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Growth and Mortality of Pin Oak and Pecan Reforestation in a Constructed Wetland: Analysis with Management Implications

D.E. Henderson[1], P. Botch[1], J. Cussimanio[2], D. Ryan[2], J. Kabrick[3], and D. Dey[3].

THE AUTHORS:

Dawn Henderson is a Resource Scientist with the Missouri Department of Conservation, Open Rivers and Wetlands Field Station[1] (3815 East Jackson Boulevard, Jackson, MO 63755). Paul Botch is a graduate student currently attending the University of Missouri at Columbia. Josh Cussimanio is a Wildlife Biologist and Doug Ryan is a Resource Technician at Four Rivers Conservation Area[2] (4347 S. 1625 Road, Rich Hill, MO 64779). John Kabrick and Dan Dey are Research Foresters with the Forest Service, Northern Research Station[3,] and Cooperative Forest Faculty with the University of Missouri, Columbia (202 Anheuser-Busch Natural Resources Bldg., University of Missouri, Columbia, MO 65211-7260).

PREFACE

The Missouri Department of Conservation (MDC) conducted the work described in this report on Four Rivers Conservation Area (FRCA) located in Vernon and Bates Counties, west-central Missouri. The project was initiated and work directly supervised by John Kabrick and Dan Dey, principle investigators, Cooperative Forest Faculty with the USDA Forest Service, Northern Research Station. Field staff assigned to Four Rivers Conservation Area conducted data collection. Summarization of data and the production of this report were assigned to the author when the lead PI left MDC. Since the last year of data collection, large and repeated flooding has damaged much of the project. Future efforts regarding data collection will focus on mortality and resprouting of the original planting stock.

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ABSTRACT
Pin oak (*Quercus palustris* Muenchh.) and pecan (*Carya illinoensis* (Wangenh.) K. Koch) trees were planted on reforestation plots at Four Rivers Conservation Area in west-central Missouri. The study was conducted to determine survival and growth rates of the two species under different production methods and environmental variables. Production methods included direct seeding, bare root seedlings, and RPM® planting stock. Combinations of planting stock and species were implemented on two elevations (mounded or unmounded soils). Survival rates were not significantly different between species for any treatments throughout the six-year study period. The lowest survival rate was observed in pecan RPM® planting stock in mounded soil (82%). Pin oak bare root seedlings had a 100 % survival rate. Pin oak and pecan exhibited the highest growth rates in mounded RPM® planting stock (9.7 cm, 4.3 cm, and 294 cm, 154 cm for pin oak and pecan dbh and height, respectively). The smallest average dbh and height in 2007 was found in direct seeded trees at high elevations for both species (2.6. cm, 1.7 cm, and 117 cm, 76 cm for pin oak and pecan dbh and height, respectively). Growth rates between species were significantly different across all treatments except unmounded RPM® planting stock for which pecan data was unavailable.

Keywords: restoration, wetland, afforestation, reforestation, seedling, greentree reservoir, RPM, bottomland hardwood, hardmast, floodplain, pin oak, pecan.

INTRODUCTION

History

It is estimated that 70% of riparian ecosystems have been altered in the United States; vegetation losses in the Midwest often exceed this national average (Brinson et al. 1981). Modifications of rivers for flood control and subsequent landscape conversions have altered historical floodplain hydrology and geomorphic processes, reduced diversity and complexity of riparian zones, (Gurnell 1997), and decreased naturally occurring functions of these areas (Bayley 1995). Bottomland hardwood (BLH) forests in the floodplains of the Mississippi (Nelson 2005) and Missouri (Galat et al. 1998) Rivers have undergone widespread reductions since European colonization. Between 1940 and 1980, nearly 560,000 ha of bottomland hardwood forests in Missouri were altered resulting in a 71% decrease of BLH (Abernethy and Turner 1987). Major conversion of natural lands including BLH to agriculture total 91% and 82%, respectively, in Bates and Vernon counties in the Osage River Basin of west-central Missouri (Fantz et al. 1995). Government programs have encouraged BLH restoration on abandoned agriculture land (Schoenholtz et al. 2005), but these efforts generally represent a fraction of the total loss of BLH (Schoenholtz et al. 2001).

Background

Reforestation failures of bottomland hardwoods are common (Hodges 1997). Physical, biological, and environmental factors effecting tree growth are complex (Fowells and Means 1990). The process of BLH reforestation requires an understanding of individual site quality and species requirements, as well as ecological and edaphic interactions (Schweitzer 1998). Stanturf et al. (2001) suggested approximately 90% of the WRP reforestation efforts in Mississippi have failed due to poor understanding of these processes. Gardiner (2001) and Allen et al. (2001) suggest failures in reforestation efforts are correlated to misunderstanding or neglecting to take into account: 1) species intolerance of flood regimes; 2) light requirements and availability; 3) herbivory; 4) poor seedling quality or seed sowing practices; 5) species-site interactions; and 6) species-species interactions.

Environmental variables such as hydrology and soil chemistry are dependent on topography (Wall and Darwin 1999). Matching species with proper site conditions such as elevation and hydrologic regime are paramount in afforestation practices (Hodges 1997). Small differences in elevation alter site suitability for seedling growth (Schoenholtz et al. 2005). Seedlings are especially vulnerable to flooding and have lower survival rates in flooded conditions (Hook 1984). Streng et al. (1989) suggests a strong relationship between flooding and first year mortality of seedlings with decreased mortality tied to flood tolerance as trees age. As such, the distribution of species along hydrologic gradients may be due in part to the flood tolerance/intolerance of seedlings and not mature trees. Conversely, black willow (*Salix nigra* Marsh.) seedlings have different moisture requirements than mature trees. Mature S. nigra, are capable of surviving in drier conditions (McLeod and McPherson 1973) than are seedlings.

Misunderstanding seedling and tree silvical characteristics can result in large-scale planting failure. Poor planting practices account for a large portion of reforestation failures in BLH forests (Schoenholtz et al. 2005 and Stanturf et al. 1998). Mechanical planting practices may improve restoration success by placing seedlings at precise depths. This technique requires less personnel and supervision than hand planting (Schoenholtz et al. 2005). In general, bare-root seedlings have an “optimal” time-period for planting while container seedlings are generally more vigorous and can be planted later in the year (Stanturf et al. 1998).

