United States Department of Agriculture

Forest Service

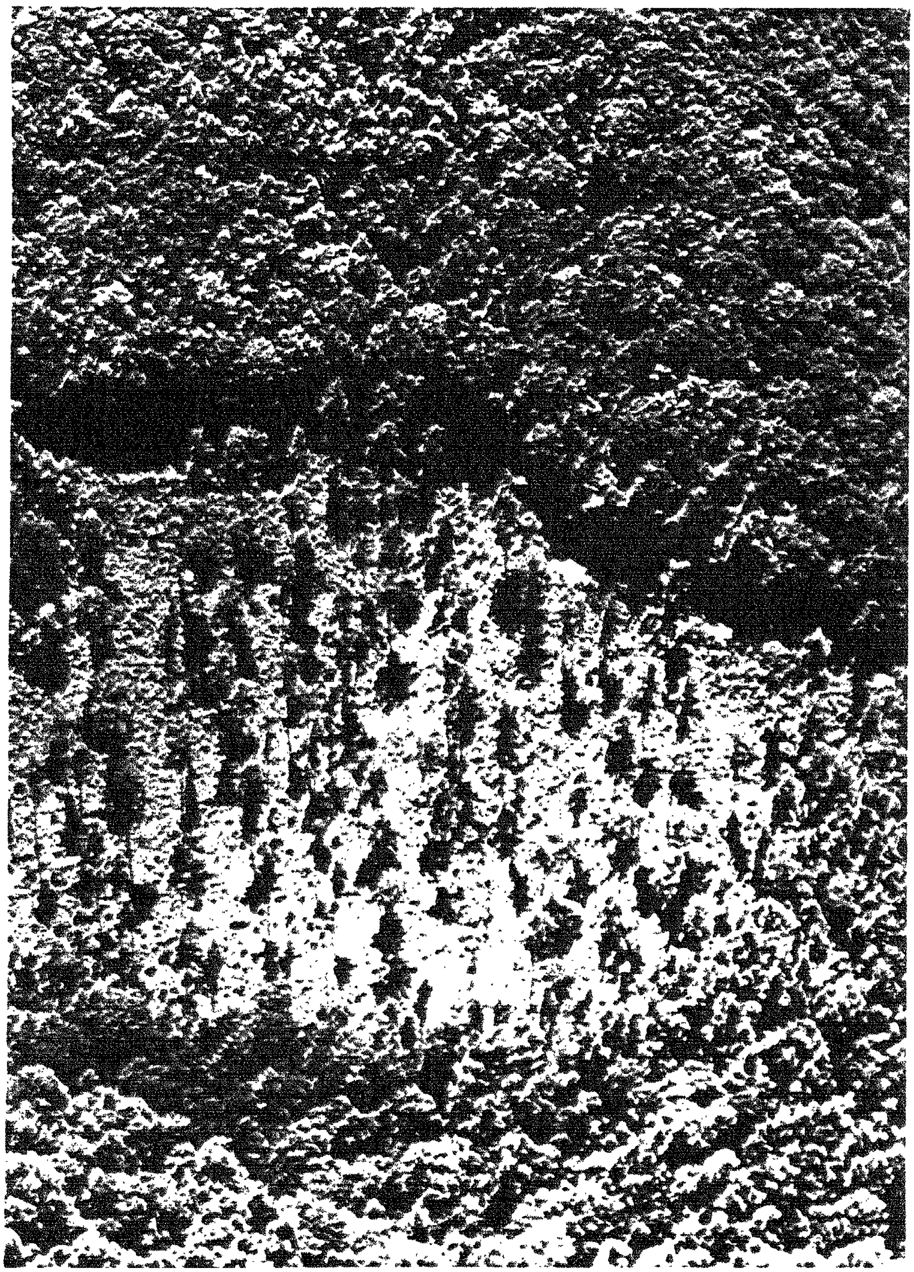
Northeastern Forest Experiment Station

General Technical Report NE-197

Proceedings

10th Central Hardwood Forest Conference

Morgantown, West Virginia March 5-8, 1995



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ACKNOWLEDGMENTS

The editors would like to acknowledge and thank all of the people who served as manuscript reviewers for the Proceedings. The quality of the Proceedings has been improved due to your efforts. We would like to thank Becky Rosenberger for her assistance in typing the program, preparation of the table of contents, typing abstracts, proofreading, and in managing the manuscripts, reviews, and letters associated with the Proceedings. We thank Gary Miller for providing the cover photograph.

Cover Photo: This 1984 aerial photograph was taken from a helicopter three years after deferment cutting in 80-year-old central Appalachian hardwoods on the Fernow Experimental Forest near Parsons, West Virginia. (Photo by James N. Kochenderfer, USDA Forest Service.)

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March 1995

10TH CENTRAL HARDWOOD FOREST CONFERENCE

Proceedings of a Meeting

Held at

Lakeview Resort and Conference Center

Morgantown, WV

March 5-8, 1995

Edited by

Kurt W. Gottschalk and Sandra L. C. Fosbroke

SPONSORED BY:

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FOREWORD

This conference is the tenth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, University of Tennessee, Southern Illinois University with the North Central Forest Experiment Station (NCFES), Pennsylvania State University with the Northeastern Forest Experiment Station, and Purdue University with NCFES. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the biology and management of central hardwoods by forest scientists from throughout the Central Hardwood Region of the eastern United States. As with previous Proceedings, a wide range of topics that represent the broad array of research programs in this area is represented.

The social and biological characteristics of the Central Hardwood Region make it unique in comparison with other forest regions of the United States. For example, one-fourth of the United States human population resides in this region. Approximately 90% of the land is in private ownership and public lands tend to be small and fragmented with private inholdings. These and related conditions play critical roles in the practice of forestry in this region. The information presented in this Proceedings is important to the long-term management of the forest resources of this unique region.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two (usually three) scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and content of their papers.

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POSTER SESSION

AUTUMN PREDATION OF NORTHERN RED OAK SEED CROPS

Kim C. Steiner[1]

Abstract: Production and autumn predation of northern red oak acorns was measured over four years in five Pennsylvania stands dominated by this species. Mean annual production was 41,779/acre, of which an average of 7.9% was destroyed by insects or decay following insect attack, and an average of 38.6% was destroyed or removed by vertebrates. White-tailed deer appeared to be the dominant vertebrate consumer of acorns.

INTRODUCTION

Numerous factors contribute to the well-known difficulty of regenerating northern red oak (*Quercus rubra* L.) (Crow 1988), but the frequent lack of seedlings even after good seed crops (Steiner and others 1993) suggests that acorn predation may be a particularly important limitation. Unfortunately, northern red oak's heavily provisioned seed, which plays such a large role in the post-germination growth patterns and ecological response of the species (Kolb and Steiner 1990, Kolb and others 1990), is also an extremely attractive food source for granivorous vertebrates and insects. Losses to seed predators are usually large (Beck 1993).

Despite a fairly large body of literature on the production and loss of northern red oak (NRO) acorns, there is still uncertainty about the relative importance of various acorn consumers because of conflicting results and inconsistent methodology. Many published studies have been based upon inadequate samples of trees, stands, or years (*e.g.*, Korstian 1927), all of which are now known to be large sources of variation not only in acorn yield but also in the relative importance of various sources of acorn loss (Olson and Boyce 1971). In other studies, there has been no accounting of acorns lost entirely from the site, creating an underestimate for some agents of loss and an overestimate of others. This appears to have been the case in the classic and otherwise excellent study by Downs and McQuilkin (1944). In others, the use of acorn traps without parallel counts of loss from ground plots has undoubtedly resulted in underestimates of loss to ground-feeding vertebrates (Christisen and Korschgen 1955). Also, in many studies, rates of predation by insects have been reported on the basis of acorns collected (presumably after some predation by vertebrates) rather than on the basis of total production, and no distinction has been made between insect infestation and failure to germinate because of insect attack. Finally, it is not always clear in published reports whether several-year average losses to predation are means of annual percentages, which give undue weight to the very high proportion of predation in years when acorn production is very low, or represent cumulative loss to various agents as expressed on an annual basis. This study of production and autumn predation of seed crops in NRO in five stands over a four-year period was undertaken to clarify our understanding of this portion of the regeneration process, specifically the fate of fully developed acorns during the months of autumn.

METHODS

The study was performed in five forest stands located over a broad portion of central Pennsylvania, two in the Ridge and Valley region and three on the Allegheny Plateau. Northern red oak was the dominant species in the overstory of each stand, with a mean of 49.3% (range 39.8 to 67.8) of stand basal area. Other common species were *Acer rubrum*

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(mean = 24.8%) and other oaks (15.2%), including *Q. alba*, *Q. prinus*, *Q. velutina*, and *Q. coccinea*. At the beginning of the study, stand mean ages of dominant and codominant NRO ranged from 70 to 123 years. More information on the characteristics of these stands may be found in Steiner and others (1993).

At each research site, a study area of 3.5 to 4.3 acres in size was delineated in October 1990 by marking corner trees. In November of each year from 1990 through 1993, the size of the NRO seed crop was determined by the cap-count method (Shaw 1974) performed in 4.31-ft^2 (0.40 m^2) ground plots. At each study site, approximately 75 quadrats were located at fixed intervals on equally spaced transects that covered the entire study area. Although most caps had fallen by the time counts were made, usually in the second or third week of November, a small number of unfallen caps sometimes remained in the tree crowns. The density of these was estimated by surveying an estimated 10-foot square portion of the canopy directly above each quadrat with binoculars, and ground counts were revised upward as needed. Depending upon year and site, unfallen caps amounted to 0 - 11% of total production. In addition to detached acorn caps, the number of fresh acorns was counted, omitting those that remained firmly attached to their caps, which were typically undersized and considered to have been aborted before full maturity. Fresh acorns were tallied by two categories: 1) intact or 2) partially consumed (by small rodents) at the proximal end of the nut. Acorns with <30% of cotyledons removed were assumed to be viable, subject to germination tests; those with >30% consumed were tallied as having been lost to vertebrate (rodent) predation. Coefficients of variation for acorn and cap counts averaged 12.8% of stand/year means.

