THE ROLE OF LARGE CONTAINER SEEDLINGS IN AFFORESTING OAKS IN BOTTOMLANDS

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Abstract—We planted large container (RPM®) and 1-0 bareroot seedlings of pin oak (*Quercus palustris* Muenchh.) and swamp white oak (*Q. bicolor* Willd.) in crop fields in the Missouri River floodplain. We also evaluated the benefits of soil mounding and a grass (*Agrostis gigantea* Roth) cover crop. RPM® oak seedlings had significantly greater survival and basal diameter increment after 3 years than bareroot seedlings. RPM® trees lost significantly more height during the first 3 years than bareroot seedlings due to rabbit herbivory, which was substantially greater in the natural vegetation than the redtop grass fields. Oak seedlings in redtop grass cover grew substantially more in diameter and height than oaks competing with natural vegetation. Soil mounding had no significant effect on oak survival or growth. Swamp white oak RPM® seedlings produced acorns annually the first 4 years. Planting large container seedlings in redtop grass improved early oak regeneration success and rapidly restored acorn production.

INTRODUCTION

Public land managers and private land owners have a strong interest in regenerating native oak species (*Quercus* sp.) on what are largely agricultural floodplains. Bottomland oak species are highly valued for timber products and wildlife habitat. They are also of conservation concern because of the substantial decline in oaks from historic levels and the difficulty in regenerating them on highly productive floodplains.

The Great Flood of 1993 inundated floodplains throughout much of the summer ruining bottomland farms and causing extensive mortality of oaks in forests along the Missouri and Mississippi Rivers. Since 1993, many abandoned bottomland crop fields have naturally regenerated to forests dominated by pioneering species such as cottonwood (*Populus deltoides* Bartr. ex Marsh.), silver maple (*Acer saccharinum* L.), sycamore (*Platanus occidentalis* L.), and willow (*Salix nigra* Marsh.). These species are abundant in remnant floodplain forests, thus ensuring a local seed supply. They are prolific annual seed producers, and their seed are easily dispersed by wind and water. Seed germination is favored on mineral soils in open environments, typical of conditions following abandonment of bottomland crop fields. Their seedlings exhibit rapid juvenile growth, which makes them highly competitive on the productive bottomland soils.

Former small- to moderate-sized bottomland crop fields have developed into well-stocked sapling stands dominated by these pioneer species in the years since 1993. Cottonwood, willow, sycamore, silver maple, and other early successional tree species are native to bottomlands and are considered desirable reproduction. A widespread pattern in forest succession on former bottomland crop fields is the lack of oaks and other nut-producing trees. For example, Shear and others (1996) found a lack of hard mast species in 50-year-old forests that naturally regenerated on bottomland crop fields in southwestern Kentucky. Thus, artificial regeneration of oaks is needed to increase the likelihood that oaks are present in future forests.

Traditional methods of planting bareroot oak seedlings or direct seeding acorns in bottomlands have not always been successful. For example, in a survey of 4-year-old Wetland Reserve Program plantings in the Mississippi River floodplain, Schweitzer and Stanturf (1997) found that only 9 percent of the total reforested land in 13 Mississippi counties met the Natural Resources Conservation Service requirement for at least 125 hard mast stems per acre in 3-year-old stands.

Oak regeneration failures in bottomland crop fields are largely a result of the low competitiveness of small oak seedlings on sites that are capable of producing tremendous herbaceous biomass in one summer. Small oak seedlings also are less competitive than the pioneer tree species that invade abandoned crop fields. In addition, oak plantings are not often maintained by controlling competing vegetation, which makes successful oak regeneration less likely. Oak species are moderately tolerant to intolerant of shade and unable to persist in the heavy shade of competing vegetation.

Oak regeneration success can be improved, in part, by planting large seedlings, particularly those having well-developed root systems (Gardiner and others 2002, Johnson and others 2002, Kormanik and others 1998, Schultz and Thompson 1997, Stanturf and others 1998). Nursery managers can produce hardwood bareroot seedlings with large root systems that have five or more large lateral roots by undercutting the taproot, growing seedlings at lower seedbed densities, or by transplanting 1-0 seedlings for a second year. Air pruning the roots of seedlings grown in open-bottomed containers is another way to promote the growth of large lateral roots and dense fibrous root systems (Dey and others 2004).

