)	4.00 (0.42)	5.32 (0.57)	6.59 (0.73)
Mound	*Direct Seed*	1.06 (0.39)	1.83 (0.65)	2.62 (0.89)	3.14 (1.14)
Mound	*Gallon*	4.34 (0.24)	5.95 (0.37)	7.60 (0.50)	9.52 (0.65)
Mound	*Tubeling*	3.34 (0.24)	4.60 (0.37)	5.93 (0.50)	7.63 (0.65)
Pit	*Bare Root*	1.29 (0.35)	1.90 (0.54)	2.69 (0.74)	3.06 (0.96)
Pit	*Direct Seed*	0.70 (0.68)	1.10 (1.06)	1.94 (1.45)	2.17 (1.86)
Pit	*Gallon*	3.01 (0.24)	3.65 (0.37)	4.85 (0.50)	5.66 (0.65)
Pit	*Tubeling*	1.85 (0.24)	2.49 (0.37)	3.39 (0.50)	4.12 (0.65)
Rip	*Bare Root*	1.84 (0.26)	2.61 (0.40)	3.57 (0.54)	4.47 (0.70)
Rip	*Direct Seed*	1.00 (0.37)	1.49 (0.57)	2.30 (0.87)	2.92 (1.12)
Rip	*Gallon*	3.30 (0.24)	4.40 (0.37)	5.78 (0.50)	7.16 (0.65)
Rip	*Tubeling*	2.66 (0.24)	3.57 (0.37)	4.87 (0.50)	6.09 (0.65)

Table 3-8 (continued). American sycamore average (SE) groundline diameter on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		Average Groundline Diameter (cm)			
		Year 1	Year 2	Year 3	Year 4
Site Preparation	***Planting Aid***	*p=0.6400*	*p=0.6227*	*p=0.9123*	*p=0.8320*
Bed	*Mat*	2.77 (0.22)	3.83 (0.34)	4.89 (0.47)	6.04 (0.60)
Bed	*None*	2.07 (0.24)	2.69 (0.37)	3.62 (0.51)	4.27 (0.65)
Bed	*Tube*	1.87 (0.23)	2.60 (0.36)	3.49 (0.50)	4.44 (0.64)
Disk	*Mat*	2.01 (0.26)	2.56 (0.41)	3.27 (0.62)	3.86 (0.80)
Disk	*None*	1.84 (0.26)	2.49 (0.49)	3.30 (0.77)	4.23 (0.99)
Disk	*Tube*	1.64 (0.26)	2.23 (0.41)	2.83 (0.77)	3.54 (0.99)
Mound	*Mat*	3.20 (0.24)	4.56 (0.37)	5.89 (0.51)	7.18 (0.65)
Mound	*None*	3.17 (0.23)	4.34 (0.38)	5.55 (0.53)	6.83 (0.68)
Mound	*Tube*	2.28 (0.25)	3.38 (0.39)	4.66 (0.54)	6.15 (0.70)
Pit	*Mat*	1.83 (0.29)	2.53 (0.45)	3.47 (0.62)	4.00 (0.79)
Pit	*None*	1.78 (0.34)	2.00 (0.53)	3.07 (0.74)	3.43 (0.95)
Pit	*Tube*	1.53 (0.28)	2.32 (0.43)	3.11 (0.59)	3.83 (0.76)
Rip	*Mat*	2.49 (0.22)	3.35 (0.34)	4.49 (0.46)	5.55 (0.59)
Rip	*None*	2.19 (0.24)	3.07 (0.37)	4.32 (0.56)	5.41 (0.72)
Rip	*Tube*	1.92 (0.25)	2.64 (0.39)	3.58 (0.54)	4.52 (0.69)
Planting Stock	***Planting Aid***	*p=0.8170*	*p=0.8605*	*p=0.9540*	*p=0.9474*
Mat	*Bare root*	2.11 (0.21)	2.97 (0.33)	4.01 (0.45)	4.78 (0.58)
Mat	*Direct seed*	1.07 (0.30)	1.66 (0.47)	2.34 (0.66)	2.98 (0.85)
Mat	*Gallon*	3.71 (0.18)	4.90 (0.29)	6.14 (0.39)	7.39 (0.50)
Mat	*Tubeling*	2.95 (0.18)	3.93 (0.29)	5.11 (0.39)	6.16 (0.50)
None	*Bare root*	2.17 (0.22)	2.93 (0.34)	3.84 (0.47)	4.68 (0.61)
None	*Direct seed*	0.62 (0.37)	1.02 (0.69)	1.95 (1.06)	2.44 (1.37)
None	*Gallon*	3.43 (0.18)	4.25 (0.29)	5.49 (0.39)	6.61 (0.50)
None	*Tubeling*	2.61 (0.18)	3.47 (0.29)	4.60 (0.39)	5.62 (0.50)
Tube	*Bare root*	1.51 (0.20)	2.31 (0.32)	3.11 (0.43)	3.80 (0.56)
Tube	*Direct seed*	0.54 (0.36)	0.88 (0.57)	1.34 (0.94)	1.84 (1.22)
Tube	*Gallon*	3.24 (0.18)	4.40 (0.29)	5.65 (0.39)	7.05 (0.50)
Tube	*Tubeling*	2.11 (0.18)	2.95 (0.29)	4.03 (0.39)	5.30 (0.50)

Table 3-9. American sycamore average (SE) dbh on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		**Average dbh (cm)**			
		Year 1	**Year 2**	**Year 3**	**Year 4**
Site Preparation	***Planting Stock***	*p=0.9630*	*p=0.9924*	*p=0.9982*	*p=0.9991*
Bed	*Bare Root*	0.54 (0.17)	1.10 (0.32)	1.83 (0.39)	2.50 (0.49)
Bed	*Direct Seed*	0.01 (0.21)	0.21 (0.39)	0.49 (0.48)	1.01 (0.60)
Bed	*Tubeling*	1.23 (0.15)	2.13 (0.28)	2.82 (0.35)	3.68 (0.43)
Bed	*Gallon*	0.90 (0.15)	1.71 (0.28)	2.46 (0.35)	3.27 (0.43)
Disk	*Bare Root*	0.48 (0.15)	1.02 (0.28)	1.41 (0.35)	1.90 (0.43)
Disk	*Direct Seed*	0.04 (0.62)	0.03 (1.16)	0.00 (1.44)	0.20 (1.80)
Disk	*Gallon*	1.05 (0.15)	1.83 (0.28)	2.47 (0.35)	3.24 (0.43)
Disk	*Tubeling*	0.67 (0.15)	1.35 (0.28)	1.86 (0.35)	2.48 (0.43)
Mound	*Bare Root*	1.10 (0.17)	2.13 (0.32)	3.00 (0.39)	4.00 (0.49)
Mound	*Direct Seed*	0.09 (0.26)	0.54 (0.49)	1.10 (0.61)	1.72 (0.76)
Mound	*Gallon*	1.63 (0.15)	3.01 (0.28)	4.05 (0.35)	5.36 (0.43)
Mound	*Tubeling*	1.30 (0.15)	2.65 (0.28)	3.15 (0.35)	4.36 (0.43)
Pit	*Bare Root*	0.29 (0.22)	0.87 (0.41)	1.30 (0.51)	1.68 (0.64)
Pit	*Direct Seed*	0.02 (0.43)	0.43 (0.80)	0.77 (1.00)	1.30 (1.25)
Pit	*Gallon*	1.04 (0.15)	1.97 (0.28)	2.59 (0.35)	3.41 (0.43)
Pit	*Tubeling*	0.50 (0.15)	1.18 (0.28)	1.80 (0.35)	2.58 (0.43)
Rip	*Bare Root*	0.59 (0.16)	1.22 (0.30)	1.89 (0.37)	2.66 (0.47)
Rip	*Direct Seed*	0.27 (0.26)	0.62 (0.48)	0.97 (0.60)	1.38 (0.75)
Rip	*Gallon*	1.15 (0.15)	2.14 (0.28)	2.91 (0.35)	3.95 (0.43)
Rip	*Tubeling*	0.90 (0.15)	1.76 (0.28)	2.52 (0.35)	3.45 (0.43)