The root production method (RPM®) growing technique creates large seedlings that may be able to overcome some difficulties surrounding afforestation in floodplains. The RPM® technique employs air root pruning to produce dense fibrous root systems (Lovelace 2002). Studies have suggested these seedlings have larger initial basal diameter growth and survival rates than bare root seedlings (Shaw et al. 2003 Dey et al. 2004, and Krekeler et al. 2006). Short (2006) reported RPM® stock oak trees had greater height increment and stem diameter than bare root seedlings after the first and second years of growth. RPM® seedlings have also been shown to produce acorns within the first four growing seasons (Dey et al. 2004), 10 to 15 years faster than most oaks in natural settings (Grossman et al. 2003), which can make them especially valuable when reforesting for wildlife habitat use. The goal of this study is to evaluate (1) mortality and (2) growth increment of direct seeded, bare root, and RPM® pin oak and pecan seedlings under different site preparation methods.

METHODS

This study took place at the Four Rivers Conservation Area (FRCA) in Vernon and Bates County, Missouri (Figure 1). The climate is a typical temperate warm climate, with cold winters and hot summers. Average growing season is approximately 200 days annually. Total annual precipitation averages near 109cm (42 inches) with mean minimum and maximum temperatures ranging from 0.5°C (33°F) to near 26°C (80°F) respectively.

The FRCA is located in the Osage River basin in the floodplains of Osage, Little Osage, Marmaton, and Marais des Cygnes Rivers. Historically, the area has supported bottomland forests, wet prairie, and riverine wetlands. Drainage and agriculture have diminished the region to less than 1% of its original wetland area (Ducks Unlimited- http://www.ducks.org/Missouri/MissouriProjects/1469/FourRiversConservationArea.html). The Missouri Department of Conservation established the FRCA in 1982 and converted much of the area back into actively and passively managed wetland units.

Study Design

Pin oak (*Quercus palustris* Muenchh.) and pecan (*Carya illinoinensis* (Wangenh.) K. Koch) trees were planted at FRCA in 1999. The trees were planted in plots at low (222.64m), medium (222.74m), and high (223.57m) elevations (all heights are NAVD 88, North American Vertical Datum of 1988). Direct seeding occurred at low and high elevations, while bare root seedlings were planted in the middle elevation plots.

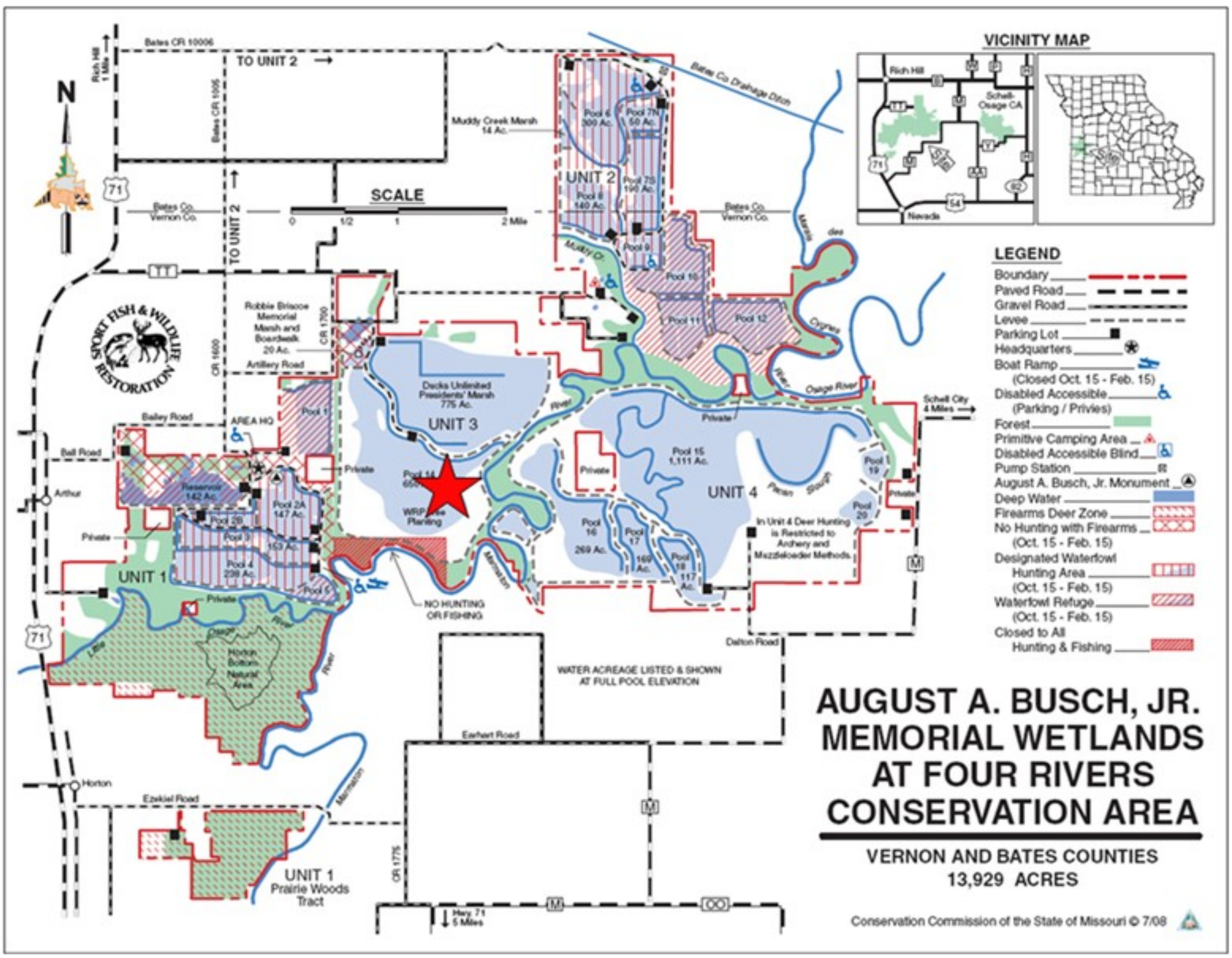

Figure 1. Four Rivers Conservation Area.

Direct seeding and bare root seedlings were randomly planted using mechanical planters at 1m x 6m spacing. RPM® trees (Figure 2 and 3) were planted throughout the site in mounded (0.5-m height and 2-m diameter) and unmounded soil. Each tree was tagged for identification purposes. The plots were maintained by mowing and weed barriers. RPM® seedlings received slow-release fertilizer the second and third growing seasons.

Figure 2. RPM® tree planted on mounded soil.

