PRODUCTION AND EARLY FIELD PERFORMANCE OF RPM® SEEDLINGS IN MISSOURI FLOODPLAINS

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ABSTRACT—A new nursery culture process has been developed to produce large container RPM® seedlings in an effort to improve the success in artificially regenerating hardwoods. Major features of the process include air root pruning of seedlings grown in a well aerated soil medium to encourage a dense, fibrous root system. Production has focused on native bottomland tree, shrub, and herbaceous species. Field plantings of RPM® seedlings have been done in agricultural floodplains throughout Missouri. In one such planting, the survival and growth of pin oak and swamp white oak RPM® and bareroot seedlings are evaluated when seedlings are established with soil mounding and a redtop grass cover crop.

It is challenging to regenerate hardwoods such as oak (*Quercus* sp.), black walnut (*Juglans nigra* L.), and pecan (*Carya illinoinensis* [Wangenh.] K. Koch) on productive floodplains because competing vegetation, flooding, and animal damage retard seedling growth and decrease survival (Stanturf and others 1998). In addition, slow (shoot) growth rates are characteristic of oak, hickory (*Carya* sp.), and pecan reproduction, which further complicates efforts to regenerate these species, and usually necessitates controlling competing vegetation. Early growth of planted bareroot seedlings can be disappointing for black walnut (von Althen and Prince 1986, Van Sambeek and others 1987) and upland oaks (Johnson 1984). However, regeneration success can be improved by planting large, big-rooted seedlings and promoting early hardwood growth through such practices as fertilization, vegetation management, and protecting seedlings from wildlife herbivory.

Johnson and others (2002) stress the importance of planting large oak seedlings with well-developed root systems to promote regeneration success and increase dominance probabilities. Kormanik and others (1995, 1998) and Schultz and Thompson (1997) demonstrated that upland oak (i.e., northern red oak [*Quercus rubra* L.] and white oak [*Q. alba* L.]) and black walnut 1+0 bareroot seedlings are more successful in open agricultural fields and forest clearcuts if they have a threshold number of first-order-lateral roots (FOLR) greater than 1 mm in diameter. Schultz and Thompson (1997) recommended that northern red oak 1+0 bareroot seedlings should have a minimum of five FOLR and black walnut at least seven FOLR.

Nursery managers can increase the number of FOLR on bareroot seedlings by undercutting the taproot during the first or second year, or by transplanting 1+0 seedlings for a second year in the nursery to produce 1+1 transplant seedlings (Johnson 1988). Undercutting hardwood seedlings is now a common practice in the production of 1+0 bareroot seedlings. Pre-plant treatments with auxins have also been used to promote enhanced root regeneration in black walnut (Van Sambeek and others 1982). Air pruning the roots of seedlings grown in open-bottomed containers is another way to promote lateral root growth and a dense fibrous root system. Based on 50 years of research in container production and hardwood regeneration, the Forrest Keeling Nursery in Elsberry, MO has developed a culture system, known as the Root Production Method (RPM®), to produce high quality hardwood seedlings that have large caliper and height, and a substantial fibrous, root system.

For the past 5 to 7 years, private landowners, public land managers and scientists have been planting RPM® seedlings to regenerate primarily agricultural bottomlands. Bottomland oak species such as pin

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oak (*Quercus palustris* Muenchh.), swamp white oak (*Q. bicolor* Willd.) and bur oak (*Q. macrocarpa Michx.*) are often planted as RPM® seedlings in Missouri. To a lesser extent, black walnut, pecan, shellbark hickory (*Carya laciniosa* [Michx. f.] Loud.), sycamore (*Platanus occidentalis* L.) and other native bottomland species are planted as RPM® seedlings. Information on the growth and survival of RPM® in floodplain plantings is lacking. In this paper, we summarize the RPM® nursery culture process and present early growth and survival of pin oak and swamp white oak RPM® seedlings in a study of regeneration methods for afforesting agricultural crop fields along the Missouri River.

PRODUCTION OF THE RPM® SEEDLING

The root production method, or RPM® (patent no. pending 60/312593) is a nursery culture process to grow seedlings with dense, fibrous root systems in large (e.g., 11- to 19-liter) containers (Lovelace 1998). Using oak as an example, acorns are collected from trees growing in floodplains within 161 km of the bottomland planting site. Acorns are graded and sized using an aspirator and gravity table. Only the largest and heaviest seeds are used to produce RPM® seedlings. Acorns are placed 4 cm deep in mesh-bottomed trays filled with a composted rice hull, pine bark and sand medium (4:4:2 by volume). The shallow depth of media with 35 to 40% air space promotes air pruning of the tap root near the root collar, production of first-order lateral roots near the soil surface and development of a fibrous root system. Slow release fertilizer, micronutrients and a wetting agent are added to the soil medium and trays are enclosed in plastic to maintain proper humidity during cold stratification at 1° C for the recommended period depending on species. Next, trays of acorns are moved into a heated greenhouse usually in early February to initiate germination.

