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The Regeneration of oak (Quercus spp.) on highly productive sites of the east Gulf Coastal Plain, Tennessee : a post-harvest approach

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To the Graduate Council:

I am submitting herewith a thesis written by Christopher M. Oswalt entitled "The Regeneration of oak (Quercus spp.) on highly productive sites of the east Gulf Coastal Plain, Tennessee : a post-harvest approach." I have examined the final electronic 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.

Wayne K. Clatterbuck, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Christopher M. Oswalt entitled "The Regeneration of Oak (*Quercus* spp.) on Highly Productive Sites of the East Gulf Coastal Plain, Tennessee: A Post-Harvest Approach." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree Master of Science, with a major in Forestry.

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We have read this thesis and recommend its acceptance:

Arnold M Saxton

Acceptance for the Council:

Vice Provost and Dean of Graduate Studies

The Regeneration of Oak (*Quercus* spp.) on Highly Productive Sites of the East Gulf Coastal Plain, Tennessee: A Post-Harvest Approach

A Thesis Presented for the
Master of Science Degree

The University of Tennessee, Knoxville

Christopher M. Oswalt

August 2003

DEDICATION

To my parents for their unending support and the morals and ethics they instilled in me. To my wife, Sonja N. Oswalt for her love, confidence and allowing me the honor of becoming her husband.

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The experience of pursuing and completing a Master of Science degree in Forestry has been utterly and completely fulfilling to the greatest degree. Quite a number of agencies, institutions and persons aided in this enlightening process and I would like to thank them all.

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ABSTRACT

Oak (*Quercus spp.*) regeneration success historically can be described as highly variable, especially within highly productive systems. Research has shown that establishing large advance oak reproduction, prior to overstory removal, is necessary to maintain oak populations in future stands. However, experience indicates that forest landowners are typically unwilling to wait the necessary time to develop natural advance oak regeneration, instead allowing short-term economics to dictate harvest times. The use of artificial oak reproduction is one alternative to maintain oak as an important component of future stands. However, to date the success of artificial oak regeneration has also been highly variable. In developing an improved understanding and enhanced methods of artificial oak regeneration we examined the growth of outplanted high-quality, genetically improved, 1-0 northern red oak (*Quercus rubra* L.) seedlings and the effects of competing herbaceous vegetation after four overstory treatments (no-cut, high-grade, commercial clear-cut, two-age) on the Ames Plantation in west Tennessee. Sixty seedlings from two known and proven genetic families were outplanted within each of twelve, two-acre treatment units, resulting in three replicates of the four treatments. Initial height, root-collar diameter (RCD) and number of first-order lateral roots (FOLR) were recorded for each seedling. Outplantings were monitored monthly during the growing season and after all seedlings entered dormancy. The greatest first-year height growth (8.80 cm) was recorded for the no-cut treatment. However, all new growth was etiolated and high levels (33 percent) of mortality were recorded. Height growth among the 3 overstory harvest treatments was similar, but less than the no-cut (control) treatment. However, mortlaity was much less (5 percent). No mortality was observed within the commercial clearcut treatment. White-tail deer (*Odocoileus virginianus*) herbivory occurred in the early growing season only and significantly influenced first-year seedling growth. Results from logistic regression analysis indicated that the initial height of the seedling at time of planting was related to herbivory of the terminal shoot. Linear regression results suggested that competition from an exotic-invasive grass, *Microstegium vimineum*, was also impeding seedling growth. This study indicates that light availability, seedling quality, herbaceous competition along with browse pressure are important factors contributing to first-year seedling development. While results from this study appear positive, only first year growth has been observed and reported. As seedling development continues, further examination and research will prove informative. Differences between treatments, genetic stock and seedling quality may become more apparent as development continues.

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CHAPTER I

INTRODUCTION

The topic of successful regeneration of oak (*Quercus* L. spp.) has acquired great attention and generated numerous research papers over past decades. However, the successional replacement of oak persists as a major concern in eastern deciduous forests, particularly on mesic or highly productive hardwood sites. Research suggests that oaks historically persisted on productive sites due to a disturbance regime that included repetitive low to moderate intensity fire events (Van Lear and Janet 1992, Johnson 1993a, Delcourt and Delcourt 1997, 1998), which no longer exists in eastern deciduous forests (Van Lear and Janet 1992, Delcourt and Delcourt 1997, Lorimer 2001). Presently, obtaining oak reproduction within intrinsic accumulator systems (areas with a high propensity to accumulate advance reproduction, generally poor-quality sites) is not difficult (Crow 1988, Johnson 1993b, Rogers et al. 1993). However, after a heavy overstory removal on highly productive sites (generally oak site index at base age 50 of > 70 ft), oaks are out-competed by other hardwood species and are quickly replaced or relegated to subordinate positions in the canopy (Johnson 1993a, Clatterbuck et al. 1999).

Research has demonstrated the need for the presence of large advance reproduction, generally a height greater than 4 ft., prior to final overstory removals (Sander 1971, Loftis 1982, 1983, Johnson 1993b). However, experience has shown that many non-industrial private forest (NIPF) landowners within the eastern deciduous forest region are unwilling to take the necessary steps to ensure adequate advance oak reproduction. Instead, short-term economics tend to drive forestland management decisions, including harvest times, resulting in highly exploitive practices that in turn can negatively impact oak composition in future stands. The unwillingness of most NIPF landowners to culture advance oak reproduction, coupled with common exploitive forest practices, presents a need for focus on post-harvest alternatives of increasing or developing oak regeneration. A shift toward practices that emphasize the use of artificial regeneration appears to hold promise.

Furthermore, highly invasive exotic species and the continuously increasing deer heard in the eastern United States present additional obstacles when attempting to establish reproduction, both natural and artificial. *Microstegium vimineum* (Trin.) Camus, an exotic, shade-tolerant Asian annual C_4 grass has invaded many hardwood sites from floodplains to mesic slopes (Barden 1987) and can potentially be a problem for private landowners, land managers and foresters. In addition, large deer herds continue to impede seedling development through repeated browse events.

Over the past ten years a number of research projects have focused on the use of nursery-grown seedlings to enhance post-harvest oak composition with varying results. Deer herbivory (Buckley et al. 1998), herbaceous competition including exotic species (Dubois et al. 2000), and competition by other woody species (McGee and Loftis 1986) have hindered success. Therefore, seedlings capable of hastened growth to attain a competitive advantage and overcome herbivory on highly productive sites are needed. Concomitantly, genetic families exhibiting growth advantages in seedling development should be identified. Currently, protocol exists for the production of large seedlings, akin to "advance reproduction" in the nursery (Kormanik et al. 1994a, 1994b, Schlarbaum et al. 1998). Through genetic selection, use of proper seed source and optimal nursery techniques, potentially successful high-quality seedlings can be developed. This study was undertaken to investigate the growth of such high-quality seedlings developed by the University of Tennessee's Tree Improvement Program outplanted within four overstory treatments. The impact of *Microstegium* on seedling growth and establishment is also considered.

CHAPTER II

REVIEW OF RELEVANT LITERATURE

2.1 Introduction

Forest communities are dynamic systems constantly changing and adapting to a continuously shifting environment. Pre-human forest communities were primarily driven by each individual species' fight to remain a part of the ecosystem in perpetuity, whether it be directly or indirectly through progeny (Smith et al. 1997). Species composition and dominance is always changing through both allogenic and autogenic processes. However, the science of silviculture attempts to control the development of forests for healthy, sustainable forest communities while supplying man with aesthetic and recreational values as well as natural resources. It is for this reason that we attempt to regenerate oak dominated ecosystems on highly productive sites that experience different environmental influences than that encountered by today's mature oak forests.

Oaks are both economically and ecologically important and any mass reduction in composition across the eastern United States could have serious implications. Oaks are considered keystone species in many of the eastern deciduous forests (Spetich et al. 2002). Oak dominated communities represent approximately 51 percent of the eastern U.S. forests including 49.8 million ha of oak-hickory forest, 19.3 million ha of oak-pine forest and 12.1 million ha of oak-gum-cypress forest (Eyre 1980, Miller and Lamb 1985, Spetich et al. 2002). Accordingly, oaks maintain a fundamental role in supplying society with wood products and supplying wildlife populations with a valuable food source and habitat. Additionally, wildlife populations have been known to fluctuate along with yearly mast production (Wolff 1996). Therefore, oaks are known to represent the base of a complex ecological web that affects many populations and numerous levels of organization within hardwood forests (Thompson and Dessecker 1997).

Today, one of the greatest challenges in hardwood silviculture is the regeneration of multi-valued oak communities on highly productive sites within the eastern deciduous forest. The "oak regeneration problem", as it has been labeled, did not surface as a serious concern until the 1970's (Lorimer 1993). Earlier foresters accused fire and grazing for the lack of adequate oak regeneration, stating "the first and most essential step in management is protection from fire" (Greeley and Ashe 1907). Lorimer (1993) claims that soon thereafter fire suppression was largely accomplished. This was not necessarily a product of concern for oak regeneration, but a product of the catastrophic fires of that time and later the U.S. Forest Service's "Smokey Bear" campaign. However, moderate fires, beneficial to oaks, were suppressed also. In recent decades, detailed investigations have suggested that fire suppression and the cessation of grazing may have only exacerbated the problem (Abrams 1992, Van Lear and Janet 1992, Delcourt and Delcourt 1998). Many advances in techniques and practices in oak regeneration have been made in the 1980's and 1990's, and economically feasible solutions appear attainable in the near future (Janzen and Hodges 1986, Johnson et al. 1989, Loftis 1990, Abrams 1992, Schlarbaum et al. 1998, Clatterbuck et al. 1999).

Another unkown component affecting oak forests is the loss of the once prominent American chestnut (*Castanea dentata* (Marsh.) Borkh.). American chestnut was largely removed from the eastern deciduous forest by disease caused by the exotic chestnut blight fungus, *Cryphonectria parasitica* (Murrill) M.E. Barr. The decimation of the chestnut population in the early to mid 1900's opened a new niche. The knowledge of the role of the chestnut blight in the subsequent shift toward oak dominance remains incomplete. However, it does appear that oaks were in a position to capture the unoccupied niche and gain importance in the eastern forest.

2.2 Oak Dominated Communities

The genus *Quercus* is generally considered the most important member of the family *Fagaceae*, the beech family (Miller and Lamb 1985, Harlow et al. 1996). Oaks are widely distributed across the United States. The oak genus is represented by over 40 species that are taxonomically distinct within the eastern deciduous forest and approximately 30 species in the western U.S. (Little 1979). Although populations of these many species sympatrically occur across gradients of elevation and soil-moisture (Martin 1978), introgressive hybridization does occur and results in many hybrid forms that are often indiscernible in the field (Steyermark 1963, Little 1979).

Of the 145 cover types defined for the United States and Canada, oak is represented in the name or list of defining species of 31 cover types, 23 of which are in the East (Eyre 1980, Miller and Lamb 1985, Johnson et al. 2002). Oak species richness within the United States reaches a maximum of 20 different species in the southeastern U.S. (Aizen and Patterson 1990, Johnson et al. 2002) and can be attributed to a wide range of environmental conditions. Even oak species with rather limited ecological amplitude are represented due to a wide variety of species niches distributed across the landscape.

Although some cover types occur extensively, the relative stability of some representative species are highly variable. For example, the white oak (*Q. alba* L.) cover type occurs across a wide range of sites along the moisture gradient. Whereas the community appears stable on xeric sites, there is a trend toward successional replacement by more shade-tolerant species on mesic sites (Johnson 1993a, Johnson et al. 2002). Therefore, broad classifications such as cover types, although regionally important, can potentially represent completely different ecologies with respect to the successional status of oak species (Johnson et al. 2002).

2.3 Paleoecology of Oak and the Development of Modern Stands

The eastern deciduous forest has been in flux ever since the retreat of the Laurentide Ice Sheet of the most recent Milankovitch Cycle triggered glacial/interglacial period (Imbrie and Imbrie 1979). Paleobotanical evidence suggests that the southern biotic communities we are familiar with today have only assembled since that time, approximately 20,000 yr ago (Delcourt and Delcourt 1993). During the period of full-glacial maximum, the southeast provided refugia for both boreal and temperate forest assemblages (Delcourt and Delcourt 1987, 1991). This refuge provided the genetic source from which present assemblages would organize (Delcourt and Delcourt 1985). Consequently, major vegetation types such as the central hardwoods developed only 8,000 to 10,000 years ago and according to Watts (1979) and Lorimer (1993), oaks have dominated this region for only the last 6,000 years.

The development of modern oak forests in the eastern United States followed a variety of ecological pathways. The current distribution is a reflection of presettlement forest composition, historical disturbance regimes and regional and edaphic influences (McCune and Cottam 1985, Abrams 1992, Clatterbuck and Meadows 1992, Hodges and Gardiner 1992). However, of major importance in the southeast is the role of disturbance, particularly fire, in the maintenance of oak-dominated communities. Forest disturbances resulting from fire, natural and anthropogenic, played a fundamental role in sustaining oak forests in the eastern U.S. (Delcourt 1987, Abrams 1992, Van Lear and Janet 1992, Delcourt and Delcourt 1993, 1997, 1998, Lorimer 2001). Yet, lightning-set fires are reported to have been very uncommon in this region due to high precipitation (Harmon 1982). Paleoecological evidence supports the belief that Pre-Colombian Native Americans were responsible by influencing the composition of vegetation through the use of fire (Delcourt and Delcourt 1997).

Humans possessed the capability of environmental exploitation and utilization upon arrival into the New World, between 12,000 and 15,000 years ago (Martin and Klein 1984, Delcourt and Delcourt 1993). Paleohumans had a profound affect on the subsequent development of biotic communities (Delcourt 1987, Delcourt and Delcourt 1993, 1997, 1998, Lorimer 2001) including oak forests (Lorimer 1989, Abrams 1992). The cultural practices common during both pre-Colombian and post-Colombian times, predominantly the use of fire coupled with the decimation of American chestnut, favored the regeneration of oak and therefore the development of areas occupied by oak communities that are apparent today.

2.4 Oak Regeneration Ecology

Due to the frequent interchangeable use of the terms 'regeneration' and 'reproduction' in the ecological and silvicultural literature, I have adopted the definition and use outlined by Johnson et al. (2002). The term regeneration refers more to a *process* and can be defined as "the ecological processes involving the establishment, growth and population changes of juvenile trees, co-occurring plants and their propagules" (Johnson et al. 2002). The term reproduction (i.e. advance reproduction), in a silvicultural sense however, does not indicate process, but "individual or populations of juvenile trees" (Johnson et al. 2002).

Within the physiology of oak reproduction rests clues to the explanation for its dominance on the landscape today and the difficulties experienced when attempting to regenerate these same stands. Through acorn production, seedling establishment and the successive accumulation of advance reproduction, oak species have evolved specialized processes that are advantageous in some situations, but not in others.

Acorn production can be described as temporally erratic and variable (Burns and Honkala 1990). In addition, acorn predation is generally high (Korstian 1927) and seed deterioration can occur rapidly after abscission, particularly in bottomland systems (Hodges and Gardiner 1992). Yet germination is not considered a limiting factor (Lorimer 1993). Acorn caching by certain rodent and avian species aids in securing yearly germinants (Darley-Hill and Johnson 1981, Crow 1988). Finding 12,000 or more new germinants per hectare beneath an existing upland or bottomland stand is not atypical (Carvell and Tyron 1961, Beck and Hooper 1986, Hodges and Gardiner 1992). However, on mesic or highly productive sites, very few, if any, of the seedlings will survive through more than one growing season (Bonner and Vozzo 1987, Hodges and Gardiner 1992, Larsen and Johnson 1998).