Analysis

The trees were monitored annually to determine the effects of site preparation methods on survival and growth rates for each stock type and each species. Heimann and Mettler-Cherry (2004) provide a more detailed description of methods used in this study. An analysis of variance (ANOVA) with Tukey's HSD multiple means test was used to compare differences in annual percent height and diameter increases between treatments and species; $p \leq 0.05$ was used to determine the level of statistical difference. Relative growth rate (RGR) was calculated for seedlings through 2007 using height and basal diameter by the equation:

$$r = \frac{\ln(H_2) - \ln(H_1)}{t_2 - t_1}$$

H_1 and H_2 were growth (height or diameter) measurements at times t_1 and t_2. Mean RGR was analyzed using ANOVA and Tukey's HSD multiple means test. Statistical differences of pin oak and pecan seedling mortality though 2007 was determined using a chi-square test ($\alpha \leq 0.05$). Differences in average height and basal diameter between species was calculated using *t* Tests with sequential Bonferroni corrections.

Figure 3. RPM® root mass (left) compared to bare root mass (right). Image obtained from http://www.fknursery.com/_ccLib/image/pages/DETA-18.jpg.

RESULTS

Mortality

Mortality, diameter, and height were evaluated for all seedlings according to the following stock types and preparation methods for pin oak and pecan respectively: 1) Direct seeding at high elevation (D-H), 2) Direct seeding at low elevation (D-L), 3) RPM® seedlings in mounded soil (RPMM), 4) RPM® seedlings in unmounded soil (RPMU), and 5) Bare root seedlings (SDLG).

Mortality rates, through year six were not significantly different between species for any treatments (Chi-square, $p \leq 0.05$) (Table 1). Pin oak bare root

	Production Method	**Survival (%)**
Pin Oak	Direct Seeded – High (D-H)	94
	Direct Seeded – Low (D-L)	96
	RPM-Mounded (RPM-M)	89
	RPM-Unmounded (RPM-U)	97
	Seedlings (SDLG)	100
Pecan	Direct Seeded – High (D-H)	96
	Direct Seeded – Low (D-L)	96
	RPM-Mounded (RPM-M)	82
	RPM-Unmounded (RPM-U)	-
	Seedlings (SDLG)	96

Table 1. Pin oak and pecan survival rates for each production method and environmental variables.

seedlings had a 100 % survival rate. The highest overall mortality rate occurred in RPM® pecan trees in mounded soil (18.2%).

Diameter

Pin oak diameter increases occurred annually for all planting stock types (direct seeding, bare-root seedling, and RPM®). Maximum diameters in 2007 were 2.60, 3.43, 9.73, 4.9, and 4.58cm for D-H, D-L, RPMM, RPMU, and SDLG, respectively (Fig. 4). The largest increases in diameter occurred in 2002 for all pin oak planting stock with the exception of RPMU, which occurred in 2004 and 2007 (Table 2

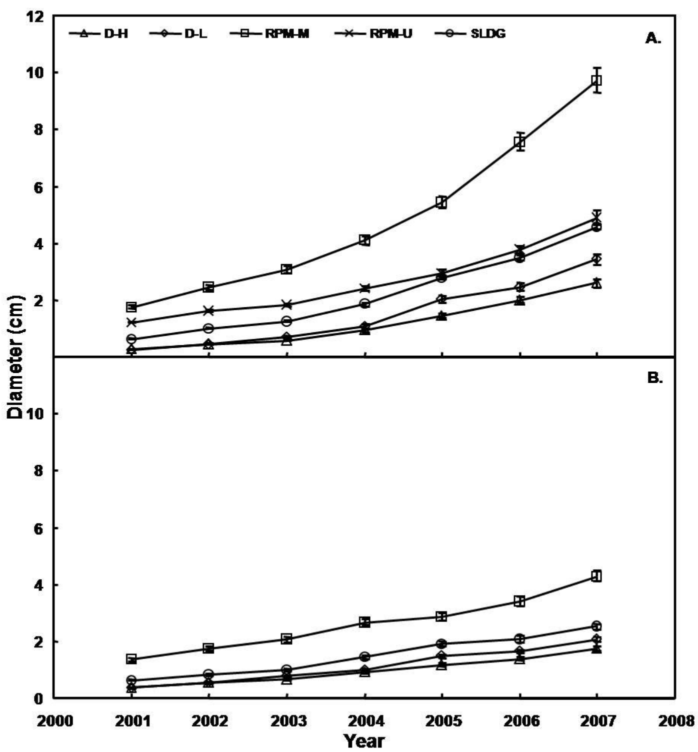

Figure 4. Average annual increase in diameter for pin oak (A) and pecan (B) with standard errors shown. D-H = direct seeded high elevation (triangle), D-L = direct seeded low elevation (diamond), RPM-M = RPM planting stock mounded (square), RPM-U = RPM planting stock unmounded (cross), SDLG = bare root seedling (circle).

and Figure 5). Cumulative RGR for diameter over the six growing seasons were 44, 50, 33, 27, and 40% for D-H, D-L, RPMM, RPMU, and SDLG, respectively (Fig. 6).

Pecan diameter increases occurred annually for all planting stock types (direct seeding, bare-root seedling and RPM®). Maximum diameters in 2007 were 1.75, 2.06, 4.29, and 2.52cm for D-H, D-L, RPMM, and SDLG, respectively (Fig. 4). The largest increases in diameter occurred in 2002 for pecan D-H, and D-L (Table 2). RPMM and SDLG diameter

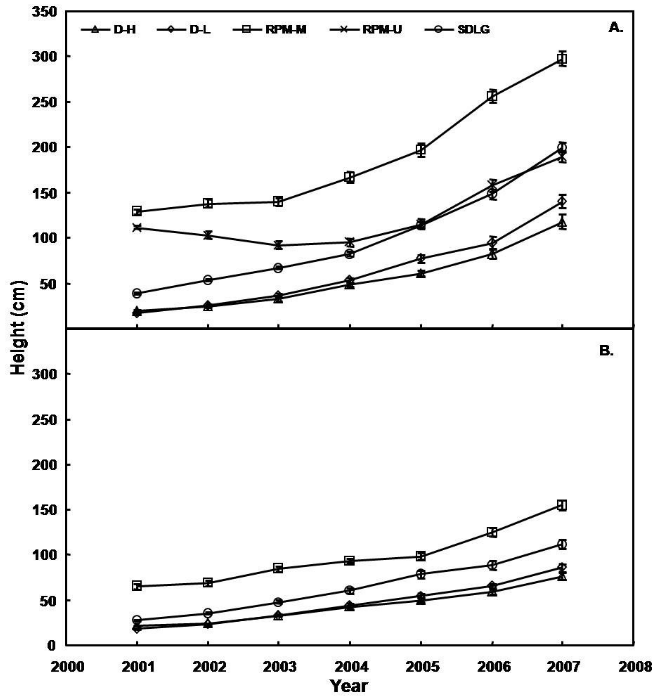

Figure 5. Average annual increase in height for pin oak (A) and pecan (B) with standard errors shown. D-H = direct seeded high elevation (triangle), D-L = direct seeded low elevation (diamond), RPM-M = RPM planting stock mounded (square), RPM-U = RPM planting stock unmounded (cross), SDLG = bare root seedling (circle).

peaked during the 2004 and 2007 growing seasons respectively (Table 2). Cumulative RGR over the six growing seasons were 31, 34, 24, and 44% for D-H, D-L, RPMM, and SDLG, respectively (Fig. 6). Data for pecan RPMU seedlings was unavailable.