Table 3-9 (continued). American sycamore average (SE) dbh on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		**Average dbh (cm)**			
		Year 1	**Year 2**	**Year 3**	**Year 4**
Site Preparation	***Planting Aid***	*p=0.7763*	*p=0.8171*	*p=0.8751*	*p=0.9063*
Bed	*Mat*	0.76 (0.14)	1.54 (0.26)	2.38 (0.32)	3.22 (0.40)
Bed	*None*	0.54 (0.15)	1.04 (0.28)	1.53 (0.35)	2.15 (0.44)
Bed	*Tube*	0.69 (0.15)	1.28 (0.28)	1.79 (0.34)	2.47 (0.43)
Disk	*Mat*	0.54 (0.18)	1.05 (0.34)	1.39 (0.43)	1.94 (0.53)
Disk	*None*	0.57 (0.23)	1.05 (0.43)	1.46 (0.53)	2.00 (0.66)
Disk	*Tube*	0.57 (0.23)	1.06 (0.43)	1.45 (0.53)	1.92 (0.66)
Mound	*Mat*	1.10 (0.15)	2.49 (0.28)	3.14 (0.35)	4.22 (0.44)
Mound	*None*	1.18 (0.16)	2.12 (0.29)	2.92 (0.36)	3.86 (0.45)
Mound	*Tube*	0.80 (0.16)	1.63 (0.30)	2.42 (0.37)	3.51 (0.47)
Pit	*Mat*	0.56 (0.18)	1.16 (0.34)	1.74 (0.42)	2.31 (0.53)
Pit	*None*	0.37 (0.22)	1.08 (0.41)	1.53 (0.51)	2.11 (0.63)
Pit	*Tube*	0.43 (0.18)	1.09 (0.33)	1.58 (0.41)	2.31 (0.51)
Rip	*Mat*	0.74 (0.14)	1.48 (0.26)	2.16 (0.32)	3.08 (0.40)
Rip	*None*	0.71 (0.16)	1.51 (0.31)	2.20 (0.38)	3.01 (0.48)
Rip	*Tube*	0.73 (0.16)	1.31 (0.30)	1.85 (0.37)	2.50 (0.46)
Planting Stock	***Planting Aid***	*p=0.6652*	*p=0.7641*	*p=0.9528*	*p=0.9167*
Mat	*Bare root*	0.58 (0.13)	1.30 (0.25)	2.07 (0.31)	2.82 (0.39)
Mat	*Direct seed*	0.11 (0.20)	0.49 (0.37)	0.90 (0.46)	1.48 (0.57)
Mat	*Gallon*	1.25 (0.12)	2.31 (0.22)	3.06 (0.27)	4.04 (0.34)
Mat	*Tubeling*	1.01 (0.12)	2.08 (0.22)	2.61 (0.27)	3.47 (0.34)
None	*Bare root*	0.69 (0.14)	1.38 (0.26)	1.94 (0.32)	2.59 (0.40)
None	*Direct seed*	0.11 (0.31)	0.42 (0.59)	0.66 (0.73)	1.07 (0.91)
None	*Gallon*	1.10 (0.12)	2.02 (0.22)	2.78 (0.27)	3.63 (0.34)
None	*Tubeling*	0.80 (0.12)	1.63 (0.22)	2.33 (0.27)	3.21 (0.34)
Tube	*Bare root*	0.53 (0.13)	1.11 (0.24)	1.65 (0.30)	2.23 (0.37)
Tube	*Direct seed*	0.01 (0.28)	0.18 (0.52)	0.44 (0.65)	0.81 (0.81)
Tube	*Gallon*	1.30 (0.12)	2.31 (0.22)	3.06 (0.27)	4.12 (0.34)
Tube	*Tubeling*	0.74 (0.12)	1.49 (0.22)	2.12 (0.27)	3.01 (0.34)

Table 3-10. American sycamore average (SE) dry weight biomass and ANPPwood on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

Treatment Interaction		**Average Biomass (Mg/ha)**		**ANPPwood (Mg/ha/yr)**
		Year 3	**Year 4**	
Site Preparation	***Planting Stock***	*p=0.7507*	*p=0.5687*	*p=0.4015*
Bed	*Bare Root*	0.52 (0.53)	1.14 (1.07)	0.61 (0.57)
Bed	*Direct Seed*	0.07 (0.58)	0.20 (1.17)	0.13 (0.62)
Bed	*Tubeling*	2.88 (0.51)	5.69 (1.04)	2.81 (0.55)
Bed	*Gallon*	1.69 (0.51)	3.60 (1.04)	1.90 (0.55)
Disk	*Bare Root*	0.46 (0.51)	0.93 (1.04)	0.47 (0.55)
Disk	*Direct Seed*	0.02 (0.55)	0.05 (1.12)	0.03 (0.59)
Disk	*Gallon*	2.12 (0.51)	4.17 (1.04)	2.05 (0.55)
Disk	*Tubeling*	0.96 (0.51)	2.01 (1.04)	1.04 (0.55)
Mound	*Bare Root*	1.12 (0.51)	2.75 (1.04)	1.64 (0.55)
Mound	*Direct Seed*	0.07 (0.51)	0.16 (1.04)	0.09 (0.55)
Mound	*Gallon*	4.50 (0.51)	9.93 (1.04)	5.44 (0.55)
Mound	*Tubeling*	2.34 (0.51)	5.63 (1.04)	3.30 (0.55)
Pit	*Bare Root*	0.10 (0.51)	0.24 (1.04)	0.13 (0.55)
Pit	*Direct Seed*	0.01 (0.51)	0.02 (1.04)	0.02 (0.55)
Pit	*Gallon*	2.22 (0.51)	4.68 (1.04)	2.46 (0.55)
Pit	*Tubeling*	1.05 (0.51)	2.94 (1.04)	1.89 (0.55)
Rip	*Bare Root*	0.56 (0.51)	1.31 (1.04)	0.75 (0.55)
Rip	*Direct Seed*	0.14 (0.59)	0.24 (1.19)	0.10 (0.63)
Rip	*Gallon*	2.46 (0.51)	5.63 (1.04)	3.17 (0.55)
Rip	*Tubeling*	1.96 (0.51)	4.34 (1.04)	2.38 (0.55)

Table 3-10 (continued). American sycamore average (SE) dry weight biomass and ANPPwood on the Virginia Piedmont for treatment combinations. Averages with within a column followed by different letters are significantly different.

		Average Biomass (Mg/ha)		ANPPwood (Mg/ha/yr)
Treatment Interaction		**Year 3**	**Year 4**	
Site Preparation	***Planting Aid***	*p=0.8811*	*p=0.9037*	*p=0.8695*
Bed	*Mat*	1.77 (0.47)	3.75 (0.96)	1.97 (0.50)
Bed	*None*	0.82 (0.44)	1.60 (0.90)	0.78 (0.47)
Bed	*Tube*	1.28 (0.47)	2.62 (0.95)	1.34 (0.50)
Disk	*Mat*	0.68 (0.46)	1.30 (0.92)	0.62 (0.49)
Disk	*None*	0.98 (0.44)	1.96 (0.90)	0.98 (0.47)
Disk	*Tube*	0.98 (0.46)	2.04 (0.92)	1.05 (0.49)
Mound	*Mat*	2.46 (0.44)	5.14 (0.90)	2.68 (0.47)
Mound	*None*	1.75 (0.44)	3.95 (0.90)	2.20 (0.47)
Mound	*Tube*	1.81 (0.44)	4.77 (0.90)	2.96 (0.47)
Pit	*Mat*	1.09 (0.44)	2.52 (0.90)	1.42 (0.47)
Pit	*None*	0.57 (0.44)	1.24 (0.90)	0.68 (0.47)
Pit	*Tube*	0.87 (0.44)	2.15 (0.90)	1.27 (0.47)
Rip	*Mat*	1.08 (0.44)	2.54 (0.90)	1.46 (0.47)
Rip	*None*	1.21 (0.44)	2.79 (0.90)	1.57 (0.47)
Rip	*Tube*	1.55 (0.49)	3.31 (1.00)	1.77 (0.53)
Planting Stock	***Planting Aid***	*p=0.7911*	*p=0.8352*	*p=0.8668*
Mat	*Bare root*	0.59 (0.40)	1.37 (0.80)	0.78 (0.42)
Mat	*Direct seed*	0.07 (0.43)	0.21 (0.86)	0.14 (0.46)
Mat	*Gallon*	3.07 (0.40)	6.29 (0.80)	3.22 (0.42)
Mat	*Tubeling*	1.93 (0.40)	4.32 (0.80)	2.39 (0.42)
None	*Bare root*	0.51 (0.40)	1.08 (0.80)	0.57 (0.42)
None	*Direct seed*	0.04 (0.40)	0.07 (0.80)	0.03 (0.42)
None	*Gallon*	2.22 (0.40)	4.79 (0.80)	2.58 (0.42)
None	*Tubeling*	1.49 (0.40)	3.29 (0.80)	1.80 (0.42)
Tube	*Bare root*	0.55 (0.41)	1.37 (0.82)	0.82 (0.43)
Tube	*Direct seed*	0.05 (0.45)	0.07 (0.91)	0.02 (0.48)
Tube	*Gallon*	3.21 (0.40)	6.97 (0.80)	3.76 (0.42)
Tube	*Tubeling*	1.37 (0.40)	3.50 (0.80)	2.12 (0.42)

4.0 FOUR-YEAR EFFECTS OF MECHANICAL SITE PREPARATION, PLANTING STOCK, AND PLANTING AIDS ON THE SURVIVAL AND GROWTH OF WILLOW OAK (*Quercus phellos* L.) FOR OLD FIELD RIPARIAN RESTORATION, PIEDMONT, USA

4.1 Abstract

Due to their timber and wildlife value, oak species are desired for bottomland hardwood restoration. However, establishment efforts for oak species on old field restoration sites have varied in success. Survival and growth of planted oaks are typically critical indices used to evaluate success of wetland restoration efforts. In order to evaluate techniques that could potentially enhance oak survival and growth, this study was implemented to evaluate five mechanical site preparation techniques (mound, bed, rip, disk, pit), four types of planting stock (gallon, tubeling, bare root, and direct seed), and three planting aids (mat, tube, none) on survival and growth of willow oak (*Quercus phellos* L.) planted on an old field riparian area in the Piedmont of Virginia. Mounding mechanical site preparation techniques had over 25% greater survival, 75% greater tree height, and over 20% greater groundline diameter compared to disking, ripping and bedding. Bare root and gallon planting stock survival rates exceeded 80% with gallon or bare root planting stock and growth indices outpaced direct seed and tubeling stock by 75%. These treatments may increase the economic incentives wetland restoration and mitigation efforts and may make restoration efforts in marginal old field areas more attractive to landowners.

