To the Graduate Council:

I am submitting herewith a thesis written by Diane W. Graveline entitled "Growth and Protection of Selected Northern Red Oak Planted on Old Field Sites in Tennessee." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Garland Ray Wells, Major Professor

We have read this thesis
and recommend its acceptance

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

GROWTH AND PROTECTION OF SELECTED NORTHERN RED OAK PLANTED ON OLD FIELD SITES IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Diane W. Graveline

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ABSTRACT

Northern red oak (*Quercus rubra* L.) seedlings, produced through the efforts of The University of Tennessee Tree Improvement Program, Tennessee Division of Forestry, and the USDA Forest Service, are currently available to landowners for planting. However, very little is known about the response of these seedlings when planted for reforestation purposes, such as on old fields. Areas of land in Tennessee which have been abandoned, or are considered unsuitable for row crops, may be suitable for the production of northern red oak. In an effort to begin establishing planting guidelines for these promising oaks, seedlings from nine different genetic families were planted in spring 1995 on formerly established grass plots on nine marginal soil series at five branch experiment stations in Tennessee. The potential of many sites for the artificial regeneration, or reforestation, of northern red oak possibly could be determined since the soils are representative (i.e. droughty, eroded, poorly drained, etc.) of marginal soils found throughout the state. The objective of this research was to determine whether graded 1+0 northern red oak seedlings would survive and grow on soils unsuitable for cultivated row crops. Should families show a range of responses, genotypes could be isolated that will perform best on various soils.

White-tailed deer (*Odocoileus virginianus* Zimmermann) heavily browsed the planted seedlings regardless of location. An evaluation scheme was then developed so that browse damage could be efficiently rated in the field according to its severity. Significant differences in growth and survival were found among seedling groups at various levels of damage. Correspondingly, a second study was initiated in spring 1996 to determine whether similar seedlings, grown and graded under the same protocol and planted on old field sites, could be protected from white-tailed deer. Four commercial repellents were applied to field-planted 1+0 northern red oak seedlings from six different genetic families. Six treatments, including Tubex® 1.2 m tree shelters and an untreated control, were replicated three times at separate plots on the Chuck Swan Forest and Wildlife Management Area in Union County, Tennessee. Two months after planting, damage by deer was evident in all treatment areas except those seedlings in the tree shelters. Results from one growing season show that neither Tree Guard™ nor Pro-Tec Garlic Sticks conferred significant protection. Repellents were reapplied during the growing season. Three months after planting, the most heavily browsed seedlings were located in the control plots (81%), the Tree Guard™ plots (78%), and the Pro-Tec Garlic Stick plots (57%). Seedlings planted in tree shelters had not incurred any damage by deer.

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CHAPTER I

INTRODUCTION

High-quality northern red oak (*Quercus rubra* L.) seedlings have been produced at the Tennessee Division of Forestry (TDF) nursery in Etowah, TN, through the efforts of The University of Tennessee Tree Improvement Programs, TDF, and the USDA Forest Service. Problems with natural oak regeneration, oak mortality and decline, and the threat of gypsy moth, only serve to intensify the need for the successful artificial regeneration of oak. Since these seedlings already are available to the public and will be planted on a variety of sites from old fields to clearcut areas, planting guidelines need to be established that will help landowners ensure the best survival and growth of their seedlings.

The objective of this research was to determine whether graded 1+0 northern red oak seedlings from different genetic families would survive and grow on soils unsuitable for cultivated row crops. For purposes of this research, these soils will hereafter be referred to as marginal soils. It was hypothesized that the potential of many sites for northern red oak possibly could be determined since the soils, selected in a previous study (Fribourg et al. 1989), are representative of marginal soils found throughout the state. It was further hypothesized that should families show a range of responses, genotypes possibly could be isolated that will perform best on various soils.

Seedlings at all planting locations incurred extensive damage by white-tailed deer (*Odocoileus virginianus* Zimmermann). Since this damage further complicated the study design, an attempt was made to quantitatively record damage done by deer, and to study the effects of the damage on growth rates of these seedlings. A second study was then established in spring 1996. This study was designed to determine whether graded 1+0 northern red oak seedlings planted on old field sites could be protected from deer and, if so, whether seedlings from different genetic families would show varying responses to different treatments.

CHAPTER II

LITERATURE REVIEW

Distribution, range, and importance of oaks

Quercus is the largest tree genus in the United States and is the most important hardwood genus. Of the estimated 500-600 species of oaks, most occur in the northern hemisphere (Smith 1992). In the United States, oaks are the dominant forest cover types in central and southern upland forests and are a major component of eastern deciduous forests. Most oaks are found in mixed stands with other hardwoods or pine and occupy approximately 38 percent of the forested land in the eastern states (Nebeker et al. 1992).

The natural range of northern red oak stretches across several climatic and ecological regions in the Eastern U.S. and Canada (Johnson 1994). It is commonly found east of the Mississippi River, except in Florida, southern Alabama and Georgia, and the eastern part of the Carolinas. Scattered areas of northern red oak also can be found in southern Mississippi and Louisiana. In the West, it is found in most of Minnesota, eastern Oklahoma, eastern Kansas, eastern Nebraska, and all of Iowa except in the northwestern part of the state. To the North, it is found in Cape Breton Island, New Brunswick, Nova Scotia, and in southern Ontario and Quebec (Millers et al. 1989).

Oaks are not only abundant, they are useful in a variety of ways. Many oaks are of great economic importance and the wood of oak is well known for its durability, beauty, and strength. Oaks are used for many commercial purposes including railroad ties, veneer (furniture and interior paneling), flooring, fence posts, kitchen cabinets and pulpwood.

Northern red oak is even a useful species for firewood because it has a high fuel value (Millers et al. 1989). Oaks are also important for wildlife. Oak forests not only provide habitat for wildlife, they provide acorns that are a primary source of hard mast which many animals, birds, and insects feed upon. In addition, oaks have high aesthetic values and uses both in rural and urban areas. They are long-lived, durable, and are treasured for their majestic beauty. Oak forests also are important for providing diverse recreational opportunities to a variety of people. Many recreational activities, such as camping, hiking, and hunting, occur in forests dominated by oaks.

Reduction of the oak component in eastern forests

Oak mortality and decline contributes to the decreased stocking level of northern red oak in Tennessee and the Southern Appalachians. In general, oak decline is characterized by a wide variety and progression of symptoms, the most common being the progressive dieback of branches from the tips. Since the early 1900's, major oak mortality or decline events have been reported in regions representing nearly the entire range of oak in the Eastern U.S. (Starkey et al. 1989). Large areas of mortality in New England and the Appalachian Mountains occurred in the early part of this century. From 1856 through 1981 more than twenty-six decline events were reported from eight eastern states (Millers et al. 1989). The distribution maps of these mortality events show that parts of east Tennessee and the southern portion of the Appalachian Mountains have been involved in every decline event that was recorded from the pre-1950's through 1986. In Tennessee, forest resource reports from 1991 show the amount of growing stock that dies has doubled since 1990, and nearly two-thirds of the increase in mortality is occurring in oaks, mostly red oaks (Nebeker et al. 1992).

Unintended conversions of oak stands to other more shade-tolerant species also contributes to the reduction of the oak component in forests of the Eastern United States. Oak stands, particularly those of red oaks, on good to excellent sites are increasingly being replaced by less desirable species after harvesting (Crow 1988, Johnson 1984, Lorimer 1992, McGee and Hooper 1970). The establishment of northern red oak is generally restricted to more open, mesic sites. Of the upland oaks, northern red oak is the least tolerant of drought and usually considered to be low or intermediate in tolerance of shade (Crow 1988). Competition control on these sites is very often needed to encourage rapid growth. The failure of northern red oak seedlings to exhibit rapid juvenile height growth is the principal cause of regeneration failures. This lack of early growth does not allow northern red oak to compete with faster growing vegetation (Beck 1970, Loftis 1979, Lorimer 1992, Olson and Hooper 1972, Russell 1973).

Gypsy moth (*Lymantria dispar* L.) is also a major threat to oak forests in the Eastern U.S. (Campbell and Schlarbaum 1994). Stands that are most susceptible to attack are those with a high proportion of oaks, since oaks are the preferred host of the moth (Gottschalk 1993). Defoliation by gypsy moths causes trees to drain energy reserves in attempting to refoliate, but a healthy tree can usually withstand several defoliations. Three years or more may be required before stand growth recovers from a single defoliation (Twery and Gottschalk 1989).

Artificial regeneration of northern red oak

One method that has been used to increase the oak component in forest stands, or for reforestation purposes, is the artificial regeneration of oak. Even though large within-species and within-family genetic variability results in the non-uniformity of response to management treatments, artificial regeneration may offer the best solution to many oak regeneration problems (Pope 1992). Johnson (1984) planted northern red oak and demonstrated that the artificial regeneration of oak can be successful on good sites in the Ozarks. However, early attempts at artificial regeneration of oaks, especially on upland sites, were not successful (McGee and Loftis 1986, Olson and Hooper 1968) and lack of success was probably related to quality of the planting stock (less than desirable size), and kind and amount of competition.

Russell (1973) stated that the planting of northern red oak will be practical only if growth rates can be increased sufficiently, through genetic improvement or other measures, to offset the high costs of competition control. McGee and Loftis (1986) concluded that the planting of red or black oak could become a viable regeneration alternative if techniques could be developed to accelerate height growth. Genetic selection for early height growth is thought to be a practical technique to enhance planting success (Bailey et al. 1992).

Grading of northern red oak planting stock

One important element to successful oak regeneration is developing large root systems that can produce vigorous sprouts (Crow 1988). In addition to the problems of slow juvenile growth and intense competition, seedlings that were commonly planted were smaller and were graded based only on aboveground characteristics. The use of large vigorous nursery stock to partially offset the problem of slow juvenile growth was recommended by Gordon (1988), Larson (1977), Teclaw and Isebrands (1992), and Wendel (1980). Research has shown that nursery practices of grading bare-root hardwood seedlings based only on shoot characteristics (e.g., height and diameter) have not provided adequate planting stock (Thompson and Schultz 1995). The morphological grading of northern red oak seedlings based on root system characteristics, as well as those of the shoot, could greatly increase growth and survival of planted seedlings (Johnson 1992, Kormanik 1986, Ruehle and Kormanik 1986, Stroempl 1985, Thompson and Schultz 1995). Schultz and Thompson (1992) found that at the end of the fourth year in the field, height and diameter growth were significantly related to the initial number of first order lateral roots (FOLR), and recommended that the root system for northern red oak should consist of five or more FOLR if the outplanted seedling is expected to survive and become a competitive grower.