Once cotyledon reserves are depleted by the new germinant, seedlings must survive on internal photosynthate production (Korstian 1927, Kramer and Kozlowski 1960). It as at this point when light becomes a limiting factor for survival and subsequent growth (Kramer and Kozlowski 1960, Bonner and Vozzo 1987, Crow 1988, Hodges and Gardiner 1992). However, light levels found in mature stands often fall below that needed to maintain a positive carbon balance, which for northern red oak (*Quercus rubra* L.) is reported as approximately 30 μmol m^2 s^{-1} of photosynthetically active radiation (PAR) (Crow 1988). Light levels at or near the forest floor are often found to be at or below the "compensation point" for most oaks (Hodges and Gardiner 1992). Hodges and

Gardiner (1992) believe the effects of a low light environment found in many mature oak stands to be "the most likely reason" for the paucity of advance oak reproduction.

Relying on periodic seed production for self-replacement requires the accumulation of advance reproduction (Larsen and Johnson 1998). Oaks are known to be an advance growth dependent species (Sander 1971). Consequently, research has demonstrated the need for the presence of large advance reproduction prior to disturbance (Sander 1971, Loftis 1982, 1983, Johnson 1993b). In addition, disturbance released seedlings must be able to grow in height as fast or faster than their competitors. However, in some cases, an early competitive advantage is not realized by oak reproduction, although, it may be expressed at a later stage (Oliver 1978, Clatterbuck and Hodges 1988).

Oak stands can be broadly classified, according to regeneration potential, into one of three categories: intrinsic accumulator systems, ambivalent accumulators and recalcitrant accumulator systems (Johnson 1993a, Johnson et al. 2002). Intrinsic accumulator systems have a high propensity of accumulating advance oak reproduction, whereas recalcitrant accumulator systems generally lack the ability to accumulate large pools of advance oak reproduction over time. This is generally associated with site productivity (Crow 1988, Lorimer 1989, Hodges and Gardiner 1992, Johnson et al. 2002) and correlated with land-form (Trimble 1960, Dey 1991, Dey et al. 1996). Highly productive hardwood or mesic sites are classified as recalcitrant accumulators and poor or xeric sites are usually classified as intrinsic accumulators (Johnson et al. 2002). Due to the gradational nature of site productivity, it is expected that the propensity to accumulate oak also would be gradational. Johnson et al. (2002) defined the ambivalent accumulator systems as those falling near the gradient center. Recognition of these systems is imperative to predict species recruitment and growth responses of each to both anthropogenic and natural disturbances and is essential to oak silviculture.

Most oak species are considered moderately shade-intolerant (Miller and Lamb 1985, Burns and Honkala 1990). Nevertheless, oaks appear to have adapted to persisting in shaded environments. McGee (1975, 1976, 1986, 1988) observed in oak, budbreak behavior similar to most other tolerant species. He suggested that some oak seedlings have the ability to initiate growth earlier, before full leaf-out in the overstory, in order to begin photosynthate production prior to canopy closure. Oak seedlings persist in the understory partially because of its ability to dieback and resprout (Hodges and Gardiner 1992, Johnson 1993a, Larsen and Johnson 1998, Johnson et al. 2002). After initial seedling establishment and survival for a few years underneath full overhead canopies, the aboveground portions of the seedling will typically dieback to the root-collar. Dieback generally occurs every 3-10 years (Larsen and Johnson 1998), depending on local edaphic and light conditions. Dormant buds located at the root-collar usually sprout after dieback if root reserves are present. Repeated dieback/resprout events have the potential to lead to the development of a very large root system with some root systems living up to 50 years (Tyron and Powell 1984). However, unpublished studies by Dr. Paul P. Kormanik (USDA Forest Service) using planted seedlings has not corroborated development of a larger root system (Schlarbaum 2003). However, the dieback/resprout process is an important factor in the accumulation of advance oak reproduction in the understory. Techniques that manipulate factors that discourage or facilitate this process are necessary tools for silviculturalists (Rogers et al. 1993, Larsen and Johnson 1998).

The development of a large root system confers many advantages to oak advance reproduction. Of particular importance are enhanced drought tolerance and the ability to produce vigorous growth following release or a disturbance such as fire or harvest. Oaks are known to have large root systems (Kramer and Kozlowski 1960). The dieback/resprout process can facilitate greater rooting volumes and therefore greater drought tolerance (Abrams 1990). Additionally, fire or other mechanical damage will often leave the root system and the dormant basal buds intact. As a result, large, intact root systems allow for a vigorous response to top damage, such as experienced during a harvest operation.

Stump sprouting also represents a significant contribution to the regeneration of oak communities. According to Johnson (1975), all oaks have the potential to sprout after stem removal. However, this relationship is negatively related to stem size, varies between species and is also known to be affected by tree age and site quality (Johnson 1975, 1977).

2.5 Management of Oak Stands

Pine silviculturalists have for many years been devising and testing methods to restrict oak reproduction where pine management is a priority. In contrast, hardwood silviculturalists have long realized difficulties in regenerating oaks where oak is the desired species. In effect, site productivity differences can be seen as the principal determinant, the more productive the site the more difficulties in successfully regenerating oak (Lorimer 1989, Clatterbuck and Meadows 1992, Lorimer 1993). Sites where oaks grow best are also sites where other hardwood species flourish. Although oaks are generally viewed as intolerant to moderately tolerant, many oak associates in the eastern deciduous forest are more shade tolerant, such as red maple (*Acer rubrum* L.), elms (*Ulmus* L. spp.), blackgum (*Nyssa sylvatica* Marsh.), beech (*Fagus grandifolia* Ehrh.) and dogwood (*Cornus florida* L.). Therefore, the maintenance of oak dominance is dependent upon canopy disturbance and/or removal that allows for adequate light to reach the forest floor. Without canopy disturbance, outside of single-tree gaps (Runkle 1985), many oak-dominated forests in the eastern U.S., particularly on highly productive sites, will most likely succeed to forests comprised of mostly shade-tolerant hardwood species (Nowacki et al. 1990, Abrams and Nowacki 1992, Nowacki and Abrams 1992).

Most silvicultural activities and disturbances impact forest stand structure and species composition. However, the subsequent composition and structure shift is dependent upon the degree of disturbance. Seed bank germinants, advance reproduction and stump-sprouts will aid in perpetuating hardwoods on most sites, particularly productive sites, in the manner of the initial floristics model presented by Egler (1954). However, oak may not be favored by the disturbance. In order to influence the degree of oak composition in the future stand, particular attention must be paid to the regeneration method or silvicultural system chosen. Where the objective is to perpetuate oaks and provide oak-dominance, traditionally even-aged silvicultural systems have been accepted as the most favorable method of securing oak reproduction, and group-selection cutting is increasingly being used. However, regeneration responses are site-specific. Methods that have been successful on xeric sites have returned inadequate results on mesic, highly productive sites (Larsen et al. 1999).

Xeric oak communities, such as those found in the Ozarks, can be considered relatively stable communities expressing very little tendency to succeed to shade-tolerant or mesophytic species (Sander et al. 1984, Dey 1991, Thompson and Dessecker 1997, Larsen et al. 1999). Sander et al. (1984) reported that within the Ozark Plateau of Missouri, several stands could accumulate advance oak reproduction for up to 50 years and are considered by Johnson et al. (2002) to be intrinsic accumulators. Generally, intrinsic accumulators have adequate numbers of advance oak reproduction to successfully stock the next stand with a large number of oak stems. Therefore, xeric oak stands are more likely to be self-replacing.

Research has shown that oak reproduction is more difficult to establish on highly productive sites or recalcitrant accumulators (Carvell and Tyron 1961, Loftis 1982, 1983, Beck and Hooper 1986, McGee and Loftis 1986, Lorimer 1989, Johnson and Deen 1992, Rogers et al. 1993) and successes remain highly variable and unpredictable. Accumulation of advance oak reproduction under the parent stand is one of the most important factors to consider when regenerating oak (Sander et al. 1984, Johnson 1993a, Thompson and Dessecker 1997, Johnson et al. 2002). However, releasable advance reproduction is generally absent on highly productive sites (Lorimer 1989, Hodges and Gardiner 1992, Hodges 1997). Consequently, many attempts to regenerate oaks on mesic sites, using the clearcut method have been unsuccessful (Loftis 1982, 1983, Beck and Hooper 1986). The seed tree method is also an even-aged method and is defined by leaving 10 or fewer seed-producers per acre (Smith et al. 1997). However, compared to the faster/greater growth of sprouts and advance reproduction, the slow growth of new germinants of oak would contribute very little if any additional reproduction to a harvested stand. Residual stems with developed and intact root systems will generally outgrow seed-initiated reproduction, with the exception of yellow-poplar (*Liriodendron tulipifera* L.) in some cases (Sander 1971, Beck and Hooper 1986). Yellow-poplar grows well from seed compared to many other hardwood species. The use of the seed tree method for regenerating oaks is not generally recommended.

Establishment of sufficient numbers of advance reproduction to successfully regenerate oak generally takes considerable time. Unlike xeric sites, intermediate operations that imitate historical disturbance are necessary to facilitate the accumulation of advance reproduction. Researchers are developing such methods utilizing shelterwood techniques that are capable of promoting the build-up of advance reproduction (Loftis 1982, 1983, 1990, Clatterbuck et al. 1999, Spetich et al. 2002). Nevertheless, the use of shelterwood techniques to regenerate oaks has met with mixed results and further investigations are needed (Johnson et al. 1989). The identification of canopy densities that allow light levels high enough to promote oak reproduction yet low enough to discourage the recruitment of competitor species is needed. It will also be important to quantify the extent of damage to advance reproduction and/or enrichment plantings when the overwood is removed and the practicality of the shelterwood method for non-industrial private forest landowners.

2.6 The Problem: Biology and Economics

Regenerating oak using traditional practices is a silvicultural problem experienced throughout the range of the genus, particularly on highly productive sites (Crow 1988, Johnson et al. 1989). Currently, fire suppression is widely regarded as the factor most responsible for the decreased regeneration of oak (Harmon 1982, Lorimer 1989, Abrams 1992, Van Lear and Janet 1992, Lorimer 1993). Recurrent fire retarded fire sensitive competitors and reduced the overall competitor seed source, thereby enhancing the competitive capacity of oak within that environment. Additionally, fire promoted optimal light levels for oak reproduction by removing the dense, more shade-tolerant, midstory that is now found on mesic sites. At first, it was believed that oaks would have the capacity to overcome numerous shade-tolerant species after a heavy overstory removal. It is now apparent that shade-tolerant midstory species such as red maple, in the absence of fire, are highly capable of displacing oaks and dominating a large number of sites, both bottomland and upland (Abrams 1998).

On xeric sites, oak reproduction often accumulates beneath the parent stand because oaks are considerably drought tolerant (Abrams 1990), solar insolation is generally high and competition is generally sparse (Carvell and Tyron 1961, Sander et al. 1984, Johnson et al. 1989, Johnson 1993b). However, better sites generally experience high midstory and understory densities allowing very little light to reach the forest floor and consequently inhibit advance reproduction accumulation (Johnson et al. 1989, Lorimer 1989, 1993, 1994).

The oak regeneration problem is exacerbated by common practices within the eastern United States. Generally, NIPF landowners are unwilling to delay harvesting timber in order to facilitate the accumulation of advance oak reproduction through intermediate operations. Instead, most NIPF landowners allow short-term economics to influence harvest timing. Little thought is given to the reproduction of the stand. Alternatively, immediate income is what is generally desired and/or needed. This attitude often results in the promotion of exploitive practices, such as high grading. High grading is essentially "taking the best, leaving the rest" and can be defined as a harvest that leaves a residual stand of lesser potential value than that removed.

The reality is that fire may not attain the extensive influence on the landscape as it once had. The use of prescribed fire as a management tool today has many social complications. A shift in social acceptance of fire as a management tool in some arenas is being realized. However, as the urban-wildland interface invades farther into rural

America and managed lands, more complications will surface. Additionally, short-term economic factors will continue to drive many forestland management decisions in the eastern U.S., making it difficult to approach the oak regeneration problem from a pre-harvest perspective. Therefore, a post-harvest approach may continue to become more important, and the use of artificial regeneration appears to provide promise.

2.7 A Possible Solution: Artificial Regeneration

The use of artificial regeneration, especially with northern red oak, to enhance the composition of oak reproduction in harvested forests has been widely studied across the eastern United States (McGee 1968, Wendel 1980, Lorimer 1994, Gordon et al. 1995, Dey and Parker 1997, Buckley 2001). Earlier success with species such as pine and yellow-poplar gave rise to the idea that utilizing artificial oak reproduction may present an immediate solution to the oak regeneration problem. Planted oak seedlings have been used to establish oaks in areas where seed or sprout sources are absent or inadequate and in areas where high densities of seed producing stems were lacking. However, the results from these studies have been highly variable.

Several studies have returned positive first-year results with artificial oak regeneration. Over time, increasing mortality and low survivorship has ultimately led to many planting failures. In North Carolina, McGee and Loftis (1986) found second year survival of planted northern red oak of 94 percent. However, by year 11, survivorship was 43 percent and only 6 percent by year 19. Given adequate light levels, competition from herbaceous vegetation and other arborecents, and herbivory are important influences on seedling survival. Demchik and Sharpe (1999) reported northern red oak mortality in Pennsylvania, three years after planting was 67 percent for seedlings receiving vegetation control and 90 percent without control.

Many researchers have investigated incorporating the use of artificial oak regeneration with common even-age silvicultural practices. The combination of clearcutting accompanied by artificial regeneration has received much attention. Generally, nursery-grown seedlings have been used. Direct seeding techniques have not typically achieved satisfactory results due to high rates of acorn predation (Marquis et al. 1976), unknown seed sources and mismanagement of acorn supplies (Post 1999). Therefore, direct seeding has not been presented as a viable option. However, Johnson (1981, 1983) reported successes with intense site preparation comparable to agricultural conversion, although predation occurred on 75 percent of the acorns within small canopy openings.

Results from studies of planted oak seedlings have been largely inconsistent. Early studies reported very minimal success (Wendel 1980, Krinard and Johnson 1981) due to relatively slow growth rates. Johnson (1984) recognized the importance of initial seedling size to subsequent growth rates. He reported that seedlings with a root collar diameter of 0.6 inch were 10-60 times more likely to achieve an annual height growth of at least 12 inches than those with smaller shoot diameters. Yet these growth rates are still relatively small when compared to growth rates of 24 to 30 inches per year for the competing vegetation such as yellow-poplar (Olson 1969).

Recognizing inconsistencies in developing natural advance reproduction utilizing shelterwood techniques, recent research is suggesting enrichment planting under heavy shelterwood may considerably increase chances of successfully regenerating oak on highly productive sites (Nix and Cox 1986, Chambers and Henkel 1988, Gordon et al. 1995, Dey and Parker 1997). However, it may be necessary to remove the dense midstory at the time of planting (Loftis 1978, Janzen and Hodges 1984, 1986, Lockhart et al. 2000). Otherwise shade-tolerant individuals in the midstory, such as red maple, will be in a position to utilize the additional light and potentially capture the growing space (Abrams 1998). Additionally, many studies reporting on techniques combining shelterwood harvests and enrichment planting have yet to remove the overwood material. Damage to the planted seedlings during overwood removal needs to be assessed and quantified.

CHAPTER III

RESEARCH OBJECTIVES

The objective for this study was to investigate the feasibility and practicability of using genetically improved, "high-quality", 1-0 northern red oak seedlings for enrichment planting of recently harvested, highly productive sites. Therefore, a long-term timber harvest and regeneration study was initiated with the following specific objectives:

1. Compare oak seedling survival to alterations of the light environment via varying levels of canopy removal within highly productive systems,
2. Evaluate the potential for enrichment oak plantings using genetically improved, high-quality seedlings from the University of Tennessee Tree Improvement Program across the various treatments,
3. Compare seedling survival and response of two genetic families of northern red oak from a local seedling seed orchard across treatments, and
4. Investigate potential relationships between artificial oak seedling growth and herbaceous biomass production with special emphasis on an exotic grass species, *Microstegium vimineum*.

