12-2010

Competitive Interactions between Appalachian Hardwoods and Different Groundcovers on Reclaimed Mine Sites

Adam David Klobucar
University of Tennessee - Knoxville, aklobuca@utk.edu

To the Graduate Council:

I am submitting herewith a thesis written by Adam David Klobucar entitled "Competitive Interactions between Appalachian Hardwoods and Different Groundcovers on Reclaimed Mine Sites." 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.

David S. Buckley, Major Professor

We have read this thesis and recommend its acceptance:

Jennifer A. Franklin, Arnold M. Saxton

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 Adam David Klobucar entitled “Competitive Interactions between Appalachian Hardwoods and Different Groundcovers on Reclaimed Mine Sites.” 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.

David S. Buckley, Major Professor

We have read this thesis
and recommend its acceptance:

Jennifer A. Franklin

Arnold M. Saxton

Accepted for the Council:

Carolyn R. Hodges
Vice Provost and Dean of the Graduate School

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

Competitive Interactions between Appalachian Hardwoods and Different Groundcovers on Reclaimed Mine Sites

A thesis Presented for the Master of Science Degree

The University of Tennessee-Knoxville

Adam David Klobucar

December 2010

Dedication

This thesis is dedicated to my amazing wife and family. Without them, I wouldn't be the person I am today. Thank you for all the guidance and support you have provided throughout my life.

Acknowledgements

I would first like to acknowledge my advisor, Dr. David Buckley, for providing the opportunity to work on this project and allowing me the privilege to pursue a M.S. in a field that really sparks my interest. I would like to thank you for allowing me to be a part of the lab family and helping me with your guidance and knowledge. Thank you for teaching me all you have about forest ecology and providing the big picture ideas when I am trying to be too particular. I would also like to thank Dr. Jennifer Franklin for all the help you provided. You were there to teach me how to use all kinds of equipment and answer any and all questions about physiology that I may have had. I would also like to acknowledge Dr. Arnold Saxton for providing all the help with my crazy statistical questions. Thank you for being a part of my committee because I know you have a lot of obligations.

I would also like to extend a large thank you to all my fellow lab mates for the help you provided with all the vigorous field work. I would especially like to thank Beth Aubuchon, Chris Miller, John Johnson, Veronica DeLima Niebles, and Aju Sahadevan for all the effort you put forth helping me complete everything on time.

I would lastly like to thank my wife, Gretchen, my family, and my friends for everything. Gretchen, I couldn’t have done all my data entry if it wasn’t for all your patience and help. Mom and Dad, you were my rock when I needed someone there to talk to when times got rough.

Abstract

Coal mining is a significant industry in Appalachia. Herbaceous groundcovers are commonly planted to reduce soil erosion and protect water quality during mine reclamation, but many groundcovers may be too competitive to be compatible with trees. The objectives of this research were to investigate the performance of trees planted within different groundcovers and to measure how different groundcovers influence resource availability, specifically soil moisture and light.

Two studies were performed; one in a greenhouse and the other on 3 mine sites in east Tennessee where seedlings were planted and grown in competition with different groundcovers. Growth, biomass, leaf area, and foliar transpiration of tree seedlings, percent cover of groundcovers, percent volumetric soil moisture, and photosynthetically active radiation (PAR) were measured.

In the greenhouse, root-to-shoot ratios of northern red oak seedlings in the presence of competition from switchgrass and in bare treatments were found to be greater than in alfalfa and annual rye treatments. Specific leaf area of seedlings in the annual rye treatment was found to be lower than in the other treatments. Seedlings in the bare and switchgrass treatments were found to have greater transpiration rates than in the annual rye and alfalfa treatments.

On the mine sites, growth and transpiration of northern red oak, American chestnut, black cherry, and shagbark hickory seedlings did not differ among groundcover treatments.

In both studies, percent soil moisture was found to be greatest in the bare and switchgrass treatments, and percent full PAR at 14 cm was found to be greatest in the

bare treatment. In the greenhouse, percent full PAR was lowest in the switchgrass treatment and was lowest in the alfalfa treatment in the field.

Many factors may explain differences in seedling growth and performance between the greenhouse study and the field study such as tremendous variability in substrates and percent groundcover in the field, micro-site influence, and other unknown factors. Results from this study suggest that of the groundcover species studied, switchgrass may be the most compatible with the hardwoods studied, but more research is warranted to definitively determine the competitive interactions between the tree and groundcover species studied.

Table of Contents

List of Tables

List of Figures

1 Chapter 1: Introduction and Literature Review

1.1 History of Coal Mining in Tennessee

Tennessee has a long history of coal mining. Coal mining started in the state in the late 1700’s, but was not a large-scale industry until the mid-1800’s. Tennessee was the tenth of 19 states that became involved in bituminous coal production (Fickle 1998), and 22nd of 26 states in total coal production (Office of Surface Mining Reclamation and Enforcement 2008). Bituminous coal is a soft coal that contains bitumen. It is a lower quality coal than anthracite coal but higher quality than lignite coal. Bituminous coal is also known as “steam coal” (American Coal Foundation 2002). The growth of the coal industry was quickly followed by a large expansion of the railroad industry, which in turn, aided coal mining and transport.

By the early 1900’s “steam coal” was the largest mining industry in Tennessee. Other industries included mining of lead, iron, zinc, and quarrying of marble. Until 1940, underground mining was the predominant method of mining coal. This was due to a lack of technology needed to access coal on steep mountain slopes. However, as technology improved, cross ridge and other forms of mining began to prevail (Fickle 1998).

Currently, 22 counties in Tennessee contain coal resources. Mining primarily occurs in the Cumberland Mountains and the Cumberland Plateau, and is mainly surface mining. The total recoverable coal reserves in Tennessee amount to 60.7 million short tons. These reserves exist in beds up to 1.2 m thick, and can be found as deep as 305 m underground (Office of Surface Mining Reclamation and Enforcement 2008).

1.2 Impacts and Regulations

When surface mining is completed, there are substantial environmental changes that must be addressed. Mountainsides are left with no vegetation, little or no topsoil, and little or no organic matter. These conditions can lead to problems such as reduced water quality, soil erosion, and mass slope failure. Before 1977, there were no laws and regulations in place that enforced the reclamation of coal mining operations. This changed in 1977, when the Surface Mining Control and Reclamation Act (SMCRA) was passed. This act established a program for the regulation of surface mining activities and the reclamation of coal mined lands. The Office of Surface Mining (OSM) was created simultaneously to enforce this act (Vories Unknown date).

1.3 Post-SMCRA Reclamation Efforts

The passing of SMCRA resulted in a large increase in efforts to reclaim mined land in the Appalachian Mountains. Initial efforts to reclaim mines focused on heavily compacting the soil, and the seeding of herbaceous groundcovers. These herbaceous plants were commonly Kentucky 31 fescue (*Festuca arundinacea*), sericea lespedeza (*Lespedeza cuneata),* and several others. These plants were successful in controlling erosion, but had detrimental effects when inter-cropped with trees. Many groundcover species grew tall and very dense, which hindered the ability of trees to grow from seeds. They also competed very heavily for resources. Along with the practice of heavily compacting the soil, this competition limited tree seedling growth and survival. Although early reclamation efforts following the passing of SMCRA were successful in protecting water quality and reducing surface erosion and mass slope failures, they resulted in levels of compaction and competition with groundcovers that were essentially incompatible with the restoration of forests on mined land (Burger et al. 2005).

1.4 Forestry Reclamation Approach

The Appalachian Regional Reforestation Initiative (ARRI) was created in 2004 to address problems associated with reclamation and reforestation techniques. This group is a conglomerate of agencies, organizations, and institutions, including the University of Tennessee. Members of ARRI have forwarded the Forestry Reclamation Approach (FRA). The FRA is a cost-effective method of reclaiming coal-mined land to forest under the SMRCA, which results in development of forest wildlife habitat, watershed protection, and many other environmental services (Burger et al. 2005). The FRA consists of a 5 step approach which is described in Burger et al. (2005).

The first step in the 5-step approach is to create a suitable rooting medium for good tree growth that is no less than 1.3 m deep and comprised of topsoil, weathered sandstone and/or the best available material. The second step is to loosely grade the topsoil or topsoil substitute established in the first step to create a non-compacted growth medium. The third step is to use groundcovers that are compatible with growing trees. In the fourth step, 2 types of trees are planted: early successional species for wildlife and soil stability, and commercially valuable crop trees. The final step is to use proper tree planting techniques (Burger et al. 2005).

There are many reasons why non-compacted growth mediums are so important for plant growth and survival. Loosely graded soil allows rainfall to penetrate the soil, the soil to hold greater amounts of air and water, and roots to have the ability to grow without restraint (Sweigard et al. 2007). There are many studies that confirm the value of this approach. Torbert and Burger (1992) performed a study that demonstrated greater growth and survivorship of various hardwood species as compaction decreased. Results of a study located on the Starfire mine in Kentucky suggested that trees planted on plots with loosely graded soils demonstrated exceptional growth and survival when compared to trees planted in plots with conventionally graded soils (Angel et al. 2006).

Surface erosion is a concern in any type of reclamation, and the planting of grasses or other groundcover species along with the seedlings is warranted on many sites. Burger and Zipper (2002) state that tree-compatible groundcovers are often sparse the first year and become denser in the following years. This allows for the tree seedlings to emerge above the groundcover and increases their survival. According to Burger et al. (2009), some compatible grasses of choice for groundcover include orchardgrass (*Dactylis glomerata*), Timothy (*Phleum pratense*), winter rye (*Secale cereale*), foxtail millet (*Setaria italica*), redtop (*Agrostis gigantea*), and perennial ryegrass (*Lolium perenne*). The legumes of choice are Kobe lespedeza (*Lespedeza striata var. Kobe*), birdsfoot trefoil (*Lotus corniculatus*), and white clover (*Trifolium repens*). These species are often short in stature.

Burger et al. (2009) have argued that these groundcovers are advantageous because they allow more sunlight to reach planted tree seedlings. These groundcovers also withdraw water and nutrients from the soil more slowly than faster-growing agricultural grasses and legumes, leaving more of these below-ground resources for the planted trees. These groundcovers also do not cover the ground as rapidly or completely. This results in more open micro-sites for wind- and wildlife- dispersed seeds to germinate and become successfully established. In Appalachian coal-mining areas, most of the seeds planted are generally native forest species. The tree-compatible species are also less attractive to animals such as deer and rodents (Burger and Zipper 2002).

The groundcovers listed above have shown promise in forestry reclamation, but problems have occurred with some of the existing pool of groundcover species. Some can persist for many years and become aggressive competitors under certain conditions. Most also prefer a soil pH of 6-7, whereas trees are typically adapted to a soil pH of 4.5-6. A very large number of potential herbaceous groundcover species exists, but many of these species have not been thoroughly tested for use in forestry reclamation.

In addition to the need for testing of an expanded set of groundcover species, there has been little research performed on steep slopes. A steep slope is defined as a 20 – 45% slope (Hungr et al. 2001) Sites located on steep slopes are more likely to have problems such as surface erosion and mass slope failure than more level sites. A simple solution to reduce surface erosion is to plant dense and aggressive groundcovers, but unfortunately these aggressive groundcovers severely hinder the survival and growth of trees needed to reduce the chances of mass slope failure.

1.5 Groundcovers studied

In this research project, effects of 3 potentially tree-compatible groundcovers with different rooting characteristics on tree growth and survival were compared, along with their potential as future selections to be used for forestry reclamation after mining. These 3 groundcovers are switchgrass (*Panicum virgatum*: Blackwell variety), Grey goldenrod (*Solidago nemoralis*), and alfalfa (*Medicago sativa*: Evermore variety).