Height

Pin oak height reached at maximum in 2007 (117, 140, 297, 190, and 199cm for D-H, D-L, RPMM, RPMU, and SDLG, respectively (Fig. 5). Maximum annual percent increase in height was found in 2002, 2004, and 2007 for D-H, D-L, and SDLG (Table 2). RPMM and RPMU annual percent height increase reached a maximum in 2006 (Table 2). Percent height increases were 50, 55, 33, 39, and 42% for D-H, D-L, RPMM, RPMU, and SDLG, respectively. Cumulative RGR for pin oak height over the six growing seasons were 35, 41, 16, 10, and 33% for D-H, D-L, RPMM, RPMU, and SDLG, respectively (Fig. 6).

Pecan height reached a maximum in 2007 (76, 85, 154, and 111cm for D-H, D-L, RPMM, and SDLG, respectively (Fig. 5). Maximum annual percent increase in height was found in 2003 for D-H, D-L, and RPMM and in 2007 for SDLG (Table 2). Cumulative RGR for pecan height over the six growing seasons were 25, 30, 18, and 28% for D-H, D-L,

		Diameter (cm)					
		Year					
		2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007
Treatment	**Species**						
DH	Pin Oak	67 Aa	30 Ab	56 Aa	57 Ab	35 Aab	31 Aa
	Pecan	52 Bab	22 Bb	38 Bab	28 Bb	19 Ba	27 Aa
DL	Pin Oak	75 Aa	56 Aa	54 Aa	91 Aa	21 Ac	39 Aa
	Pecan	55 Aa	47 Aa	28 Bb	55 Ba	11 Bbc	25 Ba
RPMM	Pin Oak	50 Aa	24 Abc	32 Ab	32 Ac	41 Aa	34 Aa
	Pecan	28 Ab	20 Ab	33 Aab	8 Bc	18 Bab	28 Aa
RPMU	Pin Oak	34 a	13 c	35 b	23 c	31 abc	35 a
	Pecan	-	-	-	-	-	-
SDLG	Pin Oak	61 Aa	25 Abc	52 Aa	51 Ab	24 Abc	32 Aa
	Pecan	31 Bab	24 Ab	44 Aa	22 Bb	8 Bc	25 Ba

		Height (cm)					
		Year					
		2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007
Treatment	**Species**						
DH	Pin Oak	23 Abc	38 Aab	50 Aa	31 Aabc	32 Aa	44 Aa
	Pecan	15 Ab	36 Aab	29 Ba	16 Bb	19 Ba	30 Aa
DL	Pin Oak	55 Aa	45 Aa	49 Aa	45 Aa	21 Ab	51 Aa
	Pecan	31 Ba	45 Aa	33 Ba	23 Bab	20 Aa	31 Ba
RPMM	Pin Oak	7 Acd	4 Ac	17 Abc	21 Ac	33 Aa	17 Aa
	Pecan	10 Ab	25 Bb	12 Ab	4 Bc	25 Ba	24 Aa
RPMU	Pin Oak	-7 d	-8 d	7 c	28 bc	39 a	24 a
	Pecan	-	-	-	-	-	-
SDLG	Pin Oak	40 Aab	27 Ab	25 Ab	42 Aab	29 Aab	37 Aa
DH	Pecan	30 Ba	36 Aab	28 Aa	28 Ba	18 Ba	50 Aa

Table 2. Pin oak and pecan percent diameter and height increase for each production method and environmental variable. Capital letters indicate significant differences between species. Lower case letters indicate significant differences between environmental variables.

RPMM, SDLG, respectively (Fig. 6). Data for pecan RPMU seedlings was available.

In 2007, average diameter and height measurements between species were significantly different across all treatments except unmounded pecan RPM® planting stock (Fig. 7) (*t* Tests, sequential Bonferroni-corrected, p≤0.05). For each year surveyed, the average height and basal diameter was greatest for RPM® mounded seedlings in both pin oak and pecan (Table 2). Direct seeded seedlings at high elevation had the lowest average height and basal diameter for both species.

For both species, direct seeded trees at low elevation had the highest overall percent growth in height and basal diameter ($p < 0.05$). Pin oak had the greatest single year mean percent height increase for the 2001-02 growing season (Figure 8). Direct seeded pin oak also had the highest mean basal diameter percent increase from 2004-05. The lowest mean annual basal diameter increase was found in pecan bare root seedlings in 2005-06 (Figure 8). RPM® seedlings tended to have the lowest mean percent growth rates with no significant difference in percent growth between mounded or unmounded soils throughout the study period.

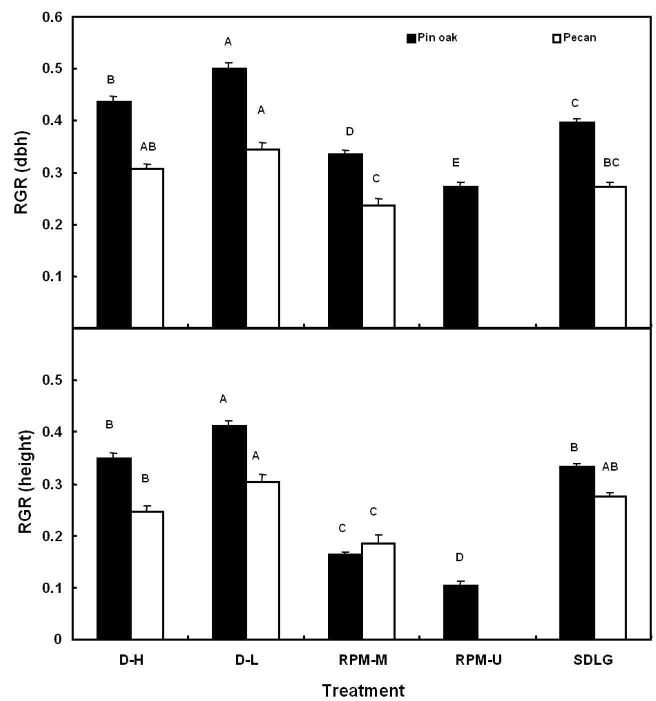

Figure 6. RGR for diameter and height for pin oak (dark bars) and pecan (light bars) shown with standard errors. Capital letters indicate significant differences between species for each environmental treatment.

