Available online at www.sciencedirect.com
SCIENCE DIRECT®

Forest Ecology and Management 204 (2005) 315–327

Forest Ecology and Management

www.elsevier.com/locate/foreco

# Soil properties and growth of swamp white oak and pin oak on bedded soils in the lower Missouri River floodplain

John M. Kabrick[a,*], Daniel C. Dey[a], J.W. Van Sambeek[a], Michael Wallendorf[b], Michael A. Gold[c]

[a]USDA Forest Service North Central Research Station, 202 Natural Resources Building, Columbia, MO 65211, USA
[b]Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201, USA
[c]Center for Agroforestry, University of Missouri, 203 Natural Resources Building, Columbia, MO 65211, USA

Received 25 May 2004; received in revised form 21 September 2004; accepted 28 September 2004

**Abstract**

Restoring bottomland hardwood ecosystems is of great interest along the lower Missouri River and within the Mississippi Alluvial Valley. However, bottomland hardwood plantings commonly have a high failure rate. Among reasons cited for failures are frequent flooding and poorly drained site conditions. Soil bedding is a commonly used site preparation method shown to increase the survival and growth of both conifer and hardwood seedlings. However, soil bedding has not always proven beneficial to seedling survival or growth and there are few published evaluations of the effects of bedding on bottomland hardwood seedlings. Objectives of this study were to evaluate the effects of bedding on soil properties and on the early survival and growth of different stock types of pin oak and swamp white oak seedlings in the lower Missouri River floodplain. Soil bedding had a minor effect on soil texture, organic carbon, cation exchange capacity, base cations, and pH. Bedding reduced soil bulk density by 7–16%, reduced gravimetric soil water content by 2–5%, and increased soil temperature by 1–2 °C. When grown with a cover crop of redtop grass, foliar N of trees in bedded soil was about 10% greater than that of trees in soil that was not bedded. There were no differences in survival, diameter growth, or height growth between seedlings grown on bedded and non-bedded soils. Despite beneficial changes to soils caused by bedding, it does not appear to enhance the survival or early growth of planted pin oak and swamp white oak seedlings on our study areas in the Missouri River floodplain.


*Keywords:* Soil bedding; Seedling survival; Seedling growth; Bottomlands; *Quercus palustris*; *Quercus bicolor*

## 1. Introduction

Restoring bottomland hardwood ecosystems is of great interest throughout the central and southern U.S.A., particularly along the lower Missouri River

* Corresponding author. Tel.: +1 573 875 5341x229; fax: +1 573 882 1977.
*E-mail address:* jkabrick@fs.fed.us (J.M. Kabrick).

0378-1127/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2004.09.014

(Dey et al., 2003; Shaw et al., 2003) and within the Mississippi Alluvial Valley (Stanturf et al., 2000, 2001). Most of the millions of hectares of bottomland forests that once covered these regions were cleared for agriculture (Patterson and Adams, 2003). Considerable effort has been made to reforest land marginally productive for row crops (Stanturf et al., 2001), however, bottomland hardwood plantings commonly have high mortality (Schweitzer and Stanturf, 1997), resulting in reforestation failures (Patterson and Adams, 2003). Reasons for these reforestation failures include frequent flooding and wet site conditions (Stanturf et al., 1998). Soil bedding (or mounding) is a commonly used site preparation method for establishing tree seedlings in poorly drained soils (Derr and Mann, 1977; Londo and Mroz, 2001). Surprisingly, there is little published information about the use of soil bedding to establish bottomland hardwoods.

Soil beds typically are constructed by mounding soil with a moldboard plow, offset disc, rice levee plow, or similar tillage implements and also with backhoe-type excavators (Londo and Mroz, 2001). Once constructed, beds are 1–2 m wide and 15–60 cm tall. In addition to improving soil aeration and drainage (Page-Dumroese et al., 1997; Lakel et al., 1999; Fisher and Binkley, 2000; Smolander et al., 2000), other noted benefits of bedding include concentrating organic matter and nutrients (Fisher and Binkley, 2000) and mechanically removing competing vegetation (Schultz and Wilhite, 1974). Variation in microtopography is inherent to many natural forest systems (Hodges, 1997; Kabrick et al., 1997; Lyford and MacLean, 1966) and bedding can restore microtopography in agricultural fields.

Bedding increases height growth of slash pine (*Pinus elliottii* var. *elliottii* Engelm.) and loblolly pine (*P. taeda* L.) in poorly drained soils in the Coastal Plain of the southeastern U.S. (Derr and Mann, 1977; Cain, 1978), the survival and growth of jack pine (*P. banksiana* Lamb.) in glacial soils of northern Ontario (Sutton and Weldon, 1993), and the growth of Douglas-fir (*Pseudotsuga menzeisii* var. *glauca* (Beissn.) Franco) and western white pine (*P. monticola* Dougl. ex D. Don) in the mountains of northern Idaho (Page-Dumroese et al., 1997). Bedding improves the growth of hardwood seedlings including beech (*Fagus sylvatica* L.) on loamy soils in southern Sweden (Gemmel et al., 1996) and increases the height growth of yellow poplar (*Liriodendron tulipifera* L.) on soils with fragipans in Tennessee (Francis, 1979). Bedding can be beneficial when establishing bottomland oaks (*Quercus* spp. L.) and other hard-mast-producing tree species because they generally are less tolerant of poorly drained soils than other bottomland tree species. Bedding increases the height of Nuttall oak (*Q. nuttallii* Palmer) seedlings by as much as 35% on poorly drained and frequently flooded soils in the Coastal Plain of Louisiana, U.S.A. (Patterson and Adams, 2003).

However, soil bedding has not always proven beneficial to seedling survival or growth. Derr and Mann (1977) summarized findings from six different bedding studies in the Louisiana Coastal Plain and found only minor increases in the survival and growth of loblolly pine and slash pine. They concluded that bedding is beneficial to these species on only very poorly drained soils of this region. Haywood et al. (1990) found bedding improved soil drainage but not enough to increase the early growth of loblolly pine on silt loams in Louisiana. Gemmel et al. (1996) found that bedding had no effect on the growth of English oak (*Q. robur* L.) seedlings 3 years after planting in southern Sweden.

The great floods of 1993 and 1995 that occurred throughout the central U.S.A. destroyed levees and altered bottomland farms by scouring and depositing sediment. In Missouri, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Missouri Department of Conservation, and other agencies have acquired thousands of acres of bottomland rendered unsuitable for farming by flooding. These agencies are now seeking methods for restoring a variety of native floodplain habitats, including bottomland hardwood forests, in these abandoned crop fields. Poor survival and growth in many bottomland tree plantings have increased interest in bedding soils for improving the survival and growth rates of oak seedlings in the Missouri River floodplain.