Each fresh, detached acorn cap was assumed to represent a viable acorn, excluding losses to vertebrate and insect predation. Differences between counts of caps and counts of fresh acorns were attributed to predation by vertebrates feeding on the ground or in tree tops prior to the November measurements. At the time of production counts in November, samples of fresh acorns were collected from each site for viability analysis. Except where no fresh acorns could be found, sample sizes ranged from as few as 18 to as many as 897, with an average of 170. Sample sizes of fewer than 100 acorns represented *all* the acorns that could be found on the site. Acorns were collected without regard to any external evidence of injury, including insect infestation. Acorn samples were fully hydrated and stored at -1.0°C until February, when they were planted in flats of moist peat moss in the greenhouse for determination of viability. In April or May, after germination had ceased, nongerminants were cut open and classed by apparent cause of death. Germination failure averaged 44.0% in acorns that had been partially consumed by rodents, and this loss was attributed to vertebrate predation. All other germination failures were attributable directly or indirectly to insects (decaying acorns were assumed to have become infected through insect attack [Oak 1993]), and this was the basis for estimated acorn losses to insect predation. Insect-infested acorns that successfully produced a seedling were not counted as lost to predators.

Signs of foraging by white-tailed deer (*Odocoileus virginianus*), especially in years of abundant acorn production, suggested that this species caused much of the loss to vertebrates. To estimate loss by deer *vs.* other vertebrates, a five-strand electrified fence was installed around two noncontiguous plots at one of the research sites on 17-18 August 1993, prior to acorn dissemination. Each plot enclosed about one-fourth of the total study area at the site, and two similar-sized plots were left unfenced. The four plots enclosed almost identical basal areas of NRO. In addition to the normal assessment of acorn production in November, the plots were remeasured five weeks later on 17 December to determine the progressive loss of acorns from fenced *vs.* unfenced plots. Where possible, the statistical significance of differences between means was determined by t-test, analysis of variance, or paired comparisons t-test.

RESULTS AND DISCUSSION

The NRO seed crop, based upon counts of fresh caps, varied from 540/acre to 198,510/acre among the four years of the study and all five stands. Mean annual NRO acorn production for all stands and years was 41,779/acre (Table 1), or 725 per ft^2 basal area of NRO. Every stand exceeded this level of production in at least one year of the four. Table 1 shows mean annual acorn production averaged across stands. The years 1991 and 1992 had relatively low production, and the years 1990 and 1993 had relatively high production. Although stands varied considerably in mean annual production, as shown in the following tabulation, only the main effect of years was statistically significant ($P < 0.05$) in analysis of variance for total production:

Stand number	Mean annual acorn production, 1990-93 (acorns/acre)
I	32,652
II	23,515
III	78,023
IV	55,200
V	19,505

The contribution of stand to variation in seed crop size was only 18% as large as the contribution of years, even though study sites were separated by as much as 66 miles. In simple terms, there was a tendency for good or poor seed crops to occur simultaneously at all sites. Downs and McQuilkin (1944) found the same result over a seven-year period of study in two stands separated by 100 miles.

Table 1. -- Production and autumn predation of northern red oak acorns from 1990 through 1993, averaged over five Pennsylvania stands. Means within a row that share the same letter are not significantly different at $P < 0.05$.

Year	Pre-November Vertebrate loss	Acorns present in November Nonviable	Viable	Total Production
1990	47,740 a	3,610 b	31,426 a	82,776
1991	9,284 a	1,488 b	1,454 b	12,226
1992	3,790 a	370 b	454 b	4,614
1993	3,626 c	7,780 b	56,094 a	67,500
Mean	16,110 a	3,312 b	22,357 a	41,779

Over all years and stands, the number of viable acorns remaining on the ground in November averaged 22,357/acre (Table 1), or 53.5% of mean annual production. Acorns that were not viable in November as a direct or indirect result of insect infestation averaged 7.9% of production. Of a total of 469 acorns that failed to germinate in viability trials, 66.3% had been attacked by *Curculio* spp. and 4.3% by *Callirhytis*. Most of the remainder were rotten, though a small percentage was infested with acorn moths. Rotten acorns were assumed to be decayed as a result of attack by insects, some of which could also have been *Curculio*. Thus, the percentage loss attributable to *Curculio* could be underestimated.

This study's mean loss of 7.9% of potential production to insects is considerably lower than the 24 - 35% insect infestation rates for NRO acorns reported in many long-term studies (Beck 1977, Downs and McQuilkin 1944, Tryon and Carvell 1962). This is due in part to the methodological discrepancies mentioned in the introduction, especially 1) the expression by others of insect infestation as a percentage of recovered acorns rather than total production and 2) the difference between occurrence of infestation and failure to germinate as a result of infestation. Walters and Auchmoody (1993) found that 53% of acorns attacked by *Curculio* spp. were able to germinate and produce seedlings. In addition, some acorns that had been infested with insects in the present study may have been consumed or cached by vertebrates and thus counted against that source of acorn loss. Linda Gribko (personal communication) found that *Peromyscus* spp. consumed weeviled acorns as readily as sound acorns in the study reported by Gribko and Hix (1993). In any event, it appears that the loss of potential NRO reproduction solely attributable to autumn-feeding insects may be considerably less than commonly supposed. Of course, insects may also contribute to losses at other stages of the reproduction process.

Autumn predation of the seed crop by vertebrates averaged 38.6% of production. Vertebrates were a significantly ($P < 0.05$) more important agent of acorn loss than insects for the four-year study period. Of course, some of the acorns that appeared to have been consumed by vertebrates before November may have been merely cached in a location suitable for germination. However, this fraction still represents a potential loss (most cached acorns are consumed), and in fact total autumn and winter losses to vertebrates (net of spring germination) have consistently exceeded 38.6% (Steiner, unpublished data). Downs and McQuilkin (1944) found an average of 24% of acorns damaged by rodents or birds *at the time of dissemination*. Subsequent predation by vertebrates from ground plots is not clearly described in their report, but in one bumper crop year only 18% of production (five oak species) remained on the ground by mid-winter. Tryon and Carvell (1962) found an average loss to arboreal and ground-feeding vertebrates of 50.2% over a four-year period of study.

Peromyscus leucopus (white-footed mouse) is a common small rodent at all five study sites (Yahner and Steiner, unpublished data). Some evidence suggests that this and a related species are important predators of NRO acorns (Gribko and Hix 1993). According to Verme (1956), *P. leucopus* typically consumes a portion of the cotyledons by feeding through a hole chewed in the cap end of the acorn. In this study, such partial feeding typically amounted to perhaps a little more than one-third of the cotyledons, leaving the embryo and most of the food reserves intact. In fact, Verme found that white-footed mice *always* consumed only a portion of NRO acorns, suggesting that partially consumed acorns may be an accurate measure of predation by this species (other than caching). Such acorns amounted to an average of only 3.9% of mean annual production in this study, and many of those were still capable of germination. This suggests relatively light predation by *Peromyscus*, although additional acorns may have been removed and cached or consumed in burrows or tree cavities. Other information also indicates that this species may have relatively minor importance as a seed predator. Verme (1956) reported an average consumption of 1.8 acorns/day when *Peromyscus leucopus* was fed a diet of only acorns. Using his assumed density of 7 mice/acre (which appears liberal in light of the census data reported by Jensen [1982] and Thorn and Tzilkowski [1991]), this species would have consumed less than 3% of the average annual acorn production in this study by the time production was measured in mid-November.

Other potentially important vertebrate predators that are known to be present at or near the study sites include gray squirrels (*Sciurus carolinensis*), eastern chipmunks (*Tamias striatus*), white-tailed deer, wild turkeys (*Meleagris gallopavo*), and black bears (*Ursus americanus*). The acorns of NRO are generally avoided by blue jays, which can be heavy predators on oaks with smaller acorns (Bossema 1979, Darley-Hill and Johnson 1981, Scarlett and Smith 1991). In 201 hours on site for the measurements reported here, there were 7 gray squirrels sighted, 8 eastern chipmunks, 3 white-tailed deer, and no wild turkeys or black bears. Despite the documented potential for heavy acorn removals by gray squirrels (Thorn and Tzilkowski 1991), population densities of this animal can be quite low (Healy 1988). From my own experience as a squirrel hunter, the infrequency with which squirrels and chipmunks were sighted in this study, despite a sometimes abundant source of food, is rather typical of deep-woods Pennsylvania stands such as these.

In contrast to small mammals, signs of deer foraging were abundant on the study plots, especially when acorn production was high. The study area that was partially fenced to exclude deer in August 1993 provided an estimate of the relative impact of deer foraging on the NRO seed crop. By mid-December, a significantly ($P < 0.05$) higher percentage of the total NRO seed crop of 45,920/acre remained on fenced plots (65.4%) compared to unfenced plots (32.3%).

Furthermore, some undetermined proportion of the acorns lost within fenced areas was also a result of deer feeding, based upon the presence within fenced areas of disturbed leaf litter, masticated pericarps, and droppings. In other words, some of the losses attributed to small vertebrates were actually caused by deer. These observations indicate that deer accounted for at least 48.9%, and probably more, of total removals by vertebrates by mid-December.

