New Forests (2006) 31:293–303
DOI 10.1007/s11056-005-7484-7

Organic matter added to bareroot nursery beds influences soil properties and morphology of *Fraxinus pennsylvanica* and *Quercus rubra* seedlings

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Received 5 October 2004; accepted in revised form 6 May 2005

Key words: Chicken manure, Compost, Green ash, Hardwood seedlings, Northern red oak, Seedling quality, Soil amendments

Abstract. Bareroot hardwood seedling production involves intensive soil management. To increase soil organic matter (OM), nurseries commonly grow a cover crop for 1 year after every 1–2 year of seedling production. Raising soil OM levels can also be achieved through addition of soil amendments. We studied the influence of chicken manure (CM) and composted leaf, tree, and lawn trimmings (Cp) on soil properties and morphology of green ash (*Fraxinus pennsylvanica* Marsh.) and northern red oak (*Quercus rubra* L.) seedlings. CM was applied at 725, 1450, or 2900 kg ha^{-1} (CM725, CM1450, and CM2900, respectively) and Cp was applied at 200 m^3 ha^{-1}. Addition of CM and Cp significantly raised soil OM levels and altered soil chemical properties compared to the control (Ctrl). Root-collar diameter increased with addition of CM1450, CM2900, or Cp compared to CM725 or Ctrl plots for northern red oak, but was largest in soils amended with CM2900 for green ash. Conversely, height was greatest with addition of CM725 for northern red oak, but green ash seedlings were shorter in Ctrl plots than in all amendments except for CM725. Root volume of green ash and northern red oak seedlings was positively influenced by addition of CM or Cp. Seedling responses to nursery soil amendments vary with different forms and amounts of OM. Benefits to seedling growth through application of appropriate materials in the proper balance can improve seedling morphological quality and positively influence soil chemical properties.

Introduction

Production of high-quality bareroot seedlings in the Central Hardwood Forest Region (CHFR) of the USA is dependent on many factors, including soil properties. Hardwood seedlings are generally more demanding than conifer seedlings in terms of soil fertility and chemical and physical properties (Williams and Hanks 1976; Davey 1984). Compared to agricultural crops, organic matter (OM) is depleted much more rapidly in forest seedling nurseries as the entire plant is removed at the end of the growing cycle. OM influences soil chemical and physical properties. Positive impacts on soil physical properties result largely from changes in soil structure. Bulk density, to which hardwood seedlings are sensitive (Simmons and Pope 1988) can be lowered through the incorporation of OM, which can increase pore space and counteract the negative impacts of heavy machinery use (Rose et al. 1995). Aggregates formed between OM and the soil help increase filtration and retention of water and increase root penetration (Allison 1973). Soil chemical properties benefit from the addition of OM as a slow-release fertilizer, which helps provide plants with essential macro- and micro-nutrients (Rose et al. 1995).

The benefits of OM additions may be short-lived if applied only once. Munson (1983) found that the addition of 89.6 t ha^{-1} of sawdust to nursery soil contained in 5 l buckets submerged into nursery beds raised soil OM levels to almost 5%, but after 35 months OM returned to ambient levels. Smaller amounts of sawdust were lost even faster. Similarly, Mexal and Fisher (1987) found that soil OM% and nutrient levels rose with addition of 67 t ha^{-1} of peat, sludge and bark and 43 t ha^{-1} of sawdust (1.2 cm amended into the top 15 cm of soil), but then returned to original levels within 18 months. Decomposition rates vary depending on climate, texture and soil fertility; in the Pacific Northwest, USA, 66% of OM applied could be decomposed by the end of the first year and 90% by the end of a typical conifer crop rotation (Davey 1984). However, repeated applications of sawdust over a 6 year period increased OM levels in a loblolly pine nursery (May and Gilmore 1985) from 1.9 to 3.2%. Thus the sustained benefits to soil physical and chemical properties through OM additions will manifest themselves only through long-term application and monitoring, which may necessitate changes in current hardwood nursery management practices.