CHAPTER IV

STUDY AREA

This study was conducted within the riparian zone of ancestral terraces and a minor bottom in the headwaters of the North Fork of the Wolf River located within the Mississippi Embayment of the Gulf Coastal Plain on Ames Plantation within Fayette County, Tennessee. The intermittent stream drains approximately 375 acres of adjacent agricultural and forested land. The stream flows in a northerly direction and contains running water for most parts of the year with the exception of the dry summer period. The site encompasses approximately 100 acres of mixed bottomland and riparian hardwood forest dominated by various oak species.

The Ames Plantation is located in Hardeman and Fayette counties in southwest Tennessee, approximately forty miles east of Memphis and approximately ten miles southeast of Somerville, TN, consisting of approximately 18,653 acres of which 14,500 acres are forested. The headwaters of the North Fork of the Wolf River (NFWR) watershed are located on Ames Plantation. This area is located entirely within the Natural Resource Conservation Service's Southern Mississippi Valley Silty Uplands major land resource area (MLRA 134) characterized by rolling hills with broad flat meandering floodplains (Bailey 1995, Christensen 2000). Although the study reach can be principally described as belonging to the Central Hardwood Region (CHR), it lies within an area that overlaps the CHR and the Southern Pine-Hardwood Region (Johnson et al. 2002) of the Southeastern Coastal Plain (Christensen 2000). Accordingly, a highly discernable ecotone is not present. Therefore, the study area retains characteristics of both regions and was described by Braun (1950) as the Western Mesophytic Forest Region, a transition region between the Mixed Mesophytic Forest to the east and the bluffs of the Mississippi River and the Interior Highlands of the Ozark and Ouachita Mountains to the west.

Climate of the study area is described as hot continental, typically exemplified by hot summers, marked by very high humidity, and mild winters (Bailey 1995). Local mean annual precipitation is approximately 61 inches (155 cm), of which more than one third falls between the months of April through September. The wettest month is January with an average of 6.18 inches (15.70 cm) of rainfall. The driest month is October with an average of 2.78 inches (7.06 cm) of precipitation. Mean annual temperature at Ames Plantation is 61.4°F (16.3°C) with mean annual extremes of 42.6°F (5.9°C) in the winter and 80.3°F (26.8°C) in the summer. The growing season averages 210 days, with the first killing frost in October and the last generally in April.

The study area is located within the Mississippi Embayment of the Gulf Coastal Plain. The Mississippi Embayment is a Late Cretaceous and early Tertiary sedimentary basin that forms a northward extension of the Gulf Coastal plain (Cox and Van Arsdale 2002). The Gulf Coastal Plain developed during the Triasic period (~200 M yr BP) when the present-day North American continent separated from North Africa creating the Atlantic Ocean (Christensen 2000). Oceanic and fluvial processes have shaped the coastal plain surface landscape over the past 2-3 M years and what remains is an environment of alluvial wetlands and hardwood forests, upland hardwood forests, upland pine forests, mesic pine communities and xeric sand communities (Christensen 2000). Local geology is dominated by the highly erodible Wilcox and Claiborne formations of Tertiary age exposed by the erosion of Quaternary and Tertiary fluvial deposits and the overlying Pleistocene loess deposits common in western Tennessee (Safford 1869, Miller 1974). The Wilcox and Claiborne formations, deposited in coastal and near-shore marine environments, comprise the oldest exposed deposits in the region and consist of primarily sand with less significant amounts of silt and clay (Safford 1869).

Soils in the adjacent uplands have generally formed in loessial deposits that followed each of the last three periods of glaciation (Safford 1869, Fenneman 1938). These deposits are generally 3 to 4 feet thick if not completely eroded due to clearing for agriculture (USDA 1964). However, most soils within the floodplain have developed in Tertiary and Quaternary fluvial sediments. Additionally, with clearing of post settlement lands, most floodplains contain deposits of reworked loess, sand, silt and clay from the adjacent upland edaphic environment. The three principally represented soil groups described on Ames Plantation are Grenada-Loring-Memphis, Falaya-Waverly-Collins and Memphis-Loring-Smithdale (USDA 1964).

According to Hodges (1997), all topographic positions within the coastal plain can be classified into one of three categories; upland, floodplain or terrace. Differences between these sites can commonly be found within the local relief and the origin of the soils. Two distinct landforms or topographic positions were identified within the study site: a minor bottom near the confluence of the stream with the NFWR and ancestral terraces of the minor stream.

4.1. Minor Bottom

The minor bottom, also called the minor stream valley, is an alluvial floodplain. The adjacent stream principally influences the hydrology of this bottom. However, due its close proximity to the NFWR, the minor bottom also receives backwater and overbank flooding from the NFWR during times of extremely high precipitation. Therefore the hydrologic processes of both hydric systems affect vegetative assemblages. Species assemblages are similar to those described by Hodges (1997) for the natural levee and first flat of a minor stream valley.

The minor bottom arborescent vegetation was dominated by yellow-poplar, various oaks, particularly cherrybark oak (*Quercus falcata var. pagodifolia* Ell.), and sweetgum (*Liquidambar styraciflua* L.). Average site index, base age 50 years, was estimated to be 75 for oaks and 85 for yellow-poplar (Carmean 1972, Carmean and Hahn 1983, Clatterbuck 1987). Other overstory species, generally in a subordinate position, included sycamore (*Platanus occidentalis* L.) and green ash (*Fraxinus pennsylvanica* Marsh.). Midstory species included winged, slippery and American elm (*Ulmus americana* L), red maple, river birch (*Betula nigra* L.) and boxelder (*Acer negundo* L). Understory species included mostly hazel alder (*Alnus serrulata* (Ait.) Willd.) and swamp privet (*Forestiera acuminata* (Michx.) Poir.), which at times created a very dense copse.

Alluvial soils of minor bottoms are commonly young and have little profile development (Buol et al. 1997). Most alluvial floodplain soils within the coastal plain have been deposited or formed in the Holocene geologic period (Hodges 1997) on top of coastal plain sands. Soils are generally clay loams or dominated by clays on the flats and are generally coarser textured material such as sand nearer the natural levee where material from flooding tends to drop out of the water column first (Bravard and Gilvear 1996). The principal soil group within the minor bottom is Falaya-Waverly-Collins, characterized by nearly level, poorly drained to moderately well drained soils (USDA 1964). The Waverly series is classified as coarse-silty, mixed, active, acid, thermic Fluvaquentic Endoaquepts

The soils of the minor bottom study area are characterized and mapped as Waverly silt loam (USDA 1964). Waverly silt loam soils are generally poorly drained, gray, acidic soils of mostly alluvial material of various depths generally deposited upon coastal plain sand. Most subsurface layers have been described as ranging from silt loam to silty clay loam.

4.2. Ancestral Terraces

The ancestral terraces are abandoned floodplains that are generally not as productive as the current floodplain yet are still considered productive systems (Wharton et al. 1982). Terrace sites infrequently experience overbank flooding (Hodges 1997) and no signs of flood events were observed for any of the terrace sites in this study. Soils of these sites were fairly similar to the bottom sites, although slightly better drained.

Oaks dominated the arborescent vegetation of the terrace sites, particularly southern red (*Quercus falcata* Michx.), with a small subordinate component of yellow-poplar and various hickory species. Site index for the ancestral terraces was similar to the bottom block.. Overstory species included oaks, yellow-poplar, black cherry, sassafras (*Sassafras albidium* (Nutt.) Nees) and sycamore. Midstory species included blackgum, dogwood, and American elm. The understory or shrub layer was generally absent however privet was occasionally encountered.

4.3. Adjacent Uplands

The adjacent uplands are predominantly lands cleared for agriculture. Soils are predominantly Memphis silty clay loams and Memphis silt loams. Soils of the Memphis series are well-drained, silty soils of broad ridgetops and sideslopes. These soils formed in loessial deposits ranging from 3.5 to 15 feet in thickness (USDA 1964). The loessial deposits around the Ames Plantation are around 3 to 5 feet in thickness.

CHAPTER V

METHODOLOGY

5.1. Study Design

Prior to harvest, in the fall of 2001, an approximately 100-acre tract of forested land was surveyed to locate experimental units for treatment. Special attention was given to species composition and stand structure. Desirable stands were to be mature riparian hardwood stands with a significant component of mature, overstory oak species. Three experimental blocks (replicates) were identified based on landform, position and stand structure (Figure 1). Significant differences in average stand basal area ($p<.05$) were found between each block, which justified the blocking procedure. Twelve 2-acre treatment units were identified within the experimental blocks; four units located within the minor bottom (bottom block) and eight units located within the terrace sites upstream from the minor bottom (four each within the east and west blocks). Species composition at the time of establishment was completely dominated by oak with the exception of the bottom block, with shared dominance between oak, yellow-poplar and sweetgum. The resulting overall design is a Randomized Complete Block (RCB) design.

5.2. Treatment Units

All treatment units were located in isolation from other units to ensure no effects from differing adjacent treatments. Treatments units are approximately 2 acres in size

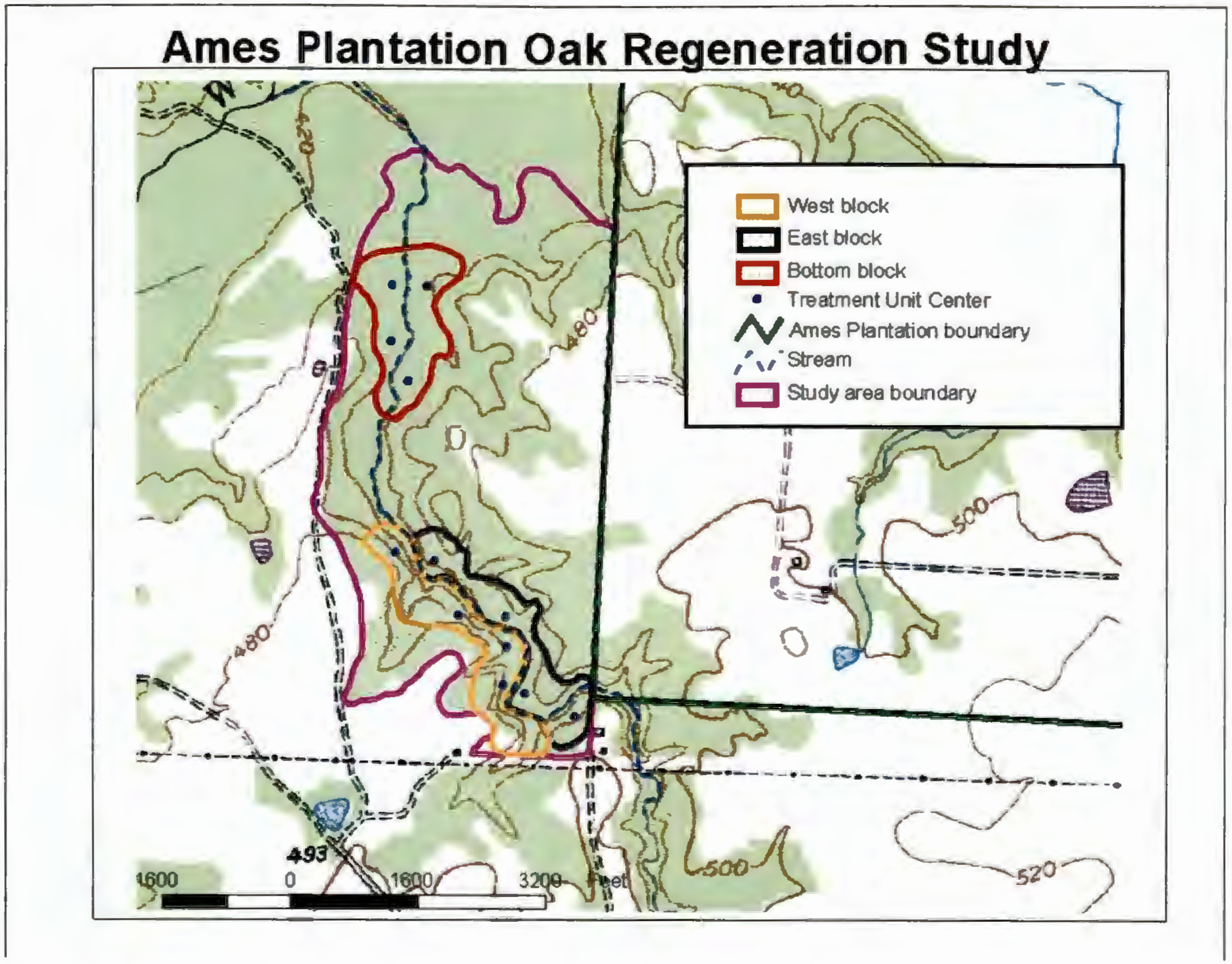

Figure 1 – Aerial photograph depicting location of experimental blocks on the landscape for the Ames Plantation oak regeneration study, Fayette County, Tennessee

and irregularly shaped (Figure 2). Generally, all units were approximately 400 ft long (parallel with the stream and contour) and 200 ft wide (perpendicular to the stream and contour). A one-acre planting block was identified within the center portion of each treatment unit for planting. Locating each planting block in this manner would reduce edge effects.

Pre-harvest structure and composition was determined through systematically established sample plots. Within each treatment unit one transect was located across the interior, parallel with the contour. Two permanent 0.10 acre plots (overstory plot) were established along each transect (Figure 2), approximately within each half of the planting block. Each plot was marked with whisker stakes for plot location after overstory removal. Species, diameter at breast height (dbh) (4.5 ft. from groundline) total height, merchantable height and crown class were recorded for all stems greater than 6 in. dbh within each plot. Distance and azimuth from plot center to each sampled stem were also recorded for relocation of stumps. Importance values (IV) were calculated for each unit, block and the total study area by summing the relative dominance, relative frequency and relative density for each species encountered. Relative dominance was calculated for each species by dividing the basal area represented by that species by the total basal area for the unit of interest (i.e. plot, unit, block etc...). Relative frequency was calculated for each species by dividing the frequency within the unit of interest by the summed frequency for all species. Relative density was calculated for each species by dividing