Annual rye (*Lolium multiflorum*) was also planted on the sites to provide for a quick-growing, but temporary, groundcover.

1.5.1 Switchgrass

Switchgrass is a perennial, warm season grass that is native to the United States. Switchgrass can be found in all of the lower 48 states except for Washington, Oregon, and California (Figure 1). Switchgrass exhibits rapid growth according to the USDA NRCS Plant Materials Program (2006). It can have a root system with roots extending up to 3 m deep in the soil profile. Along with the potential for growing deep in the soil, the roots are also very fibrous (Figure 2). Switchgrass can grow 1-3 m tall and will have a spreading top. Switchgrass has a long lifespan and grows best between the pH's of 4.5 to 8 (USDA NRCS Plant Materials Program 2006).

Switchgrass has been grown for a variety of reasons including forage production, soil conservation, ornamental uses, and more recently, biofuel production. Samson et al. (2005) state that switchgrass and other warm season grasses are ideal for biofuel production due to the high crop yields that can be attained.

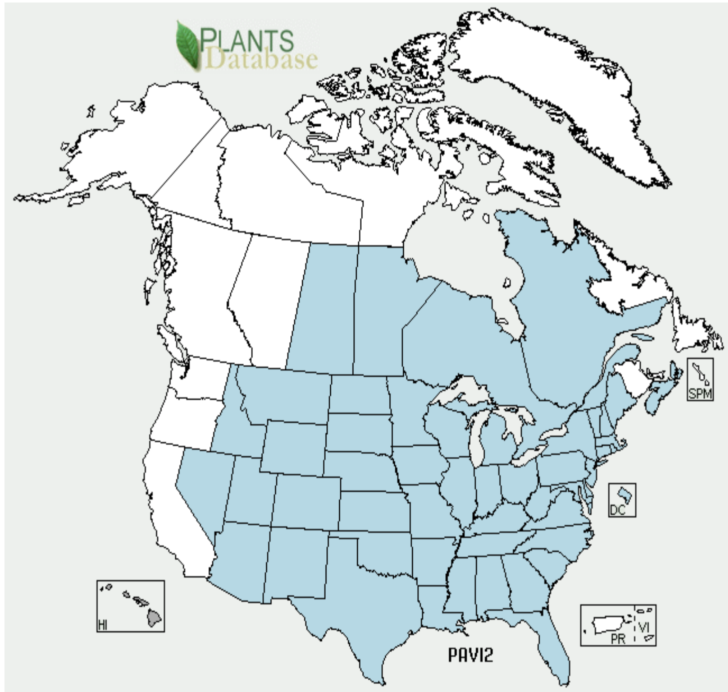

Figure 1: Native range of switchgrass (USDA Plants Database 2010)

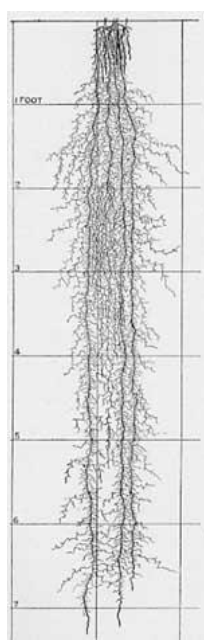
Figure 2: Root system of switchgrass (Weaver 1926)

1.5.2 Grey Goldenrod

Grey goldenrod is a perennial wildflower that is native to the United States (Figure 3). It is a vigorous pioneer plant and can become an agricultural pest in moist, warm environments. It can be found in old fields, along roadsides, along forest edges, on eroded slopes, and on sand dunes. Grey goldenrod can be used as an ornamental and is use for nested for a variety of wildlife (Belt 2009).

Grey goldenrod exhibits a rapid growth rate and a short lifespan. It grows in soils with a pH range of 5.5 to 7.5. Grey goldenrod can be found in most of the lower 48 states in the United States. Members of the goldenrod family have a deep and fibrous root system (Figure 4). When mature, grey goldenrod can attain a height of 0.76 m with a rhizomatous growth form (Belt 2009).

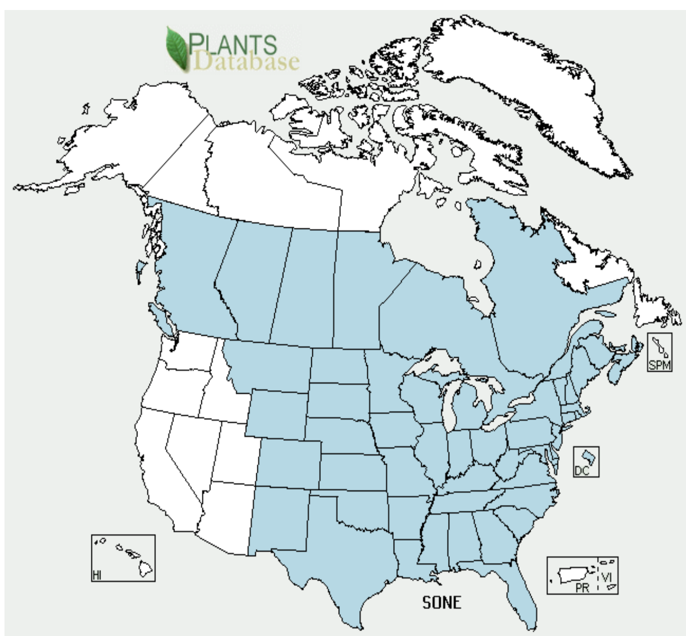

Figure 3: Native range of grey goldenrod (USDA Plants Database 2010)

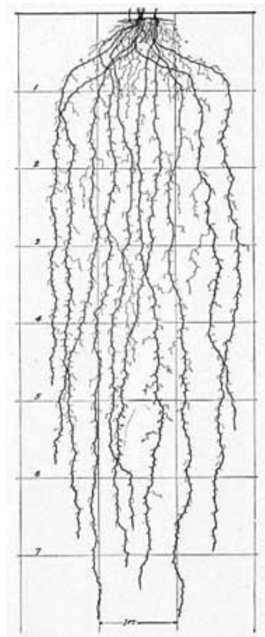

Figure 4: Root system of goldenrod family (Weaver 1926) (scale: 1 ft.^{2} per square)

1.5.3 Alfalfa

Alfalfa is an exotic groundcover that now has a range that encompasses all of the United States (Figure 5). It was introduced to North America for agricultural uses. Alfalfa is able to fix atmospheric nitrogen. It also contains the chemical Triacontanol. This chemical has been found to promote the growth of roots in some broadleaf plants. Mature alfalfa plants release a chemical to prevent the establishment of new alfalfa seedlings. This phenomenon is known as autotoxicity (USDA NRCS Plant Materials Program 2006).

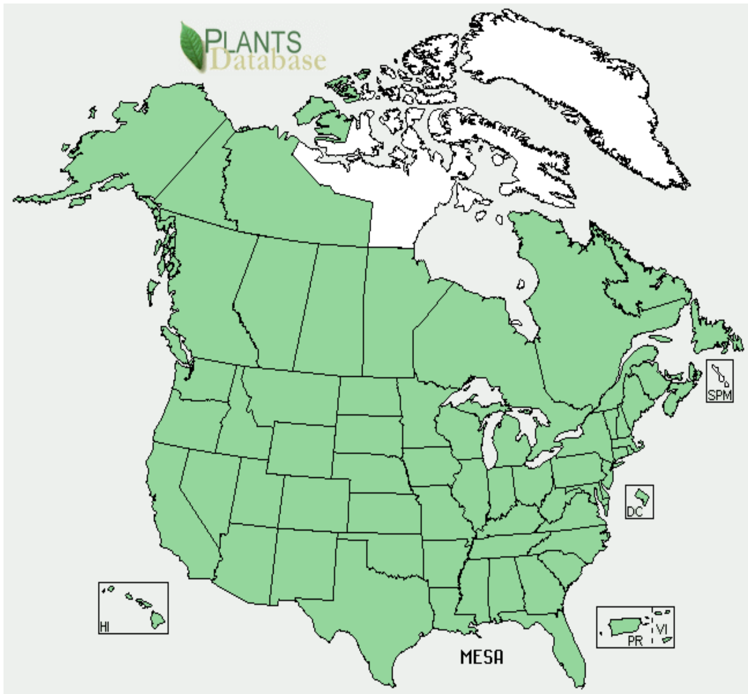

Figure 5: Current range of alfalfa (USDA Plants Database 2010)

Alfalfa is a perennial that exhibits a rapid growth rate and grows best in soils with a pH of 6.0 to 8.5. It can grow to be 1 meter tall and has a spreading form with a single crown. Weaver (1926) stated that alfalfa root systems on some sites have been documented to grow more than 2 m (Figure 6). When compared to the other 3 groundcovers, alfalfa root systems are less fibrous (USDA NRCS Plant Materials Program 2006).

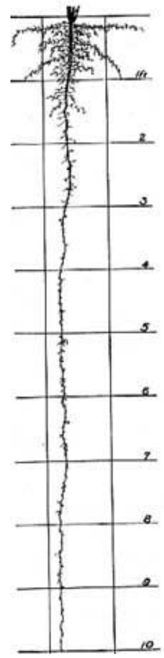

Figure 6: Two year old alfalfa root system (Weaver 1926) (scale: 1 ft.^{2} per square)

1.5.4 Annual Rye

Annual rye is an exotic plant which is native to Europe. It is also very widespread in North America (Figure 7). It closely related to perennial ryegrass but is a cool-season or winter annual. It does not withstand excessive hot and dry weather or severe cold weather. Modification of varieties to increase winter hardiness has resulted in annual rye being used for winter forage in Appalachia (Lacefield et al. 2003).

Annual rye exhibits a rapid growth rate which provides for a quick cover. It grows in soils that have a pH range from 6 to 7 (Riewe et al. 1985). Annual rye has a fibrous root system. When mature, it can attain a height of 1 meter. It has a bunchy form with many long, thin leaves forming at the base (USDA NRCS Plant Materials Program 2002).

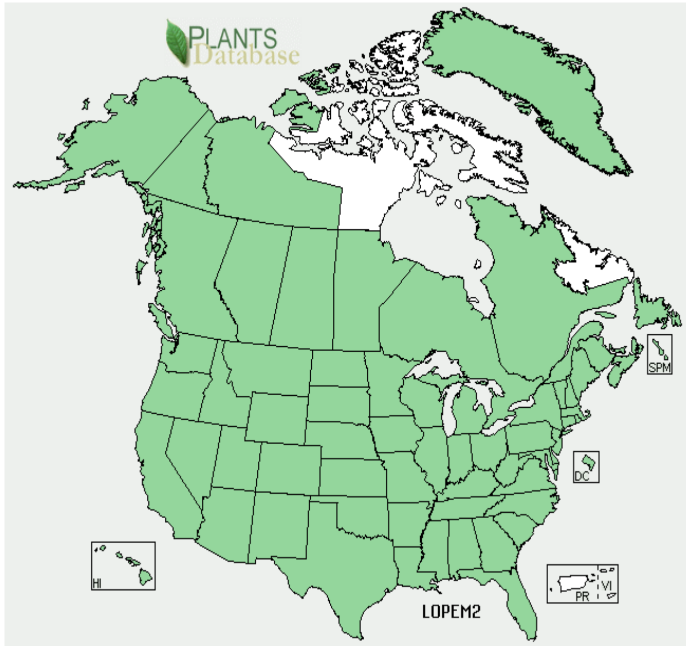

Figure 7: Current range of annual rye (USDA Plants Database 2010)

1.6 Tree Species Studied

There are many native tree species that can be found in Appalachian Mountain forests. Sites are often dominated by oaks, maples, hickories, and pines (Pijut 2005). The species of interest in this research project are northern red oak (*Quercus rubra*), American chestnut (*Castanea dentata*), black cherry (*Prunus serotina*), and shagbark hickory (*Carya ovata*). Each of these species exhibits different growing characteristics and each is native to the Appalachians.