Downs and McQuilkin (1944) obtained a similar result in another study area with high deer densities (18 - 32 per square mile). They concluded that deer were far more important than rodents as predators of acorns. Pennsylvania deer densities are higher than this prior to hunting season in late November ($37/mi^2$ in 1992 according to a personal communication from William Palmer, Pennsylvania Game Commission), but it is impossible to draw direct a direct comparison without knowing the basis for estimating density. Indirect evidence also suggests that deer are more important consumers of acorns than other vertebrates known to feed heavily on acorns, at least in Pennsylvania. Pennsylvania Game Commission estimates of population densities and animal weights indicate that mean deer biomass per forested acre is about 10 times that of gray squirrels and 60 times that of bear and turkeys (William Palmer and William Drake, personal communications). In Missouri, acorns made up 46% of the food consumed by deer during September, October, and November (Christisen and Korschgen 1955). Of course, feeding preferences vary among animals. However, the known tendency of deer to feed heavily on acorns, coupled with their overwhelming biomass abundance (in Pennsylvania) compared to other major consumers, suggests that they must necessarily have a disproportionate influence on acorn predation.

CONCLUSIONS

In five stands with a mean NRO stocking of 49% of total basal area, the annual production of mature acorns averaged 41,779/acre over a five-year period. Yearly variation in seed crop size was about five times as important as stand-to-stand differences. The number of viable acorns remaining on the ground in November averaged 53.5% of mean annual production. Of the 46.5% loss, only 7.9% was caused by insect attack or by fungal or bacterial infection following insect attack. This figure is less than other published figures for insect predation of NRO, which should be regarded as overestimates for reasons explained. The remaining 38.6% of acorn production was removed by vertebrates. In a stand that was partially fenced to exclude deer in 1993, deer predation accounted for a minimum of 48.9% of total acorn removals by vertebrates by mid-December. Other evidence supports a conclusion that deer were the dominant consumers of NRO acorns on these sites.

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PLANTING DEPTH EFFECTS AND WATER POTENTIAL EFFECTS ON OAK SEEDLING EMERGENCE AND ACORN GERMINATION

Wayne A. Smiles and Jeffrey O. Dawson[1]

Abstract: The effects of four planting depths (0, 3, 7, 11 cm) and acorn size on the percentage seedling emergence of red, pin, and black oak were determined. In a complimentary study, the effects of five water potential treatments (0, -.2, -.4, -.6, -1.0 MPa) on the percentage germination of red, pin, and black oak acorns were measured.

Percentage seedling emergence was greatest at 3 and 7 cm planting depths for all species. It was least at both the 0 cm planting depth for all species and the 11 cm planting depth for red and black oak. Percentage emergence was greater for larger acorns within a species, but pin oak, which had the smallest acorns, had the greatest percentage emergence among the three oak species studied. The number of days after planting to time of emergence was negatively correlated with acorn size and positively correlated with planting depth for a species.

Total percentage germination after 60 days in polyethylene glycol osmoticum treatments was greatest for pin oak and least for black oak at all levels. Total percentage germination decreased with decreasing water potentials for all species, with levels of -0.6 and -1.0 MPa virtually arresting germination.

These results indicate that a 3-7 cm planting depth was optimal for these oak species under our experimental conditions. Larger acorns of a given species had a higher percentage emergence than smaller acorns. The germination rate of acorns after exposure to osmotic stress did not coincide with the relative drought hardiness of the parent oak species.

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USE OF PLASTIC FILMS FOR WEED CONTROL

DURING FIELD ESTABLISHMENT OF MICROPROPAGATED HARDWOODS

J. W. Van Sambeck[1], John E. Preece[2], Carl A. Huetteman[2], and Paul L. Roth[3,4]

Abstract: This study compares the use of plastic films to conventional methods for establishing hardwoods on a recently cultivated old field site using 1-year-old micropropagated plantlets of white ash (*Fraxinus americana* L.) and silver maple (*Acer saccharinum* L.). After one growing season in the field, height of plantlets with all weed control treatments exceeded the height of the plantlets in the non-weeded control. After two growing seasons, plantlets of both species established with plastic films were taller than plantlets with conventional methods of weed control or in the non-weeded plots. No differences were found in plantlet height growth when established with opaque white film, solid black plastic, or porous black plastic. Silver maple plantlets were taller than the white ash plantlets after the first (47 vs 35 cm), second year (114 vs 72 cm), and third years (179 vs 101 cm). Soils under the plastic films had more available moisture in the spring and less available moisture during the summer than the other treatments. During the late fall, soil moisture was again near field capacity in all treatments. After three growing seasons, the solid plastic films had begun to disintegrate. Our results suggest that plastic films can be an effective alternative to chemical or mechanical weed control when establishing hardwoods.

INTRODUCTION

Successful establishment of hardwood seedlings usually requires good site preparation, weed control, and other cultural practices to maintain adequate soil moisture and fertility during the growing season. Lack of weed control during seedling establishment usually results in reduced survival and slowed tree growth (Van Sambeek and Rietveld 1983b). Currently, the most common methods used to achieve adequate weed control have included the use of mechanical cultivation or registered herbicides to control competing vegetation. Unfortunately, hardwoods such as white ash are extremely sensitive to most herbicides (Bey and Williams 1977). In addition, effective herbicides have not been registered for trees such as silver maple.

Recent evidence suggests that micropropagated plantlets are more sensitive to herbicides than conventionally propagated plants (Mudge et al. 1987; Neal et al. 1990). Micropropagated plantlets offer several advantages over the use of seed-produced seedlings for research and field plantings. Use of clonal planting stock can reduce genetic variability and experimental error thus allowing for greater precision in research studies (Libby 1974).

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[4]We thank Lisa Lambus and Rich Adams for plantlet propagation and plantation maintenance, F. Danny McBride for advise on tensiometers, Corinna Wernet for data analysis, and Tredegar Film Products for donating the plastic films. This research was partially supported by a cooperative research agreement (23-92-25) from the USDA Forest Service and a grant from Tredegar Film Products.

In addition, micropropagation has the potential to produce a high number of genetically improved plantlets inexpensively in a short period for field plantings.

With declining public acceptance of herbicide use, mulching with plastic or polyethylene films is being reevaluated as a promising technique for enhancing transplant survival and early growth (Windell 1993). Mulches can provide more or less permanent control of weeds during hardwood establishment, as well as more favorable soil conditions through reduced evaporative loss of soil moisture, reduced leaching of nutrients, and reduced soil erosion (Truax and Gagnon 1993). Plastic films are becoming more popular because equipment is available to mechanically lay these materials. Ashby et al. (1992) and Huetteman et al. (1992) both reported successful establishment of silver maple plantlets under droughty conditions using mechanically-laid opaque white-on-black plastic mulch.

Plastic films can have a wide range of optical properties that can markedly modify soil and air temperatures (Ham et al. 1993). Air temperatures immediately above plastic films can be 3 to 5° C higher than 1.5 m above the film. Recently, Trinka and Pritts (1992) recorded higher air temperatures immediately above white film than above black film. Depending on the type of film, midday soil temperatures under plastic films can be as much as 10° C higher than in adjacent uncovered soils (Heiskanen and Raitio 1992). Fritschen and Shaw (1960) reported that soil surfaces under clear films had higher mid-day temperatures than either black plastic or black plastic painted white. They also found temperature differences between bare soil and soil covered with plastic films tended to decrease as soils become drier.

Because plastic films can significantly alter the microenvironment, it is not clear what effect they would have on hardwood establishment, especially the establishment of containerized, micropropagated hardwoods or how the use of plastic films would compare to the conventional methods of weed control. The purpose of our study was to evaluate plantlet growth of white ash and silver maple and to compare changes in soil moisture potential and soil temperature when using three different plastic films and the more traditional methods of weed control for establishing hardwoods.

METHODS

The research planting was established on an old field site at the Southern Illinois University's Horticulture Research Center near Carbondale, IL. The study area measured approximately 25 x 50 m and was located along a mid-slope position with an eroded Hosmer silt loam (fine-silty, mixed, mesic Typic Fragiudalfs, pH 5.5). The tall fescue hay field, which previously was mowed annually, was plowed in April 1992 and cultivated twice before laying out the study in mid-May 1992. The research planting consisted of five rows, 4 m apart, oriented from west to east along the south-facing slope. Each row was treated as a block and marked off into six 1.0 m-wide by 7.5 m-long plots.

Six treatments were randomly assigned within each block: (a) non-weeded check, (b) clean cultivation, (c) herbicide treatment, (d) porous black plastic film, (e) solid black plastic film, and (f) solid white plastic film. The porous black film (VisPore tree mats) consists of approximately 60 microfunnels per cm^2 designed to allow rainwater and air to penetrate the 2.5 mil-thick plastic film. The solid plastic film was a highly reflective, opaque white-on-black 1.25 mil-thick polyethylene film that could be installed either white side up or black side up. The solid white film was laid with a tractor-pulled mulch laying machine in mid-May 1992. The two black films were manually laid in trenches formed with the mulch laying machine. When laid, the outside 15 cm of the 1.3 m wide plastic films was buried resulting in 1.0 m wide experimental plots.

The clean cultivated plots were hand-hoed twice in 1992 and rototilled twice in 1993 and 1994. The herbicide plots were sprayed with 55 ml/ha sulfometuron (Oust) and 6.4 L/ha glyphosate (Roundup) in June 1992. Glyphosate only at 6.4 L/ha was used in August 1993 and June 1994. Hardwoods were protected from direct application of herbicides using a stove pipe. The area between each row of plots was mowed twice in 1992, 1993, and 1994. The plantlets were protected from deer browse with a portable 3-wire electric fence. Some rabbit damage occurred on the smaller plantlets during the 1992-1993 winter.

Two white ash and three silver maple plantlets were randomly assigned to each plot and planted 1.5 m apart. Silver maple clones were planted as dormant containerized stock overwintered in a cooler and as plantlets in leaf from a shadehouse. White ash clones were planted as containerized plantlets in leaf from a shadehouse. Height of the white ash and silver maple plantlets averaged 24 and 28 cm, respectively, at the time of planting. Plantlets were established using KBC planting bars on 27 May 1992. A 9 gram starter (Agriform) fertilizer tablet (22 N - 8 P_2O_5 - 2 K_2O with 3% Ca, 1% S, 0.5% Fe, and 0.1% Zn) was placed in the first closure hole of each plantlet. Because the soils were relatively dry at the time of planting, approximately 2.5 cm of irrigation water was applied to the entire area on 29 May 1992. The plantlets received no subsequent fertilization or irrigation.

