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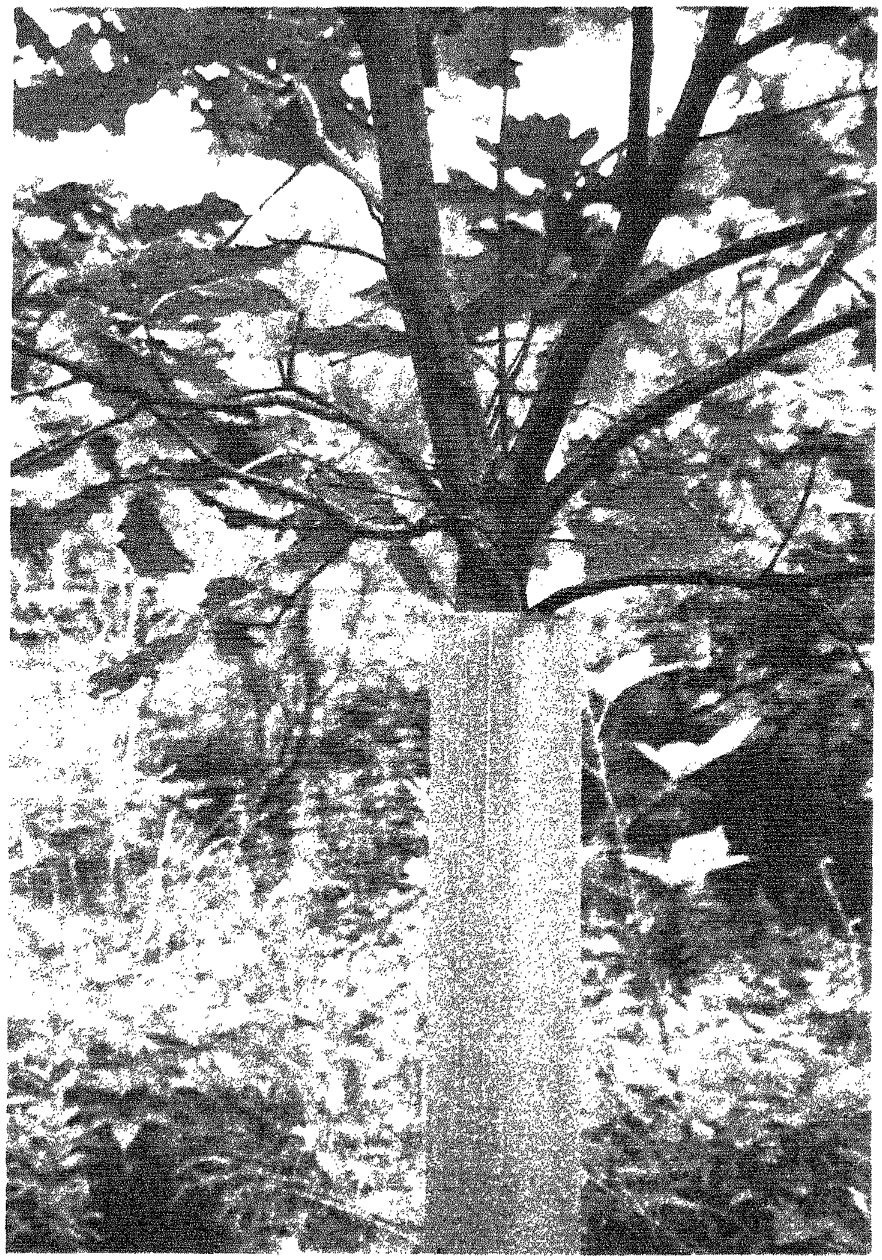
June 20-22, 1995
Harrisburg, Pennsylvania



Preface

Tree Shelters were first developed by British forestry researchers in 1979 to enhance seedling growth and establishment in forestry plantings. Tree Shelters have been marketed in North America for nearly ten years by several manufacturers and are promoted by many forestry professionals for growth response and protection from herbivores, herbicides, and mechanical damage. Their frequent use in urban and rural cooperative forestry projects makes it appropriate to review what we have learned in the field about the costs and benefits of this maturing technology.

Research on tree shelter applications and effects in North America is beginning to yield quantitative results. Tree shelters are being used for a wider range of species and on a wider range of sites. Higher unit value crops are being used. Urban forestry applications are expanding. Increased use has also included a number of failures that may indicate limits of the technology or inappropriate applications of the technology. Concerns have been raised about tree shelters costs versus benefits.

In response to these concerns, the USDA Forest Service, Northeastern Forest Experiment Station contacted the Center for Urban Forestry at the Morris Arboretum of the University of Pennsylvania to develop a conference that would survey the current state of knowledge on tree shelters for reforestation and ecological restoration. In cooperation with the Pennsylvania Bureau of Forestry, the Northeastern Area State and Private Forestry, and others, we conducted a literature review and released a call for papers. A needs assessment process concluded that it was appropriate to bring together researchers and practitioners for an open dialogue and exchange of information.

The Tree Shelter Conference was presented June 20-22, 1995, in Harrisburg, Pennsylvania. Participants came from the United States, Great Britain, and Canada. They included research foresters, field foresters, urban foresters, ecologists, manufacturers, and others. This document includes ten reviewed papers that were delivered at the conference and twelve additional abstracts. Some of the particpants responses are summarized. This is not an exhaustive compilation, but is the most complete survey of research to date. We trust that it will answer many of the questions that people have asked about tree shelters, that it will lead to more effective decisions about tree shelter use, and that it will raise other questions to be answered.

We wish to acknowledge the contributions of all the participants, the conference planners, readers, and organizers. In particular we with to thank Xavier Riva, who as USDA Forest Service/Morris Arboretum Urban Forestry Intern, saw to it that all was done well, and John Brissette who made these proceedings possible. The planning team of Jim Bailey, James Barnett, Clyde Hunt, James Klocko, Keith Windell and others were instrumental to the program's success. We also acknowledge that this program's foundation was set by the USDA Forest Service's Missoula Technolgy and Development Center and USDA Forest Service State and Private Forestry in the Southern Region.[1]

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[1] Windell, Keith. 1993. Seedling Protection in England, Trip Report. USDA Forest Service, Technology & Program Development Program, 2400-Timber, 9324-2845-MTDC.

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Proceedings of the Tree Shelter Conference

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The History, Development and Use of Treeshelters in Britain[1]

Gary Kerr[2]

Abstract. The history of the treeshelter began in 1979 at Alice Holt Lodge when Graham Tuley wrapped polythene around conventional plastic mesh guards in an attempt to increase the growth rate of newly planted trees. Hence, the first treeshelter was invented and the idea quickly gained acceptance in British silviculture; current annual use is probably between 4 and 5 million. The treeshelter has been one of the great successes of recent forestry research in Britain and is now being tested and developed throughout the world. It is hoped that this brief account of the history, development and use of treeshelters in Britain will be of interest in North America and help potential users avoid inappropriate applications.

Introduction

The development of the treeshelter began in 1979 at Alice Holt Lodge when Graham Tuley wrapped polythene around conventional plastic mesh guards in an attempt to increase the growth rate of newly planted trees (Tuley 1985). The idea was simple and brilliant - instead of growing trees in greenhouses, the greenhouse was being taken to the tree. In 1979, 180 "mini-greenhouses", as Tuley first called them, were made, in the following year 1800 were used in experiments and by 1984 over a million were commercially manufactured and sold; current annual use is probably between 4 and 5 million. The treeshelter has been one of the great successes of recent forestry research in Britain and is now being tested and developed throughout the world (Applegate et al. 1994, Buresti and Sestini 1991, Burger et al. 1992, Kittredge et al. 1992, Minter et al. 1992, Ponder 1991, Reinfeldt and Spellmann 1988, and Sun et al. 1994).

This paper reviews the history, development and use of treeshelters in Britain using the analogy of a product life cycle, which has had 3 phases:

1. Product initiation, the factors behind the treeshelter idea.

2. Product development, in which the early idea was developed by research and trial to be more "user-friendly".

3. Product maturity, in which a balanced view of the benefits and problems of treeshelters has been achieved and the emphasis has changed from research to communicating best practice to users.

Product Initiation

Forestry in Britain before the 1980s was dominated by afforestation of marginal agricultural land, usually in exposed wet areas in western and northern Britain, using non-native conifers such as Sitka spruce (*Picea sitchensis*) and Lodgepole pine (*Pinus contorta*). During this period little attention was paid to broadleaved woodlands and the problems encountered in attempts to restock and, to some extent, create new woodlands. Many owners of such woodlands had begun to use larger stock sizes than transplants in an attempt to solve the problems of weed control and damage by mammals. In addition they moved away from using high stocking densities, often in the region of 10,000 stems per hectare (sph), which had been common in the early part of the century to much lower densities such as 2,500 sph, to reduce costs.

These factors led to renewed interest in the use of individual tree guards which at the time were manufactured as a black plastic mesh (Pepper and Williams 1982). At this time Graham Tuley wrapped polythene around conventional plastic mesh guards in an attempt to increase the growth rate of newly planted trees, this development of the tree guard led to the idea of the treeshelter. As the concept of the treeshelter developed it became clear that there were four main benefits, treeshelters could:

1. improve the survival and growth of newly planted trees;
2. protect trees from mammal damage;
3. increase the speed and efficiency of herbicide application;
4. facilitate the location of trees and reduce the need for planting in straight lines for maintenance.

There is little doubt that what first caught the imagination of most foresters in Britain was the ability of the treeshelter to double or triple the growth rate of some broadleaved tree species. However, this was not the main factor for their success in Britain, the crucial factor was that it was timely. The main reasons for this were: (a) in the early 1980s Britain was experiencing a renewed interest in broadleaved woodland in response to public pressure; (b) increased levels of grant aid were given to encourage planting broadleaves; (c) minimum stocking densities were set low at 1,100 sph which favoured individual tree protection rather than fencing, and (d) the conversion of agricultural land to forestry was encouraged.

Product Development

Size

The main factor determining what height of treeshelter to use is the level at which mammals in the area can browse. Roe deer (*Capreolus capreolus*) are present around Alice Holt Lodge and the first treeshelters were made 1.2 m tall, above their maximum browse level of 1.1 m. Evidence from Kerr (1995a) suggests that many growers continue to use 1.2 m treeshelters, which many people consider to be a "standard size", even when the deer species present can browse above 1.2 m. Nevertheless, there is little point in

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

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choosing a shelter taller than that needed to provide protection from mammal damage, the faster growth rates in larger shelters will certainly not justify the extra expense. Using smaller (and hence cheaper) shelters will enable larger areas to be protected without recourse to fencing. The current recommendations for effective protection are given in Table 1.

Table 1.—What size of treeshelter? Recommendations for protecting seedlings from a range of animals in Britain.

Animal	Treeshelter Height (m)
Rabbits	0.60
Hares	0.75
Roe deer	1.20
Sheep (small breeds)	1.20
Sheep (large breeds)	1.50
Red, sika and fallow deer	1.80

Diameter is less critical than height and experiments have tested designs with diameters from 50 mm upwards. In general as diameter increases the shelter effect declines but within the range 50-200 mm this is not important. This finding has been used by some manufacturers which produce nested treeshelters of differing diameters.

Research has investigated the use of 4 m tall treeshelters, the objective being to produce 4 to 5 m of straight clean tree required by timber merchants, early in the life of the tree. However, these shelters have been very difficult and expensive to support and are not practical.

Shape

Early designs of treeshelters were made from flat sheets of polyproplene folded into square tubes. However, the large flat sides of these shelters offer considerable resistance to wind and sometimes cause the shelter to turn in the wind or blow flat against the stake; during particularly strong storms in 1987 and 1990 some very bad instances of this latter effect were recorded. In response to these concerns, and the launch in 1986 of robust tubular (extruded) treeshelters, some manufacturers which had produced square designs began to offer hexagonal designs.

Stakes

The stake is an integral part of a treeshelter and many users who have attempted to reduce costs by using low quality stakes have found that subsequent re-staking and maintenance have been expensive. A good staking material must be durable in the ground for the life of the shelter, must not be subject to warping, and offer frictional resistance to the twisting movement of the shelter around the stake and, it is preferable if the stake is reasonably easy to remove from the soil at the end of the life of the shelter. The best stakes are treated sawn softwood and cleft chestnut which are the most common types of stake currently used with treeshelters (Kerr 1995a). Potter (1991) recommends that sheltered sites with a deep soil require a 25 x 25 mm stake to support a 1.2 m treeshelter. On exposed sites or on thin or skeletal soils the advice is to increase this specification to 30 x 30 mm. The stake should be driven into the soil far enough to give the treeshelter adequate support and its top should be 10 cm above the upper tie (on 1.2 m treeshelters) and below the lip of the shelter to prevent damage to the emerging tree. The staking of 1.5 m and 1.8 m treeshelters require 40 x 40 mm in sheltered areas and 50 x 50 mm in more exposed sites; both sizes of stake should penetrate the soil at least 40 cm which may require holes to be preformed on some soils (Kerr 1995a).

The ultimate aim of many designers has been to produce a free-standing treeshelters, attempts at this for larger treeshelters have been unsuccessful. However, the "Quill" is a small treeshelters which is pushed in the ground for support rather than attached to a stake; a silvicultural evaluation of the Quill is given in Kerr (1995b).

Materials

Polyproplene is the most common material for treeshelters to be manufactured from although some designs use polyvinylchloride or polyethylene. Polyproplene has the advantage of relative cheapness and a good strength to weight ratio but will deteriorate rapidly in sunlight unless stabilized by ultra-violet inhibitors. The early shelters, made without added stabiliser, began to breakdown too quickly. Potter (1991) claimed that "experience has determined the formulation that will offer a 5-year life in full light in southern Britain, enabling the treeshelter to remain intact until the tree is able to support itself". However, this claim turned out to be premature and many growers claimed that slow breakdown of some designs was restricting the growth of trees (Kerr 1992). These concerns led to the incorporation of the "laserline" in one design, this is a line of perforations which is claimed to allow the treeshelter to breakdown in response to the growth of the tree.

Stem Abrasion

Most of the materials used to make treeshelters are capable of causing damage to the stem of the emerging tree, the majority of shelters therefore incorporate design modifications to reduce this risk. However, even the best of these modifications has been reported to be inadequate on exposed upland sites (Nixon 1994).

Colour and Light Transmission

Much research has been carried out on these aspects of treeshelters usage (Potter 1991). The main conclusions of this work have been: (a) on open sites the colour of the treeshelters will make little difference to the growth (assuming the design is translucent) and therefore colour should be chosen to blend in with the surrounding vegetation, (b) when underplanting it is best to use clear or white treeshelters to maximize the amount of light incident on the seedling.

Miscellaneous

1. Treeshelters have proven to be very useful where application of contact herbicide from tractors has been required (Williamson 1992).

2. There have been many reports that beech (*Fagus sylvatica*) has not performed well in treeshelters. The main cause of such repots has often been poor silviculture, particularly weed control and plant quality, but the presence of beech woolly aphid (*Phyllaphis fagi*) can reduce survival and growth of beech in treeshelters and must be controlled (Kerr and Evans 1993).

3. Some small bird species have been found dead in treeshelters, there is little objective information on this problem but it is not thought to be a significant problem.

Product Maturity

During the 1980s the treeshelter market was bristling with activity as manufacturers attempted to catch the eye of growers and this was supported by research (Potter 1986). However, the rate of product development has slowed in the 1990s and many people have been reflecting on the success or otherwise of early plantings. This has led many foresters to focus attention on the subject of treeshelter maintenance. A survey of treeshelter usage (Kerr 1995a) has highlighted that the following aspects of treeshelters use are not being implemented and considerable room for improvement exists.

1. The use of effective weed control in combination with treeshelters is very important to ensure rapid establishment. The level of weed control revealed by the survey, ineffective wed control at 68% of sites visited, was unacceptably low.

2. Many people involved in tree planting, foresters in particular, have a strong desire to plant trees in straight lines or in geometric grid patterns. This is often unnecessary with treeshelters and should be avoided, particularly in areas of high visual amenity.

3. On a large number of sites the choice of treeshelter height had not been made with reference to the tallest browsing mammal in the area. Trees with inadequate protection may, with very low deer densities, survive and grow to fulfil the objectives of the planting scheme, but full protection is the only sensible recommendation with current expansion of deer populations.

4. As plantings get older the angle of lean of treeshelters increases, this is probably attributable to both the choice of staking material and also to a lack of periodic inspection and maintenance.

Conclusions

Treeshelters are an effective aid to tree establishment and their place in British silviculture is well established. However, not all aspects of optimum usage are widely practised and better communication of best practice by woodland advisers will help to improve this situation.

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Deer Protection for Small Forest Plantations: Comparing Costs of Tree Shelters, Electric Fencing and Repellents[1]

Jonathan S. Kays[2]

Abstract. Hardwood and pine plantings under three acres have become more common in the Maryland area due to an increase in smaller ownerships and incentive programs for reforestation. Tree shelters have been used for more than 5 years in new hardwood plantations to protect against white-tailed deer (*Odocoileus virginianus*) browsing, with added benefits of improved tree survival, growth and vigor. Unfortunately, the high initial cost makes it difficult to protect all seedlings in hardwood plantings. Tree shelters are not widely used for conifer plantings.

Taste and odor-based repellents have not reliably protected young hardwoods and conifers until the seedlings outgrow the reach of deer (usually 3-5 years). The cost of materials and labor to make repeated applications for 3-5 years are high. In many cases, changes in environmental conditions, deer feeding patterns, and populations characteristics can cause deer to feed on treated seedlings, thereby negating any benefits gained by repellent use.

The use of temporary, electric, polywire or polytape fencing was effective for protecting plantations against deer browsing in Maryland for up to three acres. Higher acreage applications are being studied. It can be used to protect both hardwood and conifer plantings, where tree shelters are used primarily on hardwoods. Further, the diversity of vegetation inside the fence is protected, not just selected seedlings. While proper installation and regular maintenance of temporary fencing is absolutely necessary, it is cost-effective and can be moved easily to another site when needed.

This paper provides an estimated budget for protecting a three acre hardwood planting. The benefits, costs, advantages and drawbacks of using electric fencing, tree shelters and repellents are discussed. This information will help foresters and landowners make cost-effective decisions for deer management in small conifer and hardwood plantings.

Introduction

The establishment of small forest plantations and regeneration of cutover areas has been negatively affected by deer browsing in many areas of Maryland. The deer herd in Maryland has increased to over 200,000 in 1995 (D'Loughy 1995). Increases in deer populations and associated browsing effects has been noted throughout the Northeast (Kittredge et al. 1992, McCormick et al. 1993, Jones et al. 1994). The successful establishment of forest plantations or regeneration of cutover areas must include provisions for deer management or risk financial loss and ecological damage.

The majority of land in the eastern United States is controlled by nonindustrial private forest owners and accounts for 70 percent of the forestland acreage. However, the vast majority are small tracts (Powell et al. 1994), and increasing urbanization and fragmentation is resulting in more small woodlands. Techniques to protect small reforestation areas from deer browsing are needed. Further, the increase in suburban deer populations require techniques for suburban forest protection as well.

The most common deer control methods for forest plantations include tree shelters, repellents and electric fencing. While many studies have dealt with the relative effectiveness of one or more of these controls, none have attempted to compare the advantages, disadvantages and actual costs of each under practical applications by nonindustrial private landowners on small forest plantations under three acres. This paper will address these concerns.

Study Area and Methods

Phone interviews and site visits with state foresters, private forestry consultants, and utility foresters were combined with personal experience from field demonstrations to determine costs and methods for establishing a small hardwood plantation and implementing three common deer management methods in the Central and Western Maryland area. In many cases, labor demands involved with plantation establishment and deer management methods may be implemented by the landowner. However, to provide a consistent assessment, costs for materials and reasonable labor where determined. A generous labor rate of $10 per hour was used in this analysis.

Plantation Establishment

For analysis, I assumed that the planting site consists of deep, well-drained soil with average fertility that has the potential to grow good quality northern red oak (*Quercus rubra*), white ash (*Fraxinus americana*) and black walnut (*Juglans nigra*). The state forester assisted the landowner in selecting the site, making the planting prescription and locating a planting contractor. The site was previously in hay production for many years and is now being converted to trees. The plantation establishment cost of $300 per acre includes $50 per acre for the cost of chemical site preparation with Oust® in the fall prior to planting. Planting stock consists of 400 hardwood seedlings per acre obtained from the state forest nursery for a total cost of $120. Species consist of an equal mix of two-year old northern red oak seedlings and one-year old white ash and black walnut seedlings. Two-year old seedlings were used when available to reduce the time necessary for the trees to grow out of the reach of deer. All seedlings were machine planted by a private contractor at a cost of $90 per acre. One maintenance spray at a cost of $40 per acre is planned for year 2 or 3 to remove competing vegetation from the seedlings.

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[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Regional Extension Specialist, Maryland Cooperative Extension Service, Keedysville, MD.

Tree Shelters

One hundred four-foot Tubex® tree shelters were installed per acre to assure the protection of crop trees. Tree shelters were purchased from the state distributor for a cost of $2.10 each (quantities under 1,000). The one-inch stakes used to hold up the shelters were purchased from a local source for $0.65 each. The total cost for shelter and stake was $2.75 resulting in a cost per acre of $275. All shelters were installed by a private contractor at a cost of $0.85 each or $85 per acre. Plastic mesh nets provided by the shelter manufacturer were installed on top of the shelter to stop songbirds from being trapped in the tube. Total cost per installed shelter is $3.40 each. Maintenance costs over the six-year period is estimated at $0.40 each (Lantagne 1995), which is probably conservative. The total per acre cost for 100 tree shelters, stakes, installation and maintenance was $400. There is no savings as the total acreage increases.

Temporary Electric Fencing

This cost analysis included a temporary polywire fence baited with peanut butter (Figure 1). The fence consists of two strands of polywire or polytape suspended above the ground at 36 inches and 20 inches by 4-foot fiberglass rods at 35-foot intervals. At every 35 feet, 3" x 4" "flags" made of aluminum flashing were folded over and attached to the wire. The underside of the flags were baited with peanut butter. All flags were rebaited every 6-8 weeks throughout the year.

The wire is charged with an electric current from a high-voltage, low-impedance charger, which provides regularly timed pulses (45 to 65 per minute) of short duration (0.0003 second). The charger is sized to power the number of feet of polywire used. The charger and other fence materials were purchased from a national distributor of deer-fencing supplies. The rule of thumb used to select a charger was to provide one joule of charger output for each 3,000 feet of fence. This analysis assumes that an A/C power source was available within 1,000 feet, so an A/C-powered charger could be used. A piece of aluminum fence wire was run on posts to the fence site from the charger located at the power source. Aluminum wire was used instead of polywire or polytape to minimize any loss in voltage. The analysis also provides the cost for a solar-powered battery charger for a cost comparison

The cost of the fencing materials using an A/C-powered charger to enclose a three-acre area, totals $277 (Table 1) for a cost of 18 cents per linear foot. If a solar-powered unit ($530 with battery) is necessary, the cost of the materials for a three-acre area increase to $677, for a cost of 44 cents per linear foot. Increasing the size of the area to five acres results in an increase of about $32 per acre for extra posts, wire, and bait materials. Using polytape instead of polywire would result in an increase of $78 for fencing material on a three-acre area.

A mowed buffer zone of 10-15 feet will be maintained around the perimeter of the fence for the three-year period so the fence will be visible to the deer. Three mowings per year at a cost of $75 per year total $225 over three years (Table 2). Vegetation under the fence will be controlled by spraying Roundup® herbicide two times per year at a cost of $50 per year ($25 per spray), and $150 for three years. Rebaiting the fence every 6-8 weeks will cost $70 per year for labor and peanut butter, or $210 over three years. The fence will be checked once a day for the first two weeks after installation to fix any breaks, make sure the fence has sufficient voltage, and put up any section the deer may have pushed over. Thereafter, the fence will be checked every few days as needed. No labor cost is included for regular inspection of the fence over the three-year period. It is assumed that the grower will accomplish this task while performing other land management activities. The total maintenance cost per year of $195 for mowing, vegetation control and rebaiting, totals $585 over a three-year period. It should be noted that after the tree establishment period is over, the fence charger and materials can be reused to protect other forest plantations, gardens or crops.

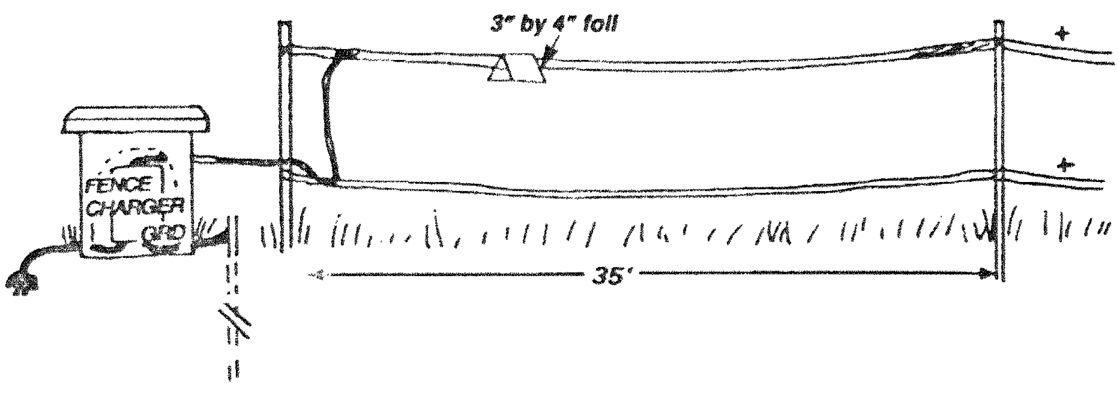

Figure 1.—Two-strand polywire/polytape electric temporary fence (adapted from Craven and Hyngstrom 1993).

Table 1.—Cost of materials for a 3- and 5-acre, 2-strand rectangular polywire fence.

Qty	Materials	Area Fenced 3-ac 1548 ft	Area Fenced 5-ac 1980 ft
		------- $ -------	
1	2-joule A/C powered electric charger + ground rod	130.00	130.00
2	Spools of polywire (1,650 ft each, 3,300 ft total)	72.00	108.00
40	Fiberglass post + clips ($1.35 each)	54.00	72.00
4	4-ft metal corner posts with 1-in PVC covering	6.00	6.00
1	Rool of aluminum flashing/electric fence signs	10.00	15.00
1	Jar of peanut butter/vegetable oil	5.00	5.00
	TOTAL COST	277.00	341.00
Cost per linear foot including A/C powered charger		0.18	0.17
Cost per linear foot including solar powered charger		0.44	0.37

Repellents

I calculated the cost of using the commercial liquid repellent Deer-Away® which was effective for reducing deer browsing in many studies (Harris 1981, Campbell 1987). Deer-Away® is a taste and odor-based repellent and is a two-part mix that was purchased with a red dye to ease detection of spray coverage. It can be difficult to use because the mix is messy, must be agitated regularly, and can clog spray tips during application. However, it is capable of providing good protection for seedlings with reapplication needed every 4-6 weeks. Noncommercial repellents (i.e. human hair, soap, and tankage), which are usually hung from branches and often provide unreliable protection, were not considered a viable option in this type of forestry application. It is assumed repellents would only be applied every 4-6 weeks on days with above freezing temperatures from late fall to early spring, when browsing on tree seedlings is most prevalent. Summer browsing was not a problem in this area. A total of four applications per year would be made for three years (Table 2). The labor cost was calculated at $10 per hour with two hours needed to treat all the seedlings on each acre. Seedlings were dipped in repellent prior to planting to deter late spring browsing.

The cost of Deer-Away® was calculated at $16 per gallon, mixed 1:6 with water. One gallon will treat 400 seedlings in the field, or 800 bundled/bagged seedlings. Therefore, one gallon is needed to treat each acre of seedlings per application.

Results and Discussion

Tree Shelters

Tree shelters have received widespread application by many public agencies, private industries, and individuals before long-term research results were available (Lantagne 1995). Tree shelters increase hardwood growth by providing protection from deer browsing and favorable growing conditions. Tree shelters have increased height growth of northern red oak (Lantagne et al. 1990, Lantagne 1991, Minter et al. 1992, Kittredge et al. 1992, Smith 1993, Walters 1993, Lantagne 1995), black walnut (Ponder 1991, Ponder 1995) and white ash (Kays, unpublished). The suitability of tree shelters for conifer species is questionable with only marginal increases in height growth reported (Ward and Stephens 1995). The improved growth of sheltered hardwood tree seedlings is probably related to the elevated air temperatures, higher CO_2 levels and higher relative humidity found in the shelters (Minter et al. 1992, Potter 1991). The environment inside the tube acts like a mini-greenhouse and promotes rapid height growth. The shelters allow the easy location of seedlings in dense brush and protects the seedling during herbicide applications.

A 4-foot shelter is commonly used, and will prevent most deer browsing. However, 5-foot shelters are recommended in areas with deep snow or severe browsing problems. Tree shelters are not a plant and walk away alternative (Smith 1993). Tree shelters will fail or lean because of rotting stakes, buck rubbing, and high winds. Distorted terminals for trees within tubes can be a problem. Wasp nests in tube interiors can form a physical barrier for terminal expansion. Emerging terminal leaders can snag on the mesh placed over the tubes to prevent bird entry, spiraling until the leader penetrates the mesh (Minter et al. 1992, Ward and Stephens 1995). Failure to install netting on the top of each shelter can result in mortality of songbirds in old-field applications. Overwintering voles in the bottom of tubes can also girdle and kill seedlings (Marquis 1977).

The height growth advantage of tree shelters appear to short-lived. Once seedlings emerge from the tree shelter tubes, growth rates appear to be the same as unsheltered seedlings (Lantagne 1995). The ability of tree seedlings to continue strong terminal growth after emergence from tree shelters appears to be dependant on the presence of competing vegetation as well as the species. Because the shelters only protect the individual stem, deer will continue to browse and reduce competing vegetation. Seedlings emerging from widely-spaced shelters may produce branching crowns characteristic of open grown trees, rather than straight, vertically-growing stems characteristic of forest grown trees.

Table 2.—Cost of plantation establishment and various deer protection options for a three and five acre hardwood forest plantation in an old field.

	Establishment Cost	w/Tree Shelters	w/Electric Fencing	w/Deer Repellents
Plantation Establishment Cost				
Site Preparation with Oust	$ 50	$ 50	$ 50	$ 50
2-0 Hardwood Seedlings (400/acre)	120	120	120	120
Machine planting	90	90	90	90
1 Maintenance Spray	40	40	40	40
Subtotal Establishment Cost	*$ 300*	*$ 300*	*$ 300*	*$ 300*
Tree Shelters (100/acre)				
4-ft shelter - $2.75 each with stake		$ 275		
Installation labor - $0.85 each		85		
Maintenance cost - $0.40 each		40		
Subtotal Tree Shelters		*$ 400*		
Temporary Electric Fence				
A/C charger - materials for 3-acre area			$ 277	
Installation labor (3 hours for 2 people)			60	
Maintenance cost				
* Mowing (3 times per year/3 years)				
* Fence weed control			225	
(2 sprays/yr/3yrs)			150	
* Rebaiting (Every 6 wks/3 years)			210	
Subtotal Electric Fencing			*$ 922*	
Repellents				
(dip at time of planting + 12 applications for 400 seedlings over 3 years)				
Deer Away® ($16/gallon - 1 gal/acre)				$ 200
Labor cost to apply				
(2 hours/acre/appl.)				240
Subtotal Repellents				*$ 440*
Total for 1 Acre	**$ 300**	**$ 700**	**$ 1,222**	**$ 740**
Total for 3 Acres	**$ 900**	**$ 2,100**	**$ 1,822**	**$ 2,220**
Total Cost Per Acre for 3 Acres	*$ 300*	*$ 700*	*$ 607*	*$ 740*
Total for 5 Acres	**$ 1,500**	**$ 3,500**	**$ 2,486**	**$ 3,700**
Total Cost Per Acre for 5 Acres	*$ 300*	*$ 700*	*$ 497*	*$ 740*

Tree shelters are costly, as reforestation projects may require from 70 to 400 shelters per acre, with a minimum of 70 per acre to protect future crop trees. Commonly, other seedlings planted without shelters and native regeneration fill in the gaps at low shelter densities. In areas with severe deer browsing, planted seedlings and other vegetation may be severely browsed by deer, resulting in the loss of competing vegetation. Fewer seedlings should be planted in areas with high deer pressure and all should be protected with tree shelters.