We evaluated the effects of bedding on soil properties and on the early survival and growth of different stock types of pin oak (*Q. palustris* L.) and swamp white oak (*Q. bicolor* Willd.). These two species are commonly planted in bottomlands throughout the Central Hardwood Region. Our study locations were representative of the broad range of soil textures and drainage classes commonly encountered in the lower Missouri River floodplain.

## 2. Methods

### 2.1. Study area

The study was located on two conservation areas managed by the Missouri Department of Conservation, Plowboy Bend (latitude 38°48′5″N; longitude 92°24′17″W; Moniteau County, MO) and Smoky Waters (latitude 38°35′9″N; longitude 91°58′3″W; Cole County, MO). 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. The water table is generally >1.5 m below the soil surface. In the Missouri River floodplain within the state of Missouri, 7211 ha of soil were mapped Sarpy. The Plowboy Bend site is protected by a 100-year levee and did not flood during our study.

Soils at the Smoky Waters site were mapped primarily as Haynie Silt Loam (coarse-silty, mixed, superactive, calcarious, mesic Mollic Udifluvents) and Leta Silty Clay (clayey over loamy, smectitic, mesic, Fluvaquentic Hapludolls), and a small area was mapped as 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). In Haynie soils, the water table is generally deeper than 1.5 m; however, in Leta and Waldron soils the water table is reported at depths ranging from 0.3 to 1 m below the soil surface. In the Missouri River floodplain within the state of Missouri, Haynie, Leta, and Waldron soils were mapped on over 177,000 ha. The site at Smoky Waters is not protected by a levee and it was flooded for several days in June of the second growing season (2001) with some portions flooded for up to 3 weeks.

During the spring of 1999 and before establishing the study, we surveyed the soils to identify patterns in soil texture, drainage, and other physical properties that could influence experimental design. Soil texture and drainage regime, as evidenced by soil morphology, were determined to a depth of 1.2 m using an auger at both Plowboy Bend and Smoky Waters. Soils were sampled systematically across the research area, and microtopographic features such as ridges, old side channels and other shallow depressions received additional sampling. Elevation, soil texture, and drainage patterns were spatially irregular at Plowboy Bend. At Smoky Waters the sand content and elevation increased and drainage improved slightly as we moved across the site toward the Missouri River. However, these changes in texture, elevation, and drainage were subtle and did not follow a gradient that could be incorporated into the study design. Row crops were grown on the study sites prior to the fall of 1998. By the late summer of 1999, all study sites had a cover of herbaceous plants.

### 2.2. Design

At each site we established two square 16.2 ha study plots and randomly assigned a cover crop treatment to each plot. The two cover crop treatments were (1) plant redtop grass (*Agrostis gigantea* L.) as a cover crop or (2) permit competing vegetation to develop naturally with the planted oak seedlings (i.e., the no redtop treatment). Cover crops can suppress competing vegetation and improve the survival or growth of planted seedlings (Van Sambeek et al., 1986). By including a cover crop treatment, we could determine if there was an interaction between the cover crop or natural vegetation and the bedding treatment.

Each plot was laid out with 44 planting rows that were 382 m long and spaced 9.1 m apart. Planting rows were oriented parallel to the Missouri River to ensure that the rows of bedded soil would not impede the downstream flow of flood water. Soil bedding treatments (bedded or non-bedded control) were randomly assigned across each plot in groups of five planting rows each, excluding border rows.

Three stock types each of pin oak and swamp white oak were evaluated. The three stock types included 1-0 nursery-grown bareroot seedlings and two sizes of RPM™ seedlings. RPM™ is a trademark for the root production method, an air root pruning process developed by Forrest Keeling Nursery in Elsberry, MO (Lovelace, 1998). This nursery culture technique produces a large container-grown seedling that has a dense, fibrous root system. Trees are grown in 11 or 19 l containers and attain heights ≥1.5 m tall in 1–2 years in the nursery. In our study, RPM™ seedlings were either 1.5-year-old trees in 11 l pots, or 2-year-old trees in 19 l pots.

Soil bedding treatments were subdivided into subplots that were five rows wide and 54.8 m long containing a total of 30 trees on a 9.1 m × 9.1 m spacing. Within subplots, a single combination of species and stock was randomly assigned. Within each plot, the bedding treatment, stock type, and species treatments were replicated four times and 408 additional trees were planted along the plot edges to complete the entire 16.2 ha planting. For each species and stock type, approximately 1232 seedlings were planted for a total of 7392 trees over the entire study.

The arrangement of treatments was a split-plot experimental design with site (Plowboy Bend and Smoky Waters) and plot (redtop or no redtop) as main plots. Within main plots were four subplots of each bedding treatment (bedded or not) each divided into six sub-subplots with a factorial arrangement of the two species and three stock types.

### 2.3. Study establishment

Prior to establishing the study, the Plowboy Bend study site was mowed in July 1999, and disked twice in orthogonal directions in August 1999, to prepare it for the tree planting. Site preparation at Smoky Waters differed slightly because the plant biomass was considerably greater. At Smoky Waters, herbicides were applied with a boom sprayer in early August 1999 prior to disking. Herbicides used at Smoky Waters were 2,4-D (0.8 l/ha) and glyphosate (0.4 l/ha) mixed with water-soluble ammonium sulfate (0.4 kg/ha).

In mid-September of 1999, the plots designated as receiving redtop grass treatments were worked with an offset disk. Soil beds were constructed on all plots with a levee plow (AMCO LF6-824). Soil beds were 0.6 m in width at the top of the bed and 2.1 m at the base; after the soil settled, mounds were 30–40 cm above the natural ground elevation. Immediately following disking and soil mounding, redtop was sown at 3.6 kg/ha with a two-gang roller (Brillion) seeder in plots designated to receive this treatment. The RPM™ trees were planted in late November 1999 and the 1-0 bareroot seedlings were planted in March 2000. Because tree planting began at least 4 months after herbicide application and subsequent soil tillage, we were not concerned about the effects of residual 2,4-D at the Smoky Waters site. Also in March 2000, a slow release fertilizer (33-3-6 NPK) was applied to the ground surface around each seedling at an approximate rate of 30 g per tree. A 1.2 m × 1.2 m woven polypropylene mat was placed around each seedling as a weed barrier.