A soil moisture tensiometer was installed in each plot from June to October, 1992 and 1993. The 50-cm-long tensiometers were installed at a 45° angle with the ceramic cup approximately 30 cm deep located midway between a silver maple and a white ash plantlet. Tensiometers were nominally read twice a week during the growing season until soil moisture returned to field capacity in the fall. Because fine silica was used to reinforce the soil-ceramic cup interface, soil water potential readings between -80 and -90 kPa could be reliably obtained in most cases. To compare effects of vegetation management treatments on soil moisture potential during the growing season, we quantified the number of days each month soil moisture potential was less than -33 kPa (little or no moisture stress), -34 to -67 kPA (moderate moisture stress), and less than -67kPA (severe moisture stress) for each plot. These values are based on previous research growing hardwood seedlings under different moisture regimes (Rink and Van Sambeek 1985, 1987a).

One soil thermocouple was also installed 15 cm deep midway between two plantlets near the middle of each plot. Soil temperatures at 0400 and 1600 hours were recorded daily for a two week period from 26 August to 12 September 1992. Daily minimum and maximum air temperature and rainfall were recorded at the Horticulture Research Center weather station located 0.5 km southeast of the planting site.

Plantlet height was measured at planting and two or three times during the first three growing seasons. The amount of winter dieback and length of the spring flush were measured during May 1993. The number and length of all lateral shoots were determined after the first growing season. During July and/or August of the first and second growing seasons, the terminal shoots of each plantlet were examined to determine if they were still actively producing new growth.

Treatment means by species were computed from individual plantlet data and subjected to analysis of variance (ANOVA) to test for effects of weed control treatments, species of plantlets, and their interaction. We used a randomized complete block with split plots design with weed control treatments as main plots and species of plantlets as the subplots. Comparison of treatment or species means were based on Fisher's protected LSD (1% and 5% t-test values). The five planned allowable orthogonal contrasts were comparison of (1) non-weeded check against the five other treatments, (2) conventional weed control (herbicide and cultivation) against the plastic films, (3) herbicide against cultivation, (4) solid plastic films against porous plastic film, and (5) solid white-on-black against solid black-on-white film.

RESULTS

Plantlet Response to Vegetation Management Practices

Plantlet survival averaged 90 percent after the first growing season with no statistical differences between the non-weeded control or plots where vegetation was controlled chemically, mechanically, or with plastic films (Table 1). All the white ash plantlets survived while mortality exceeded 20% for silver maple plantlets after the first growing season. Most of the dead silver maple plantlets were of a single clone planted as containerized stock in leaf. The spring application of sulfometuron and glyphosate killed a few additional silver maple plantlets. Little additional mortality has occurred for either species during the second and third growing seasons.

Table 1.--First year mortality, lateral shoot growth, winter dieback, and spring flush of white ash and silver maple plantlets under six different weed control practices.

Treatment and species	Mortality	Lateral Number	shoot Length	Plantlets with dieback	Spring flush 1993
	- % -		- cm -	- % -	- cm -
SPECIES MEANS:					
White ash	0	1.6	11.7	35	19
Silver maple	21	1.9	27.0	77	34
Significance[a]:	**	ns	**	**	**
TREATMENT MEANS:					
Check	20	0.7	1.5	67	24
Cultivate	17	1.4	15.9	65	26
Herbicide	10	1.3	16.2	72	34
Black Film	7	3.1	34.6	45	27
White Film	6	2.1	23.1	38	26
Porous black	5	1.9	24.7	52	29
Significance[a]:	ns	*	*	*	ns
5% t-test value:		2.4	17.5	28	
1% t-test value:		3.2	23.9	40	
Tested Contrasts:					
Check vs Others:		*	**	ns	
Conv. vs Plastic:		*	*	*	
Cultv. vs Herb.:		ns	ns	ns	
Solid vs Porous:		ns	ns	ns	
Black vs White:		ns	ns	ns	

[a] Nonsignificant (ns) or significant effects at the 5% (*) or 1% (**) according to F-test for 1 and 24 df (species) and for 5 and 20 df (treatments).

Plantlets established with plastic film for vegetation control had significantly more lateral shoots than plantlets without plastic films after the first growing season (Table 1). In addition, these plantlets also had the greatest cumulative length of lateral shoots. Silver maple plantlets produced over twice the length of lateral shoots as the white ash plantlets. All the plantlets receiving some type of weed control had significantly more and longer cumulative lenght of lateral shoots than plantlets in the non-treated check plots.

Terminal shoot dieback or winter-kill occurred on many of the silver maple and white ash plantlets in all treatments (Table 1). The lowest incidence of dieback occurred in plots with plastic mulch (38 to 52%) and the highest under the conventional cultural practices (65 to 72%). Winter dieback on the silver maple plantlets averaged 3.6 cm compared to only 1.7 cm on the white ash plantlets. No differences in the amount of winter dieback were found with respect to weed control practice.

The silver maple plantlets outgrew the white ash plantlets during the first three growing seasons (Table 2). After the first growing season, height of plantlets in all weed control treatments exceeded that of the plantlets in the non-weeded check treatment. This also remained true throughout most of the second growing season. By the end of the second growing season, plantlets established with plastic films were taller than those established with conventional methods of weed control.

Table 2.--Height of white ash and silver maple plantlets through three growing seasons under six different weed control practrices.

Treatment and Species	Oct. 1992	May 1993	July 1993	Oct. 1993	July 1994	Oct. 1994
	cm					
SPECIES MEANS:						
White ash	34	54	64	73	102	101
Silver maple	46	79	92	114	170	179
Significance[a]:	**	**	**	**	**	**
TREATMENT MEANS:						
Check	23	43	48	49	91	89
Cultivate	46	67	79	96	140	140
Herbicide	37	74	80	84	126	144
Black Film	47	73	89	111	148	150
White Film	47	71	83	105	143	144
Porous black	51	79	95	118	55	158
Significance[a]:	**	**	**	**	**	**
5% t-test value:	11.5	12.6	16.2	16.4	25.9	27.8
1% t-test value:	15.7	17.21	22.1	22.4	35.3	37.8
Tested Contrasts:						
Check vs Others:	**	**	**	**	**	**
Conv. vs Plastic:	ns	ns	ns	**	**	ns
Cultv. vs Herb.:	ns	ns	ns	ns	ns	ns
Solid vs Porous:	ns	ns	ns	ns	ns	ns
Black vs White:	ns	ns	ns	ns	ns	ns

[a] Nonsignificant (ns) or significant effects at the 5% (*) or 1% (**) according to F-test for 1 and 24 df (species) and for 5 and 20 df (treatments).

During July of the first growing season, over 90 percent of the plantlets in the plots with plastic film had actively elongating shoots while only 65 percent of the plantlets in the non-weeded control plots had actively elongating terminal shoots. In addition, 88 percent of the silver maple plantlets had elongating shoots compared to 70 percent of white ash plantlets. Similar observations were made in July of the second growing season. The percentage of plantlets with some type of weed control having elongating shoots decreased to 50 percent or less during August of the second growing season; however, only 12 percent of the plantlets in the non-weeded plots still had elongating terminal shoots. In August, nearly four times more silver maple plantlets (57 percent) still had elongating shoots compared to the white ash plantlets (15 percent).

Effectiveness of Vegetation Management

During the first growing season, the non-weeded check plots quickly developed a heavy cover of broadleaved annuals in the spring which was followed by a dense stand of foxtail (*Setaria* spp.). During the second and third growing seasons, the non-weeded check plots had a dense cover of broadleaved annuals, biennials, and perennials with fewer grasses. Mechanical cultivation generally provided short term control of competing vegetation and needed to be repeated several times during each growing season. Sulfometuron and glyphosate effectively controlled vegetation throughout the first growing season and into the second growing season before a second application of glyphosate was applied to control emergent vegetation.

Essentially no vegetation grew within the 1 x 7.5 m plots when covered with porous black, solid black, or solid white plastic film for the first two growing seasons. What vegetation there was grew mostly through the planting hole and not the plastic film. The solid black and solid white films began to disintegrate after the second growing season. The thicker porous black film remained largely intact throughout the third growing season.

The method of weed control altered soil moisture depletion and recovery during both the first and second growing seasons (Fig. 1). In general, soil moisture potential decreased most rapidly in the check plots covered with dense vegetation. Soil moisture potentials declined more slowly under the plastic film than in the other treatments; however, they were also the last to return to field capacity at the end of the growing season. All three plastic films were laid with the edges slightly higher than the center of the plots where the trees were planted. During thunderstorms, precipitation tended to initially sheet across all three films and enter through the planting holes at the base of each plantlet. Water also readily penetrated the porous black film once the micropores were wetted.

During the spring of the first and second growing seasons, plantlets in plots with weed control experienced more days with little or no soil moisture stress (soil water potentials from 0 to -33 kPa) than the non-weeded control (Table 3). Near the beginning of the first growing season, plots with the plastic mulch had more days with adequate soil moisture than the plots with conventional weed control; however, no differences were found during the fall of the first or second growing season.

Table 3.--Number of days plantlets experienced little or no moisture stress[a] during the first and second growing season under six different weed control practices[b].