In Maryland, the use of tree shelters by private landowners can be cost-shared up to 65 percent by the Stewardship Incentive Program. Without the existence of incentive programs, it is highly questionable if most landowners would be willing to pay the cost necessary to install large numbers of tree shelters. The cost of $400 per acre to install 100 four-foot shelters in this study would be prohibitive for most private landowners on a multi-acreage planting.

Inexpensive types of tree shelters, such as those constructed of rigid Vexar®, have been widely and successfully used to protect conifer seedlings from deer and elk (*Cervus elaphus*) browsing in the United States (DeYoe et al. 1985). Experience with hardwood applications is less common. The mesh design of these shelters provides no height growth advantages, however, they can still solve deer-browsing problems. Given the high cost, short-duration growth advantage, and application primarily for hardwoods of tube tree shelters, it may be prudent to reexamine research efforts in the eastern United States and develop low-cost, rigid-mesh, shelter designs that primarily address the impacts of deer browsing.

Temporary Electric Fencing

The use of expensive vertical fencing has proven effective to protect agricultural crops (Palmer et al. 1985), forest plantations and regeneration areas (George et al. 1991, McCormick et al. 1993). However, the use of inexpensive electric fencing has also been proven a cost-effective behavioral barrier in protecting row crops, fruit trees, Christmas trees, home gardens, nurseries, and other crops (Porter 1982, Hygnstrom and Craven 1988, Miller et al. 1992, Curtis et al. 1994). The majority of studies have been on small acreage areas (Miller et al. 1992, Jordan et al. 1992). Other orchard studies indicate up to three seasons of protection for sites up to 12 acres (5 ha) with light to moderate foraging pressure by deer (Porter 1983). Demonstration fences in Maryland have provided dormant season protection for orchard crops and tree seedlings on areas up to three acres (Kays 1995). The amount of acreage that can be adequately protected depends on deer density, sources of alternative food supplies, season of the year, and fence maintenance.

While many inexpensive 1-, 2-, and 3-wire fence designs have been used, this cost analysis centered on a commonly used and effective two-wire polywire fence baited with peanut butter. This temporary deer fence is a behavioral barrier, not a physical one. The use of peanut butter attracts nearby deer to the wire and encourages them to touch the wire with their nose. The resulting shock "trains" the deer to stay clear of the fence. Baiting fences with strips of cloth saturated in repellents instead of attractants has been shown to actually improve the effective of temporary electric fences (Jordan and Richmond 1992). It appears the double negative effect of the shock and the repellent better reinforced the behavioral barrier compared to the negative effect of the shock, and positive effect of an attractant such as peanut butter.

A vegetation-free buffer zone of 10-15 feet must be maintained around the fence perimeter. Deer tend to stop when coming into a clearing, notice the fence, and then walk up to investigate it. Without a cleared buffer, the deer may crash through the fence before they even know it is there. Good maintenance of the fence, especially in the first few months, is essential for success. Vegetation must be controlled under the fence to prevent grounding and voltage loss. The fence needs to be checked regularly for damage by deer and the flags rebaited every 6-8 weeks. Occasionally, the deer will knock the fence down, and it must be repaired immediately.

Spans greater than 2,600 feet of polywire can result in reductions in power and fence effectiveness. The use of 15 gauge aluminum wire on the bottom with occasional crossovers to a strand of polywire or polytape, can help sustain voltage over longer spans. Temporary electric-fenc systems have the advantage of being moved elsewhere after the trees have grown out of the reach of the deer. Thi would substantially reduce costs per acre per year for deer protection over more than one application.

The larger question is at what acreage and under what conditions will temporary fencing no longer be effective? Satisfactory control of deer browsing has been reported fo up to 12 acres in orchards (Porter 1983) with light to moderate deer pressure and up to three acres in orchards and forest plantations in Maryland under moderate to severe deer pressure (Kays 1995). While deer pressure is an important factor, landscape arrangement, existing deer travel patterns, season of the year, availability of alternativ foods and amount of snow cover are also critical factors in determining the actual acreage that can be protected. Old-field areas adjacent to wooded cover and in the path of heavily-used trails will be more difficult to protect, and it may be best to let these areas regenerate naturally. Large acreages can be divided into smaller protected parcels tha provide travel corridors for deer to move through the area on established trails. Damage to forest plantations, as with other crops, is easier to control during the growing season when other food sources are available. Most damage to planted seedlings is in the winter when other food sources are lacking or covered by snow. In many areas of the country where snow cover is not present or rare, it may be possible to protect larger acreages with temporary fencing during the dormant season. More studies are needed to determine the effectiveness of temporary fencing on large forest plantations given the factors mentioned.

Repellents

The use of deer repellents to reduce deer browsing on tre seedlings has often met with mixed success. Repellents have reduced deer browsing of orchards (Conover and Kania 1988, Swihart and Conover 1988, Byers and Scank 1987), nurseries (Conover 1984), and forest plantings (Harris 1981, Campbell 1987). However, control is inconsistent and considerable resources are necessary to apply the repellents several times during the year. The longevity of the repellent can be improved by using additives called "stickers" that improve the resistance to weathering. However, at best, most repellents provide on 4-6 weeks of protection under moderate deer pressure.

While Deer-Away® was used in this study because of its past effectiveness (Harris 1981, Campbell 1987), other repellents would be considerably cheaper per acre for material (McIvor and Conover 1991). Further, the demanding mixing requirements and clogging associated with Deer-Away® are not common with other repellents, which require less labor to apply. While the labor and material cost to apply other repellents would be less, overall effectiveness must be considered. The availability of above freezing days in the winter to make applications can be a limiting factor for repellent use in northern climates.

Deer browsing in forest plantations is most damaging in the late winter and early spring when alternative foods are not available and repellents based on odor and taste cannot always deter hungry deer. In many cases, changes in environmental conditions, deer feeding patterns, and population characteristics can cause deer to feed on treated seedlings, thereby negating any benefits gained by years of repellent use.

Discussion of Deer Protection Options

Costs for protecting a three-acre forest plantation from deer browsing vary widely. Deer-Away® repellent has the highest cost per acre at $440 followed by tree shelters at $400 per acre and temporary electric fencing at $307 per acre. While the cost per acre for tree shelters and repellents would remain constant for 3 or 5 acres, the cost per acre for temporary fencing would decrease (Table 2). The additional fencing materials needed to protect 5 acres compared to 3 acres would cost $64, with no real increase in labor requirements. Therefore, the cost per acre of $307 per acre to protect 3 acres would fall to $197 to protect 5 acres.

Tree shelters have the highest initial cost, and do require continued maintenance. In this analysis, only 100 tree per acre are protected. To protect 400 stems per acre would cost $1,600, an unrealistic investment without the use of cost-share incentive programs. The use of Deer-Away® repellent requires considerable dollars for material as well as labor to make regular applications for 3 years. In colder, northern climates, its use can be severely restricted in the winter by the lack of above freezing temperatures needed for application.

Any number of factors may result in serious browsing damage. The concentration of damage to forest plantations in the winter and early spring when other alternative foods are lacking predisposes a repellent program to likely failure. Also, if summer browsing is a problem, additional applications will result in proportional cost increases. Overall, dependance on repellents for browsing protection is uncertain, expensive, and not a recommended option for forest plantations in areas with moderate to high deer pressure.

Temporary-electric fencing provides the advantages of ease of installation and effectiveness with a commitment to ongoing maintenance required. The cost of materials, installation labor, and maintenance cost for three years is $922 for three acres, or $307 per acre. The analysis did not include the cost of checking the fence regularly over the three-year period because of the difficulty in assigning labor cost. Therefore, the assumption is that the grower will carry out this inspection during other land management activities. The three-year maintenance cost of $585 is considerable. However, in actual situations, much of the mowing, fence maintenance, and rebaiting can be built into other land management activities typically carried out by most private landowners. Unlike the other deer protection options, electric fencing can be reused after the plantation is established. This a distinct advantage that will lower the cost of protecting future plantings.

Given the best of circumstance, all three deer-protection options may be effective for protecting individual stems from deer browsing. However, tree shelters and repellents fail to protect other natural vegetation on site from browsing. While competition control of vegetation around the seedling is necessary with electric fencing, the presence of surrounding vegetation protected from browsing will help to redirect growth upward. Further, the diversity of vegetation on the site will be protected.

Summary

Cost, availability of incentive monies, effectiveness, and maintenance are significant factors in selecting a deer-protection option for a forest plantation. Given the high labor and materials cost for repellents and questionable effectiveness, they are not a recommended option in areas with moderate to heavy deer pressure. Tree shelters are effective but expensive, even when protecting a minimal number of seedlings. Proper maintenance is necessary for shelters to remain effective. Government incentive programs are key to shelter affordability by private landowners, and more research is needed on inexpensive tree shelter materials that address the specific problem of browse protection. Temporary electric fencing is the most cost-effective option, however, diligent maintenance is required. Costs are quickly reduced if landowners carry out the required maintenance activities. While proven effective on smaller acreages, more studies are needed to determine the effectiveness on larger areas, and the factors that are most important when designing a fence for a specific site.

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Early Results with Translucent Tree Shelters in Southern Ontario[1]

Silvia Strobl and Robert G. Wagner[2]

Abstract. Translucent tree shelters are being evaluated to determine whether the rapid early tree growth they stimulate can reduce the need for herbicide use during tree establishment. Growth and survival of red oak seedlings with several types of translucent tree shelters are being compared at 5 old-field sites in southern Ontario. Fifth-year (1 trial), third-year (1 trial) and second-year (3 trials) results are summarized.

Tubex® tree shelters increased ($p<0.0001$) second-year height increment of 1-year-old red oak stock 9 times more than unsheltered trees. Where 2-year-old stock was planted, second-year height increment of Tubex®-sheltered trees was 3 times greater than that of unsheltered trees. After 3 years, red oak seedlings sheltered by either Tubex® or Tree Pro® shelters were twice as tall as unsheltered trees. Height of Tubex®-sheltered red oak is still greater ($p=.0021$) than that for unsheltered trees after 5 years. The Quill® shelter which is smaller (60 cm tall) and free-standing, is not recommended; third-year red oak height with this shelter was significantly smaller ($p=.0001$) than that for either a mesh shelter or no shelter.

Due to red oak's sprouting capacity, survival was not different between sheltered and unsheltered seedlings, except at one site ($p=.0046$) where vole damage was extensive. However, tree shelters help maintain a single terminal leader.

The effect of Tubex® protection and vegetation control doubled second-year height of 1-year-old red oak planting stock as compared to Tubex®-sheltered seedlings that had no vegetation control. Although second-year height of red oak seedlings sheltered by Tubex® (with no vegetation control) was twice as tall as that for seedlings with vegetation control (and no tree shelter), it is too early to determine whether tree shelters can reduce the need for vegetation control.

Dieback damage of sheltered red oak has been minimal in southern Ontario, however, shelters require semi-annual maintenance due to poor stake durability. No sign of Tubex® shelter photodegradation was evident after 5 years.

Introduction

The first tree shelters were developed by the British Forestry Commission in 1979. These shelters increased seedling survival and increased seedling growth 7- to 8-fold (Potter 1988). Numerous types of tree shelters are now available, and depending on their size and construction, provide the sheltered tree with a greenhouse-like environment, physical support, and protection from animal damage for up to 8 years.

In southern Ontario, the use of tree shelters is being evaluated to determine whether the rapid early tree growth stimulated by the shelters can reduce the need for vegetation management during plantation establishment. Tree shelter testing is just one alternative being investigated by the Vegetation Management Alternatives Program (VMAP) in Ontario. The goal of the VMAP is to develop approaches to managing forest vegetation that can reduce dependence on herbicides in Ontario's forests.

The forests of southern Ontario are among the most diverse and productive forests in Canada, supporting over 40 species of native trees. Since settlement less than 200 years ago, the region has been altered from a predominantly forested landscape to one dominated by a wide variety of agricultural, industrial and urban land uses. For example, about 17 counties and regional municipalities have less than 20% forest cover, some with less than 5% (Riley and Mohr 1994).

Recent ammendments to planning legislation in southern Ontario encourage counties and regional municipalities with less than 30% forest cover to amalgamate or expand smaller woodlands to form larger woodlands or establish new woodlands where none now occur. Protecting planted hardwoods can accelerate restoration of native hardwood forests. Tree shelters contribute to this protection by stimulating early height growth resulting in earlier crown closure, increasing survival by minimizing losses from animal damage, and permiting planting of trees in mixed species groups and arrangements other than rows.

Methods

Five experimental sites were established throughout southern Ontario (i.e., Picton, Prescott, Ridgetown, Cayuga and Midhurst) to compare the effectiveness of tree shelter treatments for red oak establishment on old-field sites (Figure 1). A completely randomized design with at least 4 replications is used at each site. Experimental design details are shown in Table 1. Tree shelter treatments include: (1) 1.5 m tall Tubex® (one of the first commercial shelters developed in Britain); (2) 1.5 m tall Tree Pro®[3] (less expensive than Tubex®, but requires more time to install); (3) 0.6 m tall Quill® (a smaller, less expensive, version of Tubex® that does not require a stake); (4) 0.6 m tall Texguard® (a plastic-mesh tree protector); and (5) no tree shelter. According to the manufacturers, all of the shelters are designed to photodegrade.

Three of the sites (i.e., Ridgetown, Cayuga and Midhurst) include 2-way factorial experiments with tree shelter and vegetation control as the 2 factors being investigated. The 5

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[3] Tested at the Prescott site only.

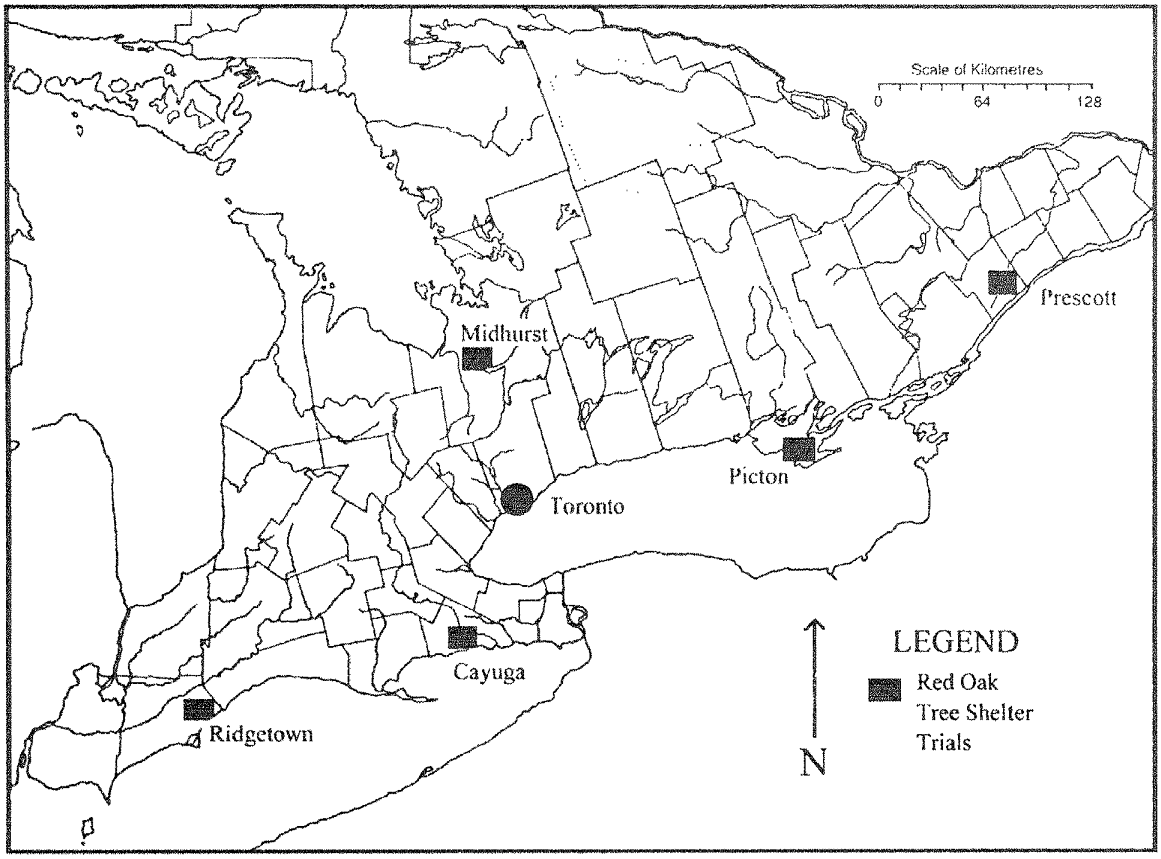


Figure 1.—Location of red oak tree shelter study sites in southern Ontario.

vegetation control treatments are: (1) a 90 cm^2 mulch; (2) annual glyphosate spot spray, with equivalent area treated as for the 90 cm^2 mulch; (3) a 120 cm^2 mulch; (4) annual glyphosate spot spray, with equivalent area treated as for the 120 cm^2 mulch; and (5) no vegetation control. Glyphosate was sprayed at least once annually and twice if necessary to maintain spots 80% weed-free. A circular template was placed around each tree to maintain consistency in spot spray size. Trees were protected with stove pipe or plastic pails. Dates of spray applications are shown in Table 1.

To minimize seedling variability and provide a better test of the tree shelter and vegetation control treatments, the 1-year-old red oak stock for the Prescott, Ridgetown and Cayuga trials was sorted during cold storage to select seedlings with more than 4 first-order lateral roots (FOLRs) with diameters greater than 1 mm. Research from the southern United States (Ruehle and Kormanik 1986) indicates that red oak seedlings with greater than 4 such roots had significantly higher outplanting success than seedlings with less than this number of FOLRs. All sites were ploughed and cultivated before trees were planted.

Height and basal diameter (taken at 2.5 cm above ground level) were measured at the end of each growing season. Shelters were not removed to measure height and a small door was cut in the bottom of shelters to measure diameter. Doors were resealed with duct tape.

Results and Discussion

5-year-old Study (Picton)

Fifth-year height of red oak in Tubex® shelters (195.7 cm) at Picton was greater (p=.0021) than that for red oak not protected by shelters (117.7 cm). However, the fifth-year height increment is not greater (p=.1540) with the Tubex® shelters (18.5 cm) than with no shelters (10.6 cm). Fifth-year basal diameter was not significantly different (p=.6933) between treatments. In comparison, fourth-year height increment was greater (p=.0207) with Tubex® shelters (55.6 cm vs. 36.5 cm for unsheltered) and basal diameter was greater (p=.0345) for unsheltered trees (13.7 mm vs 10.9 mm for Tubex®-protected). These results suggest that by age 5, Tubex®-sheltered red oak trees have shifted allocation of resources from height to basal diameter growth.

Although survival among treatments was not different (p=.2161), only 29.1% of unsheltered red oak seedlings were undamaged compared to 71.3% of Tubex®-sheltered seedlings (Figure 2). Severely damaged seedlings from

Table 1.—Summary of red oak tree shelter trials on old-field sites in southern Ontario.

Trial	5-Year-Old Study	3-Year-Old Study	2-Year-Old Studies		
Location	Picton	Prescott	Midhurst	Cayuga	Ridgetown
Frost-free days	231 days	200 days	198 days	228 days	229 days
Growing season	199 days	178 days	179 days	195 days	204 days
Soil type	Sandy Loam	Fine Sand	Silty fine Sand	Clay	Silty Loam
Drainage	Moderately Well Drained	Rapid	Moderately Well Drained	Imperfect	Imperfect
Age of planting stock	1-year-old, bare-root	1-year-old, bare-root sorted for >4FOLRs	2-year-old, bare-root	1-year-old, bare-root sorted for >4FOLRs	1-year-old, bare-root sorted for >4FOLRs
Initial height	18.9 cm	18.7 cm	26.8 cm	16.9 cm	20.3 cm
Initial basal diameter	3.7 mm	4.2 mm	6.1 mm	4.4 mm	4.9 mm
Tree shelter treatments	1)Tubex® 2)No Shelter	1)Tubex® 2)Tree Pro® 3)Quill® 4)Texguard® 5)No Shelter	1)Tubex® 2)Quill® 3)Texguard® 4)No Shelter	1)Tubex® 2)Quill® 3)Texguard® 4)No Shelter	1)Tubex® 2)Quill® 3)Texguard® 4)No Shelter
Trees per plot	10	8	8	8	8
Date of Glyphosate Spray	n/a	n/a	May 27/93 July 27/93 June 1/94	Aug. 4/93 June 15/94	June 16/93 Sept. 8/93 June 14/94
Replications	8	4	4	4	4
Spacing	10' x 5' Interplanted with Black Locust	10' x 5'	10' x 5'	10' x 5'	10' x 5'

rabbit clipping and dead seedlings accounted for 26.6% and 32.9% of unsheltered seedlings, respectively. Stem form of the typical multi-stemmed sprouts is poor. Therefore, with a tree species like red oak, that is both favoured animal browse and capable of sprouting after clipping, tree shelters will accelerate early growth and help maintain a single terminal leader.

By year 5, 12.5% of the Tubex® had fallen down (due to stakes breaking at ground level) and caused damage to the trees. Maintenance of tree shelters is necessary to minimize such losses. No sign of tree shelter photodegradation was evident after 5 years. The manufacturer of Tubex® has recently modified their tree shelter design to include a lengthwise perforation to facilitate removal when photodegradation has been insufficient.

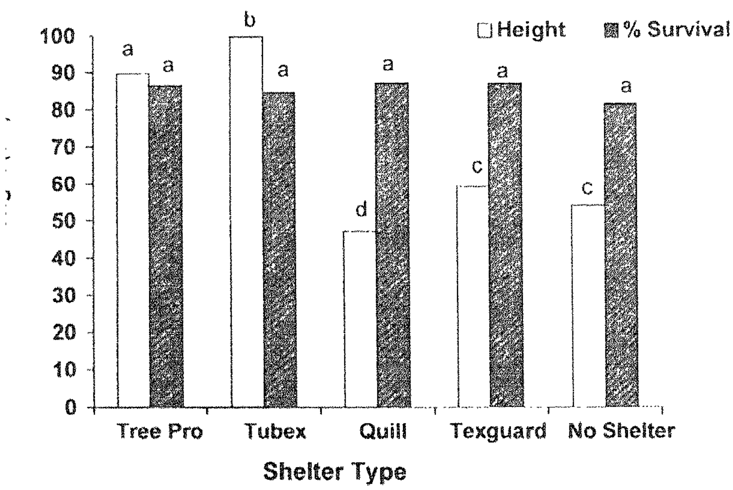
3-year-old Study (Prescott)

Red oak seedlings growing in the tall, translucent shelters (i.e., Tubex® and Tree Pro®) at Prescott were taller (p=.0001) than any of the other treatments (Figure 3) and almost twice as tall (99.7 and 89.6 cm, respectively) as unsheltered seedlings (54.9 cm).

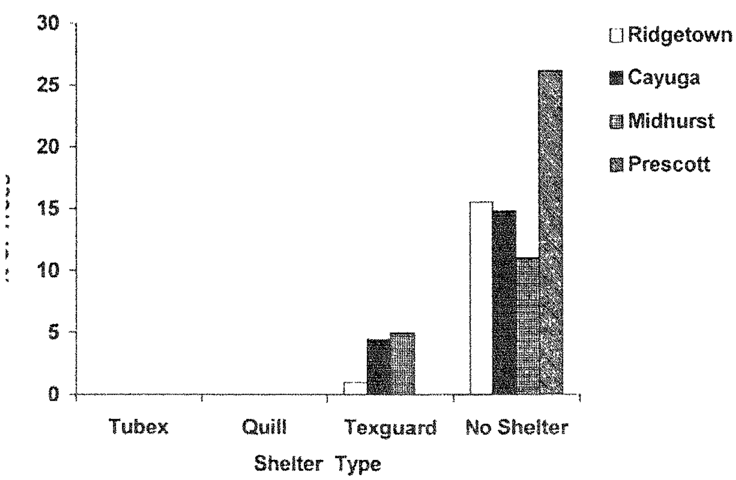
Basal diameter of Tree Pro®- and Tubex®-sheltered trees was smaller (p=.0001) than that for mesh-protected and unsheltered trees. Once trees "emerge" from the shelter, as has occurred in the Picton study, basal diameter increases (Potter 1991).

Height of red oak seedlings in the shorter Quill® shelters was less than that for seedlings treated with either the Tree Pro®, Tubex® or Texguard® shelters, or no shelter

gure 2.—Proportion of red oak seedlings in different age asses (due to rabbit clipping and sprouting) and dead and ɔwn classes after 5 years at Picton.



igure 3.—Third-year height (cm) and percent survival of red oak at 'rescott.



igure 4.—Proportion of red oak seedlings damaged by rodents in winter f 1993/94 under various shelter types at 4 sites.

(Figure 3). The poor height growth of Quill®-sheltered red oak seedlings can be attributed to root constriction as a result of the 2 tips pinching together when this free-standing shelter is inserted into the soil. Similar results have been observed in Great Britain (Gary Kerr, Silviculturist, Forestry Commission, Research Division, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH, pers. comm.) where use of this shelter for hardwood seedling establishment is not recommended.

Rodent damage assessed in spring of the third year was greater for unsheltered trees (Figure 4) than any of the shelter treatments. With red oak's sprouting ability however, no difference (p=.7282) in survival could be detected among treatments by the end of the third year.

2-year-old Studies (Ridgetown, Cayuga and Midhurst)

Second-year height increment was different (p=.0001) for all 3 studies. Tubex®-sheltered red oak seedlings at Ridgetown had 9 times grea er height growth in year 2 than unsheltered seedlings (Figure 5). At Cayuga, where extensive vole damage to unsheltered red oak seedlings was sustained during the winter of 1993/94 (Figure 4), second-year height increment of Tubex®-shelterd trees was 14 times greater than that for unsheltered trees (Figure 5). At Midhurst, second-year height increment differences between Tubex®-sheltered and unsheltered trees were not as great (as those for the Cayuga and Ridgetown sites established with 1-year-old red oak planting stock), but still resulted in a 3-fold difference (Figure 5). After 2 years, red oak seedlings protected by Tubex® shelters (106.3 cm) are twice as tall as seedlings without shelters (49.5 cm).

Second-year height increment of Quill®-sheltered seedlings at Midhurst (Figure 5) is less (p=.0001) than that for seedlings protected by either the mesh shelter or no shelter, indicating that root constriction effects occur earlier with larger, 2-year-old planting stock.

These studies also investigate the relation between tree shelters and vegetation control. At the Cayuga and Ridgetown sites established with 1-year-old planting stock, seedlings protected by Tubex® and receiving the 120 cm^2 equivalent herbicide spray were twice as tall as seedlings only protected by Tubex® (Figure 6). However, at Midhurst, where larger, 2-year-old planting stock was used, height differences between Tubex®-sheltered seedlings that did and did not receive

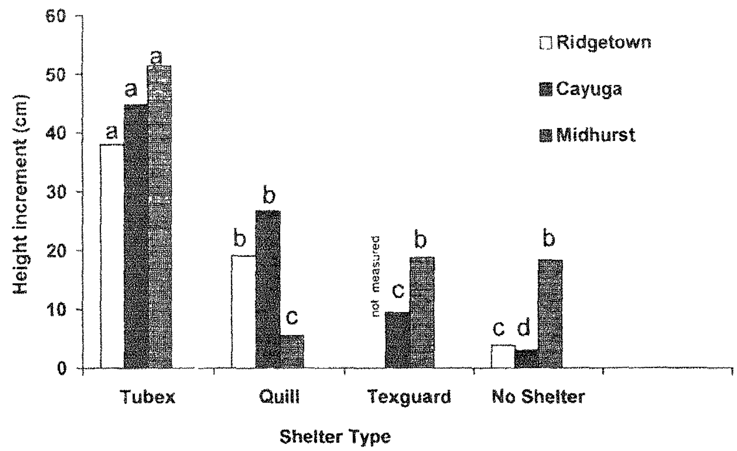


Figure 5.—Second-year red oak height increment at 2-year-old-sites.

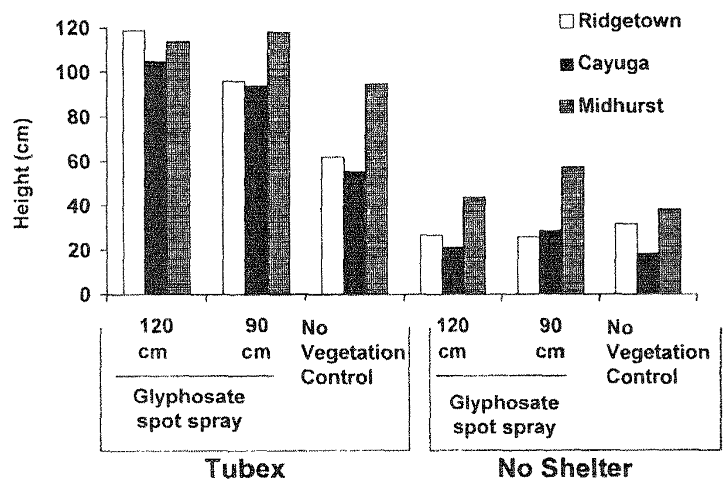


Figure 6.—Second-year height of red oak with and without vegetation control and with and without Tubex® tree shelters for 2-year-old sites.

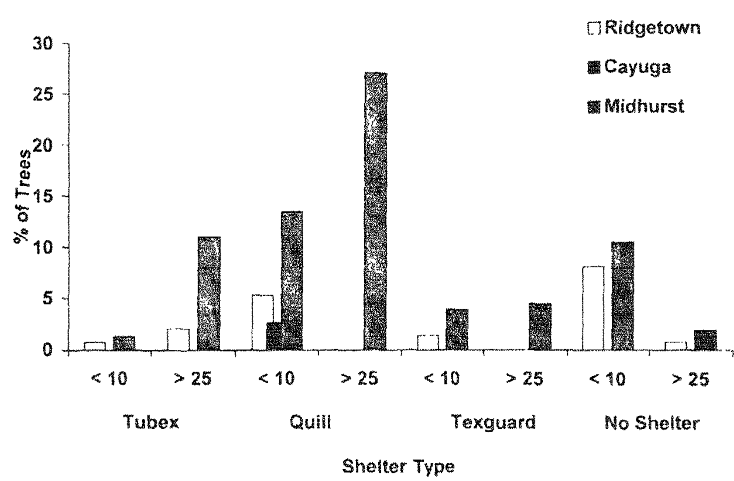


Figure 7.—Proportion of red oak seedlings with winter 1994/95 dieback damage in 2 classes (<10 cm and > 25 cm) at 2-year-old sites.

vegetation control were smaller.The results for 1-year-old planting stock support the tree shelter manufacturers' suggestion that sheltered seedlings benefit from vegetation control.