### 2.4. Soil properties

After the first growing season, we excavated soil pits at two random locations per site for soil morphology description and laboratory characterization. At each location, pairs of soil pits (one in a bedded row and one in an adjacent non-bedded control row) were excavated at least 1.5 m deep. We described soil horizons and recorded their depths. Horizon description included soil color, structure and consistence, root and pore sizes and abundances, and the presence and color of redox features. Soil samples from each soil horizon were collected and analyzed at the University of Missouri Soil Characterization Laboratory for particle size distribution, extractable cations, cation exchange capacity (CEC), base saturation, organic carbon content, and pH. Soil samples were air dried and passed through a 2 mm sieve to obtain the fine earth fraction. Particle size distribution was determined by pipette (Gee and Bauder, 1986). Cations were extracted with 1 M ammonium acetate at pH 7.0; K was determined by flame emission and Ca and Mg by atomic absorption. Total carbon was determined by dry combustion with a LECO CR 12 Carbon Analyzer (LECO Corp., St. Joseph, MI) and pH was measured in a 1:1 solution suspension.

Near each of the soil pit locations, we recorded soil temperature within and below the tree seedling rooting zone (depths of 10 and 30 cm) in both bedded and non-bedded (control) rows. Temperature was recorded for approximately 2 years (January 2000–April 2002) every 3 h with HOBO® H8 Outdoor/Industrial data loggers and permanently installed TMCx-HA temperature sensors (both from Onset Computer Corporation, Pocasset, MA). At these same locations and also at four additional random locations, soil water was monitored weekly at 10 and 30 cm depths in adjacent bedded and non-bedded (control) rows with permanently installed Watermark sensors (Irrometer Company Inc., Riverside, CA). Soil water or temperature sensors were replaced when they were damaged or failed to work properly.

Soil water meter readings were converted to gravimetric soil water content with equations developed through a calibration study with soils from the research sites. During this calibration study, meter readings were taken with sensors installed in pots of soil at known gravimetric water content. Conversion equations were developed by regressing the observed meter readings against gravimetric water content.

During the third growing season in July 2002, soil bulk density was estimated at the same eight locations and depths where soil water was monitored. Cores 8.6 cm in diameter and 7.6 cm long were taken at eight locations paired by soil treatment (bedded and non-bedded) with replicate cores taken at depths centered at 10 and 30 cm. Samples from cores were weighed, oven-dried at 105 °C for 48 h, and weighed again to determine oven dry soil weight. Bulk density was estimated by dividing the oven-dry soil weight by volume. Replicate values were averaged.

### *2.5. Vegetation measurements*

Initial total height and basal stem diameter 2.5 cm above the ground were measured on all seedlings after planting (spring 2000) and again at the end of each growing season (2001 and 2002). 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 caused by eastern cottontail rabbits (*Sylvilagus floridanus* Allen) and white-tailed deer (*Odocoileus virginianus* Boddaert). In late July 2002, seedling foliage was sampled by collecting one leaf from the mid- and upper-canopy on each tree within two randomly selected rows of each subplot (species and stock type). Composite samples were oven-dried at 60 °C and ground before determining gravimetric nitrogen content by combustion on a LECO FP428 according to AOAC official method 990.03. Other vegetation measurements included annual surveys of the ground layer vegetation on 72 1 $m^2$ quadrats and three 10 m × 20 m macroplots per plot (Shaw et al., 2003).

### *2.6. Analysis*

We compared soil properties at two different soil depths (0–20 and 20–40 cm) in bedded and non-bedded control rows using paired *t*-tests conducted separately by site. Soil properties for the two depth classes were calculated by weighting the property values of individual soil horizons by horizon thickness. Some values were converted from gravimetric to volumetric basis using bulk density estimates measured at each sampling location. Soil temperature and soil water content were not analyzed with paired *t*-tests because they were repeated measures. Instead these values were averaged by depth (centered at 10 and 30 cm) and treatment.

We used analysis of variance (ANOVA) to evaluate the effects of bedding on seedling diameter growth, height growth, and foliar nitrogen for each species and stock type combination. We also examined differences among species–stock combinations and interactions between bedding and cover crop treatments for these variables. We included site as a random effect and bedding treatment, cover crop treatment, and species-stock type combinations as fixed effects. The significance of treatment effects was determined using their respective site interactions as error terms. Because herbivory by rabbits was significant and potentially confounding to the effects of the soil bedding treatment, we analyzed survival and growth of the entire data set and also for a subset of data containing measurements from trees that were either not damaged or minimally damaged by herbivory.

## 3. Results and discussion

### *3.1. Effects of bedding on soil properties*

Soil bedding had a minor effect on soil texture, organic carbon, CEC, base cations, and pH (Table 1). At both sites, soil in bedded rows was sandier at the 20–40 cm depth class than soil in non-bedded control rows, particularly at the Smoky Waters site. This was expected because the beds in our study were constructed entirely with material from the upper 30 cm of the undisturbed soil, which was sandier than the underlying subsoil. We also found moderately significant ($0.05 < P < 0.1$) differences in Mg and K

Table 1
Physical and chemical properties of bedded soils compared to adjacent soils that were not bedded (labeled "control") at the two research sites

| | Plowboy Bend | | | | Smoky Waters | | | |
|---|---|---|---|---|---|---|---|---|
| | Soil depth | | | | Soil depth | | | |
| | 0–20 cm | | 20–40 cm | | 0–20 cm | | 20–40 cm | |
| | Bedded | Control | Bedded | Control | Bedded | Control | Bedded | Control |
| Sand (%) | 69 | 69 | 70* | 58 | 11 | 21 | 16** | 4 |
| Clay (%) | 6 | 6 | 7 | 7 | 32 | 26 | 33* | 21 |
| CEC[a] ($cmol_c\ kg^{-1}$) | 5.4 | 7.6 | 7.6 | 8.4 | 23.8 | 21.3 | 27.3** | 25.7 |
| Organic carbon ($kg\ m^{-3}$) | 8.5 | 8.0 | 7.5 | 5.5 | 15 | 15 | 12 | 15 |
| Ca ($g\ m^{-3}$) | 2255 | 2710 | 2595 | 3975 | 7475 | 6745 | 6255 | 5645 |
| Mg ($g\ m^{-3}$) | 330 | 400 | 365* | 460 | 700 | 685 | 590* | 760 |
| K ($g\ m^{-3}$) | 495* | 430 | 405 | 350 | 745 | 860 | 563 | 570 |
| pH | 7.7 | 7.6 | 7.5 | 7.4 | 7.8 | 8.0 | 7.9 | 8.0 |
| Bulk density ($Mg\ m^{-3}$) | 1.3* | 1.5 | 1.4** | 1.5 | 1.2*** | 1.3 | 1.2*** | 1.4 |

Paired *t*-tests were used to evaluate differences for each site and depth class. Within each site and depth class, soil property values of bedded soil followed by one or more asterisks are significantly different than those of control sites that were not bedded.