4.2 Introduction

An estimated 50% of wetlands in the United States have been converted to non-wetlands since the late 1600's (Davidson, 2014). The 1972 Clean Water Act led to regulatory agency mandates to reduce or eliminate the loss of wetlands, and the 2008 Compensatory Mitigation Rule addressed the preferred sources of compensatory mitigation credits (Hough and Harrington, 2019). Wetland mitigation is an important component of restoring wetland ecosystem services, as wetlands represent a fraction of the land surface, and the long-term loss of wetlands ranges from 54% to 90% worldwide (Reis et al., 2017). However, compensatory wetland mitigation site design and implementation are often less successful in replacing the functions and values of permanently impacted wetlands. Reasons for failure of compensatory wetland mitigation projects include high soil wetness and mortality of planted wetland tree species (Matthews and Endress, 2008; Zedler and Callaway, 1999). A greater emphasis has been placed on the success of planted woody species in compensatory mitigation sites, as reforestation is typically a limiting factor for the shorter term regulatory site success for wetland credit availability and may affect the longer term ecological success. Unfortunately, there has been a lack of technology transfer between the practitioners of wetland restoration and forestry silviculturists. Commercial forestry operations have been successful in harvesting and planting hundreds of thousands of wetland areas, such as wet mineral flats and bottomland hardwood areas of the southeastern United States (Aust et al., 2019). The use of commercial forestry silvicultural techniques, including mechanical site preparation, selection of planting stock, and use of planting aids are gaining momentum and support from the regulatory bodies overseeing the wetland mitigation implementation programs. At present, these techniques are not widely used by wetland design and construction groups within the current compensatory mitigation market (McLaughlin et al., 2000; Sun et al., 2001).

Oak species (*Quercus spp*.) often have higher wildlife and timber value than wind dispersed early successional species typically planted in riparian buffers and wetlands, such as American sycamore (*Platanus occidentalis* L.). Bottomland oak species, such as willow oak (*Q. phellos* L.) are commonly planted for compensatory reasons on marginal Piedmont sites. Marginal sites, which are poorly suited for agricultural cropping operations in most years, are often subject to agricultural equipment limitations, groundwater drawdown, site-reflooding, and competition from perennial herbaceous species. Bottomland oak species have adapted to hydroperiod fluctuation by reducing initial aboveground growth increasing below ground biomass and carbohydrate storage (Dey et al., 2008). Oak species also have adaptive physiological characteristics that increase survival during drought conditions by decreasing evaporative water loss. Leaf and stem adaptations, including differential stomatal response under dry soil conditions, increased root to shoot ratio, and low above ground growth during peak photosynthetic conditions have been observed among bottomland oak species (Abrams, 1996; Dey et al., 2008).

Plantation silvicultural techniques may create a supportive environment that allows for oak species to become established and more readily accrue biomass in an environment that would otherwise only support rapidly growing perennial herbaceous species. Old field compensatory mitigation sites are typically dominated by perennial herbaceous species that limit colonization by woody species, resulting in herbaceous autogenic dominance (DeBerry and Perry, 2012; Noon, 1996). Oak species planted in conjunction with pioneer woody species, including *P. occidentalis*, decrease herbaceous competition and increase middle and late successional woody species density and survival (DeBerry and Perry, 2012; Dey et al., 2010).

Landowners that engage in creation of compensatory wetland sites or marginal land conversion are often also interested in also increasing certain wildlife usage of the property. Mature oak stands are prime habitat for a wide variety of game animals and songbirds, and complement the long term management objectives of both the regulatory programs and the landowner (Millspaugh et al., 2009). Acorns provide a major winter food source in hardwood forests, particularly for large mammals favored by humans, including white tail deer (*Odocoileus virginianus*) and black bear (*Ursus americanus*). Oak have become the primary overstory hard mast producing species in eastern United States forests following the decline of American chestnut (*Castanea dentata* Marshall) from chestnut blight (*Cryphonectria parasitica*) (McShea et al., 2007). Establishing oak as a dominant stand species can also increase value of merchantable timber within the restored area; however, marginal sites typically require site preparation to decrease the impacts of adverse site conditions and may require more advanced planting methods to ensure survival (Stanturf et al. 2004).

4.2.1 Mechanical Site Preparation

Mechanical site preparation typically requires the use of heavy equipment to manipulate site soils to optimize site conditions for the establishment of woody species (Aust et al., 2019). Site preparation in wetlands is potentially beneficial, as many created forested wetlands fail due to incorrect hydroperiods and soil compaction (Morris and Lowery, 1988). Commercial forestry operations have used mechanical site preparation for decades to prepare harvested sites and to ameliorate the impacts of timber harvesting on hydric soils (Aust and Blinn, 2004; Löf et al., 2012; McLaughlin et al., 2000). Reduction of soil compaction and creation of site microtopography are primary benefits of mechanical site preparation in forested wetlands (Bruland and Richardson, 2005). The method of site preparation varies depending upon the location, site conditions, and available machinery. Primary mechanical site preparation methods include mounding, bedding, and disking (Allen et al., 2001; Bruland and Richardson, 2005; Löf et al., 2012; Londo and Mroz, 2001; Miwa et al., 2004).

Mounding is a mechanical site preparation method that can work well in bottomland hardwood sites that are generally comprised of poorly drained soils and high groundwater levels (Conner, 1994; Kolka et al., 2000). Mounding is generally accompanied by adjacent pits, creating a microtopographic gradient that allows for seedling establishment in high water table areas and increased habitat diversity in pit areas (Collins and Battaglia, 2008; Ott et al., 2020). Mounds are integral for sites that are planted with late-successional species, such as oak (Kabrick et al., 2005; Löf et al., 2012; Londo and Mroz, 2001), although the long-term impacts of pit and mounding in oak afforestation are not well documented.

Pit and mound site preparation techniques have been used in compensatory wetland mitigation sites to approximate the microtopography of naturally occurring wetlands. This technique requires excavation of pits and placement of the material directly adjacent to create a mound. These mounds are similar to those produced naturally from large tree blowdowns, which often occur after heavy rains and wind storms, and artificial creation of these landforms vary in size based upon land management goals (Löf et al., 2012; Londo and Mroz, 2001). Pits and mounds incorporate soil organic matter, decrease compaction, expose mineral soil and decrease or increase depth of the water table, which allows for simultaneous establishment of hydrophytic and upland species. Seedling survival has been shown to be greater in mound topography, due in large part to the reduction of wet soil conditions. The use of pit and mound site preparation may be more advantageous in compensatory mitigation sites, where a wider range of flood tolerant species establishment is desired, and where soil saturation may be less predictable. Similarly, pit and mound site preparation techniques may be preferable on marginal sites that have saturated soil conditions that have high competition from perennial herbaceous species.

Bedding creates a linear and uniform raised area that incorporates site organic matter and increases soil volume on wet sites (Miwa et al., 2004). This method is widely used on commercial pine plantations in the southeast for seedling establishment (Jones et al., 2010; Self et al., 2012) and has been successfully transferred to southeastern bottomland species such as Nuttall oak (*Q. texana* Buckley) and sweetgum (*Liquidambar styraciflua* L.). The long-term effect of bedding on site productivity is limited as mature trees often outgrow the prepared bedding area (Eisenbies et al., 2005; Miwa et al., 2004). Bedding is best implemented on sites with high water tables and moderate available organic matter (Carter et al., 2006; Löf et al., 2012).

Disking involves the direct mechanical manipulation of surface soils by breaking though large clods and soil clumps (Moser et al., 2009). Disking does not impact depth to groundwater, and may have limited utility in areas with high water table or large fluctuations in hydrology (Löf et al., 2012; Morris and Lowery, 1988). Tree species diversity can increase in areas that were disked prior to planting due to reduction in herbaceous competition, and impact of high groundwater levels may be reduced in disked wetland areas (Ahn and Dee, 2011; Kabrick et al., 2005; Moser et al., 2009; Rathfon et al., 1995; Self et al., 2012).