Weed control	First growing season			Second growing season			
Treatment	July	Aug.	Sept.	June	July	Aug.	Sept.
	------ days --------			--------- days ---------			
Check	0	1	23	9	0	0	9
Cultivate	2	0	18	12	14	5	16
Herbicide	2	1	27	12	6	1	12
Black film	6	1	17	19	17	7	17
White film	5	1	20	19	10	1	12
Porous black	3	0	26	24	12	0	8
Significance[c]:	*	ns	ns	*	*	ns	ns
5% t-test value:	4.2			10.6	8.9		
1% t-test value:	5.8			14.6	12.2		
Tested Contrasts:							
Check vs Others	*			*	**		
Conv. vs Plastic:	*			*	ns		
Cultv. vs Herb.:	ns			ns	ns		
Solid vs Porous:	*			ns	ns		
Black vs White:	ns			ns	ns		

[a] Soil moisture potentials between 0 and -33 kPa.
[b] Monthly precipitation from May through September was 3.30, 2.85, 6.71, 6.58, and 17.63 cm, respectively, in 1992 and was 12.52, 12.24, 8.97, 6.25, and 22.83 cm, respectively, in 1993.
[c] Nonsignificant (ns) or significant effects at the 5% (*) or 1% (**) according to F-test for 1 and 20 df (species) and for 5 and 20 df (treatments).

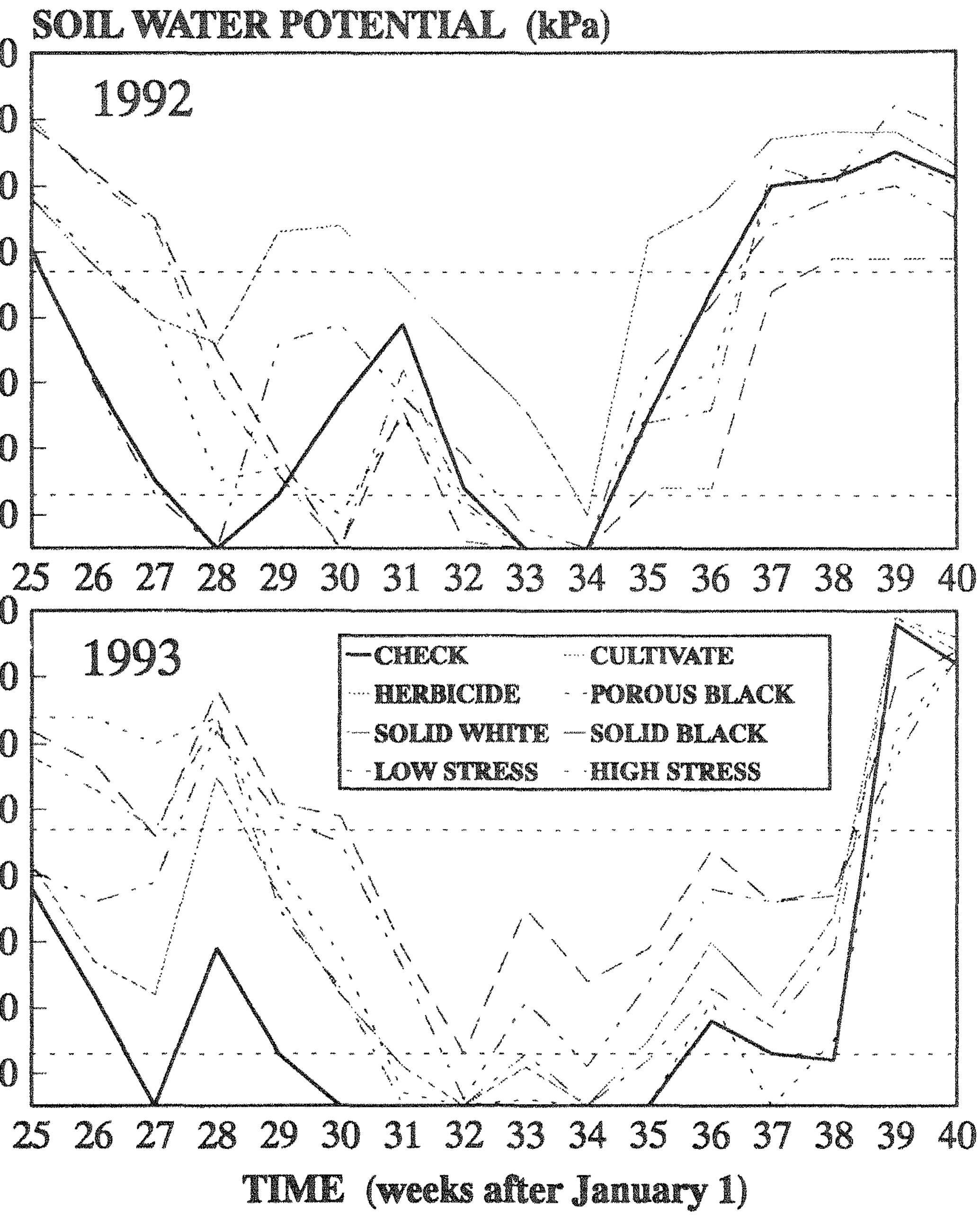

Figure 1.--Soil moisture potential under six weed control treatments for the first and second growing seasons after plantlet establishment.

During both the first and second growing seasons, plantlets in all treatments experienced 18 or more days with severe moisture stress (soil moisture potential less than -67 kPa) (Table 4). The number of days with severe moisture stress was highest in the non-weeded check plots at the beginning of each growing season. In general, the greatest number of days with severe moisture stress was least in the herbicide-treated and cultivated plots, intermediate in plots covered with plastic mulches, and highest in the check plots.

As found in other studies, the type of weed control can significantly alter the daily changes in soil temperature under both dry and wet soil conditions (Table 5). During a week of relatively clear days in late August when soil moisture potentials were under -67 kPa, the greatest daily change in soil temperatures occurred under the solid black plastic film. The same pattern was seen during a week of relatively cloudy days in early September; however, the magnitude of the daily changes under solid black plastic was not as great. The micropores in the porous black plastic may have allowed greater heat exchange, so that daily soil temperature changes were more nearly equal those for daily changes in other plots without dense vegetation. The daily change in soil temperature was least for the solid white plastic film under both clear and cloudy weather conditions. The lowest soil temperatures were found in the non-weeded control where the dense vegetation significantly reduced the amount of solar radiation reaching the soil surface.

DISCUSSION

Growth rates of the micropropagated silver maple trees were similar to that reported in other studies where height tended to double each year during the first three years (Ashby et al. 1992). This is the first report on growth rates of field-planted white ash plantlets; however, their height growth was similar to what would be expected from small bare-root seedlings of white ash.

The reduced incidence of terminal shoot dieback on plantlets in the plots using plastic films for weed control may have long-term consequences on tree form and development. Both silver maple and white ash have opposite phyllotaxy and frequently develop multiple stems following damage to the terminal bud. Because multiple stems are less desirable than a single stem for most forestry applications, the use of plastic films should have beneficial growth effects well beyond plantation establishment.

Past studies on black walnut have shown a strong correlation between the cumulative length of lateral shoots after the first growing season and rapid terminal shoot growth the second growing season (Rink and Van Sambeek 1987b). This pattern also appears to be true for white ash and silver maple, because the plantlets with the greatest cumulative lateral shoot growth after the first year tended to be the tallest after the second year.

The amount of soil warming under the solid black plastic was significantly higher than under the porous black plastic. Rapid heat exchange through the micropores appears to another important property of the porous black plastic in addition to allowing moisture to penetrate the plastic film. The changes in soil temperature we found under the solid black plastic were not as great as reported by other researchers. The rough soil surface under the black plastic or relatively dry soil conditions may have reduced the heat transfer (Ham et al. 1993, Heiskanen and Raitio 1992).

Although no root excavations were done, results from an unpublished study suggest that lateral root elongation on field-planted silver maple plantlets occurs very rapidly in moist soil and should extend beyond the edges of the plastic film late during the first growing season. With good weed control and adequate soil moisture, lateral root extension on black walnut seedlings has been shown to exceed 1.0 m after one growing season (Van Sambeek and Rietveld 1983a). The percentage of plantlets with elongating shoots in late summer and height growth of both silver maple and white ash were higher for plantlets established with plastic films than without plastic films. Increased plantlet growth early in the growing season may have resulted from a longer period without significant soil moisture stress. The solid plastic films apparently conserved the soil moisture by reducing the amount of evaporative losses when compared to changes found in soil water potentials found in the herbicide or cultivation treatments.

Table 4.--Number of days plantlets experienced severe moisture stress[a] during the first and second growing season under six different weed control practices[b].

Weed control Treatment	First growing season July	Aug.	Sept.	Second growing season June	July	Aug.	Sept.
	------- days -------			-------- days ---------			
Check	17	20	1	3	20	29	9
Cultivate	13	20	0	4	2	20	5
Herbicide	10	16	0	4	6	24	5
Black film	10	25	4	0	0	16	2
White film	15	22	2	1	8	27	8
Porous black	11	22	2	0	5	27	12
Significance[c]:	*	ns	ns	ns	**	ns	**
5% t-test value:	9.8				8.2		5.8
1% t-test value:	13.4				11.3		8.1
Tested Contrasts:							
Check vs Others:	*				**		ns
Conv. vs Plastic:	*				ns		ns
Cultv. vs Herb.:	ns				ns		ns
Solid vs Porous:	ns				ns		**
Black vs White:	ns				*		*

[a] Soil moisture potentials less than -67 kPa.
[b] Monthly precipitation from May through September was 3.30, 2.85, 6.71, 6.58, and 17.63 cm, respectively, in 1992 and was 12.52, 12.24, 8.97, 6.25, and 22.83 cm, respectively, in 1993.
[c] Nonsignificant (ns) or significant effects at the 5% (*) or 1% (**) according to F-test for 1 and 20 df (species) and for 5 and 20 df (treatments).

Table 5.--Soil temperature 15 cm below soil surface at 0400 and 1600 hours under six different weed control practices from 28 August to 12 September 1992.