OM can be added to nursery soils either through use of cover crops (also referred to as green manure) or by direct application of a wide variety of materials. Cover crops can help reduce erosion and maintain soil OM; however, over time cover crops may not increase soil OM (Davey 1984). Use of cover crops could, in fact, decrease soil OM level over time (South and Davey 1983). Because cover crops decompose rapidly, the nutrients they provide to the stable organic fraction of the soil usually are only short term (Williams and Hanks 1976). Most hardwood nurseries use cover crops, but in association with other organic amendments to supplement soil OM levels (Williams and Hanks 1976). Peat moss, sawdust, manure, and compost all have been used as OM amendments in seedling nurseries (Williams and Hanks 1976; Rose et al. 1995). Iyer and Benson (1981) found that OM of nursery soils could be adequately increased through the application of coniferous tree bark. Amendment of nursery soils using compost can increase soil pH, nutrient content, and water holding capacity (Gouin and Walker 1977). These factors can directly influence seedling growth.

There are few published studies on the effects of OM in forest tree seedling nursery soils on seedling growth. Jacobs et al. (2003) found increased soil water retention with OM use, but no differences in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedling water potential or growth. Mexal and Fisher (1987) found immediate, but short term, changes in soil OM and nutrient availability and no effect on seedling height, ground-line diameter or fresh weight of ponderosa pine (*Pinus ponderosa* P. & C. Lawson) seedlings. Results of those studies corresponded to findings presented by Coleman et al. (1987) for Douglas-fir and ponderosa pine seedlings. In a greenhouse study, Monterey pine (*Pinus radiata* D. Don) seedlings grew better in soils amended with papermill sludge and humate suspension than in non-amended soils (Iyer and Oilschlager 1977).

Current use of cover crops in forest tree nurseries may not effectively raise soil OM to desirable levels and provide associated benefits to soil properties and seedling development. Therefore, the objectives of this study were to determine the effect of OM amendments on soil physical and chemical properties and to investigate the influences of OM amendments on seedling morphology of two commonly grown hardwood species.

Materials and methods

Study site and plant materials

Northern red oak (*Quercus rubra* L.) and green ash (*Fraxinus americana* Marsh.) were chosen as the trial species based on their common use in plantation establishment in Indiana, USA (Jacobs et al. 2004). Seedlings were produced at the Indiana Department of Natural Resources Division of Forestry Vallonia Nursery (38°85′ W, 86°10′ W). An overview of cultural practices for nursery production of hardwood species in this region can be found in Jacobs (2003). The soil in the nursery beds where the study was conducted is a Bloomfield-Alvin complex with a 1–6% slope and a loamy sand texture (Nagel 1990). Taxonomically, Bloomfield soils are sandy, mixed, mesic Psammentic Hapludalfs and Alvin soils are coarse-loamy, mixed, mesic Typic Hapludalfs (Nagel 1990). Clay mineralogy is mixed and of Eolian deposits. Currently, this nursery uses a 1 year corn (*Zea* spp.) or sorghum (*Sorghum* spp.) cover crop following a 2 year tree crop cycle.

Green ash seed were sown on 8 May 2003 and northern red oak seed were sown on 9 May 2003, with seed from each species originating from bulk Indiana seed sources. Seedlings were grown at an approximate density of 75 seedlings m^{-2}.

Soil amendments

Chicken manure (CM), containing no bedding and having undergone thermophilic decomposition, was obtained from a poultry farm near the nursery (Rose Acres Farms, Seymour, IN, USA). CM was applied at 725, 1450, or 2900 kg ha^{-1} (CM725, CM1450, and CM2900, respectively). Compost (Cp), consisting of ground leaf, tree, and lawn trimmings from a municipal collection service, was obtained from a nearby city (Seymour, IN, USA) and materials had been composted for at least 2 years at the time of incorporation into the study. Cp was applied at a rate of 200 m^3 ha^{-1}. In addition to the aforementioned treatments, a control (Ctrl) with neither CM nor Cp applied was included. Amendments represented 0.033, 0.066 and 1.32% (CM725, CM1450, and CM2900, respectively) of a hectare furrow slice (by mass) while Cp was applied as 13.12% hectare furrow slice (by volume). Soil amendment materials were applied to the nursery beds on 5 May 2003. On 6 May 2003, CM and Cp were incorporated to an approximate uniform depth of 7.5 cm using a bed former.

Study design, measurement, and data analysis

This study was established as a randomized complete block design for each species. Four soil amendment treatments and a control plot were replicated four times. Seeds were sown into two adjacent nursery beds (green ash in one, northern red oak in the other). Each bed was then divided into quarters with each quarter serving as a block and treatments were randomly distributed within each block using 1.2 m $\times$ 1.8 m (2.2 m^2) plots. Between each treatment block, a 2.2 m^2 buffer plot was established to ensure that soil amendments did not influence adjacent plots.