Two-year-old red oak seedlings protected by Tubex® but receiving no vegetation control are approximately twice as tall as unsheltered seedlings treated with the 120 cm^2 equivalent herbicide spray (Figure 6). It is too early to determine whether tree shelters can reduce or eliminate the need for vegetation control. Height growth is usually significantly enhanced by tree shelters, but basal diameter growth is decreased by the presence of shelters (Potter 1991). Tree crowns must emerge from the shelter before differences in basal diameter, a better indicator of tree response to vegetation control (Walstad and Kuch 1987), can be evaluated.

Rodent damage at all 3 sites was greater for unsheltered trees (Figure 4), but due to red oak's sprouting capacity, survival among treatments was not different at the Ridgetown (p=.3858) and Midhurst (p=.7252) sites. At Cayuga were vole damage was extensive however, Tubex®- and Quill®-sheltered trees had greater (p=.0046) survival than Texguard®-sheltered and unsheltered trees. Voles were able to chew the Texguard® plastic mesh and damage 4.5% of red oak stems protected by this shelter.

Substantial stem dieback of trees in shelters has not been observed in southern Ontario. Red oak stems in the enhanced microclimate of the shelter grow later into fall and are susceptible to killing fall frosts, but resulting decreases in height growth are more than offset by increases in the following year's growth. Two classes (i.e., < 10 cm and > 25 cm) of dieback damage were assessed in spring 1995 at the Ridgetown, Cayuga and Midhurst sites. At all 3 sites, a small percentage of seedlings growing in the Quill® shelters had dieback damage in the < 10 cm class (Figure 7). Dieback damage affected a larger percentage of seedlings at the most northerly-located, Midhurst site where winter temperatures are more extreme. At Midhurst, a larger percentage of Tubex®-sheltered seedlings had dieback damage in the > 25 cm class (11.0%) whereas unsheltered seedlings had a greater percentage of seedlings with dieback damage in the < 10 cm class (10.5%). Twenty-seven percent of Quill®-sheltered seedlings at the Midhurst site had more than 25 cm of dieback damage which will likely further exacerbate the poor growth of seedlings with this shelter.

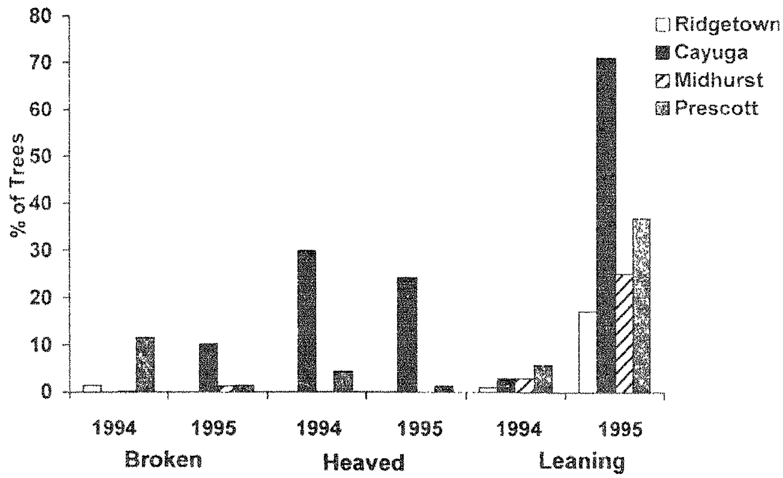


Figure 8.—Proportion of tree shelters with broken, heaved and leaning stakes at 4 sites during 1993 and 1994.

The wooden stake that supports the tree shelter is prone to heaving, leaning, and breakage. Incidence of damage to stakes was assessed in spring 1994 and 1995. Heaving occurs on some sites in winter due to soil freezing and thawing, causing the shelter to lift out of the soil and increasing risk of rodent damage to the exposed seedling. Frost heaving damage was most common at Cayuga and likely exacerbated by the heavy clay soils at this site (Figure 8). For similar reasons, leaning shelters were also more common at this site. Rotting of stakes at ground level and subsequent stake breakage has been minimized in the younger trials (i.e., Ridgetown, Cayuga and Midhurst), as compared to Prescott, by treating the bottom 20 to 30 cm of the stake with a water-based wood preservative (e.g., CIL Dulex Woodcare Latex Stain). Due to these inherent weaknesses in the wooden stake support system, tree shelters require regular maintenance. Steel rods are not a solution as they oxidise rapidly in ground contact and may be impossible to remove later (Potter 1991).

Conclusions

Protection from animal damage, and hence increased survival of the original hardwood seedlings, is the biggest advantage that tree shelters provide. The magnitude of height increment differences between sheltered and unsheltered trees decreases from up to 14-fold to less than 2-fold as trees begin to emerge from the shelters. At this time, trees shift allocation of resources from height to basal diameter growth. No sign of Tubex® shelter photodegradation was evident after 5 years.

Based on second-year and third-year results at Midhurst and Prescott, respectively, the smaller, free-standing, Quill® shelters are not recommended for red oak or other hardwood seedlings. Tree guards (to protect against rodent damage) are cheaper and equally effective.

One-year-old planting stock protected by tree shelters benefits from vegetation control. At the Cayuga and Ridgetown sites, seedlings protected by Tubex® and receiving the 120 cm^2 equivalent herbicide spray were twice as tall as seedlings only protected by Tubex®. Two-year-old red oak seedlings protected by Tubex® but receiving no vegetation control are approximately twice as tall as unsheltered seedlings treated with the 120 cm^2 equivalent herbicide spray, but it is too early to determine whether tree shelters can reduce or eliminate the need for vegetation control.

Dieback damage of sheltered red oak has been minimal in most of southern Ontario. At Midhurst, one of the more extreme sites (e.g., 198 frost-free days and 179 growing days), 11% of Tubex®-sheltered trees had more than 25 cm of dieback damage, but height growth of sheltered trees is still greater than that for unsheltered trees.

Use of tree shelters requires semi-annual maintenance due to poor stake durability. Maintenance demands will be greater on sites with heavy, clay soils. The durability of wooden stakes can be improved by treating the bottom 20 to 30 cm of the stake with a water-based wood preservative.

Acknowledgments

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Tree Shelter Effects on Stem and Root Biomass of Planted Hardwoods[1]

Felix Ponder, Jr.[2]

Abstract. The effect of tree shelters on stem and root biomass was investigated for outplanted northern red oak (*Quercus rubra* L.) and green ash (*Fraxinus pennsylvanica* Marsh.). Three red oak plantings were situated in hardwood openings and two green ash plantings were established on old fields. Seedlings were excavated in years 2 and 3 after outplanting. Their root systems were washed; they were separated into root, stem, and leaves; and dry weights were determined. An increase in stem dry weight was associated with increased stem height growth for sheltered red oak seedlings, excavated 2 years after outplanting, but not for green ash seedlings. Overall, both sheltered northern red oak and green ash seedlings that were excavated in year 3 had significantly higher stem and root dry weights than seedlings without shelters. Mean foliar phosphorus, potassium, calcium, and magnesium levels in leaves of northern read oak and green ash were affected by the use of tree shelters. The early increase in stem elongation for seedlings with tree shelters does appear to be at the expense of early root growth. But the delayed root growth for seedlings with shelters during the first year or so after outplanting is more than compensated for by year 3.

Introduction

Tree shelters have been used in artificial regeneration of hardwoods to protect trees from browsing (Morrow 1988) and to increase their survival and height growth (Potter 1988). A tree shelter's dramatic effect on height growth improvement is largely due to the greenhouse-like microclimate produced inside shelters: this includes increased temperature, lower light levels, and increased humidity when the leaves of the tree fill the inside of the shelter. Tree shelters also reduce moister lost from transpiration and evaporation, leaving more soil moisture for seedling growth.

It is not known if the improved shoot growth of seedlings attributed to tree shelters is also associated with increased root growth. Shoots of many young hardwoods dieback annually several years before shoot growth is sustainable. During this time, root growth is believed to be continuing, but inadequate to support rapid root growth. This study reports the effects of tree shelters on the accumulation of biomass in roots and stems of outplanted northern red oak (*Quercus rubra* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) seedlings during their second and third growing seasons in forest openings and previously cropped fields, respectively.

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA. June 20-22, 1995.

[2] Project Leader, USDA Forest Service, North Central Forest Experiment Station, Jefferson City, MO.

Materials and Methods

The northern red oak plantings were established on three harvested (clearcut) sites on the Mark Twain National Forest near Salem, Missouri; two were in Reynolds Count (CCC Camp and Crossville sites) and one was in Dent County (Scotia site). All sites occupy northeasterly aspect with deep, well-drained to somewhat excessively drained, with gravel and some large rocks. The mean annual precipitation over the two-county area is 105 cm.

All trees, shrubs, and stems that had not been removed i the harvest cut were removed from the sites before planting. In the spring of 1990, 328 1-0 red oak seedlings were planted on the three sites. Only seedlings with a bas diameter greater than 6 cm were planted. Root systems c all seedlings were clipped to 20 cm. Seedlings were plant on a 3.05-m square spacing.

Green ash plantings were established on two old field site in Cedar County, near Stockton. One planting (Vogel site was on a terrace landscape with moderately deep, well-drained, and fine sandy loam soils. Slopes ranged from 1 5 percent. The second planting (Berry site) was establish east of Stockton on a bottomland site with deep, somewh poorly drained, and silt loam soils. Slopes ranged from 0 2 percent.

Fields were not cultivated the year before planting. The sites were mowed in the fall of 1989 and received no oth preparation. Each site was planted with 220 1-year-old green ash seedlings in the late spring of 1990. Roots of seedlings were pruned to 20 cm. Seedlings were planted 1.5 m apart within rows that were 3.05 m apart.

Initial height and stem diameter at ground level were measured for both species before tree shelters were installed. About half (149) of the northern red oak seedli and green ash (160) seedlings were selected randomly t receive tree shelters. Tree shelters used were beige, 1.2 tall, and ranged from 7.6 to 10.24 cm in diameter. Tree shelters were fastened with self-contained plastic tie-slip 1.5-m sections of metal conduits that had been driven in the soil near seedlings. Weeds were controlled in the gre ash plantings, but not in the northern red oak plantings. Glyphosate was sprayed at the recommended rate in 61 cm-wide strips on both sides of the row soon after planti and annually thereafter in late spring. Survival, live stem height, and basal diameter at ground level have been measured annually in late autumn since 1990.

Late in summers of 1991 and 1992, (year 2 and 3 after outplanting, respectively) 60 northern red oak seedlings from each location, 10 with tree shelters and 10 without) and 80 green ash seedlings (40 from each location, 20 v tree shelters and 20 without) were randomly selected ar carefully excavated with shovels and hoedads. The excavated seedlings were placed in plastic bags, put int ice chests containing ice, and transported to the laborat

In the laboratory, soil was washed thoroughly from the with water. Leaves were removed from stems and branches, put into paper bags, oven dried, and weighed. For green ash, leaves were included with stems for seedlings excavated in 1991 and kept separate for seedlings excavated in 1992. Stems of both species were severed from root systems at the root collar. Each stem and its branches were oven dried and weighed, as were all root systems. A sample of dried leaves was removed from bags in 1991, ground in a Wiley mill, and sent to the Research Analytical Laboratory at the University of Minnesota to be analyzed for macronutrients. Study data were analyzed using a randomized complete block analysis of variance (SAS Institute 1985) and Duncan's multiple range test.

Results and Discussion

Mean survival of red oak, both with and without tree shelters, declined over the 3-year measurement period for all 3 plantings (Table 1). Differences between treatments were significant only for the CCC Camp planting. Nearly half (28) of the trees without shelters on the CCC Camp site died by the end of the second growing season compared to 5 trees with shelters.

Survival differences between tree shelter treatments were significant for both green ash plantings. Three years after outplanting, mean survival of trees with shelters was 92 percent compared to 62 percent without shelters.

Height growth differences between treatments were significant for both species and for all plantings (Table 1). Total mean height growth for trees with shelters was increased by a factor of 5.5 for the CCC Camp planting and by 3.1 for Crossville and Scotia plantings over trees without shelters. The mean height growth of green ash in shelters was more than twice that of trees without shelters.

Tree shelter effects on stem, leaf, and root dry weights were mixed. For northern red oak, only stem dry weight was significantly ($P < 0.01$) affected by treatment the second year (Figure 1). Stem dry weights for seedlings from the Crossville and Scotia plantings were nearly 3 and 2 times greater, respectively, with tree shelters than without tree shelters. However, northern red oak seedlings excavated in the third growing season had stem, leaf, and root dry weights that were significantly ($P < 0.01$) higher when grown with tree shelters than without tree shelters. For example, stem dry weights for seedlings with shelters from the Crossville and Scotia plantings were more than double those of seedlings without shelters. The mean root dry weight for northern red oak seedlings with shelters was 1.7 times greater than for seedlings without shelters.

Both stem and root dry weights of green ash seedlings excavated 2 years after outplanting were significantly ($P < 0.05$) affected by tree shelters (Figure 2). The mean stem dry weight for seedlings from the Vogel planting was 1.4 times higher for seedlings without shelters than for seedlings with shelters. Root dry weights were 2 and 1.5 times higher for seedlings without shelters than for seedlings with shelters for the Vogel and Berry plantings, respectively. The stem dry weight for seedlings in the Berry planting was not affected by treatment.

Stem and root dry weights for green ash seedlings excavated in the third year after outplanting show a reverse trend in treatment response (Figure 2). Stem dry weight for seedlings excavated from both green ash plantings differed significantly ($P < 0.05$) between treatments, but not between locations. Root dry weights were only slightly greater for seedlings with shelters than for seedlings without shelters. Differences in leaf dry weight were not significant.

The effect of tree shelters on dry matter distribution within seedlings changed as seedlings grew (Figures 1 and 2). With northern red oak, early growth (year 1 and some part of year 2) of seedlings in shelters appears to be concentrated primarily in the stem, but by year 3, root growth has also accelerated. The change in dry matter distribution caused by tree shelters increases the stem:root ratio. The mean stem:root ratios for excavated northern red oak seedlings in shelters for years 2 and 3 were 0.922 and 1.103, respectively, compared to 0.554 and 0.832 for seedlings without shelters. Rendle (1985) reported that tree shelters altered the distribution of dry matter in *Quercus rubor* as reflected in stem:root ratio, which was 1.595 for seedlings with shelters in sharp contrast to the 0.470 for field-grown seedlings without shelters.

Foliar nutrient levels were affected by tree shelters. Mean foliar phosphorus, calcium, and magnesium levels were significantly higher ($P < 0.05$) and potassium was significantly lower ($P < 0.01$) in green ash leaves from seedlings with tree shelters than in leaves from green ash seedlings without tree shelters (Table 2).

Foliar levels of calcium at all sites and magnesium at the Scotia site were significantly higher ($P < 0.05$) and potassium at all sites was significantly lower in leaves from northern red oak seedlings with tree shelters than in leaves from northern red oak seedlings without tree shelters (Table 3). The magnesium level in leaves from northern red oak seedlings with tree shelters at the CCC Camp and Scotia sites was higher ($P < 0.05$) than for seedlings without tree shelters. Phosphorus was generally higher in leaves from northern red oak seedlings with tree shelters than for oak seedlings without shelters.

The reasons for differences in foliar nutrient levels reported here can be postulated for some nutrients, but further work is needed. The uptake of phosphorus, a relatively immobile nutrient element, is closely related to the volume of soil the root system is able to occupy, and a good supply of phosphorus has been associated with increased root growth (Tisdale and Nelson 1967). The availability and uptake of potassium can be influenced by alternate moist and dry soil conditions (Tisdale and Nelson 1967). Higher relative humidity values have been reported for the inside of tree shelters than outside of them (Rendle 1985, Ponder 1995). The exact contribution of higher relative humidity and reduced moisture loss associated with wind and transpiration to soil moisture is not known, but the better moister balance in tree shelters is believed to contribute significantly to the early growth of plants in them.

Table 1.—Number of northern red oak and green ash seedlings outplanted, mean annual survival, and mean total growth after 3 years with and without tree shelters in hardwood openings and old fields, respectively.

Species/ Location	Tree shelter treatment	Seedlings planted	Survival Year 1	2	3	Height Growth
		-number-	---------- percent ----------			--cm--
Northern red oak						
CCC Camp	Without	59	88	53	48	16.3
	With	49	100*	92**	90**	89.1**
Crossville	Without	60	92	92	90	33.4
	With	50	96	96	96	104.9**
Scotia	Without	60	96	80	78	38.7
	With	50	94	76	76	122.2**
Green ash						
Vogel	Without	140	81	77	76	54.0
	With	80	89*	88*	87*	118.8**
Berry	Without	140	100	75	54	51.7
	With	80	100	97**	97**	123.9**

Note: for each species-location comparison, significant differences between tree shelter treatments are denoted by *≤0.05 and **≤.01.

Table 2.—Macronutrient concentrations in leaves of green ash seedlings grown with and without tree shelters.

Nutrient	Basis	Tree shelter Without	With
Nitrogen	%	2.01	2.05
Phosphorus	ppm	2665	3165*
Potassium	ppm	5903	5119**
Calcium	ppm	10178	13049*
Magnesium	ppm	4291	4791*

Note: for each nutrient, significant differences between tree shelter treatments denoted are by *≤0.05 and **≤.01.

Table 3.—Macronutrient concentrations in leaves of northern red oak seedlings grown with and without tree shelters in three locations.

		Location					
		CCC Camp		Scotia		Crossville	
Nutrient	Basis	Without	With	Without	With	Without	With
Nitrogen	%	1.88	1.91	2.00	1.75	1.78	2.04
Phosphorus	ppm	1146	1335	1204	1350	1150	1266
Potassium	ppm	7680	6753*	8948	8068*	8140	6768*
Calcium	ppm	5046	6876*	5904	7318*	6782	8421*
Magnesium	ppm	3885	4086	2364	2860*	3038	3000

Note: for each location-nutrient combination, significant differences between tree shelter treatments denoted are by *≤0.05.

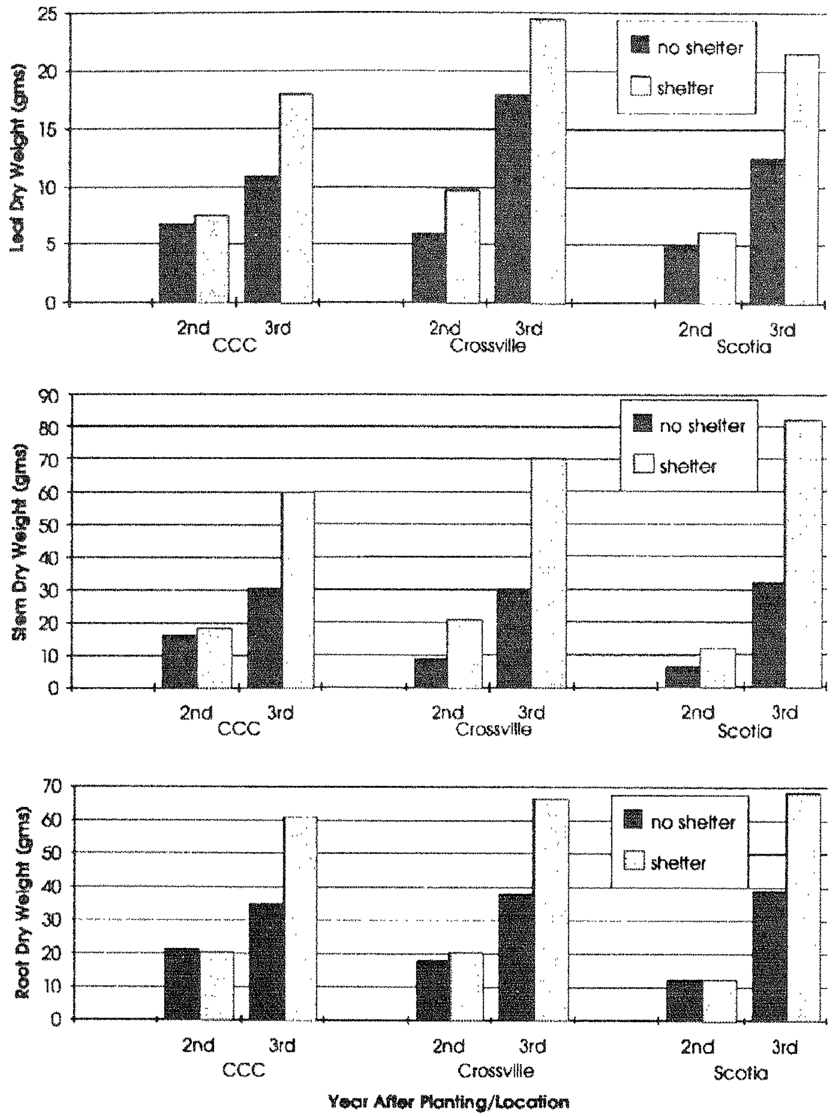

Figure 1.—Mean stem, leaf and root dry weights of northern red oak seedlings three years after outplanting in hardwood forest openings with and without tree shelters.

In addition to growth, the nutrition of young sheltered tree might have other health implications. For example, Sharpe et. al. (1952), noted increased cold damage to pecan trees (*Carya illinoinesis* [Wangenheim] K. Koch, Juglandacea) low in potassium, both in the fall and in the spring. Unusually high amounts of stem dieback have been associated with some tree species in tree shelters. Although no data are presented in the present study to demonstrate a relationship between dieback and potassium levels, it appears that adequate potassium nutrition could be a factor to evaluate in the prevention of seedling dieback.

The impact of tree shelters on dry matter accumulation in green ash seedlings differed from their impact on northern red oak. Even though height growth (Table 1) was increased with shelters, stem dry weight was higher for seedlings without shelters after 2 years. However by year 3, stem dry weights were higher for seedlings with shelters than for seedlings without shelters. The mean stem:root rations for seedlings in shelters for years 2 and 3 were 1.411 and 2.243, respectively, compared to 0.938 and 1.912 for seedlings without shelters for the same sampling period.

Increased early height growth (through year 2) for green ash seedlings with shelters did not result in a similar increase in stem dry weight, but did for northern red oak seedlings. Thus increased stem elongation in green ash may result from a modification in growth habit rather than an increase in stem dry weight.

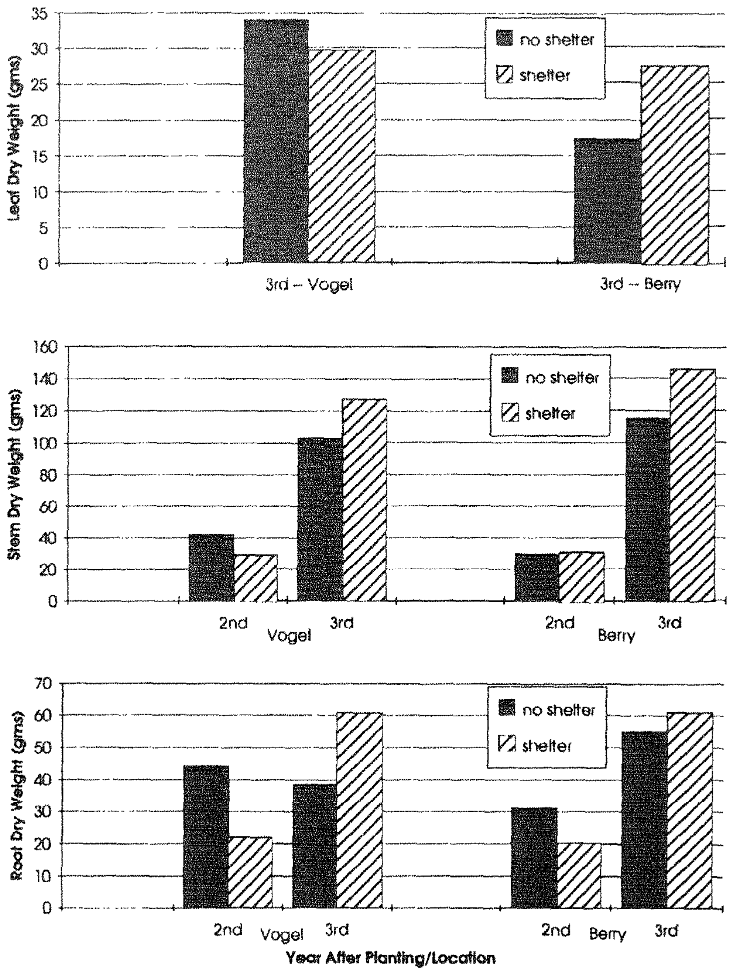

Figure 2.—Mean stem, leaf and root dry weights of green ash seedlings three years after outplanting in old fields with and without tree shelters.

Acknowlegdment

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Effects of Tree Shelters on Planted Red Oaks in Michigan[1]

Douglas O. Lantagne[2]

Abstract. A 22 year-old shelterwood treatment that failed to regenerate oaks on an upland site in Michigan was clearcut in the fall of 1986 and planted with 2-0 northern red oak (*Quercus rubra* L.) seedlings the following spring. The four planting treatments included: control (clearcut harvest only), brush control only, 48 inch tree shelters only, and brush control plus tree shelters. After three years, 65 percent of sheltered northern red oak seedlings were at least 47 inches tall and on average 21 inches taller than unsheltered seedlings. After six years, a total of 92 percent of sheltered trees had reached a minimum height of 47 inches. By 1994, the eight year height growth of sheltered trees made DBH measurements possible on 91 percent of sheltered trees (height≤4.6 ft) compared to only 77 percent of unsheltered trees. Sheltered trees had significantly greater average diameters in 1992. Tree shelters improved survival, diameter and total height growth over the first six growing seasons, however, average tree height growth was declining in the treatments without tree shelters or brush control at year eight. Results from a 4-year-old red oak planting study in Michigan's Upper Peninsula indicates that weed control alone on an old field site was as effective as using tree shelters alone in improving survival and height growth.

Introduction

The dramatic height growth results reported for sessile oak (*Quercus petraea* (Matt.)) in tree shelters in Great Britain (Tuley 1983), combined with the difficulty of regenerating northern red oak (*Quercus rubra* L.) in the United States (Lorimer 1989) contributed to the initial testing of tree shelters in the United States. The promise of improved survival and height growth for a wide variety of other species however, contributed to their widespread application by many public agencies, private industries and individuals before long-term research results were available. Early research results have indicated that tree shelters have some potential benefits under the right circumstances (Applegate and Bragg 1989, Burger and others 1992, Smith 1993).

Published research accounts on the impact of tree shelters on tree growth are limited for North American plant species. Potter (1991) wrote an excellent handbook summarizing the results of research for tree shelter use in Great Britain. Windell (1991) published an excellent compilation of information on tree shelters for use by researchers in the United States. He summarized current research and information on general use, economic feasibility, and materials and construction techniques. Early indications are that tree shelters protect planted seedlings from animal damage and increase early seedling survival and height growth (Lantagne and others 1990), however little information is available on the longevity of the benefits accrued by tree shelter use. The objective of these studies is to evaluate the long-term effectiveness of tree shelters in establishing northern red oak. This paper presents results from two tree shelter studies. The first is an eight year study in a southern Michigan clearcut and the second is a four year study on an old field site in northern Michigan.

Methods

W.K. Kellogg Experimental Forest Site

The first study is located in an oak-hickory forest at the W.K. Kellogg Experimental Forest (Kellogg) in southern Michigan. Soils are predominantly sandy loam (Alfisols) that developed from stony glacial drift on a rolling, well drained site. An average northern red oak site index of 66 (base age 50) was measured for the site before harvest. The study area underwent a shelterwood seed cut in 1954 and a removal cut in 1964 as part of a previous oak regeneration study (Rudolph and Lemmien 1976). Before the study was established, all stems greater than 2 inches diameter at breast height (DBH) were removed in a whole-tree clearcut harvest in the fall of 1986. All remaining stems greater than 1 inch DBH were removed by hand.

A 2 X 2 factorial combination of treatments was replicated on 4 one acre blocks in a split-plot design. A 22 foot buffer zone was maintained between treatment blocks. Each acre block was split to accommodate brush control treatments (main plots). Each main plot was then split to accommodate tree shelter treatments (split plots). The four treatments were: control (no brush control, no shelters); brush control only; 48 inch shelters only, and brush control and shelters. All treatments were randomly applied within replications.

Brush control occurred as a prescribed burn and basal application of triclopyr and oil to non-oak species before harvest. Basal applications of triclopyr and oil with a backpack sprayer were also applied to non-oak species in the three years following harvest at an average cost of $40 to $45 per acre per year. The highest estimated average cost to treat each tree over a three year period was $0.38 per tree at the assigned planting density of 360 trees per acre.

Tree shelters were constructed from 20 X 48 X 0.25 inch sheets of white corrugated polyethylene plastic. Each plastic sheet cost about $1.50 and stakes about $0.50 each. Individual sheets were formed into roughly 5- X 5-inch square shelters and stapled to 1- X 1-inch wooden stakes driven into the ground next to planted oak seedlings. The 48 inch tall shelters were placed close to the soil surface but were not sealed at the soil surface. Stakes were also driven into the ground next to all unsheltered seedlings. The stakes and shelters were checked and replaced as necessary each spring and fall in each year of the study. Maintenance costs in terms of labor used, averaged over 20 hours per acre per year for these shelters.

Northern red oak acorns were collected in the fall of 1984 and float tested for viability. "Sinkers" were collected and 8

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

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per square foot were sown in a prepared nursery bed. During the first lag phase of development during the second nursery season, seedlings were undercut in the nursery bed at 6 to 8 inches to encourage development of a fibrous root system (Hanson et al. 1986, Johnson et al. 1986). The 2-0 northern red oak seedlings were lifted in mid-April 1987, sorted to a minimum 3/8-inch root collar diameter (Johnson 1986), root pruned to 8 inches, wrapped and stored at 1° C until planting. Seedlings were planted over a two day period in late April 1987 with dibble bars at a 11- X 11-foot spacing for a total of 90 oak seedlings per treatment or 360 seedlings per block. After planting, seedlings were clipped 7 inches above the ground-line (Johnson et al. 1986). The 48 inch tree shelters were then installed. All work was completed by May 1, 1987.

Heights of all planted northern red oak seedlings were remeasured in the fall of 1992 and 1994. The incidence of animal browse was evaluated in previous years an found to be at less than 10 percent. DBH measurements were collected for the first time on all trees≤4.6 feet in height after the 1992 growing season. Analysis of variance was used to test for significant differences among treatment means for the 1992 data. The standard assumptions of analysis of variance were verified before data analysis. Percentages were transformed with the arcsine procedure (Little and Hills 1978). Chi-square analysis was used to test for differences in height class distributions and diameter class distributions for sheltered and unsheltered seedlings. The preliminary summary of the eighth year data is presented as treatment means only.

Upper Peninsula Tree Improvement Center Site

The second study is located on an old field site at the Upper Peninsula Tree Improvement Center (UPTIC) in the western Upper Peninsula of Michigan. Soils are predominantly fine sandy loams that developed from loamy materials of high natural fertility on a level, moderately well drained site. The site had previously been used as a pasture and hayfield. Before the study was established, a post-emergent herbicide was applied to control grasses and herbaceous weeds. Three days after planting a pre-emergent herbicide was applied to control regrowth of weeds.

A 2 X 2 factorial combination of treatments was replicated four times in a randomized complete block design. One of four treatments was randomly assigned to a 49 tree block of northern red oak in each replication. The four treatments were: control (weed control first year only), weed control, tree shelters (48 inch) and the combination of yearly weed control and tree shelters. Weed control occurred as yearly applications of glyphosate and sulfometuron methyl. Tree shelters were purchased from a commercial supplier.

The 2-0 northern red oak seedlings were purchased from the local state tree nursery. These seedlings were not undercut in the nursery bed or top pruned after planting. Seedlings were planted at 8 X 10 foot spacing in seven rows of 7 trees for 196 trees per replication. All work was completed by May 4, 1990.

Heights of all planted seedlings at the UPTIC site were measured after one and four growing seasons. No statistical analysis has been completed on this data. Only treatment means will be presented in this paper.