In the Midwest, several private nurseries have begun commercial production of large (e.g., 3- to 5-gallon) container seedlings that are being used in the afforestation of bottomland crop fields on public and private lands. The Forrest Keeling Nursery of Elsberry, MO, has developed a nursery cultural technique, the Root Production Method (RPM®), to produce high-quality hardwood seedlings that have large basal diameter and height and a substantial fibrous root system (Dey

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and others 2004). For the past 5 years or so, these large container seedlings have been planted in various floodplain situations throughout the Midwest. In 1999, we began a study to evaluate the performance of these large container seedlings in the afforestation of bottomland crop fields. This paper presents early survival and growth performance of large container seedlings compared with that of 1-0 bareroot seedlings in regenerating pin oak and swamp white oak in bottomland crop fields along the lower Missouri River. We discuss the role of large container seedlings in regenerating oaks in floodplains.

METHODS

Dey and others (2003) provided a detailed explanation of the experimental design and study establishment. In summary, a study was established to evaluate methods for regenerating pin oak and swamp white oak on former agricultural crop fields in the Missouri River floodplain in the fall of 1999. The study fields had been in crop production for years before this study. Soils at the study sites were mapped as Sarpy Fine Sand (mixed, mesic, Typic Udipsamments), Haynie Silt Loam (coarse-silty, mixed, superactive, calcarious, mesic Mollic Udifluvents), and Leta Silty Clay (clayey over loamy, smectitic, calcareous, mesic Aeric Fluvaquents). Two floodplain properties were used in this study, Smoky Waters and Plowboy Bend Conservation Areas, both managed by the Missouri Department of Conservation. The Smoky Waters site, which lies at the confluence of the Missouri and Osage Rivers, is not protected by levees and is subject to flooding. The site at Plowboy Bend, located along the Missouri River, is protected by a levee.

Both 1-0 bareroot and 3- and 5-gallon RPM® seedlings were planted to evaluate the effect of seedling size and nursery stock type on the survival and growth of pin oak and swamp white oak seedlings. Seedlings were planted in soil mounds created with a rice plow or in unmounded soil and with either a cover crop of redtop grass or with natural vegetation that normally colonizes abandoned bottomland crop fields.

Dey and others (2004) have described the RPM® cultural technique in some detail. Using oak as an example, the process generally involves (1) germinating seed on soil media in shallow, open-mesh, bottomless trays, (2) transplanting seedlings into 4-inch square bottomless band containers at the end of the first shoot flush, and (3) a final transplanting of seedlings into 3- or 5-gallon pots whether they are grown in the nursery for 1 or 2 years, respectively.

Initial total height and basal stem diameter 1 inch above the ground were measured on all seedlings after planting and again at the end of each growing season. Seedling survival was determined each year, and animal damage to seedlings was recorded. Animal damage consisted primarily of shoot clipping and girdling of main stems by eastern cottontail rabbits (*Sylvilagus floridanus* Allen) and white-tailed deer (*Odocoileus virginianus* Boddaert).

Analysis of variance (ANOVA) was used to determine significant ($P < 0.05$) growth rate differences among species and stock type combinations between fields with and without redtop grass and between mounded and non-mounded planting units. In this ANOVA, site was a random effect and cover crop treatment, mounding treatment, and species and stock type combinations were fixed effects. The significance of treatment effects on tree growth and survival was determined using their respective site interactions as error terms. For significant effects, orthogonal contrasts were used to compare mean differences. Logistic regression was used to develop models that predict survival based on seedling characteristics and management treatments.

RESULTS AND DISCUSSION

Comparison of Initial Planting Stock

Average basal diameters of 5-gallon RPM® seedlings were slightly larger than 3-gallon seedlings for both pin oak and swamp white oak, and diameters of both RPM® stock types were substantially larger than the bareroot seedlings (fig. 1). Pin oak and swamp white oak RPM® seedlings averaged 0.6 to 0.8 inches in basal diameter compared to 0.3 inches for bareroot seedlings. Similar trends were seen in average height of seedlings among the different stock types. Heights of RPM® seedlings averaged 4.9 feet or larger compared to bareroot seedlings, which averaged 2.3 feet or less. Pin oaks were generally slightly larger than swamp white oaks within a given stock type.