One to two months after emergence, when seedlings have completed their first shoot flush, they are transplanted into individual plastic, 10 cm deep bottomless band containers and placed on chicken wire and wood-framed benches in the greenhouse to permit continued air root pruning. Seedlings are graded based on height, stem caliper, and root development. Typically only the largest 50% of the seedlings continue through the RPM® process. In early May, seedlings are transplanted into 11 or 19 liter plastic containers and placed outside under mist irrigation for 48 hours to acclimatize them to the outdoor environment. Shallow containers are used to concentrate root growth in the upper 15 to 20 cm soil surface. The larger container is used for seedlings that will be grown a second year in the nursery.

After one to two growing seasons in the nursery, RPM® seedlings develop large root systems, have basal stem diameters exceeding 2.0 cm, and grow to over 1.5 m in height. Dey and others (2003) reported that root dry weight of pin oak and swamp white oak RPM® seedlings averaged 117 and 101 g for 11- and 19-liter container plants, respectively. In contrast, root dry weight of 1+0 bareroot oak seedlings averaged 18 g. Similarly, root volumes (by water displacement) of RPM® oak seedlings were substantially larger than 1+0 bareroot seedlings. Nineteen-liter swamp white oak and pin oak RPM® seedlings averaged 252 and 222 ml root volume, respectively, whereas root volume of swamp white oak and pin oak bareroot seedlings averaged 33 and 26 ml, respectively.

SMOKY WATERS AND PLOWBOY BEND RPM® PLANTING

In the fall of 1999 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 at Smoky Waters (Sec. 5, T 44 N, R 9 W and Sec. 1, T 44 N, R 10 W; Cole County, MO) and Plowboy Bend (Secs. 24 and 25, T 47 N, R 14 W; Moniteau County, MO) Conservation Areas. The study fields had been in crop production for years before this study.

Soils at the Plowboy Bend site were mapped as Sarpy Fine Sand (mixed, mesic, Typic Udipsamments). These soils are formed in sandy alluvium and consequently are excessively-drained. Soils at the Smoky Waters site were mapped as Haynie Silt Loam (coarse-silty, mixed, superacitve, calcarious, mesic Mollic Udifluvents), Leta Silty Clay (clayey over loamy, smectitic, mesic, Fluvaquentic Hapludolls), and Waldron Silty Clay Loam (fine, smectitic, calcareous, mesic Aeric Fluvaquents). These soils are formed in silty or clayey alluvium and range from somewhat-poorly drained (Leta and Waldron) to moderately well drained (Haynie). The Plowboy Bend site is also protected by a levee and the Smoky Waters is not protected by levees.

Dey and others (2003) provided a detailed explanation of experimental design and study establishment. In general, both 1+0 bareroot and 11- and 19-liter 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 (*Agrostis gigantea* L.) or with natural vegetation that normally colonizes abandoned bottomland crop fields.

Natural Disturbances

In 2 of the 4 four years (2001, 2002) the study site at Smoky Waters was flooded for up to 3 weeks in June. Also, every winter after the first year, cottontail rabbits (*Sylvilagus floridanus* Allen) have girdled and shoot clipped oak seedlings and oak sprouts, which profoundly affected oak survival and growth. 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).

Rabbit Herbivory

In the natural vegetation fields, the composition and structure of winter cover provided by forbs promoted higher rabbit densities (7.4 rabbits per ha) than in the redtop grass fields (2.5 rabbits per ha) (Dugger and others 2003). In the winter, the dead tops of forbs and clumps of Johnsongrass (*Sorghum halepense* [L.] Pers.) remained somewhat erect providing cover that was 1.0 m tall. However, redtop grass matted down to 0.20 m and provided rabbits little hiding cover 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% or more of the RPM® seedlings in the natural vegetation fields by the end of the second winter. In comparison, only 8% of the bareroot seedlings and 26% of RPM® seedlings in the redtop grass field at Plowboy Bend Conservation Area had herbivory damage from rabbits. Similarly, but to a lesser extent, 12% of the bareroot seedlings and 23% of the RPM® seedlings in the redtop grass field at Smoky Waters Conservation Area were damage free. Moreover, the severity of damage to RPM® trees in redtop grass fields was less than in the natural vegetation 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.