Protection of planted seedlings

In regions where browse pressure by herbivores is a concern, measures must be taken to protect planted seedlings. If a seedling is already under stress, further reductions in photosynthetic production due to foraging certainly could increase seedling mortality (Crow 1988). Severe browsing of tree seedlings by white-tailed deer in many sections of Pennsylvania has resulted in complete regeneration failures (Butterworth and Tzilkowski 1990, Marquis 1981). Auchmoody and Walters (1992) stated that the planting of northern red oak in northwestern Pennsylvania would only be feasible if the seedlings could be protected from deer. In a study done by Meyers et al. (1989) with planted northern red oak, browse damage was identified as a serious problem, but no quantitative measurement of the effect of browsing on height growth or survival was made.

Several researchers have found that tree shelters can be used to enhance the height growth of northern red oak seedlings (Hix 1994, Lantagne 1991, Minter 1992, Ponder 1995, Smith 1993). Results of a study done by Kitteredge (1992) indicate that a potential exists for the use of tree shelters in New England mixed hardwood stands where large red oak natural regeneration exists, but is prevented from developing in height by browsing herbivores. Hix (1994) reported that the underplanting of northern red oak appears to be an effective way of supplementing natural regeneration in the central Appalachians, although there are concerns that the high cost of shelters may limit their use in extensive forest management applications. Minter (1992) found that shelters also may be appropriate for enrichment plantings immediately following clearcutting on the good-to-excellent

Appalachian hardwood growing sites where the objective is to increase or establish a small oak component in the next stand.

Aside from tree shelters and fencing, very little research has been done on protecting oak from browsing by white-tailed deer. Several types of plastic or wire tubes were tested on natural hardwood seedlings in Pennsylvania, and the most promising devices were a 4- to 6-inch diameter plastic tube with small mesh, and a 12-inch diameter chicken wire tube (Marquis 1977). Harris (1983) conducted a preliminary screening of fourteen white-tailed deer repellents in pen trials and identified meat meal, Big Game Repellent (BGR), feather meal, Hinder, hot sauce, and several thiram repellents (Chew-Not, Chaperone, Gustafson 42-S, and Spotrete-F) as the most effective. Odor and taste repellents were tested on apples and apple shoots in Virginia, and results showed that repellents were not very effective for reducing browse damage to highly desirable food materials under very high deer pressure. BGR, Hot Sauce (Capsaicin 2.5%), and Lifebouy soap (scented or unscented) were the most effective, but they repelled deer for only 1-6 days (Byers et al. 1989). Experiments conducted by Swihart and Conover (1990), and Milunas et al. (1994) to protect ornamental shrubs and mature apple trees from damage by white-tailed deer found that BGR was the most effective compound that has consistently reduced damage to vegetation in controlled experiments. Farigone and Richmond (1995) compared the effectiveness of Hinder Deer and Rabbit Repellent (with and without Vapor Guard) and Safer Insecticidal Soap for protecting dormant apple trees from winter browsing by deer. Both repellents afforded some protection, however, the additional cost of the Vapor Guard sticker only appeared to be warranted on sites where deer pressure was expected to be intense. Hygnstrom and Craven (1988) protected cornfields with three single-strand electric fences and two commercial repellents, Hinder and Magic Circle. They found that deer pressure and the interaction between deer pressure and treatment effect accounted for 81% of the variability in loss of corn yield attributed to deer damage in the treatment fields. Because of the prohibitive cost of applying repellents to large areas, they recommended the use of single-strand electric fences for reducing deer damage in corn fields. A wide variety of commercial repellents, home remedies, scare devices, and fences are available to protect gardens, ornamental plants, fruit trees, row crops or nursery stock. Research has shown that no technique will be 100% effective for controlling damage. A combination of several techniques may be required to significantly reduce damage by white-tailed deer (King 1994).

CHAPTER III

STUDY AREAS

Marginal Soils Study-1995

Seedlings for the 1995 Marginal Soils Study were planted at five University of Tennessee branch experiment stations in Tennessee (Figure 1). These sites were used in a previous study and were selected in 1983 to represent different physiographic regions of the state and to have some characteristics of marginality: subject to flooding, eroded, droughty, or poorly drained (Wells and Fribourg 1992). Planting sites were located on formerly established grass plots on eight marginal soil series and one control (Table 1). Branch station and soil series names are as follows: Ames Plantation, Alamo series (APA), Lexington series (APL), Memphis series (APM), and Ruston series (APR); Cumberland Forest, Philo series (CFP), and Wolftever series (CFW); Oak Ridge, Armuchee series (ORA); Tullahoma, Dickson series (TFD); and West Tennessee, Collins series (WTC).

Deer Repellent Study-1996

Seedlings for the 1996 Deer Repellent Study were planted at the Chuck Swan State Forest and Wildlife Management Area in Union County, Tennessee (Figure 1). It is located approximately one and a half hours driving time north of Knoxville on Highway 33. This 24,831 acre area is jointly managed by the Tennessee Division of Forestry and

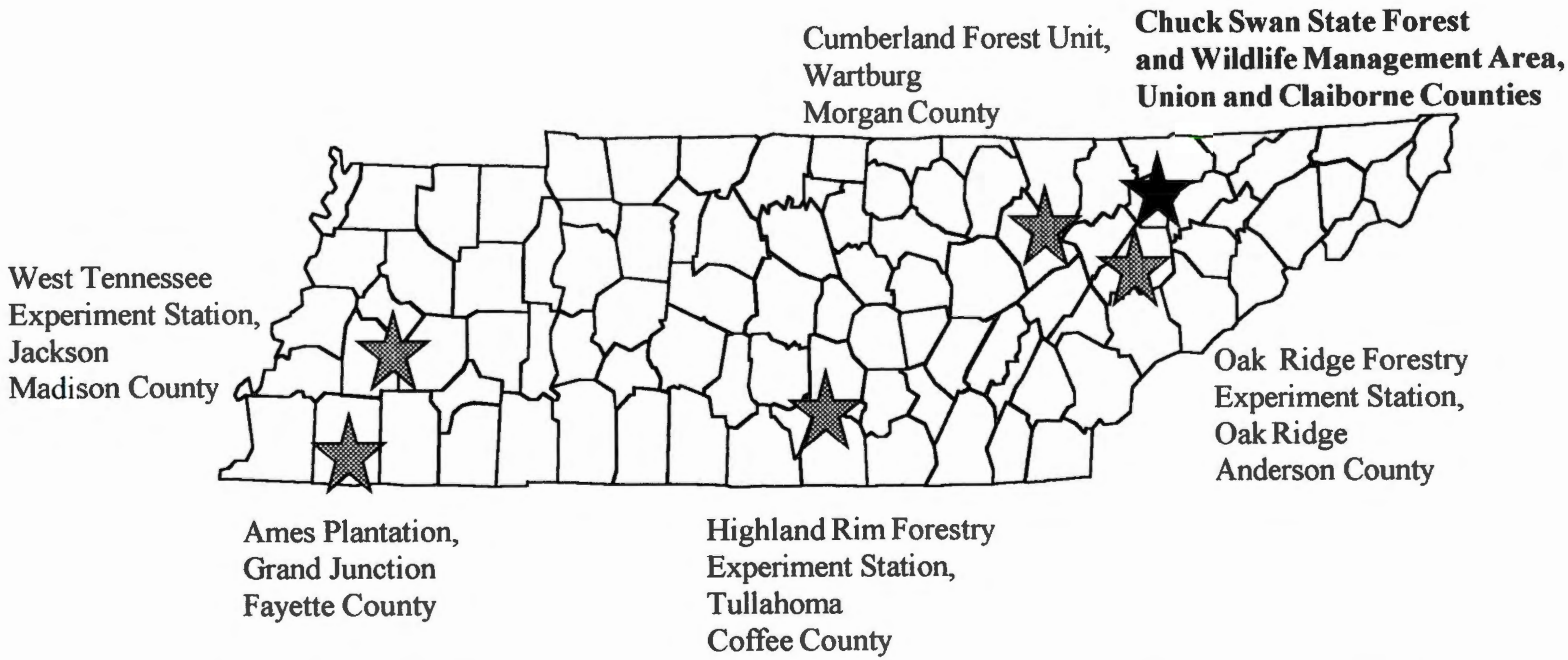

Figure 1. Locations of the five branch experiment stations used for the 1995 Marginal Soils Study, and the location of The Chuck Swan State Forest and Wildlife Management Area used for the 1996 Deer Repellent Study.

Table 1. Experiment station, soil series, and characteristics of soils used in the 1995 Marginal Soils Study.

Experiment Station	Soil Series and General Characteristics
Ames Plantation	Alamo; poorly drained
Ames Plantation	Lexington; droughty, eroded, steep and eroding
Ames Plantation	eroded Memphis[a]
Ames Plantation	Ruston; steep, severely eroded, very droughty
Cumberland Forest	Philo; poor internal drainage
Cumberland Forest	Wolftever; poor internal drainage, flooding
Oak Ridge	Armuchee; steep, rocky, eroded, droughty
Tullahoma	Dickson; poorly drained, subject to extremes of drought and wet conditions
West Tennessee	Collins; stream bottom, winter and spring flooding, poorly drained

[a] Control site -not marginal

the Tennessee Wildlife Resources Agency. Initially named the Central Peninsula Forest, it was part of the land acquisition by the Tennessee Valley Authority (TVA) prior to the construction of Norris Dam. Historical land use indicates that approximately half of this area was cultivated as part of small farms. Timber inventories and experimental forestry work began on the area around 1934. Recreational development and game management started later, in 1947, and since the area is known to have a large deer population, incidence of browse damage was expected. Many wildlife food plots and fields are maintained on the area to supplement natural habitat. In an effort to plant seedlings under open conditions similar to the marginal soils study, eighteen old field plots were located and flagged for planting. Twelve plots were predominately fescue, three plots had been invaded by blackberry (*Rubus* spp.), and three plots had been planted to lespedeza (*Lespedeza* spp.).

CHAPTER IV

MATERIALS AND METHODS

Marginal Soils Study-1995

Origin of seed source

Acorns for this study were collected from the USDA Forest Service northern red oak seedling seed orchard on the Watauga Ranger District of the Cherokee National Forest in Johnson County, Tennessee. This orchard was initially established by the Tennessee Valley Authority (TVA) as a progeny test using open-pollinated families from phenotypic selections and subsequent seed collections made in five states throughout the Tennessee Valley region. Seedlots were collected from nine mother trees in the orchard (pollen parent seed source unknown), representing nine genetic families (Table 2). Acorns were planted by family at the Tennessee Division of Forestry (TDF) nursery near Etowah in February 1994 at a density of 280 acorns m². Seedlings were grown without undercutting or top-pruning under the standard hardwood protocol used at the state nursery. During lifting operations in the fall of 1994, tap roots were undercut at a depth of 15.2 - 20.3 cm, and roots were laterally pruned to 30.5 cm in the nursery bed prior to lifting. Seedlings were then packaged and over-wintered in cold storage. Seedlings were made available for this study by The University of Tennessee's Tree Improvement Program.

Table 2. Genetic seed source locations for northern red oak used in 1995 Marginal Soils Study.