Soil samples were collected for analysis immediately following incorporation of soil amendments (Table 1). Samples were taken to a depth of approximately 7.5 cm. Nutrient analyses were performed by A&L Great Lakes Laboratories, Inc. (Ft. Wayne, IN, USA) using standard analytical protocols. Percentage OM, cation exchange capacity (CEC), soil pH, and P, K, Mg, and Ca (parts per million, PPM) were determined for the soil samples. Available P was determined according to Bray and Kurtz (1945) and cations were determined by atomic absorption using extracted aliquots. The amount of a particular component of material added can be calculated by multiplying the application rate by the corresponding value (Table 1). For example, CM725 resulted in 725 kg ha^{-1} CM $\times$ 54.15% OM for a total of 393 kg ha^{-1} OM.

Seedlings were lifted on 2 April 2004. Within each plot, seedlings were randomly collected for measurement but not within 0.3 m of the plot boundary. For each treatment replication, 25 seedlings were randomly selected and stored at 2 °C at Purdue University until measured for height, root-collar diameter, and root volume using the water displacement method (Burdett 1979) in June 2004.

Data were analyzed using analysis of variance (ANOVA) for a randomized complete block design to identify differences between treatments for seedling height, root-collar diameter, and root volume. ANOVA was also used to identify differences in soil physical and chemical properties between treatments. To minimize the possibility of making a Type II error, a significance level of $\alpha = 0.10$ was selected for analysis of treatment differences using Tukey's mean separation test. For seedling parameters the experimental unit was each group

Table 1. Composition of chicken manure and compost soil amendments.

Property	Chicken manure	Compost
Moisture content (%)	15.68	52.25
pH	8.6	8.2
N (%)	3.93	1.39
P (%)	2.08	0.21
PO_4^3 (%)	4.78	0.48
K (%)	3.39	0.30
K_2CO_3 (%)	4.07	0.36
S (%)	0.58	0.18
Mg (%)	0.80	1.98
Ca (%)	13.31	8.24
Na (%)	0.68	0.01
Fe (%)	0.24	0.74
Al (%)	0.10	0.49
B (mg kg^{-1})	45	36
Cu (mg kg^{-1})	165	48
Mn (mg kg^{-1})	538	433
Zn (mg kg^{-1})	573	165
Soluble salt (dS m^{-1})	10.62	0.69
Ash (%)	45.85	55.83
Organic matter (%)	54.15	44.17
C (%)	27.08	22.09
C:N	7:1	16:1

of 25 seedlings from a treatment replication and the observational unit was each individual seedling. SAS® software (SAS Institute, Cary, NC, USA) was used for all data analyses.

Results and discussion

Soil properties

Addition of CM or Cp significantly altered soil properties compared to Ctrl plots. OM levels were significantly ($p = 0.0658$) influenced by the application of Cp, which raised levels above Ctrl plots (Table 2). The resulting differences in soil chemical properties show the influence of the amendments used. Application of Cp ($p = 0.0144$) resulted in an increase of pH (6.88 ± 0.09, mean ± SE), which was significantly less acidic than all other treatments except for application of CM2900 (6.00 ± 0.41, Table 2). Correspondingly, application of a compost comprised of sewage sludge and wood chips raised nursery soil pH (Gouin and Walker 1977), while Iyer and Oilschlager (1977) found a similar result for greenhouse soils amended with OM. All amendments increased CEC ($p = 0.0007$) above Ctrl plots (Table 2).

Table 2. Soil properties (mean ± SE) of control plots (Ctrl) and plots immediately following amendment with compost (Cp) at 200 $m^3 ha^{-1}$ or chicken manure at 725, 1450, or 2900 kg ha^{-1} (CM725, CM1450, CM2900, respectively). For each property, different letters within a row indicate significant differences among treatments at $\alpha = 0.10$.