[a] CEC is cation exchange capacity.

* Significance level is <0.1.

** Significance level is <0.05.

*** Significance level is <0.01.

at Plowboy Bend and in the CEC and Mg at Smoky Waters between soil in bedded rows and non-bedded control rows; however, these differences were small and probably not biologically important.

We found fewer effects of bedding on these soil properties than reported by others. Page-Dumroese et al. (1997) reported that bedding increased organic matter and base cations in Alfisols of northern Idaho, and Schultz and Wilhite (1974) found that bedding increased organic matter and base cations in the surface horizons of Spodosols in the Florida Coastal Plain. We found fewer differences in organic carbon and base cations caused by bedding because the concentrations of these properties at our study sites did not change appreciably with depth, as is often the case with alluvial soils. Bedding likely has a greater effect in soils where the properties differ consistently with soil depth such as in uplands.

Bedding had a significant and long-lasting effect on soil bulk density (Table 1). Nearly 3 years after the study was established, the soil bulk densities in the bedded rows remained significantly lower than those in the non-bedded control rows, particularly in the finer-textured soils at the Smoky Waters site. This suggested that the total porosity and potential rooting volume was greater in bedded soil (Morris and Lowery, 1988). This also means that bedded soil potentially was less restricting to root growth than soil that was not bedded (Fisher and Binkley, 2000). However, the soil bulk densities of the non-bedded rows probably were not limiting to oak seedling root growth. The relatively high bulk densities measured at the Plowboy Bend are common in sandy soils, and the soils at Plowboy Bend did not exceed the growth-limiting bulk density thresholds identified by Morris and Lowery (1988). Our findings differ from those of Page-Dumroese et al. (1997) who found that bedding had no effect on the bulk density in Andisols and Alfisols in northern Idaho. However, the soil parent materials at their study were partially of volcanic origin, which inherently have low bulk densities. Our findings are consistent with those of Morris and Lowery (1988) who point out that disking can improve soil physical properties including soil bulk density.

Soil in the bedded rows was warmer and drier than soil in the non-bedded control rows (Figs. 1 and 2). Bedding increased the average temperature as well as the average maximum and average minimum temperature by 1–2 °C and decreased the average gravimetric soil water content by 2–5%. Similar trends were observed when averaged seasonally (data not shown). Although annual and seasonal soil temperature and water content differences were small, we observed that the soil water content in bedded soil

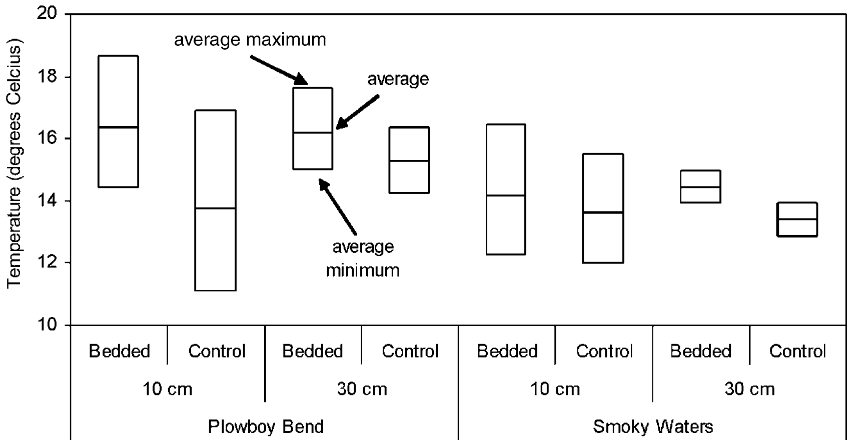


Fig. 1. Average daily maximum temperature (top of bar), average daily minimum temperature (bottom of bar) and overall average temperature (middle of bar), of bedded soil and of soil that was left un-bedded (control) at the two research sites. Temperature was measured at two randomly selected locations per site. At each location, temperature sensors were installed at two depths each in a bedded planting row and in an adjacent non-bedded planting row. Measurements were taken every 3 h. At Plowboy Bend, soils were warmer than those at Smoky Waters because they were sandier (Table 1) and, consequently, drier (Fig. 2).

was often 10–25% lower than in soil that was not bedded shortly after rainfall (Fig. 3). This suggested that bedded soil had better drainage and was seldom saturated for long periods except when flooded.

Our findings are similar to those reported by Gemmel et al. (1996) and by Lindstrom and Troeng (1995) in Sweden where bedding is routinely used to increase soil temperature and improve soil drainage

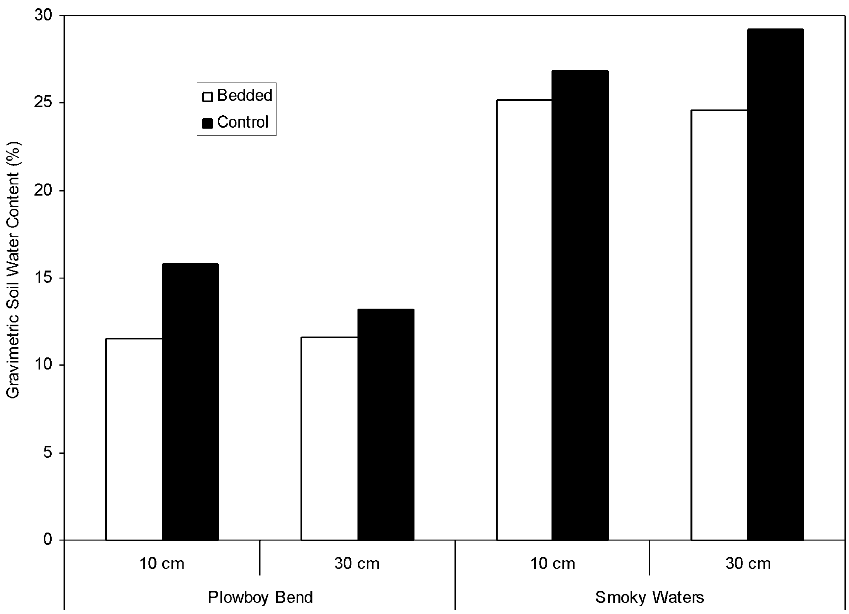


Fig. 2. Average gravimetric soil water content at 10 and 30 cm depths in bedded and non-bedded (control) soil at the two research sites. Soil water content readings were taken at four randomly selected locations per site. At each location sensors were installed at two depths each in bedded soil and in soil that was not bedded (control). Measurements were taken approximately weekly.