Ripping, or subsoiling, improves site conditions by increasing root depth by fracturing the traffic pan and increasing aeration. The fractured traffic pan also increases infiltration capacity, and soil water availability to seedlings (Duplissis et al., 2000; Löf et al., 2012). Ripping has similar application method as disking, except it utilizes a chisel plow or ripping shank to rip soil at a depth up to 0.5 m below ground surface. Ripping and disking are commonly used in forest restoration sites due to the low relative cost in proportion to the increase in seedling survival and growth (Espelta et al., 2003).

Previous research suggests that mechanical site preparation may increase seedling resilience to unpredictable hydrologic cycles, increase the biodiversity of restoration areas, decrease competition, and decrease overall restoration cost per acre. However, there are many adverse site conditions that require additional measures, including planting of more mature planting stock, to meet land management goals. Planting of seedlings or broadcast of seed is typically the next phase of the mitigation plan for old field marginal area restoration (Stanturf et al. 2004).

4.2.2 Planting Stock

The type of planting stock can be an important factor in success of mitigation sites that utilize marginal old field areas. Traditional commercial forestry operations use a variety of planting stock optimized for the specific site conditions. These options typically include direct seeding, bare root seedlings, tubelings, and containerized seedlings (Self et al., 2010; Stanturf et al., 2014). Each of the planting techniques have associated cost/benefits, and a combination of these techniques can be used during the construction and planting of wetland sites to address soil/hydrologic gradients (Gardiner et al., 2004). Most mitigation site planting plans use the most economical planting stock due to the anticipated need to re-plant to meet regulatory planting density requirements. Planting stock is selected based on the immediate economics of purchasing the planting stock, and very often ignores the cost to replant or plant different stock of plant survival densities are not achieved at the site (Gardiner et al., 2000; Kruse and Groninger, 2003). Oak species are predominantly planted as bare root seedlings on compensatory mitigation sites and wildlife plots. Bare root seedlings, most often germinated in nursery and greenhouse conditions because they are typically the most cost effective (Dey et al., 2008). Larger planting stock, such as containerized seedlings, are employed when site conditions are unfavorable, due to soil compaction, flooding, or other environmental controls (Stanturf et al. 2004).

Direct seeding, which simply involves collection, storage, and dissemination of seed has a less restrictive planting window and low overall cost in comparison to other popular planting methods. However, direct seeding success may require more intensive mechanical site preparation and is susceptible to rodent damage (Allen, 1997; Bullard et al., 1992). Acorns are a highly utilized wildlife food source, limiting the establishment of oak seedlings from seed, potentially making direct seeding less economical from a site success, labor and site management perspective. Oak direct seeding historically is most successful when natural oak stands are near the planting area (Nuttle and Haefner, 2005; Stanturf et al., 2014). Other factors to consider regarding direct seeding include obtaining the seed, particularly in years having poor acorn production, and acorn size as oak species with larger acorns have been reported to be more successful than oak species having smaller acorns (Dey et al., 2008).

Bare root seedlings, which are grown in nurseries and lifted without intact soil, are a planting stock that is often employed on sites that have been mechanically prepared by bedding, pits and mounds, or other means. Survival rates are higher among oak bare root seedlings than direct seeding (Williams and Craft, 1998). Planting is generally limited to geographically specific planting periods and are susceptible to changes in hydrology (Self et al., 2010). Bare root seedlings are the most common planting stock for oak regeneration on marginal sites, particularly in areas that have frequent inundation (Stanturf et al., 1998).

Containerized seedlings, most commonly tubelings and gallon or No. 1 potted stock, are utilized in wetland areas where surface inundation is likely to lower the likelihood of planting success in comparison to direct seed and bare root seedlings (Stanturf et al., 2014). Containerized planting stock costs are generally higher than other seedling types, and containerized seedlings are susceptible to inundation and temperature stress during transport. Survival is typically greater with containerized seedlings when directly compared to other planting types, potentially making these stock types a more economical option for planting on marginal sites with poor soil/hydrologic conditions (Self et al., 2010; Williams and Craft, 1998).

Previous research suggests that, in addition to manipulating the planting stock size to the site conditions, planting aids may increase the survival and growth of planted stock. Area restoration area managers deploy planting aids after seedlings have been planted but before herbaceous vegetation has increased vegetative competition or use mechanical and chemical controls in conjunction with planting aids for the first growing season (Allen et al., 2001).

4.2.3 Planting Aids

Planting aids are devices used in combination with planting to promote survival of seedlings by limiting competition with early successional herbaceous and woody species. Common planting aides include tree tubes and planting mats. Planting aids may reduce requirements for herbicides, which are often restricted or strictly controlled in wetlands, and the mechanical damage associated with trimmers and mowers (Allen, 1997; Bradburn et al., 2010). Mechanical and chemical control of herbaceous competition are common for mitigation and bioenergy sites and are often required for multiple years until planted seedlings have become established. Planting tubes have been shown to effectively prevent tree girdling and browsing by herbivores (Correll, 2005), and mats can effective in controlling herbaceous competition, and are typically installed after significant earth moving activities (Zedler, 2000). However, the effects of matting are limited when installed in upland buffer areas where competition from perennial herbaceous species is strong (Bruland and Richardson, 2005).

4.3 Study Objectives

The existing information from compensatory wetland restoration efforts, combined with silvicultural techniques commonly used to establish commercial plantation forests, indicate that mechanical site preparation, type of planting sock, and use of planting aids may be beneficial to survival and growth of woody species planted in marginal old field settings. However, such information is typically lacking or restricted to only the first year of survival. Regeneration of oak species in restoration areas are of particular concern, as there are well documented issues with regeneration, including intolerance to drought, slow growth rate and seedling transplant stress (Dey et al., 2008). The goal of this study was to evaluate the effects and interactions of five traditional silvicultural mechanical site preparations, four common planting stock types, and three planting aids on the survival and growth of willow oak in Piedmont old field riparian areas that are suitable for mitigation and afforestation.

4.4 Methods

4.4.1 Study Site Description

Field research was conducted at the R.J. Reynolds Homestead Forest Resources Research Center, which is located in the Piedmont physiographic province near Critz, Virginia (Figure 2-1). The area is dominated by former agricultural fields historically used for tobacco cultivation in the uplands and corn and pasture in the bottomlands. The study site is in the riparian area of a first order perennial unnamed tributary to Mill Creek with a 197-hectare watershed. The watershed is predominantly mixed upland hardwoods and pine, with interspersed managed pine plantations. Common riparian species include yellow poplar (*Lirodendron tulipifera* L.), American boxelder (*Acer negundo* L.), and red maple (*A. rubrum* L.). The primary dominant soil series are French soils, taxonomically classified as fine-loamy over sandy or sandy-skeletal, mixed, active mesic Fluvaquentic Dystrudepts on 0 to 3 percent slopes. The second soil series is the Braddock series, taxonomically classified as fine, mixed, semiactive mesic Typic Hapludults on 2 to 8 percent slopes. Soils are moderately to moderately well drained with colluvium and alluvium parent material. Legacy sediment comprised the upper soil layers resulting in buried mineral soil horizons observed throughout the site. Site soils exhibited field hydric soil indicators consistent with wetland soil diagnostic criteria (U.S. Army Corps of Engineers, 1987). Yearly temperatures range from 19.4°C to 7.2°C, with an average annual rainfall of 1,380 mm and 290 mm of snowfall for a total average annual precipitation of 1,670 mm. Although there were no monitored hydroperiod data, the on-site manager reported that the site floods to a depth of approximately 2530 cm foot once or twice during most normal years and this corresponds to our observations of primary and secondary hydrology indicators (U.S. Army Corps of Engineers, 1987).

4.4.2 Study Layout

Five treatment blocks (replications) were established within the old field riparian area for evaluation of willow oak survival and growth within a marginal agricultural area. Blocks were 25.6 x 29.3 m (0.075 ha) in size and were established using staff compass and surveyor tape (Figure 4-2). Corners were marked with rebar and surveyed with a total station. Each site preparation area measured 7.3 m in width, with each block having a width of 29.3 m. Five mechanical site preparations were established within each of the five blocks: disking, ripping, bedding, pit, and mound. Pit and mound were applied together with the pits situated directly adjacent to the mound. Mounds and pits were created using a farm tractor equipped with a backhoe. Mound heights and pit depths were approximately 90 cm deep. Pits and mounds were approximately 0.5 m wide. Beds were created using a John Deere 450 bulldozer with a six-way articulated blade to create linear beds of approximately 50 cm height. Ripping was conducted to a depth of approximately 60 cm with a ripping skank installed on a John Deere 450 Bulldozer. Disking was conducted with a farm tractor and gang disks. The factorial combination of four planting stock types: direct seed, bare root, tubeling, gallon, and three planting aids: control, tube, mat, were installed within the mechanical site preparation plots. Four stock types were planted within each of the 12 combinations of seedling type and planting aid (Figure 4-3). The layout allowed for 1,200 trees with a planned planting density of 3,200 stems/ha. Planting density was considerably higher than typical riparian plantings within compensatory mitigation sites but was used to utilize available space and model multiple resource objectives (timber, wildlife, riparian restoration). Planting of the combination of planting stock and planting aids were installed in factorial combination for a total of 48 stems per block.