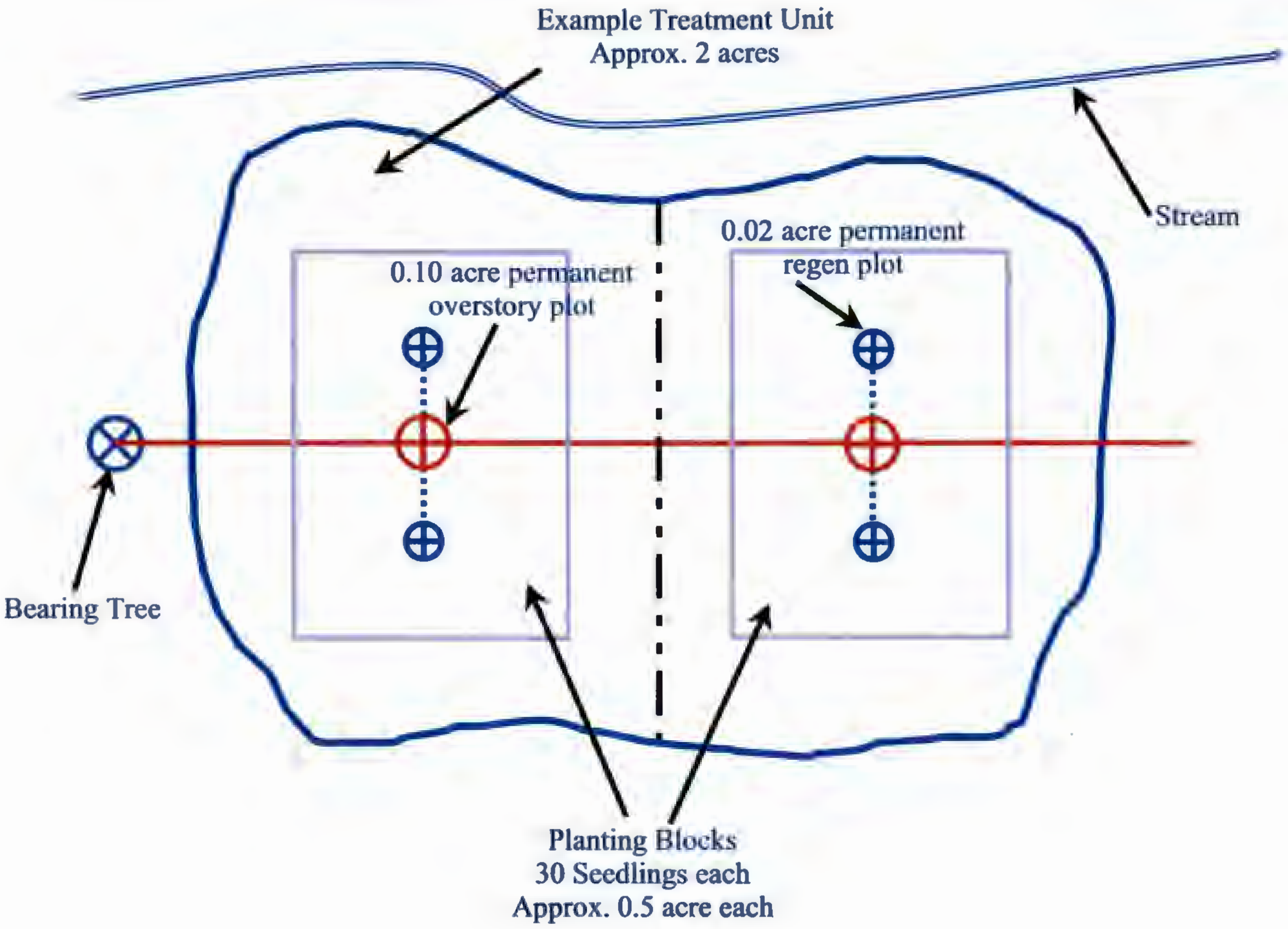

Figure 2 – Example sampling and planting layout of treatment units

the number of occurrences for that particular species by the summed number of occurrences for all species. Each relative measure was multiplied by 100 to convert to a percentile. Merchantable volumes were also calculated.

5.3. Treatments

Four treatments, including a control, with 3 replications were randomly assigned to the 12 units using a randomized complete block (RCB) design. Harvesting for all treatments was completed in the winter of 2001-2002. Overstory treatments are described below.

- Commercial Clearcut — is defined by the removal of all material greater than 6 in. diameter breast height (dbh). This treatment is designed to represent a common practice on industrial forestland.

- High Grade — is a standard diameter limit cut where all material greater then 14 in. dbh is removed. This treatment is designed to represent a common practice on NIPF lands.

- Two Age — is where a uniformly distributed residual stand basal area of 15-20 ft^2/ac was targeted. Residual stems were chosen based on spacing criteria (uniformly spaced residuals) and the desire to leave stems of desirable species with an opportunity to increase in value. Desirable species included white oak, red oak, hickories and yellow-poplar.

- No-Cut— is designed to act as the study control, wherein no harvest treatment or activity occurred. .

5.4. Natural Regeneration

A pre-harvest assessment and inventory of the natural reproduction was conducted to later assess the effects of each overstory treatment on natural regeneration. For each overstory plot established, two permanent 0.02-acre regeneration plots were systematically installed 20 ft on either side of the overstory plot center and perpendicular to the established transect (Figure 2). Species and height class were recorded for all stems less than 5.9 in. dbh and dbh was recorded for all stems greater than 1 in. and less than 5.9 in. Height classes were defined as 1) less than 2 ft, 2) greater than 2 ft less than 4 ft and 3) greater than 4 ft.

5.5. Artificial Regeneration

5.5.1. Pre-Planting

In the winter of 2001-2002, seedlings from the University of Tennessee Tree Improvement Program (UTTIP) were evaluated. High-quality 1-0 northern red oak seedlings originating from two genetic families (families 321 and 234) in a seedling seed orchard on the Ames Plantation (Schlarbaum et al. 1998) were chosen for planting following harvest. The seedlings were grown at the Georgia Forestry Commission's Flint River Nursery under fertilization and irrigation protocols developed by Kormanik et al. (1994a, 1994b). The seedlings were undercut at approximately 12 in., mechanically lifted in February 2002. The seedlings were evaluated using ocular grading procedures developed by Kormanik et al. (1994a, 1994b), as modified by Clark et al. (Clark et al. 2000). The mother trees for both families originated from Henderson County, Tennessee in accordance with the seed source zones of Tennessee developed by Post (1999) and Post et al. (2003).

Before initial measurements, all seedling roots were pruned back to approximately 6 inches from the taproot in order to facilitate ease of measurement and subsequent planting. For all seedlings height and root collar diameter (RCD) was measured and the number of first-order lateral roots (FOLR) (Ruehle and Kormanik 1986) counted. All seedlings were then visually classified (graded) into one of three categories (cull, good, premium). Two aggregations of 15 randomly chosen seedlings (premium and good) of a single family were assembled for transport to individual treatment units. Seedlings were kept in cold storage for approximately four weeks before time of planting. Two weeks were during the grading period when seedlings were being handled and two weeks after, where seedlings were not handled. Thirty seedlings from the good and premium classes in each family, 60 seedlings total, were planted by shovel, due to large root systems, on 20 x 20 ft spacing in March 2002 within each of the 12 treatment units for a total of 720 seedlings (Figure 3).

5.5.2. Post-Planting

Planted seedlings were monitored monthly (every 35-45 days) throughout the growing season for a total of four periods. Seedling condition (signs of survival and browse damage) was monitored for all seedlings in all four periods. Total height measurements were recorded for one half of all planted material during the last three measurement periods to quantify early, mid, and late season growth. However, the same seedlings were not measured over successive periods. Instead, a random sample was taken. Shoot growth was calculated by subtracting the previous height measurement from the corresponding subsequent height measurement and means calculated for each treatment for each period. End-of-season, first-year survival and growth (RCD, number of flushes and height) data were obtained in January 2003 for all seedlings after the onset of dormancy.

In order to investigate differences in herbivory among treatments a "browse pressure classification" was used (Buckley 2001). Browse pressure was classified into one of 4 categories; no browse, terminal browse, lateral browse and complete browse. No browse was defined by no visible signs of herbivory, lateral bud browse was defined as herbivory limited to only lateral shoots, terminal browse was herbivory limited to only the terminal shoot and complete browse was defined as observed herbivory on both

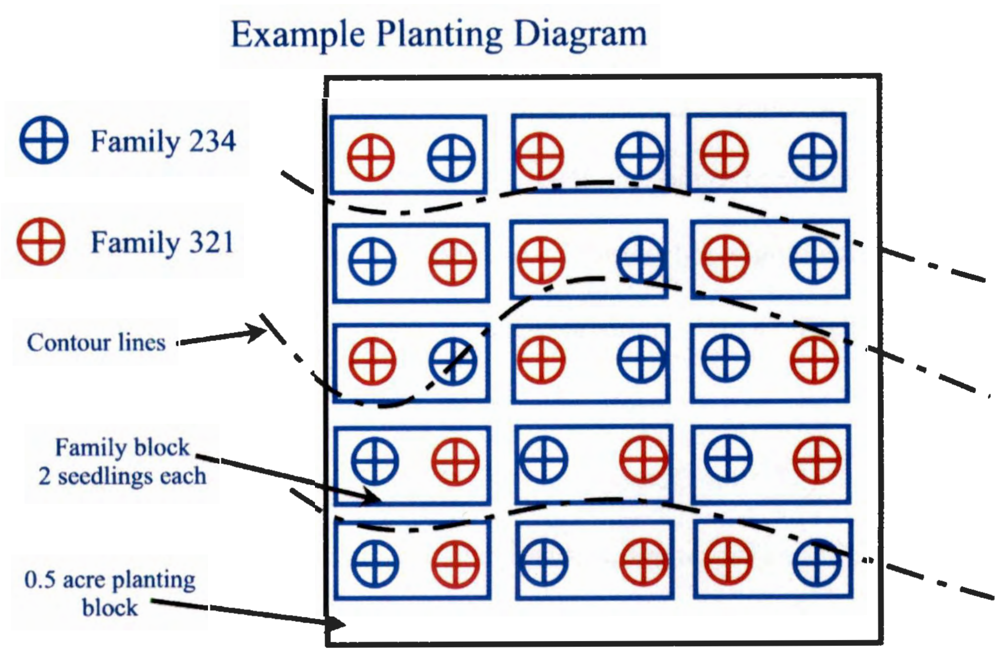

Figure 3 – Example layout of each 0.5 acre planting block, 2 located within each treatment unit,(Premium and Good seedlings randomly chosen for planting) for the Ames Plantation oak regeneration study, Fayette County, Tennessee

lateral and terminal shoots. When the terminal bud did not flush, it was recorded and the terminal shoot was then defined as the shoot expressing dominance.

5.6. Herbaceous Biomass

In conjunction with growth data, herbaceous biomass production was estimated. During each period, 5 randomly placed 18-in.^{2} samples were collected within each unit for a total of 60 samples across the entire study area. All material was clipped at ground level and transported to the lab. Each sample was categorized into one of thirteen categories including woody shrubs and seedlings (vegetation categories defined in Appendix 1). The woody shrub and seedling vegetation category was removed to determine the "herbaceous biomass". Before weighing, all material was dried for 48-50 hours at 40° C (Mueller-Dombois and Ellenberg 1974). To ensure each sample was completely dried, a subsample was weighed at 48 hours and returned to the oven for two hours, then reweighed. If any difference in weight was detected, all samples remained in the oven and the process was repeated after 2 to 4 hours. All material was weighed to the nearest 0.01 gram. Measurements represented cumulative weights through the early, mid and late growing season measurement periods. The late growing season (August 2002) biomass measurements are also considered the end-of-season or total biomass measurements.

5.7. Analysis

Statistical analysis was conducted using both SAS (SAS Institute Inc. 1989) and NCSS software (Hintze 2001). Differences among treatments and between family and seedling quality class means in seedling height growth, RCD growth, browsing and seedling mortality were analyzed through mixed model analysis of variance (ANOVA) (Saxton 2002). Tukey-Kramer Multiple-Comparison tests were used to identify significant differences among treatments. When testing for differences between genetic family and seedling quality class, a randomized complete block split-plot design was used, splitting on family and quality for each test. Statistical significance for all analyses were determined at the $\alpha = 0.05$ level.

Three independent simple linear regression analyses were used to explore possible relationships between end-of-season seedling height growth and total herbaceous biomass production, percent *Microstegium* production and seedling browse pressure. Additionally, simple linear and multiple regressions were used to explore possible effects of pre-planting measurements (i.e. initial height, RCD, FOLR…) on seedling growth and survival. Chi-square test of independence was used to evaluate possible effects of quality class and genetic family on seedling mortality within the no cut treatment units. Furthermore, additional analyses of survival among the treatments were conducted using chi-square test of independence with Fisher's Exact Test.

Logistic regression techniques were used to help explain effects of pre-planting seedling measurements on subsequent growth and mortality when categorical data (presence-absence) were used. Logistic regression techniques were also used to explore the possible effect of initial seedling height on observed patterns of herbivory.

CHAPTER VI

RESULTS

6.1. Pre-Harvest Composition and Structure

Pre-harvest species composition was dominated by oak on the ancestral terraces and yellow-poplar, sweetgum and cherrybark oak in the bottom block. Importance values were calculated for the common midstory and overstory species located within each block (Table 1). Average site index, base age 50 yr, was estimated to be 75 for oaks, 85 for yellow-poplar and 70 for sweetgum on both sites. Average age for the dominant and co-dominant stems across the study site was 70 yr.

The east block was dominated by southern red oak (*Quercus falcata* Michx.) and post oak (*Q. stellata* Wangenh.) with a few large stems of cherrybark oak, yellow-poplar and sweetgum (Table 1). The midstory was comprised of multiple small stems of dogwood, elms and blackgum. The west block was dominated by stems of white oak and post oak with a few large stems of sweetgum and yellow-poplar. Northern red and southern red oaks were also represented in the overstory. The midstory was comprised of multiple small stems of mockernut hickory (*Carya tomentosa* Nutt.), dogwood, elms and sassafras. Stems of yellow-poplar, sweetgum and cherrybark oak dominated the

Table 1 –Pre-harvest relative dominance, density and frequency and importance values for the common overstory and midstory species of the three experimental blocks for the oak regeneration study, the Ames Plantation, Fayette County, Tennessee

	East				West				Bottom			
Species	Dominance	Density	Frequency	IV 1	Dominance	Density	Frequency	IV	Dominance	Density	Frequency	IV
	relative percent				relative percent				relative percent			
American elm	1.90	3.45	6.06	11.41	0.76	2.53	3.45	6.74	4.60	5.88	11.43	21.91
American sycamore									0.65	0.98	2.86	4.49
Black cherry	1.02	2.30	3.03	6.35								
Black oak									1.68	0.98	2.86	5.52
Blackgum	0.74	2.30	6.06	9.10								
Boxelder									2.53	5.88	8.57	16.98
Cherrybark oak	7.94	3.45	9.09	20.48	1.92	1.27	3.45	6.64	13.91	7.84	5.71	27.47
Dogwood	0.81	3.45	6.06	10.32	1.38	3.80	10.34	15.52	0.45	1.96	5.71	8.13
Eastern red cedar	1.83	3.45	6.06	11.34								
Green ash	1.75	3.45	6.06	11.26								
Mockernut hickory	1.91	1.15	3.03	6.09	2.80	5.06	10.34	18.21	0.90	0.98	2.86	4.73
Northern red oak					6.67	6.33	6.90	19.90				
Osage-orange									0.25	0.98	2.86	4.09
Persimmon									1.46	1.96	2.86	6.28
Post oak	18.45	14.94	9.09	42.48	18.82	15.19	10.34	44.36				
Red maple					1.53	1.27	3.45	6.24	0.24	0.98	2.86	4.08
Red mulberry	1.00	4.60	3.03	8.62	0.28	1.27	3.45	4.99	0.19	0.98	2.86	4.03
Redbud									0.24	0.98	2.86	4.08
River birch									2.46	1.96	2.86	7.27
Sassafras	0.89	2.30	6.06	9.25	0.78	2.53	6.90	10.21				
Slippery elm									0.71	0.98	2.86	4.55
Southern red oak	37.89	27.59	12.12	77.60	6.34	5.06	6.90	18.30	2.18	1.96	5.71	9.85
Sweetgum	4.53	6.90	6.06	17.49	4.14	7.59	10.34	22.08	17.56	20.59	11.43	49.58
Walnut	3.61	4.60	6.06	14.27	7.34	5.06	3.45	15.85				
White oak	4.06	6.90	6.06	17.02	33.09	35.44	13.79	82.32	1.73	0.98	2.86	5.57
Winged elm									2.43	4.90	8.57	15.90
Yellow-poplar	11.66	9.20	6.06	26.92	14.15	7.59	6.90	28.64	45.83	38.24	11.43	95.49

1 Importance values (IV) calculated by summing relative dominance, density and frequency

Scientific names are located in Appendix 2 overstory of the bottom block (Table 1). The midstory was dominated by numerous small stems of boxelder, elms and dogwoods. A few pole size river birch were also located within the block.