1.6.1 Northern Red Oak

Northern red oak can be found in most of the eastern United States (Figure 8). It is in the *Fagaceae* family. Northern red oak is considered a mid-successional species (Tirmenstein 1991). It was reported that northern red oak does not colonize aggressively like most early successional species do, and it is not shade tolerant like late successional species (Sander 1990).

Northern red oak seedlings often do not grow fast enough to compete with the other woody vegetation or groundcover (Beck 1970). This includes oak seedlings that were established naturally or planted just following a clearcut. In order for northern red oak seedlings to compete in new stands, the seedlings must be of sufficient size, and the root system must be well established (Sander 1990).

Northern red oak is monoecious and produces clusters of 2 to 5 acorns that take 2 years to mature. The germination pattern of northern red oak acorns is hypogeous, and germination occurs in the spring after the seed dispersal in the fall. Acorns germinate best when buried slightly in bare mineral soil and covered by leaf litter (Sander 1990).

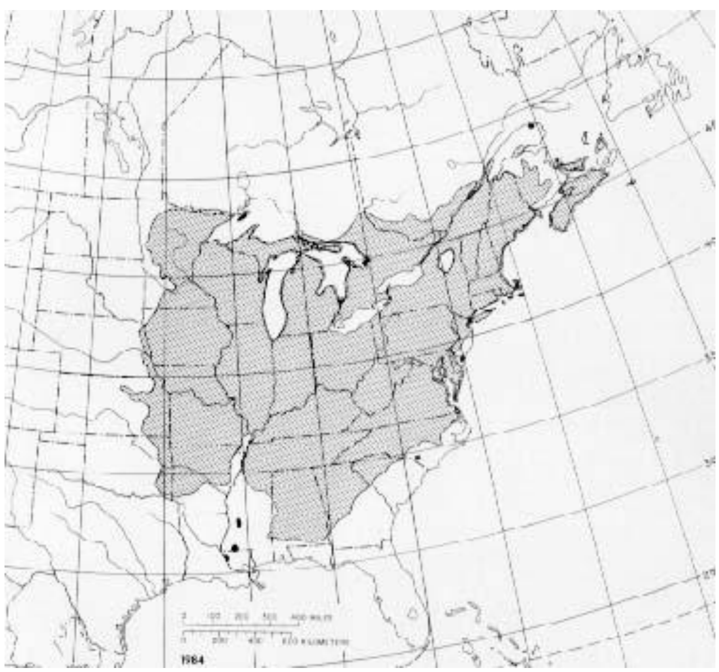

Figure 8: Native range of northern red oak (Sander 1990)

1.6.2 Shagbark Hickory

The range of shagbark hickory also encompasses most of the eastern United States (Figure 9). Shagbark hickory is within the *Juglandaceae* family. Shagbark hickory is considered intermediate in shade tolerance (Graney 1990, Nelson 1965), and is a climax species in the oak-hickory forest type. Hickories, in general, exhibit a slow shoot growth habit during early stages of development. This puts hickories at a disadvantage when competing with other tree species in a stand for light resources. However, shagbark hickory seedlings typically develop a large and deep taproot and will not have

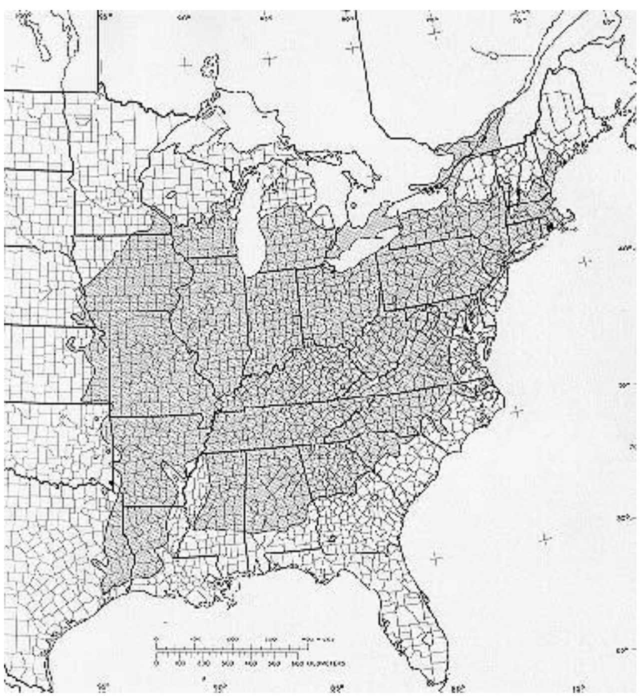

Figure 9: Native range of shagbark hickory (Graney 1990)

many lateral roots. The main taproot may penetrate to a depth of 0.6 to 0.9 m in the first 3 years, with a correspondingly slow growth of seedling shoots (Graney 1990).

In a study conducted in the Ohio River valley, 1-year-old seedlings produced an average root length of 30 cm and a top height of 7 cm. By age 3, the taproot extended to about 0.8 m, while the top increased only to 19.8 cm (Graney 1990, Nelson 1965). This study suggested that primary growth of the roots is much greater than that of the stems.

Shagbark hickory is monoecious. The fruit is a nut, and can be found in clusters of 1 to 3. The seeds ripen between the months of September and October and can be dispersed as late as December. Shagbark hickory nuts are very heavy and are dispersed by gravity. Movement of the nuts by animals helps extend the range of dispersal (Graney 1990).

1.6.3 American Chestnut

At one time, American chestnut had a range that extended from Maine to Georgia (Figure 10). However, this was before the exotic disease known as the chestnut blight (*Cryphonectria parasitica*) came to North America and decimated the American chestnut population. There has been much research focused on creating a hybrid that is tolerant to this disease. American chestnut is monoecious. The fruit is a nut, and 2-3 nuts are enclosed by a spiny husk.

American chestnut can be regenerated from both stump sprouts and seeds. In this project, this species was planted as a seedling. According to Saucier (1973), the growth of sprouts is relatively rapid. Sprouts can be up to 4 m tall by age 5. It has been reported that before the blight kills them, American chestnut sprouts can reach

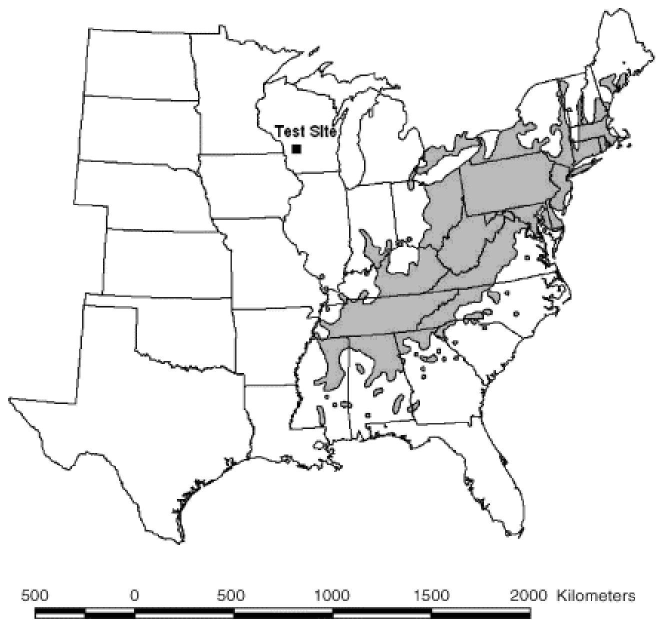

Figure 10: Native range of American chestnut (Little 1977)

12.8 m in height and 17.27 cm in diameter (Saucier 1973). Similar to many oak species, American chestnut seedlings can persist in the absence of disturbance. However, growth is stimulated by increased light (Clark et al. 2006). Jacobs (2007) states that chestnut is a broad generalist and a strong competitor for resources.

1.6.4 Black Cherry

Black cherry has a large range that spans the eastern United States as well as coastal Mexico and parts of Texas and Nevada (Figure 11). Black cherry is in the *Roseaceae* family.

Black cherry is considered to be intolerant of shade. Black cherry seedlings are found in the understory of natural stands and can survive up to 5 years in these

Figure 11: Native range of black cherry (Marquis 1990)

conditions. However, they cannot live for extended periods or move into more mature classes without a disturbance that causes an opening in the overstory canopy that allows full sunlight to reach the seedling. The root system of black cherry initially has a distinct taproot with many laterals. As time progresses, a shallow, spreading root system develops where there is no apparent taproot (Marquis 1990).

Black cherry grows quickly in the seedling, sapling, and pole stages. It will generally outgrow and overtop many hardwood competitors such as sugar maple and American beech. In the first few years after planting, it has been recorded that juvenile height growth of black cherry can average 46 cm. Black cherry seedlings grow best in full sunlight (Marquis 1990).

Black cherry flowers are perfect and are insect pollinated (Grisez 1974). The fruit is a small, one-seeded drupe. It has a bony stone or pit and is black in color when ripe.

In the southeastern United States, where this research project is occurring, the fruit of black cherry will ripen in late June, and the seedfall is complete by early July.

1.7 Competition

There are many factors that affect the performance of trees. Some of these factors include sunlight, rainfall, soil nutrients, and topographic location. Disturbances such as fire, insect outbreaks, storms, and human development can also greatly influence the performance of trees (Kozlowski et al. 1991).

Competition for resources plays an important role in the performance of a tree. Some of the resources competed for are light, water, and mineral nutrients (Samra et al. 1999). Each tree species performs differently in a given competitive environment. This is due to differences in factors such as the particular adaptations of the tree species, the quality of the site, the time of the seedling's arrival, and the adaptations of the competing plants in the tree's vicinity (Harmer and Robertson 2003).

1.7.1 Types of Competition

There are two kinds of competition: interspecific and intraspecific competition. Interspecific competition occurs when members of different species are competing for the same resources. (i.e. light, water, and nutrients). Intraspecific competition occurs when members of the same species are competing for the same resources (Kozlowski et al. 1991; Park et al. 2003). In this research project, interspecific competition will be further examined between the tree species and groundcovers of interest.

1.7.2 Effect of Competition on Growth and Survival

It has been noted that grasses can compete with trees and can hamper their growth and survival (Kozlowski et al. 1991). Karl and Doescher (1993) found that a reduction in the height of grasses surrounding seedlings will enhance the establishment of the seedlings. However, under dry weather conditions, the moist microclimatic conditions provided by these grasses may be more favorable than bare exposed soil and may enhance tree growth. Hook et al. (1991) found that in the steppe region, areas without vegetation are generally drier and warmer due to enhanced evaporation, but seedlings will experience less root competition for soil water and nutrients. Farmer (1997) found that increased light availability in areas without vegetation may decrease with time as other plant species become established. Areas without vegetation may have negative or neutral effects on tree seedling establishment (Burton and Bazzaz 1991) and survival (Berkowitz et al. 1995). Seedlings that receive shading from surrounding vegetation may experience a reduction in evaporation and greater protection against heat injury. Both evaporation and heat injury are often responsible for high seedling mortality (Farmer 1997).

In general, the greater the intensity of competition, the greater the decrease in the rate of tree cambial growth. This results in small increases in diameter. The general presence of grass on a site has also been shown to result in reduced seedling heights and dry weights (Harmer and Robertson 2003). Kozlowski et al. (1991) state that competition tends to reduce the extent and density of root systems. Harmer and Robertson (2003) add that competition for water tends to increase the allocation of biomass to roots and the length of the tap-root. However, the growth of lateral roots is reduced, thus the total length of the overall root system is reduced.

