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An artificial regeneration system for establishing northern red oak on dry-mesic sites in the Lake States, USA

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Summary — Artificial regeneration of northern red oak is difficult to achieve in the Lake States, USA. A replicated study was established in northern Wisconsin in 1990 to determine the effect of overstory density and understory competition on the performance of bareroot and containerized northern red oak seedlings on dry-mesic sites. The relationship between seedling performance and the number of first-order lateral roots on the seedlings was also tested. Seedling performance was evaluated under 3 overstory densities (each 0.3 ha) — a clearcut, 25%, and 50% crown covers in combination with (and without) understory vegetation control with herbicide. Height growth was greater for containerized seedlings than bareroot stock after 2 and 3 growing seasons. After 2 yr seedling growth was greatest in the sprayed clearcut plots, but was only slightly greater than the unsprayed plots under the 25% crown cover (bareroot 25.5 *vs* 23.8 cm, and containerized 33.0 vs 31.2 cm, respectively). After 3 yr seedling height growth was significantly greater in the unsprayed plots under the 25% crown cover for both the bareroot and containerized seedlings when compared to all other overstory/understory treatment combinations examined in the study. Early performance results suggest that the light shelterwood silvicultural method (*ie* 25% crown cover) without chemical control of vegetation is preferred for establishing northern red oak on dry-mesic sites, when compared to the more traditional management schemes.

Quercus rubra **/ clearcut / herbicide / shelterwood / bareroot stock / containerized stock / silviculture**

Résumé — Une technique de régénération artificielle pour l'installation du chêne rouge dans les stations sèches de la région des lacs (États-Unis). *La régénération artificielle du chêne rouge est difficile à réaliser dans la région des lacs (États-Unis). Une expérimentation a été mise en place en 1990 dans le Nord Wisconsin, afin de déterminer les effets de la densité du couvert et de la compétition du sous-étage sur les performances de plants de chêne rouge (à racines nues ou en containers) plantés dans des stations sèches. Les relations entre les performances des plants et le*

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nombre de leurs racines latérales d'ordre 1 ont aussi été étudiées. Les performances des plants furent évaluées sous 3 densités de couvert : 0%, 25% et 50% (placettes de 0,3 ha) en combinaison avec (ou sans) un sous-étage contrôlé par herbicide. Après 2 et 3 saisons de végétation, la croissance en hauteur des plants a été supérieure pour les plants en containers par rapport à ceux à racines nues. Après 2 ans, la croissance des plants était supérieure dans les placeaux coupés à blanc et traités par herbicides, mais seulement un peu plus élevée que dans les traitements non contrôlés par herbicides avec un couvert de 25% (plants à racines nues 25,5 et 23,8 cm, plants en containers 33,0 et 31,2 cm, respectivement). Après 3 ans, sous un couvert de 25% (avec ou sans sous-étage), la croissance en hauteur des plants était significativement plus élevée dans les traitements sans herbicides pour les plants à racines nues comme pour ceux élevés en containers, par rapport à l'ensemble des autres traitements sous couvert de cette étude. Les résultats initiaux laissent à penser qu'une méthode de sylviculture par abris légers (25% de couvert) et sans contrôle chimique de la végétation est préférable pour l'introduction du chêne rouge sur les stations sèches, par rapport aux méthodes plus traditionnelles des aménagements sylvicoles.

Quercus rubra / *coupe à blanc / herbicide / ombrage / racines nues / container / sylviculture*

INTRODUCTION

Developing regeneration systems is a key aspect of the management of any tree species. The goal of an artificial regeneration system is to establish a vigorous seedling as economically as possible. Achieving this goal requires creating conditions through cultural practices and manipulation of the microenvironment to meet the biological needs of the species. In all cases, these systems should be viewed on a site-specific basis until the forest manager has the knowledge to generalize across site types.