Survival

Survival of oak RPM® seedlings remained high (i.e., > 94%) during the first 3 years (Fig. 1), while survival of bareroot seedlings continued to decline for both swamp white oak and pin oak. After 3 years in the field, survival of swamp white oak bareroot seedlings was significantly higher ($P < 0.01$) than pin oak bareroot seedlings, based on an analysis of variance of treatment effects on survival (Dey and others 2003). Swamp white oak bareroot survival averaged 76%, while survival for pin oak bareroot seedlings was 54%. There was no significant difference ($P = 0.24$) between 11- and 19-liter RPM® seedlings, nor between swamp white oak and pin oak RPM® seedlings ($P = 0.87$). Survival of oak seedlings was not significantly affected by soil mounding or cover crop treatments. However, an assessment of the survival of individual trees that were not damaged by rabbits indicated that redtop grass cover crop did significantly increase survival over that of trees grown with natural vegetation (Fig. 2) based on logistic regression analysis conducted by Dey and others (2003). There were no significant differences in survival among trees on mounded and unmounded soils.

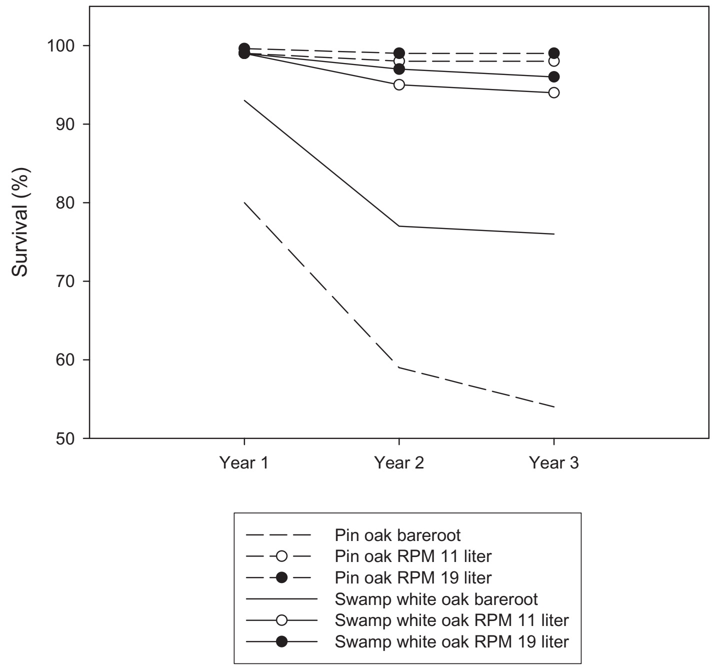

Figure 1.—Annual survival of oak seedlings by species and nursery stock type.

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. 3), based on an analysis of variance (Dey and others 2003). The average basal diameter of all RPM® oak seedlings increased 0.8 cm in the first 3 years, whereas bareroot seedlings increased only 0.3 cm. There was no significant difference ($P = 0.34$) in basal diameter increment between the 11- and the

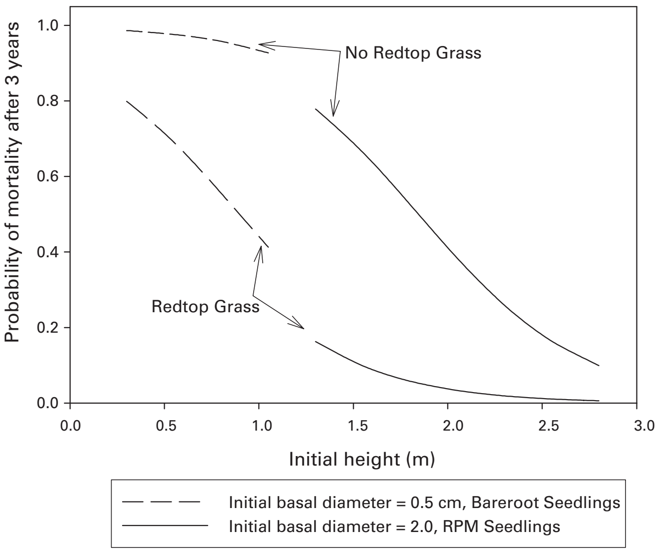

Figure 2.—The probability of mortality after three years in relation to initial seedling height of pin oak seedlings planted with a cover crop of redtop grass or in natural vegetation that develops in abandoned bottomland crop fields at Smoky Waters Conservation Area. In this illustration, mortality is estimated for oak seedlings with initial basal diameter = 0.5 cm (representative of the average pin oak bareroot seedling in our study); and for seedlings with initial basal diameter = 2.0 cm (representative of the average RPM® pin oak in our study).