6.2. Post-Harvest Composition and Structure

Harvest prescriptions resulted in mean basal areas of 142, 20, 14 and 0 ft^2/ac for the no-cut, high-grade, two-age and commercial clearcut treatments respectively (material greater than 6 in.). Little difference in mean basal area existed between the high-grade and two-age treatments, however, spacing and species composition of the residual stand differed between the two treatments due to harvest criteria. Stems averaging 13 inches in diameter were evenly distributed for the residual stand of the two-age treatments. White oak was the prominent species. The midstory was completely removed during harvest. The residual stands of the high-grade treatment were characterized by unevenly distributed clumps of stems averaging 9 inches in diameter with a relatively intact midstory component. The residual stand for the high-grade treatment was generally comprised of sweetgum that had occupied (pre-harvest) a suppressed or subordinate position within the stand and elms and dogwoods from the midstory.

6.3. Artificial Regeneration

From the two genetically known seedling families, 1,515 seedlings were examined and 960 were rated as acceptable planting stock (Table 2). Approximately 31 percent and 42 percent of the seedlings were culled from families 234 and 321, respectively. Premium seedlings represented 19 percent and 15 percent of families 234 and 321, respectively, while seedlings classified as good represented the successive 49 percent and 44 percent, respectively. For family 234, 240 seedlings classified as good were outplanted and 120 classified as premium were outplanted (Table 3). Family 321 was represented by outplanting 264 seedlings classified as good and outplanting 96 premium seedlings. Those seedlings classified as premium and good represented the acceptable planting stock and all others were culled. The acceptable planting stock represented the top 63 percent of total available seedlings within the two utilized genetic families. Total planted material was approximately 75 percent of the acceptable planting stock.

Mean initial RCD, initial shoot height (planting height) and number of FOLR for premium seedlings (n=216) were 12.55 mm, 124.30 cm and 21.49 (Table 4), respectively. Mean initial RCD, initial shoot height and number of FOLR for good seedlings (n=504) were 10.23 mm, 103.85 and 16.46 respectively (Table 4). Family 234 was characterized by a mean of 11.74 mm, 111.14 cm and 18.43 for initial RCD, initial height and number of FOLR, respectively. Family 321 was characterized by a mean of 11.04 mm, 117.01 cm and 19.52 for initial RCD, initial height and number of FOLR, respectively (Table 4).

Table 2 – Number of northern red oak (*Quercus rubra* L.) seedlings classified as Premium, Good or Cull and acceptable planting stock for each family used in the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

	------Premium------		---------Good--------		---------Cull---------		Total	Planting Stock [1]
Family	count	%	count	%	count	%	count	count
234	158	18.68	412	48.7	276	32.62	846	570
321	97	14.5	293	43.8	279	41.7	669	390
Total	255		705		555		1515	960

[1] Acceptable planting stock is the combination of premium and good seedlings.

Table 3 – Number of outplanted northern red oak (*Quercus rubra* L.) seedlings for each quality classification within each genetic family for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Family #	Good	Premium	Grand Total
234	240	120	360
321	264	96	360
Grand Total	504	216	720

Table 4 – Mean root collar diameter, mean initial height and mean number of first-order lateral roots for each family and quality class of outplanted northern red oak (*Quercus rubra* L.) seedlings prior to planting in March of 2002 for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

		--------Good-------		------Premium------		--------All--------	
Family #		mean	n	mean	n	mean	n
234	Root Collar Diameter (mm)	10.65	240	12.83	120	11.74	360
	Initial Height (cm)	102.28	240	120.00	120	111.14	360
	First-order lateral roots	15.79	240	21.08	120	18.43	360
321	Root Collar Diameter	9.81	264	12.26	96	11.04	360
	Initial Height	105.42	264	128.60	96	117.01	360
	First-order lateral roots	17.13	264	21.91	96	19.52	360
All	Root Collar Diameter	10.23	504	12.55	216	11.39	720
	Initial Height	103.85	504	124.30	216	114.07	720
	First-order lateral roots	16.46	504	21.49	216	18.98	720

No significant differences were found when comparing means for initial seedling height, initial root collar diameter and number of FOLR between genetic families.

No significant difference existed between genetic family, seedling quality class or treatment for time of bud break. More than 99 percent of planted seedlings experienced either terminal or lateral bud break prior to May 4th, 2002. However, chi square tests indicated ($p < 0.01$) that the number of seedlings in which the terminal bud flushed was dependent upon treatment. The number of seedlings in which the terminal bud flushed trended downward ($p = 0.009$) as residual cover increased with mean percent of seedlings experiencing terminal bud break of 38 percent, 38 percent, 33 percent and 27 percent for the commercial clearcut, two age, high grade and no cut, respectively (Figure 4). The remaining seedlings flushed from a lateral bud rather than the terminal bud. The experimental block had no significant effect on terminal bud break ($p = 0.16$).

6.3.1. Mortality

6.3.1a. Within Growing Season

At the beginning of the growing season in May, there were few signs of seedling dieback or mortality (Table 5). At that time, only six dead seedlings were observed: 1 in the two-age treatment, and 5 were observed in the no-cut treatments. No dead seedlings were found in either the high-grade or commercial clearcut treatments. Signs of stress were more apparent in the early or June observation period. The high-grade and two-age treatments had experienced a loss of two seedlings and some seedlings were showing

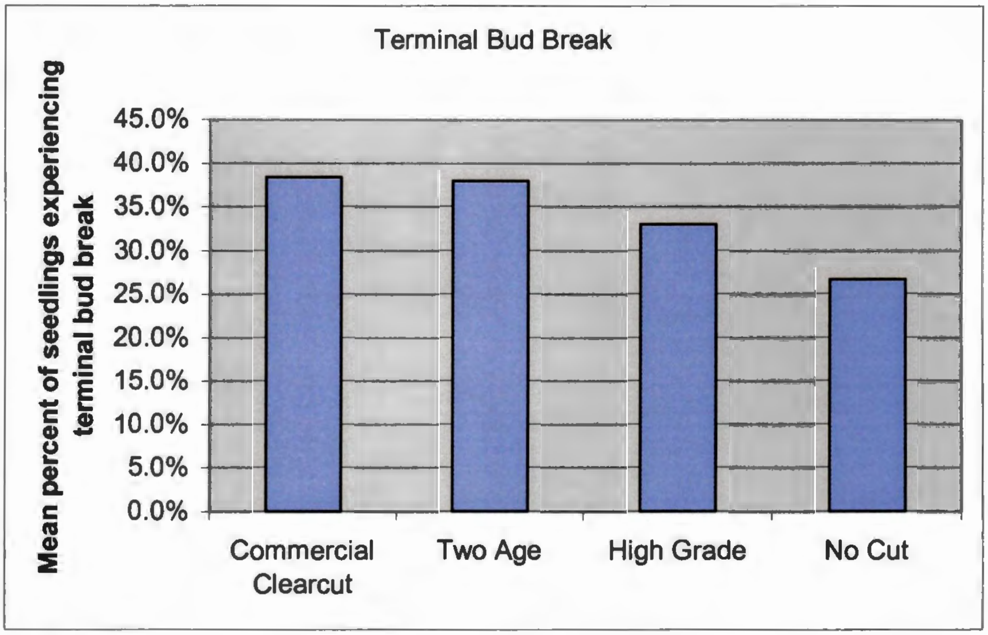

Figure 4 – Mean percent of seedlings experiencing terminal bud break in the 2002 growing season for the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Table 5 – Number of observed northern red oak (*Quercus rubra* L.) seedlings exhibiting signs of top die-back, dead top or completely dead for each of four periods within the 2002 growing season and the end of the growing season mortality

Observation Period [1]	Severity [2]	------------------Treatment------------------			
		Commercial Clearcut	Two Age	High Grade	No Cut
May	Top Die-back	0 [3]	0	0	0
	Dead Top	0	0	0	0
	Dead	0	1	0	5
June (Early)	Top Die-back	0	1	0	31
	Dead Top	1	2	0	3
	Dead	0	2	2	6
July (Mid)	Top Die-back	4	3	6	23
	Dead Top	2	2	3	6
	Dead	0	4	3	31
August (Late)	Top Die-back	7	4	12	15
	Dead Top	2	4	2	3
	Dead	0	5	3	46
End-of-Season	Dead	0	10	9	59

[1] Sample Dates – May = 5/04/02, Early = 6/10/02, Mid = 7/14/02, Late = 8/25/02, End-of-Season = 1/04/03

[2] Top Die-back defined as exhibiting signs of top wilt and die-back of new growth, Dead top defined as showing signs of complete new growth abandonment or die-back, dead was defined as no visible signs of green material.

[3] All seedlings were observed each period within each treatment for a total of 720 seedlings

signs of top dieback. However, within the no-cut treatments, signs of stress were more apparent. Top dieback was more extensive with 31 seedlings, 3 seedlings exhibited completely dead tops and 6 seedlings were classified as dead. During the mid growing season observation period in July, little change occurred in the commercial clearcut, two-age and high-grade treatments. However, within the no-cut treatments many seedlings having expressed top dieback in the early period had progressed to being classified as dead. A total of 17 percent of the seedlings were classified as dead with 13 percent of the seedlings showing signs of top dieback (Table 5). Observations in the late growing season period in August revealed slight increases in the number of dead seedlings in the two-age and high-grade treatments. However, no seedlings in the commercial clearcut treatments were classified as dead, although some signs of top dieback were beginning to be expressed. Yet within the no-cut treatment, by the late growing season observation period, a total of 26 percent of the seedlings were classified as dead, 8 percent showing signs of top dieback and 2 percent possessing dead tops (Table 5).

6.3.1b. End of Season

End of growing season mortality for all seedlings was significantly greatest for the no-cut treatment with mean percent mortality of 33 percent or 59 seedlings (n = 180, p = 0.004) followed by the high-grade and two-age treatments with 5 percent each, 10 and 9 seedlings, respectively (Table 5). The commercial clearcut experienced no seedling mortality. Tukey-Kramer comparisons indicated no difference between the three overstory cut treatments. ANOVA suggested no significant differences in mortality between genetic families ($p > 0.05$) with mean percent mortality of 11 percent for each family across the entire study. Analyzed independently, the no-cut treatment indicated that genetic family and seedling quality had no effect on seedling mortality for the 2002 growing season ($p = 0.91$ and $p = 0.38$, respectively).

Logistic regression techniques were used to further investigate first-year growing season seedling mortality by testing if the initial height, number of FOLR and the initial RCD influenced seedling mortality. Initial model results were weak (R-square = 0.02) and indicated that the three variables were not important factors ($p = 0.77$, 0.17 and 0.13 for the FOLR, initial height and RCD, respectively) and were not related to seedling mortality. However, models delineating one explanatory variable indicated that initial height (R-square = 0.07, $p = 0.009$) and initial RCD (R-square = 0.06, $p = 0.006$) were related to seedling mortality. The number of FOLR was determined not to be a significant factor ($p = 0.08$).

6.3.2. Height Growth

6.3.2a. Within Growing Season

Eighty-one percent of all seedlings experienced only one growth flush. Early season height growth for the no-cut treatment was significantly greater than the cut treatments ($p = 0.0008$) with mean growth of 12.40 cm., 11.46 cm., 8.73 cm and 26.21 cm for the commercial clearcut, high-grade, two-age and no-cut treatments, respectively

(Table 6). No significant differences were observed among the cut treatments. Mid-season growth was significantly differed among treatments ($p = 0.009$). The commercial clearcut and high-grade treatments differed from the two-age and no-cut treatments with mean mid-season growth of 3.17 cm, 3.42 cm, 0.00 cm and –0.18, respectively. Late season growth was not different across treatments ($p = 0.53$) (Table 6).

6.3.2b. End of Season (Total)

First growing season end-of-season height growth was significantly greater for the no-cut treatment ($p = 0.0005$). Mean total growth was observed as 12.43 cm, 13.48 cm, 9.18 cm and 22.33 cm for the commercial clearcut, high-grade, two-age and no-cut treatments, respectively (Table 6). Post-ANOVA analysis resulted in no strong differences between the three cut treatments. No significant differences in mean height growth were observed between genetic families ($p = 0.79$) with mean height growth of 14.13 cm and 14.51 cm for families 234 and 321 respectively (Table 7). Mean growth for all Premium seedlings (18.09 cm) was greater ($p < 0.001$) than Good seedlings (12.76 cm) (Table 8). Mean growth for Premium and Good seedlings was 18.09 cm and 12.76 cm respectively. Mean height growth differed among blocks ($p < 0.0001$) with mean height growth of 17.72 cm, 16.35 cm and 9.00 cm for the east, west and bottom blocks, respectively (Table 6).

Table 6 –Mean initial height, average height growth for each sampling period and mean total height growth (cm) of 1-0 high-quality northern red oak (*Quercus rubra* L.) seedlings for each sampling period during the 2002-growing season for each treatment and block for the oak regeneration study on Ames Plantation, Fayette County, Tennessee

Treatment	Initial Height[1]		Period of Growth						Total Growth	
			Early		Mid		Late			
Commercial clearcut	43.50	(180)[2]	4.88 A[4]	(89)	1.25 A	(41)	0.36	(43)	4.90 A	(180)
High grade	42.83	(180)	4.51 A	(91)	1.35 A	(30)	2.42	(33)	5.31 A	(171)
Two age	43.15	(180)	3.44 A	(92)	0.00 B	(27)	-1.10	(28)	3.61 A	(170)
No cut	43.58	(180)	10.32 B	(90)	-0.07 B	(20)	-0.08	(30)	8.80 B	(121)
	p = 0.89[3]		p < 0.0008		p < 0.01		p = 0.52		p < 0.0006	
Block										
East	43.19	(240)	6.57 A	(119)	1.13	(38)	0.39	(40)	6.98	(222)
West	43.41	(240)	6.14 A	(121)	0.65	(57)	0.23	(65)	6.44	(213)
Bottom	43.20	(240)	4.65 B	(122)	0.11	(23)	-3.05	(29)	3.54	(207)
	p = 0.92		p < 0.04		p = 0.85		p = 0.98		p < 0.0001	

[1] Sample Dates – Initial = 2/08/02, Early = 6/10/02, Mid = 7/14/02,
Late = 8/25/02, End = 1/04/03

[2] Sample size (n), 50% of seedlings were randomly measured at each period during the growing season with n representing the number of actual seedlings in the sample cross-referenced directly from previous sample. Total height growth was measured at the end of the growing season for all seedlings.

[3] Mixed model ANOVA results

[4] Mean separation by Tukey-Kramer multiple comparison tests. Means followed by the same letter are not significantly different at the alpha 0.05 level.

Table 7 – End-of-season (total) mean height growth for each northern red oak (*Quercus rubra*) genetic family for the 2002 growing season utilized for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Family	End-of-Season Height Growth (cm)
234	14.13
321	14.51
	p = 0.79 [1]

[1] Results of ANOVA

Table 8 -- End-of-season (total) mean height growth for each northern red oak (*Quercus rubra*) quality classification for the 2002 growing season for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Seedling Quality	End-of-Season Height Growth (cm)
Premium	18.09
Good	12.76
	$p < 0.001$ [1]

[1] Results of ANOVA test

6.3.3. Root Collar Growth

Root collar diameter (RCD) growth, after one growing season, differed among treatments (p = 0.03). Mean RCD growth observed for the commercial clearcut, high-grade, two-age and no-cut treatments were 0.066 cm, 0.033 cm, 0.018 cm and –0.056 cm, respectively (Table 9). Post ANOVA mean comparison analysis resulted in the no-cut treatment and commercial clearcut differing from one another. However, neither the no-cut nor the commercial clearcut treatment differed from the high-grade or two-age treatments (Table 9).