Northern red oak (*Quercus rubra* L) is one of the most valuable hardwood species in the Lake States, USA and is of increasing importance in central Europe. However, at present forest managers do not have reliable site-specific regeneration systems for red oak. For example, systems that are successful on one site may not be on another. Growth potential of red oak is believed to be highest in full light conditions. Successful regeneration systems have been developed for northern red oak in the central hardwoods region of the USA, which include a 1 or 2 shelterwood cut, competition control, planting bareroot stock with a caliper of ≥ 9.5 mm followed by a complete overstory removal harvest after 3 yr (Johnson *et al*, 1986). Traditionally shelterwood systems that retain a crown cover of ≈ 70% have been prescribed in the Lake States for regeneration of northern red oak. In fact, regeneration failures are predicted if the overstory is reduced < 50% crown cover (Sander, 1979; Loftis, 1980). Moreover, Lorimer (1989) suggests that the slow growth habits of oak are responsible for regeneration failures with shelterwood management, and that any type of overstory reduction will likely lead to the replacement of oak by other woody species. However, attempts at artificial regeneration of northern red oak with medium density shelterwood management (*eg* 70% crown cover) have not been successful in the Lake States, probably because of improper site selection, use of inferior planting stock, intense understory competition, and insufficient light to support sustained growth during establishment phases.

Unfortunately, planting stock of the size recommended by Johnson cannot often be produced in a single year in northern Lake

States nurseries, and 2–0 stock (*ie* 2 yr in the nursery bed) is more costly and often too large to be planted efficiently. While there is some correlation between root collar diameter and field performance, there is growing evidence that the number of first-order lateral roots on an oak seedling may be a better predictor of field performance (Kormanik, 1989). Recent modifications of forest tree nursery cultural practices have led to an increase in the overall seedling size and the number of first-order lateral roots on 1–0 (*ie* 1 yr in the nursery bed) northern red oak nursery stock (Buchschacher *et al*, 1991). However, production of 1–0 northern red oak seedlings in northern regions is currently not up to the standards outlined by Johnson. Seedlings with at least 6 lateral roots are being successfully used for regenerating northern red oak (Schultz and Thompson, 1991), although seedlings with more lateral roots may permit the use of somewhat smaller stock.

Northern red oak generally grows best on rich-mesic sites, but planting seedlings on such sites in the past required herbicide applications to control competing vegetation. However, environmental concerns have led to a reduction in the use of herbicide on some public lands in the USA in much the same way as in some European countries; thus, herbicide control of vegetation may not be a viable management option in the future. Fortunately, northern red oak also grows reasonably well on drier sites (*ie* dry-mesic) where understory competition is less intense. Kotar (1991) suggested that these sites may afford the best opportunities for oak regeneration in the Lake States. The objective of this study was to develop an artificial regeneration system for northern red oak on dry-mesic sites in northern Wisconsin that may be applied to other similar sites in the Lake States, USA. The study was designed to evaluate overstory density (*ie* crown cover), competition control and stock type as components of such a regeneration system.

MATERIALS AND METHODS

The study was conducted within a mixed northern hardwood stand consisting of predominately of paper birch *(Betula papyrifera)*, red maple *(Acer rubrum)*, and northern red oak *(Quercus rubra)* at Bird Lake on the American Legion State Forest in northern Oneida County, Wisconsin, USA (45°N 89°W). The site is a moderately fertile, dry-mesic site with sandy loam soils and habitat type AVVib *(Acer/Vaccinium–Viburnum)* according to Kotar *et al* (1988). The average stand diameter was 19 cm and the basal area averaged 27.5 m^2/ha. The site index for northern red oak is 18.6 m (at age 50 yr). The dominant understory vegetation is *Rubus pteridium* and *Carex*. The study design was a randomized complete block with a split plot arrangement of treatments (fig 1). It consisted of 3, 0.3-ha replications of each of 3 overstory densities – a clearcut (LAI = 0; LAI based upon ceptometer measurements), 25% (LAI = 0.56), and 50% (LAI = 1.24) crown cover, and 2 levels of herbicide – sprayed and unsprayed. The shelterwood harvests were in January and February, 1989. Crown cover was estimated based on the relationship between tree diameter and crown area (Godman and Tubbs, 1973) and tables modified by G Erdmann (unpublished observations) were used to mark trees for the shelterwood cuts. Gly-