Results

W.K. Kellogg Experimental Forest Site

Over the first six years, control of non-oak woody species had no significant effect on the total height of planted red oak (P=0.24), but survival and total height of sheltered and unsheltered trees have differed significantly (Table 1). After eight years, it appears that survival and growth are declining in treatments that have not received brush control There were no significant brush control X shelter interactions for any measured variable after six years, but the decline in survival and growth without weed control may result in significant interactions in the future.

Seedling survival and height for sheltered seedlings were significantly greater than for unsheltered seedlings after six

Table 1.—Analysis of variance for total tree height for planted trees.

Factors	degrees of freedom	Mean Square	F-Ratio
Main Plots			
Replication (Rep)	3	877.05	
Brush Control (BC)	1	527.49	2.03
Rep X BC (Error a)	3	260.02	
Split Plots			
Shelters (S)	1	10257.48	34.03**
BC X S	1	533.80	1.77
Error	6	301.39	

** = Significant (P<0.0011)

years (Table 2). However, the eight year data shows a larger decline in survival and height growth for sheltered versus unsheltered seedlings. Although sheltered trees maintained a 19 inch total height advantage for years 3 through 6, the lack of brush control now appears to be a factor affecting height growth of sheltered and unsheltered trees (Table 2).

In 1992, after six growing seasons, 67 percent of the total number of sheltered trees originally planted were tall enough (≥4.6 ft) to collect DBH measurements compared to a total of 38 percent of unsheltered trees ($P<0.005$). Sheltered trees were also found to have significantly larger diameters than the measured unsheltered trees ($P<0.0029$) (Table 2). The data for eight growing seasons has not yet been fully summarized.

Figure 1 illustrates the effect of shelters on seedling height class distribution after six years. Sheltered seedlings dominate every category above five feet. A Chi-square analysis indicated that the distributions were significantly different ($P<0.0001$). A similar analysis of six-year diameter distributions between sheltered and unsheltered trees also indicated a significant shift towards larger diameters for sheltered seedlings ($P<0.0001$).

Upper Peninsula Tree Improvement Center Site

The results are much less encouraging than the Kellogg site about the beneficial impacts of tree shelters on survival and total height growth. Although no statistical analyses have yet been conducted on this data, it appears that weed control alone resulted in survival and total height growth comparable to the combined weed control and shelter treatment (Table 3). The tree shelter alone treatment resulted in no better height growth than the control. In addition, after four growing seasons, no treatment had seedlings which had reached shelter height or its equivalent.

Table 2.—Effect of shelters and brush control on survival and height of planted northern red oak seedlings after the sixth and eight growing seasons[1].

Treatments	Survival		Total Height		Height Increase[2]		DBH[3]
	6yr	8yr	6yr	8yr	6yr	8yr	6yr
	---- % ----		---- in ----		--- in/yr ---		- in -
Main Plots							
Brush Control	83a	81	75a	88	11a	6.5	0.5a
No Brush Control	73a	67	80a	71	12a	-4.5	0.5a
Split Plots							
Shelter	84a[4]	79	87a[5]	92	11a	2.5	0.6a[6]
No Shelter	73b	69	68b	66	12a	-1.0	0.5b

[1] Means within columns for main and split plots followed by the same letter are not significantly different at $P<0.05$ as found in the Analysis of Variance. There was no statistical analysis of the preliminary summary of eight year data.

[2] Average yearly height increase was determined by subtracting 1989 total height from 1992 total height for each individually measured seedlings and dividing by three or 1992 total height from 1994 total height and dividing by two.

[3] DBH measurements for all trees ≥4.6 feet in height after six growing seasons.

[4] Survival percentages were significantly different at $P<0.0042$ for 6 year data.

[5] Total height was significantly different at $P<0.0011$ for 6 year data.

[6] DBH was significantly different at $P<0.0029$ for 6 year data.

Table 3—Effect of shelters and weed control on survival and height of planted northern red oak seedlings after the fourth growing season in Northern Michigan.

Treatments	Survival 4 year	Total Height 1yr	Total Height 4yr
	- % -	----------- in	----------
No weed control/No shelter	74	7	6
Weed control/shelter	93	11	33
Shelter only	84	6	6
Weed control only	98	10	31

Discussion

Tree shelters can improve the early survival and height growth of oak seedlings under the correct conditions (Minter et al. 1992, Lantagne 1991, Tuley 1983). As the northern Michigan study site shows however, shelters by themselves are not always the key to survival and accelerated height growth. Survival differences between brush control and tree shelter treatments were not a major factor over the first 6-years at the Kellogg site, but the importance of brush control is beginning to show at 8-years (Table 2). Although it appeared at age 6, that either brush control or tree shelter treatments were sufficient to maintain survival above 80 percent, the faster growing competing hardwoods are beginning to overtop planted oak in the shelter only treatments and cause mortality. It appears that some type of cleaning in the shelter only treatments at age 6 would have helped maintain the codominant position of planted red oak. In many cases, competing hardwoods have begun to outgrow the oak and overtop them by age 8, placing them in an intermediate to suppressed condition. In addition, the 4-year survival of northern red oak at the UPTIC site indicates the importance of weed control over the use of tree shelters on old field sites not subject to heavy animal browsing.

Although the analysis of the third year data affirmed the potential benefit of tree shelters on early growth and total tree height at the Kellogg site, sixth year results showed no growth differences among treatments (Figure 2). Preliminary eight year results show declines in height growth and a widening of the total height gap between trees in the sheltered and unsheltered treatments. As was expected, the sixth year results indicate that once these trees grew out of the shelter, overall terminal shoot growth slowed, and by the eighth year, net height growth was beginning to decline due to competition from other hardwoods. In contrast to early results at the Kellogg site, tree shelters do not appear to have accelerated height growth at the northern Michigan site.

Although terminal shoot growth has slowed, the initial DBH measurements at six years for sheltered trees were significantly greater than those measured for unsheltered trees. The early accelerated terminal shoot growth of sheltered seedlings did result in larger diameters after the trees exited the shelters. The reasons for this relationship are unclear but may be a result of being at DBH for a longer period combined with the stimulation of diameter growth in response to wind movement (Neel and Harris 1971, Jaffe 1973).

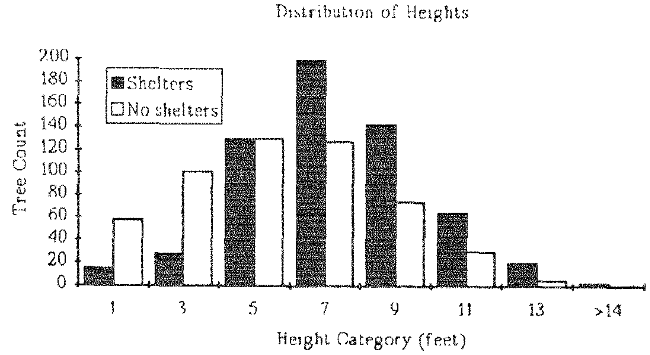

Figure 1.—Height distributions of sheltered and unsheltered northern red oak seedlings after the sixth growing season. The mid-range of each category is indicated on the x-axis. Distributions of the two classes of seedlings differ significantly based on Chi-square ($X^2 = 135$, $p < 0.0001$).

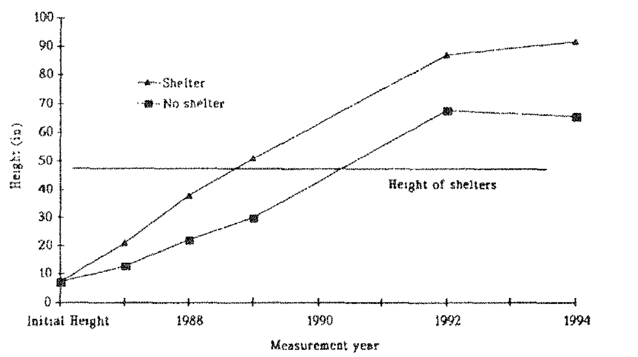

Figure 2.—Mean Heights of surviving planted northern red oak seedlings at the Kellogg site. (All seedlings were top pruned at 7 inches above the groundline immediately following planting. Sheltered seedlings were significantly taller at the end of each growing season.)

Summary

Many sheltered and unsheltered trees are losing their codominant crown positions to competing hardwood vegetation on the Kellogg site. The strong growth and development of unsheltered trees after six growing seasons may show the importance of using large, undercut and top clipped planting stock on the success of oak regeneration (Johnson et al. 1986). This idea may further be supported by the slow growth of conventionally produced oak seedlings at the UPTIC site.

The cost of using and maintaining tree shelters, and the problem of plastic litter remaining in the forest, have to be fully evaluated considering the level of survival and growth response of unprotected trees in these studies. The minimum cost for the tree shelter materials was over $2.00 per tree in each study. There were also additional costs associated with installation and maintenance that pushed the overall cost per tree higher. The cost of labor and material for controlling brush with herbicides for three years at the Kellogg site averaged less than $0.40 per tree. Even adding two additional years of brush control would only add $0.26 per tree for a total cost of less than $0.70 per tree over five years. Using high quality planting stock with brush or weed control to increase the amount of northern red oak regeneration is less expensive then the use of tree shelters and may be sufficient in areas free of heavy browsing by rabbits and deer.

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Tree Shelters for Plantation Establishment of Bareroot Red Oak and Black Walnut in 5 Midwestern States[1]

R.C. Schultz and J.R. Thompson[2]

Introduction

State forest nurseries in six central states (Illinois, Indiana, Iowa, Missouri, Ohio, and Wisconsin) have participated in a research cooperative since 1987 to improve hardwood seedling quality. Studies by the nursery cooperative (Schultz and Thompson 1989, 1990) indicated that performance of outplanting stock could be related to seedling morphology, and particularly seedling root system morphology. Two- and 3-year results from large-scale field studies indicated that red oak seedlings with 5 to 7 or more permanent first-order lateral roots and black walnut seedlings with 7 to 9 or more permanent lateral roots demonstrated better survival and greater height and diameter growth than seedlings with fewer roots. Subsequent work of the cooperative focused on increasing the number of permanent lateral roots of northern red oak, white oak, and black walnut seedlings. Cultural treatments used in the nurseries to increase numbers of permanent roots included bed density control, undercutting, and genetic selection.

With the attendant significant improvement in hardwood seedling quality, and in particular seedlings with larger root systems, it was then necessary to develop guidelines to ensure proper planting and maintenance to consistently obtain fully stocked plantations. In 1991, plantations were established in each of the cooperating states to demonstrate the influence of seedling quality, planting technique, use of tree shelters, and plantation maintenance on survival and growth of hardwood seedlings. One objective of the cooperative was to have plantations in place for use by state agency personnel as well as cooperative members for technology transfer to field foresters and planting contractors.

Specifically, the following factors in plantation establishment were evaluated:

- Seedling morphological characteristics (especially root systems);
- Method of seedling planting;
- Effectiveness and economic feasibility of tree shelters.

Plastic tree shelters have been used to protect seedlings from animal damage (especially deer and small mammals) and to promote seedling growth by creating a favorable "microclimate" (high humidity, enhanced CO_2 level, increased temperature) (Smith 1993). Tree shelters can also protect seedlings from mower and herbicide damage. Plastic tree shelters are purportedly photo-degradable after a period of 5 to 7 years. However, commercially available shelters are expensive, installation is very labor-intensive, and annual maintenance is required. In addition, if improperly installed the tube can create a "chimney effect" which can lead to desiccation of the seedling.

Tree shelters have had most widespread use in Great Britain, and some use in the eastern United States, but have not been used on a large scale in the central United States. The shelters were used in this study to determine the effects they would have on seedling growth (in relation to initial seedling morphology) in an open field setting in the Midwest, as well as to determine the economic feasibility of their use on a relatively large plantation scale.

Experimental Design and Procedures

Seedling grown in each cooperating nursery during the 1990 growing season were graded for height, diameter, and number of permanent first-order lateral roots (roots that were >1 mm proximal to the taproot and likely to survive lifting, handling, and transplanting). "Crop tree" species used in this study included 1+0 red oak, 2+0 red oak, 2+0 white oak, and 1+0 black walnut (two stock types were used per state). Half of the seedlings used were undercut in the nursery bed during the season prior to lifting (Table 1).

Undercut or not undercut crop seedlings with different numbers of permanent first-order lateral roots constituted one of the variables studies (Table 1). Two planting techniques (machine- and auger-planting) were evaluated in most states (dibble-bar planting was also evaluated in Indiana). The same large planting machine (a "Kaylor" planter) with a 32" coulter and a large shoe to accommodate relatively large seedlings (with large root systems) was used in every state except Indiana, where another comparable machine was used. Auger-planted seedlings were established using a two-person 3.5-HP motor-driven auger with an 8" bit that drilled approximately 12" deep holes.

In 5 of the states (all except Indiana) involved in this project, 4-foot Tubex® tree shelters were installed on half of the crop trees planted in each plantation (about 500 trees per species, or 1,000 trees per state). Opaque, tan-colored tubes recommended for use under open field conditions were installed with 1" by 1" hardwood anchoring stakes. A protective mesh (bluebird guard) was placed on the top of each tube at the time of installation.

Figure 1 is a schematic diagram showing the plot layout used in most states.

Interplant species included green ash and white pine. Trees were planted at an 8' by 10' spacing, with crop trees in every other row. In most plantations, there were 960 seedlings planted per crop species. A total of about 4,000 seedlings (nurse trees + crop trees) were planted in each plantation. Outplanting sites in each of the cooperating states were abandoned agricultural fields (formerly in either rowcrop production, hay production, or grazed sod).

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[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
[2] Department of Forestry, Iowa State University, Ames, IA.

Table 1.—Treatments and species compared, and locations of plantation demonstration project.

Treatment number	Number of permanent lateral roots	Root Culture technique
1+0 red oak (Illinois, Indiana, Iowa, Ohio, Missouri and Wisconsin)		
1	0-4	undercut
2	5-9	undercut
3	>10	undercut
4	0-4	not undercut
5	5-9	not undercut
6	>10	not undercut
1+0 black walnut (Illinois, Iowa, Missouri and Wisconsin)		
1	0-6	undercut
2	7-11	undercut
3	>12	undercut
4	0-6	not undercut
5	7-11	not undercut
6	>12	not undercut
2+0 red oak (Indiana)		
7	6-13	undercut
8	>14	undercut
2+0 white oak (Indiana and Ohio)		
7	6-13	undercut
8	>14	undercut

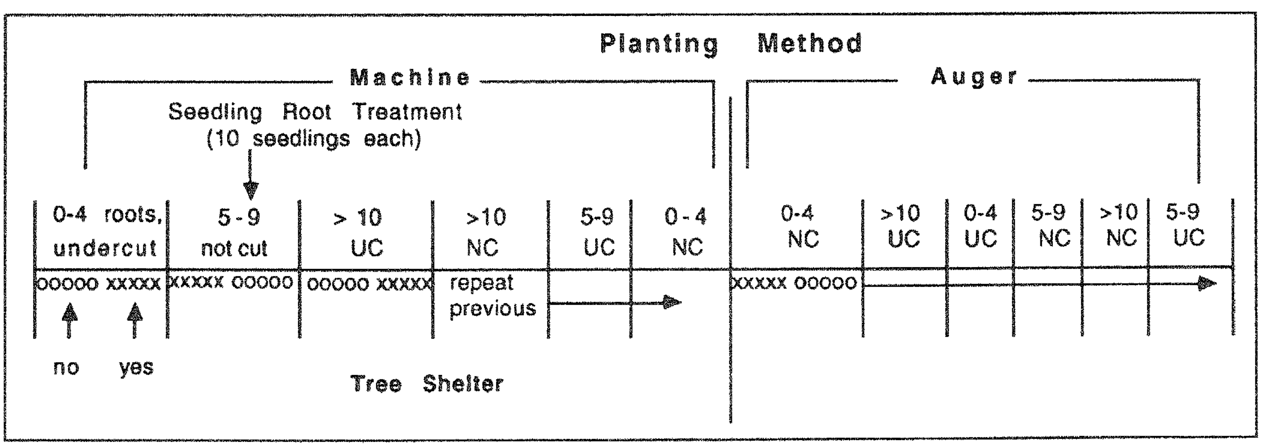

Figure 1.—Schematic diagram of one row of crop trees showing experimental design in all states except Indiana.

Results and Discussion

Questions not addressed in earlier studies included how the characteristics of planting stock might influence planting method, use of tree shelters, and amount of plantation maintenance necessary to ensure rapid early growth and adequate stocking. The study was designed to assess seedling performance relative to seedling root system morphology/nursery root culturing techniques and to examine the interaction of those factors with different plantation establishment techniques.

Results of this study will be presented in three parts. First, the influence of seedling morphology will be discussed. Second, results of seedling morphology characteristics combined with results of different planting methods will be given. Last, the influence of tree shelters on performance of seedlings by morphological group and for specific planting methods will be discussed. For brevity, in each part of the discussion, data are presented only for selected (representative) state-species combinations.

Seedling Morphology

Red Oak Seedlings Outplanted in Indiana. For 1+0 red oak seedlings in Indiana (considering all planting methods and levels of weed control) 4-year survival rates showed differences attributable to numbers of first-order lateral roots (FOLR) (Figure 2a). Four-year survival rates varied from 68% for undercut (UC) seedlings with 4 or fewer large first-order lateral roots. At an 8' by 10' spacing, 68% survival leaves only 370 trees per acre, which may not be adequate stocking to lend flexibility (choice of trees) as the stand approaches the age/size for thinning. Generally, the undercut seedlings demonstrated lower survival than their not undercut counterparts (growth rates of surviving undercut seedlings, however, were faster than those of not undercut seedlings). For 2+0 seedlings, survival rates were not significantly affected by numbers of roots. Survival rates for these seedlings were above 90%.

Differences in fourth-year average height and diameter attributable to numbers of large first-order lateral roots were also significant. Average fourth-year height ranged from 82 cm for the not undercut seedlings with 4 or fewer roots to 126 cm for the undercut seedlings with more than 10 large first-order roots (Figure b). Within each category of root numbers, undercut seedlings were taller than not undercut seedlings, even though they were initially shorter. It is likely that the altered root:shoot balance of undercut seedlings supported more rapid height growth during the first four years in the field (e.g., among seedlings with 10 or more roots, 4-year height increment was 66 cm for undercut seedlings versus 41 cm for not undercut seedlings).

Average height and height increments for the 2+0 red oak seedlings were considerably lower than for the 1+0 stock (fourth-year average height was 74 cm for 2+0 seedlings with 6 to 13 permanent laterals and 93 cm for seedlings with 14 or more large lateral roots). The 2+0 seedlings may be smaller than the 1+0 stock because of different conditions of culture while the seedlings were still in the nursery or because of different physiological response to being transplanted (e.g., related to leaf area and transpiration demand or different carbon allocation strategy). Height was affected by root numbers to a greater degree for the 2+0 seedlings than survival was.

Average diameter after 4 years for 1+0 red oak planted in Indiana ranged from 15.8 mm for not undercut seedlings with 4 or fewer permanent lateral roots to 23.8 mm for undercut seedlings with 10 or more lateral roots (Figure 2c). Again, differences in seedling diameter attributable to root morphology were statistically significant. Based on the formula volume=d^2h, the undercut red oak seedlings with more than 10 permanent lateral roots carried nearly 3 times the volume of the not undercut seedlings with 4 or fewer permanent lateral roots after 4 years in the field (714 cm^3 versus 254 cm^3). Differences in average diameter for the two groups of 2+0 red oak seedlings were also statistically significant although not as great as among the 1+0 stock (13.7 mm versus 16.3 mm).

Generally, the results for all states indicate better survival and more rapid early growth of seedlings with greater numbers of permanent first-order lateral roots. As previously suggested based on earlier work of the Nursery Cooperative, black walnut seedlings with at least 7-9 large first-order lateral roots and red oak seedlings with at least 5-7 permanent first-order lateral roots performed better after outplanting than seedlings with fewer roots (Schultz and Thompson 1990). Undercutting produces smaller seedlings, but a greater proportion of them have "target" root numbers, and in most cases the altered root:shoot balance results in more rapid growth for the undercut seedlings after outplanting. Although survival rates were excellent for the 2+0 red oak stock, growth rates were considerably less than for the 1+0 stock. There is probably little advantage to growing 2+0 red oak stock, although holding the 1+0 stock over if it is unusually small or cannot be sold does not appear to negatively affect seedling survival.

Planting Method

One concern related to production of larger seedlings, especially those with large root systems, was whether the seedlings could be planted correctly with existing technologies that are appropriate and cost-effective for establishment of large-scale plantations. This study included three common tree-planting methods: machine planting and auger planting were used in all cooperating states, and dibble-bar planting was used in Indiana. In the following discussion, results for the different planting methods are stratified according to the initial number of seedling roots.

Red Oak Seedlings Outplanted in Missouri. Four-year survival rates were affected by both planting method and number of first-order lateral roots for 1+0 red oak seedlings planting in Missouri. Survival rates ranged from 69% for machine-planted, undercut seedlings with 4 or fewer large first-order laterals to 94% for auger-planted, undercut seedlings with more than 10 permanent lateral roots (Figure

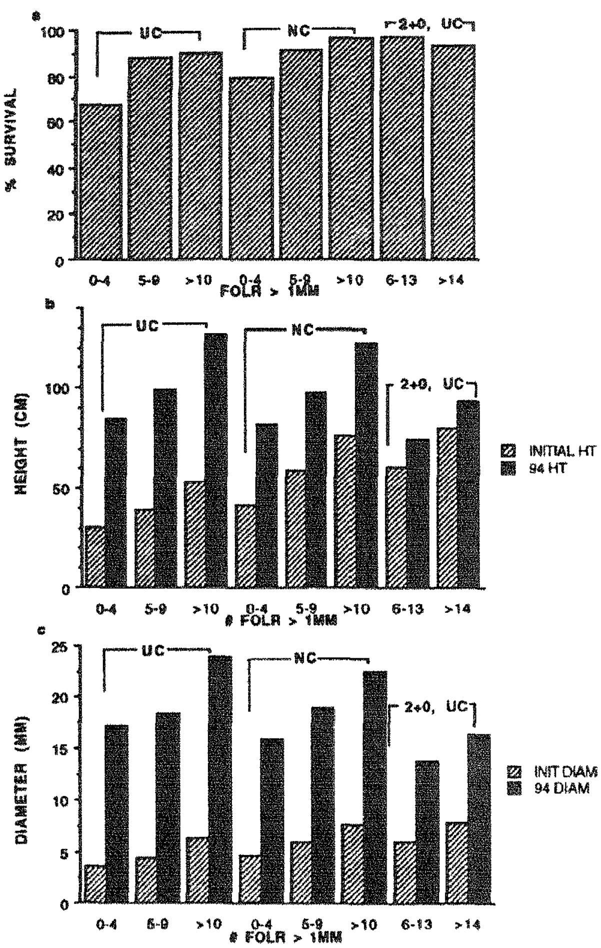

Figure 2.—Four-year results for (a) survival, (b) height, and (c) diameter of red oak planted in Indiana.

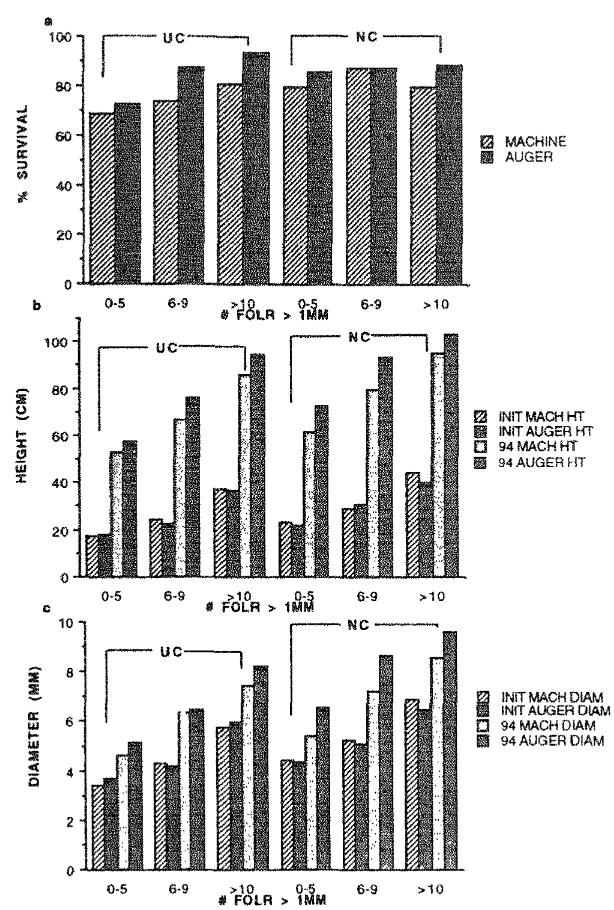

Figure 3.—Four-year results for (a) survival, (b) height, and (c) diameter of red oak planted in Missouri, by planting method.

3a). The magnitude of differences in survival rate between seedlings with different numbers of roots were similar to those between different planting methods.

Initial height and diameter data are included in Figures 3b and 3c to confirm that there were not significant differences in planting stock randomly divided between the planting methods before the seedings were planted. Average fourth-year height of 1+0 red oak seedlings in Missouri varied from 53 cm for undercut seedlings with 4 or fewer permanent lateral roots planted by machine to 104 cm for not undercut seedlings with 10 or more first-order lateral roots planted by auger (Figure b). The magnitude of differences in fourth-year height attributable to root numbers was greater than that attributable to planting technique, although in each case the auger-planted seedlings were taller.

Trends in fourth-year diameter data are similar to those described for height, and again difference in diameter attributable to planting technique were not as great as differences between root grades. Average diameter ranged from 4.7 mm for undercut seedlings with 4 or fewer permanent laterals planted by machine to 9.6 mm for not undercut seedlings with more than 10 permanent lateral roots planted by auger (Figure 3c).

Black Walnut Seedlings Outplanted in Iowa. Overall 4-year survival for black walnut planted in Iowa was excellent, from 93% for undercut seedlings with 6 or fewer large first-order roots planted with the machine to 100% for most of the remaining seedling categories (Figure 4a). There were no statistically significant differences in survival attributable to either planting method or number of first-order lateral roots.

Average fourth-year height was affected by both planting method and number of first-order lateral roots for the black walnut. Average height varied from 110 cm for not undercut seedlings with 6 or fewer roots planted with the machine to 141 cm for undercut seedlings with 12 or more lateral roots planted with the auger (Figure 4b). With a root number category, auger-planted seedlings were generally taller after

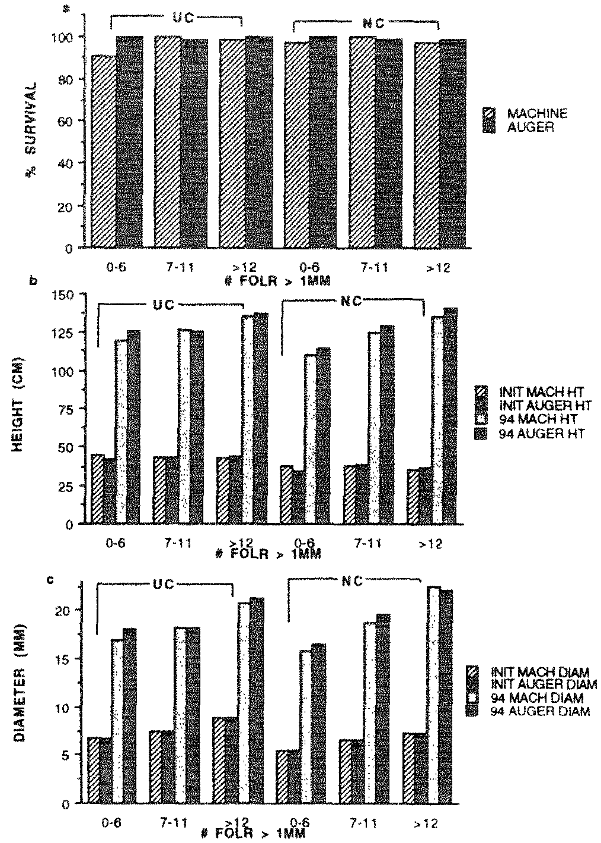

Figure 4.—Four-year results for (a) survival, (b) height, and (c) diameter of black walnut planted in Iowa, by planting method.

four years than their machine-planted counterparts. The relative magnitude of differences attributable to number of first-order lateral roots were greater than those between planting methods. Although differences attributable to planting method were statistically significant, they were probably not large enough to be economically or biologically significant.

Diameter was similarly affected by both planting method and number of roots. Average fourth-year diameter ranged from 15.8 mm for not undercut seedlings with fewer than 6 lateral roots planted with the machine to 22.6 mm for not undercut seedlings with 12 or more lateral roots, also planted with the machine (Figure 4c). Corresponding volumes were 275 cm^3 for the smaller seedlings versus 720 cm^3 for the larger seedlings.

For the most part, planting technique affected seedling survival and growth to a lesser degree than numbers of permanent lateral roots. There was a general tendency for auger-planted seedlings of a given root category to be larger than machine-planted seedlings in other plantations with statistically significant differences in fourth-year heigh and diameter due to planting method (for example red oak in Wisconsin, black walnut in Missouri). This may be because auger-drilled planting holes were filled in by hand with well-mixed soil material. Even though these difference were statistically significant, they may not be biologically important. On somewhat "difficult" planting sites (for example, shallow to bedrock soil at the Missouri plantation there were significant interactions between planting technique and stock type. Generally, the larger seedlings performed better when planted with an auger.

Tree Shelters

For simplicity, only data for seedlings planted with the aug are included in this discussion of the effects of tree shelte Similar trends were characteristic of machine-planted seedlings.

Red Oak Seedlings Planted in Wisconsin. Survival rate were excellent for all 1+0 red oak seedlings planted in Wisconsin. The lowest survival rate, 96%, was for not undercut seedlings with 4 or fewer roots that were unsheltered (Figure 5a). There were no significant differences in survival related to tree shelters, although unsheltered seedlings had slightly lower survival overall.

There were dramatic differences for average fourth-year height between sheltered and unsheltered seedlings. Initia heights are included in Figure 5b to demonstrate that seedlings were evenly distributed between sheltered and unsheltered treatments at the time of planting. Average fourth-year height ranged from 105 cm for undercut, unsheltered seedling with 4 or fewer permanent lateral roc to 210 cm for undercut, sheltered seedlings with more tha 10 large first-order lateral roots (Figure 5b). Among sheltered seedlings, there were still measurable difference in height after 4 years in the field that could be attributable to number of permanent roots (e.g., for undercut seedling mean height increased from 180 cm to 210 cm with increasing numbers of permanent roots, for not undercut seedlings the range is from 180 cm to 205 cm). At the en of the first field season, some seedlings in shelters appeared "etiolated". Several seedlings emerged from the shelters during the first year.

There were no statistically significant differences in diameter between sheltered and unsheltered seedlings. Ir most cases, the diameters of unsheltered seedlings were slightly greater than the diameters of sheltered seedlings (Figure 5c). Thus, since the sheltered seedlings were clos to twice the height of the unsheltered seedlings, the height:diameter balance of the sheltered seedlings was ve different from unsheltered seedlings. Seedling diameter w influenced to a much greater degree by number of permanent lateral roots than by the presence or absence tree shelters.