6.3.4. Herbaceous Biomass Growth

6.3.4a. Within Growing Season

Mean early season herbaceous biomass production was not significantly different among treatments (Table 10) or blocks (Table 11) (p = .07 and p = .72), respectively. Mean mid season herbaceous biomass production significantly differed among the treatments (p < 0.004) with production highest for the commercial clearcut followed by the two-age, high-grade and no-cut treatments (Table 12). However differences did not exist among blocks (p = 0.47). Mean herbaceous biomass production trended upward with increasing overstory removal intensity (Figure 5). A similar pattern existed among treatments for the late growing season period with the exception of the two-age treatment. Mean biomass production differed significantly among treatments (p < 0.003), however, it did not differ among blocks (p = 0.78). For the late growing season, mean herbaceous

Table 9 -- End-of-season (total) mean root collar diameter (RCD) growth of northern red oak (*Quercus rubra*) seedlings for the 2002 growing season for each of the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Treatment	RCD Growth (cm)
Commercial clearcut	0.066 AB [1]
High grade	0.033 BC
Two age	0.018 BC
No cut	-0.056 CD

[1] Results of post-ANOVA Tukey-Kramer Multiple Comparisons test. Same letter indicates no significant difference at the alpha 0.05 level

Table 10 – Mean early growing season understory vegetative biomass production in the 2002 growing season for each of the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Vegetation Codes [1]	No Cut	Two Age	High Grade	Commercial Clearcut
	---------------------------- Kg/acre (dry weight) ----------------------------			
1	39.85	6.52	39.82	14.29
2	5.89	55.77	60.16	37.94
3	0.80	185.18	80.45	120.90
4	0.00	5.11	0.00	59.22
5	2.41	10.18	0.00	40.05
6	6.54	0.00	18.33	3.74
7	1.93	18.87	23.95	15.88
8	46.91	237.93	171.71	229.06
9	9.33	24.49	7.64	20.83
10	40.23	27.09	24.26	63.53
11	0.00	31.94	3.82	5.30
12	0.00	6.60	8.47	12.56
13	0.00	0.00	3.06	1.13
All	143.92 A[2]	608.03 A	431.70 A	620.83 A

[1] Corresponding species groups for each vegetation code are found in Appendix 2. Vegetation code 9 corresponds to woody seedlings and shrubs with the remainder corresponding to herbaceous material

[2] Means with common letter are not different at alpha 0.05

Table 11 – Mean understory vegetative biomass production in the 2002 growing season for each of the three experimental blocks within the three sample periods for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

	Early			Mid			Late		
Vegetation Code	East	West	Bottom	East	West	Bottom	East	West	Bottom
	Kg/acre (dry weight)								
1	21.73	35.55	18.07	32.16	18.65	7.00	42.81	21.06	3.93
2	57.76	91.27	10.72	63.00	91.40	6.65	50.62	165.96	2.36
3	180.29	148.16	58.88	700.77	345.22	411.17	1047.02	615.40	241.78
4	0.00	38.24	26.10	0.00	31.00	27.95	0.00	77.42	81.43
5	0.69	7.87	44.07	0.00	61.23	5.39	0.00	11.36	4.90
6	6.54	0.00	22.06	0.00	1.41	12.44	0.00	15.58	6.75
7	43.70	11.06	5.87	74.18	14.12	0.55	70.14	55.49	0.62
8	57.24	230.48	397.89	104.16	541.93	1028.11	169.88	505.30	1427.72
9	46.88	11.99	3.42	24.04	63.93	2.24	37.33	79.29	5.68
10	52.18	60.38	42.55	40.31	91.80	4.46	41.22	94.06	0.00
11	33.27	7.49	0.29	124.98	47.34	0.00	113.63	29.58	59.05
12	12.88	14.29	0.47	16.09	18.00	0.62	12.40	32.16	0.00
13	0.84	3.35	0.00	3.13	4.92	0.00	4.73	5.67	0.00
All	513.98	660.12	630.38	1182.80	1330.94	1506.58	1589.78	1708.33	1834.21

[1] Sample Dates – Early = 6/10/02, Mid = 7/14/02, Late = 8/25/02

Table 12 – Mean mid growing season understory vegetative biomass production in the 2002 growing season for each of the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Vegetation Code [1]	No Cut	Two Age	High Grade	Commercial Clearcut
	Kg/acre (dry weight)			
1	30.67	0.18	26.51	19.72
2	10.83	62.02	68.16	73.72
3	2.44	598.62	491.01	850.81
4	0.00	13.94	6.85	57.80
5	0.00	1.20	18.37	69.26
6	12.91	0.00	5.56	0.00
7	0.74	57.07	48.59	12.07
8	98.65	878.16	540.44	715.02
9	5.06	9.18	29.56	76.47
10	34.74	18.78	100.65	27.92
11	0.05	57.55	114.12	58.04
12	0.00	0.85	30.27	15.17
13	0.00	7.69	0.00	3.03
All	196.08 A[2]	1705.24 B	1480.08 B	1979.02 B

[1] Corresponding species groups for each vegetation code are found in Appendix 2. Vegetation code 9 corresponds to woody seedlings and shrubs with the remainder corresponding to herbaceous material

[2] Means with common letter are not different at alpha 0.05

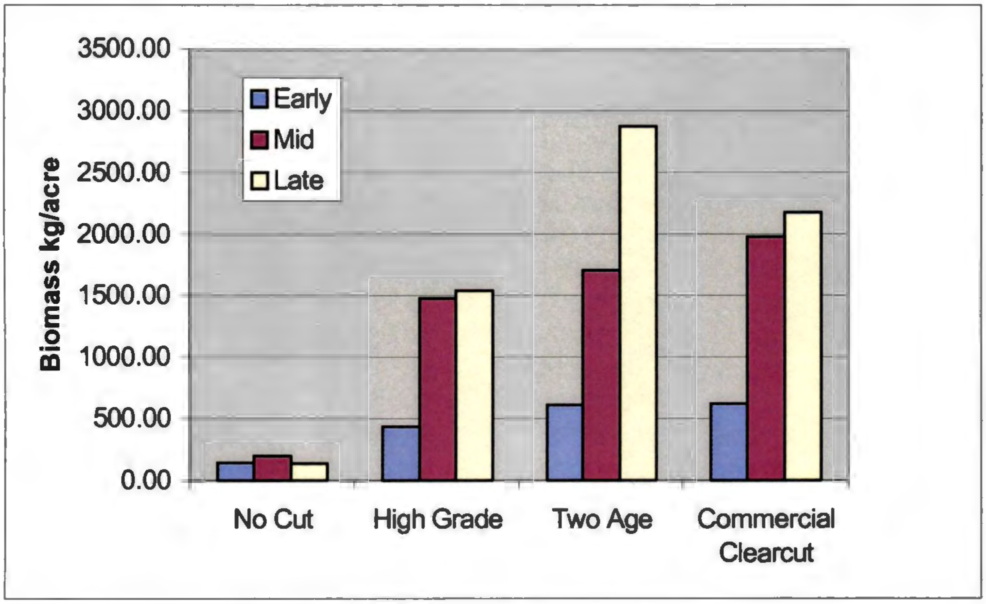

Figure 5 – Mean understory biomass production in kg/acre for each of three sample periods for the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee (Sample Dates – Early = 6/10/02, Mid = 7/14/02, Late = 8/25/02)

biomass production was greatest for the two-age treatment followed by the commercial clearcut, high-grade and no-cut treatments (Table 13).

6.3.4b. End of Season

Total end-of-season herbaceous biomass production and end-of-season (total) height growth were significantly negatively related among treatments (p = 0.006) (Figure 6). Herbaceous biomass production appears to have a strong negative relationship with total height growth (r = –0.74). Although total herbaceous biomass production is inversely related to total height growth, it appears to be only a moderate to weak predictor (r-square = 0.55) (Figure 6). Mean end-of-season herbaceous biomass production differed across treatments (p = 0.003). Mean production was greatest within the two-age treatment, measuring 2874 kg/acre followed by the commercial clearcut, high-grade and no-cut treatments with 2174 kg/ac, 1538 kg/ac and 135 kg/ac, respectively (Table 13).

6.3.5 Microstegium Growth

6.3.5a. Within Growing Season

Mean *Microstegium vimeneum* (vegetation code 8) biomass production did not differ among treatments or blocks for the early growing season period (p = 0.24 and p = 0.61), respectively. However, mean early season *Microstegium* production appeared to be the greatest in the commercial clearcut and two-age treatments followed by lower amounts in the high-grade treatments with production lowest in the no-cut treatments (Table 10).

Table 13 – Mean late [1] growing season understory vegetative biomass production in the 2002 growing season for each of the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

Vegetation Code [1]	No Cut	Two Age	High Grade	Commercial Clearcut
	Kg/acre (dry weight)			
1	7.27	4.47	22.88	44.50
2	9.03	18.37	150.27	116.17
3	0.00	1132.12	652.35	754.46
4	3.07	14.43	86.33	107.96
5	10.00	2.37	3.57	5.73
6	29.78	0.00	0.00	0.00
7	0.83	68.21	52.59	46.70
8	46.98	1421.66	323.89	888.00
9	14.82	54.76	14.98	90.00
10	0.21	39.96	89.65	50.56
11	0.00	96.31	132.26	41.11
12	13.42	15.18	9.21	21.61
13	0.00	6.31	0.00	7.56
All	135.40 A[2]	2874.15 B	1537.97 AB	2174.36 B

[1] Lat and end-of-season growing period data are the same

[2] Corresponding species groups for each vegetation code are found in Appendix 2. Vegetation code 9 corresponds to woody seedlings and shrubs with the remainder corresponding to herbaceous material

[3] Means with common letter are not different at alpha 0.05

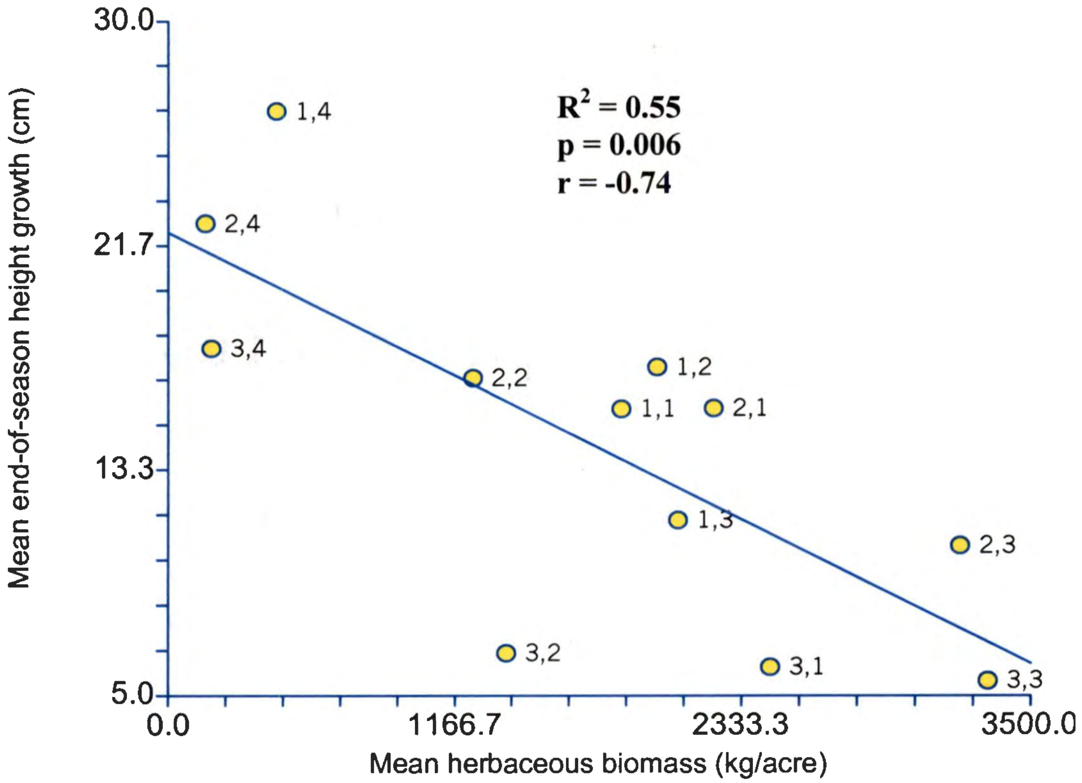

Figure 6 – Simple linear regression of mean end-of-season seedling height growth and mean end-of-season herbaceous biomass production (2002 growing season) for the twelve study units for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee. The first number corresponds to the associated experimental block (1 = East, 2 = West, 3 = Bottom). The second number corresponds to the associated treatment (1= Commercial clearcut, 2= High Grade, 3= Two Age and 4 = No Cut)

Similar patterns existed for the mid and late growing season periods, again significant differences among treatments were not found (Table 12 and 13). *Microstegium* biomass appears to be a significant component within each block, treatment and unit, often comprising approximately 50 percent of production (Table 10, 12 and 13).

6.3.5b. End of Season

Microstegium production within some units of the study was extremely large. Simple linear regression techniques were used to explore the possible effects of *Microstegium* production on mean seedling height growth within individual units. Although a strongly negative relationship was found, percent *Microstegium* appeared to be only a moderate to weak predictor of end-of-season seedling height growth (r-square = 0.54, p = 0.006, r = -0.74) (Figure 7). Interestingly, with the removal of *Microstegium* from the analysis, the above relationship did not exist. Simple linear regression analysis of mean end-of-season height growth and mean herbaceous biomass production without Microstegium resulted in an R^2 of only 0.008 and a correlation of –0.09 (p = 0.78) (Figure 8). Although no differences in percent *Microstegium* production were found between treatments (p = 0.29), mean biomass production of *Microstegium* ranged from 45 percent in the two-age treatment followed by the commercial clearcut, high-grade and no-cut treatments with 37 percent, 24 percent and 23 percent respectively (Table 13).