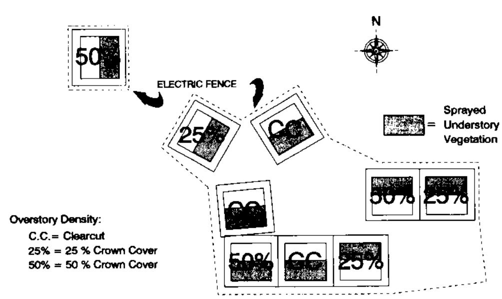

Fig 1. Overview of Bird Lake oak regeneration study design. Each overstory treatment plot is 0.30 ha with a 10-m buffer trip around the perimeter.

phosate (Roundup*) herbicide was sprayed on half of each plot at manufacturer's recommended rate of 4.7 l/ha in September, 1989. The entire study area was enclosed by a high tensile electric fence to minimized the impact of white tailed deer *(Odocoileus virginianus)* browse (fig 1).

In May 1990 2 separate experiments were planted within the study design. One experiment compared the responses of bareroot stock *vs* containerized seedlings among the overstory density and herbicide spray treatments. The bareroot seedlings selected for planting had at least 10 permanent first-order lateral roots (roots > 1 mm in diameter) with a minimum stem height of 13.0 cm and stem caliper at the root collar of 7.0 mm. These criteria would result in a cull rate of ≈ 50% under traditional nursery practices. These seedlings averaged 31.5 cm in height and 7.6 mm in caliper. The containerized seedlings were glasshouse-grown in 10 x 36 cm 4-ml polyethylene pots with 1:1:1 peat/sand/soil and 2.7 kg NPK slow-release fertilizer. The containerized seedlings had a minimum 20 cm stem height and 3.8 mm stem caliper at the root collar, and averaged 29 cm and 5.7 mm.

In the other experiment, seedling performance was evaluated relative to root-grade. The seedlings were graded as follows: grade 1 = 0 to 5; grade 2 = 6 to 10; grade 3 = 11 to 15; grade 4 = 16 to 20; grade 5 = > 20 lateral roots. The root-graded seedlings had an average stem height of 21 cm and stem caliper of 6.0 mm.

All seedlings were planted in 10-cm diameter augered holes. This practice is not currently widely used, but is gaining in popularity as a result of research. The study included 48 bareroot, 12 containerized and 35 root-graded seedlings (*ie* 5 grades x 7 seedlings/grade) in each overstory x spray treatment combination, for a total of 1 710 seedlings in the study. It should be noted that containerized seedlings are not often traditionally used in practice because of costs. Seedlings were planted at 2.4 x 2.4 m spacing with subplots reserved for containerized stock.

Seedling performance is reported here for 2 and 3 yr after planting. Height growth is expressed as 2-yr cumulative growth (*ie* seedling height after 2 yr minus planting height), and 3rd yr growth was the difference between total seedling height after 2 and 3 yr. Some seedlings had a negative net growth in the 3rd yr because of partial dieback. Dieback is a common problem in the central US and appears to be a result of either frost or winter desiccation of current terminal bud. The negative growth values for these seedlings were included in our analysis, but seedlings that died back to the ground completely and did not resprout were excluded. Statistical analysis was by analysis of variance for split plot designs with SAS (1988).

RESULTS

Survival

After 2 yr, seedling survival was very high and ranged from 98% for the containerized seedlings to 99% for the bareroot seedlings (table I). After 3 yr, the survival ranged from 94% for the containerized seedlings to 98% for the bareroot seedlings. Specifically, the 3-yr survival for the bareroot seedlings ranged from 95% in the unsprayed clearcut plots to > 99% in the unsprayed 50% crown cover plots. The survival for containerized seedlings ranged from 86% in unsprayed 25% crown cover plots (due to unexplained mortality in 1 subplot) to 100% in sprayed 50% crown cover plots. Overall survival was exceptionally high throughout the study reflecting the benefit of planting high quality stock and the auger planting method.