As the seedling crown developed above the tree shelter, there was a tendency for the seedling height growth rate t decrease and for the diameter growth rate to increase

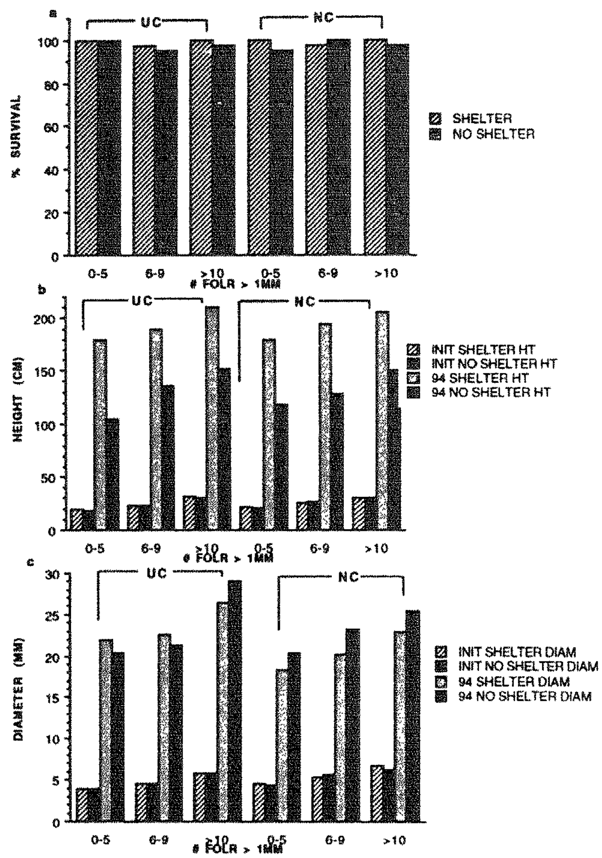

Figure 5.—Four-year results for (a) survival, (b) height, and (c) diameter of red oak planted in Wisconsin, with and without tree shelters.

(Figure 6). For seedlings without shelters, early height growth was slow but tended to increase by the end of the second year in the field (Figure 6).

Black Walnut Seedlings Planted in Missouri. Survival of black walnut in Missouri was somewhat greater for sheltered seedlings than for not sheltered seedlings (Figure 7a). Survival rates varied from 88% for not undercut seedlings with fewer than 6 permanent lateral roots that were not sheltered to 100% for undercut seedlings with more than 12 permanent lateral roots (sheltered or unsheltered).

Black walnut seedlings grown in shelters were on the average almost twice as tall after four years as seedlings grown without shelters (Figure 7b). Average fourth-year height ranged from 55 cm for undercut seedlings with 6 or fewer large lateral roots that were not sheltered to 124 cm for not undercut seedlings with 12 or more permanent laterals that were sheltered. In addition to the dramatic effect of tree shelters on seedling height, four years after planting there were still height differences among sheltered seedlings that were attributable to initial numbers of permanent lateral roots.

During the first year in the field, the stems of sheltered walnut seedlings were not lignified and had a tendency to curl and spiral inside the shelters. Dieback of stem tips was especially common for sheltered walnut seedlings at the end of the first year. In addition, while still in the shelters,

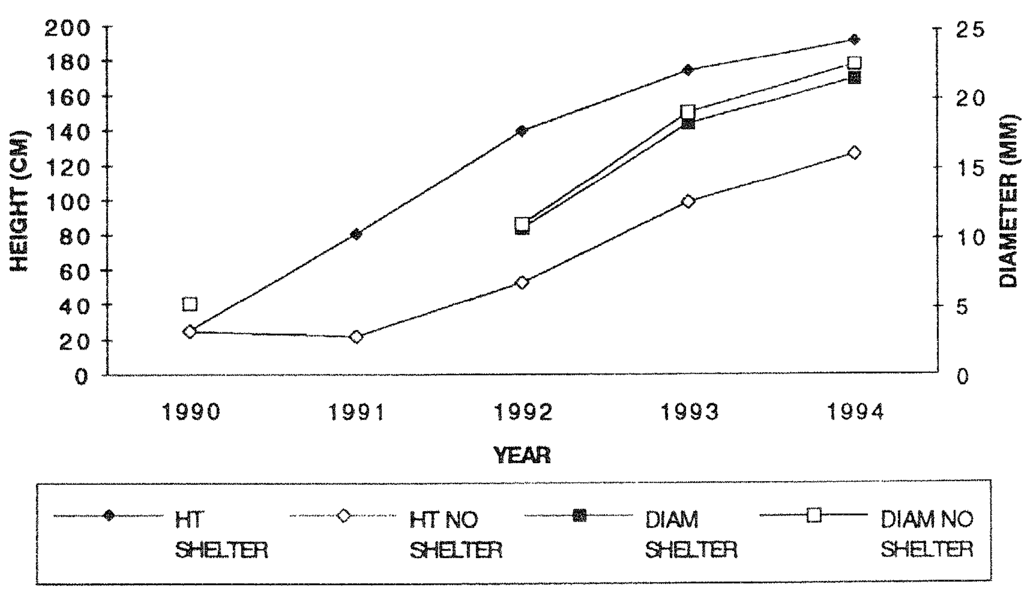

Figure 6.—Four-year growth curves for height and diameter of sheltered and unsheltered red oak seedlings in Wisconsin.

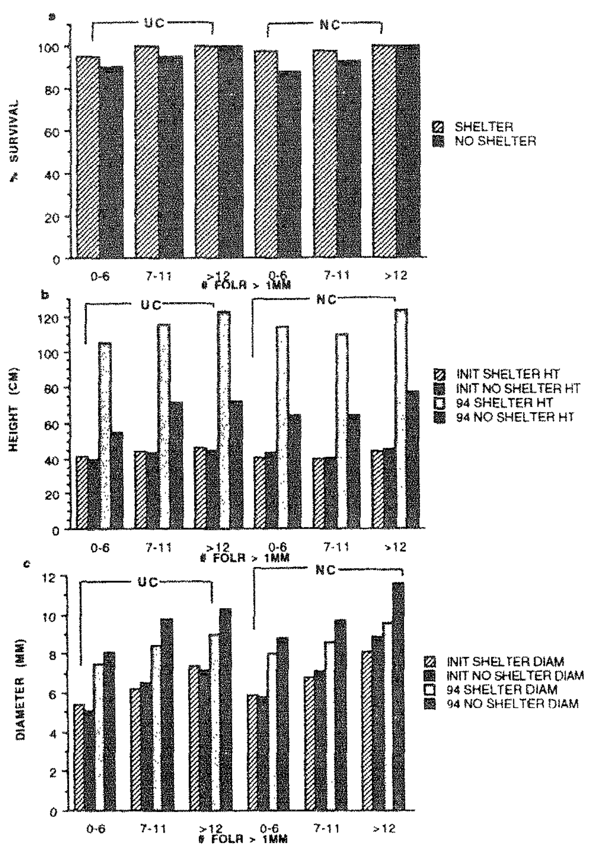

Figure 7.—Four-year results for (a) survival, (b) height, and (c) diameter of black walnut planted in Missouri, with and without tree shelters.

sheltered seedlings did not have leaf areas comparable to unsheltered seedlings. However, unlike the red oak (and black walnut in other states) height growth rate of the black walnut in Missouri did not appear to decrease after the seedlings emerged from the tubes (Figure 8). On the average, unsheltered seedlings demonstrated very little height growth over the four years.

Average fourth-year diameter ranged from 7.5 mm for undercut seedlings with fewer than 6 first-order lateral roots that were sheltered to 11.6 mm for not undercut seedlings with 12 or more first-order laterals that were not sheltered (Figure 7c). Diameters of sheltered seedlings within a root number category were consistently and significantly smaller for sheltered seedlings in spite of the fact that those seedlings were much taller than their unsheltered counterparts.

In general, the data indicate very rapid height growth of sheltered seedlings but an imbalance in the height:diameter relationship of those seedlings. Height differences attributable to initial numbers of permanent lateral roots were still evident for sheltered seedlings after four years in the field.

Stem morphology improved and diameter growth rates of sheltered seedlings increased as seedlings developed a crown above the shelters. These results may be revised in 2 to 4 years when shelters begin to decompose and are removed from the plantations.

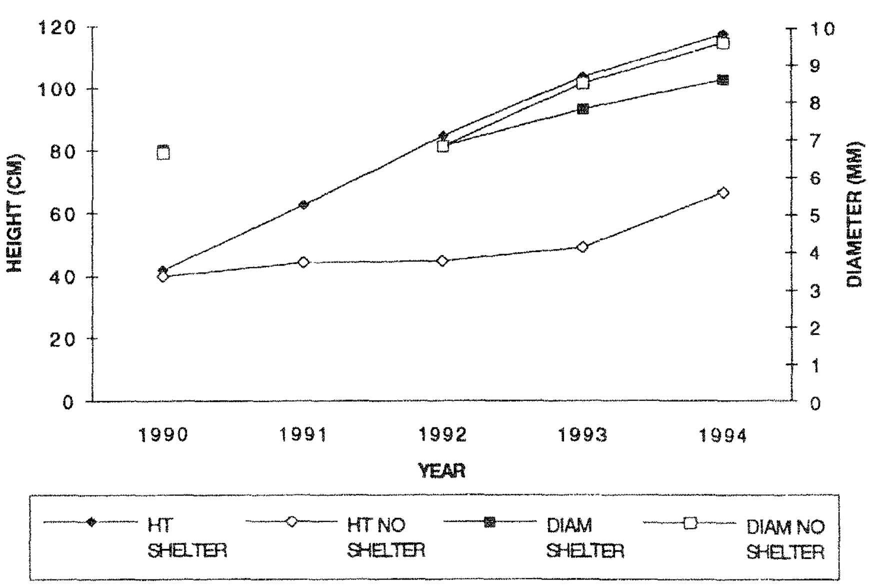

Figure 8.—Four-year growth curves for height and diameter of sheltered and unsheltered black walnut seedlings in Missouri.

Economics of Tree Shelters

At an 8- by 10-foot spacing with "nurse" trees in every other row (544 trees/acre total), these plantations (only half of the crop trees were sheltered) had approximately 136 tree shelters/acre. The cost for all of the trees (assuming 1+0 bareroot hardwood seedings, including nurse trees (including the cost of actually planting them) was about $185.00/acre (seedlings at $0.22 each, planting at $0.12 each). At current prices the cost of shelters (with stakes) for one-fourth of the trees (136 shelters/acre) including installation would amount to $625.00/acre ($4.35 each for shelters, and $0.25 each for installation). The total cost of establishment was approximately $810.00/acre. Maintenance of the tree shelters has been labor-intensive and contributed a significant additional cost. As many as half of the shelters had to be re-set each spring due to frost-heave or animal activity. Stakes and shelters tended to be "pushed over" by wind, contact with mowing equipment, or animal activity.

The bird netting use on the top of the shelters was not completely effective in excluding bluebirds, and caused some deformation of the seedlings when their terminal buds did not grow through the hole in the netting.

Installation of tree shelters added a major expense to plantation establishment, and further analysis of height growth for the next several years will be necessary to determine if that investment is warranted. Shelters may be useful for a limited number of trees in a plantation.

Summary

1. Planting stock characteristics are of paramount importance regardless of what happens during establishment or after seedlings are outplanted (e.g., seedlings can be planted by machine, or auger, tree shelters can be used, but differences attributable to initial numbers of first-order roots are still evident).

2. Undercutting produces higher numbers of roots on a greater proportion of seedlings from a nursery bed. Although there may be some sacrifice in initial size and survival rate, undercut seedlings grow more rapidly than not undercut seedlings, and are taller than their not undercut counterparts after 4 years of growth in the field.

3. Method of planting was only important on difficult sites (e.g., shallow soil). Four-year height and diameter growth of seedlings with 10 or more large first-order lateral roots was greater for auger- and then machine-planted stock. However, the effect of seedling characteristics overshadowed the effect of planting method.

4. Tree shelters nearly doubled seedling height during the first four years but there were no statistically significant differences in seedling diameter due to tree shelters. Thus, sheltered seedlings had an unusual height:diameter relationship. A final analysis of the effects of tree shelters is reserved until they break down or are removed from the plantations. The long-term benefits of tree shelters would need to be very large in order to offset the cost of the shelters and their installation and maintenance.

5. Although differences between seedling root grades in the 1991 plantations were significant, overall there sere smaller differences in height and diameter growth between seedling root grades for this study than were observed among seedlings outplanted by the Cooperative in 1988 and 1989. Bareroot 1+0 seedlings should have characteristics that enhance their chances of success after outplanting regardless of subsequent climatic conditions, which are difficult to predict at the time of planting. Red oak 1+0 seedlings with at least 5 large first-order lateral roots and black walnut seedlings with at least 7 large first-order lateral roots had better survival and growth under all circumstances in plantations established by the Cooperative.

Acknowledgments

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Guidelines for Using Tree Shelters to Regenerate Northern Red Oak[1]

Thomas M. Schuler and Gary W. Miller[2]

Abstract. Regenerating northern red oak (*Quercus rubra* L.) on good to excellent growing sites is a common problem for forest managers throughout the eastern and central United States. Natural regeneration using shelterwood methods is still being refined and depends on existing natural seedlings of sufficient size that can compete in the newly regenerated stand, an uncommon situation in many of today's forests. A possible alternative is the use of plastic tree shelters in conjunction with a planted or natural seedling. Research has shown that tree shelters promote a period of rapid seedling height growth and protect the seedling from injury due to animal activity. Because the use of tree shelters represents a significant financial investment, judicious use of this technique is warranted. Preliminary guidelines are presented to maximize the probability of early seedling survival, growth, and potential competitiveness in the newly regenerated stand. Recommendations are based on research in the use of tree shelters conducted since 1990 in north-central West Virginia. Considerations include the age and origin of planting stock; color, and height of tree shelter; stake material; planting location, density, and timing in relation to overstory removal; the use of herbicides or mulch to retard competing vegetation; and costs for installation.

Introduction

Successful natural regeneration of northern red oak (*Quercus rubra* L.) requires adequate numbers of advanced regeneration of sufficient size before overstory removal (Sander and others 1984). Shelterwood regeneration methods continue to be evaluated (Schuler and Miller 1995) and refined to achieve oak regeneration objectives (Schlesinger and others 1993, Loftis 1990). The shelterwood regeneration method, if successful, may still require a period of 10 to 20 years or longer to develop seedlings of sufficient size before final overstory removal. The time period needed may well exceed the use of this land management option, especially for non-industrial private forest landowners who dominate the ownership patterns in the eastern United States. An alternative regeneration technique is the use of plastic tree shelters to protect seedlings from deer browsing and to stimulate juvenile height growth (Smith 1993a, Kittredge and others 1992, Lantagne and others 1990).

A tree shelter is usually a plastic tube that is placed over a planted or natural seedling to provide protection during the early years of development. Seedling height growth inside a tree shelter is accelerated relative to non-sheltered seedlings (Smith 1993b). This accelerated height growth allows seedlings to compete with surrounding vegetation for an extended period of time. Sheltered seedlings are also protected from deer and rodents when they are most vulnerable. Tree shelters can aid in establishing desirable seedlings in forest clearings and fields where there is minimum shade.

Tree shelters evolved from combining two distinctly different devices: a tree mesh guard used to prevent deer browsing and a small inverted plastic cup used to modify the environment surrounding conifer seeds sown in forest settings (Lahde 1979, Saksa and Lahde 1982). The combination of the two devices resulted in the design of a plastic tube that was tall enough to prevent deer browsing and also was reported to enhance environmental conditions. The design was first used in Great Britain with several hardwood species (Tuley 1983, 1985).

Seedlings growing in tree shelters exhibit improved survival and accelerated early height growth (Lantagne 1995, Ward and Stephens 1995, Smith 1993a, Kittredge and others 1992, Zastrow and Marty 1991, Lantagne and others 1990). The environment inside a shelter has increased carbon dioxide concentrations relative to ambient conditions (Mayhead and Jones 1991) and provides increased humidity which reduces the possibility of moisture stress (Potter 1988).

As unsheltered seedlings grow, the main stem tapers so that they are not broken or pushed over by the wind. By contrast, sheltered seedlings are supported by the tube, and do not taper like open-grown seedlings (Tuley 1983). As a result, seedlings growing within the shelter are often not as rigid as open-grown seedlings. However, the development of better-than-usual shoot elongation is beneficial to the establishment of the sheltered seedlings.

Once the seedlings emerge from the top of the shelters, height growth typically slows and returns to rates typical of unsheltered seedlings and the main stem begins to taper. After emergence, the shelter has little effect on the seedlings that have emerged from the shelters because all photosynthetic activity is occurring outside of the shelter. Once the tree becomes wind and snow-firm, usually one growing season after the seedling emerges from the shelter, the shelter can be removed and possibly reused, thus reducing the cost of using shelters.

Although much has been learned about the impact of tree shelters on tree growth, many details regarding their operational use need to be clarified. This paper addresses such issues and clarifies the management options regarding the use of tree shelters. Guidelines are formulated for the most effective use of tree shelters in regenerating forest stands. Our principal objective is to maintain the species diversity of the site following harvesting activities by retaining the difficult to regenerate oak component.

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
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Materials and Methods

The studies used to formulate the guidelines presented in this paper were conducted primarily on the Fernow Experimental Forest within the Monongahela National Forest in north-central West Virginia (39.03°N, 79.67°W). The ecological land type is referred to as the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest (M221B) according to the U.S. Department of Agriculture, Forest Service National Hierarchical Framework of Ecological Units (McNab and Avers 1994). The land type association has been designated recently as the Allegheny Front Sideslopes (Ba10) (DeMeo and others 1995). The potential natural vegetation of this area is referred to as mixed mesophytic (Braun 1950, Kuchler 1964). Characteristic species include red oak, basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), and sweet birch (*Betula lenta* L.). Annual precipitation is about 55 to 58 inches with 120 to 140 frost-free days during the growing season.

Hickman

This 5-acre study area on a northern red oak site (site index (SI) 80) was clearcut during the 1988-89 dormant season. Sawlog-size material (11.0 inches d.b.h. and larger) was skidded from the site, and all other stems (1.0 inch d.b.h. and larger) were felled and left in place. In March 1989, 126 2-0 northern red oak seedlings at least 0.5 inch in basal diameter were planted. An acorn crop from the fall of 1988 also resulted in the germination and establishment of natural seedlings on the same site. Treatments designed to control competing vegetation were applied to both the natural (n=126) and planted (n=126) seedlings. Natural seedlings were not treated until May when the seedlings were about 6 inches tall. These treatments consisted of the following: a 4 mil black plastic weed barrier (5 by 5-foot square) placed around the seedling, and an herbicide, hexazinone (Velpar-L), applied in a 6-foot radius around each seedling (excluding a 2-foot radius buffer adjacent to the seedling). The herbicide was applied as a pre-emergent at the start of the second growing season at the rate of 6 gallons per acre. Tree shelters, not part of the original study design, were also incorporated just before the start of the second growing season and were 5-foot-tall brown plastic shelters manufactured by Tubex. The treatments were applied singly and in combination resulting in seven different treatments plus a control group for both the natural and planted seedlings (Table 1). Changes in the design of the study resulted in an uneven number of replications between treatments.

The data were analyzed with analysis of variance techniques using a completely randomized design and single degree of freedom sums of squares tests to make relevant comparisons between treatments. However, natural and planted seedlings were not mixed spatially nor randomly, and this lack of randomization may introduce bias in the study conclusions about the tree shelter effects. In this study, we determined the relative performance of natural versus planted seedlings and assessed the merits of secondary treatments related to the control of competing vegetation in conjunction with the use of tree shelters.

McGowan Mountain Gate

This 4.5-acre study area, also on a northern red oak site (SI 80), was clearcut during the 1990-91 dormant season with all sawtimber skidded tree-length from the site. Site preparation for regeneration included felling all trees 1.0 inch d.b.h. and larger. Limited firewood cutting was also permitted before initial planting and sheltering treatments. During March 1991, 200 2-0 red oak seedlings that were root pruned at the end of the first growing season in the seedbed at the nursery were planted on a 25- by 25-foot grid pattern. The seedlings were at least 0.5 inch in basal diameter and were top-pruned to about 1.5 feet tall before being lifted from the seedbed at the nursery. Within a few

Table 1.—Hickman site treatment descriptions and combinations for both planted and natural northern red oak seedlings.

Treatment	Description	Planted	Natural
		---- number ----	
1	No treatment	48	47
2	Shelter (5' brown)	15	16
3	Herbicide (Velpar-L)	15	17
4	Shelter and herbicide	6	5
5	Weed barrier (5'x5' black plastic)	17	16
6	Weed barrier and herbicide	16	15
7	Shelter, weed barrier and herbicide	4	5
8	Shelter and weed barrier	5	5

Note: Weed barrier applied at the start of the first growing season (1989). Shelter and pre-emergent herbicide treatment (Velpar-L) applied at the start of the second growing season (1990).

days after the planting operation, 80 white and 80 brown, seamless, twin-walled shelters (5 foot tall) manufactured by Tubex were installed over the seedlings throughout the area leaving 40 seedlings as unsheltered controls. Data were analyzed using analysis of variance techniques incorporating the completely randomized design. No other secondary treatments have been applied to date.

One growing season later, 162 shelters were installed over northern red oak acorns planted in the spring of 1992 just before the start of the growing season, half with white and half with brown 5-foot shelters of the same design. Unsheltered acorns were not included in this study because previous attempts to do so resulted in almost complete predation of the acorns by rodents and other animals within weeks after planting (Smith 1993a). In this study we determined the differences between seedlings and acorns protected with shelters of different colors and assessed whether acorns can be used in forest settings in conjunction with shelters to protect them from predation by animals.

Results and Discussion

Planted versus Natural Seedlings - Hickman

An analysis of variance was conducted on the total height of the seedlings after the 1994 growing season. All treatments had been applied for 5 years except for the plastic weed barriers, which were installed 1 year earlier. Seedling heights were transformed using natural logarithms to account for unequal variance among the treatments. The analysis indicated no interaction between seedling origin (planted versus natural) and treatment method ($p=0.565$). Although there was clearly a treatment effect on seedling heights ($p<0.001$), an effect on seedling origin alone could not be established ($p=0.445$).

These results suggest that both planted and naturally occurring seedlings can be sheltered with similar results. Sheltering a natural seedling eliminates the cost required to plant a seedling and ensures seed-source compatibility with the site. Sheltering should take place before spring leaf out and should occur following dormant season overstory removal; thus, seedlings can be present before logging or may germinate in the spring following logging operations. In the latter case, as in this study, it may be advisable to wait 1 year so that the seedling can be sheltered before leafing out before the start of the second growing season. Plannin(logging operations to coincide with desired numbers of natural seedlings may be the greatest limitation to using natural seedlings.

Shelters and Weed Control - Hickman

All of the shelter treatments increased height growth relative to the untreated control group, though the weed control treatments alone did not increase seedling height growth (Table 2). Although the shelter used in isolation was as effective as the shelter used in conjunction with weed control (Table 2), there may be some advantage in using them with some form of weed control (Figure 1). Treatment groups that received some form of weed control in conjunction with a shelter averaged more than 10 feet tall—almost 2 feet taller than seedlings that received a shelter alone. Moreover, survival was also highest for all three treatments groups that received both weed control and shelters (Table 3). So, it may be more cost effective to utilize more resources on fewer seedlings to increase survival probabilities and improve competitive position of individual seedlings and saplings. There was not any significant difference between weed barriers and herbicide: regarding height growth when used with shelters. As such, the advantages and disadvantages of each can be evaluated for particular situations, and either form of weed control can be applied when appropriate. There appears to be no advantage to using both an herbicide and a weed barrier in combination (Table 2).

Tree Shelter Color - McGowan Mountain Gate

Tree shelters are sold in translucent colors ranging from white to brown. One brand of shelter, Tubex, specifies light transmittance of 27 percent for brown shelters and 59 percent for white shelters. After four growing seasons, the results from the McGowan Mountain Gate study were analyzed and there were differences in total height betweer the control seedlings (no treatment) and the sheltered seedlings ($p<0.001$). Sheltered seedlings averaged more than 7 feet tall while the unsheltered seedlings were only about 3 feet tall (Figure 2). Survival of the sheltered

Table 2.—Single degree of freedom sums of squares contrasts of tree heights for relevant treatment combinations (Hickman site). Tree heights were tested after natural logarithm transformations to account for unequal variance. Planted and natural seedlings were combined.

Treatment	Description	Pr > F
1 vs. 2-8	No treatment versus all other treatments	0.002
1 vs. 2, 4, 7, 8	No treatment versus all shelter treatments	0.000
1 vs. 3, 5, 6	No treatment versus weed control treatments	0.446
2 vs. 4, 7, 8	Shelter alone versus shelter plus weed control	0.298
4 vs. 8	Shelter plus herbicide versus shelter plus weed barrier	0.898

Table 3.—Total height and survival of planted and natural northern red oak seedlings after 6 growing seasons at the Hickman installation on the Fernow Experimental Forest in north-central West Virginia.

Treatment	Survival Number	Survival Percent	Height	Std Dev	Min	Max
			feet	feet	feet	feet
Shelter + Velpar	9	82	10.98	2.14	7.00	14.20
Shelter + plastic	7	88	10.14	1.57	8.20	12.00
Shelter + plastic + Velpar	7	78	10.13	1.56	7.10	11.50
Shelter	18	58	8.57	2.47	3.00	13.20
Velpar	21	66	6.26	3.22	2.20	12.50
Control	51	54	5.87	3.74	0.00	14.00
Plastic	18	55	5.07	3.65	0.80	11.40
Plastic + Velpar	21	68	4.78	3.19	0.70	13.00

Note: Shelter and herbicide treatments were applied just prior to the start of the second growing season.

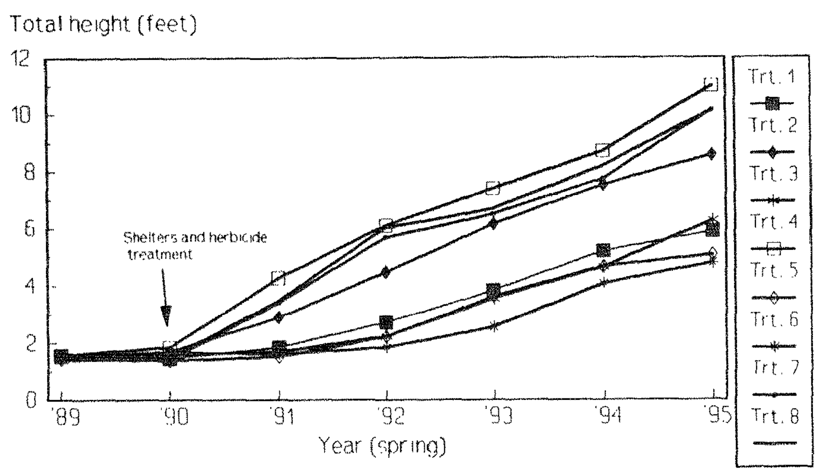

Figure 1.—Total height of northern red oak seedlings, both planted (2-0) and natural, growing in a new forest opening (Hickman site). Treatments: (1) no treatment; (2) shelter; (3) herbicide; (4) shelter and herbicide; (5) weed barrier; (6) weed barrier and herbicide; (7) shelter, weed barrier and herbicide; and (8) shelter and weed barrier.

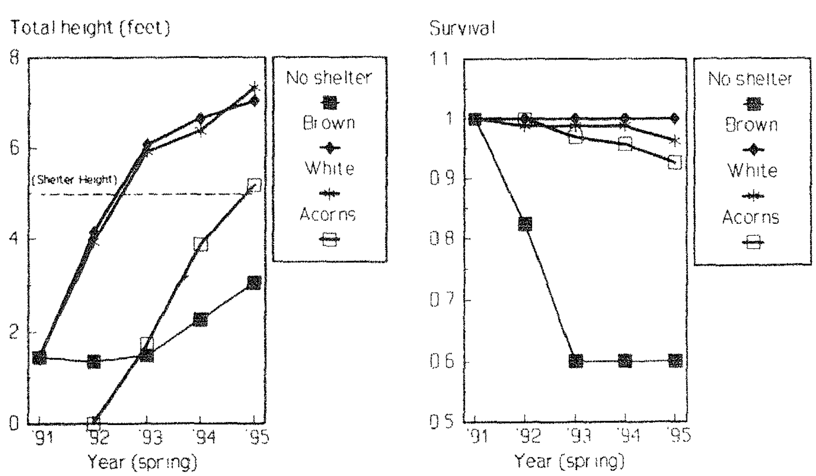

Figure 2.—Total height and survival of 2-0 red oak seedlings and acorns in a new forest opening (McGowan Mountain site). Treatments included seedlings planted in white (n=80) and brown (n=80) shelters, seedlings planted without a shelter (n=40), and red oak acorns planted and sheltered (n=162). Tree shelters were seamless twin-walled polypropylene 5 feet tall and were installed shortly after planting. Seedlings were spring planted in 1991 and acorns were planted one year later.

Table 4.—Equations predicting total height (Ht; feet) of northern red oak as a function of number of growing seasons after outplanting (Yr) for both seedlings and acorns on an excellent growing site at the McGowan Mountain installation.

Origin	Equation			R^2	SE	N
Acorn	Ht =	0.146 +	1.724 (Yr)	0.573	1.217	462
Seedling	Ht =	1.927 +	1.716 (Yr)	0.708	1.234	637
Seedling (no shelter)	Ht =	1.148 +	0.425 (Yr)	0.256	1.047	141

Note: SE = Standard error of estimate for the regression.

seedlings was also much greater with over 95 percent surviving after four growing seasons, contrasted with the unsheltered seedlings that had about 60 percent survival. However, there were no meaningful differences in the height between the brown and white sheltered seedlings ($p=0.266$) using a single degree of freedom sums of squares contrast. Furthermore, now that the sheltered trees have reached heights where most of the photosynthetic activity is occurring above the shelter (Figure 2), future differences probably will not develop.

Planting and Sheltering Acorns - McGowan Mountain Gate

Viable seeds, such as acorns or walnuts, also can be planted and sheltered, and offer some advantages over seedlings. These include ease of planting, the ability to collect acorns from a known source, which ensures site compatibility when proper guidelines are followed, and less initial cost. However, growth rates and survival of acorns versus seedlings have not been fully addressed. At this site, shelter color had no effect on seedling height growth of planted acorns ($p=0.960$) according to the analysis of variance results. After three growing seasons, we used regression techniques to compare the growth rates of acorns planted at the McGowan Mountain Gate site with the growth rates of planted seedlings. Planted seedlings and seedlings from planted acorns showed no evidence of heterogeneity of growth rates ($p=0.918$) while growing inside the shelter (Table 4, Figure 2). If the equations in Table 4 are used to predict seedling height, planted seedlings should typically reach the top of a 5-foot shelter in 2 years while an acorn will require 3 years to reach the same height. The difference is attributed to the initial height of the seedling. Once the seedlings emerge from the top of the shelter, growth rate declines and the equations presented in Table 4 are not valid. The importance of the initial height advantage of the seedling in the newly forming stand is unknown and remains an area of interest.

Survival of planted acorns was less than that of planted seedlings, but acorn survival was above 90 percent after three growing seasons at the McGowan Mountain Gate site (Figure 2). However, at other locations on the Fernow, acorn survival has been less favorable. Second-year survival of less than 70 percent has been observed, suggesting that acorns may be more sensitive to environmental parameters.

Shelterwoods and Tree Shelters

Tree shelters have a beneficial effect with regeneration methods that expose sheltered seedlings to full sunlight conditions. In full sunlight, shelter color does not appear to have any influence on red oak seedling performance, though other species may react differently. With regeneration methods where light is more limiting, shelter color may be more critical. Stocking level guidelines for shelterwood regeneration methods vary by site (Loftis 1990) and region (Johnson and others 1986) and are an attempt to create conditions that provide sufficient light for oak development, but insufficient light for shade intolerant species. Using tree shelters in conjunction with residual stocking guidelines for shelterwood regeneration methods may result in insufficient light levels for oak development in shelters. In studies on the Fernow Experimental Forest, brown shelters installed over natural red oak and white ash seedlings in both 60 and 75 percent residual stocking shelterwood treatments have resulted in mortality rates near 100 percent after three growing seasons (Schuler and Miller 1995). Also, Walters (1993) reported poor oak seedling development in brown shelters under a residual overstory relative density of 53 percent in western Pennsylvania. Reducing the residual overstory density further to compensate for the light absorption characteristics of the shelter may result in increased competition from shade intolerant species. So, we do not recommend using brown shelters with the shelterwood regeneration method.