Family No.[a]	Orchard Identification No. (family, blocks, row, tree)	Seed Source[b]	Elevation (m) of origin of mother tree
100	100-1-10-1	Wise, VA	457
200	200-6-14-1	Limestone, AL	213
323	323-3-4-1	Trigg, KY	152
526	526-4-11-2	Morgan, TN	610
605	605-7-15-1	Buncombe, NC	1067
613	613-4-24-1	Transylvania, NC	1067
728	728-2-5-1	Franklin, TN	457
913	913-6-2-1	Henderson, TN	152
2459	2459-4-14-1	Claiborne, TN	366

[a] All acorns were produced at the Watauga Northern Red Oak Seed Orchard, Johnson County, Tennessee.
[b] Seed source refers to origin of mother tree; pollen parent seed source unknown.

Grading and selection of seedlings

Before outplanting in spring 1995, seedling stock was graded by the number of FOLR, stem form and bud set. Seedlings exhibiting good form and intact terminal buds were desired. Larger seedlings in good condition and having a minimum of six FOLR were selected for planting. Before planting, all lateral roots were manually pruned to 15.2 cm. Approximately two-thirds of the seedlings were culled by the grading process at the nursery.

Study design and plantation establishment

Seedlings were then outplanted in a split-plot incomplete block design on formerly established grass plots as described previously. The split-plot included two grasses per replication; bermudagrass (*Cynodon dactylon* L.) and tall fescue (*Festuca arundinacea* Schreb.), two common grass sods in Tennessee. The number of replications on each soil series had been previously determined by soil type in an earlier study done by Fribourg et al. (1989). The order in which families were planted in each replication was determined by the use of random number tables. The number of families per replication and soil series was determined by available space. Since all nine families were not planted in each replication or at every location, families were assigned to the five branch stations favoring nearby seed sources over more distant ones (Table 3). Seedlings were planted in five rows (each row a separate family) of eight tree plots on a 1.8 x 2.4 m spacing, with four seedlings on each of the two grass types. Because of seedling size, augers or shovels were

Table 3. Northern red oak outplanting locations by family and experiment station for 1995 Marginal Soils Study.

Experiment Station and Soil Series	Family No.	Replications
Ames Plantation	200, 323, 526, 728, 913	
Alamo (APA)		3
Lexington (APL)		3
Memphis (APM)		3
Ruston (APR)		2
Cumberland Forest	100, 526, 605, 613, 2459	
Philo (CFP)		2
Wolftever (CFW)		2
Oak Ridge	100, 200, 526, 728, 2459	
Armuchee (ORA)		4
Tullahoma	200, 526, 728, 913, 2459	
Dickson (TFD)		3
West Tennessee	200, 323, 526, 728, 913	
Collins (WTC)		3

used to ensure holes were big enough to accommodate the large root systems. A total of 1000 seedlings were planted for the Marginal Soils Study on five branch experiment stations; 440 at the Ames Plantation, 160 at the Cumberland Forest, 160 at Oak Ridge, 120 at Tullahoma, and 120 at West Tennessee.

Treatments

Glyphosate herbicide (Roundup®) was sprayed around each seedling one month after planting. After browse damage by deer became apparent in June, Pro-Tec Garlic Sticks were applied to each seedling at every location except Tullahoma. Damage by deer at the Tullahoma location was not evident until mid-summer, and garlic sticks were belatedly applied at that time.

Browse damage assessment

A browse damage rating system was developed for this study, to assess the severity of browse damage, and possibly to determine whether there were actual location or family differences. For maximum efficiency, no further measurements were taken. Instead, seedlings were assigned a subjective rating of 0 to 4, based on an ocular estimate of the deer browse damage (Table 4). Seedlings that were unbrowsed received a rating of 4, seedlings that had 25 percent or less damage were rated 3 (lightly browsed), seedlings rated 2 (heavily browsed) received damage from 26-75 percent, and seedlings damaged from 76-99 percent were rated 1 (severely browsed). Seedlings rated 0 (completely

Table 4. Browse damage rating system used to assess severity of browse damage to northern red oak seedlings.

Rating	Designation	Percent Damage
4	Unbrowsed	0
3	Lightly browsed	<25
2	Heavily browsed	25-75
1	Severely browsed	76-99
0	Completely defoliated	100

defoliated) appeared to be dead at the time of assessment, but could be capable of resprouting.

Data collection and statistical analysis

Height and root collar diameter (RCD) measurements were taken after outplanting, and at the beginning and end of each growing season for two years. Measurements of height were made to the nearest 0.1 cm and diameter was measured to the nearest 0.01 mm. Browse damage ratings were recorded for each seedling in late July 1995 and in late May 1996. Data for survival, field measurements, and browse damage ratings were analyzed using the Type III General Linear Model analysis of variance procedure of the Statistical Analysis System (SAS Institute, 1985) and comparisons were made using Tukey's Studentized (HSD) Range test. The sources of variation specified for the data were soil series (locations), genetic families, browse damage, all first- and second-order interactions, and a three-way interaction of location, family, and browse damage. Individual analyses of each location did not reveal family differences. Effects were deemed significant when the null hypotheses, using the residual term as error, were rejected at a $P \leq 0.05$. Dependent variables were survival, height growth, and diameter growth. Independent variables were locations, families, and the quantitative measurement of browse damage. Multiple linear regressions were calculated to identify the model with the largest fraction of the total variation due to the variables in the model (R^2) and the fewest significant independent variables.

Deer Repellent Study-1996

Origin of seed source and grading of seedlings

Acorns for this study also were obtained from the northern red oak seed orchard in Johnson County, Tennessee. Acorns from six open-pollinated genetic families were collected and planted at the TDF state nursery (Table 5). Northern red oak seedlings for this study were grown and graded under the same protocol as was presented for the marginal soils study above. Seedlings were lifted in fall 1995 and over-wintered in cold storage.

Study design and plantation establishment

Seedlings were planted on old field sites in spring 1996 in an unbalanced incomplete block design adapted from a balanced incomplete block design in Cochran and Cox (1957). Eighteen separate plots represented one of three replications of six total treatments. In a few cases where the plots were within 150 m of each other, treatments were arranged so that tree shelters or an untreated plot would separate any odor or taste repellent treatments in order to eliminate any possible interactions of repellents (Figure 2). All six treatments were replicated on seedlings from six genetic families (two families in each replication). After the plots were mown, a total of 288 seedlings were planted in late March on a 3 x 3 m spacing in two rows of eight tree plots per replication.

Table 5. Genetic seed source locations for northern red oak used in 1996 Deer Repellent Study.

Family No.[a]	Orchard Identification No. (family, blocks, row, tree)	Seed Source[b]	Elevation (m) of origin of mother tree
200	200-8-8-2	Limestone, AL	213
630	630-2-19	Campbell, TN	366
735	735-2-6	Franklin, TN	366
902	902-6-20	Henderson, TN	152
903	903-6-8	Henderson, TN	152
2459	2459-4-14	Claiborne, TN	366

[a] All acorns were produced at the Watauga Northern Red Oak Seed Orchard, Johnson County, Tennessee.
[b] Seed source refers to origin of mother tree; pollen parent seed source unknown.

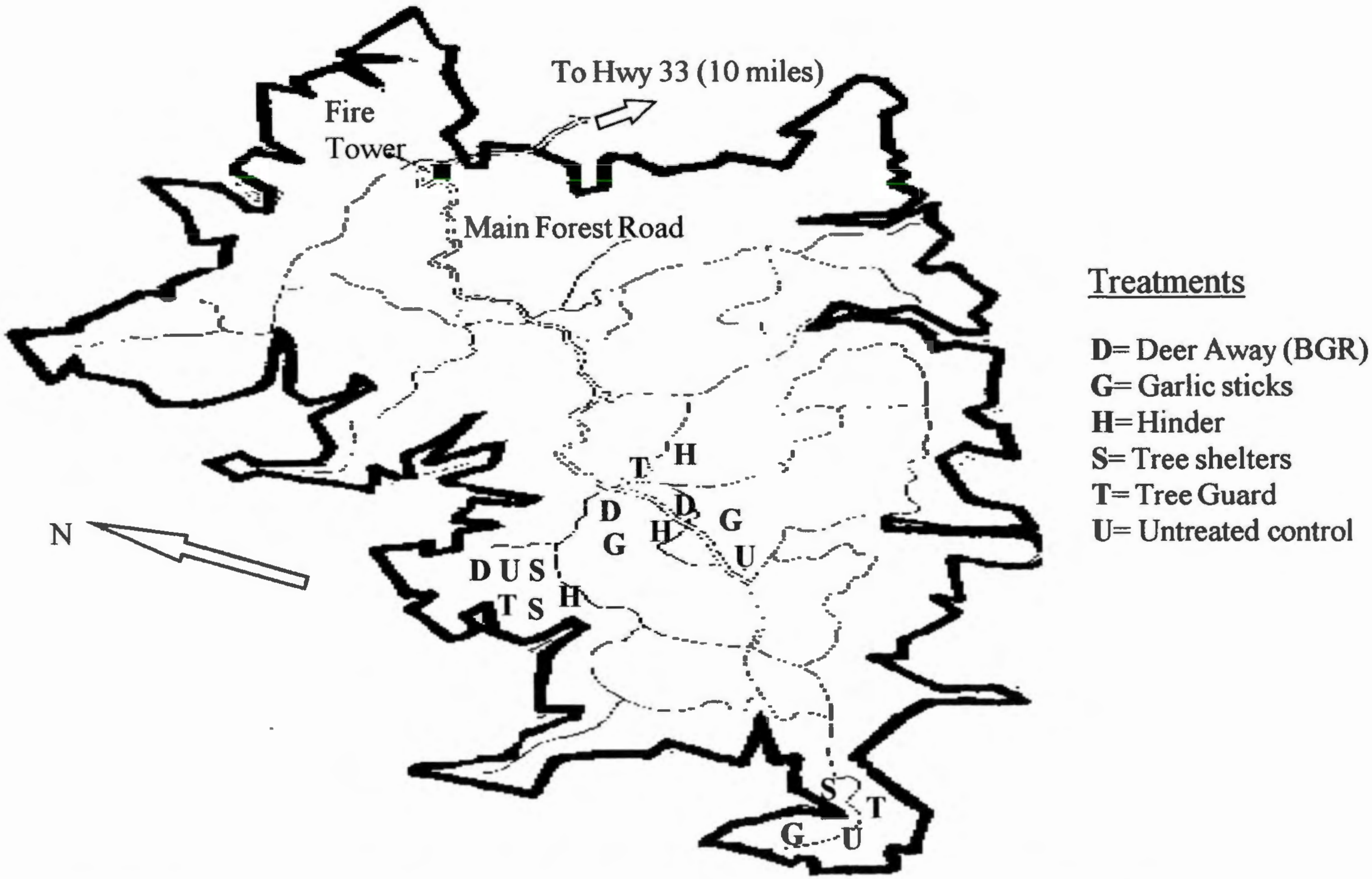

Figure 2. Map of Chuck Swan State Forest and Wildlife Management Area showing the distribution of deer repellent treatments.