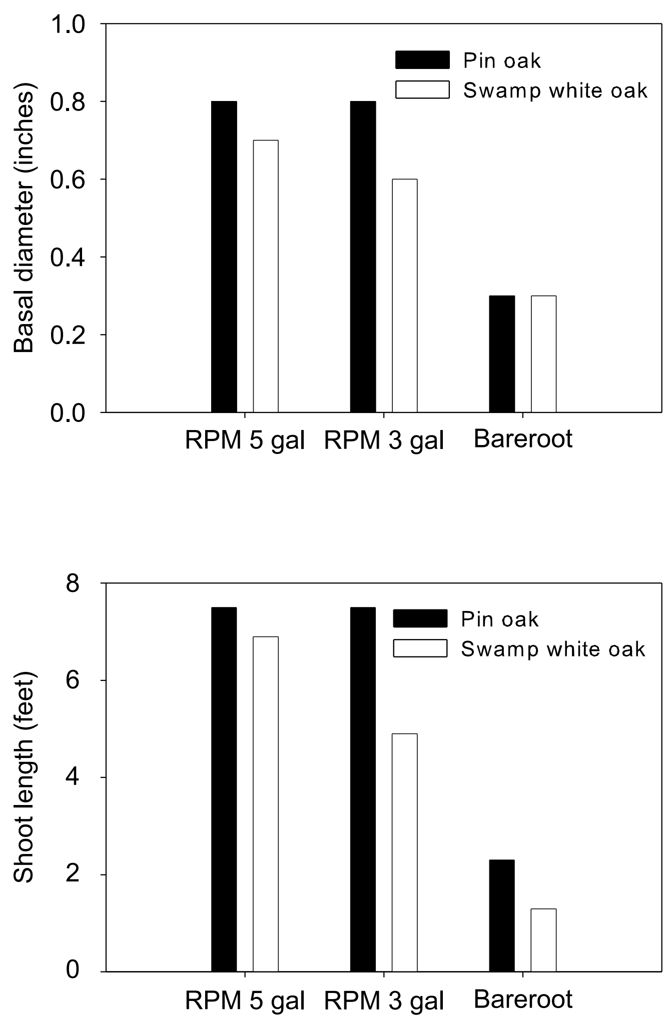

Figure 1—Average basal diameter (1-inch above the root collar) and shoot length of pin oak and swamp white oak RPM® and bareroot seedlings typical of those used in this study.

Table 1—Root system differences between 1-0 bareroot (BR) and RPM® pin oak and swamp white oak seedlings planted in this study

Stock type	Root volume	Root dry weight
	cm³ H_2O	*g*
Pin oak BR	26	17
Pin oak RPM® 3 gallon	236	117
Pin oak RPM® 5 gallon	223	118
Swamp white oak BR	33	20
Swamp white oak RPM® 3 gallon	141	64
Swamp white RPM® 5 gallon	252	138

The root systems of RPM® seedlings had substantially more volume and dry weight than bareroot seedlings, regardless of species (table 1). The root systems of 3- and 5-gallon pin oak RPM® seedlings were similar in volume and dry weight. For all RPM® seedlings, root volume and dry weight were greatest for 5-gallon swamp white oak RPM® seedlings and smallest for 3-gallon swamp white oak. However, the smallest RPM® root systems were substantially larger than those of bareroot seedlings.

The RPM® process builds a large root mass with numerous sizeable lateral roots concentrated just below the root collar in a short period of time (e.g., 210 days to produce a plantable 3-gallon pin oak seedling). Johnson and others (2002), Kormanik and others (1998), and Schultz and Thompson (1997) have emphasized that the key to successful oak regeneration, both natural and artificial, is the formation of a large root system. Any silvicultural systems or nursery practices that create favorable conditions for the growth of oak root systems enhance oak's competitiveness.