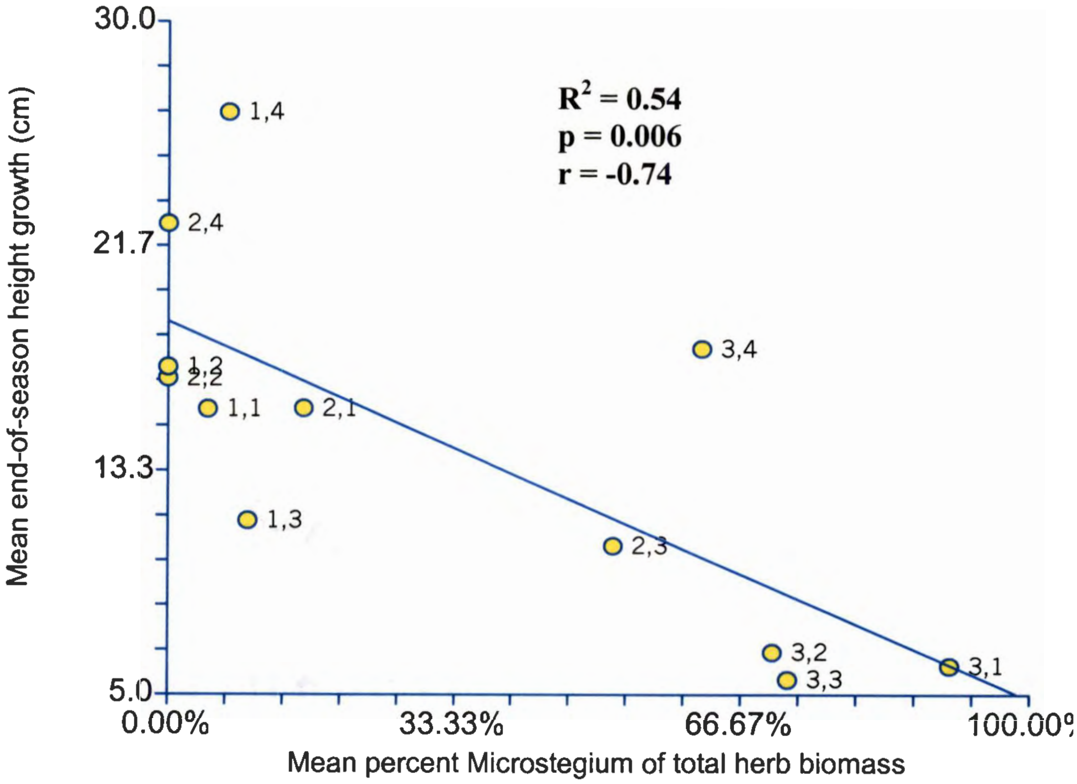

Figure 7 – Simple linear regression of mean end-of-season seedling height growth and mean percent *Microstegium* of total herbaceous biomass production (2002 growing season) for each of the twelve study units for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee. The first number corresponds to the associated experimental block (1 = East, 2 = West, 3 = Bottom). The second number corresponds to the associated treatment (1= Commercial clearcut, 2= High Grade, 3= Two Age and 4 = No Cut)

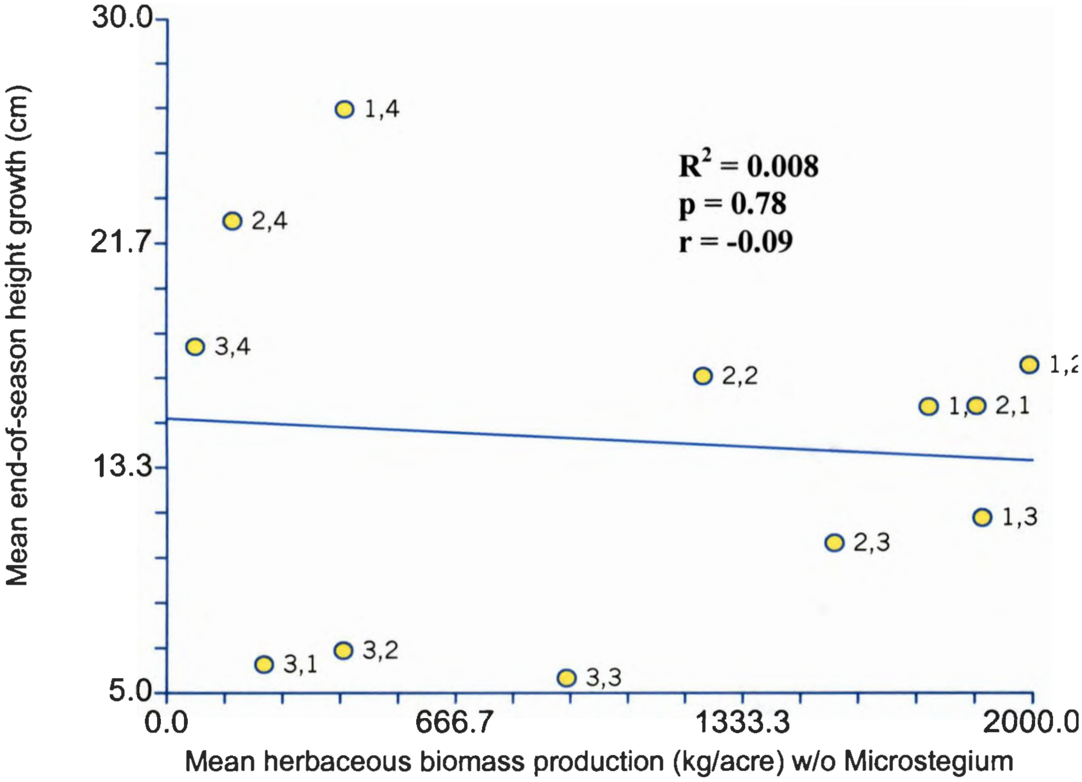

Figure 8 – **Simple linear regression of mean end-of-season seedling height growth and mean herbaceous biomass production, excluding *Microstegium* (2002 growing season), for each of the twelve study units for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee. The first number corresponds to the associated experimental block (1 = East, 2 = West, 3 = Bottom). The second number corresponds to the associated treatment (1= Commercial clearcut, 2= High Grade, 3= Two Age and 4 = No Cut)**

6.3.6. Browse Pressure

Herbivory was concentrated in the early part of the growing season and was not recurrent. No additional browse was observed after the May observation date. Observed browse pressure was concentrated in the bottom block with 44 percent of seedlings (n = 240 seedlings) completely browsed (Table 14). Comparatively, in the west block 22 percent of the seedlings were completely browsed along with 12 percent for the east block (Table 14). Browse pressure for the terminal buds only and lateral buds only were similar among all three blocks. Browse pressure was least severe for the no-cut treatments with 77 percent of seedlings experiencing no browse and only 13 percent being completely browsed (Table 15). The three cut treatments realized similar pressure with 32 percent, 33 percent and 27 percent of seedlings being completely browsed for the two-age, high-grade and commercial clearcut treatments, respectively (Table 15). Browse levels for lateral bud browse only and terminal bud browse only were similar among all treatments.

Pooled dataset (Any browse = complete browse, terminal browse and lateral browse) ANOVA suggested differences in observed seedling browse pressure among blocks ($p = 0.006$), with mean percent seedlings browsed equaling 20 percent, 35 percent and 57 percent for the east, west and bottom blocks, respectively (Table 16). Differences were observed between treatments ($p < 0.02$) due to the decrease of browse pressure experienced by the no cut treatment (Table 17). No differences in browse pressure were observed between the three cut treatments.

Table 14 -- Number of northern red oak (*Quercus rubra* L.) seedlings with observed browse pressure by category (completely browsed, no browse, terminal browse and lateral browse) in the 2002 growing season among the three experimental blocks for the oak regeneration study, the Ames Plantation, Fayette County, Tennessee

	----------East----------		----------West----------		---------Bottom---------	
Browse Class [2]	count [1]	n [3]	count	n	count	n
No browse	190	239	159	238	102	237
Lateral bud browse	15	239	19	238	20	237
Terminal bud browse	5	239	7	238	9	237
Complete browse	29	239	53	238	106	237

[1] Observations were made between May 4th and 5th during the 2002 growing season

[2] No browse was defined by no visible signs of herbivory, lateral bud browse was defined as herbivory limited to only lateral shoots, terminal browse was herbivory limited to only the terminal shoot and complete browse was defined as observed herbivory on both lateral and terminal shoots

[3] Sample size (n) reflects seedling mortality at time of sample from a total of 240 for each block

Table 15 – Number of northern red oak (*Quercus rubra* L.) seedlings with observed browse pressure by category (no browse, terminal browse, lateral browse and complete browse) in the 2002 growing season for the four treatments for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee

	-Commercial Clearcut-		--------Two Age-------		------High Grade------		-------No Cut-------	
	count[1]	n	count	n	count	n	count	n
Browse Class[2]								
No browse	114	180	98	179	101	180	138	175
Lateral bud browse	12	180	15	179	15	180	12	175
Terminal bud browse	6	180	9	179	4	180	2	175
Complete browse	48	180	57	179	60	180	23	175

[1] Observations were made between May 4th and 5th during the 2002 growing season

[2] No browse was defined by no visible signs of herbivory, lateral bud browse was defined as herbivory limited to only lateral shoots, terminal browse was herbivory limited to only the terminal shoot and complete browse was defined as observed herbivory on both lateral and terminal shoots.

[3] Sample size (n) reflects seedling mortality at time of sample from a total of 180 for each treatment

Table 16 – Pooled observed browse pressure (Any browse) among the three experimental blocks in the 2002 growing season for the oak regeneration study, the Ames Plantation, Fayette County, Tennessee

	----------East----------		----------West----------		---------Bottom---------	
Browse Class [2]	count [1]	n [3]	count	n	count	n
No browse	190	239	159	238	102	237
Any browse	49	239	79	238	135	237

[1] Observations were made between May 4th and 5th during the 2002 growing season

[2] No browse was defined by no visible signs of herbivory, any browse defined as any discerneable level of browse pressure

[3] Sample size (n) reflects seedling mortality at time of sample out of a total of 240 for each block

Table 17 -- Pooled observed browse pressure (Any browse) in the 2002 growing season among the four overstory treatments for the oak regeneration study, the Ames Plantation, Fayette County, Tennessee

	-Commercial Clearcut-		--------Two Age-------		------HighGrade------		-------No Cut-------	
	count [1]	n	count	n	count	n	count	n
Browse Class [2]								
No browse	114	180	98	179	101	180	138	175
Anybrowse	66	180	81	179	79	180	37	175

[1] Observations were made between May 4th and 5th during the 2002 growing season

[2] No browse was defined by no visible signs of herbivory, any browse defined as any discernable level of browse pressure

[3] Sample size (n) reflects seedling mortality at time of sample out of a total of 180 for each treatment

When examined independently of all other variables, browse pressure accounted for approximately 67 percent of the variation in total seedling height growth (r-square = 0.6720) with a slope different from zero ($p = 0.011$). Total browse pressure exhibited a strong negative relationship ($r = -0.82$) with total growth (Figure 9).

Terminal browse and complete browse data were pooled for logistic regression and is referred to as terminal shoot removal. A model with initial seedling height indicated a relationship with terminal shoot removal and initial seedling height ($p < 0.001$). In an attempt to identify "browse height", chi-square was used to test 4 categories of initial height and terminal shoot removal. No seedling with an initial height greater than 148 cm experienced terminal shoot removal ($p < 0.001$).

6.4. Periodic Cicada

During the summer of 2002 the 13-year periodical cicada (*Magicicada* spp.) (Brood XXIII) (Simon 1988) emerged in western Tennessee. In early June of 2002 Carbaryl (Sevin) was applied aerially in order to control ovipostional damage. However, after close examination, it appeared that many female cicadas' had already oviposited, which is where the considerable damage can be caused. The damage that did occur was randomly scattered throughout the study in a random pattern, including all treatment units. The periodical cicada appeared to have little effect and was not considered in any analyses.

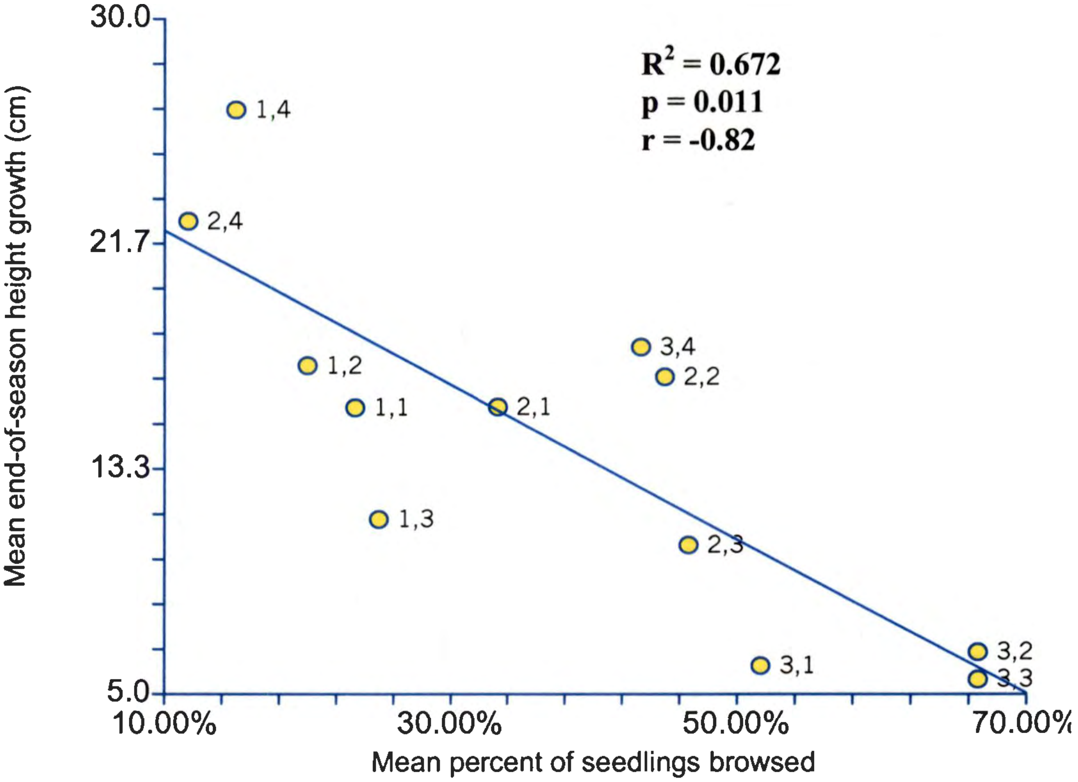

Figure 9 – Simple linear regression of mean end-of-season growth and mean percent of seedlings browsed per unit (2002 growing season) for all twelve study units for the oak regeneration study on the Ames Plantation, Fayette County, Tennessee. The first number corresponds to the associated experimental block (1 = East, 2 = West, 3 = Bottom). The second number corresponds to the associated treatment (1= Commercial clearcut, 2= High Grade, 3= Two Age and 4 = No Cut)

CHAPTER VII

DISCUSSION

The results indicate that using large, high-quality oak seedlings to maintain oak on highly productive sites with the four harvesting treatments appears promising. The large, high-quality northern red oak seedlings averaged 114 cm in height at the time of planting and grew an average of 9.18 cm, 12.43 cm, 13.48 cm and 22.33 cm in the two-age, commercial-clearcut, high-grade and no-cut treatments, respectively in the first growing season. Light availability, seedling quality, herbaceous competition along with browse pressure appear to be important factors contributing to seedling development for the oak regeneration study at the Ames Plantation.

7.1 Browse Pressure

Herbivory damage, especially that resulting from very large populations of white-tailed deer (*Odocoileus virginianus* Boddaert.), has been reported as one of the major factors hampering the successful establishment of artificial regeneration, particularly oak. More specifically, in this study, herbivory damage or browse pressure had a significant impact on first-year seedling shoot growth, accounting for 67 percent of variation when examined independently. However, one of the key benefits in using large, high-quality seedlings with a greater initial height at the time of outplanting is the capability of these seedlings to exceed browse height more rapidly, and therefore escape damage from herbivory. Conventionally, “browse lines” have been loosely defined at approximately

4.5 ft or 137 cm. Results from this study indicate the browse line for this particular site is at 4.9 ft or 148 cm. Additionally, results from logistic regression analysis suggest that a definite relationship exists between initial planting height and experienced browse pressure.

After the first growing season, heights of many seedlings, particularly the Premium seedlings, have already approached or surpassed the "local browse line". If second year growth is similar to the first year, it is reasonable to suggest that a majority of both good and premium seedlings will have developed beyond this boundary. High-quality seedlings, like those used in this study, have a greater initial advantage over commonly available seedling stock due to the larger initial height. However, herbivory will continue to be problematic until seedling stock with initial shoot heights greater than browse height can be produced.

For this study, seedlings were planted on 20 by 20 ft spacing. Planting on such a wide spacing was consistent with enrichment plantings and not an attempt to establish an oak plantation. However, such a wide spacing also was hypothesized to reduce seedling apparency and minimize herbivory. Although browse levels were greater early in the growing season, protection appeared to be realized owing to the cessation of herbivory once herbaceous vegetation flushed. The measured herbaceous biomass for the mid growing season resulted in an approximately 300 percent increase from the early growing season. This marked increase in herbaceous material was concomitant with the absolute cessation of browse pressure. Following the first sample period, no detectable shoot browse was observed. However, clear signs of herbivory were observed on surrounding herbaceous material. Therefore, it appears that the flush of herbaceous material aided in concealing the planted seedlings from herbivores. Further empirical investigations need to address the question of spacing influences on seedling apparency.