Treatments

Four commercial repellents, Deer-Away® Big Game Repellent (BGR), Hinder® Deer and Rabbit Repellent, Nortech's Tree Guard™, and Pro-Tec Garlic Sticks were applied to the field-planted 1+0 northern red oak seedlings (Table 6). Tree Guard has not been approved for use in Tennessee, but permission was obtained from the Tennessee Agricultural Extension Service for its use for research purposes. Two other treatments were Tubex® 1.2 m tree shelters and an untreated control. Deer repellent treatments and tree shelters were applied at planting time according to the manufacturer's instructions. Tree shelters were installed using 3 m rebar in place of wooden stakes for easier maintenance. Steel support stakes are scheduled to be removed after the third growing season. Glyphosate herbicide (Roundup) was sprayed around each seedling approximately one month after planting. Seedlings treated with liquid spray applications of Hinder, BGR, and Tree Guard were re-treated 50 days after planting when new growth averaged 10 cm. Missing garlic sticks were also replaced.

Data collection and statistical analysis

Initial height and RCD were measured to the same specifications as were given above for the marginal soils study. Seedlings were monitored approximately every 10 days for signs of browse damage the first two months after planting, and browse damage ratings (as described for the 1995 study) were recorded for each seedling at the time of re-treatment. Browse damage ratings were then recorded three more times throughout May

Table 6. List of commercial deer repellents and their active ingredients used for the 1996 Deer Repellent Study.

Deer Repellent	Active Ingredient
Deer-Away® Big Game Repellent (BGR)	37% Putrescent whole egg solids
Hinder® Deer and Rabbit Repellent	15% Ammonium Soaps of Higher Fatty Acids
Pro-Tec Garlic Repellent Sticks	Garlic oil, chili pepper
Tree Guard™	0.02% Benzyldiethyl ammonium benzoate

and June. Data for survival and field measurements of the seedlings were analyzed using the same procedure as was presented for the 1995 study. The sources of variation specified for the data were treatments, genetic families, browse damage, all first- and second-order interactions, and a three-way interaction of treatment, family, and browse damage. Effects were deemed significant when the null hypotheses, using the residual term as error, were rejected at a $P \leq 0.05$. Dependent variables were survival, height growth, and diameter growth. Independent variables were treatments, families, and the quantitative measurement of browse damage. Multiple linear regressions were calculated to identify the model with the largest fraction of the total variation due to the variables in the model (R^2) and the fewest significant independent variables.

CHAPTER V

RESULTS

Marginal Soils Study-1995

Seedling survival

First-year survival rates were high, and ranged from 86 percent at Tullahoma, to 98 percent at two locations; Ames Plantation (APM), and the Cumberland Forest (CFW) site (Table 7). Survival by family ranged from 100 percent for family 613, to 85 percent for family 2459 (Table 8). Overall survival rates declined from 94 percent in the first year to 58 percent at the end of the second growing season. No differences in growth or browse damage were found between grass types. Location, family, browse damage ratings, all two-way, and three-way interactions were significant in terms of first-year survival ($R^2 = 0.52$).

Survival in the second growing season was highest at three Ames Plantation locations on the Alamo (APA), Memphis (APM), and the Ruston (APR) soil series sites, and ranged from 85 to 90 percent. Seedlings planted at the Oak Ridge (ORA), Cumberland Forest (CFW), and West Tennessee (WTC) sites exhibited survival rates less than 30 percent. Second-year survival by family ranged from 70 percent for family 913, to 31 percent for family 100. Variables which showed significance in terms of second-year survival ($R^2 = 0.82$) were location, browse damage rating 1995 (DR1), browse damage rating 1996 (DR2), and the two-way interaction of location by DR2. Two three-way

Table 7. Mean survival by location of northern red oak seedlings planted at five branch experiment stations in Tennessee for the Marginal Soils Study.

Experiment Station and Soil Series	Year[a] 1995	1996
	---------pct---------	
Ames Plantation		
Alamo (APA)	97a	90a
Lexington (APL)	92ab	78bc
Memphis (APM)	98a	88ab
Ruston (APR)	91ab	85ab
Cumberland Forest		
Philo (CFP)	98a	62d
Wolftever (CFW)	95a	29e
Oak Ridge		
Armuchee (ORA)	92ab	28e
Tullahoma		
Dickson (TFD)	86b	68cd
West Tennessee		
Collins (WTC)	97a	9f
Mean	94	58

[a]Means within a column with the same letter are not significantly different ($p<0.05$) using Tukey's Studentized Range (HSD) Test

Table 8. Mean survival by family of northern red oak seedlings planted in Tennessee for the Marginal Soils Study.

Genetic Family	Year[a] 1995	1996
	---------pct---------	
100	88cd	31d
200	97ab	67a
323	88bcd	62ab
526	96abc	62ab
605	98a	60ab
613	100a	53bc
728	97ab	54bc
913	95abc	70a
2459	85d	42cd
Mean	94	58

[a]Means within a column with the same letter are not significantly different ($p<0.05$) using Tukey's Studentized Range (HSD) Test

interactions of both DR1 and DR2 with family or location also were significant. Results obtained from correlation analyses reveal a strong relationship between second-year survival and browse damage assessments (DR1 and DR2) in both growing seasons.

Seedling growth

Seedlings planted at the Ames Plantation (APM) location, which served as the control and is not a marginal soil, outperformed seedlings at all other locations. Height growth in the first year ranged from approximately 10 cm at the control site (APM), to 0.7 cm at the Ames Plantation (APA) site. Height growth by family ranged from 2.7 cm for family 200, to 6.7 cm for family 605 (Figure 3). Families 323, 526, and 913 were the only families which showed an increase in height above their initial height. First-year height growth variables which were significant ($R^2 = 0.36$) were; location, family, DR1, and all two- and three-way interactions, except family by DR1.

Seedlings at three Ames Plantation locations (APM, APL, and APR), which exhibited high survival percentages, continued to increase in mean height in the second growing season (Figure 4). However, seedlings at most of the remaining sites did not increase in mean height, and were in fact, shorter than when planted due to browse damage. Increases in mean height during the second year only occurred at three locations and ranged from 22.6 cm at the control site (APM), to 3.7 cm at the APR site. Three families also showed positive increases in mean height during the second growing season, and ranged from 8.5 cm for family 323, to 3.8 cm for family 913. In terms of second-year

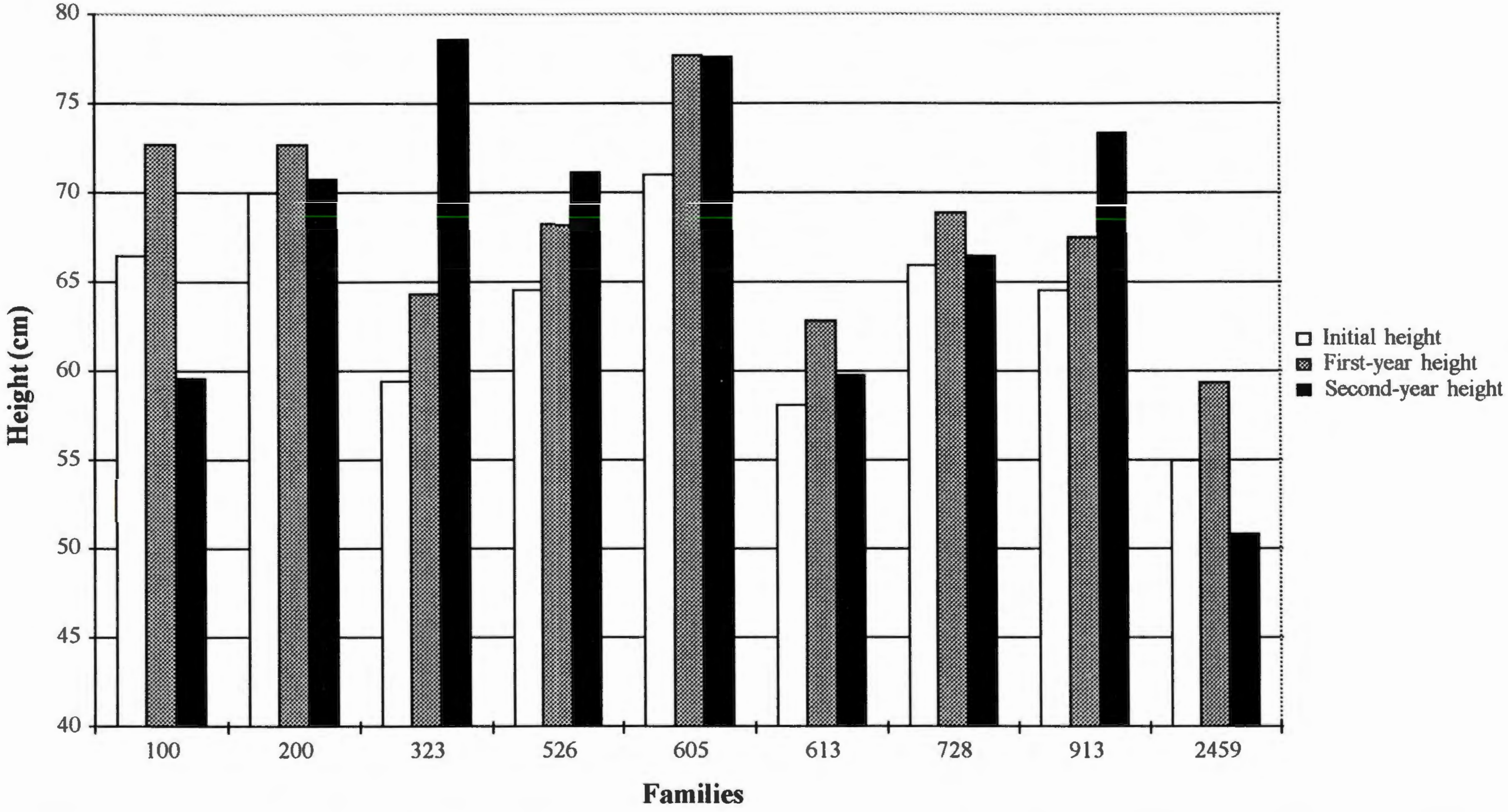

Figure 3. Initial, first, and second-year heights, by family, of northern red oak seedlings planted in Tennessee for the Marginal Soils Study.