The perceived advantages of container grown RPM® seedlings include (1) rapid early growth that is driven by a large, intact root system, which minimizes transplant shock and facilitates early root growth in the establishment year; and (2) seedlings tall enough (e.g., ≥ 5 feet) to minimize deer herbivory on the terminal shoot and to improve chances that the live crown will remain above growing-season floods. Survival of seedlings is greatly enhanced if their live crowns avoid inundation during growing-season floods. Floods that cause defoliation of hardwood seedlings force trees to expend their remaining energy forming a second crown, which places them at a greater disadvantage with other competing vegetation on these highly productive sites.

Natural Disturbances

Rabbit herbivory—Every winter after the first year, cottontail rabbits have girdled and shoot clipped oak seedlings and oak sprouts. The amount and severity of rabbit damage to planted oaks varied greatly between the cover crop treatments (i.e., redtop grass versus natural vegetation fields).

In the natural vegetation fields, the composition and structure of winter cover provided by forbs promoted higher rabbit densities (3 rabbits per acre) than in the redtop grass fields (1.0 rabbit per acre) (Dugger and others 2004). In the winter, the dead tops of forbs and clumps of Johnsongrass [*Sorghum halepense* (L.) Pers.] remained somewhat erect, providing cover that was as high as 3 feet. However, redtop grass matted down to 0.6 feet and provided little hiding cover for rabbits from predators. Thus, rabbits were able to move freely across the natural vegetation fields causing damage to nearly all of the seedlings each winter. Rabbits clipped the shoots of all bareroot seedlings and severely girdled (more than half of the circumference of the stem) 90 percent or more of the RPM® seedlings in the natural vegetation fields by the end of the second winter. In comparison, damage to oak seedlings by rabbits was much less extensive and severe in the redtop grass fields. These differences in winter habitat between the cover crop treatments affected rabbit densities and movements, which in turn contributed to the significant differences in oak seedling survival, growth, and acorn production between the cover crop treatments.

Flooding—In 2 of the past 4 years (2001, 2002), the study site at Smoky Waters was flooded for up to 3 weeks in June. Duration of flooding was variable across the redtop grass and natural vegetation fields due to differences in elevation. Depth of flooding was also variable, with maximum depths reaching 4 to 5 feet, enough to completely inundate bareroot seedlings and oak sprout clumps formed by rabbit-girdled RPM® trees.

Survival

Survival of oak RPM® seedlings remained high (> 94 percent) during the first 3 years (fig. 2), while survival of bareroot seedlings continued to decline for both swamp white oak and pin oak. There was no significant difference in survival between 3- and 5-gallon RPM® seedlings. After 3 years in the field, survival of swamp white oak bareroot seedlings was significantly higher ($P < 0.01$) than pin oak bareroot seedlings. Swamp white oak bareroot survival averaged 76 percent, while survival for pin oak bareroot seedlings was 54 percent. There was no significant difference ($P = 0.24$) between 3- and 5-gallon RPM® seedling survival, nor between swamp white oak and pin oak RPM® seedling survival ($P = 0.87$). Soil mounding and cover crop treatments did not significantly affect oak seedling survival.

Basal Diameter Growth

Basal diameter increment after 3 years was significantly greater ($P < 0.01$) for RPM® seedlings than bareroot stock, regardless of species (fig. 2). There was no significant difference in basal diameter increment between 3- and 5-gallon RPM® seedlings. The average basal diameter of all RPM® oak seedlings increased 0.3 inches in the first 3 years, whereas bareroot seedlings increased only 0.1 inches. There was no significant difference ($P = 0.34$) in basal diameter increment between the 3- and the 5-gallon RPM® seedlings. The basal diameter of pin oak 5-gallon RPM® seedlings increased the most during the first 3 years, averaging 0.4 inches of new growth. Basal diameter increment was least (0.03 inches in 3 years) for pin oak bareroot seedlings. The above analysis includes rabbit-damaged and undamaged trees. By removing the rabbit-damaged trees, average basal diameter increment was 0.6 inches for RPM® seedlings and 0.1 inches for bareroot trees.