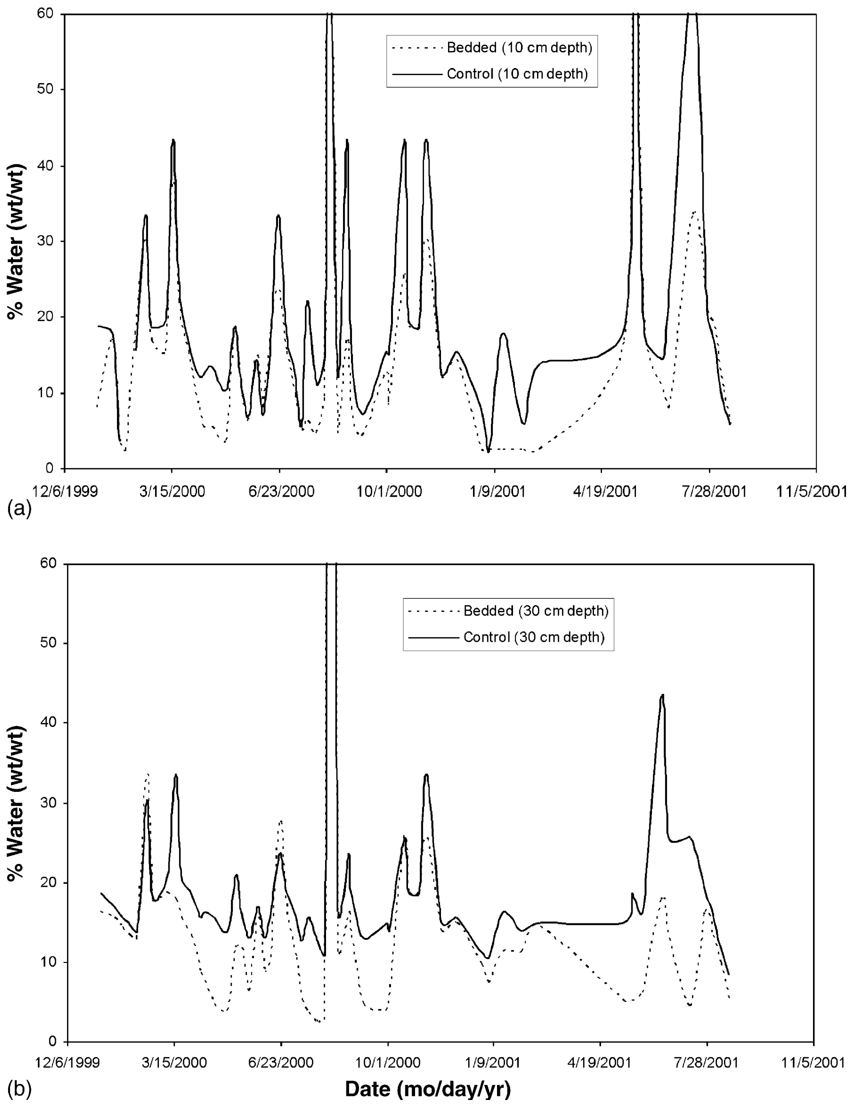


Fig. 3. Weekly gravimetric soil water content at depths of 10 cm (a) and 30 cm (b) in bedded soil and soil that was not bedded (control) at the Plowboy Bend site measured from 6 January 2000 to 17 August 2001. These readings show the wide variation in soil water content occurring between the two bedding treatments at a single location.

prior to tree planting. In boreal climates, there is some concern that bedded soil is too exposed and may become too cold and dry during winter, thereby damaging planted seedlings (Lindstrom and Troeng, 1995). In temperate climates, there is little concern about cold damage to seedlings in bedded soil. However, it is possible for bedded soil to become too dry during the summer, especially during drought. Bottomlands are probably less susceptible to drought than uplands and we rarely recorded low soil water content readings at our study sites.

Overall, bedding reduced soil bulk density, increased soil temperature, and improved the drainage of the bottomland soils of our study. We viewed these changes to the soil as favorable for the growth of planted seedlings. In general, reduced density improves soil aeration and the ability of fine roots to penetrate the soil; the warmer soil temperatures enables seedling roots to begin growing earlier in the spring and to continue later into the fall. Improved soil drainage provided more oxygen in the soil for root respiration on these sites. In theory, the drier and warmer soil conditions should have increased organic matter decomposition (Trettin et al., 1996; McLaughlin et al., 2000) and N mineralization (McLaughlin et al., 2000) thereby increasing N availability to planted seedlings.

### 3.2. Effects of bedding on survival, growth, and foliar nitrogen of oak seedlings

Bareroot seedlings initially were substantially smaller than RPM™ container stock and had lower survival rates after 2 years (Fig. 4). The RPM™ stock, particularly pin oak, had significantly greater basal diameter growth ($P < 0.001$) than bareroot stock. Even though the RPM™ stock remained taller than bareroot stock during the first two growing seasons, the RPM™ stock had a decrease in height due to browse by rabbits and deer. Thus height growth for the RPM™ stock was significantly less ($P < 0.001$) than the height growth of the bareroot seedlings. Soil bedding had no detectable effect on seedling survival and no significant effect on seedling diameter growth ($P > 0.3$) or height growth ($P > 0.8$) regardless of species and stock type. The interactions between the bedding and cover crop treatments were not significant for diameter growth ($P = 0.7$) and height growth ($P = 0.8$). We also examined the growth of seedlings that were not browsed and found no significant differences in diameter growth ($P > 0.5$) and height growth ($P > 0.3$) between seedlings in bedded rows and those planted in non-bedded rows (data not shown).