Relative Growth Rate

Cumulative relative growth rates of pin oak diameters were significantly different in 2007 (DL > DH > SDLG > RPMM > RPMU) with no grouping of similarities from multiple means post hoc tests. Relative growth rates for pin oak height were also significantly different (DL > DH = SDLG > RPMM > RPMU) (DH did not differ significantly from SDLG (Fig. 6)). Relative growth rates of pecan diameters were significantly different (DL > DH = SDLG > RPMM). Relative growth rates for pecan height were also significantly different (DL = SDLG = DH > RPMM (Fig. 6)).

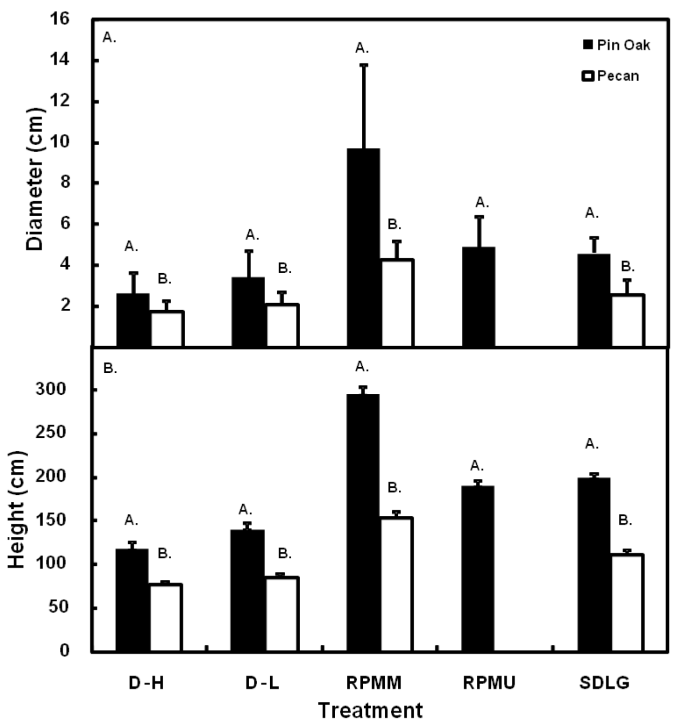

Figure 7. Average diameter (A) and height (B) for pin oak and pecan through 2007 with standard error bars. Pin oak is shown as the dark bars; pecan is shown in the light bars.

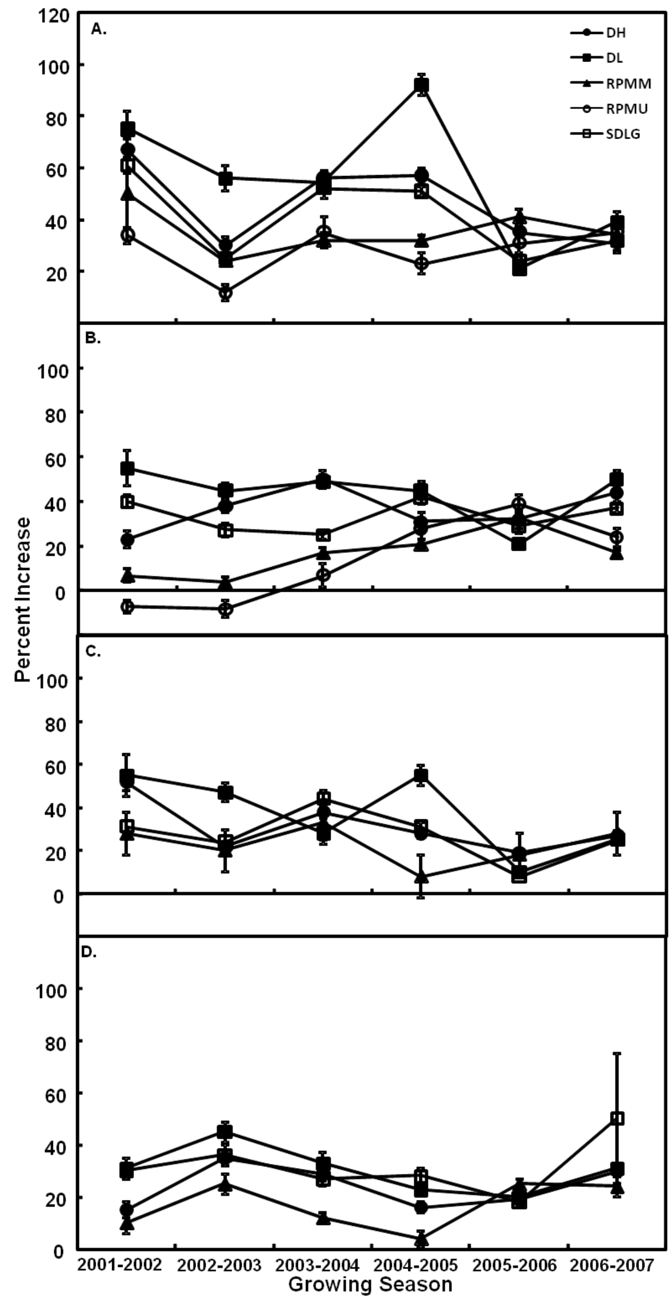

Figure 8. (A) Percent increase of pin oak diameter for each growing season. (B) Percent increase of pin oak height for each growing season. (C) Percent increase of pecan diameter for each growing season. (D) Percent increase of pecan height for each growing season. Standard error of the mean represented by the bars on each data point.

DISCUSSION

Flooding and Growth Relationships

Short duration, periodic flooding is a characteristic of most alluvial bottomlands and the ability to tolerate inundated anaerobic soil conditions is a biological adaptation of tree species native to these areas (Gardiner 2001). However, Schoenholtz et al. (2005) also suggests that prolonged floodwaters that overtop seedlings can hamper afforestation efforts by causing seedling death or increasing seedling vulnerability to future stresses. Some of the plots in this study were inundated 20+ days during first two years (Heimann and Mettler-Cherry 2004). Nonetheless, very low mortality was recorded for pin oak and pecan seedlings suggesting that inundation was not long or deep enough to illicit an undesirable effect during the first few years (Table 1). Pin oak and pecan trees are categorized as moderately flood tolerant, which is defined as the ability to survive growing season flooding for one to three months (Kabrick and Dey 2001). Hosner (1960) reported pin oak seedlings recover rapidly from short-term submergence and can survive several weeks of inundation.