Although soil mounds functioned as anticipated by improving drainage and aeration, they did not significantly affect diameter growth. Kabrick and others (2005) have reported more

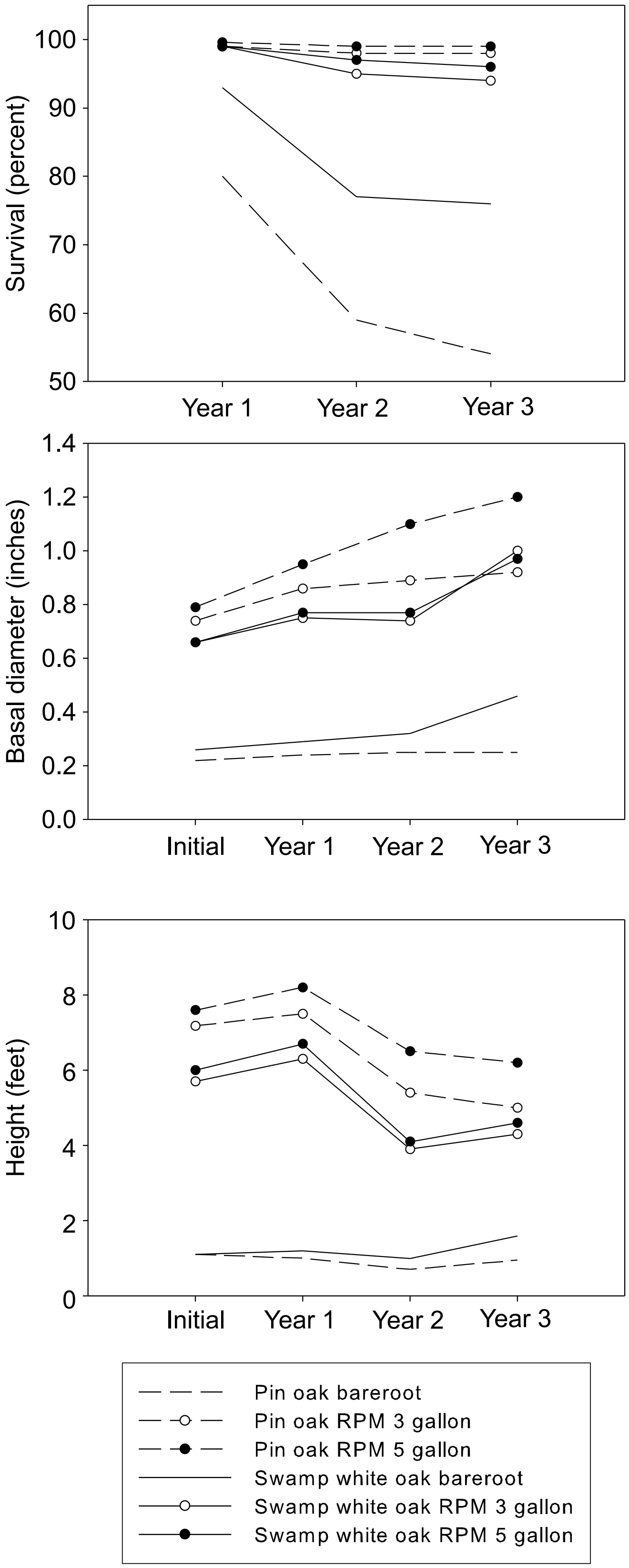

Figure 2—Survival, basal diameter and height of swamp white oak and pin oak RPM® and bareroot seedlings during the first 3 years in this study.

detailed effects of soil mounding on soil properties and oak regeneration based on the results from this study. Basal diameter increment of all trees combined was substantially larger in redtop grass fields (0.6 inches) than in natural vegetation fields (0.1 inches); however, no significant differences can as yet be reported ($P = 0.08$). For undamaged trees, average basal diameter increment was 0.6 inches for RPM® seedlings in redtop grass fields and 0.2 inches in natural vegetation fields, while the basal diameter of bareroot seedlings increased by 0.1 inches in redtop grass but decreased by 0.1 inches in natural vegetation fields.

Height Growth

Average height increment after 3 years was negative for most species and nursery stock types, because cottontail rabbits caused extensive damage by girdling the stems of RPM® seedlings or by clipping the shoots of bareroot seedlings at ground-level (fig. 2). Severely girdled or clipped trees that survived produced multiple-stemmed sprout clumps, but new shoot growth was insufficient to recover to original seedling heights, especially for RPM® seedlings.