Seedling performance

Height growth was significantly greater for containerized seedlings than for barefoot seedlings after 2 and 3 growing seasons. After 2 growing seasons, growth of both seedling types was significantly greater in

* The mention of trade names is for the reader's information and does not constitute endorsement by the US Department of Agriculture, Forest Service.

Table I. Survival for bareroot and containerized seedlings after 2 (1991) and 3 (1992) yr for 3 overstory densities (*ie* clearcut, 25%, and 50% crown cover) and 2 glyphosate herbicide treatments (*ie* unsprayed and sprayed).

Year	*Stock type*	*Clearcut*		*25% Crown cover*		*50% Crown cover*		*Overall average (%)*
		% sprayed	*% unsprayed*	*% sprayed*	*% unsprayed*	*% sprayed*	*% unsprayed*	
1991	Bareroot	99	99	100	99	97	98	99
	Containerized	97	94	97	97	100	100	98
1992	Bareroot	97	95	98	97	95	99	97
	Containerized	94	92	97	86	100	97	94

the clearcut and 25% crown cover plots than in the 50% crown cover plots. However, in the 3rd yr, performance declined in the clearcut plots for both seedling types. The best growth for both bareroot and containerized stock occurred in the unsprayed 25% crown cover plots (fig 2). The containerized seedlings grew more than the bareroot seedlings even though the average height of the containerized seedlings at establishment was less than that of the bareroot seedlings (29.1 *vs* 31.5 cm, respectively) (table II).

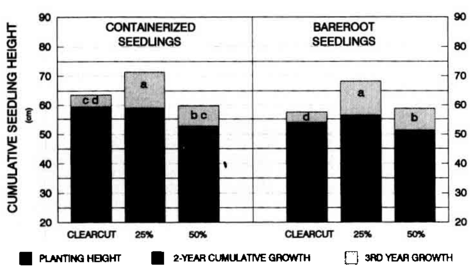

Fig 2. Cumulative seedling height (cm) at time of planting and after 2 and 3 growing seasons of containerized and bareroot seedlings growing under 3 overstory densities (*ie* clearcut, 25% crown cover, and 50% crown cover) for both herbicide treatments. Growth segments labeled with the same letter are not significantly different for the respective growth periods ($P = 0.05$).

More specific analysis for the containerized seedlings showed that the 2-yr cumulative growth was greatest in the sprayed clearcut, and unsprayed 25% crown cover plots; however, when all overstory density/spray treatment combinations were considered, the difference in 2-yr cumulative growth between the "best" and "poorest" treatment was 12 cm (fig 3). After 3 growing seasons, a more definite pattern developed. Third-yr growth was greatest in the unsprayed, 25% crown cover plots while growth was approximately equal in all oth-

Table II. Mean establishment height and caliper for bareroot, containerized, and root-graded seedlings.

	Height (cm) Mean ± SE	*Caliper (mm) Mean ± SE*
Bareroot [a]	31.5 ± 0.31	7.6 ± 0.03
Containerized	29.1 ± 0.32	5.7 ± 0.04
Root graded [b]	21.1 ± 0.32	6.0 ± 0.04

[a] Bareroot seedlings had minimum of 10 lateral roots > 1 mm diameter; [b] root grades: 1 = 0–5 laterals > 1 mm; 2 = 6–10 laterals > 1 mm; 3 = 11–15 laterals > 1 mm; 4 = 16–20 laterals > 1 mm; 5 = > 20 laterals > 1 mm.