Weed control Treatment	28 August to 4 September[a] 0400	1600	Diff.	5 September to 12 September[b] 0400	1600	Diff.
	------°C -----			----- °C -----		
Check	16.2	17.6	1.33	14.9	15.6	0.71
Cultivate	17.3	19.0	1.68	15.7	16.8	1.12
Herbicide	17.4	19.0	1.56	15.8	16.9	1.14
Black film	16.4	20.1	3.71	15.5	18.4	2.83
White film	16.6	17.1	0.52	15.9	16.2	0.31
Porous black	16.2	18.3	2.06	15.2	16.8	1.64
Significance[c]:	**	**	**	**	**	**
5% t-test value:	0.26	0.24	0.34	0.33	0.53	0.57
1% t-test value:	0.35	0.33	0.46	0.44	0.72	0.77
Tested Contrasts:						
Check vs Others	**	**	**	**	**	**
Conv. vs Plastic:	**	**	**	*	ns	*
Cultv. vs Herb.:	ns	ns	ns	ns	ns	ns
Solid vs Porous:	*	**	ns	**	*	ns
Black vs White:	*	**	**	*	**	**

[a] Clear days with an average air temperature of 21.9 °C.
[b] Cloudy, rainy days with an average air temperature of 23.4 °C.
[c] Nonsignificant (ns) or significant effects at the 5% (*) or 1% (**) according to F-test for 5 and 30 df.

Preliminary estimates suggest costs to establish hardwood seedlings using repeated mechanical cultivation for only one year will exceed that for laying plastic films. Costs for applying herbicides for two years are comparable to laying plastic films. Although thicker plastic films will cost slightly more, the cost should be recovered quickly through improved tree growth if the plastic film provides three or more years of weed control. Technologies already exist for manufacturing plastic films capable of giving three or more years of weed control under continual exposure to sunlight. Conversely, soil can be used to partially cover the plastic film or higher density plantings can be established that will result in more rapid canopy closure and prolong life of the plastic mulch. Future research is needed on developing the most appropriate methods for laying plastic films for forestry applications and their effects on tree growth.

SUMMARY

We found the use of plastic films to control competing vegetation to be as effective as the conventional methods currently used when establishing hardwood plantings. Plastic films slowed changes in soil moisture potential during the spring, thus prolonging the period before plantlets were exposed to moisture stress. Soil moisture potential returned to field capacity relatively quickly under all treatments late in the fall. Overall the best tree growth occurred in plots where competing vegetation was controlled with plastic films. Because the plastic mulches remained intact for 2 or 3 years, they also reduced maintenance costs following plantation establishment. We expect with closer spacings and more rapid accumulation of leaf litter the durability of plastic mulches can be further increased.

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PROTECTION OF TREE SEEDLINGS FROM DEER BROWSING

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Abstract: Browsing by large deer herds has seriously impaired successful regeneration on some Connecticut forests. Six plots were established in 1990 to examine the effectiveness of 5 deer browsing protection devices for 5 tree species. Protective devices included plastic mesh sleeves (60-cm), Reemay (spunbonded polypropylene) sleeves (60-cm), Tubex tree shelters (120 and 180-cm), and Corrulite tree shelters (120-cm) to be compared to unprotected controls. Species included eastern white pine, eastern hemlock, Norway spruce, northern red oak, and black walnut. After 3 growing seasons, seedlings within tree shelters were significantly taller than seedlings protected by plastic mesh and Reemay sleeves, except for eastern hemlock. Tree shelters stimulated growth of hardwood seedlings more than conifer seedlings. Mortality was lower for seedlings protected by tree shelters than for other treatments. Unprotected black walnut seedlings were actually shorter after 3 yr than when planted because of browsing. The Reemay sleeves and plastic mesh were not durable; most were damaged by weather or animals. The mesh caps placed over tree shelters to prevent bird mortality distorted many trees emerging from tree shelters. Browse damage was observed on trees growing out of 120-cm tree shelters.

INTRODUCTION

Heavy browsing by large deer herds has seriously impaired natural regeneration on some forests in Connecticut. The deer herd in Connecticut has increased from an estimated 19,000 in the mid-1970s (Anderson 1984) to over 50,000 in 1993 (Kilpatrick 1993). Deer browsing has become a problem throughout much of the central hardwood region (Marquis 1977, Kelty and Nyland 1983, Kittredge and others 1992). Deer browsing is especially acute in parks and natural areas where hunting is prohibited and herd sizes are artificially high because of the lack of natural predators (Miller and others 1992, Girard and others 1993).

Early work showed that hardwood growth was increased by protection from deer browsing using mesh tubes (Marquis 1977). Tree shelters (solid plastic tubes) increase hardwood tree growth by providing protection from browsing and providing favorable growing conditions. Tuley (1985, cited from Potter 1988) discovered that early oak height growth in England was dramatically increased by using plastic tubes. Tree shelters have increased height growth of northern red oak (Lantagne and others 1990, Lantagne 1991, Minter and others 1992, Kittredge and others 1992, Smith 1993, Walters 1993), and black walnut (Ponder 1991).

Alternatives to tree shelters include fencing the planting area and repellents. Deer fences are effective in reducing browse damage (McCormick and others 1993, George and others 1991), but may require frequent maintenance inspections (George and others 1991) and also increase growth of less desired species such as red maple (McCormick and others 1993). Although repellents have reduced deer browsing of orchards (Conover and Kania 1988, Swihart and Conover 1988, Byers and Scanlon 1987), nurseries (Conover 1984), and Christmas tree plantations (Raymond[2]); control is inconsistent (Conover 1984, Swihart and Conover 1988) and needs to be applied several times a year (Conover 1987, Raymond[2]). Clearly, repellents are inadequate for forest plantations. This report will examine how various browsing protection methods affect growth and survival of seedlings.

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[2]Raymond, R. 1991. Personal communication, Conn. Dept. Envir. Protec. Goodwin Conservation Center, RR1, N. Windham, CT.

METHODS

In spring 1990 six study sites were established: 3 at Mohawk State Forest and 3 at Lake Gaillard. Both forests are actively managed for timber and hunting is prohibited. Consequently, large deer herds have developed which prevent natural regeneration and destroy artificial forest plantations. Study sites on Mohawk State Forest were recent red pine clearcuts. Two Lake Gaillard study sites were former pasture with scattered woody regeneration, the other was a newly abandoned corn field. All plots were cleaned with chainsaw and machete prior to planting and 2 years later.

Northern red oak (*Quercus rubra*), eastern white pine (*Pinus strobus*), and Norway spruce (*Picea abies*) were planted at both forests. Additionally, eastern hemlock (*Tsuga canadensis*) was planted at Mohawk State Forest and black walnut (*Juglans nigra*) was planted at Lake Gaillard. Seedling height (cm) and root collar diameter (mm) were measured prior to planting. Mean root collar diameters were: black walnut-7.1 mm, northern red oak-5.8 mm, eastern white pine-5.7 mm, Norway spruce-3.6 mm, and eastern hemlock 2.6 mm. Seedlings were stratified by root collar diameter before assignment to treatments. At each of the six sites 8-20 seedlings received each treatment.

The 6 treatments included: 60 cm high plastic mesh sleeve supported by a bamboo stake, 60 cm high spunbonded polypropylene (Reemay[3]) sleeve supported by a bamboo stake, 120 cm Tubex[3] tree shelter, 180 cm Tubex[3] tree shelter, 120 cm Corrulite[3] tree shelter, and an unprotected control. Both bamboo and wood stakes were untreated. Mesh caps provided were placed over all tree shelters to prevent songbird entry into the tubes.

Tree heights (nearest cm), browse damage, and any distortions of the terminal leader were measured at the end of each growing season (~15 September). Browse damage was noted at the beginning (~1 December), middle (~15 February), and end of winter (~1 April). Damage to protective devices was noted during each field check. Failure of protective device was defined as a fallen tree shelter or sleeve, removal of mesh or Reemay sleeve by animals, or disintegration of sleeve to degree that terminal leader was not covered.

Deer density was estimated by the pellet-group count technique (Neff 1964) in 1991 at both forests and 1992 at Lake Gaillard. Five of the study sites were separated by at least 5 km to increase probability that each study area was browsed by distinct deer herds. There was a single pellet-group survey for the 2 study areas at Mohawk State Forest which were only 1 km apart. At each study site 37 to 50 1/247 ha circular plots were randomly located within 1 km of each plot center. Rabbit pellet groups were also counted.

Tukey's HSD test (SYSTAT 1992) was used to test differences in height growth among treatments by size class and year. Chi-square statistics were used to determine whether cumulative browse differed among treatments and whether cumulative browse of unprotected seedlings differed among species. Chi-square statistics were used to determine whether mortality and cumulative failure differed among treatments by species. Preliminary analysis found no difference in growth, mortality, browse, or failure among tree shelter types. Therefore, data for the 3 tree shelter types were combined. Differences were considered significant at $P \leq 0.05$.

RESULTS

Deer density was estimated to be 18/km² at both Mohawk State Forest study areas in 1991. Estimates of deer density at Lake Gaillard ranged from 17-31/km² in 1991 (mean 24/km²) and from 13-24/km² in 1992 (mean 18/km²). At least one pellet-group was found on 62% of sample plots in 1991 at Lake Gaillard; 17% of sample plots had at least one rabbit pellet-group. At Mohawk State Forest, 49% and 26% of sample plots had at least one deer and rabbit pellet-group, respectively. The 1992 survey found deer pellet-groups on 47% of plots and rabbit pellet-groups on 12% of plots.

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[3]Use of tradenames does imply endorsement by the Connecticut Agricultural Experiment Station.

Heights of all species, except eastern hemlock, were significantly greater after 3 growing seasons when protected by tree shelters than when unprotected or protected by sleeves (Table 1). The increased height of seedlings protected by tree shelters was significant after 1 growing season. Unprotected black walnuts were actually smaller after 3 growing seasons than when planted. Seedlings protected by sleeves were not significantly taller than unprotected seedlings after 3 growing seasons, except for black walnut protected by mesh sleeves. Hardwoods clearly responded better to tree shelters than conifers. Relative to unprotected controls, trees in tree shelters were taller; black walnut, 215%; northern red oak, 145%; white pine, 70%; Norway spruce, 30%; and hemlock, 20%.