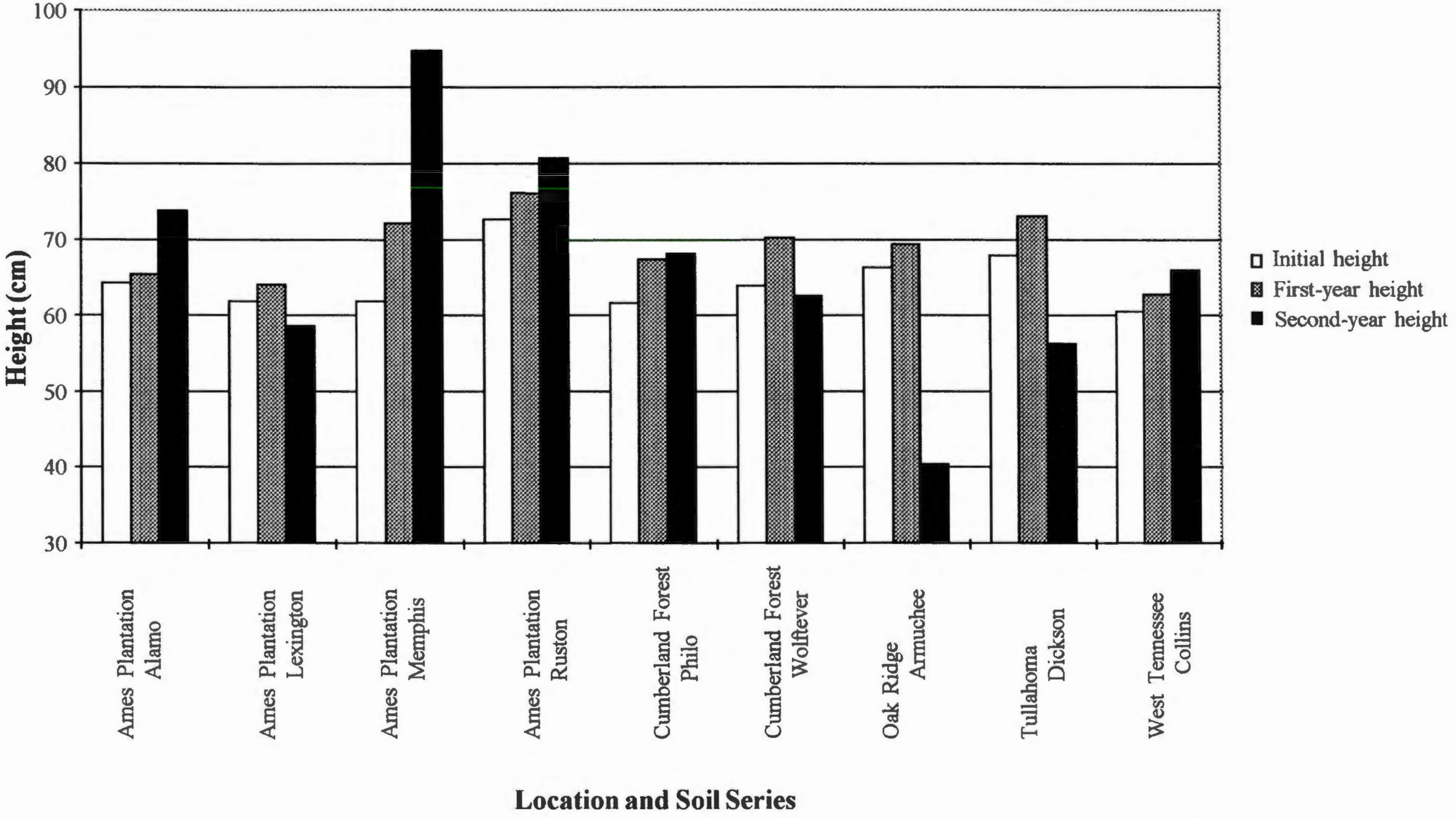

Figure 4. Initial, first, and second-year mean heights, by location, of northern red oak seedlings planted in Tennessee for the Marginal Soils Study.

and total height growth, only location, DR1, and DR2 variables showed significance in the models ($R^2 = 0.66$).

No differences in root collar diameter growth (RCD) were found among any of the families or locations in the first year. Correlation coefficients between height and diameter showed that RCD growth was related more to height growth in the first year, rather than the initial height of the seedlings. In the second growing season, variables of location, DR1, DR2, and location by DR2 were significant ($R^2 = 0.66$). The Ames Plantation (APM) site had the largest diameter increase in the second year, and growth ranged from 4.7 mm at this site, to 0.01 mm at the Tullahoma site.

Damage assessment

Variation in survival which could be attributed to browse damage was highly significant in both growing seasons. There were no differences in first-year survival by browse damage level among browsed seedlings rated 3, 2 or 1 (99, 99, and 96 percent). Survival of 72 percent for seedlings rated 0 (totally defoliated) was different than survival at all other browse damage level ratings. Second-year survival was significantly different for every level of browse damage. Survival was 100 percent for seedlings given a rating of 3 (lightly browsed), 87 percent for heavily browsed seedlings, and 64 percent for severely browsed seedlings. Of the seedlings that were totally defoliated in 1995, 96 percent did not change rank when rated in 1996, and mean survival of seedlings in this group dropped to 3 percent (Table 9). Strong relationships between survival and browse damage were not apparent in the first year (correlation coefficient of 0.34), however, the

Table 9. Mean survival by browse damage level of northern red oak seedlings planted in Tennessee for the Marginal Soils Study.

Damage Level	Year[a] 1995 Rating	1996 Rating
	---------pct---------	
0=Defoliated	72b	3d
1=Severe	96a	64c
2=Heavy	99a	87b
3=Light	99a	100a
Mean	**94**	**58**

[a]Means within a column with the same letter are not significantly different ($p<0.05$) using Tukey's Studentized Range (HSD) Test

correlation coefficients between second-year survival and browse damage in the first, and second year (0.66 and 0.73 respectively), increased substantially.

Differences in mean height due to browsing occurred between seedling groups rated 3 and 2 in both the first and second growing seasons (Table 10). There were no differences between seedling groups rated either 0 or 2 in the first year. Seedlings with the smallest increase in height in the first year, those rated 0 and 1 (completely defoliated and severely browsed), were not different in 1995 and 1996.

There were no differences in RCD growth among any of the four browse damage ratings which were assigned to seedlings in the first year. In the second year, seedlings rated 1 and 0 were not different from each other. Seedlings rated 2 and 3 showed the largest increase in diameter (1.4 and 3.5 millimeters, respectively) and were different from each other and from seedlings rated 0 or 1 (Table 10).

Deer Repellent Study-1996

Seedling survival

First-year survival was high. Survival across all treatments was 98 percent. Survival by treatment was 94 percent in the control, 96 percent for Hinder, 98 percent for Garlic sticks, and 100 percent for the tree shelter, Tree Guard, and BGR treatments. Correlation analysis did not reveal significant relationships between first-year survival and any of the measured variables of interest (treatments, genetic families, and browse damage).

Table 10. Annual and cumulative incremental height, and diameter growth, by four deer damage levels, of northern red oak planted in Tennessee for the Marginal Soils Study.

Damage Level	First Year[a]	Second Year	Cumulative (2 yrs)
		Height (cm)	
0=Defoliated	2.3bc	-12.6c[c]	-9.1c
1=Severe	0.9c	-17.4c	-15.3c
2=Heavy	3.0b	2.2b	7.3b
3=Light	7.4a	19.5a	26.3a
Mean	3.8	0.4	5.1
MSD[b]	1.9	12.0	12.4
		Diameter (mm)	
Defoliated	0.52a	0.06c	0.31b
Severe	0.50a	-0.19c	0.58b
Heavy	0.48a	1.43b	2.10b
Light	1.09a	3.47a	4.66a
Mean	0.68	1.39	2.13
MSD[b]	0.61	1.31	2.46

[a]Means within a column with the same letter are not different ($p<0.05$) using Tukey's Studentized Range (HSD) Test
[b]Minimum Significant Difference ($p<0.05$)
[c]Negative values represent a deviation from initial measurement due to browsing

Seedling growth

Differences in height growth attributed to treatment were apparent. Mean height growth ranged from 0.6 cm in the control, to 52.8 cm for seedlings in tree shelters (Table 11). Seedlings treated with two commercial repellents, Hinder and BGR, showed favorable growth of 13.1, and 9.1 cm respectively. Seedlings in tree shelters had substantial increases in height the first year, and were different from all other treatments. Forty-eight percent of seedlings in the tree shelters had grown out the top of the shelter approximately twelve weeks after planting.

Diameter growth across all treatments was 1.0 millimeter. The largest increase in diameter was recorded in the BGR treatment (1.4 mm), and the smallest was in the Garlic stick plots (0.6 mm). Seedlings in tree shelters had the second largest increase in diameter, and apparently diameter growth occurred even when seedlings had large increases in height (Table 11).

Damage assessment

Differences in survival by browse damage level were apparent in the first growing season. Survival of seedlings with a damage level of 1 (85 percent) was different from that of seedlings rated 2, 3, or 4 (99, 100, and 98 percent). There were no seedlings rated 0 in this study. Comparison of browse damage percentages among the six treatments shows that tree shelters clearly surpassed all other deer repellent treatments (Figure 5).

Level of browse damage also was significant for height growth. Correlation analyses showed that height growth and browse damage relationships became stronger

Table 11. Height and diameter growth of northern red oak planted at Chuck Swan Forest and Wildlife Management Area by treatment and deer damage level.

Treatment	Mean[a]	Damage Level			
		1= Severe	2= Heavy	3= Light	4= Unbrowsed
				Height (cm)	
Deer Away	9.6bc	-25.5[c]	8.7	7.6	15.5
Garlic Sticks	5.6bc	-7.5	6.3	10.8	5.5
Hinder	13.1b	--	8.2	16.9	12.8
Tree Guard	5.8bc	0.00	5.4	10.8	--
Tree Shelters	52.8a	--	--	56.0	52.7
Untreated	0.6c	-6.7	2.5	--	--
Mean[b]	15.4	-8.3c	5.4b	12.9b	33.2a
				Diameter (mm)	
Deer Away	1.44a	0.06	1.32	1.57	1.57
Garlic Sticks	0.57c	0.32	0.54	0.64	1.50
Hinder	1.09ab	--	0.79	1.09	1.18
Tree Guard	0.78bc	0.10	0.69	1.70	--
Tree Shelters	1.14ab	--	--	1.00	1.15
Untreated	0.94abc	0.87	0.96	--	--
Mean[b]	1.01	0.55b	0.80ab	1.28a	1.25a

[a]Means within a column with the same letter are not different ($p<0.05$) using Tukey's Studentized Range (HSD) Test
[b]Means with the same letter within rows are not significantly different
[c]Negative values represent a deviation from initial measurement due to browsing