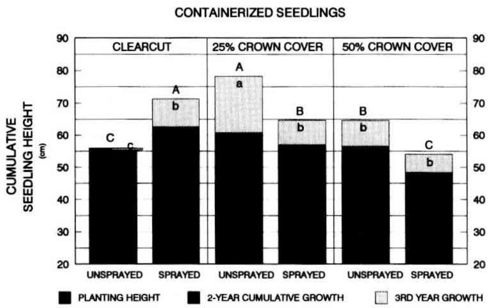

Fig 3. Cumulative seedling height (cm) for containerized seedlings at planting date and after 2 and 3 growing seasons relative to overstory density and herbicide spray treatments. Growth segments labeled with the same letter are not significantly different for the respective growth periods. Capital letters represent significant differences in total seedling height after 3 yr ($P = 0.05$).

er treatment plots with the exception of the unsprayed, clearcut plots which had negative net growth (–0.5 cm). The sprayed 25% crown cover plots performance was poor because of intense competition of *Betula papyrifera* seedlings.

The reduced growth in the clearcut is attributed to rapid invasion of competing vegetation and to seedling dieback caused by a late spring frost in 1992. Herbicide spraying temporarily reduced the density of competing vegetation in the clearcut during the first 2 yr, but such vegetation redeveloped rapidly in the 3rd growing season causing interference and likely reduced availability of resources of oak seedling growth. This result is typical of sprayed clearcuts in our region, because of invasion of rapidly growing seed-origin intolerant woody species such as *Rubus*. Although we are of the opinion that the reduced resource availability is the major factor in reduced growth, the frost in June, 1992 also caused some damage to the seedlings in the clearcut plots. Although the damage was not extensive, it occurred only in the clearcut plots and not in any of the shelterwood plots. Similar frost damage occurred at another study site located ≈ 32 km from this study where 100% of the seedlings in a large clearcut (31 ha) were severely damaged by frost, while there was no damage in adjacent shelterwoods of 50 and 75% crown cover.

When bareroot seedling performance was analyzed, it was found to be quite uniform for the first 2 growing seasons with only slightly better growth in the sprayed clearcut, and in both the sprayed and unsprayed 25% crown cover plots when compared to the other plots. During the 3rd growing season, more dramatic growth differences in the treatments began to appear. Growth was significantly greater in the unsprayed 25% crown cover plots (14.1 cm) than in any other overstory/understory treatment combination. The poorest growth was in the unsprayed clearcut plots (0.3 cm) with the next poorest growth in the sprayed clearcut plots (6.9 cm); however, the latter growth was not significantly different than growth in the 50% crown cover plots (fig 4).

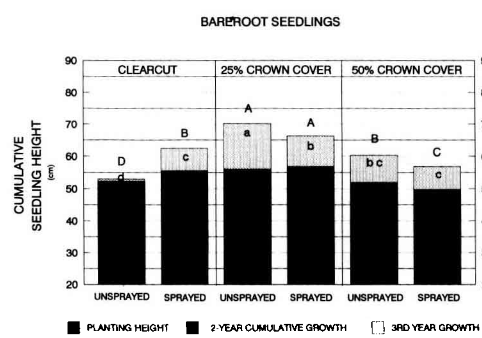

Fig 4. Cumulative seedling height (cm) for bareroot seedlings at planting date and after 2 and 3 growing seasons relative to overstory density and herbicide spray treatments. Growth segments labeled with the same letter are not significantly different for the respective growth periods. Capital letters represent significant differences in total seedling height after 3 yr ($P = 0.05$).

Trends for bareroot and containerized seedling growth were similar and are most likely the result of the intense competition and frost that we mentioned previously. The "best" conditions for seedling growth occurred in the clearcut and 25% overstory, but it is necessary to control vegetation competition in a clearcut as illustrated by the difference in growth between the sprayed plots (25.5 cm) and unsprayed plots (20.9 cm) for 2-yr cumulative growth, and 6.9 cm and 0.3 cm for 3rd-yr growth, respectively. Furthermore, because of the high probability of late spring frost in the northern Lake States, clearcutting as a regeneration method for oak may not be an option.