In a study involving removal of early-successional plants from a site, it was found that nutrient uptake, growth, and survivorship of later-successional species were all increased (Cater and Chapin 2000). Results of other studies suggest that the removal of early successional vegetation increased the diameter growth of white spruce seedlings (Cater and Chapin 2000). Davis et al. (1999) found that oaks that were planted in weeded plots had greater biomass than oaks did on plots planted with herbaceous vegetation. Further, McCormick and Bowersox (1997) found that planted grasses reduced the growth and survival of northern red oak, white ash, yellow poplar and white pine.

1.7.3 Effect of Competition on Specific Leaf Area

Specific leaf area (SLA) is an index of leaf thickness, calculated by dividing the area of a portion of a leaf by the dry weight of that same portion of leaf (Garnier et al 2001). Wilson (1999) states that in conditions where moisture and nutrients are limiting, a species with leaves that have low SLA will perform better in water and nutrient poor environments. Results of a study by Knops and Reinhart (2000) support this conclusion. They found that the SLA was lower in plants that received less nitrogen fertilizer. Poorter and Remkes (1990) found that leaves with high SLA are more productive in water and nutrient rich environments. However, the leaves are short lived. This suggests that seedlings grown in competition with groundcovers for belowground resources should have smaller specific leaf areas than seedlings not in competition.

1.7.4 Effect of Competition on Transpiration

If a tree seedling is in competition with groundcover vegetation, it is possible that nutrients, sunlight, or water availability may become limiting, and the seedling will respond by conserving more if its resources. One way plants conserve water is by closing the stomata. By closing the stomata, transpiration rates and photosynthetic rates would be lowered, and water loss from the seedling would be reduced. It has been documented that transpiration of oaks is affected by soil water availability (Seidel 1972) and also nutrient availability (Guehl et al. 1995). Davis et al. (1999) also found that the reduction of soil water causes lower transpiration rates of tree seedlings. Fotelli et al. (2001) found that transpiration rates of European beech seedlings were lower when in competition for resources with an early successional species, possibly due to the reduction of soil water. Transpiration measurements provide a rough index of competition for water between groundcover species and tree seedlings.

1.7.5 Effect of Competition on Soil Moisture

Different results have been reported when investigating the effects of vegetation on soil moisture. Richards and Caldwell (1987) and Bradshaw and Goldberg (1989) found that soil moisture increases in the presence of plants on old agricultural fields. They argued this result was due to decreased evaporation and increased infiltration. However, Zutter et al. (1986) found that the presence of vegetation can decrease soil moisture. A study performed by Davis et al. (1999) also found that herbaceous vegetation can considerably reduce soil water.

It has been well documented that increased competition causes a decrease in soil moisture percent during times of drought. Mitchell et al. (1993) found that during droughty conditions, soil moisture was depleted from the surface layer at a much greater rate as the amount of vegetation on the site increased. Harrington (1991) found that soil moisture stress was found to affect establishment and mortality in grasslands negatively. It was found that mortality was greater, and occurred at a faster rate, in plots that received less irrigation.

1.7.6 Effect of Competition on PAR and Photosynthesis

As the amount sunlight captured by a plant increases, the rate of photosynthesis increases. An increased rate of photosynthesis would increase the growth of a plant. Due to certain groundcovers being able to grow taller than tree seedlings and compete with seedlings for sunlight, less sunlight is available for the seedlings to utilize for photosynthesis. This decrease in photosynthetic rates could decrease the growth of the seedlings (Holt 1988). Measuring percent full photosynthetically active radiation (PAR) would determine how much sunlight is available for a tree seedling to potentially capture and utilize for photosynthesis when competing against different groundcover species.

1.8 Objectives of Research

There were 2 objectives underlying the research performed. The first objective was to investigate and compare the performance of trees planted within different groundcovers. The second objective was to measure how different groundcover species influence resource availability, specifically soil moisture and light. To achieve the two objectives, 2 studies were performed: the first in the University of Tennessee greenhouse and the other on the steep slopes of cross-ridge mine sites in the Appalachian coal fields.

References

American Coal Foundation (2002) Coal: Ancient Gift Serving Modern Man. American Blacksmith Association.

Angel, P., D. Graves, C. Berton, R. Warner, P. Conrad, R. Sweigard, and C. Agouridis (2006) Surface mining reforestation research: Evaluation of tree response to low compaction reclamation techniques: 45-58. Proceedings, American Society of Mining and Reclamation

Beck, D. E. (1970) Effect of competition on survival and height growth of red oak seedlings. United States Department of Agriculture Forest Service, Research Paper SE-56. Southeastern Forest Experiment Station.

Belt, S. (2009) USDA Plant Data Sheet: Gray Goldenrod (*Solidago nemoralis*). United States Department of Agriculture.

Berkowitz, A.R., C.D. Canham, and V.R. Kelly. 1995. Competition versus facilitation of tree seedling growth and survival in early successional communities. *Ecology* 76:1156-1168.

Bradshaw, L. and D.E. Goldberg (1989) Resource levels in undisturbed vegetation and mole mounds in old fields. *American Midland naturalist* 121:176-183.

Brix, H. and L.F. Ebell (1969) Effects of Nitrogen Fixation on Growth, Leaf Area, and Photosynthesis Rate in Douglas- Fir. *Forest Science* 15(2):189-196.

Burger, J.A., and C.E. Zipper (2002) How to Restore Forests on Surface Mined Lands. Virginia Cooperative Extension.

Burger, J., C.E. Zipper, and J. Skousen (2009) Establishing Ground Cover for Forested Post-Mining Land Uses. Publication Number 460-124.

Burger, J., P. Angel, V. Davis, D. Graves, and C. Zipper (2005) The Appalachian Reforestation Initiative. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 1.

Burger, J., P. Angel, V. Davis, D. Graves, C. Zipper (2005) The Forestry Reclamation Approach. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 2.

Burger, J., V. Davis, J. Franklin, C.E. Zipper, J. Skousen, C. Barton, and P. Angel (2009) Tree-Compatible Ground Covers For Reforestation and Erosion Control. The Appalachian Reforestation Initiative. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 6.

Cater, T.C. and F.S. Chapin (2000) Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. *Ecology* 81(4):1086-1099.

Collin, P., P.M. Badot, and B. Millet (1996) Croissonce rythmique et developpement du chene rouge d' Amerique, *Quercus rubra* L. cultive en condiflons controlees. *Journal of Ann. Science* 53: 1059-1069.

Cook, S.J. (1985) Effect of nutrient application and herbicides on root competition between green panic seedlings and a *Heteropogon* grassland sward. *Grass and Forage Science* (40) 171-175.

Cui, M. and W.K. Smith (1991) Photosynthesis, water relations and mortality in *Abies lasiocarpa* seedlings during natural establishment. *Tree Physiology* 8:37-46.

Davis, M.A., K.J. Wrage, P.B. Reich, M.G. Tjoelker, T. Schaeffer, and C. Muermann (1999) Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology* 145: 341–350.

Fickle, J. (1998) "Mining." The Tennessee Encyclopedia of History and Culture.

Grisez, T.J. (1974) *Prunus* L. Cherry, peach, and plum. Seeds of woody plants in the United States: 658-673. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

Graney, D.L. (1990) Carya ovata (Shagbark hickory). Silvics of North America. United States Department of Agriculture Forest Service, Washington D.C.

Guehl, J.M., C. Fort, and A. Fehri (1995) Differential response of leaf conductance, carbon isotope discrimination and water-use efficiency to nitrogen deficiency in maritime pine and pedunculate oak plants. *New Phytologist* 131: 149-157.

Harmer, R. and M. Robertson (2003) Seedling root growth of six broadleaf species grown in competition with grass under irrigated nursery conditions. *Ann. For. Sci.* 60: 601-608.

Harrington, G.H. (1991) Effects of soil moisture on shrub seedling survival in a semi-arid grassland. *Ecology* 72(3):1138-1149.

Henry, J. 2006. USDA Plant Data Sheet: Stiff Goldenrod (Solidago rigida).

Hook, P.B., I.C. Burke IC, and W.K. Lauenroth (1991) Heterogeneity of soil and plant N and C associated with individual plants and openings in North American shortgrass steppe. Plant and Soil 138: 247–256.

Holt, J.S. (1988) Reduced Growth, Competitiveness, and Photosynthetically Efficiency of Triazine-Resistant Senecio vulgaris from California. *Journal of Applied Ecology* 25 (305-317).

Hungr, O, S.G. Evans, M. Bovis, and J.N. Hutchinson (2001) Review of the classification of landslides of the flow type. *Environmental and Engineering Geoscience* 7: 221-238.

Jacobs, D.F. (2007) Toward development of silvical strategies for forest restoration of American chestnut (Castanea dentata) using blight-resistant hybrids. *Biological Conservation* 137(4): 497-506.

Lacefield, G., M. Collins, J. Henning, T. Phillips, M. Rasnake, R. Spitaleri, D. Grigson, , and K. Turner (2003) Annual Ryegrass. Cooperative Extension Service, University of Kentucky. College of Agriculture.

Little Jr., E.L. (1977) Atlas of United States Trees: Minor Eastern Hardwoods, Vol. 4. USDA Misc. Pub. No.1342.

Karl, M.G. and P.S. Doescher (1993) Regulating competition on conifer plantations with preregulating competition on conifer plantations with prescribed cow grazsing. *Forest Science* 39: 405-418

Knops, J.M.H. and K. Reinhart (2000) Specific Leaf Area along a Nitrogen Fertilization Gradient. *American Midland Naturalist* 144(2): 265-272.

Kozlowski, T.T., P.J. Kramer, and S.G. Pallardy (1991) The Physiological Ecology of Woody Plants. Academic Press, Inc. San Deigo, CA.

Landsburg, J. J. and S.T. Gower (1997) Applications of Physiological Ecology to Forest Management. Academic Press. San Diego.

Marquis, D. A. (1990) Black Cherry (Prunus serotina). Silvis of North America. United States Department of Agriculture Forest Serivice, Washington D.C.

McCormick, L.H. and T.W. Bowersox (1997) Grass or fern competition reduce growth and survival of planted tree seedlings. United States Department of Agriculture Forest Service, Washington D.C.

Mitchell, R.J., B.R. Zutter, T.H. Green, M.A. Perry D.H. Gjerstad, and G.R. Glover (1993) Spatial and temporal variation in competitive effects on soil moisture and pine response. *Ecological Applications* 3(1):167-174.

Nelson, T.C. (1965) Silvical characteristics of shagbark hickory (Carya ovata (Mill.) K Koch). Silvics of forest trees of the United States: 128-131. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.

Office of Surface Mining Reclamation and Enforcement. (2008) Annual Evaluation Summary Report for the Regulatory Program Administered by the Knoxville Field Office of Tennessee for Evaluation Year 2008 (October 1, 2007, to September 30, 2008).

Park, S., L.R. Benjamin, and A.R. Watkinson (2003) The Theory and Application of Plant Competition Models: an Agronomic Perspective. *Annals of Botany* 92:741-748.

Pijut, P. M. (2005) Native Hardwood Trees of the Central Hardwood Region. Research Paper FNR-218. United States Department of Agriculture Forest Service, North Central Research Station.

Poorter, H and C. Remkes (1990) Leaf area and net assimilation rate of 24 wild species differing in relative growth rate. *Oecologia* 83 (4): 553–559.

Richards, J.H. and M.M. Caldwell (1987) Hydraulic lift: Substantial nocturnal water transport between soil layers by *Artemisia tridentata* roots. *Oecologia* 73: 486-489.

Riewe, M. E., R.F. Barnes, and D.S. Metcalfe (1985). Forages: The Science of Grassland Agriculture. Iowa State University Press, Ames, Iowa.