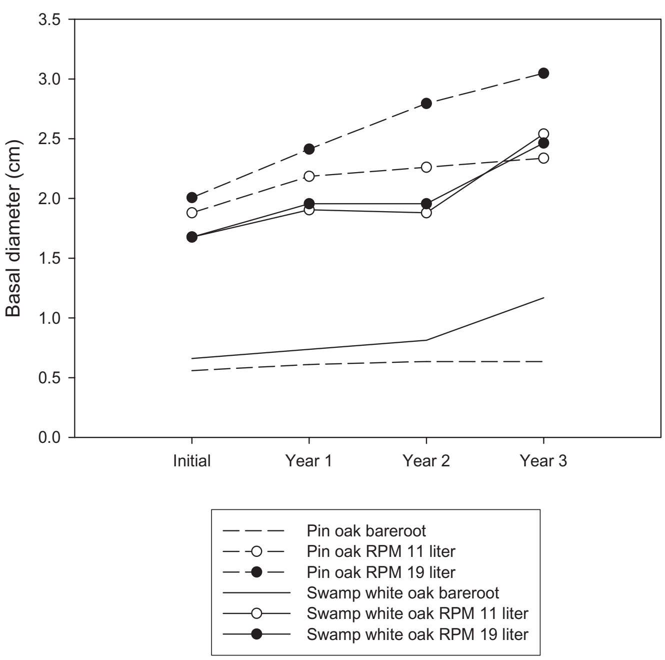

Figure 3.—Average initial and annual basal diameter (measured 2.5 cm above the ground) of oak seedlings by species and nursery stock type.

19-liter RPM® seedlings. The basal diameter of pin oak 19-liter RPM® seedlings increased the most during the first 3 years, averaging 1.0 cm of new growth. Basal diameter increment was least (0.1 cm 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 1.6 cm for RPM® seedlings and 0.2 cm for bareroot trees.

Although soil mounds functioned as anticipated by improving drainage and aeration, diameter growth was not significantly affected by soil mounding. Basal diameter increment of all trees combined was substantially larger in redtop grass fields (1.4 cm) compared to natural vegetation fields (0.2 cm); however, no significant differences can be reported as yet ($P = 0.08$). For undamaged trees, average basal diameter increment was 1.6 cm for RPM® seedlings in redtop grass fields and 0.4 cm in natural vegetation fields, while the basal diameter of bareroot seedlings increased by 0.3 cm in redtop grass but decreased by 0.2 cm 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, which caused shoot dieback and loss of height (Fig. 4). Three year height increment was significantly less ($P < 0.01$) for RPM® seedlings than bareroot, based on an analysis of variance (Dey and others 2003). 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 RPM® trees because rabbit girdling, which occurred in the lower 0.30 m of the stem, caused shoot dieback to near ground-level, and annual sprout growth was not enough to recover the original height. In addition, trees were often repeatedly damaged by rabbits each winter. Three year height increment averaged -0.50 m for the RPM® seedlings. Despite rabbit browsing, RPM® trees remained taller than bareroot seedlings three years after planting. Undamaged trees in the redtop grass fields had slightly positive average height growth (0.10 m for bareroot and RPM® seedlings), but net growth was negative in natural vegetation fields, averaging -0.53 m for RPM® and -0.13 m for bareroot seedlings.

Height growth of undamaged RPM® seedlings may be low because these trees were planted on a

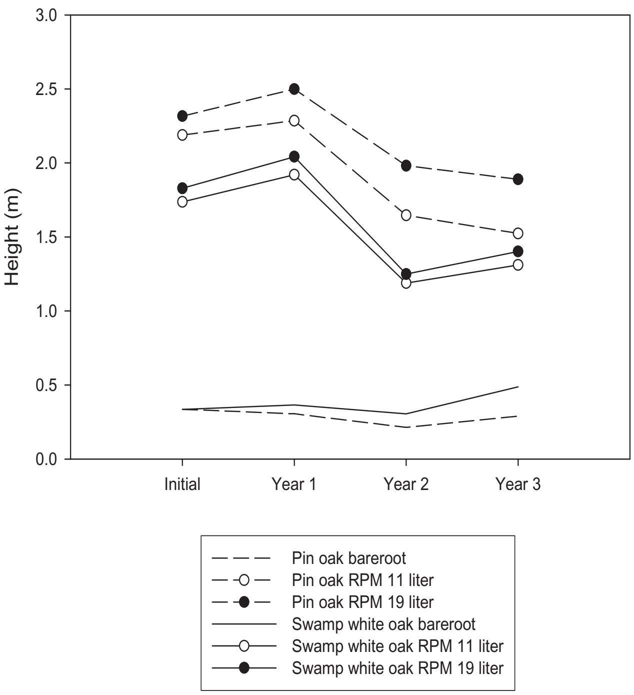

Figure 4.—Average initial and annual height of oak seedlings by species and nursery stock type.