Mechanical site preparation was conducted in April 2011 and planting was completed by May 2011. Planting was conducted with shovel or dibble bar depending on stock type and was conducted or supervised by professional foresters familiar with these planting techniques. Glyphosate 4+ (41% glyphosate) (Alligare, LLC, Opelika, Alabama) herbicide was applied once in June of the first growing season and mowing was conducted between June and September of the first growing season. No weed control was conducted after the first year of the study.

4.4.3 Planting Stock

Acorns were sourced from counties located in the Piedmont physiographic provinces of Virginia and were collected by a combination of direct ground collection and tarps placed under dominant trees. Acorns were float tested before planting (Johnson et al., 2013). Bare root 1-0 seedlings were obtained from the Virginia Department of Forestry (Crimora, Virginia) and were transported to the site in March 2011. Both seeds and bare root seedlings were held in refrigeration until planting. Gallon containerized plants and tubelings were obtained from Wetland Studies and Solutions, Inc (Gainesville, Virginia). Tubelings and gallon stock seedlings were stored outside in the open and watered daily until planting.

4.4.4 Planting Aids

Mats were 1 m^2 VisPore mats (Landscape Supply, Inc., Roanoke, Virginia) and were installed with steel landscape staples. Tubes were 1 m Tubex Standard Tree Shelters (Tubex USA, Old Hickory, Tennessee) and were installed using a 1 m wooden support stake. Planting aids were installed in June 2011 after planting and before weed control measures were initiated.

4.4.5 Data collection and analysis

Survival, ground line diameter, diameter at breast height (dbh) and height were collected at the end of each growing season starting in January 2012. Successful germination of seeds or survival of seedlings were visually evaluated during each data collection. Total height (m) were collected using a height pole to the nearest 2.5 cm. Ground line diameter and dbh (mm) for each stem were collected to the nearest 0.1 mm using digital calipers. Due to lack of requisite tree height, dbh was only collected at the end of year 4. A stem volume index as calculated as diameter^2 (cm) * height (cm). The percent survival at year 4 was applied to the year 4 stem volume (cm^3 * % survival) to determine a productivity index for each main effect for year 4.

The experimental design was a split plot within a randomized complete block design (Box and Jones, 1992) to evaluate the treatment and interaction effects on survival and growth. The mechanical site preparation techniques were the whole plots, while the combinations of plant stock type and planting aids provided the split plot treatments. Shortages in planting stock due to tubeling mortality prior to planting, and low availability of the Visipore matting during planting aid installation compromised the original design and resulted in a planted n = 860 and an unbalanced split treatment for both planting stock and planting aids. The unbalanced split treatment did not allow for analysis of all interaction effects within the original split plot model, resulting in the analysis of only the main effects of site preparation, planting stock and planting aid, with an evaluation of the combinations for the most successful main effects. Statistical analyses were conducted using JMP Pro version 14.2.0 (SAS, n.d.). Least square means were generated using the REML analysis, and multiple comparisons among means were calculated using post hoc Tukey's HSD. An alpha level of 0.05 was applied to indicate statistical significance. The assumption that data were normally distributed with constant variance were tested using studentized residuals comparison to predicted values to test for constant variance and normal quantile plots to test for normal data distribution. Data were determined to have constant variance and normal distribution. Only surviving stems were included in diameter, height, and biomass calculations.

4.5 Results

4.5.1 Site Preparation Treatments

Mound (73.3%) and bed (61.7%) survival percentage were significantly greater than all other treatments in year 1 ($p<0.0001$). Survival trends were similar for year 2 and 3 ($p<0.0001$). Mounding (71.7%) was significantly greater from all site treatments by year 4, and no statistical difference was observed between bedding, ripping, or disking ($p<0.0001$). The pit treatment had significantly lower survival than all other treatments across all years (Table 4-1).

Mound effects on tree height were significantly greater than all other site preparation treatments, with an average of more than 30% greater height (2.1 m) than the other treatments by year 4 (Table 3-2). Mounding groundline diameter (2.91 cm by year 4) was significantly greater than all other site preparation treatments across all years, averaging 20% greater groundline diameter in year 1 and increasing to almost 40% greater groundline diameter by year 4 (Table 3-3). Mounding average dbh (1.48 cm) was significantly greater than all other mechanical site preparation methods by year 4 ($p<0.0001$) (Table 3-4). Year 4 mound tree volume (2,376 cm^3) was significantly greater than all other treatments, and no statistically significant differences were observed between rip (1,349 cm^3) and bed treatments (1,305 cm^3)(Table 3-5).

4.5.2 Planting Stock

Gallon had an average survival rate in year 1 of 84.7% and bare root averaged 86%, while tubeling averaged 22.5% ($p<0.0001$). No statistical difference was observed between direct seed (30.2%) and tubeling (22.5%) survival. Survival trends continued across all years (Table 4-1). Gallon and bare root planting stock had greater height than direct seed and tubeling across all years and were on average 75% taller than the combined tubeling and direct seed heights

(Table 3-2). The differences between the planting stocks were similar in average groundline diameter, dbh and volume. In year 4, both gallon (2.73 cm) and bare root (2.81 cm) planting stock had fourfold greater average diameters than tubeling (0.71 cm) and direct seed (0.29 cm) combined (Table 3-3). Gallon (1.38 cm) and bare root (1.60 cm) planting stock dbh were significantly greater than tubeling (0.28 cm) and direct seed (0.09 cm) in year 4 (Table 3-4). Bare root had significantly greater year 4 volume (2,431 cm^3) than all other planting stock combined, and no significant differences were observed between tubeling (429 cm^3) and direct Seed (81 cm^3) tree volumes (Table 3-5).

4.5.3 Planting Aids

Survival percentages for tree tubes (64.1%) were significantly greater than mat (54.3%) and no treatment (49.1%) survival rates (p=0.0017). Survival trends were similar for year 2 and 3, although no significant difference was observed between Tube and Mat or Mat and No treatment. No significant effect on survival was observed by Year 4 (Table 4-1). Tube treatment had significantly higher height at year 1 (0.79 m) and year 2 (0.99 m) than mat and no treatment, but planting aids had no significant effect on average tree height by Year 4 (Table 3-2). Planting aids did not have a significant relationship with average groundline diameter across all years (Table 3-3). A significant relationship was observed in year 4 between planting aids and dbh, but no significant difference was observed between tube and mat or mat and no treatment (Table 3-4). No significant relationships between planting aids and volume were observed in year 4 (Table 3-5).

4.6 Discussion

Marginal site conditions coupled with large changes in soil saturation are often identified as the limiting factors for mitigation site success (Matthews and Endress, 2008). The observed survival and growth results of this study indicated that the proper species selection, application of site preparation techniques along with proper application of species appropriate planting stock for site conditions and use of planting aids in situations where site preparation or planting stock options are limited may increase survival and early growth within old field and marginal agricultural sites in the Piedmont. Our findings are similar to previous studies evaluating the effectiveness of planting oak species in Piedmont riparian areas (Bradburn et al., 2010). Based upon evaluation of the site using the Baker and Broadfoot site index model (Baker and Broadfoot, 1979), the site was considered suitable for willow oak with a 50-year site index of 65-70 feet (20-21 m).

The survival rates observed in this study for both site preparation, planting stock and planting aids are similar to previous studies of oak afforestation survival, which characterized year 1 survival between 84% and 100%, and year 4 survival rates as low as 64% (Duplissis et al., 2000; Löf et al., 2012; Rathfon et al., 1995; Self et al., 2011). Overall, mortality was consistent across the span of the study. The high survival rates of gallon stock have historically been attributed to greater groundline diameter, root development and hydrologic resilience (Stanturf et al., 2004), while mounding, bedding and ripping site preparation have reduced soil compaction, increased microsite organic matter content and decreased vulnerability to high groundwater levels that have been observed in marginal agricultural field settings (Löf et al., 2012; Londo and Mroz, 2001).

Bare root stock also had high survival rates, which has been attributed to the higher root and stem development observed in willow oak, particularly when planted in areas that do not experience frequent inundation (McCurry et al., 2010; Zaczek et al., 1997). Previous studies using willow oak tubelings at the same study location had survival rates ranging from 85 to 93%, indicating that the quality of the planted stock in this study may have influenced tubeling survival (Steele, 2020). Planting aids had a minor effect on survival in comparison to site preparation and planting stock. Tree tubes had a positive effect on the year 1, 2 and 3 survival, but effects were disappearing by year 4. This is similar to the results shown in other studies throughout North America. Use of tree shelters, such as tree tubes, have been shown to increase initial survival, with the effects waning as the trees age (McCreary, 1997; Vaughan and Smith, 2018; West et al., 1999).