Samson, R., S. Mani, R. Boddey, S. Sokhansanj, D. Quesada, S. Urquiaga, V. Reis, and C. Ho Lem (2005) The Potential of C4 Perennial Grasses for Developing a Global Bioheat Industry. *Critical Reviews in Plant Sciences* 24:461-495.

Samra, J.S., M.K. Vishwanatham, and A.R. Sharma (1999) Biomass production of trees and grasses in a silvopasture system on marginal lands of Doon Valley of north-west India. *Agroforestry Systems* 46: 197–212.

Sander, I.L. (1990) Quercus rubra (Northern red oak). Silvics of North America. U.S. Department of Agriculture Forest Service, Washington D.C.

Saucier, J.R. (1973) American Chestnut... An American Wood(*Castanea dentata* (Marsh.) Borkh.). United States Department of Agriculture Forest Service. FS-230.

Seidel, K. (1972) Drought resistance and internal water balance of oak seedlings. *Forest Science* 18:34-40.

Sweigard, R., J. Burger, D. Graves, C. Zipper, C. Barton, and J. Skousen (2007) Loosening Compacted Soils on Mine Sites. The Appalachian Regional Reforestation Initiative U.S. Office of Surface Mining. Forest Reclamation Advisory No. 4.

Tirmenstein, D.A (1991) Quercus rubra. In: Fire Effects Information System. U.S. Department of Agriculture, Rocky Mountain Research Station, Fire Sciences Labortory.

Torbert, J.L. and J.A. Burger (1992) Restoring forests on surface mined lands: Results of a 10 year study. *Virginia Forests* 48(1):9-12.

USDA NRCS Plants Database (2010) *Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot: Italian ryegrass.

USDA NRCS Plants Database (2010) *Medicago sativa* L.: alfalfa.

USDA NRCS Plants Database (2010) *Panicum virgatum* L.: switchgrass

USDA NRCS Plants Database (2010) *Solidago nemoralis* Aiton: gray goldenrod

USDA NRCS Plant Materials Program. (2006) USDA Plant Data Sheet: Alfalfa *(Medicago sativa).*

USDA NRCS Plant Materials Program (2002) USDA Plant Data Sheet: Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot).

USDA NRCS Plant Materials Program (2006) USDA Plant Data Sheet: Switchgrass (*Panicum virgatum).*

Vories, K.C. Unknown Date Published. The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines. United States Department of Interior: Office of Surface Mining.

Weaver, J.E. (1926) Root Development of Field Crops, 1st ed. McGraw-Hill Inc., NY.

Wilson, P.J. (1999) Specific leaf area and leaf dry matter content as alternative predictors of plant strategies. *New Phytologist* 143:155-162.

Zutter, B.R., G.R. Glover, and D.H. Gjerstad (1986) Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. *Forest Science* 32: 882-899.

2 Chapter 2: Competitive Interactions among Appalachian Hardwoods and Different Groundcovers in a Controlled Environment

2.1 Abstract

Coal mining is a significant industry in Appalachia. Environmental challenges associated with mining include the potential for reduced water quality and soil erosion. Herbaceous groundcovers are commonly planted to reduce soil erosion and protect water quality, but many groundcovers may be too competitive to be compatible with trees during reforestation.

The overall objective of this research was to investigate competitive interactions between different groundcovers and northern red oak seedlings by documenting oak seedling growth, biomass, leaf area, and transpiration, and the availability of soil moisture and light. Twelve seedlings were planted in pots receiving 1 of 4 different groundcover treatments, which were alfalfa, switchgrass, annual rye, and no groundcover or bare. The experiment was conducted in a University of Tennessee greenhouse.

New growth of the apical meristem and root collar diameter growth did not differ between treatments. Fresh and dry root-to-shoot ratios of seedlings planted within the switchgrass and bare treatments were greater than those in the rye and alfalfa treatments. Specific leaf area of oak seedlings in the annual rye treatment was found to be less than that of seedlings in all other treatments. Seedlings planted in the bare and switchgrass treatments were found to have greater transpiration rates than oaks planted in the annual rye and alfalfa treatments. Under a consistent watering regime, soil moisture was greatest in the bare and switchgrass treatments. Photosynthetically active radiation was found to be greatest in the bare treatment, and lowest in the switchgrass treatment.

Overall, the oaks in the switchgrass treatment performed most similar to those in the bare treatment, suggesting that of the groundcover species tested, switchgrass may be the most compatible with northern red oak seedlings.

2.2 Introduction

2.2.1 Mine regulations

Surface mining leads to substantial environmental changes that must be addressed. Mined areas are left with no vegetation, little or no topsoil, and little or no organic matter. These conditions have the potential to produce problems such as reduced water quality, soil erosion, and mass slope failure. Before 1977, there were no laws and regulations in place that enforced the reclamation of coal mining operations. The Surface Mining Control and Reclamation Act (SMCRA) was passed in 1977 to address the potential environmental problems described above. This act established a program for the regulation of surface mining activities and the reclamation of coal mined lands. The Office of Surface Mining (OSM) was also created to enforce this act (Vories Unknown date).

2.2.2 Mine Reclamation

The passing of SMCRA resulted in a large increase in efforts to reclaim mined land in the Appalachian Mountains. Initial efforts to reclaim mines focused on heavily compacting the soil and seeding herbaceous groundcovers. These herbaceous plants were commonly Kentucky 31 Fescue (*Festuca arundinacea*), sericea lespedeza (*Lespedeza cuneata*), and several others. These plants were successful in controlling erosion, but had detrimental effects when inter-cropped with trees. Many groundcover species grew tall and very dense, which hindered the ability of trees to grow from seeds. They also competed very heavily for resources. Along with the practice of heavily compacting the soil, this competition limited tree seedling growth and survival. Although early reclamation efforts following the passing of SMCRA were successful in protecting water quality and reducing surface erosion and mass slope failures, they resulted in levels of compaction and competition with groundcovers that were essentially incompatible with the restoration of forests on mined land (Burger et al. 2005).

2.2.3 Forestry Reclamation Approach

The Appalachian Regional Reforestation Initiative (ARRI) was created in 2004 to address problems associated with reclamation and reforestation techniques. This group is a conglomerate of agencies, organizations, and institutions, including the University of Tennessee. Members of ARRI have forwarded the Forestry Reclamation Approach (FRA). The FRA is a cost-effective method of reclaiming coal-mined land to forest under the SMRCA, which results in development of forest wildlife habitat, watershed protection, and many other environmental services (Burger et al. 2005). The FRA consists of a 5-step approach which is described in Burger et al. (2005).

The first step in the 5-step approach is to create a suitable rooting medium for good tree growth that is no less than 1.3 m deep and comprised of topsoil, weathered sandstone and/or the best available material. The second step is to loosely grade the topsoil or topsoil substitute established in the first step to create a non-compacted growth medium. The third step is to use groundcovers that are compatible with growing trees. In the fourth step, 2 types of trees are planted: early successional species for wildlife and soil stability and commercially valuable crop trees. The final step is to use proper tree planting techniques (Burger et al. 2005).

There are many reasons why non-compacted growth mediums are so important for plant growth and survival. Loosely graded soil allows rainfall to penetrate the soil, the soil to hold greater amounts of air and water, and roots to have the ability to grow without restraint (Sweigard et al. 2007). There are many studies that confirm the value of this approach. Torbert and Burger (1992) performed a study that demonstrated greater growth and survivorship of various hardwood species as compaction decreased. Results of a study located on the Starfire mine in Kentucky suggested that trees planted on plots with loosely graded soils demonstrated exceptional growth and survival when compared to trees planted in plots with conventionally graded soils (Angel et al. 2006).

2.2.4 Tree-Compatible Groundcovers

Surface erosion is a concern in any type of reclamation, and the planting of grasses or other groundcover species along with the seedlings is warranted on many sites. Burger and Zipper (2002) state that tree-compatible groundcovers are often sparse the first year and become denser in the following years. This allows for the tree seedlings to emerge above the groundcover and increases their survival. According to Burger et al. (2009), some compatible grasses of choice for groundcover include orchardgrass (*Dactylis glomerata*), Timothy (*Phleum pratense*), winter rye (*Secale cereale*), foxtail millet (*Setaria italica*), redtop (*Agrostis gigantea*), and perennial ryegrass (*Lolium perenne*). The legumes of choice are Kobe lespedeza (*Lespedeza striata var. Kobe*), birdsfoot trefoil (*Lotus corniculatus*), and white clover (*Trifolium repens*). These species are often short in stature.

Burger et al. (2009) have argued that these groundcovers are advantageous because they allow more sunlight to reach planted tree seedlings. These groundcovers also withdraw water and nutrients from the soil more slowly than faster-growing agricultural grasses and legumes, leaving more below-ground resources for the planted trees. These groundcovers also do not cover the ground as rapidly or completely. This results in more open micro-sites for wind and wildlife dispersed seeds to germinate and become successfully established. In Appalachian coal-mining areas, most of the seeds planted are generally native forest species. The tree-compatible species are also less attractive to animals such as deer and rodents (Burger and Zipper 2002).

The groundcovers listed above have shown promise in forestry reclamation, but problems have occurred with some of the existing pool of groundcover species. Some can persist for many years and become aggressive competitors under certain conditions. Most also prefer a soil pH of 6-7, whereas trees are typically adapted to a soil pH of 4.5-6. A very large number of potential herbaceous groundcover species exists, but many of these species have not been thoroughly tested for use in forestry reclamation.

2.3 Objectives

The overall goal of the study was to investigate interactions between different groundcover species and northern red oak seedlings (*Quercus rubra*). There were 3 specific objectives in this study. The first was to compare the effects of different groundcover treatments (annual rye, switchgrass, alfalfa, and bare soil) on the performance of 2-0 northern red oak seedlings. The second objective was to determine the influence of each groundcover species on soil moisture and light. The third objective was to document the relationship between amounts of soil moisture and foliar transpiration in northern red oak seedlings.

The null hypothesis in relation to the first objective was that there would be no differences between new growth of the apical meristem, root collar diameter growth, root-to-shoot ratios, leaf weight, number of leaves, leaf size, specific leaf area, and foliar transpiration rates of northern red oak seedlings planted between different groundcover treatments.

The null hypothesis corresponding to the second objective was that there would be no differences in percent full photosynthetically active radiation (PAR) at 14 cm above the surface and soil moisture between the different groundcover treatments. The null hypothesis under the third objective was that there would be no relationship between soil moisture and foliar transpiration rates of northern red oak seedlings.

2.4 Materials and Methods

2.4.1 Seedlings and planting date

In early spring of 2010, 2-0 northern red oak seedlings were purchased from the Kentucky Division of Forestry State Nursery. These seedlings were germinated and initially grown in West Liberty, Kentucky. On March 13, 2010, 48 of these seedlings were planted in pots in the University of Tennessee-Knoxville greenhouse (35º56'N 83º56'W) located in Knox County, Tennessee (Figure 12).

2.4.2 Pot size and soils

Seedlings were planted in pots that were 19 cm in diameter by 36 cm deep. The pots were all equal in size to control the amount of growing space. Each pot was filled with a 1:1 ratio of sand and vermiculite. This uniform mixture was used to prevent variance due to various soil factors.

2.4.3 Groundcovers

On March 13, 2010, 12 pots planted with northern red oak seedlings were seeded with each of the following groundcover treatments: alfalfa (*Medicago sativa*), switchgrass (*Panicum virgatum*), and annual rye (*Lolium multiflorum*) at a rate of 12

Figure 12: Northern red oak seedlings and groundcovers approximately a month after being planted in the greenhouse.

grams per pot. No seeds were planted in the bare treatment. The Evermore variety of alfalfa was utilized for this study and purchased at the Foothills Farmers Coop in Maryville, Tennessee. The seeds came from Wyoming seed sources. The germination rate for this variety was predicted to be 85% and the purity was 65.80 %. The Alamo variety of switchgrass was utilized for this study. The seeds were purchased from Bamert Seed Company located in Muleshoe, Texas and came from Texas seed sources. The germination rate for this variety was predicted to be 81% and purity was 88.77 %. The annual rye seeds were purchased from Foothills Farmers Coop in Maryville, Tennessee and came from Oregon seed sources. The germination rate was predicted to be 89% with a purity of 93.74 %.