9 x 9 m 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% at Smoky Waters and 1.71% at Plowboy Bend Conservation Areas (J.W. Van Sambeek and N. Sullivan, Research Physiologist and Research Forester, U.S. Forest Service, North Central Research Station, personal communication).

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 0.4 to 0.6 m whereas herbaceous ground cover in the natural vegetation fields grew to over 2 m in height, overtopping many of the oak seedlings. Also, rabbit densities were less in the redtop grass fields 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 1). Acorn production occurred in a small proportion (3.5%) of the 2,522 swamp white oak RPM® seedlings their first year in the field. Most of the production (60%) occurred in oaks from 19-liter containers, but larger 11-liter container RPM® trees also produced acorns. During the first 4 years in the field, average RPM® acorn production increased from 4.3 to 12.5 acorns per tree. Individual trees were able to produce as many as 125 acorns. A single pin oak RPM® seedling produced acorns for the first time in year 4.

The probability of a RPM® swamp white oak seedling producing at least one sound acorn in the first year after planting was significantly ($P < 0.001$) related to initial basal diameter and height of the seedling, based on logistic regression analysis by Grossman and others (2003). Acorn production was more likely to occur in the first year for large diameter (> 1.3 cm), tall (> 1.5 m) RPM® seedlings. For example, the probability of producing a sound acorn after 1 year is 2% for a 1.5 m RPM® seedling with a basal diameter of 1.8 cm, but increases to 15% for a 2.5 cm basal-diameter tree of similar height. Consistent, early production of acorns was 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.

Table 1.—Acorn production by swamp white oak RPM® seedlings planted at Plowboy Bend and Smoky Waters Conservation Areas.

Years After Planting	Number of Trees With Acorns	Mean Number of Acorns Per Tree	Standard Deviation	Range
1	86	4.3	4.4	1-21
2	29	5.2	9.2	1-45
3	70	6.3	7.5	1-42
4	151	12.5	17.0	1-125

SUMMARY

Large container RPM® seedlings had significantly greater survival and basal diameter growth than bareroot seedlings after three years. Three-year height increment for RPM® seedlings was negative and significantly less than that of bareroot seedlings largely due to the loss of initial height from rabbit herbivory on oak seedlings. There was no difference in growth or survival to-date between the 11- and 19-liter RPM® trees.

A redtop grass cover crop benefited oak regeneration by controlling competing vegetation and reducing the amount and severity of rabbit damage to oak seedlings. Redtop grass was effective in preventing the development of much of the forb and woody growth that normally forms on abandoned bottomland crop fields, thereby reducing plant competition for light and the quality of winter habitat for rabbits. Oak seedlings growing in redtop grass fields had significantly greater height increment and substantially larger basal diameter growth after 3 years than trees competing with natural vegetation.

After 3 years, and two June floods at Smoky Waters Conservation Area, soil mounding did not improve height and diameter growth, or survival of oak seedlings at either site. Use of soil mounding to improve drainage, reduce flooding effects on trees and improve soil environments for root growth may be worthwhile on soils that are more poorly drained, and clayey than those of our study site but this remains to be tested.

One- to two-year-old swamp white oak RPM® seedlings produced acorns in the first year after planting in Missouri River floodplain crop fields. The number of acorn bearing trees and production per tree has increased during the first four years. Acorn production did drop in year two because rabbit girdling caused shoot dieback in RPM® trees in the natural vegetation field, taking them out of production. But production rose in years 3 and 4 as more trees came into production. Most acorn bearing trees are located in the redtop grass fields. Pin oak RPM® have begun producing acorns in year 4. Larger RPM® seedlings are more likely to produce acorns within the first few years of plantation establishment.

Under controlled conditions in the nursery, the RPM® process produces seedlings with very large root systems that have numerous large diameter lateral roots (or multiple taproots), and a high density of fine roots. These are desirable root characteristics that many have recognized as being essential for successful regeneration of species such as the oaks. Early results from this study indicate that planting RPM® seedlings of large size in a redtop grass ground cover appears to be a successful formula for regenerating oaks and restoring acorn production in agricultural floodplains. It is critical to successful oak regeneration on productive bottomlands that high quality nursery stock be planted in combination with vegetation management practices that control competing vegetation and animal damage. Further research is needed to evaluate the how RPM® seedlings, soil mounding, and cover crops may enhance black walnut establishment in bottomlands.

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