Table 1. Seedling height (cm) at end of growing season by species, treatment, and years since planting.

	Initial	Years since planting		
		1st	2nd	3rd
Northern red oak				
Control	31.1 a[a]	28.9 a	32.6 a	45.1 a
Mesh	30.3 a	32.0 a	41.2 a	50.5 a
Reemay	31.8 a	31.2 a	38.1 a	50.2 a
Tubes	30.2 a	37.4 b	71.2 b	110.6 b
Black walnut				
Control	34.0 a	38.3 a	38.8 a	28.2 a
Mesh	35.4 a	41.9 a	45.6 b	48.3 b
Reemay	34.1 a	39.7 a	42.0 ab	40.1 ab
Tubes	36.1 a	46.8 b	65.5 c	89.0 c
Eastern white pine				
Control	21.5 a	23.0 a	31.0 a	51.8 a
Mesh	22.1 a	23.9 ab	38.2 b	57.8 a
Reemay	21.8 a	23.6 a	37.4 b	57.4 a
Tubes	21.5 a	25.6 b	51.0 c	88.3 b
Eastern hemlock				
Control	19.6 a	18.3 ab	21.8 ab	40.4 ab
Mesh	19.6 a	17.2 a	28.0 b	35.9 a
Reemay	18.9 a	17.5 a	18.0 a	28.1 a
Tubes	19.1 a	20.2 b	34.7 c	48.5 b
Norway spruce				
Control	21.6 a	25.2 ab	29.9 a	47.2 a
Mesh	22.3 a	24.1 a	31.3 a	46.7 a
Reemay	22.6 a	24.9 ab	31.0 a	45.8 a
Tubes	22.4 a	26.3 b	40.6 b	61.4 b

[a]Column values for each species followed by the same letter do not differ significantly at $P \leq 0.05$.

Table 2. Cumulative mortality[a] (%) by species, treatment, and years since planting and original sample size in 1989.

	Years since planting			Sample
	1st	2nd	3rd	size
Northern red oak				
Control	6	12	8[a]	36
Mesh	7	8	14	72
Reemay	3	3	8	72
Tubes	0	8	2	108
Black walnut				
Control	0	0	8	24
Mesh	0	0	0	48
Reemay	2	4	6	48
Tubes	0	12	0	72
Eastern white pine				
Control	28	32	37	60
Mesh	29	36	38	120
Reemay	23	32	35	120
Tubes	24	26	28	180
Eastern hemlock				
Control	30	50	57	30
Mesh	27	47	44	60
Reemay	28	27	40	60
Tubes	4	19	21	90
Norway spruce				
Control	8	30	34	50
Mesh	17	28	29	100
Reemay	11	32	36	100
Tubes	10	25	27	150

[a]Cumulative mortality may decrease because some trees resprouted following aboveground dieback.

Total mortality after 3 growing seasons was not independent of treatment for all species (Table 2). Mortality of seedlings protected by tree shelters was much lower than other treatments. Again, there was a difference between hardwoods and conifers. Mortality of conifers protected tree shelters was reduced by about one-third compared with other treatments. In contrast, northern red oak mortality was reduced by at least 75% and there was no mortality of black walnut protected by tree shelters.

Browse of terminal buds was not independent of treatment ($\chi^2 = 302.3$, d.f.= 3, $P \leq 0.001$). Cumulative browse of seedlings protected by tree shelters was 75-89% lower than for other treatments (Table 3). Sleeves reduced browsing by 34-56% relative to unprotected seedlings. Browse of seedlings within tree shelters was caused by either mice gnawing through tubes and then on seedlings or deer browsing on seedlings which had grown out of 120-cm tree shelters.

There was a significant difference among species in the percentage of unprotected seedlings which were browsed ($\chi^2 = 27.7$, d.f.= 4, $P \leq 0.001$). Terminal buds of hardwoods were browsed much more frequently than conifers. Ninety-two percent of both unprotected northern red oak and black walnut were browsed compared with 57% of white pine, 54% of Norway spruce, and 47% of eastern hemlock.

The principal reason for higher browse levels of seedlings protected by mesh and Reemay sleeves was a higher failure level compared with tree shelters (Table 4). There was a significant difference of failure rate among protection devices ($\chi^2 = 213.4$, d.f.= 2, $P \leq 0.001$). By the end of the winter after the 3rd growing season fewer than half of seedlings protected by sleeves were still protected, compared with 75% of seedlings protected with tree shelters.

Distorted terminal growth of unprotected seedlings was rare, only 1.5% of total (Table 5). The proportion of seedlings (combined species) with distorted tops was not independent of treatment ($\chi^2 = 68.1$, d.f.= 2, $P \leq 0.001$). The proportion of seedlings with distorted tops was not independent of treatment for all species except black walnut. Distortion rates were approximately 3 times higher for seedling protected by sleeves than by tree shelters. Reemay sleeves caused more distortions than mesh sleeves for all species except Norway spruce.

Table 3. Annual browse of terminal bud (%) and cumulative browse (1989-1992) by treatment and years since planting.

Treatment	Years since planting 1st	2nd	3rd	Cumulative browse (%)	Sample size
Control	47.5	31.0	25.5	65.0	200
Mesh sleeves	5.0	12.8	18.8	28.5	400
Reemay sleeves	6.5	24.8	25.8	43.0	400
Tubes	0.0	5.8	2.5	7.3	600
Combined	8.8	15.4	15.3	28.8	1600

Table 4. Failure of browsing protection devices (%) by treatment and years since planting. See text for description of types of failure. Percentages may not add because of rounding error.

Treatment	Years since planting 1st	2nd	3rd	Cumulative failure (%)	Sample size
Reemay	0.0	44.5	26.0	70.5	400
Mesh	0.3	27.8	27.5	55.5	400
Tubes	0.0	8.0	17.3	25.3	600

Table 5. Percent of seedlings with distorted top growth by the end of the 3rd growing season by species and protection device.

Treatment	Northern red oak	Black walnut	Eastern white pine	Norway spruce	Eastern hemlock	Combined species
Control	5.6	0.0	1.7	0.0	0.0	1.5
Mesh	22.2	14.6	10.0	47.0	15.0	22.8
Reemay	43.1	22.9	24.2	17.0	28.3	26.3
Tubes	22.2	8.3	4.4	4.7	2.2	7.8

DISCUSSION

Study sites for this research were selected because natural regeneration was inadequate and browsing damage was heavy in recent plantations. Regeneration was dominated by browse resistant species such as *Carpinus caroliniana, Ostrya virginiana, Acer pensylvanicum, Berberis* spp., and ferns. Earlier studies have established that natural regeneration may be inadequate when deer densities exceed 7-8 deer/km^2 (Behrend 1970, Anderson 1984, Tilghmann 1989). The lowest deer density observed in this study, 13 deer/km^2, was clearly too high to obtain sufficient natural regeneration. A browse line has developed in the areas with more than 20 deer/km^2. It should be noted that pellet-group counting has been criticized as unreliable (Fuller 1991), although studies have reported good correlations with track counts (Mooty and Karns 1984) and drive-line census (deCalesta and Witmer 1990). Therefore, deer densities reported here should only be considered as approximations.

Compared with unprotected seedlings and seedlings protected with sleeves, hardwood seedlings protected by tree shelters have grown taller, lower mortality rates, lower percentage of distorted terminal leaders, and lower browse pressure. This research concurs with earlier studies that tree shelters increase growth of individual hardwood seedlings (Lantagne and others 1990, Lantagne 1991, Ponder 1991, Minter and others 1992, Kittredge and others 1992, Walters 1993, Smith 1993). Tree shelters have the added benefit of reducing browse damage (Table 3).

Tree shelters are not a plant and walk away alternative (Smith 1993). Tree shelters failed not only because of rotting stakes, which we expected, but also because of buck rubbing and wind rocking in wet soils. It is difficult to properly set stakes in rocky and shallow soils. There were 3 causes of distorted terminals for trees within tubes. Wasps nests in tube interiors formed a physical barrier for terminal expansion, especially second flush growth. Emerging terminal leaders often snagged on the mesh placed over tubes to bird entry. Snagged terminals spiraled until penetrated the mesh. Lastly some trees gradually spiraled against tube interiors until emerging.

It is still too early to determine if tree shelters are suitable for conifer species. Although height of eastern white pine and Norway spruce protected by tree shelters was higher than for other treatments, the increased height was only equivalent to one year's growth (Table 1).

Both types of sleeves were unsuitable for newly planted seedlings due to high failure and terminal distortion rates. Consequently, seedlings protected by sleeves were not taller than unprotected seedlings after 3 growing seasons . High failure rates resulted in unacceptable levels of terminal buds browsing, especially of hardwoods. The most common cause of sleeve failure was disintegration of sleeve to degree that the terminal leader was not covered. Other causes were removal by deer pulling sleeves off seedlings and animal gnawing of sleeves. Reemay sleeves gradually fray and the sleeve interior can become a dense fiber web which snags and distorts expanding terminal growth. Most distortions associated with mesh sleeves occurred when sleeve alignment deviated from vertical and expanding terminals became snagged. Sleeves were pulled from vertical alignment by animals, competing vegetation, wind, and rain, ice, and snow loads.

ACKNOWLEDGMENTS

A special thanks to Bureau of Forestry, Connecticut Department of Environmental Protection, and the South Central Regional Water Authority who donated the land, materials, and manpower which made this research possible. This research was partly funded by McIntire-Stennis Project No. CONH-541.

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EFFECTS OF TREE SHELTERS ON PLANTED RED OAKS

AFTER SIX GROWING SEASONS

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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 1992, the height growth of sheltered trees made DBH measurements possible on 80 percent of sheltered trees (height $\geq$ 4.6 ft) compared to only 52 percent of unsheltered trees. Sheltered trees had significantly greater average diameters. Tree shelters have improved survival, diameter and total height growth over the first six growing seasons. The data showed however, that average tree height growth was comparable between sheltered and unsheltered trees for the past three growing seasons. The 19 inch total height advantage appears to be the result of accelerated growth during the first three growing seasons when trees were within the 48 inch tall shelters.