Each of the different groundcover species planted differs in establishment, rates of growth, rooting depths, and shoot lengths. Annual rye is an exotic that exhibits a rapid growth rate which provides for a quick cover. Annual rye also has a fibrous root system, and when mature, it can attain a height of 1 meter. It has a bunch grass form with many long, thin leaves forming at the base (USDA NRCS Plant Materials Program 2002).

Switchgrass is a perennial, warm season grass that is native to the United States and our study area. According to the USDA NRCS Plant Materials Program (2006), switchgrass exhibits rapid growth. It can have a root system extending up to 3 m deep in the soil. Along with the potential of growing deep, the roots are also very fibrous. Switchgrass can grow to a height between 1-3 m tall and will have a spreading top.

Alfalfa is a perennial legume that exhibits a rapid growth rate. It is exotic and can fix atmospheric nitrogen. Alfalfa can grow to be 1 meter tall and has a spreading growth form (USDA NRCS Plant Materials Program 2006). Weaver (1926) stated that alfalfa root systems on some sites were documented to reach depths greater than 2 m.

2.4.4 Watering Regime and Fertilizer Treatment

Throughout the 2010 growing season, pots were watered on Mondays and Wednesdays from the top of the pot. On Fridays, each pot was fertilized with a 1 liter solution composed of 50 percent deionized water and 50 percent Hoagland solution (Hoagland and Arnon 1939) which was applied from the top of the pot. This created a uniform amount of nutrients available for the plants within the pots.

2.4.5 Measurements

2.4.5.1 Objective 1

For the first objective, initial root collar diameter was measured on 3/13/10. New growth of the apical meristem and root collar diameter of seedlings planted within the groundcovers were measured on 7/12/10 to determine how the groundcovers affected seedling growth. The new growth of the apical meristem was measured to the nearest cm, and the root collar diameter was measured to the nearest 0.1 mm. New growth from the apical meristem was determined by measuring the length of the apical meristem from the bud scale scar corresponding to the beginning of the growing season to the terminal bud at the end of the growing season.

Seedlings were excavated on 7/12/2010 and root and shoot biomass of the northern red oak seedlings were subsequently measured to allow calculation of freshly harvested and dry root-to-shoot ratios. Northern red oak seedlings were removed from the pots on 7/12/10. Leaves of the seedlings were removed on 7/12/10. The number of leaves on each seedling was counted, and then their leaf area was measured with a Li-

Cor LI-3100 Area Meter (Li-Cor, Inc., Lincoln, NE). Leaves were washed to remove any contaminants, their surfaces were dried, and they were weighed on a Mettler Toledo PL3001-S balance (Mettler-Toledo, Inc., Columbus, OH) to determine their green weight. After weighing, the leaves were then placed in a FreeZone 4.5 Freeze Dry System (Labconco Inc., Kansas City, MO) for 48 hours. The leaves were taken out of the drier and weighed again on the balance described above to obtain the dry weight. Specific leaf area (SLA) was calculated by dividing total leaf area by the dry weight.

Harvested seedlings and groundcovers were separated at the root collar. The roots and stems of the seedlings were weighed immediately after harvest and added to the weight of freshly harvested leaves to obtain the green weight of the seedlings. Roots and stems were then placed in a drying oven. Root and stem biomass was dried at 50 degrees Celsius until desiccant indicators changed colors from pink (indicates the presence of moisture) to blue (indicates lack of moisture). The samples took approximately 5 days to dry. When dry, the mass of the roots and shoots of seedling and groundcover biomass was recorded.

Two dry-down periods within the normal watering regime were performed for the transpiration portion of the first objective. The first dry-down period began on 5/15/10 and ended on 5/20/10. The second dry-down period began on 7/3/10 and ended on 7/7/10. No water was applied to the pots during these time periods. Foliar transpiration was measured on the upper most, undamaged, fully expanded leaf of each live seedling every morning between 9 a.m. and 12 p.m. using a Li-Cor LI-1600 Steady State Porometer (Li-Cor, Inc., Lincoln, NE). Foliar transpiration was measured on consecutive days until the rate fell below 0.50 µg cm^{-2} s^{-1}.

2.4.5.2 Objectives 2 and 3

Percent volumetric soil moisture was measured during the same two dry-down periods described above for the second objective. Percent volumetric soil moisture was measured each day foliar transpiration was measured using a TRASE 6050X1 TDR Soil Moisture Probe (Soil Moisture Equipment Corp. Santa Barbara, CA). The soil moisture measurements obtained provide data pertaining to total volumetric soil moisture in the pots.

PAR was simultaneously measured at 14 cm above the surface of the pots receiving groundcover treatments with a Li-Cor LI-190SA quantum sensor (Li-Cor, Inc., Lincoln, NE) mounted on the sampling probe of a Li-Cor LI-1600 Steady State Porometer, and at a station that received ambient levels of full sunlight using a Li-Cor LI-190SA Quantum Sensor and LI-1400 Data Logger. All measurements were obtained on July 6 and 7, 2010 within 30 minutes of solar noon. To obtain percent full PAR, PAR measurements from the ambient sunlight station were divided by synchronous measurements of PAR obtained 14 cm above the rim of each pot.

Biomass of herbaceous groundcover species was harvested on July 13, 2010. It was placed in a drying oven at a temperature of 50 degrees Celsius for 48 hours. After drying, biomass was measured using a Mettler Toledo PL3001-S balance.

2.4.6 Statistical Analyses

Data for this project were analyzed using SAS© software version 9.2 (SAS Institute, Cary NC). The statistical methods utilized in this study were regression analysis and mixed models analysis of variance. The hypothesis under objective 1 concerning root collar growth, new growth of the apical meristem, root-to-shoot ratios, leaf weight, number of leaves, total leaf area, leaf area average, and specific leaf area was investigated with an ANOVA model for appropriate for a Completely Random Design (CRD). The model used to analyze the differences in foliar transpiration rates, soil moisture, and light was appropriate for a CRD with repeated measures. Regression analysis of the relationship between soil moisture and foliar transpiration was conducted for objective 3. An alpha level of 0.05 was utilized in all analyses.

2.5 Results

2.5.1 Objective 1

Of the 48 seedlings planted within the different groundcover treatments, 33 seedlings flushed (10 in the bare treatment, 9 in the switchgrass treatment, 7 in the alfalfa treatment, and 7 in the rye treatment). No differences were found between treatments in either northern red oak seedling root collar diameter growth (p= 0.9499) or new growth of the apical meristem (p= 0.8593) (Table 1).

The root-to-shoot ratio of freshly harvested seedlings differed significantly (p=0.0016) between treatments. Seedlings in the bare and switchgrass treatments were found to have the highest fresh overall root-to-shoot ratio (Table 1). Seedlings in the switchgrass treatment had a lower fresh root-to-shoot ratio than seedlings in the bare treatment, but the difference was not statistically significant. The seedlings in the rye

Table 1: July 2010 root collar diameter growth, new growth of the apical meristem, freshly harvested root-to-shoot ratio, and dry weight root-to-shoot ratio of northern red oak seedlings within each groundcover. Means, standard errors, letter groups, and p-values are shown for treatment main effects for each variable. The red colored p-values indicate significant differences (P<0.05).

	Groundcover	Mean	Standard Error	Letter Group	P-Value
RCD Growth (mm)	Bare	0.4	0.4874	a	p=0.9499
	Switchgrass	0.1	0.4874	a	
	Alfalfa	0.3	0.5714	a	
	Rye	0.1	0.5714	a	
New Growth of the Apical Meristem (cm)	Bare	8.6	1.9443	a	p=0.8609
	Switchgrass	10.2	1.9443	a	
	Alfalfa	8.8	2.2047	a	
	Rye	7.7	2.2047	a	
Freshly Harvested Root-to-Shoot Ratio	Bare	1.22	0.0636	a	p=0.0046
	Switchgrass	1.03	0.0636	ab	
	Alfalfa	0.80	0.0722	c	
	Rye	0.87	0.0722	bc	
Dry Weight Root-to-shoot Ratio	Bare	0.73	0.0682	ab	p=0.0195
	Switchgrass	0.89	0.0682	a	
	Alfalfa	0.62	0.0773	b	
	Rye	0.61	0.0773	b	

treatment were found to have fresh root-to-shoot ratios similar to seedlings planted in the switchgrass and alfalfa treatments. However, the fresh root-to-shoot ratio in the rye treatment was greater than in the alfalfa treatment and less than in the switchgrass treatment. The seedlings in the alfalfa treatment were found to have the lowest fresh root-to-shoot ratios (Table 1).

Similar to root-to-shoot ratio of freshly harvest seedlings, the root-to-shoot ratio calculated for dried root and shoots also differed significantly (p=0.0169) between treatments. Seedlings from the switchgrass treatment had the highest average dried root-to-shoot ratio. The seedlings in the rye and alfalfa treatments had the lowest root-to-shoot ratio (Table 1).

Freshly harvested leaf weight (p=0.0220) of the seedlings was found to differ significantly between treatments. Results indicate that the alfalfa treatment yielded the highest weight of freshly harvested leaves. The bare treatment was statistically the same as the alfalfa treatment but had a lower average weight. It was also the same as the switchgrass treatment but had a higher average weight. The rye treatment yielded the lowest weight of freshly harvested leaves (Table 2).

The weight of dried leaves (p=0.0036) from the seedlings also differed significantly between treatments, but differences between treatments varied from those for freshly harvested leaves. Seedlings in the alfalfa treatment were found to have the greatest weight of dried leaves, and dried leaf weights of seedlings in the bare treatment were less than those in the alfalfa treatment, but did not differ statistically. The switchgrass and rye treatments were found to be statisically similar, although the switchgrass treatment had the largest average and the rye had the lowest average dry

Table 2: July 2010 freshly harvested leaf weight, leaf dry weight, number of leaves, total leaf area, and leaf area average of northern red oak seedlings within each groundcover treatment. Means, standard errors, letter groups, and p-values are shown for treatment main effects for each variable. The red colored p-values indicate significant differences (P<0.05).

	Groundcover	Mean	Standard Error	Letter Group	P-Value
Freshly Harvested Leaf Weight (g)	Bare	8.9	1.82	ab	p=0.0220
	Switchgrass	4.2	1.82	bc	
	Alfalfa	10.5	2.07	a	
	Rye	2.2	2.07	c	
Leaf Dry Weight (g)	Bare	4.0	0.71	ab	p=0.0036
	Switchgrass	2.4	0.71	b	
	Alfalfa	6.2	0.81	a	
	Rye	2.0	0.81	b	
Number of Leaves	Bare	18	8.27	b	p=0.0018
	Switchgrass	16	8.27	b	
	Alfalfa	64	9.38	a	
	Rye	30	9.38	b	
Total Leaf Area (cm^2)	Bare	718.79	166.73	ab	p=0.0092
	Switchgrass	443.96	166.73	b	
	Alfalfa	1173.23	189.06	a	
	Rye	242.99	189.06	b	
Avg. Leaf Area (cm^2)	Bare	36.81	3.73	a	p=0.0003
	Switchgrass	26.62	3.73	ab	
	Alfalfa	18.85	4.23	bc	
	Rye	9.36	4.23	c	

weight of leaves (Table 2). The number of leaves (p=0.0026) and total leaf area (p=0.0092) of the seedlings differed significantly between treatments. The alfalfa treatment produced a significantly greater number of leaves per seedling than all other treatments. The other treatments produced statistically similar numbers of leaves and total leaf area (Table 2). The seedlings in the alfalfa treatment had the greatest total leaf area of all the treatments, but the bare treatment did not significantly differ. The other two treatments had the lowest total leaf area. Average leaf area differed (p=0.0003) among treatments. The bare treatment had the greatest average leaf area, but the switchgrass treatment was not different from the bare treatment. The seedlings in the switchgrass treatment and the alfalfa treatment produced statistically similar averages. However, the seedlings in the alfalfa treatment had a slightly lower average. The seedlings in the rye treatment produced the lowest average leaf area, but were statistically similar to the alfalfa treatment (Table 2).