Tree growth indices, as measured by average height, groundline diameter and dbh, were highest in the lowest mortality treatments. Growth indices on mounding site preparation were significantly greater than for all other site preparation techniques through year 4, and directly supports greater hydrologic resilience for planted stock in marginal agricultural areas. Gallon and bare root stock treatment effects on growth indices were consistently greater in all areas of tree growth and met established regulatory success criteria for tree height by year 4 of the study. Planting aids did not provide any significant benefit beyond year 3, which is consistent with previous research (West et al., 1999). The observed results support use of site preparation, particularly mounding, followed by bedding and ripping, in combination with gallon and bare root planting stock, to expedite willow oak growth to meet compensatory mitigation site success criteria. Further evaluation of the combination of planting stock and site preparation, specifically gallon and bare root planting stock, combined with mound, bed and rip plating stock, showed that mounding combined with gallon and bare root planting stock yielded greater height than any of the individual site preparation or planting stock treatments (Figure 4-4).

Economically, the use of site preparation techniques and planting stock accelerate meeting site success criteria, increasing the availability of wetland and buffer credits, which are typically available starting in year 3 after planting. While gallon stock has been shown to increase survival and growth indices in other studies, the results of this study indicate that the use of site preparation and bare root planting stock may provide a more economical restoration option that may increase the likelihood of meeting landowner and regulatory success criteria. Typical costs for site preparation range from $182 to $286 per acre ($358 to $623/hectare) in 2018 dollars, with mounding having a higher cost than bedding or ripping due to the amount of earthwork required (Maggard and Barlow, 2018). Planting costs vary widely, with gallon plants typically an order of magnitude more expensive than bare root plants (Roquemore et al., 2014). However, bare root planting stock can be purchased in large quantities and planted more efficiently than gallon stock. The cost of handplanting ranged from $60 to $112 per acre ($136 to $178/ha) in 2018 at an average of 580 seedlings per acre (Callaghan et al., 2019; Maggard and Barlow, 2018). Comparatively, the price range for compensatory wetland in-lieu fee advanced credits range from $52,00 to $100,000 per wetland acre ($128,000 to $247,000/ha) for Piedmont wetland credits in Virginia and North Carolina (Conservancy, 2018; Department of Mitigation, North Carolina Department of Mitigation, N. C. (n.d.). Statewide Stream, Wetland and Riparian Buffer Rates. Retrieved January 1, 2020, n.d.) Under current regulatory conditions, wetland and buffer credits are released for sale if site conditions meet success criteria, which generally include stem density per acre and growth requirements by the third and fifth years after planting. The calculated productivity index of volume corrected for percent survival for the statistically significant treatments indicate that gallon and bare root planting stock are more likely to have higher growth indices across marginal sites, and mounding is the preferred option for site preparation (Table 3-6). Based upon the observed study results, implementation of site preparation techniques and planting bare root stock could potentially increase the likelihood of attaining required success criteria and enable compensatory sites to release wetland and buffer credits for purchase earlier. The observed results of this study suggest that bare root planting stock generally meet regulatory thresholds for success for density or growth, and due to the survival rates observed, may require less investment in re-planting, which may increase the financial incentive to create wetland areas in compensatory mitigation sites.

4.7 Conclusions

Marginal agricultural lands in the Piedmont have less utility for row crop agriculture due to equipment limitations and flood potential, therefore agricultural operations on such sites may be of limited ecological and economic benefits to landowners or the environment. The productivity of these areas for row crop agriculture is typically limited due to reduced equipment access, soil compaction (wet weather trafficking) and excessive site hydrology. Use of silvicultural site preparation techniques, specifically mounding, bedding, and ripping, increases the potential productivity of these sites for willow oak growth. Use of bare root planting stock could potentially provide an even greater economic return, and the combination of site preparation and planting stock increases growth indices of willow oak. Using proper planting techniques, along with proper storage and handling of seedlings, and proper seedling preparation before planting are also integral to the survival and growth of hardwoods on marginal sites. Site preparation techniques decrease the negative effects of soil compaction, excessive hydroperiod, and unpredictable precipitation and increase early root establishment, which increases survival and growth. The use of planting aids may not be warranted unless site conditions preclude the use of site preparation or use of proper planting stock. Planting aids are not economically feasible for most marginal restoration sites, as the benefits are short term in comparison to other factors.

Use of marginal agricultural areas for compensatory mitigation increases the environmental and economic options of these sites and may increases the willingness of landowners to partition historically low productivity lands for applications that increase the net ecological landscape benefit. Further investigation into the effects of co-planting pioneer species with mid-successional species, increasing planting density, and long-term sustainability of marginal lands for wildlife value and timber production are needed to determine best management practices for optimization of ecological and economic services for marginal lands. Increasing the economic viability will provide more opportunity to utilize these areas for a net positive ecological gain by increasing landscape ecosystem services.

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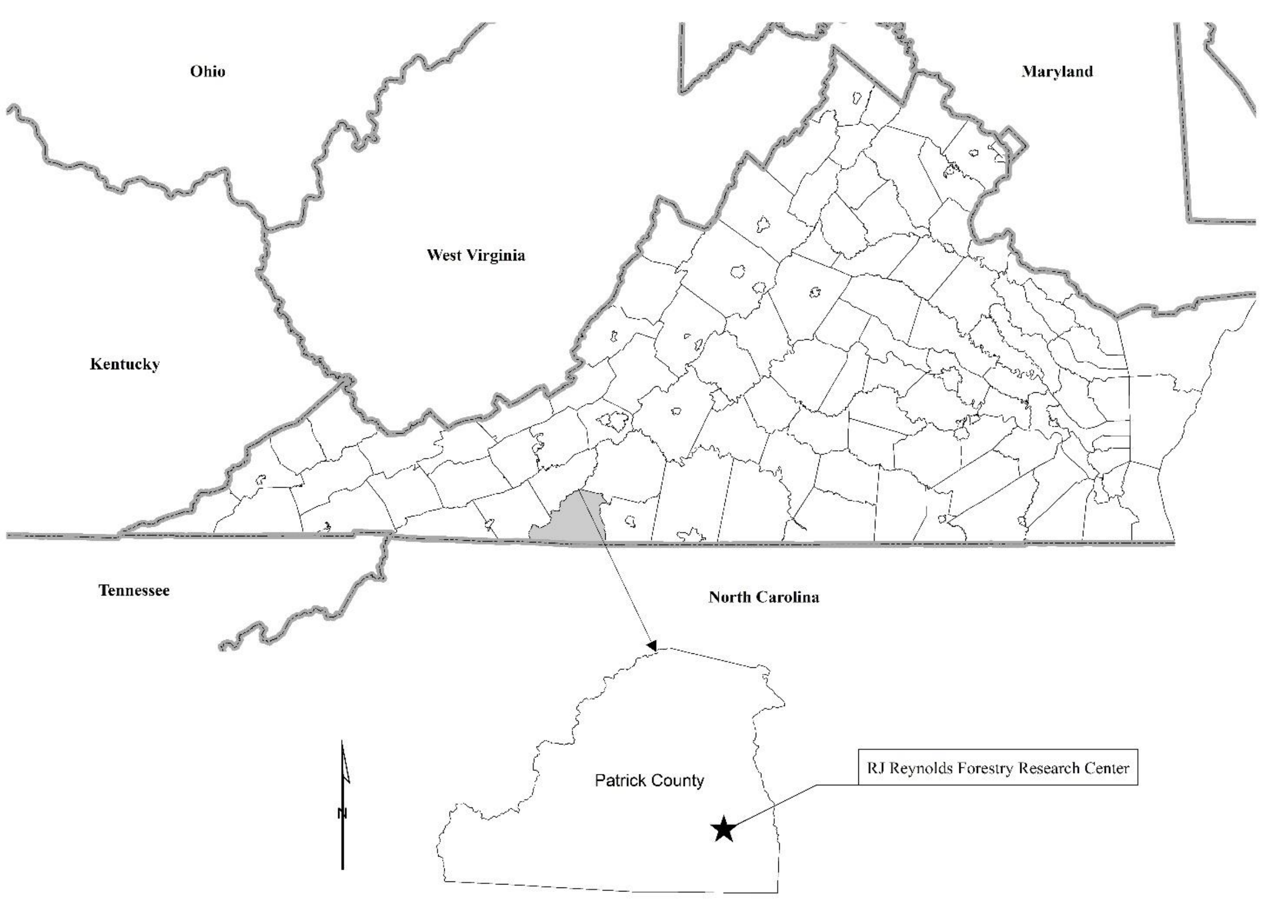
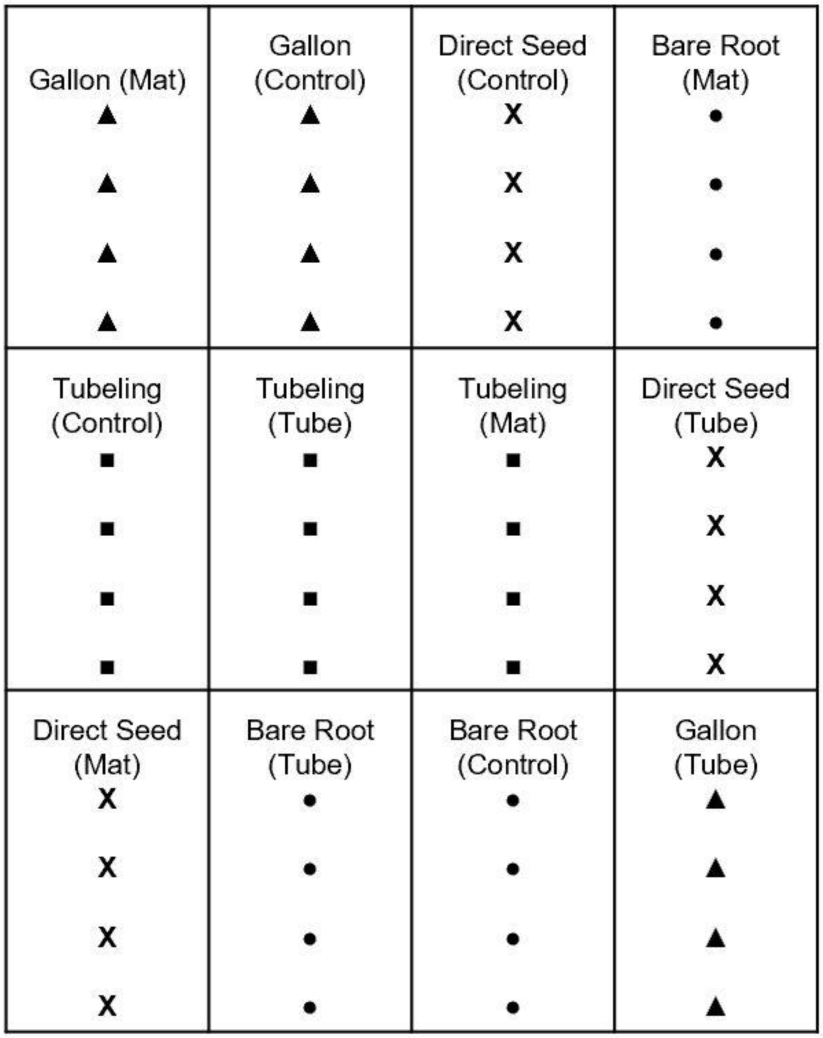