Three-year height increment was significantly less ($P < 0.01$) for RPM® than bareroot seedlings. There was no significant difference in height increment between 3- and 5-gallon RPM® seedlings. For bareroot seedlings that had been shoot-clipped by rabbits, annual sprout growth came close to, or slightly exceeded, the initial height, resulting in small negative or positive increments in height. In contrast, net height increment was much lower in initially tall RPM® trees, because rabbit girdling, which occurred in the lower 1.0 foot of the stem, caused shoot dieback to near ground-level. In addition, trees were often repeatedly damaged by rabbits each winter. Three-year height increment averaged -1.6 feet for the RPM® seedlings. Despite rabbit browsing, RPM® trees remained taller than bareroot seedlings 3 years after planting. Undamaged trees in the redtop grass fields had slightly positive average height growth (0.3 feet for bareroot and RPM® seedlings), but net growth was negative in natural vegetation fields, averaging -1.7 feet for RPM® and -0.4 feet for bareroot seedlings.

Height growth of undamaged RPM® seedlings may be low because these trees were planted on a 30 by 30 foot spacing; and widely spaced, open-grown trees often experience reductions in height growth, especially trees with weak epinastic control such as the oaks (Oliver and Larson 1996). Also, height growth of oak reproduction is slow at first, because seedlings characteristically allocate photosynthates to root growth often at the expense of shoot growth (Johnson and others 2002). Height growth of RPM® and bareroot seedlings may also be limited by low levels of foliar nitrogen, which averaged 2.05 percent at Smoky Waters and 1.71 percent at Plowboy Bend Conservation Areas (Kabrick and others 2005).

An analysis of all trees by cover crop treatment showed that 3-year height increment was significantly higher ($P = 0.02$) for oak seedlings growing in the redtop grass fields than those trees competing with natural vegetation. There may be less light competition in the redtop grass fields during the growing season than in the natural vegetation fields. Redtop grass typically grows to a height of 1.5 to 2.0 feet, whereas herbaceous ground cover in the natural vegetation fields grew to over 6.6 feet in height, overtopping many of the oak seedlings.

Also, rabbit densities were less and fewer trees were damaged in the redtop grass than in the natural vegetation fields. There was no significant difference in height growth among trees on mounded and unmounded soils.

Acorn Production

Swamp white oak RPM® seedlings that were 18 to 24 months old at time of planting produced acorns in each of the first 4 years following outplanting (table 2). Acorn production occurred in a small proportion (3.5 percent) of the 2,522 swamp white oak RPM® seedlings their first year in the field. Most of the production (60 percent) occurred in oaks from 5-gallon containers, but larger 3-gallon container RPM® trees also produced acorns. Individual trees were able to produce as many as 125 acorns. The probability of a RPM® swamp white oak seedling producing at least one sound acorn in the first year after planting was significantly related to initial basal diameter and height of the seedling (Grossman and others 2003).

The number of trees bearing acorns dropped in year 2 because rabbit herbivory and shoot dieback took RPM® trees in the natural vegetation fields out of production. Production in years 3 and 4 came almost exclusively from RPM® trees growing in the redtop grass fields. A single pin oak RPM® seedling produced acorns for the first time in the fourth year. Consistent, early production of acorns is surprising considering that open-grown oaks do not begin producing seed until they are 20 to 30 years old (Burns and Honkala 1990). In contrast, no bareroot oak seedlings have produced acorns after four growing seasons. Early fruiting and nut production in RPM® trees is a substantial benefit for wildlife, and it restores the ability for oaks to regenerate naturally on former bottomland crop fields where lack of local seed supply is a factor limiting oak regeneration.

Role of Large Container Seedlings in Regenerating Hard Mast Species

In the afforestation of bottomland crop fields, managers need to consider the contributions that can be expected from natural regeneration and the need for artificial regeneration. In extremely large fields, artificial regeneration may be needed even for pioneering species such as cottonwood, silver maple, sycamore, and willow (Allen 1990, Twedt and Wilson 2002). Relying on natural regeneration in large fields may result in understocked stands, in part because of the difficulty in timing an appropriate seedbed and adequate competition control with seed dispersal to the site. In smaller fields, pioneering species often are able to regenerate to well-stocked stands because establishment conditions are easier to control through site preparation and seed sources are often adjacent to the area. Regardless of field size, managers are almost always forced into artificially regenerating heavy nut species such as the oaks due to the lack of a natural seed source.