We found no significant differences in survival among all planting stock; however, RPM® mounded seedlings (Figure 9 and 10) for pin oak and pecan suffered the highest percent mortality at 89% and 82% respectively (Table 1). We did not find significant differences in mortality rates for the oak trees planted in mounded or unmounded soils. Large nursery-grown seedlings have been shown to improve oak regeneration in bottomlands (Kormanik et al. 1995). Typically, the larger seedlings have a higher tolerance to adverse wetland conditions and survival rates than direct seeded trees (Williams et al. 1999). Dey et al. (2004) reported a higher percent survival of oak RPM® seedlings than for bare root seedlings, but found no significant difference in mortality between oak trees planted in mounded and unmounded soils. Gwaze et al. (2006) found significantly greater survival rate of 2-0 container grown shortleaf pine seedlings than 2-0 bare root seedlings. The same study also found container and bare root seedlings showed no significant difference in mortality when 1-0 seedlings were tested. The seedlings used in this study were also 1-0 stock suggesting that our conclusions complement results of other studies.

Figure 9. RPM® seedlings after two years of growth.

Basal diameters for mounded pin oak and pecan RPM® seedlings exceeded that of bare root or direct seeded seedlings for every year surveyed (Fig. 4). Unmounded RPM® seedlings had the second highest average diameter for pin oak (Figure 4). Other studies, (Krekeler et al. 2006, Dey et al. 2004 and Shaw et al. 2003), have shown similar results for RPM® planting stock. However, Gwaze (2006) found no significant differences in basal area or height for 2-0 container or bare root shortleaf pine suggesting differences in species-specific growth rates as well as site quality.

Bare root seedlings had the third highest average diameter for both pin oak and pecan trees followed by both direct seeded treatments (Table 2). Williams and Craft (1998) found bare root nuttall oak (*Quercus nuttallii*, Palmer) out performed container seedlings in Mississippi, however there was a three-month difference in age of the seedlings. Another study by the same author (Williams et al. 1999) suggests similar results for diameter increases, however when subjected to flooding, containerized seedlings were more likely to survive because of greater initial height growth. A study in Tennessee (Mullins et al. 1998) found that cherrybark oak (*Quercus falcata* var. *pagodaefolia* Ell.) seedlings, bare root versus containerized planting stock, showed no significant differences in diameter after five years. The variation in findings between these studies indicates planting technique as well as site conditions regulate biomass accumulation for several years.

Direct seeded trees at low elevation had a greater average basal diameter than direct seeded trees at high elevation (Figure 4). After five years, Mullins et al. (1998) found no significant differences between the diameters of planting stock type, (container, bare root, or direct seeding) when tree shelters were put in place at the beginning of the study suggesting differences in diameter increase between similarly aged planting stock is not necessarily related to initial size differences.

More likely, small changes in topographic elevation significantly affect seedling growth (Schoenholtz et al. 2005), suggesting that for this study, low elevations may have provided optimal edaphic conditions necessary for direct seeded bottomland hardwood species.

Percent Diameter growth (%) was lower in unmounded RPM® seedlings compared to mounded RPM® seedlings during the first two years of growth (Table 2). Perhaps this was due, in part, to flooding during the first two years in which some seedlings were inundated for >20 consecutive days (Heimann and Mettler-Cherry 2004). Plant growth is often adversely affected by flooding (Kozlowski 1984), although some evidence suggests that flood tolerant species such as bur (*Quercus macrocarpa*, Michx.) and swamp white (*Quercus bicolor*, Willd) oak increase basal diameter as a physiological response to flooding (Walsh 2007). Pin oak and pecan are categorized as moderately flood tolerant (Kabrick and Dey 2001), but may not have the same adaptations as more flood tolerant oak species.

Figure 10. RPM® seedling.

Comparing Stock Types

Annual percent growth and RGR were lowest in RPM® stock (Table 2 and Figure 6). This suggests that although RPM® seedlings have a head start on other planting stocks in terms of basal diameter and height, they do not necessarily grow at significantly higher rates. Mullins et al. (1998) found similar growth characteristics between seedlings and containerized planting stock. There were no significant differences in annual percent growth rate by the sixth growing season, indicating that differences in growth rates between treatments may eventually taper off.

Average tree height by 2007 was greatest for mounded RPM® stock for both species in this study. Krekeler et al. (2006) compared height increments of different stock types and reported greater heights for RPM® seedlings. Unmounded RPM® pin oak seedlings had negative height increments from 2001-2003 due to animal herbivory. Dey et al. (2004) reported similar effects of herbivory on RPM® seedlings. Herbivory may have confounded our results in this study. Herbivory may have confounded our results in this study and was reported for all treatments throughout all growing seasons, but was most noticeable in unmounded pin oak seedlings from 2001-2003. During these years, negative percent increases in height were recorded (Table 2). Buckley (2002) reported significantly greater browsing on high quality seedlings than standard seedlings. Therefore, high quality seedlings with greater leaf biomass may be a preferred target for herbivores. Herbivory by rodents on container grown seedlings has been reported at levels >95% in the Yazoo National Wildlife Refuge (Burkett and Williams 1998). Despite these findings, Oswalt et al. (2006) suggests high quality seedlings may cross the "browse line" faster than other seedlings and have more success of establishment. Trees over five feet in height tend to be mostly out of reach from deer browsing (Halls and Crawford 1960). In contrast to these studies, pin oak mounded RPM® seedlings in this study averaged above this threshold three years after planting. Average height of unmounded pin oak RPM® seedlings did not surpass this benchmark until the 2006 growing season, while bare root pin oak and mounded RPM® pecan seedlings did not average over five feet until measured in 2007. The average height for bare root pecan and all direct seeded trees did not surpass the five-foot mark; however, survival was high for these planting stocks (Table 1) with no major herbivory recorded until 2006.

Recommendations

Trees are slow growing, and therefore, long term monitoring of growth and mortality are necessary to determine the success of forest regeneration efforts and the relationships between environmental variables. Bottomland hardwood trees exhibit an array of tolerances to edaphic and hydrologic conditions, so it is therefore paramount to match species silvical characters with conditions best suited for successful forestry management practices. Precipitation, flood duration, flood frequency, canopy closure, and other complex interactions can change from year to year (Heimann and Mettler-Cherry 2004 and Lockhart et al. 2005) and it may take several seasons to assess these effects on tree growth. Information regarding optimal conditions is either minimal or lacking with respect to those key species typically used for reforestation projects in Missouri.