Figure 4-1. Location of the RJ Reynolds Forestry Research Extension Center, Critz, Virginia.

Figure 4-2. Layout of willow oak treatment blocks (0.075 ha) along the floodplain of an unnamed tributary to Mill Creek, Patrick County, Virginia.



Gallon (Mat) ▲ ▲ ▲ ▲	Gallon (Control) ▲ ▲ ▲ ▲	Direct Seed (Control) X X X X	Bare Root (Mat) ● ● ● ●
Tubeling (Control) ■ ■ ■ ■	Tubeling (Tube) ■ ■ ■ ■	Tubeling (Mat) ■ ■ ■ ■	Direct Seed (Tube) X X X X
Direct Seed (Mat) X X X X	Bare Root (Tube) ● ● ● ●	Bare Root (Control) ● ● ● ●	Gallon (Tube) ▲ ▲ ▲ ▲

Figure 4-3. An example block field layout with each large block representing one site preparation technique, and each internal block representing one experimental unit consisting of the planting stock and planting aid treatments.

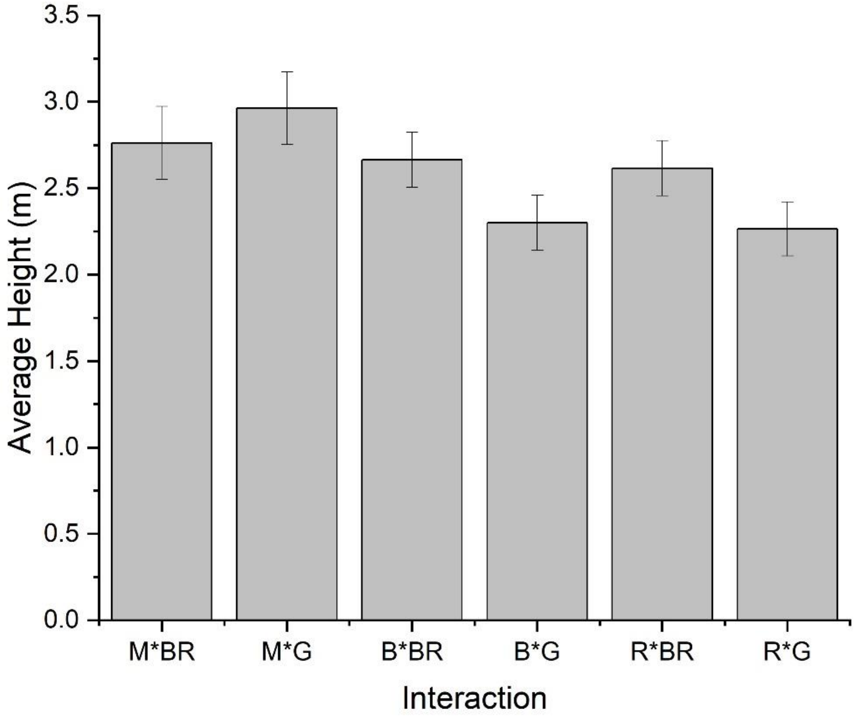


Figure 4-4. Year 4 average height for site preparation (M = mound, B = bed, R = rip) and stock type (G = gallon, BR = bare root) interaction effects (p<0.0001).

Table 4-1. Average percent survival (SE) for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average Survival (%)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Mound	73.3 (7.40)	a	71.7 (7.30)	a	71.7 (7.3)	a	71.7 (7.3)	a
Bed	61.7 (10.1)	ab	58.8 (10.1)	ab	57.5 (10.2)	ab	55.0 (10.4)	b
Rip	55.4 (10.8)	b	50.6 (12.1)	b	50.6 (12.1)	bc	49.2 (11.9)	b
Disk	51.3 (10.3)	bc	49.2 (10.6)	bc	49.2 (10.8)	bc	47.5 (10.8)	b
Pit	37.5 (9.80)	c	35.0 (9.70)	c	36.7 (10.0)	c	30.8 (8.40)	c
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Bare Root	86.0 (4.2)	a	83.0 (4.9)	a	84.0 (4.3)	a	79.0 (5.2)	a
Gallon	84.7 (3.6)	a	84.8 (3.6)	a	85.2 (3.4)	a	83.7 (4.0)	a
Direct Seed	30.2 (6.3)	b	23.7 (5.7)	b	22.7 (5.7)	b	21.0 (5.8)	b
Tubeling	22.5 (4.3)	b	20.7 (4.2)	b	20.7 (4.3)	b	19.7 (4.1)	b
Planting Aid	*p=0.0017*		*p=0.0145*		*p=0.0388*		*p=0.3289*	
Tube	64.1 (7.5)	a	59.8 (7.9)	a	58.8 (7.9)	a	54.0 (7.8)	
Mat	54.3 (7.7)	b	51.6 (7.9)	ab	52.4 (8.0)	ab	50.8 (7.9)	
None	49.1 (8.1)	b	47.8 (8.4)	b	48.3 (8.5)	b	47.8 (8.5)	

Table 4-2. Average height (SE) for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average Height (m)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Mound	0.79 (0.04)	a	1.19 (0.06)	a	1.58 (0.08)	a	2.07 (0.10)	a
Bed	0.72 (0.03)	ab	0.98 (0.04)	b	1.23 (0.06)	b	1.47 (0.07)	b
Rip	0.64 (0.03)	bc	0.86 (0.04)	bc	1.11 (0.06)	b	1.41 (0.08)	b
Disk	0.58 (0.03)	c	0.75 (0.04)	c	1.01 (0.06)	b	1.23 (0.07)	b
Pit	0.32 (0.04)	d	0.38 (0.06)	d	0.47 (0.08)	**c**	0.48 (0.10)	c
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Bare Root	1.01 (0.03)	a	1.44 (0.04)	a	1.87 (0.06)	a	2.29 (0.07)	a
Gallon	1.03 (0.03)	a	1.37 (0.04)	a	1.75 (0.06)	a	2.18 (0.07)	a
Direct Seed	0.13 (0.03)	b	0.15 (0.04)	b	0.21 (0.06)	b	0.25 (0.07)	b
Tubeling	0.26 (0.04)	c	0.37 (0.05)	c	0.49 (0.07)	c	0.61 (0.09)	c
Planting Aid	*p<0.0001*		*p<0.0001*		*p=0.0043*		*p=0.0600*	
Tube	0.78 (0.03)	a	0.99 (0.04)	a	1.20 (0.05)	a	1.44 (0.07)	
Mat	0.55 (0.03)	b	0.79 (0.04)	b	1.08 (0.05)	ab	1.32 (0.07)	
None	0.49 (0.03)	b	0.71 (0.04)	b	0.96 (0.05)	b	1.23 (0.07)	