Property	Ctrl	Cp	CM725	CM1450	CM2900
Organic matter (%)	1.13 ± 0.07b	2.03 ± 0.17a	1.80 ± 0.26ab	1.63 ± 0.28ab	1.60 ± 0.13ab
pH	5.63 ± 0.39b	6.88 ± 0.09a	5.43 ± 0.07b	5.60 ± 0.22b	6.00 ± 0.41ab
CEC (meq 100 g^{-1})	4.08 ± 0.66b	7.38 ± 0.54a	8.33 ± 0.66a	7.25 ± 0.47a	9.55 ± 0.97a
P (ppm)	133.50 ± 7.42c	184.00 ± 2.58bc	217.00 ± 18.99b	211.50 ± 5.98b	289.00 ± 25.28a
K (ppm)	121.75 ± 8.99c	239.00 ± 12.54b	284.00 ± 36.67b	338.25 ± 8.09b	569.50 ± 54.35a
Mg (ppm)	56.25 ± 9.66b	150.00 ± 5.40a	103.75 ± 9.66ab	103.75 ± 13.90ab	142.50 ± 14.79a
Ca (ppm)	412.50 ± 149.13b	1087.50 ± 96.56a	687.50 ± 74.65ab	625.00 ± 143.61ab	900.00 ± 145.77ab

P and K are essential macronutrients needed to facilitate plant development. The amount of available P ($p < 0.0001$) and K ($p < 0.0001$) were highest for those treatments that received CM2900 and lowest in Ctrl plots (Table 2). Mg levels ($p < 0.0001$) were highest in plots that received either CM2900 or Cp and were lowest in Ctrl plots (Table 2). Ca levels were higher ($p = 0.0168$) than Ctrl plot levels with addition of Cp, but there was no difference with the addition of any quantity of CM (Table 2). These results suggest potential of OM for improved nutrient management in hardwood seedling nurseries. Since most hardwood seedling nurseries apply granular fertilizer throughout the growing season (Williams and Hanks 1976), leaching of nutrients into groundwater is an environmental concern, which may potentially be reduced by effective use of OM (Oele 1996).

Seedling morphology

Both green ash and northern red oak seedling morphology were significantly influenced by soil amendment treatments. For green ash seedlings, root-collar diameter (RCD) was greatest ($p < 0.0001$) in plots receiving CM2900 than in other treatments (Figure 1a) while northern red oak RCD was greater ($p < 0.0001$) in plots that received CM1450, CM2900, or Cp compared to seedlings in those plots that received CM725 or Ctrl plots (Figure 1a). These results indicate that there may be species-specific or genotypic responses in RCD growth to different soil amendments.

Green ash height growth was significantly greater for seedlings in plots that received either CM2900 or Cp compared to Ctrl plots; conversely, northern red oak seedling height was greatest ($p < 0.0001$) for seedlings in plots that received CM725 and lowest for those that received CM2900 (Figure 1b). The inverse relationship between northern red oak height and amount of CM could be associated with the degree of decomposition of organic amendments. Although highly decomposed organic matter increases soil water availability, material which is in early stages of decomposition may result in less available soil water for plant uptake (Rose et al. 1995). Jacobs et al. (2003) found that greater water retention of soils amended with organic matter did not facilitate an increase in Douglas-fir seedling xylem water potential. Less available soil water may have prompted a decrease in northern red oak seedling height (Figure 1b) and increase in diameter (Figure 1a) to aid in shoot:root adjustment. Northern red oak is prone to episodic growth, consistently adjusting shoot:root in response to changing environmental conditions such as water availability (Reich et al. 1980). While these results also illustrate differences in responses to different soil amendments by species, they generally agree with previous findings.

Gouin and Walker (1977) found that yellow poplar (*Liriodendron tulipifera* L.) and flowering dogwood (*Cornus florida* L.) responded to screened compost with an increase in height growth. In a study examining bareroot conifer