7.2 Seedling Mortality and Morphological Influences

The use of high-quality seedlings with high survival rates may minimize the need to rely on saturating areas with artificial reproduction anticipating "acceptable" mortality. Having fewer stems on the landscape with greater confidence that each individual will survive would be more desirable. Morphological investigations in this study suggest a reduction may be possible. Both initial seedling height and initial RCD were related to end-of-season mortality indicating that with greater initial height and greater initial RCD, lower rates of mortality can be expected. Although logistic regression results indicate that seedling mortality was not related to the number of FOLR present at the time of outplanting, a probability level of 0.08 was found. Therefore, the greater root surface area resulting from a greater number of FOLR would probably afford the seedling greater chances of survival, and therefore lower mortality rates. Low first-year mortality rates for the harvested treatments in this study suggest high-quality seedlings may have improved chances of survival. However, a number of artificial regeneration investigations have reported low first-year mortality only to report exponentially increasing mortality in subsequent years (McGee and Loftis 1986, Myers et al. 1989). Consequently, it will be important to assess mortality in this particular study as time progresses to ascertain long-term survival advantages offered by using high-quality seedling stock. It is also important to point out that most studies to date did not use high-quality seedlings, instead using commonly available seedlings.

Multiple factors may have contributed to seedling mortality including herbivory, herbaceous competition and limited light resources. Within the harvest treatments (Commercial clearcut, High grade and Two age), seedling mortality was limited and the ANOVA results indicated that the treatment effect was similar for the two-age and high-grade treatments. However, the commercial clearcut treatment, which produced the environment with the greatest amount of light, experienced no first-year mortality. In contrast, the no-cut treatment, with the highest residual cover and therefore the least available light, experienced the greatest end-of-season mortality. This trend of increasing mortality with increasing residual overstory cover suggests that overstory shade is presumably an important factor in first-year mortality rates in this study. This would suggest that pre-harvest enrichment planting might not be favorable if higher mortality rates are unacceptable. In order to ameliorate the site and aid in the development of the underplanted seedlings, removal of the dense midstory, as proposed by Loftis (1978, 1990), may be necessary. In contrast, the open environment created by the three cut treatments realized very little mortality in the first year. However, control of midstory species may remain necessary for long-term survival of planted seedlings, even within the harvested treatments.

7.3 Seedling Development

Although more than 99 percent of the seedlings exhibited signs of bud break by early May of the 2002 growing season, signs of terminal bud break were observed on only 55 percent of seedlings. The numbers of seedlings with observed terminal bud break decreased with increasing residual cover suggesting light availability is an important factor. However, the last growth flush of the seedlings in the nursery was often damaged because the size of the high-quality seedlings. Many seedling tips protruded from the seedling bags and were subject to damage when moved or transported. In addition, it appeared the late season growth flush in the nursery may not have completely suberized and set a viable terminal bud in some instances. Subsequently the tip would dieback to the previous growth flush.

Most of the increase in seedling height occurred early in the growing season in conjunction with the first growth flush. Although individuals with multiple flushes were identified, these seedlings did not comprise a very large number of the population. Multiple flush individuals represented 24 percent of the surviving seedlings at the end of the first year. The majority of the seedlings experienced only one growth flush during the first growing season in the field. However, it appeared that family 321 had a higher propensity to flush multiple times. End-of-season growth differed only among treatments when comparing the no-cut treatment with all cut treatments. The three harvest treatments experienced similar growth rates. Kramer and Kozlowski (1960) found that photosynthetic rates increase with increasing light availability, yet begin to level at approximately 1/3 of full sunlight. Therefore, it is not surprising that differences were not detected after one growing season. One growing season may not be adequate for the planted seedlings within the harvested units to express variable growth potential until crowns of residual overstory canopies respond to increased growing space. Additionally, a lag in growth response may be attributed to the disruption of the seedling physiology due to "nursery shock" (Schlarbaum 2003).

Comparatively, the no-cut treatment experienced the greatest growth. However, growth was etiolated, or pale and slender, and the seedlings appeared to succumb to the low light environment created by the intact forest canopy and dense midstory. According to McGee (1968), seedlings under dense full canopies have fewer leaves and less mass. Although no photosynthetically active radiation (PAR) measurements were taken in this study, Johnson et al. (2002) found that PAR levels of dense canopies often fall below 2 percent of full sunlight. The low light environment is also culpable for the negative growth realized in the no-cut treatments in the mid and late growing season periods. This was due to top dieback and the slow death of the seedlings under full canopy.

Although significant differences were not found between the two genetic families used in this study, apparent growth trends existed. Family 321 continued to grow throughout the growing season whereby family 234 remained in a period of stasis after the first growth flush early in the growing season. This further suggests that it may be possible to identify genetic families that offer growth advantages during the crucial early stages of seedling development.

7.4 Herbaceous Biomass Production

Herbaceous biomass production appeared to have a significant competitive effect on the development of the oak seedlings used in this study. When analyzed independently, herbaceous biomass production accounted for approximately 55 percent of the variation in end-of-season height growth. Herbaceous biomass production and seedling growth were also negatively correlated. Highly productive systems have the ability to support a great deal of biomass and competition is generally intense. Therefore, a limited amount of competition from herbaceous material can be expected. However, the herbaceous growth may be responsible for the cessation of herbivory.

One particular herbaceous species had a greater influence than all other herbaceous material. *Microstegium*, an introduced invasive appeared to be significantly influencing seedling development and at times comprised 50 percent or more of the herbaceous material sampled. *Microstegium*, when analyzed independently, accounted for the same amount of variation as total herbaceous biomass. When *Microstegium* was removed from the analysis, all other herbaceous material accounted for less than 1 percent of the variation in mean seedling height growth. Therefore, the results indicate that *Microstegium* is the overwhelming competitive influence in this particular study during the first growing season. In reality, if *Microstegium* is removed then some other herbaceous material would replace the vacated niche and may affect seedling growth. However, Microstegium is driving the herbaceous influence in this study.

The post-harvest release of this exotic grass appeared as an "explosion" due to the species' ability to completely overwhelm the invaded site. In this particular study, as both *Microstegium* biomass and percent of plot occupied by *Microstegium* increased, a decrease in end-of-season seedling height growth was realized. In addition, the two age treatment units experienced the largest *Microstegium* explosion and concomitantly the least amount of new growth. Silviculturalists may find *Microstegium* and other exotics contributing to more oak regeneration failures in the future. Although herbaceous biomass affected seedling height performance and provided some benefit with the cessation of herbivory, *Microstegium* will probably become the overriding herbaceous competition impacting future seedling growth.

7.5 Cost vs. Benefit

If the extra cost incurred by growing large, high-quality seedlings or by culling a larger number of smaller seedlings is not prohibitive, the use of only Premium seedlings can provide additional benefits. The end-of-season growth for premium graded seedlings was greater than those graded as good for the first growing season. In addition to greater initial height and growth rates, a few premium seedlings recorded first-year height growth of 24 inches or 61 cm. Although this height growth can be viewed as isolated in this particular study, it can be suggested that a limited number of individual oaks are capable of faster juvenile growth. Slow juvenile growth is one of the major factors seen as contributing to the poor competitive capacity of oak on highly productive sites

(Lorimer 1993, Spetich et al. 2002). Additional research will be necessary to aid in the identification of the genetic stock capable of such growth. Furthermore, planting high-quality seedlings may allow a reduction in the total number planted per acre, thereby reducing the total cost.

Planting high-quality seedlings generally presents a larger initial investment because of higher nursery costs, large root systems and constraints presented by current planting procedures and equipment. However, some of this increased expense can be offset through reductions in mortality, reductions in planted seedlings, more competitive growth rates and surpassing the perceived browse height sooner. Seedlings in this study were all hand-planted, which requires substantial labor costs. Additionally, holes necessary for planting were dug with a shovel and required contract labor to expedite planting. Even after root-pruning each seedling, the root mass was approximately 12 inches in diameter and 8 – 12 inches from root-collar to the tip of the taproot. Such large root systems at this point cannot be accommodated by mechanized planting machines on most sites and will continue to necessitate hand-planting except possibly when reforesting retired agricultural land. Although there will tend to be a requisite larger initial investment, economic returns may still prove reasonable. To date, many attempts to successfully establish artificial oak reproduction on highly productive sites have resulted in less than promising survival and many times ultimate failure. Attempts that must be repeated accrue planting costs each time. High-quality seedlings may render repetitive plantings unnecessary or at least reduce them to partial replantings. Detailed economic analysis has not been conducted to determine whether these additional benefits outweigh the initial investment. Additionally, some short-term benefits may not be realized long-term.

CHAPTER VIII

CONCLUSIONS

Practices emphasizing post-harvest enrichment planting of high-quality oak seedlings can be a management alternative for maintaining oak as an important component on highly productive sites and for rehabilitating stands harvested using exploitive practices. High-quality oak seedlings used in this research have exhibited growth rates similar to other studies using high-quality seedlings and may aid in re-establishing oaks on this site.

Results suggest that light environment is an extremely important factor determining the subsequent development of artificial reproduction. Therefore the differential development in this study can primarily be attributed to the light environment associated with the four overstory treatments. However, the competitive influences of the exotic *Microstegium v.* cannot be ignored because it composed such a large portion of the herbaceous component. Additionally, results from this study indicate that it may be possible to identify genetic stock capable of fast juvenile growth and therefore help solve one of the major hurdles, slow juvenile growth, encountered when attempting to successfully establish oak enrichment plantings.

Highly productive or mesic hardwood sites generally include complex species mixtures (Johnson et al. 2002) and pose greater uncertainty to sustaining oak dominated forests. Johnson et al. (2002) state that each step of the oak regeneration process is plagued with difficulties and unknowns. The use of high-quality seedlings for post-harvest enrichment planting may aid in reducing the number of necessary steps, unknowns and difficulties in establishing a new cohort of oaks on these sites.

While these results appear positive, only first year growth has been observed and reported. Further examination and research as seedling development continues will prove informative. Differences between treatments, genetic stock and seedling quality might become more apparent as development continues. Not only herbaceous competition but also competition from woody species along with a more detailed investigation of the competitive effects of *Microstegium v.* should be further studied. Field observations of other plantings suggest that enrichment planting with high-quality seedlings without subsequent silvicultural treatments may not be completely effective in maintaining a high proportion of oak on highly productive sites. Competition from fast growing nonoak species such as yellow-poplar coupled with the slow juvenile growth of oak indicate the need for a release treatment to ensure continued seedling survival.

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APPENDICES

Appendix 1

Vegetation Biomass Category Codes

Botanical Grouping	Code
Poison Ivy	1
Japanese Honeysuckle	2
Forbs	3
Smartweeds	4
Semi-woody plants	5
Ferns and fern allies	6
Sedges	7
Microstegium v.	8
Woody shrubs and seedlings	9
Vines	10
Grasses	11
Rushes	12
Unidentifiable	13

Appendix 2

Species list for each vegetation biomass category

Species	**Common Name**
1 – Poison Ivy	
Rhus radicans L.	Poison ivy
2 – Japanese Honeysuckle	
Lonicera japonica Thunb.	Japanese honeysuckle
3 – Forbs	
Acalypha gracilens Gray.	Three-seeded mercury
Asteraceae L.	Aster family
Boehmeria cylindrical (L.) Sw.	False nettle
Centrosema virginianum (L.) Bent.	Spurred butterfly-pea
Commelina spp. L.	Day-flower
Desmodium spp. Desv.	Tick-trefoil
Erechtites hieracifolia (L.) Raf.	Fireweed
Erigeron spp. L.	Fleabane
Gamochaeta purpurea (L.) Cabrera	Spoonleaf purple everlasting
Impatiens capensis Meerb.	Spotted jewelweed
Phytolacca americana L.	Pokeweed
Plantago spp. L.	Plantain
Solidago spp. L.	Goldenrod
Trifolium spp. L.	Clover
Verbascum spp. L.	Mullein
Viola spp. L.	Violet
4 – Smartweeds	
Polygonum hydropiperoides Michx.	Hydropiper
5 – Semi-Woody Plants	
Rubus argutus Link.	Bramble
6 – Ferns and Fern Allies	
Phegopteris hexagonoptera L.	Broad beech-fern
Polystichum acrostichoides (Michx.) Schott.	Christmas fern
Onoclea sensibilis L.	Sensitive fern

Species	Common Name
7 – Sedges	
Carex spp. L.	Sedge
Cyperus globulosus Aubl.	Galingale
8 – Microstegium	
Microstegium vimineum (Trin.) Camus	Japanese stilt grass
9- Woody Shrubs and Seedlings	
Acer negundo L.	Boxelder
Acer rubrum L.	Red maple
Asimina triloba (L.) Dunal.	Pawpaw
Cornus florida L.	Flowering dogwood
Crataegus spp. L.	Hawthorn
Liquidambar styraciflua L.	Sweetgum
Liriodendron tulipifera L.	Yellow-poplar
Nyssa sylvatica Marsh.	Blackgum
Platanus occidentalis L.	American sycamore
Prunus serotina Ehrh.	Black cherry
Quercus alba L.	White oak
Ulmus spp. L.	Elm
10 - Vines	
Campsis radicans (L.) Seem.	Trumpet-creeper
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper
Smilax spp. L.	Smilax
Vitis aestivalis Michx.	Summer grape
Vitis spp. L.	Grape
11 – Grasses	
Dichanthelium commutatum (Schult.) Gould	Variable witchgrass
Panicum spp. L.	Panic grass
12 – Rushes	
Juncus spp. L.	Rush

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[1] Binomial nomenclature and authority follows Gleason and Cronquist (1963).

Appendix 3

Common understory and overstory arborescent species

Species[1]	**Common Name**
Acer negundo L.	Boxelder
Acer rubrum L.	Red maple
Betula nigra L.	River birch
Carya tomentosa (Poir.) Nutt.	Mockernut hickory
Cercis canadensis L.	Redbud
Cornus florida L.	Flowering dogwood
Diospyros virginiana L.	Persimmon
Fraxinus pennsylvanica Marsh.	Green ash
Juglans nigra L.	Walnut
Juniperus virginiana L.	Eastern redcedar
Liquidambar styraciflua L.	Sweetgum
Liriodendron tulipifera L.	Yellow-poplar
Maclura pomifera (Raf.) Schneid.	Osage-orange
Morus rubra L.	Red mulberry
Nyssa sylvatica Marsh.	Blackgum
Platinus occidentalis L.	American sycamore
Prunus serotina Ehrh.	Black cherry
Quercus alba L.	White oak
Quercus falcata Michx.	Southern red oak
Quercus falcata var. pagodifolia Ell.	Cherrybark oak
Quercus rubra L.	Northern red oak
Quercus stellata Wang.	Post oak
Quercus velutina Lam.	Black oak
Sassafras albidum (Nutt.) Nees.	Sassafras
Ulmus alata Michx.	Winged elm
Ulmus americana L.	American elm
Ulmus rubra Muhl.	Slippery elm

[1] Binomial nomenclature and authority follows Gleason and Cronquist (1963).

VITA

Christopher M. Oswalt was born in Memphis, Tennessee on October 24, 1975 to J. Elmer and Deborah K. Oswalt. He was raised throughout the southeast spending schooldays with his parents in the Florida panhandle and Tennessee and his summers with his grandfather, C.B. Tanner, in the foothills of the Arkansas Ozarks. His lifelong commitment to the natural resources began at his grandfather's farm. He quickly became his grandfather's apprentice, of sorts, as he attempted to disseminate a lifetime of knowledge learned from necessity—flora, fauna, and basic principles of ecology. Chris took that knowledge and entered the University of Tennessee in the fall of 1996 and graduated with a Bachelor of Science degree in Forest Resource Management in the Spring of 1999. Chris went on to work in Alaska for the Bureau of Land Management, Colorado for the U.S. Forest Service and a private timber company in west Tennessee before returning to the University of Tennessee in the Fall of 2001. Working under the direction of Dr. Wayne K. Clatterbuck, Chris earned a Master of Science degree in Forestry in the summer of 2003.