We are currently evaluating the use of white shelters in conjunction with the shelterwood regeneration method. From preliminary observations, it appears that growth rate of sheltered trees decline as residual overstory density increases, this is likely due to decreased sunlight and increased competition for moisture. The concern is that the reduced growth rates will make the sheltered seedlings less competitive in relation to the other species that grow at greater rates in partial sunlight. However, in some situations, deer browsing may severely limit understory development and possibly make the use of tree shelters feasible under a partial overstory reduction. Continued research is needed to fully evaluate the potential for this method of regeneration. Special tree shelters for use in low-light conditions may be needed. Large-scale underplantings with white tree shelters should be conducted only with the commitment to control competing vegetation and with the understanding that such an approach has not been evaluated fully.

Limitations of Sheltered Seedlings

At some point, if planting and sheltering activities have been successful, the management objective will be to maintain previously sheltered seedlings in a sapling-size stand or cohort. Silvicultural options include a cleaning to enhance oak survival as the stand develops. Cleanings should be delayed as long as possible but not until the desired trees have become overtopped and have declined in vigor. This will likely occur between 5 and 10 years after establishment. The need for release results from the rates of oak height growth relative to other species in sapling-size stands. During this stage of stand development, typical oak height growth will lag behind other faster growing species (Figure 3). A vigorously growing codominant oak will be about 40 feet tall in 20 years (Schnur 1937). Yet, other Appalachian species will be about 60 feet tall in the same time period. These faster growing species include yellow-poplar, black cherry, and black birch. As a result, an individual oak stem will be overtopped when surrounded by these other species, necessitating the release operation.

The degree of release is another area for continuing research. Ward (1995) found only slight height growth suppression in young red oaks following a full release. These results suggest a four-sided crown touching release as described by Perkey and others (1993) may be the most appropriate method.

Costs

The prices of shelters vary by manufacturer and quantity purchased. Prices for spring 1995 are summarized in Table 5. Costs should range between $175 and $400 per acre to plant and shelter 70 seedlings per acre. In Pennsylvania, Crothers (1991) reported that cost averages about $760 to plant and shelter 200 seedlings per acre through contractual agreements. Reducing the planting density to 100 seedlings per acre could reduce total costs significantly. Smith (1993b) estimated that it would cost $170 to plant and shelter 30 seedlings per acre. Reusing plastic and fiberglass stakes and possibly reusing shelters and doing the work yourself can also reduce costs. Ultimately, planting density will be determined by the expected survival rate and management objectives.

To enhance survival and development of northern red oak seedlings with tree shelters follow these guidelines:

1. Sunlight - Use tree shelters in full sunlight to near full sunlight conditions. Shaded seedlings in tree shelters grow at slower rates and often fail to survive the recruitment phase associated with partial-cutting practices. Preliminary observations from northwestern Pennsylvania suggest that residual stocking levels above 30 square feet of basal area or about 30 percent relative density should be avoided when using white translucent plastic tree shelters that are commercially available. As noted earlier, the only exception to this may be in areas where competing vegetation is slow to respond to reductions in overstory density, perhaps due to high deer densities. Typically, even light shelterwood removals stimulate woody species development (Schuler and Miller 1995) and the competition for light created by the understory development may be unsuitable for northern red oak survival and growth. In openings, site preparation before planting should include felling any residual sapling-size or pole-size stems within the planting area where shelters will be used. This can be done more efficiently before tree shelters are in place. Mast, den or other residual trees are often retained for wildlife or aesthetic purposes. Avoid using sheltered seedlings within the shaded areas near these trees.

2. Size - For the most consistent results, use 2-0 seedlings that have been root-pruned in the nursery bed at the end of the first growing season or natural seedlings. Ideally, basal diameter should be 0.5 inch or greater. Although some success has been achieved with acorns, this technique has been less reliable than using a planted or natural seedling. Additionally, even with the best results, seedlings from acorns will lag in size even though the rate of development can be similar to an existing planted or natural seedling. If natural seedlings are present, shelters should be installed before leaves emerge in the spring. Top-pruning may facilitate the use of shelters with older natural seedlings that have multiple branches since the seedlings will readily resprout.

3. Location - Plant seedlings where the soil is deep and advantageous for growth. Do not plant near stumps where sprouts will likely dominate the immediate vicinity. Avoid portions of skid roads where soil compaction and topsoil removal may inhibit root growth. When planting on a grid, do not adhere to preset spacing requirements when unfavorable conditions exist.

4. Technique - Dig a hole deep enough so that the roots are not "J" shaped after planting. Set the root collar just below the surface of the soil and make sure the hole is filled with soil and not leaves and other organic material. Make sure the hole is free of air pockets where the roots will invariably dry out and die. Proper planting technique is imperative with a sheltered seedling because of the additional investment.

5. Shelter - Use tree shelters that are at least 5 feet tall to prevent deer browsing. Even in areas with low deer densities we have observed that deer tend to browse planted seedlings before other vegetation. Color of the shelter is not important for growth response in full sunlight conditions. Although the light transmittance of different colors does vary, this ceases to influence photosynthetic activity as soon as the leaves emerge from the shelter. After 5 years of field use, we have not observed any visible

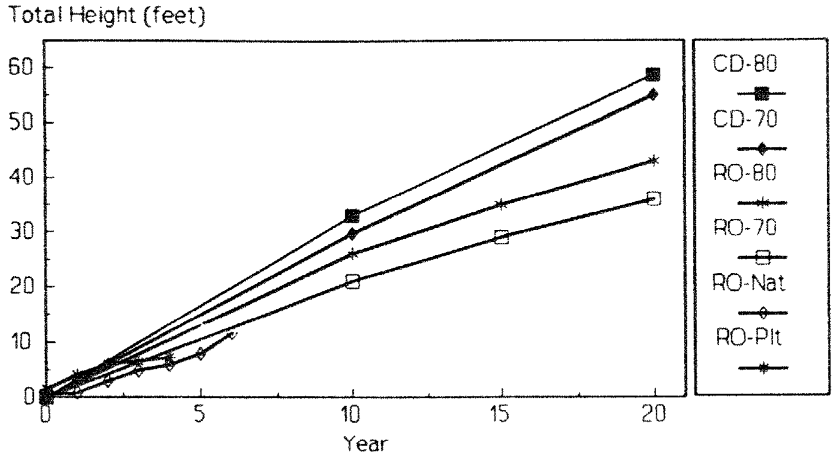

Figure 3.—Total height of codominant trees (black cherry, yellow-poplar, black locust) in forest openings by red oak site index 70 (CD-70) and 80 (CD-80) and northern red oak height growth for site index 70 (RO-70) and 80 (RO-80). Also, included are mean northern red oak seedling heights from both planted (RO-Plt) and natural (RO-Nat) origin that were sheltered in new forest openings.

Table 5.—Price range for using tree shelters per unit in the spring of 1995.

Item	Price range	
	Low	High
	---------- dollars ----------	
Shelter (5 foot)	2.00	3.25
Stake	0.50	1.25
Seedling	0.00	0.15
Herbicide/Mulch	0.00	0.70
Labor	0.00	0.60
TOTAL	2.50	5.95

signs of shelter degradation. Consequently, some exceptionally fast-growing trees may require early shelter removal or that the shelter be split and left in place to provide protection from rodents and buck-rubbing. Nets on the tops of shelters have been used to prevent birds from becoming entrapped inside. However, remove all nets before the shoot reaches the top of the shelter to prevent deformation of the stem. Stems that become entangled in the nets should be clipped below the deformation and allowed to resprout.

6. Installation - Set the shelter carefully over the planted seedling and make sure the shelter is firmly seated into the ground. Pile some loose topsoil around the base of the shelter to prevent air from being drawn up through the shelter creating a chimney effect that may dry and kill young seedlings. Some reports suggest that seating the shelter into the ground may not be needed (Lantagne 1995), but in the central Appalachians, we recommend sealing the shelter until further evaluations are made.

7. Stake - Use a durable stake. The most common problem we have encountered when using tree shelters is stake failure. We found that white oak stakes often break at ground level within 2 years after installation. When this happens, the shelter falls over and pulls the seedling down with it resulting in the loss of the seedling unless corrected. The shelter system should remain intact for up to 5 years. After this, even if the stake breaks, the tree will often support itself. We strongly recommend plastic, fiberglass, or possibly treated wood as a stake material. You should be able to drive the stake into the ground 12 to 18 inches and have at least 12 inches of stake above the top shelter fastener. We have recently started using recycled-plastic electric fence posts. These can be purchased from farm and builder's supply stores. Such stakes are reusable, thus reducing future planting cost. However, the slick surface of plastic stakes may allow the shelter to lift away from the ground. In addition to the fasteners, we have started taping the shelter to the stake to discourage the upward movement of the shelter on the stake.

8. Maintenance - Inspect and maintain shelters for several years to protect your investment in reforestation. The cost of maintenance may be tax deductible. Maintenance is almost always due to broken stakes and using a durable stake will greatly reduce the need to maintain shelters. However, there are other factors that can damage the

shelter system. In the central Appalachians, we find that bear occasionally damage shelters. Rodents may also damage the shelter or the seedling inside it. The ties that hold the shelter to the stake may also break. A dormant season inspection can correct many of these problems. Down shelters are visible from a distance when the vegetation is still only a few feet tall and can be attended to without walking to every shelter. Net removal also may be another required maintenance activity. If using nets, time the removal to minimize the time period that the shelter does not have a seedling at or above the top of the shelter. This can be difficult considering shoot elongation of individual seedlings can range from no growth to several feet per year.

9. Density - Planting density depends upon objectives and success rate of the sheltered seedlings. Definitive guidelines cannot be given until long-term trials have been completed. However, we have adopted a spacing of 25 by 25 feet, which provides a planting density of approximately 70 seedlings per acre. This spacing also permits ground application of herbicides, if needed, without the risk of damaging adjacent sheltered seedlings.

10. Competing vegetation - Maximum survival and height growth have been observed when sheltered seedlings also receive some type of competing vegetation control such as an herbicide or plastic weed barrier. However, further research is needed to clarify the benefits of secondary treatments. Examples of such treatments include glyphosate applied at the end of the first or second growing season and hexazinone applied as a pre-emergent at the start of the second growing season. Weed barriers that retard vegetation development but permit water penetration may provide similar results. The additional cost can be offset by reducing planting density.

11. Secondary Treatments - Between 5 and 10 years after overstory removal, the newly regenerated stand will achieve crown closure. Once this stage is reached, new recruitment of individual stems will cease and competition for survival will result in the loss of some stems as existing ones becomes larger in height and diameter. Sheltered seedlings that have not become part of the newly established overstory in a codominant or strong intermediate position are unlikely to survive beyond this stage. We recommend a cleaning to release any vigorously growing oak stems that are being overtopped by other faster growing species. The cleaning should be delayed as long as possible, but not until the oak stem has declined in vigor. Because the shade of the stand will slow the response of the cut stem or its replacement, we do not recommend a heavy thinning at this stage. The release can be done mechanically or by using a basal spray herbicide such as tricolpyr.

Summary

The use of tree shelters can aid in the early establishment and development of northern red oak and other desirable species. Secondary treatments as well as long-term survival are still being evaluated. While the potential to achieve some regeneration objectives appears promising, those interested in using tree shelters should be aware of silvics of the species involved and proceed knowing that long-term trials are not yet completed. Following the guidelines presented above should increase the likelihood of success.

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Intermediate Results of a Treeshelter Durability Study[1]

Keith Windell and James D. Haywood[2]

Abstract. Solid plastic tubes, marketed as "Treeshelters" are currently being used to aid in the establishment of tree seedlings. These tubes have been shown to accelerate the initial height growth of the seedlings. Delayed stem diameter development has also been a common observation. Once the spindly trees are out of the tube, they rely on the shelter to keep them from toppling over. Past studies with treeshelters indicate that they must possess enough structural integrity to support the rapidly growing seedling until it is self-supporting or the tube will actually become detrimental to the seedling. There are several different shelter designs and a couple of different shelter materials currently available from commercial vendors. The products being sold vary from heavy duty extruded tubes to very flimsy sheet materials that must be assembled on site. To get an indication of relative performance of different materials and designs, a 5-year "Treeshelter Durability Study" was initiated by the USDA Forest Service Missoula Technology and Development Center and Southern Research Station. The study is being replicated at seven different sites across the U.S. Although the study is still in progress, the intermediate results presented in this paper may be helpful to shelter purchasers by identifying material and design problems.

Introduction

Treeshelters are solid plastic tubes that are installed around a seedling at the time of planting or placed around natural regeneration. Foresters in England developed the concept in 1979 to help establish their hardwood forests. Their original studies with these "treeshelters" focused on the survival and growth of Sessile Oak. The tubes are approximately 4 inches (10.2 cm) in diameter and range from 8 inches (20.3 cm) to 6 feet (1.8 m) tall. They serve as small greenhouses to create a micro-climate that has been observed to increase seedling survival and promote accelerated initial height growth. They act as a physical barrier to protect against animals, chemicals, and mechanical equipment. They also mark the location of the seedling in dense vegetation.

The USDA Forest Service is interested in determining whether these solid tubes can be used successfully to accomplish their reforestation goals. Published success of the shelters when used in the United States has ranged from exceptionally good to dismal. Sometimes the failures have been a direct result of the shelter material or design. The Missoula Technology and Development Center (MTDC) has been interested in the material and design aspects of the treeshelters since 1991. Past studies have shown that successful shelter designs must maintain their structural integrity for a predetermined length of time, which depends on species planted and management goals. Shelters are buffeted by wind, rain, and animal contact. To withstand these harsh conditions all commercially manufactured treeshelters are currently made of plastic. These plastics degrade under the effects of ultraviolet light exposure.

It is common for hardwoods grown in 4-foot (1.2 m) tall treeshelters to emerge out the tube top after two or three growing seasons. When they initially emerge they exhibit a tall slender profile and cannot stand upright without aid. Firm support may be required for up to 2 years or more depending on the species of tree and height of shelter. Early published reports recommended that shelters last a minimum of 5 years and some even recommended 7. If the shelter is not capable of providing this support there is a good chance the seedling will die. It is very important that a treeshelter "system"—shelter, stake, and tie—not degrade excessively before the seedling is self supporting.

The Treeshelter Durability Study initiated by MTDC was under the direction of a "Seedling Protection Guidance Group." The study objectives were to test several currently available tree shelters for structural durability, ability to remain upright (staking integrity), and ease of installation. Members of the group included personnel from USDA Forest Service Research and the National Forest System. MTDC located and obtained the materials to test and coordinated the evaluation effort. The Southern Research Station wrote the test plan, installed one study and analyzed the data for all sites. The study was installed at seven different sites across the U.S.

The installation of seedlings in the shelters was not required as part of this study. This continuing study assumes that the climate change inside the tube due to the seedlings' presence does not significantly increase water absorption by the plastic shelter wall material. Absorption of moisture could compromise the structural integrity of the shelters. If a seedling were present, it could cause mechanical damage to the top of the shelter when it emerges and is whipped about by the wind. A sharp or jagged rim could cause damage to the seedling stem. Since this potential problem exists, special attention will be paid to the condition of the shelter rim during field evaluations.

The parent plastic in the shelter, the staking material, and any ties used to connect the shelter to the stake are being evaluated over a period of up to 5 years. Any apparent material or design flaws should become apparent. In addition, results from this study will determine approximate service life of each of the shelter designs tested. Since seedling response is not part of this materials study, no correlation between seedling development and variables such as shelter opacity can be made. There is however, a high probability that if a shelter collapses in or falls down, the seedling will die. The study is still in progress but the intermediate results presented in this paper (six of the

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

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seven sites) may be helpful to shelter purchasers by identifying material and design problems. Although it is too early to predict final service life for all shelters tested, some of them have already shown themselves to be inferior designs that should be avoided. Information contained in this paper will help managers make the proper shelter and stake selection to meet their needs.

The objective of this study was to test several of the currently available tree shelters for structural durability, ability to remain upright (staking integrity), and ease of installation.

Materials and Methods

Outdoor Durability Study

This study a shelter "system" consists of three components—the shelter, stake, and attachment tie. Each of the individual components will be evaluated separately. Touching and visual observation will determine when a "system" component has failed. A failure of any one of the components will constitute a failed treeshelter "system". In addition to the outdoor durability study, in which shelters were installed as recommended by manufacturers (seven sites), an accelerated weathering study was installed on angled racks (one site). If a good correlation between the standard study and accelerated rack study can be made, future shelter designs can be tested in a shorter period of time.

The commercial treeshelter brands being tested at most sites are: Tubex®, Tree Sentry®, Tree Pro® (slit top and flop top), International Reforestation Suppliers (IRS) Rigid Seedling Protectors® (yellow and blue fertilizer), and Quadra® (brown and white). Although the IRS protectors were really mesh tubes rather than solid they came with a plastic sleeve (grow chamber) which was presumed to create the desirable micro-climate of the heavier treeshelters. The availability of the Quadra ceased before all the study sites were established. The Southern Research Station will be the only unit testing the following late additions to the study: TreePee®, Acorn Shelterguard® (imported from England), Correx (Plus® and Galemaster® - imported from England), and Norplex®. The Forest Products Laboratory (FPL) in Madison, WI is also testing their own experimental tube, which was prepared from a standard space-board paper core and dipped in paraffin wax/polyethylene mixture. Four-foot (1.2 m) tall shelters where chosen as the standard size to install (if available) in the outdoor durability studies (exceptions included the TreePee and the FPL prototypes which were each 2 feet (61 cm) tall).

Guidelines for site selection and installation included: shelters were to be installed as if they were actually being used (following any special manufacturer instructions); stakes were to be pounded into the ground approximately 10 inches (25.4 cm); shelters could be optionally sunk into the ground approximately 1 to 2 inches (2.5 to 5.1 cm); study site was to be in the open so that the amount of solar radiation and moisture the shelter is exposed to was a maximum value and could be measured accurately; recommended shelter spacing was 10 feet (3.0 m) to minimize shading from adjacent shelters and to keep any toppled shelter from knocking others over (the FPL installed on 5 foot (1.5 m) centers to conserve space usage in its fenced test site); site was to be mowed at least once a year to eliminate shading effect from vegetation; and if permitted, herbicide application was encouraged around the base of the shelters. Any adverse reaction between the shelter material and herbicide was of interest. It was thought that following these guidelines would generate a conservative value for the useful life of a shelter system.

Each site was instructed to lay out the tree shelters (treatments) in a randomized complete block design with 10 blocks serving as replications. A single treeshelter "system" formed each of the plots per block. Blocking was utilized to simplify installation and measurement.

Since this study is mainly concerned with shelter "system" durability and not survival or growth response of seedlings the cooperators were told that it was not necessary to plant anything inside the shelters.

Due to late availability of some products not all treeshelters were installed at the same time.

It was requested that total solar radiation and rainfall information be collected and included in study records. An on-site automated system with precipitation and total solar radiation (pyranometer) sensors was recommended. Only the Southern Research Station and the Stroud Water Research Center still have on-site weather data acquisition capability. Weather data were not included in this intermediate report.

Every 4 months the condition (ability to stay intact) of the treeshelter "systems" was to be visually evaluated as excellent, usable, unusable, or missing according to these standards:

Shelter material
- 1 - Excellent - Not buckled, no cracks
- 2 - Usable - Not buckled, some minor cracks but not on top rim, no gapping holes on side (< 3/4 inches (1.9 cm))[3]
- 3 - Unusable - Shattered, buckled, abrasive/cutting edge on top rim, holes on side (> 3/4 inches (1.9 cm)), reversion
- 4 - Missing - Gone

[3] This definition for usable was only intended to apply to shelters up to 24 months. After 24 months, all holes on the side were acceptable. This is because after a seedling emerges from the top of a shelter (typically 1-2 years for a 4-ft (1.2 m) tall shelter), the microclimate ceases to accelerate the growth of the seedling. The integrity of the tube can then degrade to the point that it only has to support the seedling from folding over on itself but still must not present sharp/abrasive edges that will allow the seedling to girdle itself while swaying in the breeze.

Stake
- 1 - Excellent - New like condition
- 2 - Usable - Firmly upright, slight leaning, minor warpage and decay allowable
- 3 - Unusable - Exaggerated stake/shelter leaning, unsteady stake, high decay, broken stake
- 4 - Missing - Gone

Tie
- 1 - Excellent - New like condition, holds shelter firmly to stake
- 2 - Usable - Holds shelter firmly to stake
- 3 - Unusable - Broken or too loose which allows shelter to migrate up stake and/or possibly cause shelter to revolve around the stake
- 4 - Missing - Gone

Any broken stakes or ties encountered during the study were to be replaced and evaluations were to be continued until the shelter wall material was rated as unusable. Stake or tie breakage was to be documented so that the adequacy of these components can be evaluated. Photo documentation of failures was requested. Failure of any one of the system components constituted a failure of the "system".

Shelter durability results were analyzed using NPAR1WAY PROCEDURES (probability of a greater chi-square = 0.10) (SAS® User's Guide: Statistics, Version. SAS Institute Inc. Cary, North Carolina). There were 10 blocks at each site; so the analyses were based on up to 140 observations per study site. Stake and tie durability were also analyzed in this manner. The stake analyses were based on up to 140 observations and the tie analyses were based on up to 160 observations per study site.

Accelerated Weathering Study

The objective of this study was to determine the performance of commercial and prototype treeshelters exposed outdoors (outdoor durability study) and correlate results with the accelerated rack testing results. The FPL was the only cooperator performing this study.

A 2-foot (61 cm) tall assembled shelter (including stake and tie) was the specimen installed on the rack. The rack was positioned 45 degrees to the horizontal and facing south. Ten replications of each commercial shelter type were attached. Only three of the FPL experimental tubes were installed (they were not evaluated in the same fashion as the commercial shelters). The rack study was installed in close proximity to the standard outdoor durability study.

The shelters are being inspected (in a non-destructive manner) every 2 months for up to 3 years. Based on past rack studies with sign materials it is expected that weathering on the racks would be accelerated about two times over the standard installation. Inspection consists of squeezing and visually inspecting each tree shelter using durability criteria already presented in the standard durability study.

Weather data was being collected on-site at the beginning of the study but equipment failed and was not replaced.

The FPL will determine if a correlation between the results of the outdoor durability study and the accelerated rack study exists when sufficient data is collected. If an accurate correlation between the two studies can be determined future shelter designs and materials can be evaluated quicker. The study results will also provide a history for comparing future shelter materials or designs.

Results and Discussion

Southern Research Station, Louisiana

Brief site description: The generally level site was sheared and wind-rowed in summer of 1991. Vegetation was primarily grasses and forbs with some woody regrowth. Site was rotary mowed before installation and was periodically mowed after establishment to keep plant development in check so the shelters would be uniformly exposed to climatic conditions.

Installation notes: Fourteen different types of shelters were installed at this location. The Tubex shelters came with the ties already in place, which speeded up installation. Ties for the Tree Sentry and Tree Pro shelters had to be inserted into the tubing at the job site, and the ties for the Tree Pro shelters were the most difficult to install. The collar-ties for the square shaped Quadra shelters were difficult to install unless care was taken to press in the tube corners to ensure the collar-tie was properly fitted around the tube.

Installation of the two tree protectors from International Reforestation Suppliers (IRS) was not difficult. However, the polythene® mesh tends to bend inward and become oblong rather than circular in circumference. The use of two bamboo stakes can help overcome this problem only if the stakes bend away from each other. That is, the stakes force the tube walls outward from center and force the mesh into a circular shape. If this is not done, the serrated ends of the mesh entwine and close the top opening. We believe the IRS tree protectors were flattened in shipment, and better packing may eliminate this problem.

The packed TreePee shelters became compressed in shipment and were difficult to separate. Once separated, they were easy to install. However, the TreePee is the shortest shelter tested. The Acorn Shelterguards and Norplex shelters were light weight, easy to transport, and not difficult to install. The Correx Galemaster takes up space in shipment because they are shipped as stacked cylinders, and additional time is needed in transporting and separating the Galemasters on-site. However, they are easy to install. The Correx Plus is a four-sided shelter that are flattened for shipment. The Correx Plus is easy to transport and install on-site, and takes no more time to install than the Galemasters. Both Correx shelters come with the ties preinserted which is always an advantage over having to insert the ties on-site.

Transporting the stakes and shelters to their proper locations was tedious, but we had no carts available for on-site transport. Mistakes made while inserting the ties might have caused some initial misalignment of shelters, and therefore, it is an advantage to use shelters that require little on-site assembly. The bamboo stakes are too small in diameter and drive crookedly. The fiberglass stakes have to be handled carefully because they splinter. The wood stakes were the easiest to work with. Attaching the shelters to the stakes was not difficult.

Durability and integrity: After 11 months seven of the Tree Sentry shelters were thought to be too narrow in diameter because the plastic had drawn-in. We worried that this might impede tree development. However, these shelters were not cracked or buckled so they were still given an excellent rating at that time.

After 27 months, all Tubex brown, Quadra white, Quadra brown, and Tree Pro slit top shelters remained in excellent condition (table 1). One of the Tubex white and Tree Pro flop top shelters buckled over because of tie failure, and one of the Tubex white and three of the Tree Pro flop top shelters had some cracks or holes. The Tree Sentry shelters had the poorest mean durability. Two of the Tree Sentry shelters were in excellent condition, but two of the shelters had deteriorated and six had some cracks. After 1 months, the wire mesh of three of the 20 IRS tree protectors had buckled inward blocking the tube opening. Three of the shelters were still usable although the tube opening was partially blocked, and 14 of the shelters were still in excellent condition. Through 10 months, all Acorn Shelterguard, Correx Galemaster, Correx Plus, and Norple shelters remained in excellent condition. However, the upper section of three of the TreePee shelters had popped

Table 1.—Shelter and staking durability at Pineville, LA over a 10 to 27 month period. Evaluation date: 10/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
July 22, 1992					
Tubex brown	10	0	0	0	10
Tubex white	8	1	1	0	10
Tree Sentry	2	6	2	0	10
Quadra white	10	0	0	0	10
Quadra brown	10	0	0	0	10
Tree Pro (slit top)	10	0	0	0	10
Tree Pro (flop top)	6	3	1	0	10
June 28, 1993					
IRS (yellow)	7	2	1	0	10
IRS (blue - impregnated with fertilizer)	7	1	2	0	10
December 15, 1993					
TreePee	5	2	3	0	10
Acorn Shelterguard	10	0	0	0	10
Correx Galemaster	10	0	0	0	10
Correx Plus	10	0	0	0	10
NorPlex	10	0	0	0	10
	Number of stakes per durability class				
July 22, 1992					
Wolmanized pine	13	5	2	0	20
White oak	37	8	5	0	50
June 28, 1993					
Bamboo	7	11	2	0	20
December 15, 1993					
Bamboo	11	4	5	0	20
Fiberglass	20	0	0	0	20
Steel	10	0	0	0	10
	Number of ties per durability class				
Not explicitly recorded	--	--	--	--	--

Note: Shelter and stake durability results were analyzed using non-parametric statistics. The durability of 14 kinds of shelters and 5 kinds of stakes were significantly different (probability of a greater chi-square=0.0001).

loose, and two of the top sections were loose but still well-enough in place to be usable.

After 27 months, five of the 50 oak stakes and two of the 20 pine stakes failed, and eight of the oak stakes and five of the pine stakes were still usable but slightly warped or leaning. Several of the plastic fasteners have been replaced with metal ones over the 27 month period. Although they were in the field for only 10 to 16 months, the bamboo stakes had the lowest mean durability rating among the tested materials. Seven of the 40 bamboo stakes failed, and 15 were still usable but slightly warped or leaning. The fiberglass stakes and steel supports were all in excellent condition after 10 months.

Forest Products Laboratory, Wisconsin

Brief site description: The study site is in an open field surrounded by an animal exclosure. Site was originally instrumented to collect solar radiation data but the collection sensor failed.

Installation notes: The Tubex tree shelters came from the manufacturer as round tubes with the ties in place. They were the only ones not requiring any form of assembly. The Quadra shelters came from the manufacturer in a flattened square shape. They needed to be shaped into a square and held in position with clips. The clips had ties attached to them for secure fastening to the stake. The Tree Pro shelters came as flat sheets of corrugated plastic that had to be assembled in a cylindrical shape and held together with ties. These ties are also used to fasten the shelter directly to the stake. The Tree Sentry shelters came as round tubes and required the ties to be threaded into the tube. The only purpose for the ties was to hold the shelter to the stake. The IRS tree protectors have no tie. The bamboo stake is woven into the shelter. The FPL experimental shelters had a rope tied around the tube and then to the stake.

Durability and integrity: Two months after installation the FPL thought the diameters on the Tree Sentry design were too small and crowding the seedlings; however, the tubes were mostly in excellent condition (table 2).

After 24 months all of the Tubex brown and Quadra white shelters are still in excellent shape (table 2). With one Tree Pro flop top missing the remaining nine were also in excellent condition. All 10 Tree Pro shelters with the fold tabs (slit top) showed reversion as the tabs reoriented themselves to a vertical position. They are still rated as usable but this condition could present a sharp edge for the seedlings to rub against. One of the Tree Pro slit top shelters also showed general degradation. Of the remaining

Table 2.—Shelter durability at the Forest Products Laboratory, Madison, WI. Evaluation date: 10/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
October, 1992					
Tubex brown	10	0	0	0	10
Tubex white	2	8	0	0	10
Tree Sentry	8	2	0	0	10
Quadra white	10	0	0	0	10
Quadra brown	9	1	0	0	10
Tree Pro (slit top)	0	10	0	0	10
Tree Pro (flop top)	9	0	0	1	10
June, 1993					
IRS (yellow)	9	1	0	0	10
IRS (blue - impregnated with fertilizer)	10	0	0	0	10
	Number of stakes per durability class				
All stakes received an excellent rating. This is odd because the narrative mentions several mesh tree protectors by IRS toppling over and attributes part of this to the bamboo. The bamboo stakes were probably in great shape but were just pulled up by the wind and then reinstalled.					
	Number of ties per durability class				
October, 1992					
Nylon	107	12	1	0	120
Polypropylene bracket	34	6	0	0	40

Note: Shelter and tie durability results were analyzed using non-parametric statistics. The durability of 9 kinds of shelters were significantly different (probably of a greater chi-square=0.0001). The 2 kinds of ties did not differ in durability (probability of a greater chi-square=0.4953).

usable shelters eight Tubex white shelters had cracks and showed signs of being brittle when they were squeezed, one of the Quadra brown shelters was cracked, and two of the Tree Sentry shelters were cracked at the top of the tube.

The IRS tree protectors, which are plastic mesh tubes with a plastic sleeve and use bamboo stakes, have a tendency to catch the wind which causes the shelter to become unstable resulting in many of the shelters being knocked over. The bamboo stakes may have been a contributing factor.

The FPL experimental shelters have lost their cylindrical shape and have become distorted because of water absorption. They also seem to be ideal for mildew growth.

Both kinds of ties worked well and received a mean rating of excellent (table 2).

Forest Products Laboratory (Accelerated Rack Study), Wisconsin

Brief site description: The study site is in an open field surrounded by an animal exclosure. Site was originally instrumented to collect solar radiation data but the collection sensor failed. Racks for mounting shelter specimens were oriented 45 degrees from vertical and faced south.