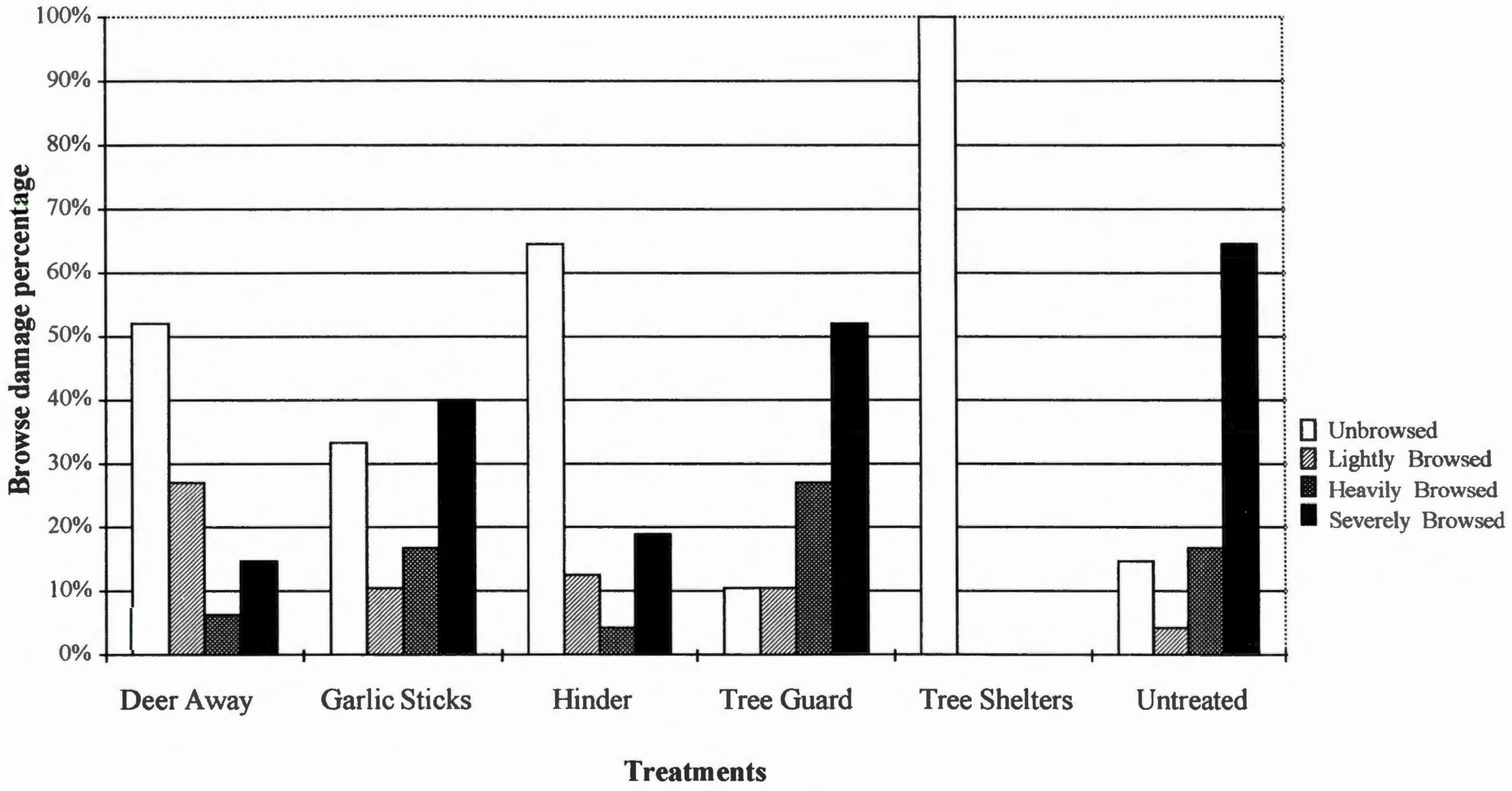

Figure 5. Comparison of four levels of browse damage among six treatments, three months after planting northern red oak at the Chuck Swan State Forest and Wildlife Management Area.

throughout the growing season. Correlation coefficients between final height and browse damage assessments increased from the first damage rating to the last (0.44 to 0.52). Seedlings rated 4 (unbrowsed) had a mean height growth of 33.2 centimeters and were significantly different from seedlings rated 3, 2, or 1. Seedlings rated 3 and 2 were not different from each other (12.9 and 5.4 centimeters), but were different from seedlings rated 4 or 1. Seedlings which received a rating of 1 (severely browsed) did not increase in height. However, only six percent of the seedlings fell into this category.

Percentage of browse damage varied greatly by treatment, and family within treatment. Although family by treatment effects were not significant statistically, observations reveal that certain families seem to perform better with specific repellents. Approximately fifteen weeks after planting, family 2459 remained unbrowsed in both the BGR and Hinder treatments (Figures 6 and 7). Garlic sticks and Tree Guard afforded less protection for the seedlings (Figures 8 and 9), however, family 200 was damaged less than the other seedlings. Untreated seedlings suffered the most damage (Figure 10), and of the seedlings which grew out the top of the tree shelters, very little damage was done (Figure 11).

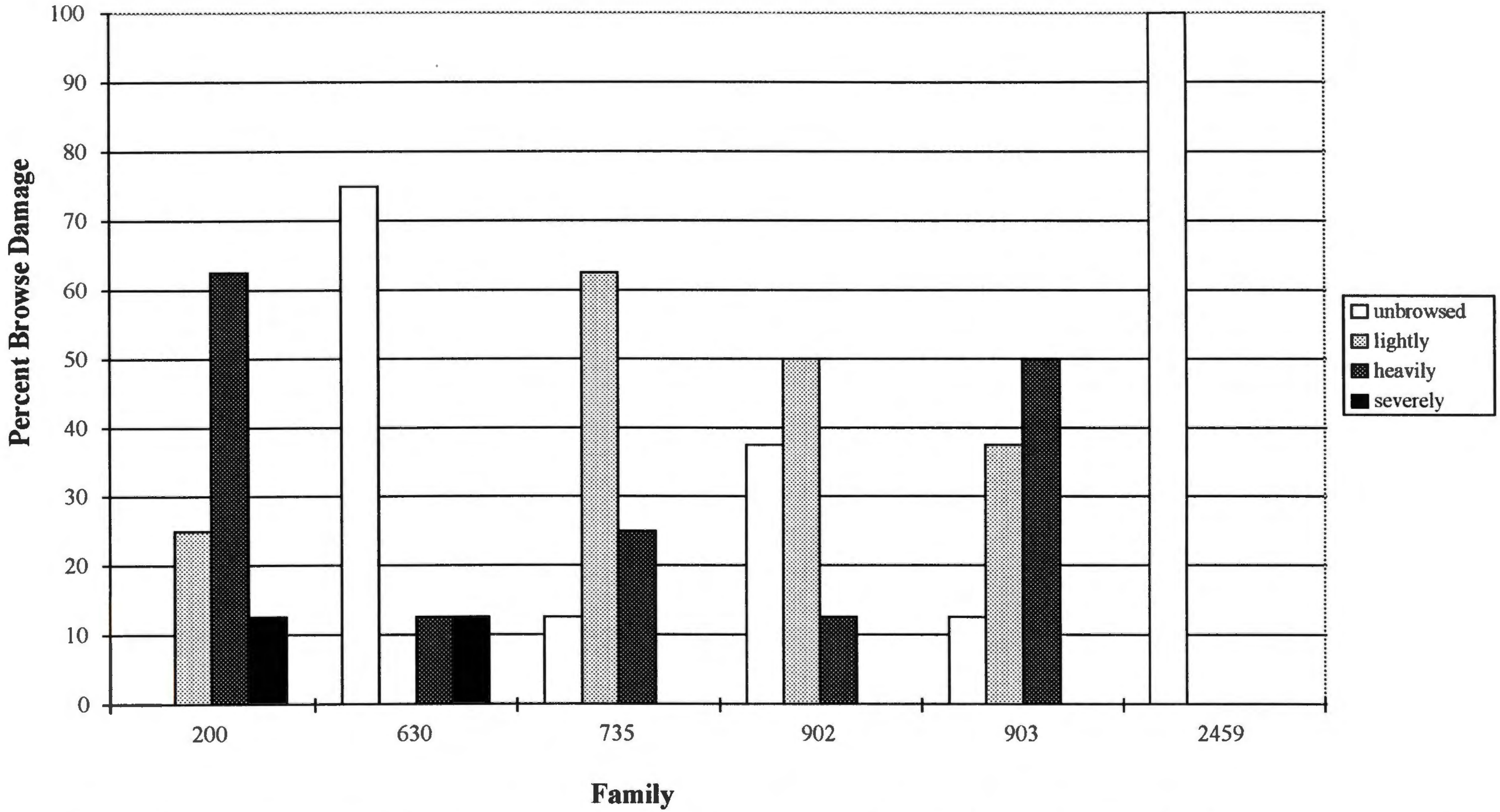

Figure 6. Percentage of four levels of browse damage, by family, for northern red oak seedlings treated with Deer-Away Big Game Repellent (BGR) and planted at the Chuck Swan State Forest and Wildlife Management Area.