SLA differed (p=0.0453) for seedlings in the rye treatment as compared to all other groundcover treatments. The SLA for the seedlings in the rye treatment was less than those found in the other three treatments. No differences in SLA were found between these three treatments (Figure 13).

Foliar transpiration rates of the seedlings varied (p<0.0001 for both periods) between groundcover types during both dry-down periods (Figures 14 and 15). During the first dry-down period, seedlings in the bare and switchgrass treatments were found to have the highest foliar transpiration rates. Seedlings in the alfalfa and rye treatments had the lowest foliar transpiration rates. During the second dry-down period, seedlings in the bare treatment had the highest foliar transpiration rates and the rye treatment had

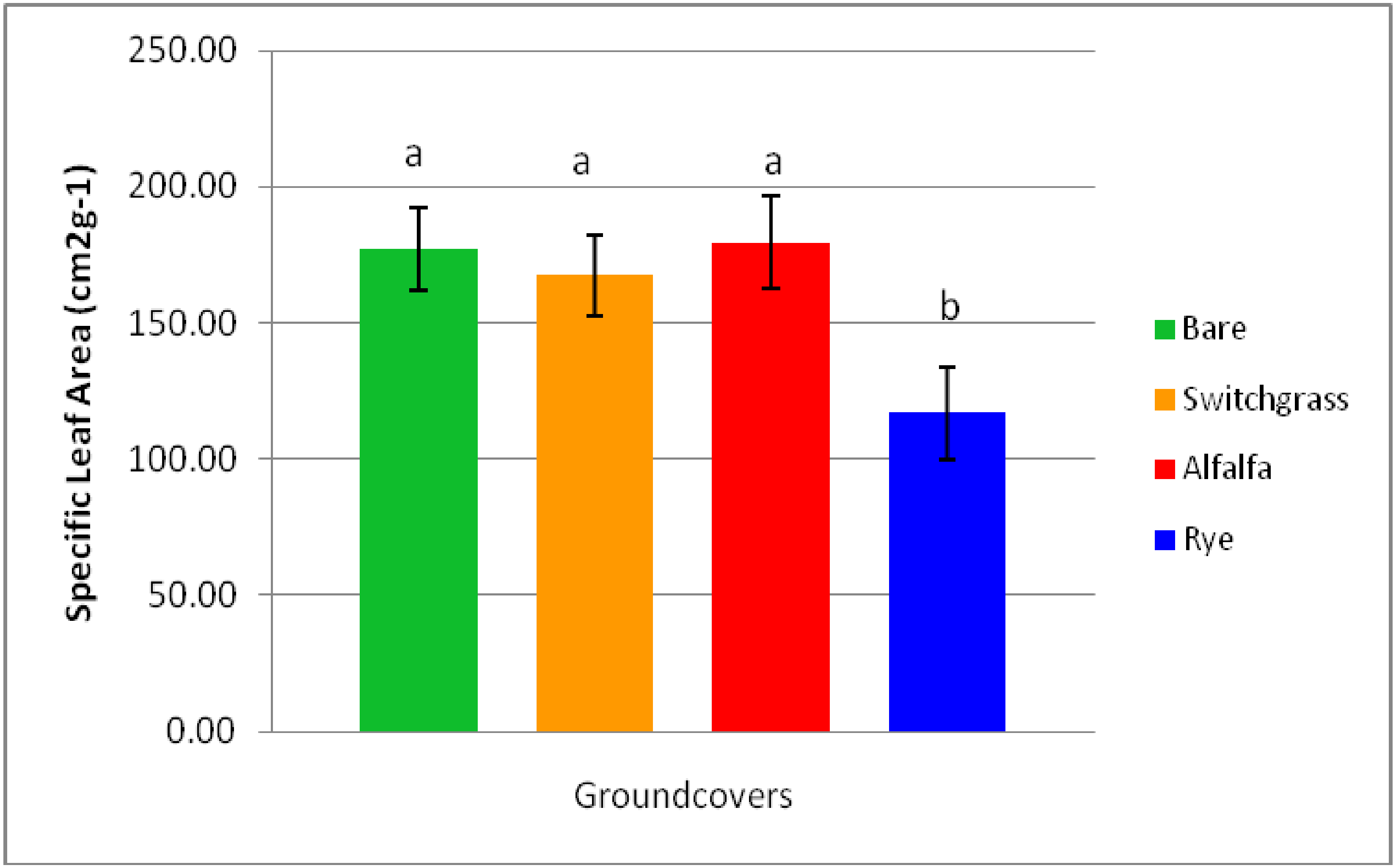

Figure 13: Specific Leaf Area of seedlings within each groundcover. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Specific leaf area was 176.98, 167.48, 179.36, and 116.99 cm^2g^{-1} in the bare, switchgrass, alfalfa, and rye treatments, respectively.

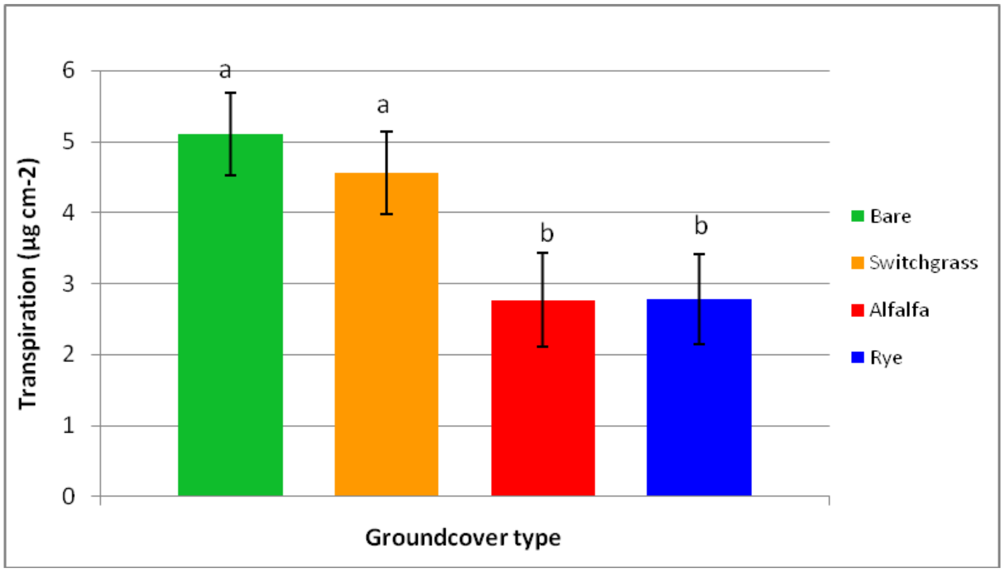

Figure 14: Mean foliar transpiration rates of seedlings between groundcover types during the May dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Foliar transpiration rates were 5.11, 4.56, 2.77,and 2.78 µg cm^{-2} in the bare, switchgrass alfalfa and rye treatments, respectively.

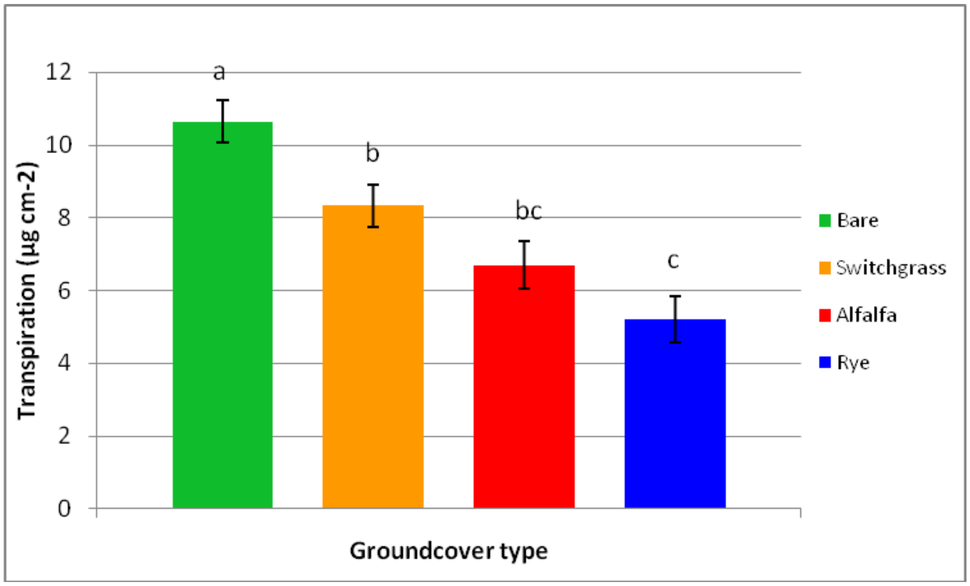

Figure 15: Mean foliar transpiration rates of seedlings between groundcover types during the July dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Foliar transpiration rates were 10.65, 8.33, 6.70, and 5.22 µg cm^{-2} in the bare, switchgrass, alfalfa, and rye treatments, respectively.

the lowest. Seedlings in the alfalfa and switchgrass treatments were found to have the second highest and were statistically the same.

During both of the May and July dry-down periods, it was found that foliar transpiration rates of the seedlings changed significantly ($p<0.0001$ and $p=0.0239$, respectively) as the date progressed (Figures 16 and 17). During both dry-down periods, as time progressed foliar transpiration rates increased to a peak point and then started decreasing. The date peak foliar transpiration rates occurred for both dry-down periods was found in the middle of the period.

For both dry-down periods, a significant interaction ($p<0.0001$ and 0.0084, respectively) was found between date and groundcover type (Figures 18 and 19). During the first dry-down period, foliar transpiration rates were either greater in the alfalfa than in the rye treatment, or the opposite was true, depending on the day. Also on May 16, seedlings in the switchgrass treatment had slightly higher foliar transpiration rates than the seedlings in the bare treatment. Interactions also occurred during the second dry-down period on July 7, 2010, foliar transpiration rates of seedlings in the switchgrass treatment fell below those in the alfalfa treatment for the first time.