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 this study is to evaluate the long-term effectiveness of tree shelters in establishing northern red oak. This paper presents 6-year results of a tree shelter study established in a Michigan clearcut.

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METHODS

The study is located in an oak-hickory forest at the W.K. Kellogg Experimental Forest 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.

Plastic 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 collected from the study site in the fall of 1984 were float tested for viability. "Sinkers" were collected and 8 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 measured in the fall of 1992. The incidence of browse was not formally evaluated as surveys in previous years had found < 10 percent of unprotected trees affected. 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. 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.

RESULTS

Over the first six years of the study, control of non-oak woody species has 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). There were no significant brush control X shelter interactions for any measured variable. Seedling survival and height for sheltered seedlings were significantly greater than for unsheltered seedlings (Table 2). Although sheltered trees have maintained a 19 inch total height advantage, the height growth of sheltered and unsheltered trees over the past three growing seasons has not differed (Table 2). Early growth gains resulted in 77 percent of the trees originally planted in shelters to average over 47 inches high after six growing seasons compared to only 50 percent of the unsheltered trees originally planted in the study ($P < 0.001$). Sixty-seven percent of the total number of sheltered trees originally planted were tall enough (≥ 4.6 ft) in 1992 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).

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

Factors	DF	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 ($p < 0.0011$)

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 diameter distributions between sheltered and unsheltered trees also indicated a significant shift towards larger diameters for sheltered seedlings ($P < 0.0001$).

DISCUSSION

Tree shelters can improve the early survival and height growth of oak seedlings (Minter et al. 1992, Lantagne 1991, Tuley 1983). Survival differences between brush control and tree shelter treatments were not a major factor in this experiment. Over the first three growing seasons, survival averaged above 90 percent for all treatments. Results similar to these have been reported by Minter et al. (1992). After six growing seasons, survival was 10 percent greater in treatments receiving brush control or tree shelters as compared to the controls (Table 2). It appears that either brush control or tree shelter treatments are sufficient to maintain survival above 80 percent for the first six growing seasons after establishment. Therefore, tree shelters are not necessarily required to maintain acceptable survival rates for planted northern red oak on this site.

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

Treatments	Survival	Total Height	Height Increase[2]	DBH[3]
	-- (%) --	-- (in) --	-- (in) --	-- (in) --
Main Plots				
Brush Control	83a	75a	11a	0.5a
No Brush Control	73a	80a	12a	0.5a
Split Plots				
Shelter	84a[4]	87a[5]	11a	0.6a[6]
No Shelter	73b	68b	12a	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.
[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.
[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.
[5] Total height was significantly different at P<0.0011.
[6] DBH was significantly different at P<0.0029.

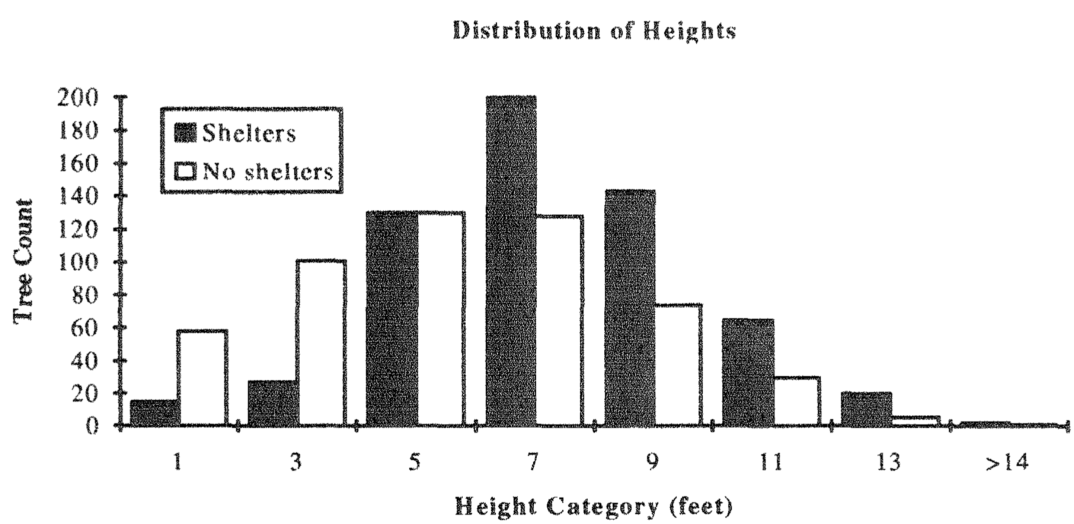

Figure 1: Height distributions of sheltered and unsheltered northern red oak seedlings after the sixth growing season. (The mid-range of each category is indicated on the x-axis. Distributions of the two classes of seedlings differ significantly based on Chi-square ($X^2 = 135$, $p < 0.0001$).

Although the analysis of the third year data affirmed the potential benefit of tree shelters on early growth and total tree height, sixth year results show no growth differences among treatments (Figure 2). Sheltered northern red oak seedlings have maintained an average height advantage of 19 inches, but growth rates between the treatments have stabilized. In the first three growing seasons, sheltered trees averaged over 11 in/year height growth, compared to less than 8 in/year height growth for unsheltered trees. In the last three years of the study, unsheltered trees grew over 11 in/year compared to less than 11 in/year for sheltered trees. In an earlier report on this study it was shown that increased linear stem elongation of the initial terminal flush was more important to total height growth than an increased number of flushes (Lantagne 1991). As would be expected, the latest results indicate that once these trees grew out of the shelter, overall terminal shoot growth slowed. This reduction in growth has been documented for northern red oak seedling sprouts that were clipped at ground level and placed in tree shelters (Kittredge et al. 1992). Tuley (1983) reported sessile oak height growth also slowed after year three in a tree shelter experiment in Great Britain. Potter (1991) did not report third year height growth decline for other tree shelter studies conducted in Great Britain. However, the maximum number of growing seasons for tree shelter research reported in the literature is five (Potter 1991). In this study, it appears that the apparent growth stimulus of tree shelters was lost over the last three growing seasons, similar to that found by Tuley (1983).

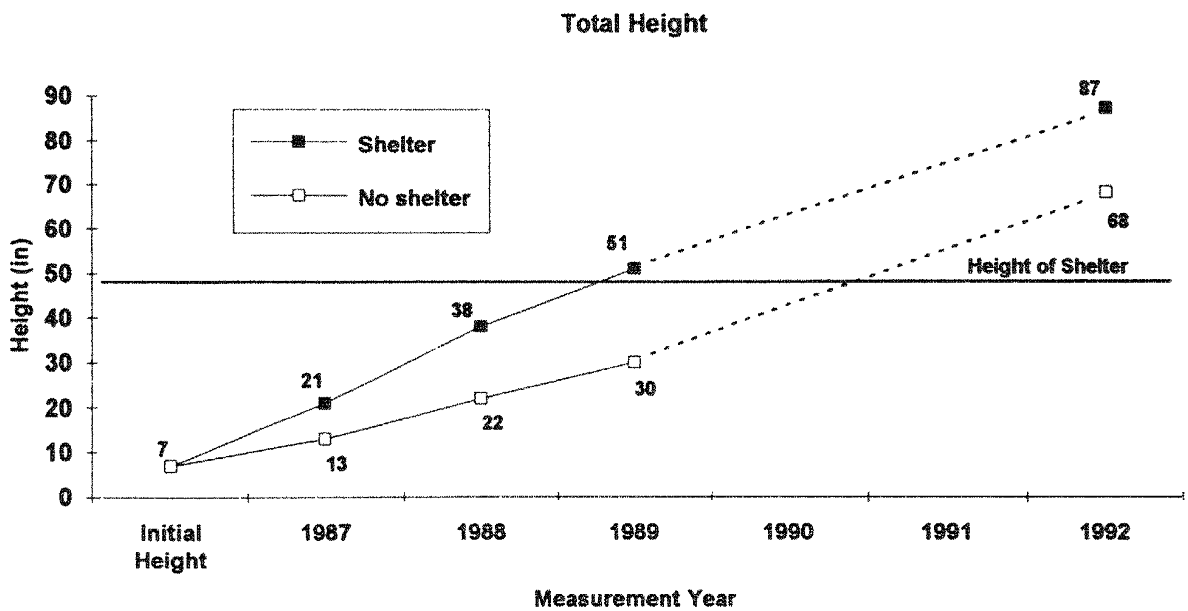

Figure 2: Mean Heights of surviving planted northern red oak seedlings. (All seedlings were top pruned at 7 inches above the groundline immediately following planting. Sheltered seedlings were significantly taller at the end of each growing season.)

The lack of a sheltered environment for the first flush may be the reason for reductions in average yearly height growth during the last three growing seasons. Tree shelters appear to increase the number of leaves available for photosynthesis (McNeel et al. 1993, Kittredge et al. 1992), and the length of time these leaves may remain active in producing photosynthate (Minter et al. 1992).

The interior of shelters have also been found to have elevated air temperatures, higher levels of CO^2 and a higher relative humidity which may contribute to the improved growth of sheltered seedlings (Minter et al. 1992, Potter 1991). In addition, trees protected from movement, as are seedlings in tree shelters, tend to grow taller and have smaller diameters (Rosenberg et al. 1983).

Although terminal shoot growth has slowed, the initial DBH measurements 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 (Rosenberg et al. 1983).

SUMMARY

Many sheltered and unsheltered trees continue to maintain codominant crown positions with competing vegetation on the study 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). The cost of using and maintaining tree shelters, and the problem of plastic litter remaining in the forest, have to be evaluated considering the level of survival and growth response of unprotected trees in this study. The minimum cost for the tree shelter materials was over $2.00 per tree in this 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 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 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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