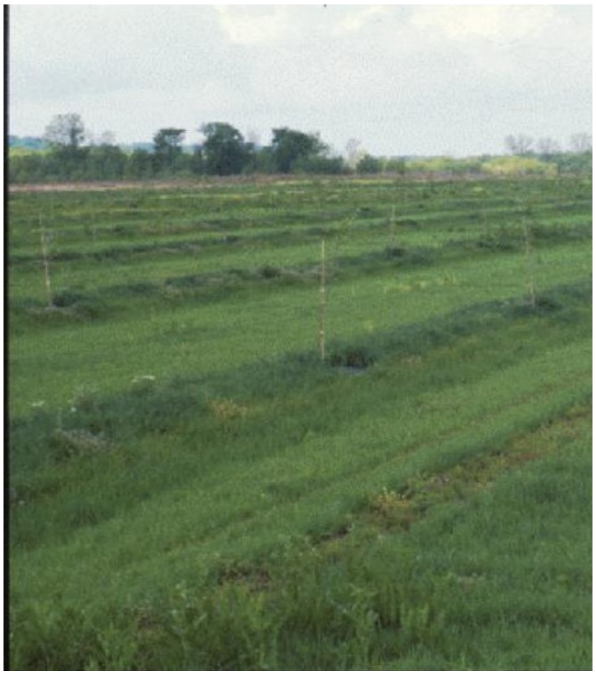

Figure 11. Mounded RPM® seedlings.

Studies like this that document restoration success and failure over multiple growing seasons provide valuable information to managers and foresters. The relationship between flood frequency and topographic elevation information are often missing from many bottomland hardwood reforestation plans. Minor variation in topography can have dramatic effects on seedling growth and presumably on mortality rates for bottomland hardwoods (Schoenholtz et al. 2005). Soil mounding (or bedding) can improve drainage and increase the overall height above flood water levels for bottomland hardwoods (Figure 11) that are less tolerant of flooding (Dey et al. 2008). Few published reports have documented the affects of soil mounding on bottomland hardwood establishment (Dey et al. 2008). In this study, pin oak planted in mounded (Figure 12) soils were taller and had greater basal diameters than pin oak planted in unmounded soils by 2007 (Figure 5). Pin oak in mounded soils also had a greater cumulative relative growth rate by 2007 than pin oaks in unmounded soils. Planting oaks in mounded soils may also be an effective method of accelerating canopy closure and should be considered by managers seeking restoration in floodplain forests. However, because of the paucity of similar studies, the efficacy of planting other species on mounded soils is not yet available. While it is not known with any certainty that flooding was responsible for tree mortality in this study, most of the tree mortality in this study was recorded after the third year of monitoring further necessitating long-term study. If monitoring had not occurred for at least four years, this information would not have been known and valuable insight would have been lost.

Another important factor for reforestation success is competition. Competition can be stated as occurring in two forms: 1) vegetative competitors and 2) the associated animal interactions with seedlings and volunteer vegetation in the reforestation area (i.e. browsing or herbivory). For instance, when grasses and small shrubs are the dominant competitors, which are often the case during afforestation on agriculture fields and in floodplains along large rivers, it typically takes 2-5 years before a stand becomes dominant to the point of out competing nearby vegetation for resources (Dey et al. 2008). When other trees, (light seeded invaders or early successional species such as silver maple (*Acer saccharinum* L.) or green ash (*Fraxinus pennsylvanica* Marsh.)) are dominant competitors, as is often the case during reforestation, it can take as long as 8-10 years before planted stands become dominant (Dey et al. 2008) if they are not overtopped by competition earlier on. Consequently, restoration success cannot be determined reliably in the early years after planting (Dey et al. 2008).

Selected MDC Experiences

One observation (by MDC Foresters) suggests that barrier mats used to reduce weedy competition near new plantings can become problematic. Small rodents build nests under the mats that cause a two-fold problem. The first arises when rodents disturb the roots (Heimann and Mettler-Cherry 2004). A close inspection suggests they may forage on the roots during winter. Secondly, as predators such as fox search for prey, they dig under the mats, which may disturb the root system and result in tree mortality (Lonnie Messbarger, MDC Forester NW Region personal communication). Finally, floodwaters, particularly those with a moderate current, tend to lift the mats, which then become tangled in the above ground biomass, frequently damaging woody tissues (Lonnie Messbarger, MDC Forester NW Region personal communication). Additional observations suggest that tree tubes placed at the base of plantings to protect seedlings from deer rubbing and damage due to mowing rarely last past the second or third growing season (Ryan Kelly, Area Manager MDC, Ted Shanks, CA, personal communication, Stanturf et al. 2004). While deer rubbing is prevented with tree tubes, browsing remains the highest concern of most managers (Lonnie Messbarger, MDC Forester NW Region personal communication and Stanturf et al., 2001).

Mounded high quality seedlings may have the additional effect of reducing deer browsing. Poorly established seedling plots often lead to a pattern of annual deer browsing that maintains trees near shrub level (Netzer 1984). High quality seedlings alone may not be sufficient for reducing deer browsing. In this study, unmounded pin oak seedlings experienced negative mean height increments during two growing seasons as an artifact of heavy deer browse, while mounded pin oak seedlings were not equally affected by browsing. The combination of planting RPM® seedlings in mounded soil may provide a means to breach the deer browse line quickly and lessen the effects of herbivory.

Deer browsing of tender vegetation have damaged many recent plantings. Anecdotal evidence suggests deer and animal repellants (Tree Guard® and Plantskydd®) loose efficacy requiring reapplication after precipitation. Additionally, observations indicate longer lasting repellants generally require reapplication on an annual basis. Plantings that have not had weedy competition removed tend to have less damage from browsing; observations suggest the plantings are "camouflaged" by the nearby vegetation. However, plantings without weed control tend to have slower growth rates as smaller seedlings struggle against competition. In areas protected by levees, Johnson grass (*Sorghum halepense*, L. Pers.) tends to be the strongest competitor for nutrients and growing space. In batture areas, woody vines such as trumpet creeper (*Campsis radicans*, Seem.), bur cucumber (*Sicyos angulatus*, L.), and kudzu (*Pueraria montana* var. *lobata*, (Willd.), create competition and over-topping problems (Gardiner et al 2002).

In general, information gathered from managers and literature sources indicates that direct seeding (Figure 13) of hard mast species can be the most cost-effective way of attempting reforestation with respect to labor and material costs (McKevlin 1992, Schweitzer and Stanturf 1997, King and Keeland 1999, Allen et al. 2001, Stanturf et al. 2001, and Schoenholtz et al. 2005). However, direct seeding has been described as having intermediate to very poor success, working well in some places and not at all in others (Schweitzer 1998). For example, areas that were direct seeded at Nishnabotna CA showed inconsistent and patchy germination. Additionally, information shared by Mike Anderson, (MDC Forestry Supervisor, SE Region), suggests acorn germination can be problematic and unreliable. His experiences with acorn germination trials have shown successful germination in experimental situations, but when acorns from the same batch were used for direct seeding no successful germination occurred.