Installation notes: The shelters for the rack study were attached to the rack with a 26 inch (66.0 cm) stake through the center of the shelter and fastening the stak with screws (the shelter stake was fastened to the shel with the tie). Each shelter is 8 inches (20.3 cm) from th next resulting in two staggered rows of shelters on the rack.

Durability and integrity: After 22 months all of the Quadr white and Tree Pro flop top shelters are still in excellent shape (table 3). All 10 of the Tree Pro designs, with the tabs (slit top), showed reversion as the tabs re-oriented themselves to a vertical position and were rated as usal Of the useable shelters five of the Tubex white, four of t Tree Sentry, one of the Tubex brown, and one of the Quadra brown shelters have developed cracks.

After 14 months all 20 of the IRS tree protectors are still excellent shape (table 3). The oak stakes were very dur over the 14 to 22 month period.

Beech Creek Seed Orchard, North Carolina

Brief site description: Study site is in the middle of this North Carolina seed orchard. Site was originally instrumented to collect solar radiation data. Lightning eventually struck data collection equipment.

Table 3.—Shelter durability in an accelerated rack study at the Forest Products Laboratory, Madison, WI. Evaluation date: 8/22/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
October, 1992					
Tubex brown	9	1	0	0	10
Tubex white	5	5	0	0	10
Tree Sentry	6	4	0	0	10
Quadra white	10	0	0	0	10
Quadra brown	9	1	0	0	10
Tree Pro (slit top)	0	10	0	0	10
Tree Pro (flop top)	10	0	0	0	10
June, 1993					
IRS (yellow)	10	0	0	0	10
IRS (blue - impregnated with fertilizer)	10	0	0	0	10
	Number of stakes per durability class				
October, 1992					
Oak (26" long)	66	4	0	0	70
June, 1993					
Oak (26" long)	20	0	0	0	20
	Number of ties per durability class				
	--[1]	--	--	--	--

Note: Shelter durability results were analyzed using non-parametric statistics. The durability of 9 kinds of shelters were significantly different (probably of a greater chi-square=0.0001).
[1] All ties and brackets received an excellent rating

Installation notes: No problems with installation were noted.

Durability and integrity: Initial observations showed that after one year 100% of the Tree Sentry shelters show detrimental signs of curling (internal constriction) and plastic break down. At 20 months (2/7/94 inspection) eight of these shelters were rated as usable and two as unusable due to general deterioration. At 24 months (6/14/94 inspection) nine of these shelters were rated as unusable due to general deterioration and the 10th was missing (table 4).

At 28 months (11/7/94 inspection) comments occurring three or more times for an individual shelter type include the phrase "curling" associated with four of the Tree Pro slit top and three of the Tree Pro flop top shelters. The phrase "cracking" or "breaking up" was applied to seven of the Tubex white shelters. The phrase "cracking at top" was applied to three Tubex brown shelters. All of these shelters were still rated as usable.

After 28 months the oak stakes had the greatest mean durability; still, 14 of the original oak stakes failed or were missing (they were replaced as long as the shelter was still rated usable) (table 4). Seven of the original plain bamboo stakes failed or were missing. Three of the original coated bamboo stakes failed or were missing. Fourteen of the original nylon ties and four of the original polypropylene brackets installed on the Quadra shelters failed or were missing. However, both kinds of ties worked well and received a mean rating of excellent.

Ocala Seed Orchard, Florida

Brief site description: The study site is in the middle of this Florida seed orchard. Site is susceptible to termites and tornadoes.

Installation notes: No problems with installation were noted.

Durability and integrity: After 30 months all of the following shelters were still rated excellent: Tubex brown, Quadra

Table 4.—Shelter durability at Beech Creek Seed Orchard, Murphy, NC. Evaluation date: 11/7/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
June, 1992					
Tubex brown	4	5	0	1	10
Tubex white	0	10	0	0	10
Tree Sentry	0	0	9	1	10
Quadra white	6	3	0	1	10
Quadra brown	8	2	0	0	10
Tree Pro (slit top)	4	6	0	0	10
Tree Pro (flop top)	4	5	0	1	10
July, 1993					
IRS (yellow)	7	2	0	1	10
IRS (blue - impregnated with fertilizer)	10	0	0	0	10
	Number of stakes per durability class				
June, 1992					
Oak	52	4	11	3	70
July, 1993					
Bamboo (plain)	3	0	6	1	10
Bamboo (coated)	5	2	3	0	10
	Number of ties per durability class				
June, 1992					
Nylon	106	0	14	0	120
Polypropylene bracket	36	0	4	0	40

Note: Shelter, stake and tie durability results were analyzed using non-parametric statistics. The durability of 9 kinds of shelters were significantly different (probability of a greater chi-square equaled 0.0001), as was the durability of 3 kinds of stakes (probability of a greater chi-square=0.0087). The 2 kinds of ties did not differ in durability (probability of a greater chi-square=0.7733).

white, Quadra brown, Tree Pro slit top, Tree Pro flop top, and IRS (blue/fertilizer) (table 5). Five of the Tree Sentry shelters had shattered bottoms which left gapping holes and were rated as unusable. One of the Tubex white shelters was also rated as unusable. Of the tubes still rated as useable six Tubex white and one Tree Sentry tube were caving in at the midsection or showing significant cracking.

This site has been plagued with staking problems. During the last recorded 4 month period alone 13 shelters were down and were reinstalled or removed. A tornado hit the orchard on March 13, 1993 (20% of the orchard was lost) and termite damage is common. Of the original 50 oak stakes 23 failed or were missing. One of the treated pine stakes, nine of the plain bamboo stakes, and one of the coated bamboo stakes were unusable (table 5). On average the plain bamboo stakes were the least durable while the treated pine stakes were the most durable ones tested. The polypropylene brackets were less durable than the nylon ties. Two out of 120 nylon ties broke while three out of 40 polypropylene brackets failed.

Tahoe National Forest, California

Brief site description: Site is a previously planted logging unit.

Installation notes: No problems with installation were noted. Shelters were installed over existing Jeffrey pine seedlings.

Durability and integrity: Comments from the data sheet indicated that after 16 months three of the IRS tree protectors folded over on themselves. Three of the 20 plastic sleeves installed over the IRS tree protectors had either worked up or down the tube.

After 16 months the following shelters types each had one that was rated as unusable: Tubex brown, Tree Sentry, and Quadra white (table 6). Three of the IRS (yellow) tubes were also rated unusable. Fourteen shelters were missing so there is no way of knowing their condition (stake or ties probably broke and they were blown away). On average, the IRS tree protectors were the least durable and the Tubex shelters were the most durable ones tested.

Table 5.—Shelter durability at Ocala Seed Orchard, Silver Springs, FL. Evaluation Date: 1/18/95.

Date installed and	Classifications				
Shelter or Stake type	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
July 2, 1992					
Tubex brown	10	0	0	0	10
Tubex white	1	8	1	0	10
Tree Sentry	2	3	5	0	10
Quadra white	10	0	0	0	10
Quadra brown	10	0	0	0	10
Tree Pro (slit top)	10	0	0	0	10
Tree Pro (flop top)	10	0	0	0	10
June 29, 1993					
IRS (yellow)	8	2	0	0	10
IRS (blue - impregnated with fertilizer)	10	0	0	0	10
	Number of stakes per durability class				
July 2, 1992					
Oak	14	13	22	1	50
Treated pine	18	1	1	0	20
June 29, 1993					
Bamboo (plain)	1	0	9	1	10
Bamboo (coated)	5	4	1	0	10
	Number of ties per durability class				
July 2, 1992					
Nylon	108	9	2	0	120
Polypropylene bracket	0	37	3	0	40

Note: Shelter, stake and tie durability results were analyzed using non-parametric statistics. The durability of 9 kinds of shelters, 4 kinds of stakes, and 2 kinds of ties were significantly different (probability of a greater chi-square=0.0001).

Among the stakes, the oak ones had a greater mean durability than did the bamboo stakes (table 6). Of the original stakes eight of the oak stakes failed or were missing. Seven of the bamboo stakes failed or were missing. All 15 of these stakes were replaced or reinstalled if shelter material was still usable. One of the polypropylene brackets failed. The bracket was not repaired.

Ochoco National Forest, Oregon

Brief site description: The study site is located in a plantation in the Pine Springs Basin Fire Area. Site conditions include a flat, windy, site with residual soil with little or no rock content. There are a number of standing dead snags in the area. Gophers were very active.

Installation notes: No problems with installation were noted. Shelters were installed over 2-0 ponderosa pine seedlings.

Durability and integrity: A short report from the Ochoco stated that the IRS tree protectors with the plastic sleeves required the most maintenance, mostly re-staking the bamboo rods. The Tubex and Tree Pro shelters required the least maintenance and will withstand more seasons of weathering. The Tree Sentry shelter was thicker than the other shelters and had more broken ties than the other shelters.

After 15 months all of the Tubex, Tree Sentry, and Tree Pro shelters were in excellent condition (table 7). Nineteen of the IRS tree protectors were still rated as usable. One of the plastic sleeves was missing. With this gone, the tree protector still offered some animal protection but the enhanced micro-climate effect was gone. Although the mesh material was still usable a rating of unusable was given to the tree protector because it was not fully functional.

Among the stakes the oak ones had greater mean durability than did the bamboo stakes (table 7). After 15 months four of the original white oak stakes, four of the plain bamboo stakes, and four of the coated bamboo stakes failed or were missing.

Table 6.—Shelter durability on the Tahoe National Forest, Truckee, CA. Evaluation date: 11/24/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
July, 1993					
Tubex brown	8	1	1	0	10
Tubex white	9	0	0	1	10
Tree Sentry	7	0	1	2	10
Quadra white	8	0	1	1	10
Quadra brown	7	2	0	1	10
Tree Pro (slit top)	7	1	0	2	10
Tree Pro (flop top)	3	2	0	5	10
IRS (yellow)	3	2	0	5	10
IRS (blue - impregnated with fertilizer)	3	2	3	2	10
	Number of stakes per durability class				
July, 1993					
Oak (short)	22	0	1	1	24
Oak (tall)	14	0	0	4	18
Oak (large)	15	0	1	1	17
Bamboo (plain)	5	0	0	2	7
Bamboo (coated, green)	7	1	1	3	12
Bamboo (tall)	0	0	0	1	1
Flat stake	1	0	0	0	1
	Number of ties per durability class				
July, 1993					
Nylon	90	0	0	0	90
Polypropylene bracket	39	0	1	0	40

Note: Shelter, stake and tie durability results were analyzed using non-parametric statistics. The durability of 8 kinds of shelters were significantly different (probability of a greater chi-square=0.0361), as did 3 of the kinds of stakes (oak, bamboo-plain and bamboo-coated) (probability of a greater chi-square=0.0798). However, the 2 kinds of ties did not differ significantly (probability of a greater chi-square=0.1336).

Conclusions

- Shelters which require little on-site assembly or have pre-inserted attachment ties speed up installation time.
- Although the square brackets supplied with the Quadra shelter are necessary to maintain an open shelter they are also more difficult to work with when compared to the nylon tie system used with other shelters.
- Bamboo stakes are difficult to drive into the ground and the plain bamboo stakes were less durable on average than the other stakes.
- Fiberglass stakes have a tendency to splinter during installation.
- Pressure treated pine stakes and plastic coated bamboo stakes provide better structural integrity than oak and plain bamboo stakes on termite infested sites.
- Problems with the recycled polyethylene plastic material used in the Tree Sentry shelter are readily apparent. The internal diameter of the shelter is prone to shrinking and plastic brittleness has led to a significant number of failures.
- The top flaps of the Tree Pro slit top shelter are susceptible to reversion.
- The IRS tree protectors are very susceptible to crushing damage during transport from factory to job site.
- The TreePee shelter uses a plastic coupling joint between its sections which is susceptible to failure after prolonged exposure to sunlight.
- Lightning is hard on pyranometers.

Recommendations

- Perhaps a plastic coated oak or pine stake could be offered by the manufacturer.
- The manufacturer of the Tree Sentry shelter has been made aware of the failures observed in this study. An explanation was offered which traced the root of the problem to the uncertainty in the amount of ultraviolet inhibitor present in the recycled plastic. It was recommended that extra U.V. inhibitor be added by the shelter maker to ensure a reasonable shelter life.

Table 7.—Shelter durability on the Ochoco National Forest, Burns, OR. Evaluation date: 11/16/94.

Date installed and shelter or stake type	Classifications				
	Excellent	Usable	Unusable	Missing	Total
	Number of shelters per durability class				
July 8, 1993					
Tubex brown	10	0	0	0	10
Tubex white	10	0	0	0	10
Tree Sentry	10	0	0	0	10
Tree Pro (slit top)	10	0	0	0	10
Tree Pro (flop top)	10	0	0	0	10
IRS (yellow)	0	9	1	0	10
IRS (blue - impregnated with fertilizer)	0	10	0	0	10
	Number of stakes per durability class				
July 8, 1993					
White oak	33	13	3	1	50
Bamboo (plain)	0	6	2	2	10
Bamboo (coated, green)	0	6	2	2	10
	Number of ties per durability class				
July 8, 1993					
Nylon	114	1	5	0	120

Note: Shelter and stake durability results were analyzed using non-parametric statistics. The durability of 7 kinds of shelters and 3 kinds of stakes were significantly different (probability of a greater chi-square=0.0001).

- The possibility of a seedling being abraded or severed by the Tree Pro slit top shelter make it inferior to their other shelter the Tree Pro flop top.

- The use of IRS tree protectors with plastic sleeve is not recommended on windy sites. They are too susceptible to collapsing in and doubling over. The plastic sleeves can work their way up the tube and block of the exit for the seedling. The bamboo stakes provided with the tubes have a difficult time holding the shelter on-site after the plastic sleeve catches a strong wind.

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Tree Shelters Improve Desert Planting Success[1]

David A. Bainbridge and Robert MacAller[2]

Introduction

Desert revegetation projects face many difficult challenges. Often, survival of transplants is low due to the combined destructive forces of wind abrasion, temperature extremes, moisture stress, and herbivory (Bainbridge et al. 1990). Treeshelters have been found to be very effective in forest replantings (Windell 1993), and initial results indicate shelters may benefit transplants in arid environments. Many companies have introduced tree shelters in the last two years, commonly plastic tubes of various configurations and materials. Hand made wire cages or chemical deterrents are also used. This paper reviews results of plant protection tests on a restoration project at Red Rock Canyon State Park in the Mojave Desert of California.

Abiotic Stress

Protection from the physical environment can be critical in extreme environments (Bainbridge 1991). High winds and blowing sand damage and kill plants (Mosjidis 1983). In addition to sand blast effects plants may be damaged and killed by the mechanical action of high winds. Multiple branching has been observed as a common response to damage from wind, either at the ground surface or above shelter protection. Winds and extremely high temperatures increase the moisture stress on young seedlings. Shelters can reduce evapo-transpiration and increase moisture available to seedlings by creating a favorable micro-environment. This appears to be most critical in the first 6-8 weeks after transplanting. In addition, treeshelters can protect plants from low temperature stress as well. While freezing is not often considered important in the desert ecosystems, young transplants are very sensitive to low temperatures and freezing (Bowers 1980) and temperatures affect distribution of many desert plants.

Biotic Stress

Herbivory is increasingly recognized as a critical factor in tree survival in arid environments (McAuliffe 1986). Newly established seedlings are often the most succulent plants available and rodents, rabbits, reptiles, domestic livestock and insects can prove fatal to young plants unless adequate protection is provided. Blacktail jack rabbits (*Lepus californicus*) have been the most destructive herbivores in our trial plantings at Red Rock Canyon State Park.

The 1993-94 (treeshelter trial year) season was reported as the worst year for herbivory in 30 years and tested systems to the extreme. Grazing of many species has been severe and jack rabbits even browsed mature resinous creosote bush (*Larrea divaricata*) heavily, chewing off branches up to 1 cm thick. Jack rabbits also learned how to kick over shorter treeshelters and consumed virtually all of the seedlings in two test plots.

Materials

Several shrub protection types were studied in the Red Rock trials, including: hand made wire cages, Tubex® treeshelters, and TreePee® treeshelters (Figure 1). The wire cages are composed of 3.8 cm wire mesh threaded and staked to the ground with pencil rod (7 mm) rebar. Tubex are 3 inch diameter twin-wall plastic tan or white colored tubes available in a variety of heights. TreePee shelters are thin wall, recycled plastic, red colored open-top conical tubes (Figure 1).

Red Rock Canyon State Park Field Trials

Two experimental test plots were installed at Red Rock Canyon State Park using different shrub species.

(A.) *Hymenoclea salsola* (burrobrush) at the South Flat

Study Site

Research was conducted at a revegetation site located on the south east edge of Red Rock Canyon State Park in the Mojave Desert. The area is bordered to the north and west by hill climbs (hills denuded of vegetation by off-road vehicles), to the south by a dry wash, and to the east by a state highway. The study site has sparse vegetation, with a shrub community composed primarily of *Larrea divaricata, Hymenoclea salsola, Isomeris arborea, Ambrosia dumosa* and *Cassia armata* shrubs. The area was heavily damaged by off-road vehicle recreation before being added to the state park in 1989.

On October 23, 1993, 40 *Hymenoclea salsola* seedlings were planted in 10 blocks, placed in areas denuded of vegetation, several meters away from large shrubs within the South Flat revegetation site. Each block was configured in a square, two feet between individuals, and contained four treatments: TreePee Treeshelters, Tubex Treeshelters, wire cages and no shelter. Each plant received an equal amount of water (a total of 8 liters) and all plants were monitored on November 7, December 28, April 4, and June 2. Each individual was rated on a scale of 0-4 (0, dead; 1, some live stems; 2, some green stems; 3, mostly green and bushy; 4, very green and bushy) for health. Damage from grazing was noted. Plants were monitored after 14, 65, 163, and 219 days.

Statistical Analysis

The data acquired from this investigation was ordinal, therefore treatment differences were analyzed with a non-parametric analysis of variance, using Kruskal-Wallis (at a significance level of 0.05). When tests were significant, multiple Mann-Whitney U tests were run to analyze the differences between treatments at a significance level of

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
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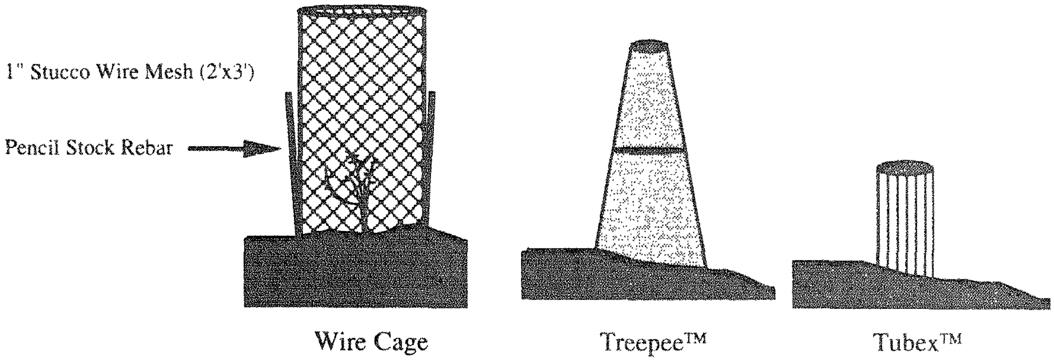

Figure 1—The three forms of tree protection commonly used by restoration researchers.

0.01, to control for experiment wise error, although this will decrease the power of the comparison.

Results and Discussion

The statistics reveal a highly significant protection effect on plant health ($p<0.0001$) at the final sampling date. The Mann-Whitney U test indicates that the presence of any shelter improves health ratings when compared to the control. Evidence of grazing was most pronounced in unprotected plants and in those protected by Tubex, while little grazing occurred on plants protected by treepees or cages. Transplants were healthiest when planted with TreePees or Tubex (Figure 2). The individuals planted in Tubex were as healthy as those grown in TreePees, but suffered increased herbivory. However, damage from grazing did not result in an overall decrease in health for these plants. Cages provided adequate protection from herbivory, but the plants did not receive the other benefits related to Tubex and TreePee Treeshelters (improved irrigation delivery, wind protection, temperature protection, etc.) and were not as healthy over the entire length of the study. Eighty percent of the individuals without protection died, presumably from grazing, within 14 days after outplanting, and all of the unprotected plants had died after 65 days, from grazing or from stress related to grazing pressure. Protected plants had over 90% survival. The plants protected by cages suffered decreased health, but had high survival. The plastic treeshelters appear to provide additional benefits, minimizing herbivory (particularly TreePees), while maximizing growth.

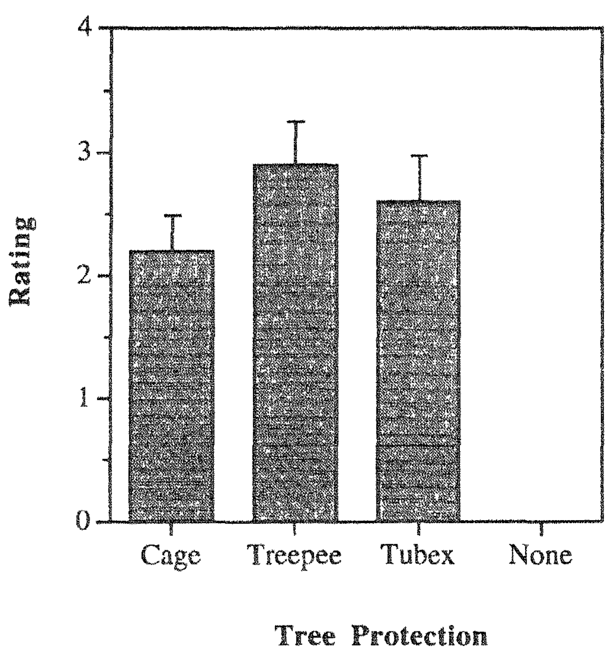

Figure 2.—*Hymenoclea salsola* health ratings on a scale of 0-4 (0=dead, 4=green and healthy) 219 days after transplanting. There were 10 replicates of each treatment.

(B.) *Ambrosia dumosa* (White bur sage) at the Jurassic Park Movie Site

Study Site

The White bur sage trial was conducted on the exposed south-east facing slopes of the ridge at the Jurassic Park movie site located in the central portion of the park on a hillside road denuded of vegetation. The site was bordered by washes to the east and west. The surrounding vegetation was composed primarily of *Ambrosia dumosa*, *Atriplex hymenolytra*, *Atriplex canescens*, *Larrea divaricata*, and *Ephedra nevadensis*.

Methods

On November 6, 1993, 44 *Ambrosia dumosa* seedlings were planted in 11 blocks, placed near the center of the road disturbance. Each shrub was planted in a block and one of four treatments was applied: TreePee Treeshelters, Tubex Treeshelters, wire cages or herbivore deterrent (double strength Hinder® spray repellent). Each plant received an equal amount of water. Plants were monitored periodically and rated on the 0-4 health scale.

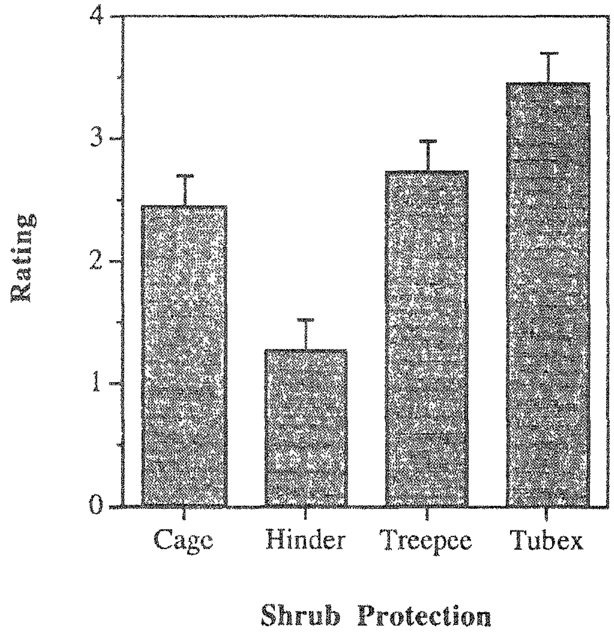

Figure 3.—*Ambrosia dumosa* health ratings on a scale of 0-4 (0=dead, 4=green and healthy) 95 days after transplanting. There were 11 replicates of each treatment.

Results and Discussion

There was a highly significant effect of plant protection on bur sage health at 95 days ($p<0.0001$). The Tubex and TreePees treated transplant health ratings were not significantly different, nor were TreePee and cage treatments. Tubex treated plants did slightly better than cages and treeshelters and cages were more effective than Hinder® repellent (Figure 3). After 477 days no repellent treated plants survived and only 18% of caged plants survived. This compares to 45% of seedlings protected by TreePees and 36% of those in Tubex treeshelters.

Conclusions

These studies indicate the effectiveness of tree shelters for two desert shrubs, previous experience has provided similar data for other species. The benefits in reducing transplant shock seem likely to extend to most other species. The value of the tree shelter may be related to irrigation system, water schedule, and fertilizer and the interaction of these factors with the microclimate created by the shelter.

There are costs associated with the use of some shelters. Light may be reduced to as low as 30% of ambient with the tan Tubex tree shelters tested (Sorensen 1993). Although transpiration often keeps shelter temperature below ambient air temperature the leaf temperature may rise when plants are dry, not uncommon on these desert plants, and this may have adverse effects on some species. Tree shelters have occasionally trapped lizards and a stick to enable them to climb out should be placed in the shelter if it is not netted. Netting or cross-threaded fish line near the top may be needed in some areas to restrict access by birds.

Minor problems have included changes in plant shape and difficulty in removing shelters from plants that have grown rapidly. In these cases shelters have to be cut away from the shrub, which can be labor intensive. The shape of many tree protectors may result in mushroom shaped plants, these may be more vulnerable to wind damage when the shelter is removed, but most shrubs have recovered well and now look much the same as native shrubs.

Research comparing results of various protection options on many other species is needed. In addition time trials should be encouraged to determine when protection detriments outweigh the benefits.

Acknowledgments

Special thanks to Pam Beare, John Crossman, Laurie Lippitt, Ronie Clark, Mark Faull, and Matt Fidelibus. Support provided by the California Department of Transportation and California Department of Parks and Recreation.

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Valley Coal Tree Shelter Field Trial[1]

Mitchell E. Farley, Philip S. Perry and Peter R. Woyar[2]

Abstract. Environmental conditions on land mined for coal and reclaimed under PL 95-87, the Surface Mining Reclamation and Control Act, has created a situation detrimental to the reestablishment of forest tree species. A study was designed to assess the significance of modifying environmental conditions related to planting tree seedlings in an effort to increase survival and height growth. One half of the study area was subsoiled with a rock ripper the fall prior to planting. One half of the tree seedlings planted in the ripped and unripped areas respectively were protected with Tubex brand tree shelters. Three measurements of height growth and survival were made over a four year period, the most recent measurements collected in May 1994. Analysis of the data to date indicates that subsoiling and the use of tree shelters resulted in increased height growth and survival as compared with the other treatments.

Introduction

Reclamation of surface mined lands regulated by the Surface Mining Reclamation and Control Act (PL 95-87) requires grading disturbed areas to original contour, replacement of topsoil, and establishment of dense herbaceous cover of grasses and legumes in order to stabilize the soil surface and rapidly alleviate conditions contributing to soil erosion. This cover is maintained for 5 years until the performance bond is released. Most land mined for coal in Ohio is located in hardwood forest regions. The original tree cover was removed to facilitate mining and has not been reestablished due to economic, regulatory, and site related factors.

The most important site related factors are soil compaction and competition from herbaceous vegetation. Associated with these problems are soil chemistry changes and mechanical damage to seedlings by rodent and deer browsing. Microclimate changes from the original forest conditions manifest themselves in terms of elevated soil temperatures, decreased soil pore space, and increased exposure to wind. The combination of these factors produces an extremely hostile environment for native hardwood tree species, especially those which prefer more mesic sites.

The objective of the Valley Coal Field Trial is to assess the effects of specific environmental modifications on tree seedling survival and growth. Two treatments—subsoiling or "ripping" of the compacted soil and protecting seedlings with plastic tree shelters—have been evaluated over a 4 year period in order to assess their respective influence on seedling survival and height growth. The control treatment consists of planting identical seedlings with no site modifications or tree protection.

Valley Coal Field Trial Site

The Valley Coal site is located in the Wayne National Forest, Starr Township, Hocking County, Ohio. The site was mined and reclaimed using conventional surface mining techniques for the period. This site is similar to many sites reclaimed under PL 95-87, the Surface Mining Reclamation and Control Act (SMRCA), 1977.

A cooperative field trial was conducted by Ohio Department of Natural Resources (ODNR), Division Of Reclamation; USDA Forest Service, Wayne National Forest and Hocking College, School of Natural Resources and Ecological Sciences, to evaluate the effectiveness of tree shelters and soil ripping in initial establishment and growth of northern red oak (*Quercus rubra*) on this site. Red oak was selected as representative of a native species which has significant economic and wildlife value.

The area selected for the trial is an upper slope, gently sloping (10-15 percent), west facing aspect. A soil test performed in 1990 indicated a soil pH of 6.1. Soils are shallow, compacted, and stony. The site is completely vegetated with herbaceous species, mainly tall fescue (*Festuca arundinacea*).

Methods

The site was subsoiled (ripped) with a 30 inch rock ripper, rear mounted on a crawler tractor. Ripping was done on the contour during October 1989, the fall previous to tree planting. Fall ripping in dry soil increases the amount of fracturing of the subsoil, further reducing compaction, and in addition creates an area of bare soil similar to plowing. This is significant in that no herbicide treatments were prescribed to control competing herbaceous vegetation.

Two hundred and forty 1-0, bare-root red oak seedlings were hand planted by volunteers from Hocking College on the trial site. The seedlings were nursery inoculated with the ectomychorrhizal fungi *Pisolithus tinctorius* (Pt).

Two trial plots were established, each with six rows with 20 seedlings in each row. One plot was ripped, the other was not. Seedlings in alternate rows of each plot were protected with 48 inch tall plastic tree shelters manufactured by Tubex. The shelters were secured with white oak stakes. Planting was completed April 21, 1990.

The tree shelter manufacturer (Tubex 1990) claims that increased survival and faster growth will result from the use of tree shelters. The shelter acts as a mini-greenhouse, reducing water loss and recycling available water. Measurements by Potter (1991) in England caused him to conclude that the tree shelter prevented water loss and mechanical abrasion which "helped explain the increased growth and survival observed for newly-planted trees

[1] Paper presented at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Reclamation Specialist, Ohio Department of Natural Resources, Jackson OH; Silviculturist, USDA Forest Service, Athens, OH; Instructor, Hocking College, Nelsonville, OH.

protected by tree shelters." In addition, the shelter protects the seedling from animal damage and desiccation. A mesh guard is placed over the top of the shelter to exclude birds. The shelters should biodegrade in 5 to 7 years.

Evaluation of the outplanting was conducted September 1990, April 1992, and May 1994. All trees were measured for survival. Twenty-five percent of the trees were selected for height measurement. A report was prepared for each evaluation, and these were published in the Ohio Tree Farm News (Schatz 1991), Tubex Tree Shelters Catalog (1990-1991), and a USDA Forest Service publication on tree shelters (Windell 1991). Charts were prepared which compared initial survival and growth for the outplanting year with survival and growth two years later. This information was presented at a technical meeting of the Ohio Society of American Foresters at Zanesville, Ohio, in August 1993.

Results

1. Trees with tree shelters showed a higher rate of survival than those with no shelters. This observation is the same for all three measurement periods. (table 1).

2. Trees in the ripped areas showed a higher rate of survival than those in the non-ripped area. This observation is the same for all three measurement periods (table 1).