Bedding with a cover crop of redtop appeared to increase foliar N concentrations ($P > 0.07$) during the second growing season of both swamp white and pin oak (Fig. 5). At Plowboy Bend, this trend occurred regardless of cover crop. However, at Smoky Waters, the trend differed by cover crop treatment. In the plot without redtop grass, trees on bedded soil had lower foliar N than those on soil that were not bedded. Although we cannot fully explain why this occurred at Smoky Waters, it appears that the forbs in the plot without redtop competed more successfully for the N on the bedded soils. There are few published reports comparing the nutrition and growth of hardwood seedlings grown with redtop and with native forbs. We do note that Van Sambeek and Garrett (2004) summarized the findings of the limited number of these studies and found that hardwood seedling growth with redtop was similar to growth of hardwood seedlings with mixed forbs. We also found a significantly higher ($P = 0.04$) foliar nitrogen content for swamp white oak (1.85%) than for pin oak (1.78%). Pin oak showed visible nitrogen deficiency symptoms and swamp white oak did not, suggesting that the swamp white oak may be more tolerant of the high pH in our bottomland soils.

It was not surprising that bedding did not improve the survival and growth of seedlings at Plowboy Bend because the soils there were well drained and the site did not flood. However, we did expect that bedding would improve the survival and growth at Smoky Waters because the soils at that site had moderate to poor drainage and because the site flooded for several weeks in June 2001 during the second growing season. Although the depth and duration of this flood varied across the site because of variation in topography, reference markers indicated that at peak flood stage, the water was at least 1.5 m deep at the lowest locations at the site. Even though the bedded soils were also inundated, they emerged sooner than soil that was not bedded once flood waters receded and should have drained more rapidly. However, our seedling data from Smoky Waters showed a slight but insignificant trend of better growth within non-bedded rows than within the bedded rows (Fig. 4) suggesting that the soil that was not bedded may be more favorable for seedling growth at this site. This occurred despite the fact that foliar N, overall, was greater at the Smoky Waters site and greater in trees on bedded soil in the redtop plot (Fig. 5).

Our findings differ from those of studies conducted in boreal or mountain climates with conifers. Sutton and Weldon (1993) reported bedding increased survival and growth of jack pine of both bareroot and container (paperpot) stock in northern Ontario. Macadam and Bedford (1998) found a 17% increase in diameter growth and a 22% increase in height growth of both container and bareroot stock hybrid white spruce (*Picea glauca* × *P. engelmannii* [Parry ex Engelm.]) (S × w) in west-central British Columbia. Page-Dumroese et al. (1997) reported that bedding

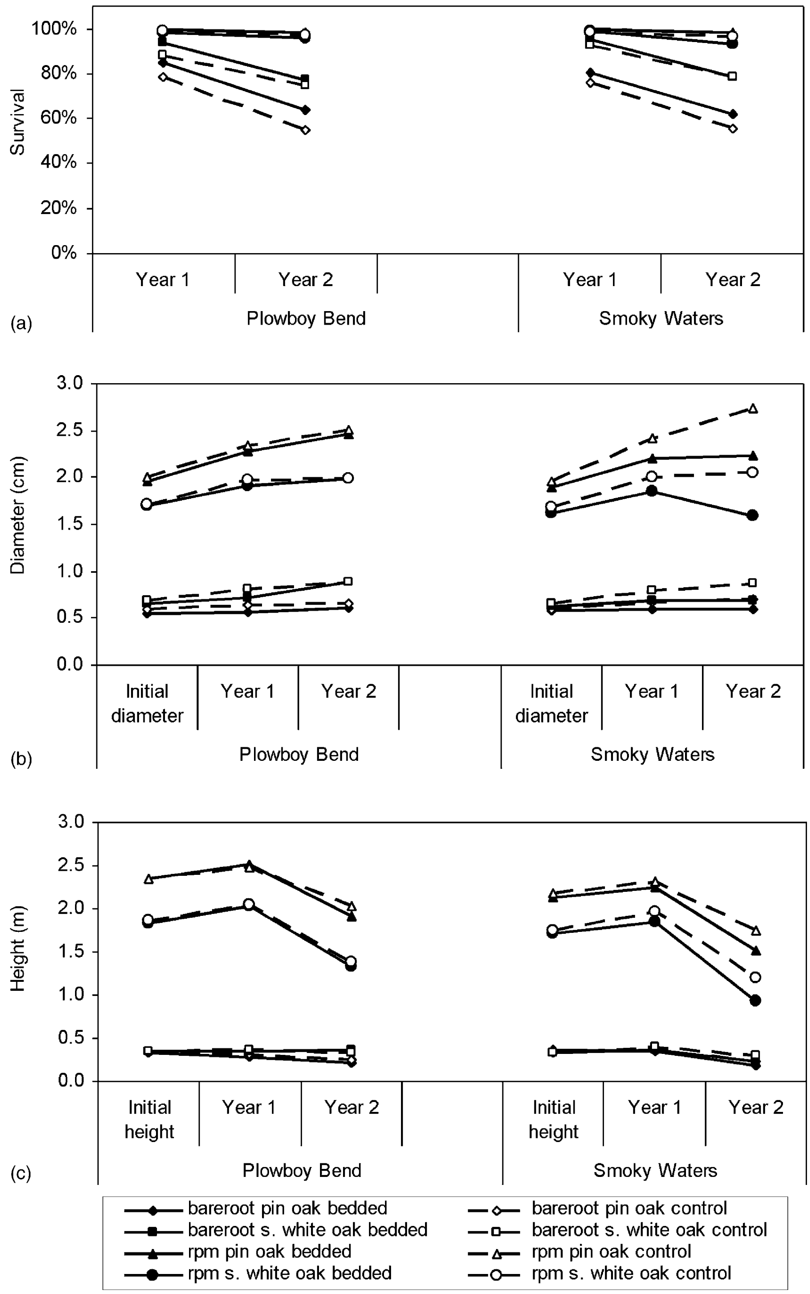


Fig. 4. Survival (a), diameter (b), and height (c) of bareroot and RPM™ container stock pin oak (*Quercus palustris* L.) and swamp white oak (*Q. bicolor* Willd.) seedlings planted in bedded and non-bedded (control) rows at the two research sites. In this figure, the two RPM™ stock types (i.e., 11 and 19 l container) were combined because there were no significant differences between them. After 2 years, there were no statistical differences in survival and growth between seedlings planted in bedded and non-bedded rows.