Table 4-3. Average groundline diameter (SE) for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average Groundline Diameter (cm)							
Treatment	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
Site Preparation	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Mound	0.92 (0.05)	a	1.46 (0.07)	a	2.13 (0.10)	a	2.91 (0.13)	a
Bed	0.74 (0.03)	b	1.03 (0.05)	b	1.42 (0.07)	b	1.82 (0.10)	b
Rip	0.66 (0.03)	bc	0.91 (0.05)	bc	1.26 (0.07)	bc	1.65 (0.10)	bc
Disk	0.57 (0.03)	c	0.75 (0.05)	c	1.02 (0.07)	c	1.34 (0.10)	c
Pit	0.33 (0.05)	d	0.33 (0.07)	d	0.45 (0.10)	d	0.45 (0.13)	d
Planting Stock	*p<0.0001*		*p<0.0001*		*p<0.0001*		*p<0.0001*	
Bare Root	1.09 (0.03)	a	1.54 (0.05)	a	2.17 (0.07)	a	2.81 (0.09)	a
Gallon	1.15 (0.03)	a	1.58 (0.05)	a	2.13 (0.07)	a	2.73 (0.09)	a
Direct Seed	0.11 (0.03)	b	0.12 (0.05)	c	0.20 (0.07)	c	0.29 (0.09)	c
Tubeling	0.23 (0.04)	b	0.34 (0.06)	b	0.53 (0.09)	b	0.71 (0.12)	b
Planting Aid	*p=0.1438*		*p=0.3661*		*p=0.2524*		*p=0.4939*	
Tube	0.68 (0.04)		0.94 (0.06)		1.32 (0.10)		1.68 (0.13)	
Mat	0.63 (0.04)		0.84 (0.06)		1.16 (0.10)		1.54 (0.13)	
None	0.63 (0.04)		0.92 (0.06)		1.32 (0.10)		1.72 (0.13)	

Table 4-4. Average year 4 dbh (SE) for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Average dbh (cm)	
Treatment	**Year 4**	
Site Preparation	*p<0.0001*	
Mound	1.48 (0.09)	a
Bed	0.97 (0.07)	b
Rip	0.92 (0.07)	bc
Disk	0.67 (0.07)	c
Pit	0.14 (0.09)	d
Planting Stock	*p<0.0001*	
Bare Root	1.60 (0.06)	a
Gallon	1.38 (0.06)	a
Direct Seed	0.09 (0.06)	b
Tubeling	0.28 (0.08)	b
Planting Aid	*p=0.0155*	
Tube	0.97 (0.06)	a
Mat	0.79 (0.06)	ab
None	0.75 (0.06)	b

Table 4-5. Average year 4 tree volume (SE) for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

Treatment	**Average Volume (cm^3)** **Year 4**	
Site Preparation	*$p<0.0001$*	
Mound	2,369.98 (490.06)	a
Bed	1,305.48 (397.30)	b
Rip	1,349.27 (388.84)	b
Disk	815.62 (244.01)	bc
Pit	116.46 (40.98)	c
Planting Stock	*$p<0.0001$*	
Bare Root	2,364.70 (369.93)	a
Gallon	1,889.47 (322.38)	a
Direct Seed	81.94 (34.31)	b
Tubeling	429.34 (186.65)	b
Planting Aid	*$p=0.5124$*	
Tube	1,336.13 (332.22)	
Mat	1,151.66 (290.02)	
None	1,086.30 (319.07)	

Table 4-6. Average (SE) year 4 productivity index for willow oak on the Virginia Piedmont as influenced by site preparation, planting stock type and planting aid. Averages with different letters are significantly different.

	Productivity Index	
Treatment	**Year 3**	
Site Preparation	*p<0.0001*	
Mound	2,013 (491)	a
Bed	1,145 (374)	b
Rip	1,134 (365)	b
Disk	643 (216)	bc
Pit	69 (25)	c
Planting Stock	*p<0.0001*	
Bare Root	2,073 (352)	a
Gallon	1,710 (322)	a
Direct Seed	41 (20)	b
Tubeling	178 (103)	b
Planting Aid	*p=0.6072*	
Tube	1,128 (312)	
None	954 (318)	
Mat	919 (247)	

5.0 OVERALL ASSESSMENT OF THE INFLUENCE OF SILVICULTURAL PRACTICES TO IMPROVE SURVIVAL AND GROWTH OF PIONEER AND MID-SUCCESSIONAL HARDWOODS ON OLD FIELD RESTORATION SITES

Current wetland mitigation practices have resulted in lower hardwood survival and growth rates than silvicultural hardwood plantation sites on similar marginal sites. It appears reasonable that wetland mitigation efforts might benefit from a transfer of silvicultural techniques. Therefore, the overall purposes of this research were to determine if the application of common bottomland silvicultural site preparation and planting techniques used in forested wetlands, as well as augmentation of common nursery seed sourcing and preconditioning practices, could increase the survival and growth of commonly planted hardwood species in Piedmont marginal old field agricultural areas. Marginal agricultural lands in the Piedmont are often utilized for riparian areas restoration, wildlife habitat enhancement and ecosystem restoration. Historically, these areas are difficult to establish hardwood trees within the timeframe required to meet regulatory success criteria. Successfully establishing early and mid-successional hardwoods instrumental in increasing the economic and ecological viability of these areas and may increase the willingness of landowners to use historically low productivity lands for restoration efforts that also increase landscape ecological benefit.

The riparian area of streams in the Piedmont are often used as forested conversion areas for a variety of water quality improvement programs. Restoration of these old field areas to forest are the focus of Federal and State programs including the Conservation Reserve Enhancement Program (CREP), and these areas have increased importance for meeting regulatory thresholds for nutrient pollution reduction within the Chesapeake Bay watershed (Irby and Friedrichs, 2019). Functioning forested buffer areas are a primary method to reduce sediment loading from upgradient agricultural sites while also reducing thermal loading within buffered streams. This study illustrated that the use of mound mechanical site preparation, in conjunction with species appropriate planting stock size, will increase the success of old field riparian area conversion efforts and make these areas more likely to meet regulatory water quality goals. Furthermore, use of seeds sourced from upland areas for American sycamore and wet areas for willow oak may increase the likelihood of seedling survival along anthropogenically impacted Piedmont streams, which will facilitate more rapid canopy closure. Previous studies have indicated that lack of canopy closure, which allows for establishment of invasive species, may be one of the primary reasons riparian area conversions fail to meet regulatory success criteria (Bradburn et al., 2010).

Establishing a variety of hardwood tree species will facilitate wildlife use of riparian areas and floodplains. An estimated 85% of species interact with forested edge areas throughout their life histories (Crawford and Semlitsch, 2007; Pfeifer et al., 2018). American sycamore and willow oak provide a variety of wildlife benefits within a fragmented agricultural landscape, including nesting and feeding areas. The pit and mound mechanical site preparation technique can create a patchwork of microsites across the riparian areas, which will provide habitat areas for stream breeding amphibians and reptiles, while mammals can utilize these areas for foraging habitat and nesting (Crawford and Semlitsch, 2007). Canopy closure in riparian areas may also increase the use of buffer areas as transportation corridors for large mammals, and many vertebrates utilize the forest edge as primary nesting and reproductive habitat. Use of more mature planting stock, including gallon plants and tubelings, may increase wildlife use within restored floodplain and riparian areas and increase biomass accumulation.

There are a variety of methods that have been used in greenhouse and field settings in the attempt to increase hardwood seedling survival and growth. This study illustrated that the use of greenhouse preconditioning treatments (flooding or water stress) did not increase survival or growth of American sycamore or willow oak and do not appear to be warranted for seedlings grown under proper nursery conditions. While oak afforestation in agricultural fields has historically had low survival and growth due to herbaceous competition and improper site conditions, this study illustrated that the use of mounding with traditionally planted bare root planting stock will increase survival and growth and reduce the need for planting aids, which had a marginal impact on seedling survival and growth beyond year 3. American sycamore survival and growth was greatest with mound site preparation. While use of more mature planting stock did increase American sycamore biomass accumulation, mounding combined with bare root planting stock had significantly higher survival and growth indices that previous studies, indicating that use of the mound site preparation method should be applied for plantings in old field agricultural settings. A variety of mechanized pit and mound machinery area available for large scale site preparation applications, although many areas with saturated soils utilize excavators to mechanically prepare sites. Previous studies have shown that excavation of mounds on sites with saturated soils average approximately 340 mounds per hour at an average hourly cost of $560 (Makovskis et al., 2019). Regulatory success criteria typically require stem densities range from 625 to 1,000 stems/ha, making the cost of excavation and planting of these areas well below the current credit value from in-lieu fee providers and riparian restoration programs.

In summary, the research presented in this dissertation indicates that the use of seeds sourced from appropriate floodplain sources, implementation of mechanical site preparation techniques that reduce soil compaction and increase depth to groundwater, and planting of species appropriate planting stock will increase the survival and growth of common early and mid-successional Piedmont tree species on marginal agricultural lands. The establishment of these species will increase the likelihood that these areas will develop and replace ecosystem functions and values of the natural systems they were constructed to replace.

5.1 References

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