Figure 12. Implementation of mounds for RPM® seedlings at FRCA.

Furthermore, in years where acorn production was considered significant and acorn germination did occur, little or no natural regeneration resulted in areas such as Duck Creek CA (Mike Anderson, MDC Forestry Supervisor, SE Region, personal communication). The same techniques and procedures used at Nishnabotna CA appear to have been somewhat successful at Worthwine Island CA (Lonnie Messbarger, MDC Forester NW Region, personal communication). To date, no MDC studies have occurred to support anecdotal observations of when, where, or how direct seeding works or could be improved. In general, scant recorded data suggest why direct seeding works in some areas and not others (Schweitzer 1998). Information shared with MDC foresters suggests that direct seeding operations in Iowa have had some success using a combination of techniques. Pre-stratified seeds, disking, and weed control for site preparation, followed up with applications of herbicide for two years resulted in fair success along the Missouri River floodplain in Iowa (Lonnie Messbarger, MDC Forester NW Region, personal communication). Whereas direct seeding operations at Duck Creek CA have had little success (Mike Anderson, MDC Forestry Supervisor, SE Region, personal communication).

Figure 13. Direct seeding of acorns at FRCA.

On rare occasions where direct seeding has been successful, observations suggest there could be a lag time of two to three years before acorns germinate (Mike Anderson, MDC Forestry Supervisor, SE Region, personal communication and Lonnie Messbarger, MDC Forester NW Region personal communication) making some direct seeding efforts initially appear unsuccessful. Where germination has been deemed successful (obvious germination and growth of seedlings from acorns), seedling spacing may be problematic. Patchy germination rates within a site can lead to "gaps" within the reforestation effort requiring re-entry into the stand to transplant or supplement the initial planting (Schweitzer 1998). Additionally, germination may be "too thick" on other places requiring moving the seedlings or brush mowing the area to create openings or rows for future TSI (timber stand improvement) and to eliminate competition (Schweitzer 1998). If brush mowing must be delayed, application of herbicides with a backpack sprayer may be required to reduce weedy competition (Schweitzer 1998).

When compared with direct seeding and planting large container seedlings, bare root planting (Figure 14) stock appears to be the second most cost effective manner to complete reforestation efforts (McKevlin 1992, Schweitzer and Stanturf 1997, King and Keeland 1999, Allen et al. 2001, Stanturf et al. 2001, and Schoenholtz et al. 2005). Staff time can be reduced by using mechanized planting operations and/or hand planting of bare root when compared to planting container seedlings. However, machinery must be obtained for both planting and site preparation (mowing, disking, or ripping the soil). Observations suggest planting stock must be carefully handled to ensure minimal damage during planting operations. If the seedlings are hand planted, J-rooting and insufficient contact between the soil and the roots can result in unsuccessful reforestation efforts. Moderate success has been noted from trimming roots to avoid J-rooting, although this practice is not typical.

Figure 14. Bare root seedling planted at FRCA.

Allen et al. (2001) provides proper planting techniques with hand tools and makes suggestions for proper handling of planting stock. Additionally, some success has been noted from using "cuttings" in areas where soil remains moist but well drained. In areas such as Bluffwoods CA where bare root plantings occurred 15 years ago, TSI has been used to release trees from above- and below-ground competition allowing for further growth.

The most costly form of reforestation includes using RPM® planting stock. Besides the cost disparity of RPM® planting stock (compared to bare-root or direct seeding efforts), the large size of the trees and root biomass, either require the use of a tractor with an auger attachment or hand digging large holes for planting. Forrest Keeling advertises RPM® trees as a "walk-away system" (http://www.fknursery.com/Walk_away_System/default.asp). Their prescribed manner of planting includes regular and gradual increases in fertilization through the first four years after planting. In many instances, RPM® planting stock has been treated as "walk away" with little or no follow up treatments after planting. In some instances, initial observations suggest that bare root seedling percentage growth rates (both diameter and height) meet and can exceed that of RPM® planting stock (first year results from John Kabrick 2003 at Plowboy Bend and Smoky Waters CAs, personal communication). A specific project designed to collect information will be needed to determine whether additional fertilization requirement would enhance RPM® growth rates (Figure 15).

Figure 15. Pin oak RPM® planted on mounded soil at FRCA.

CONCLUSIONS

Matching tree species to edaphic conditions can be essential in meeting with successful regeneration, restoration, reforestation, and afforestation efforts. Conditions that are difficult or impossible to control such as temperature, hydrology, light levels, soil pH, and structure must be considered (Dey et al. 2008, Allen et al. 2001, Stanturf et al. 1998). Flood frequency and topographic elevation information needs are also necessary. Species silvical characters must be matched with these conditions.

Single species plantings appear to have lower performance as well as adding little to species or structural diversity to altered floodplain forests. Mixed species plantings seem to offer a wider use of above and below ground growing space (Lockhart et al. 2005). Additionally, the crown architecture, branching patterns, fruiting patterns, and overall benefit to a wide range of wildlife appears to be best mimicked with mixed species plantings (Lockhart et al. 2005). Future ME (Management Evaluation) projects designed to identify the best mix of species for optimum "crop" tree performance are in the planning stages.

Further study is needed to determine why the most cost effective method of restoration, reforestation, and afforestation is direct seeding, yet is also the least reliable. Questions still remain regarding the link between "good" acorn crop production and lack of natural regeneration seen in bottomland forests, as well as the length of time needed for germinates to reach the minimum size/age class to successfully compete for resources. Defining the requirements for successful acorn germination will be paramount. Many questions still exist regarding edaphic conditions that control germination, acorn predation, and light levels needed to allow for seedling development into the overstory. Without studies geared toward determining when competition becomes problematic for young germinates, light requirements, and understanding how historical conditions affect germination and recruitment, keys to successful direct seeding efforts will remain a mystery.

A few key elements are needed to aid in directing managers toward successful restoration, reforestation, and afforestation efforts. Without consistent and required data collection, (mortality, height, and dbh for instance) very little information can be given as examples for other managers. While some managers and foresters do attempt to keep this type of information, it is not standardized nor is it housed in such a way that information is easily accessible. One difficulty lies in trying to reproduce a project or avoid similar unwanted outcomes without sound data to base decisions upon especially when conducted in the absence of an adaptive management approach. Similarly, clear information on edaphic (i.e. soil type and flooding frequent) conditions appear to be lacking even when there is sufficient efforts made in data collection. A tool that may aid in this information sharing would be a standardized data sheet listing pertinent information. In addition, because trees are slow growing, it must be realized that information needs far exceed a standard 3-5 year study. Trees often have a lag time in their response to treatments requiring additionally follow up to obtain all pertinent information.

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