3. There was a significant difference in height growth among sheltered trees when comparing the ripped and non-ripped treatments. Trees in the ripped area were significantly taller than those in the non-ripped area. This conclusion differs from the 1990 and 1992 reports which indicated no significant difference in height growth (table 2).

4. There are no significant differences in height growth for non-sheltered trees in the ripped and non-ripped areas. This observation is the same for all three measurement periods (table 2).

Conclusions

The Valley Coal Field Trial indicates that tree shelters do increase survival and height growth of red oak seedlings. In addition, it appears that ripping to reduce compaction improves height growth if tree shelters are used. Only 4 of 120 seedlings planted in tree shelters grew out of the shelter during the four year trial. On the area on which both

Table 1.—Survival of red oak seedlings with and without tree shelters and on ripped and non-ripped areas of the Valley Coal reclamation site on the Wayne National Forest.

	Survival		
Treatment	1990	1992	1994
	------	percent	------
With shelter	80	77	51
Without shelter	50	36	17
Ripped	75	63	47
Not ripped	55	50	21

Table 2.—Height growth of red oak seedlings with and without tree shelters and on ripped and non-ripped areas of the Valley Coal reclamation site on the Wayne National Forest.

	Height growth		
Treatment	1990	1992	1994
	------	cm	------
With shelter			
Ripped	23	26	53
Not ripped	21	25	35
Without Shelter			
Ripped	17	17	14
Not ripped	17	15	21

Note: The decrease in height growth from 1990 to 1992 was caused by mortality of measured trees and browsing by deer and rodents.

ripping and tree shelters were used survival and growth are encouraging on a decidedly adverse site. After four growing seasons survival is 63 percent compared with 3 percent for the control. Total height is 53 centimeters compared with 21 centimeters for the control (only 1 control tree still alive). Readers should be cautioned to compare these results with growth and survival rates from non-mined lands such as old fields, or recent harvest areas. Smith (1993) reports mean survival of 70 percent and mean height growth of approximately 280 centimeters for red oak after three growing seasons on a new clearcut area of excellent site quality. Obviously, severely disturbed land will not produce comparable growth or survival.

Species selection for the Field Trial deserves some comment. Based on our experience, red oak would not be a species recommended for reforestation of reclaimed mined lands. Low site quality would dictate that other species more commonly associated with poor sites be utilized. Red oak was used for two reasons, first the availability of Pt inoculated seedlings produced for planting on unreclaimed lands, and second, for establishing a native commercial timber species beneficial to wildlife. Common reforestation species for this specific soil situation are black locust (*Robinia pseudoacacia*), green ash (*Fraxinus pennsylvanica*), and virginia pine (*Pinus virginiana*). None of these are particularly valuable commercial species or producers of abundant hard mast. In addition, red oak was planted in consideration of species diversity. Limited species suitability for reclaimed mined land reforestation does little to alleviate the problem of low plant species diversity on reclaimed areas.

Recommendations

Tree shelters can be used to increase survival and height growth of red oak on SMRCA reclaimed mined lands. Survival and height growth data indicate that growing red oak on this site could not be justified economically. Because of the high cost of planting stock, ripping, shelters, and labor, significantly greater survival and growth rates are required. The authors believe that production of a commercial timber crop will take much longer than average for forest land in southeastern Ohio, and that the value of that timber will probably be less than normal.

The authors suggest that planting 25 to 50 trees per acre to increase species diversity and enhance wildlife and aesthetic values might prove to be environmentally valuable. The cost of this type of planting is detailed in Appendix A. The USDA Stewardship Incentive Program currently cost shares on site preparation, planting stock, and tree shelters. The remainder of the planting (400-600 trees per acre) might be completed with pioneer species known to survive and grow on reclaimed sites without special treatment. The intent of this type of planting method is to produce a greater variety of species, to introduce valuable hard mast producing species, and to achieve adequate stocking levels to meet regulatory requirements. This represents a departure from the idea that any tree, regardless of its potential to satisfy multiple objectives, is satisfactory for reforestation of reclaimed mined lands.

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Appendix A: Valley Coal Tree Shelter Field Trial Cost Documentation (Updated to 1995 costs)

1. Current Forest Service reclaimed strip mine planting:
   - 1/3 Pt inoculated Virginia pine
   - 1/3 Black locust
   - 1/3 Green ash

Total 681 trees per acre, 8' x 8' spacing.

	Number planted	Cost per seedling	Cost per acre
		---------- $	----------
Virginia pine (Pt)	227	0.25	56.75
Black locust	227	.20	45.40
Green ash	227	.25	56.75
Planting contract	681	.10	68.10
Total			227.00

2. Current Forest Service planting including oaks with tree shelters:
   - 1/3 Virginia pine (Pt) - 8' x 8' spacing
   - 1/3 Black locust - 8' x 8' spacing
   - 1/3 Green ash - 8' x 8' spacing
   - 50 Oaks per acre with tree shelters - 30' x 30' spacing

Total 681 trees per acre

	Number planted	Cost per seedling	Cost per acre
		---------- $	----------
Virginia pine (Pt)	211	0.25	52.75
Black locust	210	.20	42.00
Green ash	210	.25	52.50
Oak	50	.30	15.00
Planting contract	681	.10	68.10
Tree shelters	50	1.85	92.50
Wooden stakes	50	.25	12.50
Placement of shelters	50	.40	20.00
Total			355.35

Tree seedlings from Ohio DNR, Division of Forestry
Tree shelters from Treessentials, order of 1040 or more
Ripping cost was $175 per acre

A Comparison of Four Tree Shelter Systems Using Planted Seedlings and Direct Seeded Acorns of Northern Red Oak at Three Sites in Pennsylvania[1]

J.K. Bailey, J.J. Zaczek and K.C. Steiner[2]

Abstract. The slow initial height growth of planted northern red oak (*Quercus rubra* L.) is frequently cited as the principal obstacle to artificial regeneration of this species. The tree shelter system, a technology that was developed in England in the late 1970s, has been reported to stimulate height growth of hardwood tree seedlings including oak. In an attempt to evaluate in more detail the practical advantages of tree shelters for improving planting performance of red oak, three planting trials were established in May 1991. Planting treatments were a factorial combination of two planting stock types (2-0 northern red oak seedlings and direct seeded red oak acorns) and four tree shelter types (two commercial designs-Tubex and Tree Pro, and two prototype designs-PVC and paper) and an unsheltered control. All planting trials were established in recent clearcuts. Competing vegetation at all sites was controlled by 2% glyphosate for the first two years, and electrical fences were erected to reduce the likelihood of browsing of unprotected seedlings by white-tail deer at all planting sites. Significant differences ($P<.05$) were detected among the ten planting stock-shelter treatment combinations at all planting sites. Orthogonal contrasts were used to compare fourth-year mean heights among treatments. After four growing seasons, 2-0 seedlings protected by commercial tree shelters consistently had the tallest average heights across all three planting sites; average heights of the sheltered seedlings ranged from 8.9 to 5.3 ft. Height advantages of 2-0 seedlings protected by commercial shelters over unsheltered 2-0 seedlings and across all planting sites ranged form 3.2 to 0.9 ft. Fourth-year heights of direct seeded stock protected by commercial tree shelters were comparable to fourth-year heights of unsheltered 2-0 seedlings at all planting sites. Fourth-year heights of direct seeded and 2-0 planted stock protected by commercial shelters were significantly taller than similar planting stock types protected by prototype shelters at all planting sites. Direct seeded and 2-0 planted seedlings protected by Tree Pro shelters were slightly taller as compared to similar stock protected by Tubex. Only at the site where late spring frosts were frequent was survival of 2-0 seedlings improved by tree shelters. However, across all sites, commercial tree shelters substantially improved the survival of direct seeded stock. The commercial tree sheltered 2-0 planting stock after four years had the highest percentage of self-supporting trees ranging from 100% to 53%.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Forest Geneticist, Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, Harrisburg, PA; Research Assistant and Professor, School of Forest Resources, Pennsylvania State University, University Park, PA.

Preliminary Results of a Tree Shelter Durability Study[1]

Mark Knaebe[2]

Abstract. Tree shelters used to provide protection and create a micro climate for the first few years of a tree were tested for their weathering characteristics at the USDA Forest Products Lab in Madison Wisconsin. Tree shelters from 5 companies and a "home made" paper based shelter were exposed vertically (normal) and at 45 degrees. Ideally, shelters are sturdy for 5 years and then self destruct. After 3 years most of the shelters were in excellent shape with some hints of future self destruction. From the beginning, one style proved unsatisfactory (a bag over bamboo supports) at our full exposure (high wind) test site. A few problems were noted with other shelters but on the whole, the question becomes will the shelters self destruct at the appropriate time?

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] USDA Forest Service, Forest Products Laboratory, Madison, WI.

Tree Shelters in a Landscape Nursery[1]

Robert Witmer and Henry Gerhold[2]

Abstract. Seven species or cultivars of landscape trees were planted in brown TUBEX Treeshelters approximately 5' long and 3.1" in diameter. Bare-root or potted stock was planted May 10 and 11, 1994 at Root's Nursery, Manheim, Pennsylvania in tilled soil free of other vegetation. At the end of the first growing season the height growth of Cercis canadensis, Cornus galaxy, and Magnolia stellata was promoted substantially compared to open-grown controls. Little or no stimulation was detected for Acer griseum, Magnolia Merrill, Malus Adirondack, or Syringa Summer Snow. Height growth, branching, and pruning requirements will be evaluated in the next two years to determine the practicality of using tree shelters in a nursery.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] School of Forest Resources, Pennsylvania State University, University Park, PA.

Direct Seeding Using Tree Shelters[1]

Larry R. Severeid[2]

Abstract. For years, we have gathered nuts from superior trees to plant in our nursery. Tree shelters were designed to protect seedlings from predators, primarily deer and rodents. It seemed obvious that shelters would afford the same protection to planted seeds and solve the biggest problem with direct seeding—seed predation. When shelters were introduced, we began experimenting with them for direct seeding. We have used tree shelters for planting walnut, oak and American chestnut seeds.

Our first consideration was cost, would it be practical to use tree shelters? The Tubex Company, now Treessentials, had tree shelters in lengths of 6 inches, and 2 and 4 feet. We tried all three. The 6 inch tube had no stake and provided no significant protection. Squirrels reached down into the tubes for the nuts, and skunks and turkeys knocked them over in order to get the seeds. The 6 inch tube was abandoned.

The 2 and 4 foot tubes have been very effective in preventing seed predation. Once the germinating nuts become seedlings, they are afforded all the benefits planted seedlings get from tree shelters. They protect germinating seeds and allow for safe and easy weed control. The protective environment of the tube also reduces water loss and prevents wind damage.

We prefer the 2 foot tall shelters. They are less expensive than the 4 foot shelters and can be used a second and even third time. With walnuts, the tube can be removed after the second year; generally walnut will emerge from the 2 foot tube by the end of he first growing season. Once the leaves are out of the tube, the tree is exposed to wind and vertical growth is reduced in favor of stem growth and stability. We always leave the tube in place during the winter as protection from rodents. Dieback has not been a problem with the 2 foot tubes.

The 4 foot shelters work fine but can only be used once. Also, dieback the first year can be a problem in the 4 foot tubes, probably because the stems are too thin and the trees do not harden off if the leaves do not emerge from the tubes. However, in areas where deer browsing is severe, the 4 foot shelters are necessary; deer relish oak buds and sprouting leaves.

We have tried a new type tree shelter, and it has great potential. The "Tree Shepherd" is cone shaped with a 8 inch diameter base. It comes in two 1 foot sections that join, if desired. It has three 8 inch prongs at the base that are easily driven into the ground. These prongs are studier, more reliable and more convenient than a wooden stake. However, because of the relatively wide base, on hillsides one must contour a flat surface so the shelter is vertical and makes a good seal with the soil.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
[2] Woodland Owner, La Crosse, WI.

Effects of Two Types of Tree Shelters on Artificial Regeneration of Northern Red Oak in Northern Wisconsin[1]

Ron Teclaw and John Zasada[2]

Abstract. A study of the effects of overstory density and understory vegetation control on the establishment and early growth of northern red oak regeneration was established in 1989 on a mesic, nutrient rich, mixed hardwood site in northern Wisconsin. One objective, was to test the effects of tree shelters on tree growth. The study is conducted under four different overstory canopy densities each 8 ha (20 acre) in size including 50%, 75%, 100% crown cover and a clearcut (CC). The understory vegetation was controlled in the clearcut and in the 50% and 75% crown cover blocks according to a factorial design of spraying glyphosate (3 qts/A) and disking in strips. Four hundred, 1-0 bareroot and 128, 1-year containerized seedlings were planted at 2.4 x 2.4 m (8 x 8 ft) spacings in each overstory block. Four-foot tall tan-colored Tubex shelters (average diameter approximately 3.75 inches) and four-foot tall by 8-inch diameter clear fiberglass shelters were installed on 32 of each type of seedling in each overstory block. Seedling survival and growth after five growing seasons is reported in this abstract.

After 3 years, seedling mortality was 100% for containerized seedlings in fiberglass shelters and for both types of seedlings in tubex shelters in the 100% crown cover block. Survival was less than 40% for bareroot seedlings in fiberglass shelters after five growing seasons, and height growth was actually negative for all seedlings, both sheltered and unsheltered. After five growing seasons, unsheltered bareroot seedling survival was 66% in the clearcut and 96% in the 50% and 75% blocks. Non-sheltered containerized seedling survival was 58% in the clearcut, 59% in the 75% crown cover and 75% in the 50% crown cover blocks. Survival of bareroot seedlings in Tubex shelters was 59%, 61%, and 91% in the clearcut, 75% and 50% crown cover blocks respectively; survival for containerized seedlings in Tubex shelters was 56%, 25%, and 59% in clearcut, 75% and 50% blocks. Bareroot seedling survival in fiberglass shelters was 47% (clearcut), 84% (50%) and 97% (75%). Survival for containerized seedlings in fiberglass shelters was 81%, 90% and 91% for the respective overstory blocks.

Seedling height growth after 5 years was best in the 50% block, where growth in fiberglass shelters was 97 cm and 75 cm for containerized and bareroot seedlings respectively. Growth in Tubex shelters was 73 cm and 42 cm for bareroot and containerized seedlings respectively. Unsheltered bareroot and containerized seedlings grew 61 cm and 43 cm respectively. Height growth in the 75% crown cover block for unsheltered seedlings was 15 cm and 19 cm for bareroot and containerized seedlings respectively. Both bareroot and containerized seedlings grew an average 17 cm in fiberglass shelters, and average growth was -1 cm and 6 cm for bareroot and containerized seedlings in Tubex shelters. Overall, seedling performance with and without tree shelters was poor in the clearcut, where the best 5-year height growth was 25 cm for the bareroot seedlings in fiberglass shelters; growth was actually negative in Tubex shelters. The greatest growth differential between sheltered and unsheltered seedlings was in the 50% block where height growth was 54 cm greater fiberglass shelters, however there was no growth differential for containerized seedlings in Tubex shelters. Bareroot seedlings grew 14 and 12 cm more in fiberglass and Tubex shelters respectively than did unsheltered seedlings. In the 75% block, height growth of unsheltered seedlings was about the same as that in fiberglass shelters and much greater than in Tubex shelters. We believe the poorer growth in Tubex shelters is attributable to reduced light intensity and quality in the darker shelters. This hypothesis needs to be verified with additional studies.

Tree shelters did not provide any benefit to seedlings in the clearcut. The main factor affecting growth in the clearcut was freezing temperatures in late spring and early summer. During the 5 years of the study, subfreezing temperatures occurred in every growing season; the lowest temperature was -10°C. Temperatures in shelters can be much warmer on clear sunny days, but shelters provide no protection from frost events at night.

[1] Abstract of presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
[2] Biologist and Research Forester, USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI.

Tree Shelter Use on National Forests in the Northeast[1]

Robert R. Burt[2]

Abstract. Use of tree shelters to meet a number of objectives has been evaluated on national forests in the Northeast. Evaluations have been conducted because of concerns about insect and disease damage in tree shelters, and to assess the use of shelters for direct seeding of acorns and for reintroducing species in riparian areas.

Surveys were conducted by health protection specialists from State and Private Forestry to determine damage from defoliating insects and foliage diseases in tree shelters. These surveys were conducted between May and August on both the Green Mountain (Vermont) and Finger Lakes (New York) National Forests. The excellent growing conditions that promote tree growth inside shelters also benefit developing soil-borne insects and stem and leaf diseases. However, tree shelters may offer an environmentally friendly way to suppress gypsy moths.

In cooperation with a vocational education program in Addison County Vermont, personnel of the Green Mountain National Forest planted germinated acorns in tree shelters. At the end of the first growing season, 70 to 90 percent of the acorns survived and grew to an average of 6 to 8 inches in height.

Tree shelters are being used with an oak planting along the White River Travelway on the Green Mountain National Forest. The objective of the planting is to provide streamside shading and reintroduce oak in this riparian ecosystem. The long-term plan is for these trees to eventually become large woody debris to benefit Atlantic salmon, which are also being reintroduced.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

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Growth of Red Oak Seedlings in Tree Shelters Inside the Greenhouse[1]

William E. Sharpe, Bryan R. Swistock and Kelly A. Mecum[2]

Abstract. Tubular plastic tree shelters have come into wide use in the last few years. They have been reported to enhance tree seedling growth by creating a "mini-greenhouse" around the sheltered seedling. Increased height growth of sheltered tree seedlings has been attributed to this "greenhouse" effect. In order to test the hypothesis that tubular plastic tree shelters enhanced tree seedling growth, we compared the growth of potted red oak seedlings in two types of shelters to a control group of unsheltered red oak seedlings. The experiment was arranged in a randomized block design with 4 blocks x 3 treatments x 5 seedlings per treatment within each block for a total of 60 seedlings. Five foot long clear acrylic and brown shelters, 4 inches in diameter, were used to shelter the red oak seedlings. Water and light were not limited and air temperature ranged between 48 and 91°F. Height growth of red oak seedlings in the control and clear tree shelter groups was significantly greater than the brown plastic shelters. Root mass was significantly greater for the control red oak seedlings indicating that sheltered seedlings may allocate more resources to stem elongation at the expense of root development. Clear tree shelters transmitted almost twice as much photosynthetically active radiation as brown plastic shelters. Red oak seedling growth was greater in the clear shelters when compared to brown shelters. The lack of a large height growth advantage for shelter-grown seedlings and their reduced root mass may indicate that enhanced height growth of field-grown red oak seedlings was in part attributable to a thigmotropic response to the physical support provided by the tree shelter. These results indicate that the reported advantages to seedling growth from tree shelters require further evaluation.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] School of Forest Resources, Pennsylvania State University, University Park, PA.

Plastic Tubes and Tree Improvement—Eight Years Experience Tree Shelters on Grafted Black Walnut and Northern Red Oak[1]

Lawrence K. Miller[2]

Abstract. White-tailed deer populations in Minnesota have been increasing steadily sir early 1980s, placing heavy browse pressure on planted seedlings of most species. The considerable investment in selecting plus trees, collecting scion material, producing gra planting seed orchards, and managing these sites are seriously threatened without pro from deer browsing. Individual grafted stock are worth $5 to $15 each before planting; hundreds more in management costs before the orchard produces seed. Tree shelters been used on black walnut grafted stock in Minnesota since 1988, and on red oak sinc 1991. Tree shelters clearly are effective in protecting grafted stock from deer browsing Growth responses have been variable, and dieback is particular on walnut. Dieback is related to the date when the new growth emerges from the top of the shelter. If the ne growth emerges after the end of July, varying degrees of dieback can be expected. Tr that emerge prior to the end of July suffer little damage. This response has led to the u shorter tree shelters on newly planted grafts, replacing with taller tubes as the trees gr Observations and other experiences with tree shelters on grafted stock in Minnesota v also discussed.

[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22

[2] Tree Improvement Specialist, Minnesota Department of Natural Resources, Division o Forestry, Willow River, MN.

Effects of Tree Shelters on Initial Growth of Bottomland Hardwood Seedlings[1]

Wayne K. Clatterbuck[2]

Abstract. Bottomland hardwood species were planted with and without tree shelters during the 1991-1992 planting season to determine the effect of tree shelters on early seedling survival, growth, and development. Two separate bottomland sites were planted: a cultivated agricultural field (Site A) and a recently harvested forest stand (Site B). Six species were evaluated on Site A (northern red oak, cherrybark oak, yellow-poplar, black walnut, green ash, and common persimmon), while the only species planted on Site B was cherrybark oak. Four foot, Tubex-brand tree shelters were used. Competing vegetation was not treated on Site B: one-directional mowing once during each growing season was used on Site A.

Preliminary results after two growing seasons indicate that the sheltered seedlings exhibited significantly greater height growth as compared to the controls regardless of species or site. There was no significant difference in survival rates. Most sheltered seedlings of all species had emerged from the tubes after two years and averaged at least twice the height of those without shelters.

Tree shelters show promise for increasing the competitiveness of slower growing, desirable species on productive bottomland sites. However, it is not known whether this height differentiation between sheltered seedlings and the controls will continue after seedlings emerge from the shelters. This ongoing study will continue to monitor the long-term effects of shelters on tree growth, development, and ability to compete with adjacent vegetation. Guidelines for the use of tree shelters and an economic analysis are also presented.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.
[2] Tennessee Division of Forestry, Nashville, TN.

Tree Shelters and Weed Control Aid Establishment of Tree Seedlings in Central Texas[1]

Brad L. Barber[2]

Two studies were initiated in central Texas to provide information on increasing performance of outplanted containerized tree seedlings in central Texas. Factorial treatment designs were used to test tree shelters (Tree Sentry®, Tubex®, or none) and weed control (with or without Roundup®) on 5 native tree species (Shumard oak, live oak, chinkapin oak, bur oak, cedar elm, and baldcypress). First-year survival and growth were increased by weed control. Survival, height growth, and diameter growth were also increased with use of tree shelters with the exception of diameter growth in one study where seedlings outplanted without shelters were larger in diameter at the end of one growing season.

[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Staff Forester, Texas Forest Service, College Station, TX.

Tree Shelters Overcome Initial Establishment Problems for Containerized Seedlings of *Paulownia tomentosa* Over a Wide Range of Planting Conditions[1]

Jeffrey W. Stringer[2]

Abstract. First year growth and survival of *Paulownia tomentosa* containerized seedlings (<10 cm height) and root cuttings established with and without tree shelters were monitored on five sites in eastern Kentucky. Results showed that tree shelters were critical for the initial survival on 3 surface mined sites, an alluvial bottom, and a hardwood seedling nursery bed site. Shelters were used in a split-plot design with other cultural treatments including, hardwood bark mulch, soil amendment, combined mulch/amendment treatment, and a control. Sites were composed of a complete randomized split-plot design, with 3 replicate blocks per site. Cultural treatment plots within a block contained 8 seedlings planted on a 1 x 1 meter spacing. Each treatment plot was split and 4 seedlings received a 12" Tubex® shelter. Stock was planted in May and mortality and height measures taken monthly throughout the growing season.

Data pooled over all sampling sites showed significant ($p<0.01$) increase in survival percent of sheltered versus non-sheltered containerized seedlings for all cultural treatments (except the control), averaging 80% and 40%, respectively. One month after outplanting, heights were significantly greater ($p<0.01$) for sheltered seedlings compared to non-sheltered seedlings for all cultural treatments including the control. Sheltered seedlings averaged 35 cm while non-sheltered seedlings averaged 20 cm. Sheltered seedlings established in the nursery bed averaged 150 cm in height and were significantly taller than unsheltered seedlings averaging 70 cm. Survival was 100 percent for sheltered seedlings and 35 percent for unsheltered seedlings in the nursery bed. Tree shelters had no effect on survival or height growth of sprouts from root cuttings.

Within one to two weeks after planting the seedlings on all sites emerged from the top of the shelters and no seedling losses occurred after this phase. This indicates that tree shelters can be used to overcome initial establishment problems encountered by this species over a wide range of sites.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

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Protection of White Pine Seedlings from Deer Browsing Using Tree Shelters[1]

Jeffrey S. Ward and George R. Stephens[2]

Abstract. Browsing by large deer herds has seriously impaired successful regeneration on some Connecticut forests. A study was established in 1990 to examine the effectiveness of tree shelters for preventing deer browse and increasing height growth of eastern white pine (*Pinus strobus*) 2-2 transplants. Seedling height (cm), root length (cm), and root collar diameter (mm) were measured prior to planting. Seedlings were stratified into 10 block of 30 seedlings by root collar diameter. Ten seedlings of each block were randomly assigned to one of 3 treatments: 120 and 180 cm (4 and 6 ft) Tubex tree shelters, and unprotected controls. At the end of each growing season seedling height (cm) was measured and presence of distorted growth was noted. Quarterly measurements included terminal bud browse, lateral bud browse, and top dieback.

Seedlings protected by tree shelters were significantly taller than unprotected seedlings after 5 growing seasons ($F=5.023$, $p\leq0.007$). However, the difference was small: 180 cm tree shelters (210 cm tall), 120 cm tree shelters (196 cm tall), and unprotected (190 cm tall). There was no significant difference among treatments when only unbrowsed seedlings were included ($F=1.827$, $p\leq0.126$). The terminal bud of 67% of unprotected seedlings was browsed at least once compared with only 5% for seedlings protected by tree shelters. Lateral buds were browsed on 87% of unprotected seedlings, compared with 37% and 2% for seedlings protected by 120 and 180 cm tree shelters, respectively. Unprotected seedlings had lower rates of top growth distortion (2%) and higher rates of top dieback (40%) than 120 cm (20% and 17%) and 180 cm treeshelters (11% and 15%). Mortality was much higher for seedlings protected by tree shelters (22%) than for unprotected seedlings (6%). The resource manager needs to balance the decreased browsing and marginal height growth increase afforded eastern white pine seedlings by protecting with tree shelters against the cost and increased mortality.

Acknowledgments: A special thanks to Northeast Utilities and Ferrucci and Walicki, LLC who donated the land, materials, and manpower that made this research possible. This research was partly funded by McIntire-Stennis Project No. CONH-541.

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[1] Abstract of a presentation at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Department of Forestry and Horticulture, Connecticut Agriculture Experiment Station, University of Connecticut, New Haven, CT.

Pros and Cons for Tree Planters: Summary Comments of the 1995 Tree Shelter Conference[1]

Clyde Hunt[2]

What are Tree Shelters?

Tree shelters are rigid tubes, typically of corrugated plastics, that create extended growing conditions much like a cold frame. Young seedlings are forced to grow straight up, through protected space to the open end of the tube. Most tubes are from 12 to 48 inches in height and 4 to 5 inches in diameter. The tubes are attached to a vertical stake. These tubes may or may not degrade before the seedlings emerge and are ready to become self-supporting.

What are Some of the Advantages and Disadvantages of Using Tree Shelters?

A brief historical review by keynote speaker Gary Kerr of the (British) Forestry Commission summarized the potential advantages of tree shelters:

1. Enhanced early growth.
2. Protection from animal, mechanical and/or herbicide damage.
3. Assistance in relocating seedlings in meadows or among weed competition.
4. Reduced competitive effects from nearby vegetation.

These advantages were confirmed by those attending the conference. They also noted that some makes of shelters performed better than others and that plant response varied with handling, site, species, and climate. Furthermore, the participants discussed some of the problems experienced with tree shelters, including:

❖ Taller stems are often weak and unable to stand upright as they emerge from the tube shelters.

❖ Stakes may be too short to keep both tube and tree upright or may rot before the tree can stand alone.

❖ Rodents may gnaw through the tube base. Birds and wasps are attracted to the open top. Vandals may damage the tubes, but the seedlings may escape harm.

❖ Planters often plant too many seedlings, use too many tubes or insist on planting in perfectly straight lines rather than just plant better locations.

❖ Weed control may not remain effective until trees are established. Tubes alone do not protect trees from competition.

❖ Although tubes can be formulated to break down, they rarely deteriorate before trees need to break out or escape.

❖ Planters must choose appropriate tube lengths. Long tubes may discourage frequent checking of seedling growth. Short tubes may not offer adequate protection.

❖ Seedlings planted in tree shelters on floodplains or floodways may be the first to be washed away.

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[1] Summary of presentations and discussion at the Tree Shelter Conference, Harrisburg, PA, June 20-22, 1995.

[2] Urban Forester (retired), USDA Forest Service, Northeastern Area State and Private Forestry, Radnor, PA.

What are Some Research Results from Experiments with Tree Shelters?

The following comments offer a glimpse into some of the research findings reported at the conference:

- Jonathan Kays:[3]
  - Consider other options to reduce deer browsing which may prove less costly than tube shelters, such as electric fencing and deer repellents.
  - Bird netting can deform terminal growth and discourage apical dominance.
  - Continued need to maintain hardwood seedlings adds to establishment costs.
  - We need to learn more about both deer and seedlings.

- Sylvia Strobl:
  - Some seedlings survived better without tree shelters, especially in clay soils when frost heaves tree shelters.
  - Except for damage by voles, there was little survival difference between sheltered and unsheltered seedlings (voles preferred shelters).
  - Tree shelters on some sites may decrease the need for weed control.

- Felix Ponder:
  - Biomass and foliar analyses demonstrated a re-allocation of photosynthates to the stems (from the roots) of trees in shelters.
  - Higher potassium levels were found in the roots of controls than found in the roots of sheltered trees.

- Douglas Lantangne: An older study (with and without brush control) demonstrated that generally:
  - The first flush of growth in the shelters is the greatest.
  - There is a reduction of height growth after the seedling exits the tube.
  - If competing brush were present in proximity to the seedlings they first demonstrated increased height growth before slowing or falling behind.
  - Some species, such as red oaks, cannot long sustain years of rapid height growth against more rapidly growing species. We need to seek out individual that genetically can maintain more rapid height growth rates.

- Jim Bailey:
  - You get what you pay for! Sound stakes are critical to planting success. In the end what counts are self-supporting saplings!
  - The best individual will become dominant. In this respect six acorns are better than three acorns! You need <u>not</u> always start with seedlings.

- Richard Shultz:
  - Be as specific as you can when spelling out your objectives.
  - The quality of your nursery stock is the real indicator of value. This may be judged largely by the number and size of seedling roots.
  - Undercutting the roots of seedling red oaks after the third flush of growth during the first growing season or after the first flush of growth during the second year, should result in the best quality nursery stock.

- Philip Perry:
  - The best survival and height growth on former mine spoils resulted when sheltered tree seedlings were planted into ripped or deep-plowed furrows. These differences were not immediately apparent, however they developed over four growing seasons. One way to improve results would be to plant pioneer species on such sites.
  - The need for better stakes was brought out during discussion of this paper. One suggestion, from an experienced Pennsylvania spoilbank pioneer, was to use iron reinforcing rods.

These comments are but a brief overview of the valuable information presented during the conference. The full texts of these and other papers are included in these proceedings.

[3] For full list of names and addresses of participants, see list in appendix.

Appendix

List of Tree Shelter Distributors

Quadra Tree Shelters
3825 Highridge Road
Madison, WI 53704
Contact: Albert F. Kubiske
608-837-9093

Tree House Treeshelters
American Forestry Technology, Inc.
1000 North, 500 West
West Lafayette, IN 47906
Contact: Richard Bailey
317-583-3311
FAX: 317-583-3318

Tree Ssentials
Riverview Station
PO Box 7097
St. Paul, MN 55107
Contact: Paul Klocko or Kevin Sturgeleski
800-248-8239
FAX: 612-228-0554

Tree Pro-Tree Protectors
445 Lourdes Lane
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3699 Wentworth Lane
Lilburn, GA 30247
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404-923-1681

Tree Sentry and Tree Pee
PO Box 607
Perrysburg, OH 43552
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419-874-1159
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International Reforestation Suppliers
PO Box 5547
2100 Broadway
Eugene, OR 97405
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