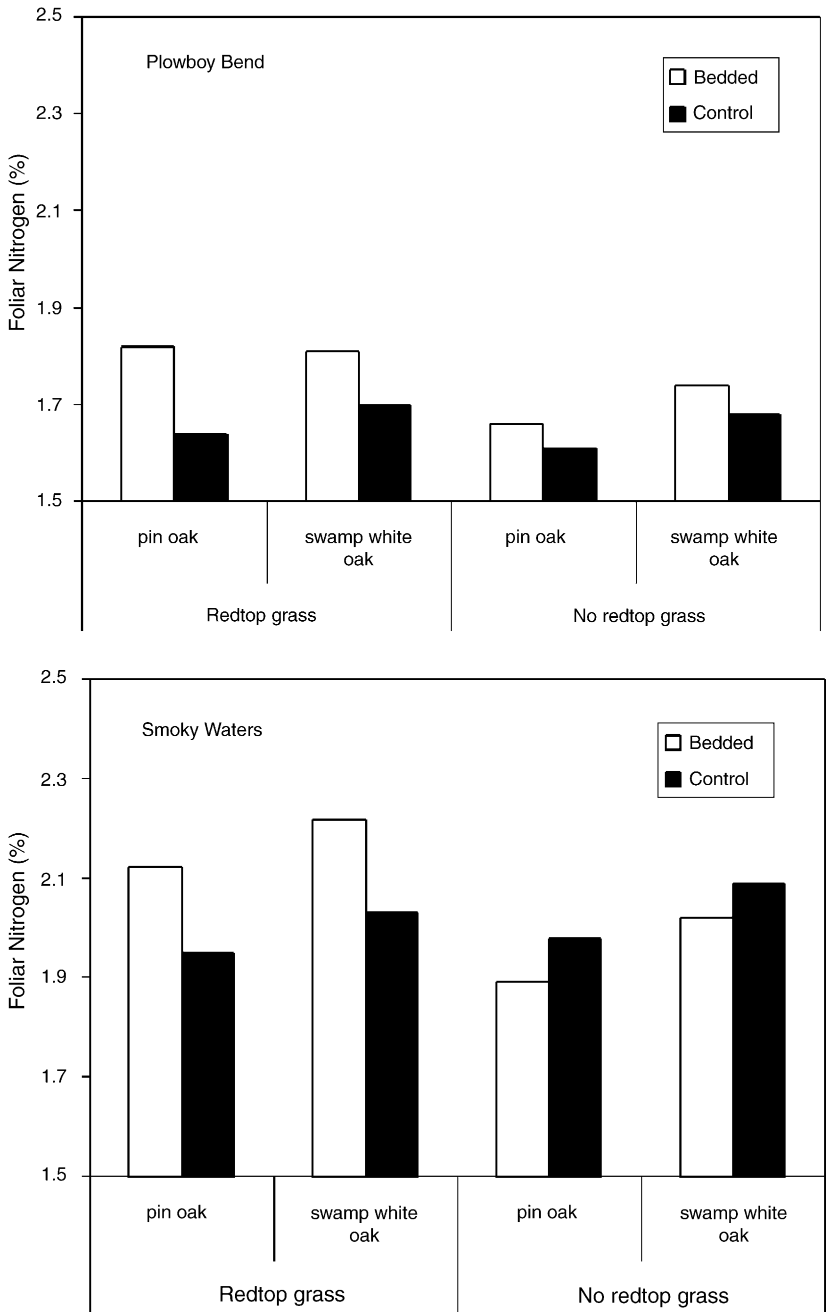


Fig. 5. Foliar nitrogen content during the second growing season of pin oak (*Quercus palustris* L.) and swamp white oak (*Q. bicolor* Willd.) established in a cover crop of either redtop grass (*Agrostis gigantea* L.) or mixed forbs without redtop on bedded and non-bedded (control) rows at the Plowboy Bend and Smoky Waters sites. There was a trend of higher foliar nitrogen in seedlings planted in bedded rows in redtop.

increased the growth of bareroot Douglas-fir and western white pine in the mountains of northern Idaho.

Our findings are more consistent with studies conducted in the Coastal Plain in the southern U.S.A. where bedding is only marginally beneficial to hardwoods and conifers unless soils are very poorly drained and the water table is near the soil surface (Derr and Mann, 1977; Cain, 1978; Patterson and Adams, 2003). Perhaps most relevant, Patterson and Adams (2003) found that bedding increased the height of planted and direct-seeded Nuttall oak seedlings from 32 to 54% in clayey, poorly drained soils in frequently flooded backswamps in the Louisiana Coastal Plain. However, they found no significant growth effect in Nuttall oak caused by soil bedding in better drained soils in natural levees. Moreover, Patterson and Adams (2003) found that regardless of soil drainage, bedding had no effect on planted green ash (*Fraxinus pennsylvanica* Marsh.). Green ash is generally considered very flood tolerant (Kennedy, 1990) compared to most bottomland oaks.

## 4. Conclusions

Bedding soils in the Missouri River floodplain does change many of the physical and chemical properties and, overall, appears to improve the rooting environment for seedlings. However, despite these favorable soil responses, bedding does not appear to benefit establishment and early growth of planted pin oak and swamp white oak seedlings in soil conditions commonly encountered in the Missouri River floodplain. Nor have modest increases in foliar nitrogen content of trees in bedded rows resulted in improved oak seedling growth. We do not believe bedding soil can be justified based upon its effects on the survival and growth of bottomland oaks in plantings in the Missouri River floodplain of Missouri. Our findings may apply to other bottomland hardwood reforestation efforts with these same species elsewhere in the lower Missouri River floodplain and the Mississippi Alluvial Valley where soils and hydrology are similar to those of our study sites. As other studies suggest, we suspect that bedding to improve drainage, reduce flooding effects, and improve root growth may be beneficial where soils have a higher clay content, have very poor drainage, or are more frequently flooded or flooded for long durations. However, these remain as hypotheses to be tested.

## Acknowledgements

This work was funded by the University of Missouri Center for Agroforestry under cooperative agreements AG-02100251 with the USDA ARS Dale Bumpers Small Farms Research Center, Booneville, AR, C R 826704-01-0 with the US EPA, and by the USDA Forest Service North Central Research Station. The results presented are the sole responsibility of the principal investigators and may not represent the policies or positions of the ARS or EPA. We thank Dr. Stephen R. Shifley of the USDA Forest Service North Central Research Station and Dr. John P. Dwyer of the University of Missouri for reviewing earlier drafts of this manuscript.

## References

Cain, M.D., 1978. Planted loblolly and slash pine response to bedding and flat disking on a poorly drained site-an update. USDA Forest Service Research Note SO-237, p. 6.

Derr, H.J., Mann Jr., W.F., 1977. Bedding poorly drained sites for planting loblolly and slash pines in southwest Louisiana. USDA Forest Service Research Paper SO-134, p. 5.