Because there was not a significant difference in growth between the sprayed and unsprayed treatments in the 50% crown cover plots, it appears that the denser overstory is having a major influence on light and other resource availability. Apparently the herbicide treatment did not provide benefits to seedling growth under the 25% overstory density on these sites as we had expected. This trend, although examined here at an early stage in regeneration, is an especially important finding considering the recent restrictions on the use of herbicides in the US. It also reinforces the importance of selecting sites where understory competition is minimal while at the same time providing adequate conditions for sustained oak growth.

After three growing seasons, the poorest growth and most dieback and mortality in the 25% crown cover plots occurred in the close proximity to stump sprouts that over-shadowed some planted seedlings. This reduction in growth and incidence of mortality is likely attributed to the micro-environment created by the stump sprouts and reduced the growth potential of the overall environment of the 25% crown cover treatment. Companion studies are being conducted to quantify the light environment relative to the overstory density and lower canopy composition to better evaluate seedling performance relative to specific micro-environments. Moreover, we expect the "best growth" to occur in the unsprayed 25% crown cover plots in future years. Thus far the seedlings in these plots are the tallest seedlings in the study, and even greater growth is expected from these larger, well-established seedlings.

Root-graded seedlings

Root-graded seedlings were included in this study to test the hypothesis that the number of first-order lateral roots are correlated with field performance (Kormanik, 1989). When 2-yr growth data were pooled from all overstory/understory plots, grade 5 seedlings (*ie* seedlings with > 20 lateral roots) grew an average 23.5 cm; however, there was no significant difference between grade 5 seedlings and grade 4 seedlings (x = 21.5 cm). Grade 3 seedlings averaged 18.8 cm after 2 growing seasons and grade 2 averaged 18.0 cm. However, there was no significant statistical difference in 2-yr height growth among root grades 2, 3 and 4 seedlings. In all cases, grade 1 seedlings grew significantly less than other root-graded seedlings with an average 2-yr height growth of 12.5 cm (fig 5). When seedling performance was analyzed according to overstory density, 2-yr cumulative height growth was poorest under the 50% crown cover for all root grades. In general, the higher grade seedlings with more lateral roots performed better than the lower grade seedlings in all overstory densities (table III). Third-yr growth data showed no significant differences in the seedling height growth by root grade (table IV). Total height of the seedlings after 3 yr was significantly greater for root grade 3 to 5 than for root grade 1 and 2, due to differences in growth during the first 2 yr (fig 5). While the use of 2–0 seedlings with a minimum caliper of 9.5 mm (Johnson *et al,* 1986) has merit, our study shows that smaller caliper seedlings can be successfully used in regeneration plantings on dry-mesic sites if the seedlings have a significant number of first-order lateral roots. In the Lake States, USA, large 2–0 nursery stock are not often used for artificial regeneration because of increased nursery costs associated with production, handling and shipping, and the belief that larger stock is more difficult to plant properly. This study illustrates the feasibility of using 1–0 northern red oak nursery stock when essential criteria are met. However, the quality of the seedlings must meet minimum standards based on field performance. In this study, the bare-

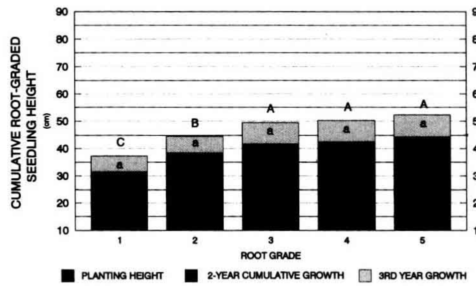

Fig 5. Cumulative seedling height (cm) at planting date and after 2 and 3 growing seasons relative to root grade pooled across all treatments. Growth segments labeled with the same letter are not significantly different for the respective growth period. Capital letters represent significant differences in total seedling height after three years ($P = 0.05$).

Table III. Average cumulative 2-yr height growth ± SE (cm) for root-graded seedlings relative to overstory density.