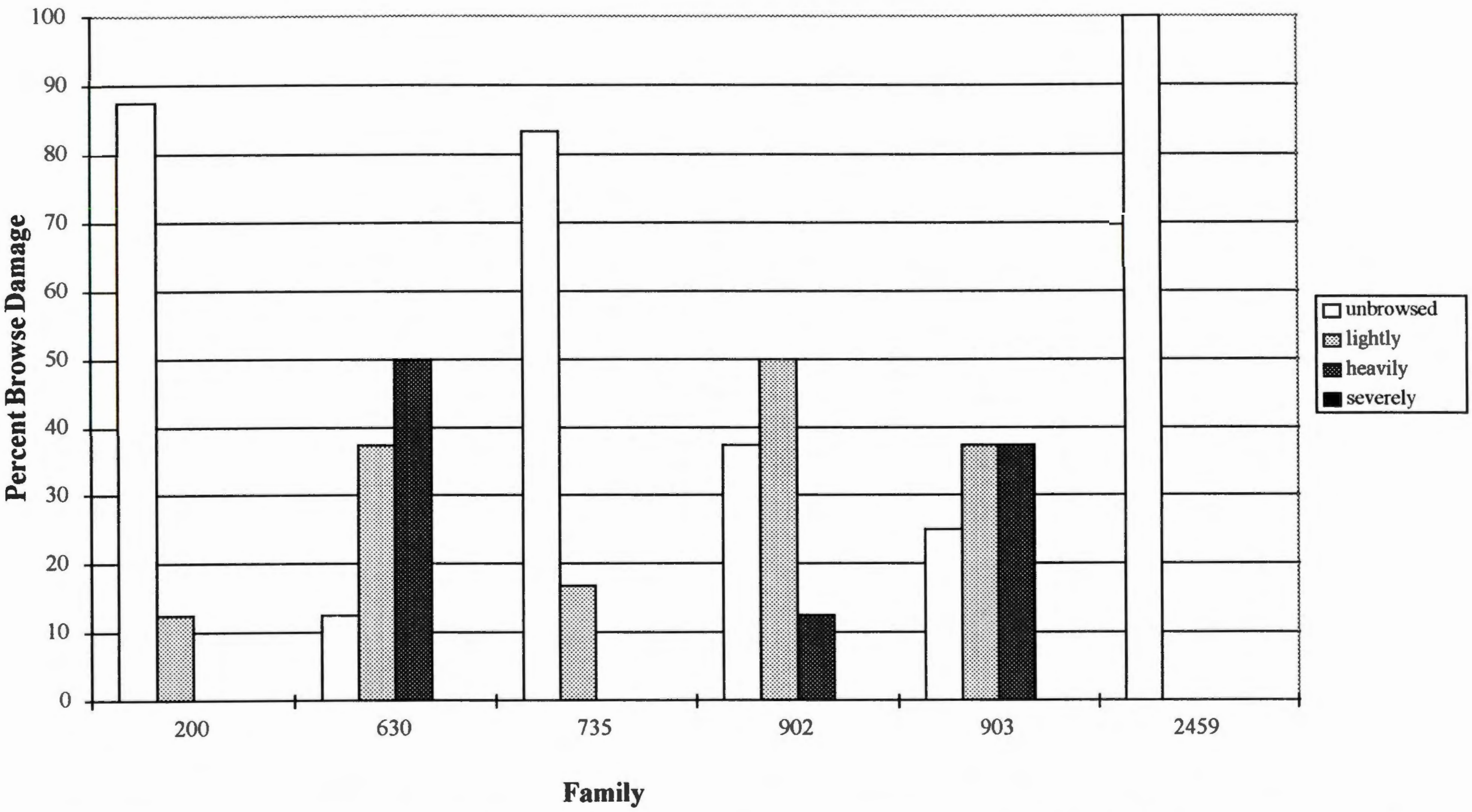

Figure 7. Percentage of four levels of browse damage, by family, for northern red oak seedlings treated with Hinder Deer and Rabbit Repellent and planted at the Chuck Swan State Forest and Wildlife Management Area.

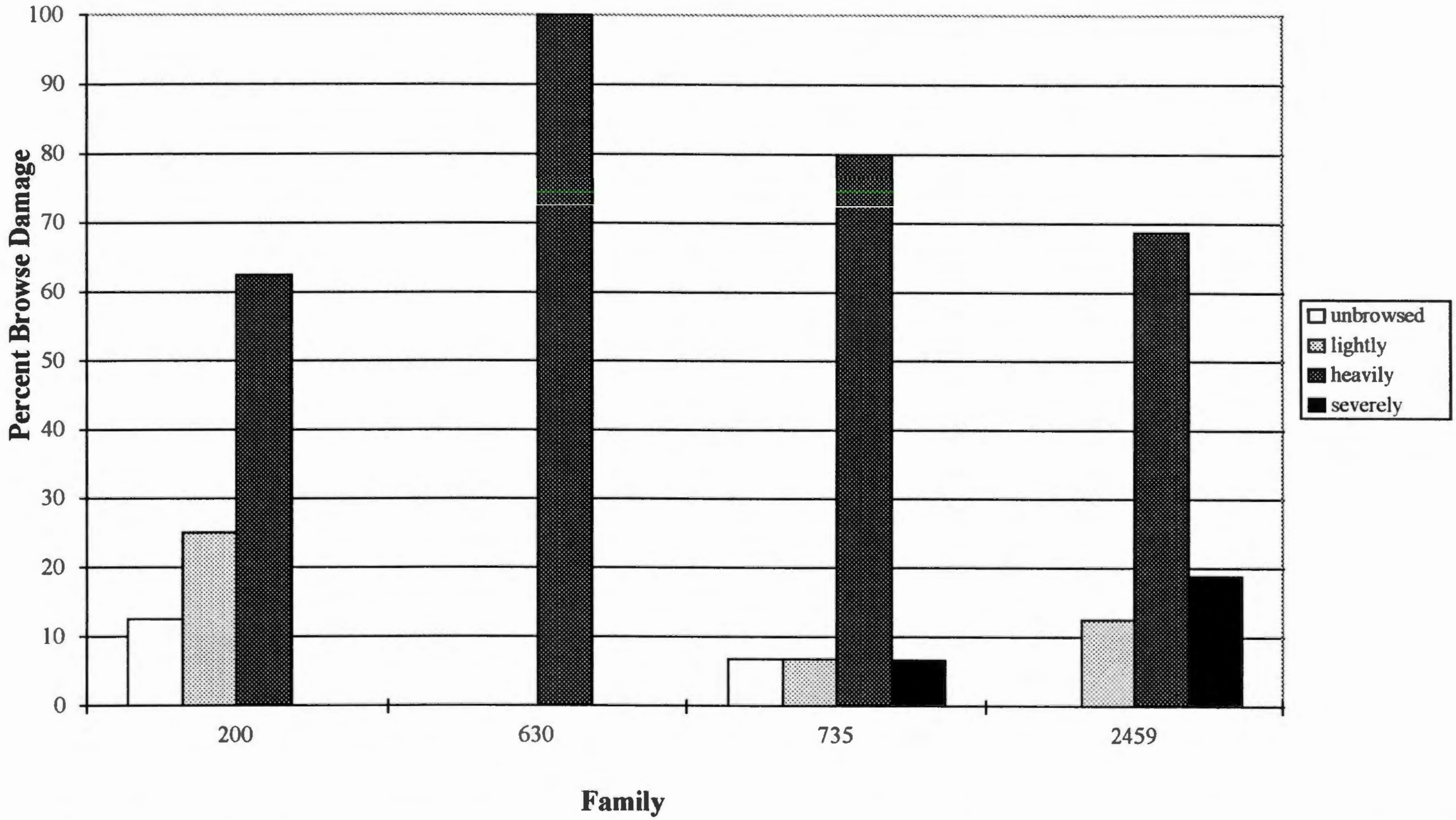

Figure 8. Percentage of four levels of browse damage, by family, for northern red oak seedlings treated with Pro-Tec Garlic Sticks and planted at the Chuck Swan State Forest and Wildlife Management Area.

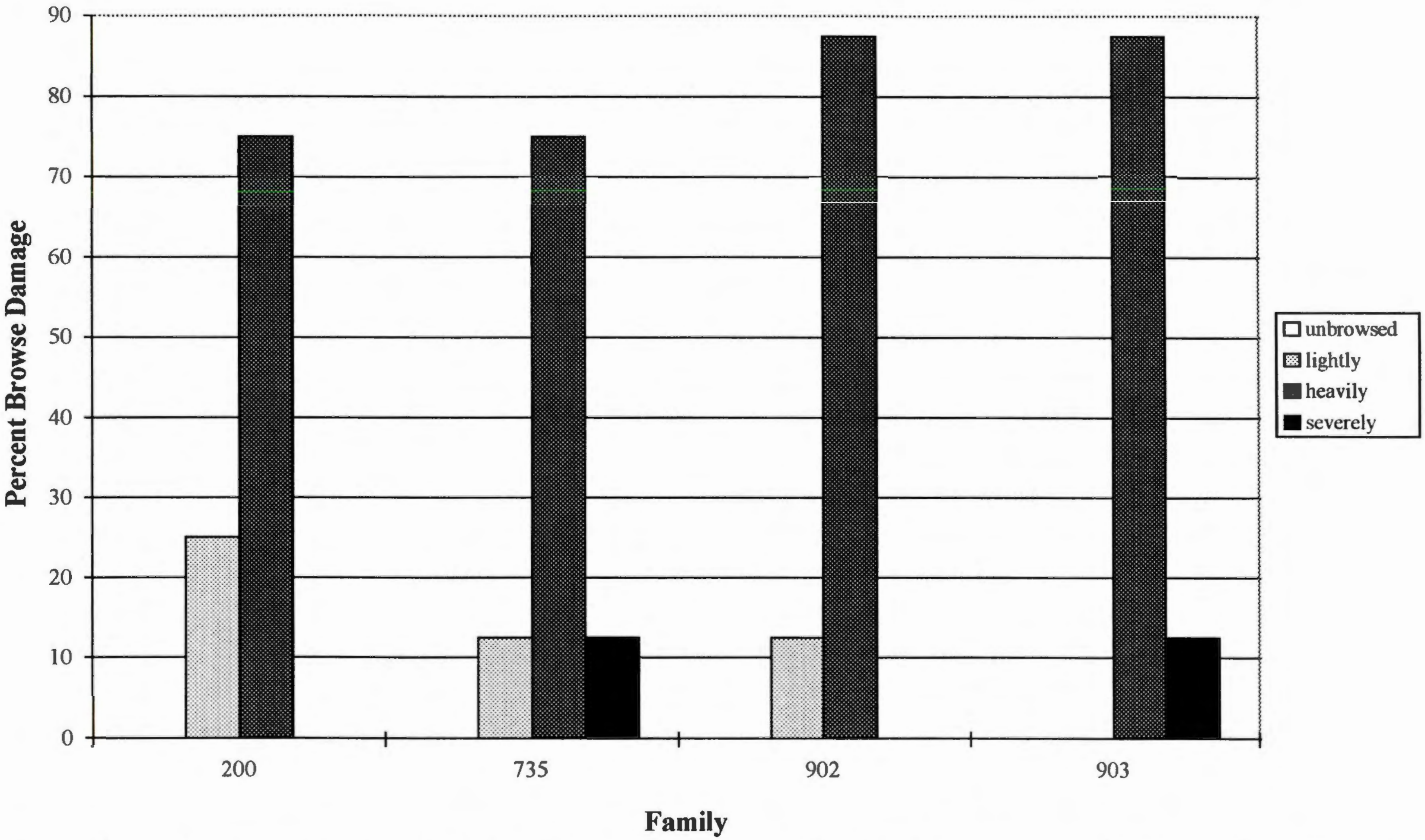

Figure 9. Percentage of four levels of browse damage, by family, for northern red oak seedlings treated with Nortech's Tree Guard and planted at the Chuck Swan State Forest and Wildlife Management Area.