Table 2—Acorn production in swamp white oak RPM® seedlings during the first 4 years at Smoky Waters and Plowboy Bend Conservation Areas

Year	No. nut-bearing trees	Average no. acorns per tree
1	86	4.3
2	29	5.2
3	70	6.3
4	152	12.5

Planting bareroot seedlings and direct seeding are the most common methods for regenerating oaks in agricultural floodplains. Planting container seedlings is less common, especially trees grown in very large (3- to 5-gallon) containers. Of course, the initial cost of these seedlings is much higher than bareroot seedlings. For example, a 3-gallon container oak seedling may cost $8.00 compared to $0.50 to $1.00 for a bareroot seedling. Our study is too young to consider an economic analysis, which should consider the cost of the entire regeneration prescription needed to produce a successful tree, one that is free-to-grow and that will be in a codominant or dominant position in the mature forest.

We have seen that large container seedlings have significantly higher survival and diameter growth than bareroot seedlings after 3 years. It is still too early in our study to determine if a planted oak is successful or not in the context of our definition of success but if trends continue, it will take fewer large container seedlings to get a successful tree than if bareroot seedlings are planted.

The manager's objectives must be considered before identifying artificial regeneration methods for restoring forests to agricultural floodplains. Public managers often want hard mast species as a component of a native bottomland forests. Thus, planting large container seedlings on a 60 by 60 foot spacing (12 trees per acre) may be an affordable way to increase the probability that hard mast species will be a component of the overstory and capable of producing good mast crops periodically. Interplanting with bareroot seedlings or direct seeding may be used to supplement hard mast regeneration and diversify the forest. Natural regeneration of pioneer species may fill in if an adequate seed source is available and site preparation is properly done.

In managing the greater floodplain property, which may be as large as 3,000 acres or more, it may be desirable to have hard mast production somewhere on the property but not necessarily on every acre. In this case, managers may choose to plant large container seedlings on tighter spacings, e.g., 30 by 30 feet (48 trees per acre) or 20 by 20 feet (109 trees per acre) and manage them more intensively on small parcels, e.g., 1 to 5 acres or so, located throughout the floodplain.

Commonly on abandoned bottomland crop fields, young (< 10 years), dense sapling stands of cottonwood, willow and sycamore have developed. In these stands, managers may consider planting large container oak seedlings in group openings. Openings can be created by combinations of mechanical and chemical treatments. Or, large container seedlings may be underplanted in thinned cottonwood sapling stands.

The early nut-producing capacity demonstrated by large container oak seedlings is of particular interest to owners of properties managed as waterfowl hunt clubs or public greentree reservoirs. In many cases, acorn production on these properties is limited by the low abundance of oak trees, by the advanced age of oak trees that are declining in their acorn production capacity, or because many of the mature oak trees were lost in a catastrophic flood such as the Great Flood of 1993. Although the initial cost of large container stock is relatively high compared to bareroot seedlings, acorn production is so desirable and such a part of waterfowl management that greentree reservoir managers and duck club owners are willing to pay for restoring acorn production.

There is no single silver bullet for regenerating oaks and other hardmast species in agricultural floodplains. More often managers are designing afforestation projects using a diversity of species and by combining natural regeneration with a variety of artificial regeneration techniques including direct seeding, planting bareroot and container seedlings, and using cuttings as a means of vegetatively reproducing a species. This integrated approach to regeneration is more likely to produce a diverse forest that is more resilient to flooding and other perturbations than are less-diverse monoculture forests and plantations.

Plant succession proceeds rapidly once bottomland crop fields are abandoned. Hence, there is a narrow window of opportunity for establishing trees in high enough stocking that they dominate the growing space before other competing vegetation establishes its dominance. Using natural and artificial regeneration in a planned manner improves the chances of obtaining well-stocked forests. Planting large container stock may be one way of ensuring that the forest has a component of oak.

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