Overstory density	*Root grade* 1	2	3	4	5
	Height (cm)				
Clearcut	16.8 ± 2.9	18.8 ± 1.9	20.3 ± 2.3	25.4 ± 1.8	22.8 ± 2.4
25% Crown cover	11.5 ± 2.9	20.2 ± 2.4	20.8 ± 1.6	21.1 ± 2.1	26.0 ± 2.2
50% Crown cover	9.7 ± 1.9	14.7 ± 1.6	15.3 ± 1.5	17.6 ± 1.0	21.4 ± 2.0

Table IV. Average 3rd-yr height growth ± SE (cm) for root-graded seedlings relative to overstory density.

Overstory density	*Root grade* 1	2	3	4	5
	Height (cm)				
Clearcut	2.4 ± 4.5	2.2 ± 3.0	6.4 ± 2.0	5.0 ± 2.4	7.9 ± 2.2
25% Crown cover	7.3 ± 3.0	9.7 ± 2.4	8.7 ± 1.5	11.1 ± 2.2	8.7 ± 2.7
50% Crown cover	7.0 ± 1.5	5.6 ± 1.5	8.3 ± 1.5	7.0 ± 1.4	7.2 ± 1.8

root seedlings all had at least 10 first-order lateral roots > 1 mm in diameter with a height of at least 13 cm and a caliper of 7.0 mm (table II). While nurseries in the northern Lake States can produce 1–0 seedlings that meet these minimum standards, usually the percentage of cull seedlings in the seedbed is too high with current nursery practices. However, if nursery managers utilize quality seed sown at bed densities no greater than 85 per m^2 and make multiple applications of fertilizer at low rates (Teclaw and Isebrands, 1991), seedling uniformity and overall quality can be improved dramatically. Thus, a high percentage of 1–0 northern red oak seedlings can be produced that meet high-quality standards.

DISCUSSION

Our studies in the Lake States, USA show that oak regeneration must be viewed as a regeneration system, with the goal to obtain an established vigorous free-to-grow seedling. The artificial regeneration system that produces this seedling begins with collection of high quality acorns and includes a number of important steps – any one of which may affect achieving the ultimate goal. Results from this study suggests that the use of high quality seedlings, planted with augers on dry-mesic sites, under a light overstory afford good conditions for the establishment of northern red oak without the use of herbicides. Our best results were with a 25% crown cover, although our study is preliminary in that we have only 3-yr results. Thus far, our results support Kotar's (1991) premise that dry-mesic sites are good sites on which to regenerate and grow northern red oak. Although regeneration systems that include clearcutting or 2-cut shelterwoods may perform well for regenerating oak in some regions (Johnson *et al*, 1986), the species composition and its reponse to such management often differ by regions, suggesting that these methods cannot be universally applied. Moreover, the high probability of dieback due to late spring/early summer frosts in the Lake States alone make these systems suspect in the region. Phenological studies are being conducted to clarify this problem.

Our results suggest that seedlings with at least 10 lateral roots (*ie* root grade 3 or more) performed best. Although at this time we recommend planting high quality bareroot seedlings as the primary stock type, our results suggest that containerized northern red oak seedlings merit future consideration. At present, production costs are high for containerized northern red oak seedlings, but under the conditions of this study they clearly outperformed bareroot nursery seedlings over a 3-yr period. Comparative ecophysiological studies on above and below ground morphology and carbohydrate reserves of bareroot and containerized seedlings need to be conducted to help understand why the 2 types of seedlings perform differently. Moreover, more research is needed on development of an ideal container system for northern red oak.

In this paper we have outlined a successful regeneration system for northern red oak on dry-mesic sites in the Lake States, USA. The system is a departure from the traditional methods in that region that currently employ medium density shelterwood cuts and chemical control of competing vegetation to establish seedlings, and then conclude with a total overstory removal for sustained growth. Our results suggest that for dry-mesic sites, light shelterwood cuts without herbicide spraying can be a very successful and more aesthetic alternative system for forest managers in the Lake States to consider, and perhaps these methods have applications elsewhere.

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