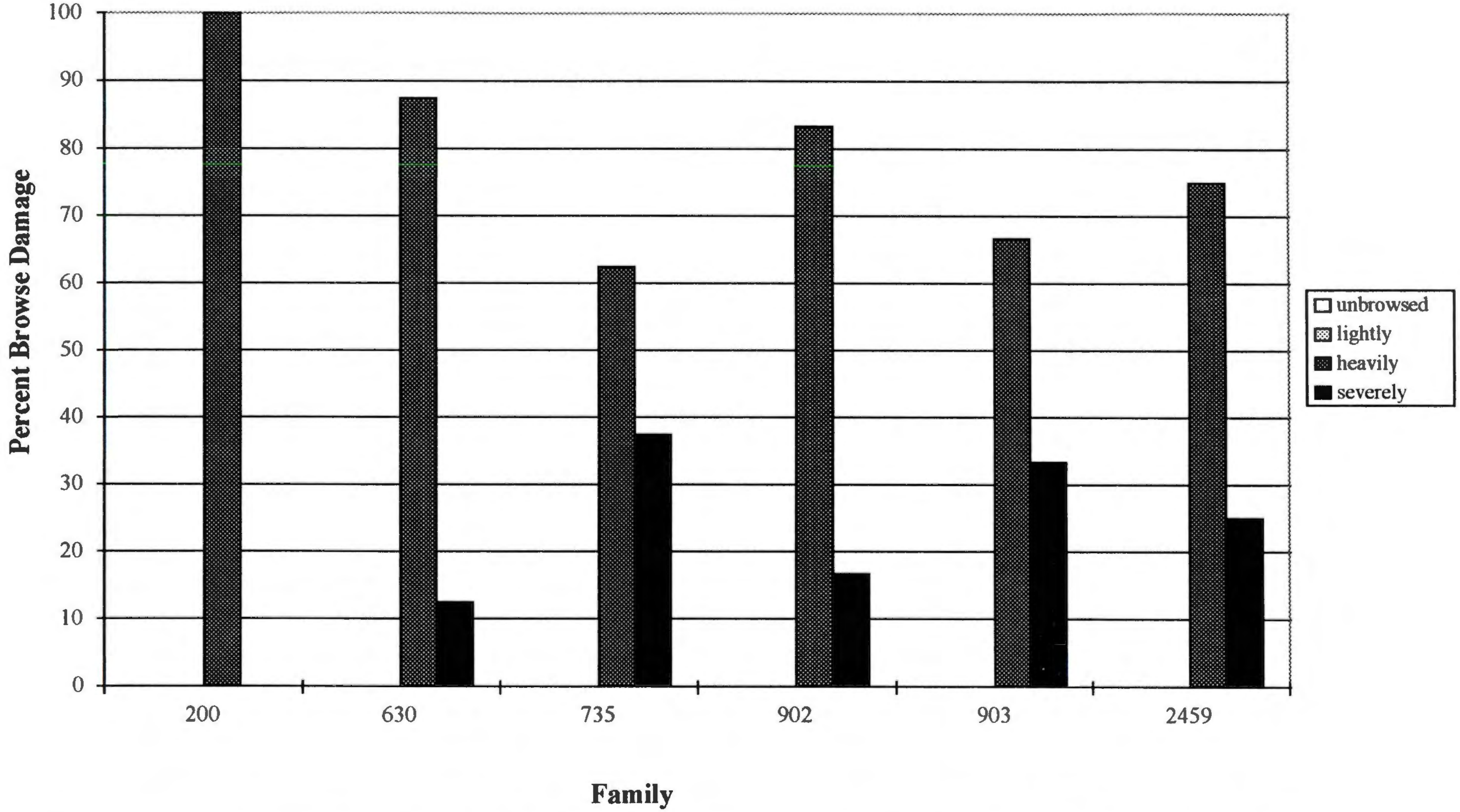

Figure 10. Percentage of four levels of browse damage, by family, for untreated northern red oak seedlings planted at the Chuck Swan State Forest and Wildlife Management Area.

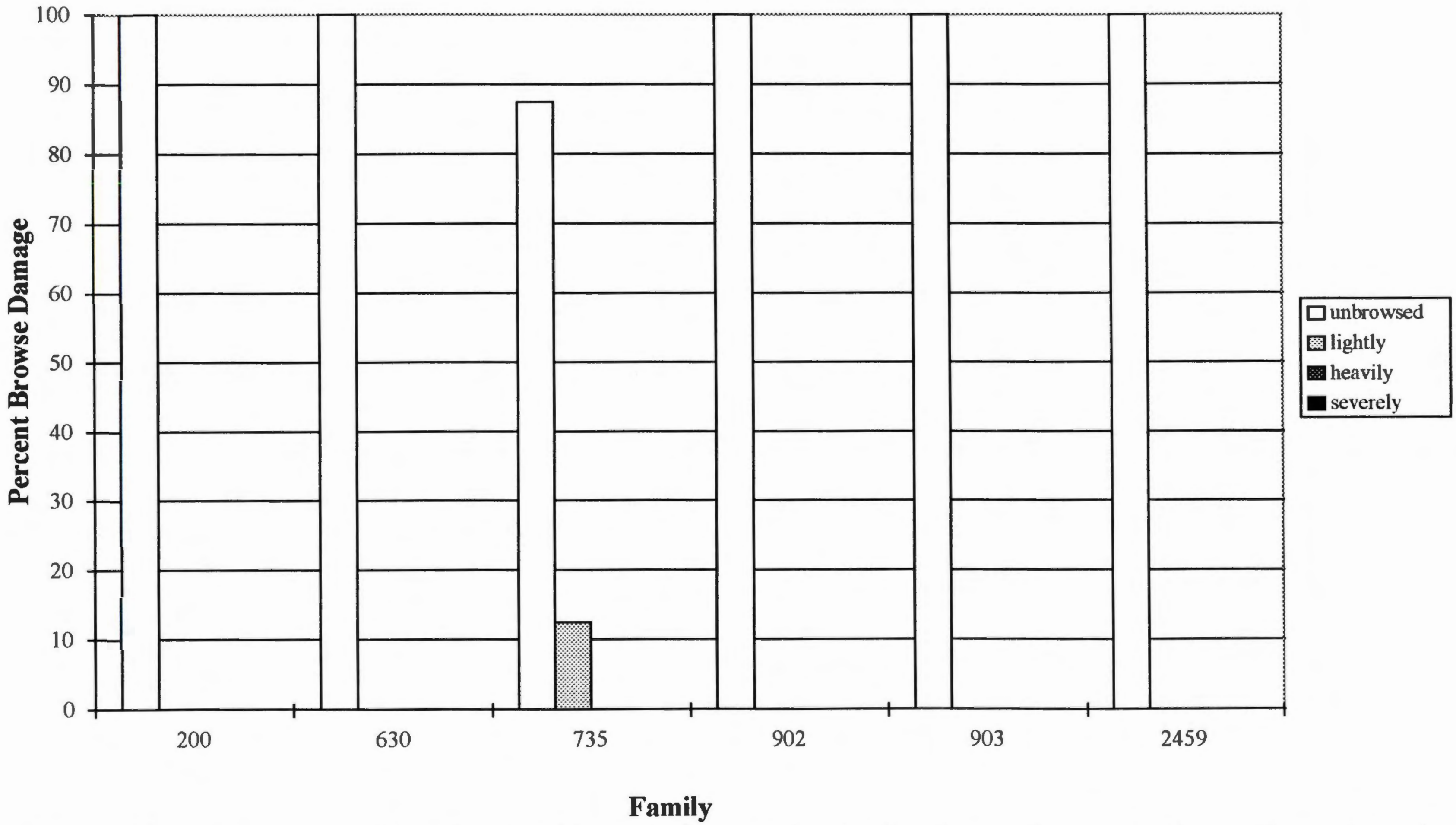

Figure 11. Percentage of four levels of browse damage, by family, for northern red oak seedlings planted in Tubex Tree Shelters at the Chuck Swan State Forest and Wildlife Management Area.

CHAPTER VI

DISCUSSION

Seedlings at a few locations grew well in 1995, but overall performance was discouraging. Loftis (1979) has reported that height growth of less than 30.5 cm per year is considered poor, and even at the location where best results were obtained, mean growth in the 1995 study was less than 10 cm in the first year. These results are similar to those found by Auchmoody and Walters (1992), who demonstrated that the height of planted seedlings was affected more by browsing pressure than by light if unprotected from deer. Seedlings that had been completely defoliated by deer had the highest mortality. Growth rates were unacceptably slow, damage by deer was widespread, and mortality was high in the second year.

Extensive damage to seedlings by deer was recorded in both the 1995 and 1996 studies. Presently, outside of Pennsylvania, published evidence on the effects of deer browsing on oak has been very limited. Lorimer (1992) stated that researchers have found that establishing hardwood plantations is often like "setting the table for deer", and more evidence is needed on the effects of moderate deer browsing on growth rates of oak. Gillingham and Bunnell (1989) conducted research on the feeding habits of black-tailed deer (*Odocoileus hemionus columbianus* Richardson) and found that memory may play an important role in the foraging activities of deer. The results of the marginal soils study demonstrate that some form of protection from deer is needed at planting time, and should be applied before feeding habits are established.

Seedlings planted for the deer repellent study in 1996 were protected initially and several repellent treatments seemed to deter further browsing. From planting time until budbreak, no browse damage was recorded, and even in the untreated plots deer did not begin to browse the seedlings until approximately six weeks after planting. After seedlings were retreated, levels of browse damage decreased for all treatments except garlic sticks. However, ten days after retreatment, browse damage began to increase. From the end of May to the end of June, browse damage once again decreased for all treatments, except shelters and BGR which stayed about the same. Records kept during the growing season reveal that families 200 and 2459 were slower to bud than the other families, and these were the same families which appeared to receive lower levels of browse damage. Differences in time of bud break may account for this observed variability. Between bud break and the fully developed mature foliage of these oaks, there would seem to exist a window of opportunity for protection from deer. It is still unknown whether specific genetic families develop mature foliage faster than others, but further study may reveal these differences, and thus may require protection for a shorter period of time. No seedlings were completely defoliated in the 1996 study, and there may be two possible reasons for this outcome: deer did not become accustomed to browsing the seedlings because protection was applied at planting time or, because it is a wildlife management area, plenty of other food sources were available.

Seedlings that were treated with some form of deer repellent outperformed unprotected ones. Garlic sticks and BGR seemed to be most effective early on. Protection provided by Tree Guard was limited. Hinder and BGR performed relatively better than any of the other commercial repellents. The increased height growth of seedlings in shelters was similar to the results of Lantagne and others (1990) with northern red oak planted in a Michigan clearcut. Larger select seedlings planted in shelters were not only protected from browse, they may be less spindly and have the possible advantage of removal from the shelter two or three growing seasons after they have grown out the top of the shelter. The increased growth rate and excellent early performance of these select seedlings in tree shelters deserves further study.

Results from both studies indicate that browse damage ratings assigned to northern red oak seedlings are helpful in identifying which trees are expected to respond and recover, and which seedlings are more likely to die. In areas where browse pressure is a concern, protection from deer in the first few years after planting is crucial to the early growth and development of northern red oak seedlings.

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VITA

Beverly Diane Warwick Graveline was born in Knoxville, Tennessee in 1962. She attended Central High School in Knoxville where she graduated in 1980. She began her college education at The University of Tennessee in 1988. Following the birth of her son, Thomas Joseph, in 1989, she returned to The University of Tennessee in 1990 and received her Bachelor of Science degree in Forest Resource Management in May 1993. After working for two seasons in the Resource Management Division of the Great Smoky Mountains National Park, she returned to The University of Tennessee in 1995 as a graduate research assistant. She will earn her masters degree in Forestry in August 1997.