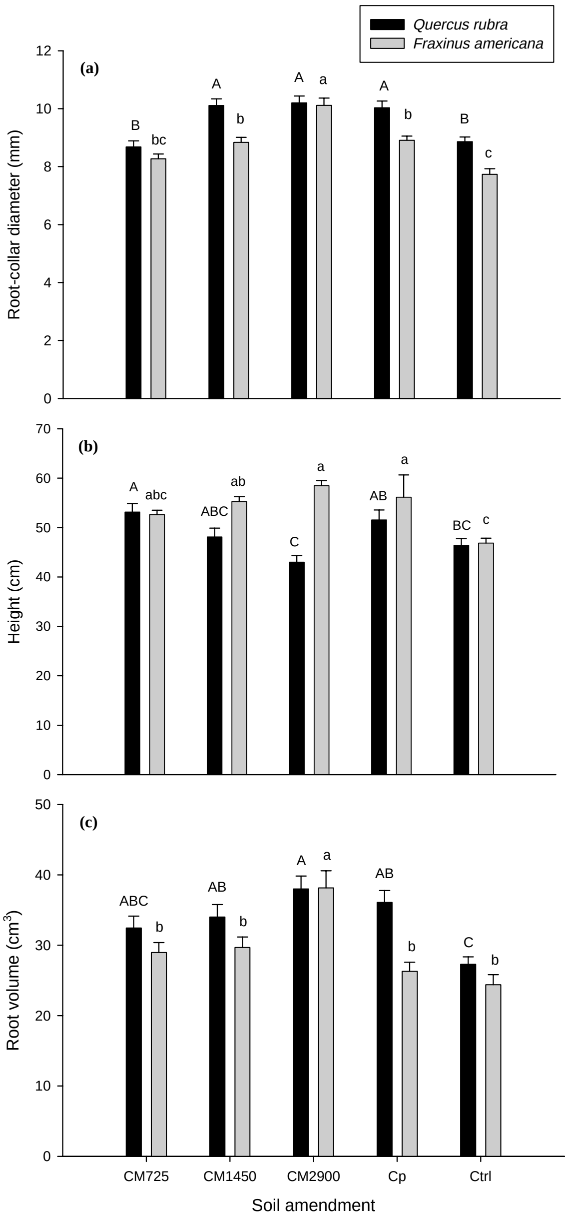

Figure 1. Influence of soil amendments on root-collar diameter (a), height (b), and root volume (c) after one nursery growing season for *Fraxinus pennsylvanica* and *Quercus rubra* seedlings in control plots (Ctrl) and plots amended with compost (Cp) at 200 m^3 ha^{-1} or chicken manure at 725, 1450, or 2900 kg ha^{-1} (CM725, CM1450, CM2900, respectively). For each species and variable, different letters represent differences significant at $\alpha = 0.10$.

seedling response to amendment with compost, ponderosa pine seedlings grew taller with compost but there was no difference in Douglas-fir and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) growth (Coleman et al. 1987); however, in an examination of OM amendments to nursery soils, Mexal and Fisher (1987) found no increase in survival, biomass or yield of ponderosa pine seedlings. Correspondingly, Jacobs et al. (2003) did not find a difference in growth of bareroot Douglas-fir seedlings when grown in substrates amended with manure, peat, or vermiculite. Thus, variations in seedling response to amendment of nursery soils with OM likely depend on the type and quantity of materials used in addition to the genetic composition of plant material used.

Root volume of both green ash ($p < 0.0001$) and northern red oak ($p < 0.0001$) seedlings was influenced in a similar manner, with greatest values for those seedlings that received CM2900 and lowest for those seedlings in Ctrl plots (Figure 1c). These results reflect the ability of OM amendments added to nursery soils to influence seedling root morphology, likely through the reduction of bulk density. Simmons and Pope (1988) found reduced root growth in yellow poplar (*Liriodendron tulipifera* L.) and sweetgum (*Liquidambar styraciflua* L.), while Tworkorski et al. (1983) found a similar negative impact on root growth of white oak (*Quercus alba* L.) as bulk density increased. Minimizing impediments to root proliferation in bareroot nursery beds may provide a useful means of increasing hardwood seedling root system quality.

Conclusion

Organic amendment of nursery soils can lead to improved height and RCD growth and larger root volume of bareroot hardwood seedlings. Seedling responses to amendment of nursery soils can vary with different forms and amounts of OM. Benefits to seedling growth through application of appropriate materials in the proper balance may improve seedling quality and positively influence soil chemical properties. Concerns of nutrient leaching from traditional fertilizers in bareroot seedling nurseries could potentially be alleviated through the use of available surplus organic matter, which may otherwise be destined for landfills. It is important to ensure that quality materials are used however, and that the composition of the materials used is known. These findings help clarify the important contributions to seedling quality that soil management can make. Future research is needed to better understand the influence of soil amendments on soil physical properties, nutrient leaching, and how best to integrate soil amendments with traditional fertilization protocols. Establishment of studies to examine the long-term influence of organic amendments on nursery crops and soil properties is needed to help define soil management practices. This knowledge would likely improve bareroot seedling nursery culture.

Acknowledgements

This study was funded by the USDA Forest Service and Purdue University. Ron Overton, Amy Ross-Davis, Vallonia nursery (Jim Wichman, Bob Hawkins, Phil O'Connor, and Jeannie Redicker) and Mike Spalding helped in the establishment and maintenance of this study. Rose Acres Farms and the City of Seymour, IN provided materials. Barbara Hawkins and two anonymous reviewers provided insightful comments on an earlier version of this manuscript.

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