Dey, D., Kabrick, J., Grabner, J., Gold, M., 2003. Restoring oaks in the Missouri River floodplain. In: Proceedings of the 29th Annual Hardwood Symposium Sustaining Natural Resources on Private Lands in the Central Hardwood Region, May 16–19, 2001, National Hardwood Lumber Assoc., French Lick, IN, pp. 8–20.

Fisher, R.F., Binkley, D., 2000. Ecology and Management of Forest Soils, 3rd ed. Wiley, New York, p. 489.

Francis, J.K., 1979. Bedding improves yellow-poplar growth on fragipan soils. USDA Forest Service Research Note SO-244, p. 3.

Gee, G.W., Bauder, J.W., 1986. Particle-size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI, pp. 383–411.

Gemmel, P., Nilsson, U., Welander, T., 1996. Development of oak and beech seedlings planted under varying shelterwood densities and with different site preparation methods in southern Sweden. New For. 12, 141–161.

Haywood, J.D., Tiarks, A.E., Shoulders, E., 1990. Loblolly and slash pine height and diameter are related to soil drainage in winter on poorly drained silt loams. New For. 4, 81–96.

Hodges, J.D., 1997. Development and ecology of bottomland hardwood sites. For. Ecol. Manage. 90, 117–125.

Kabrick, J.M., Clayton, M.K., McBratney, A.B., McSweeney, K., 1997. Cradle-knoll patterns and characteristics on drumlins in northeastern Wisconsin. Soil Sci. Soc. Am. J. 61, 595–603.

Kennedy Jr., H.E., 1990. Green ash. In: Burns, R.M., Honkala, B.H., technical coordinators, Silvics of North America, 2., Hardwoods, Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC, pp. 348–354.

Lakel, W.A., Aust, W.M., Carter, E.A., Stokes, B.J., Buford, M.A., Sanchez, F.G., 1999. Slash incorporation for amelioration of site, soil and hydrologic properties on pocosins and wet flats in North Carolina. In: Haywood, J.D. (Ed.), Proceedings of the 10th Biennial Southern Silviculture Research Conference, General Technical Report SRS-30, Shreveport, LA, February 16–18, 1999, U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC, pp. 298–301.

Lindstrom, A., Troeng, E., 1995. Temperature variations in planting mounds during winter. Can. J. For. Res. 25, 507–515.

Londo, A.J., Mroz, G.D., 2001. Bucket mounding as a mechanical site preparation technique in wetlands. North. J. Appl. For. 18, 7–13.

Lovelace, W., 1998. The root production method (RPM) system for producing container trees. Combined Proc. Int. Plant Propagators Soc. 48, 556–557.

Lyford, W.H., MacLean, D.W., 1966. Mound and pit microrelief in relation to soil disturbance and tree distribution in New Brunswick, Canada. Harvard For. Paper 15, p. 18.

Macadam, A., Bedford, L., 1998. Mounding in the sub-boreal spruce zone of west-central British Columbia: 8-year results. For. Chron. 74, 421–427.

McLaughlin, J.W., Gale, M.R., Jurgensen, M.F., Trettin, C., 2000. Soil organic matter and nitrogen cycling in response to harvesting, mechanical site preparation, and fertilization in a wetland with a mineral substrate. For. Ecol. Manage. 129, 7–23.

Morris, L.A., Lowery, R.F., 1988. Influence of site preparation on soil conditions affecting stand establishment and tree growth. South. J. Appl. For. 12, 170–178.

Page-Dumroese, D.S., Jurgensen, M.F., Harvey, A.E., Graham, R.T., Tonn, J.R., 1997. Soil changes and tree seedling response associated with site preparation in northern Idaho. West. J. Appl. For. 12, 81–88.

Patterson, W.B., Adams, J.C., 2003. Soil, hydroperiod and bedding effects on restoring bottomland hardwoods on flood-prone agricultural lands in north Louisiana, USA. Forestry 76, 181–188.

Schultz, R.P., Wilhite, L.P., 1974. Changes in a flatwood site following intensive preparation. For. Sci. 20, 230–237.

Schweitzer, C.J., Stanturf, J.A., 1997. From okra to oak: reforestation of abandoned agricultural fields in the Lower Mississippi Alluvial Valley. In: Meyer, D.A. (Ed.), Proceedings of the 25th Annual Hardwood Symposium, May 7–10, 1997, Cashiers, NC, National Hardwood Lumber Assoc., Memphis, TN, pp. 131–138.

Shaw, G.W., Dey, D.C, Kabrick, J.,Grabner, J., Muzika, R.M. 2003. Comparison of site preparation methods and stock types for artificial regeneration of oaks in bottomlands. In: Van Sambeek, J.W., Dawson, J.O., Ponder Jr., F., Loewenstein, E.F., Fralish, J.S. (Eds.), Proceedings of the 13th Central Hardwood Forest Conference, General Technical Report NC 234, Urbana-Champaign, IL, April 1–3, 2002. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN, pp. 186–198.

Smolander, A., Paavolainen, L., Malkonen, E., 2000. C and N transformations in forest soils after mounding for regeneration. For. Ecol. Manage. 134, 17–28.

Stanturf, J.A., Gardiner, E.S., Hamel, P.B., Devall, M.S., Leininger, T.D., Warren Jr., M.E., 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. J. For. 98, 10–16.

Stanturf, J.A., Schweitzer, C.J., Gardiner, E.S., 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A.. Silva Fenn. 32, 281–287.

Stanturf, J.A., Schoenholtz, S.H., Schweitzer, C.J., Shepard, J.P., 2001. Achieving restoration success: myths in bottomland hardwood forests. Restor. Ecol. 9, 189–200.

Sutton, R.F., Weldon, T.P., 1993. Jack pine establishment in Ontario: 5-year comparison of stock types ± bracke scarification, mounding, and chemical site preparation. For. Chron. 69, 545–553.

Trettin, C.C., Davidian, M., Jurgensen, M.F., Lea, R., 1996. Organic matter decomposition following harvesting and site preparation of a forested wetland. Soil Sci. Soc. Am. J. 60, 1994–2003.

Van Sambeek, J.W., Garrett, H.E. 2004. Ground cover management in walnut and other hardwood plantings. In: Michler, C.H., et al. (Eds.), Proceedings of the Sixth Walnut Council Research Symposium on Black Walnut in a New Century, General Technical Report NC-243. Lafayette, IN, July 25–28, 2004. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN, pp. 85–100.

Van Sambeek, J.W., Ponder Jr., F., Rietveld, W.J., 1986. Legumes increase growth and alter foliar nutrient levels of black walnut saplings. For. Ecol. Manage. 17, 159–167.