2.5.2 Objective 2

2.5.2.1 Soil Moisture

During both of the May and July dry-down periods, it was found that soil moisture declined significantly ($p<0.0001$ for both periods) as the date progressed (Figures 20 and 21). Soil moisture also varied significantly ($p<0.0001$ for both periods) between groundcover types during both dry-down periods (Figures 22 and 23). During both dry-down periods, the bare treatment had the highest percent soil moisture, and the rye

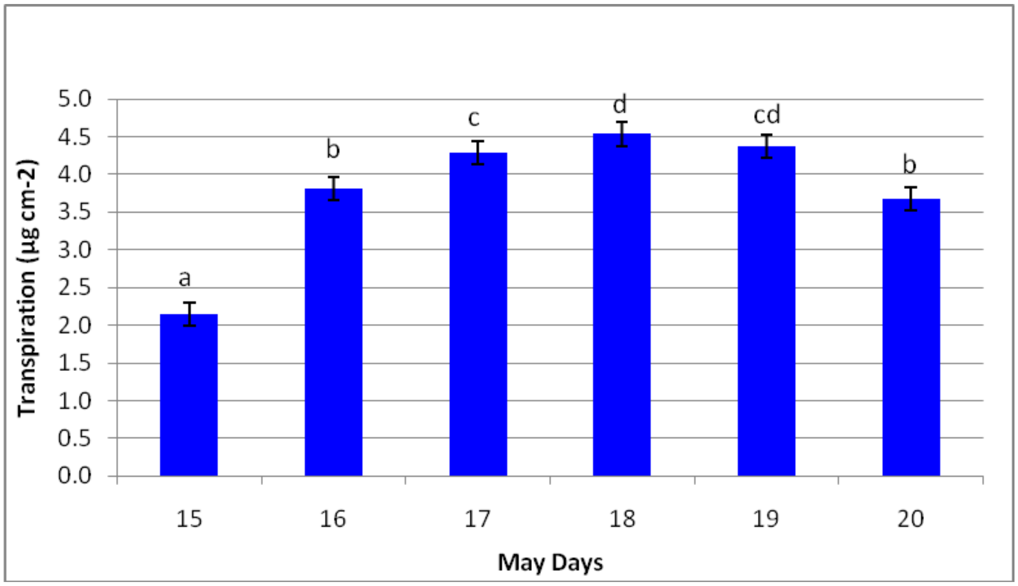

Figure16: Mean foliar transpiration rates of seedlings during the May dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Foliar transpiration rates were 2.15, 3.82, 4.28, 4.54, 4.37, and 3.67 µg cm^{-2} for May 15, 16, 17, 18, 19, and 20, respectively.

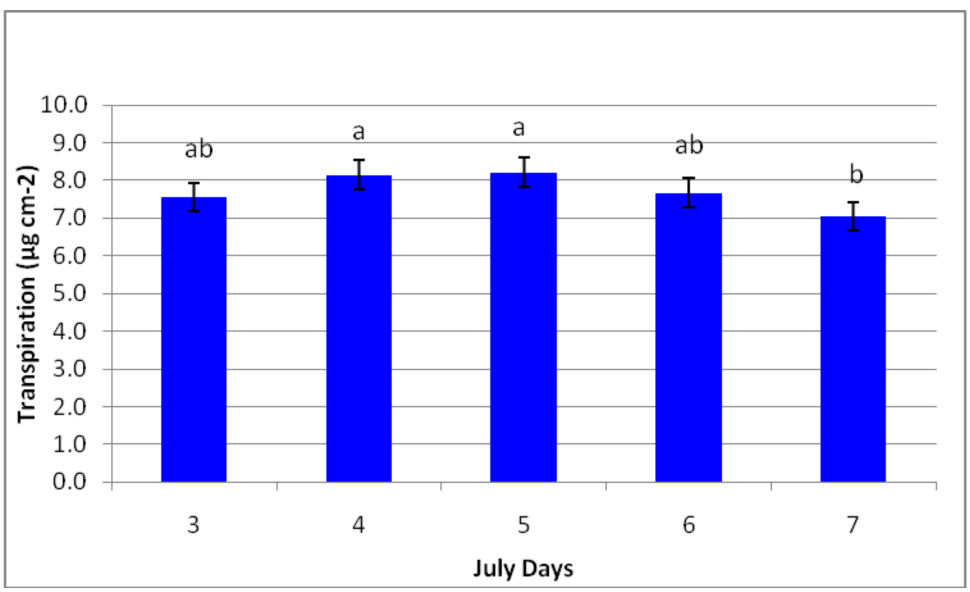

Figure 17: Mean foliar transpiration rates of seedlings during the July dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Foliar transpiration rates were 7.55, 8.14, 8.21, 7.67, and 7.04 µg cm^{-2} for for July 3, 4, 5, 6, and 7, respectively.

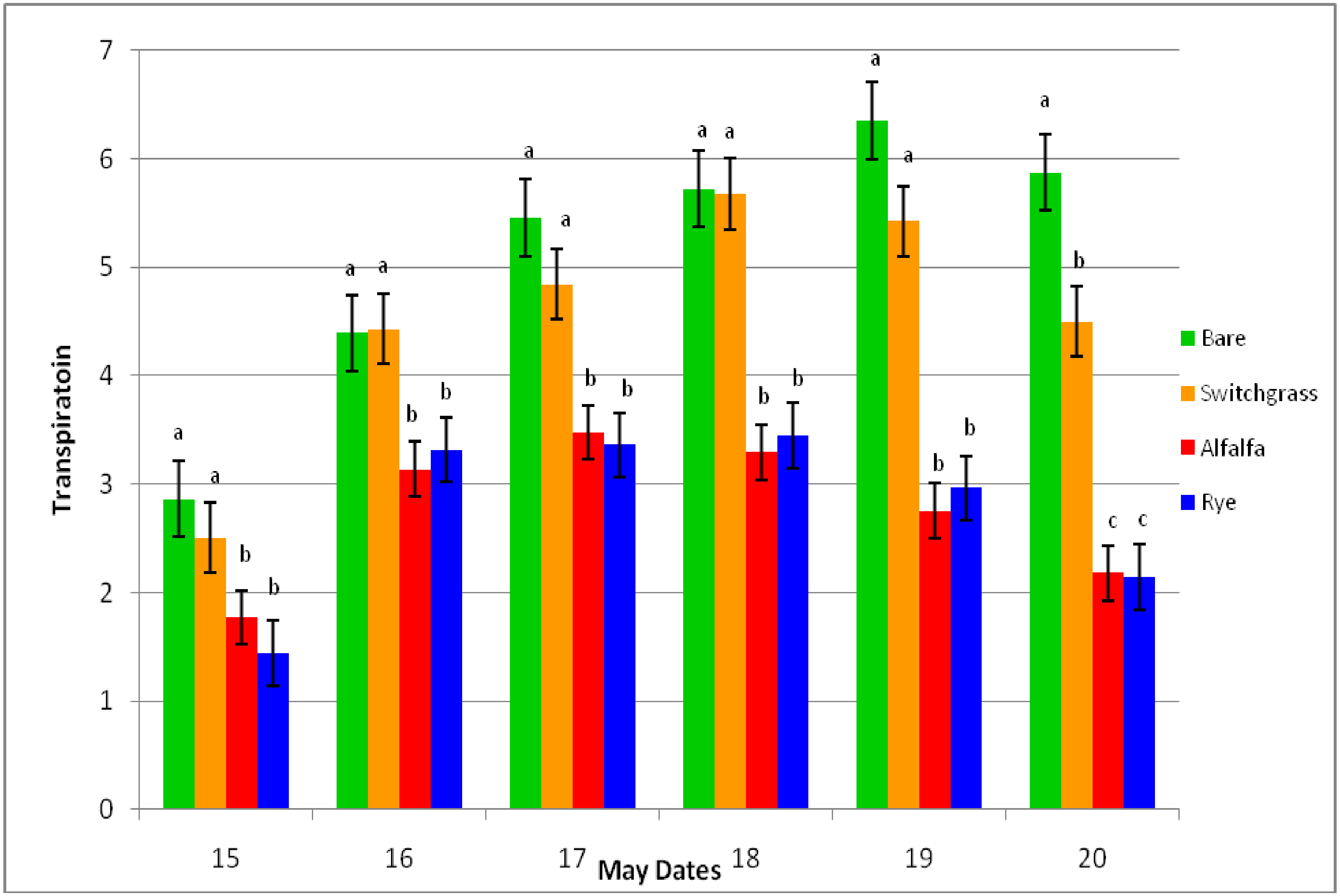

Figure 18: Mean foliar transpiration rates of seedlings between groundcovers during days in the May dry-down period in µg cm^{-2}. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means within individual days (P<0.05).

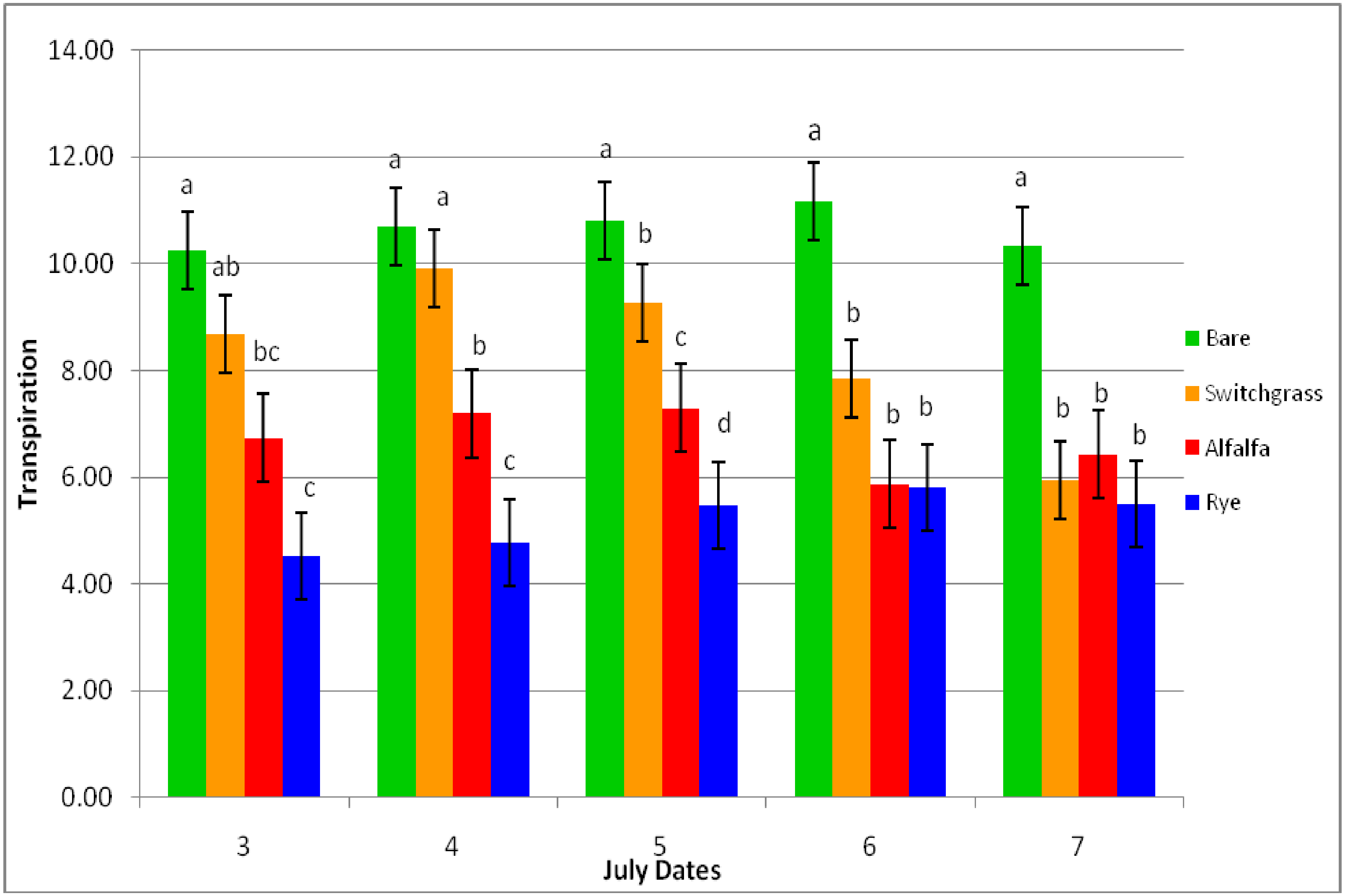

Figure 19: Mean foliar transpiration rates of seedlings between groundcovers during days in the July dry-down period in µg cm^{-2}. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means within individual days.

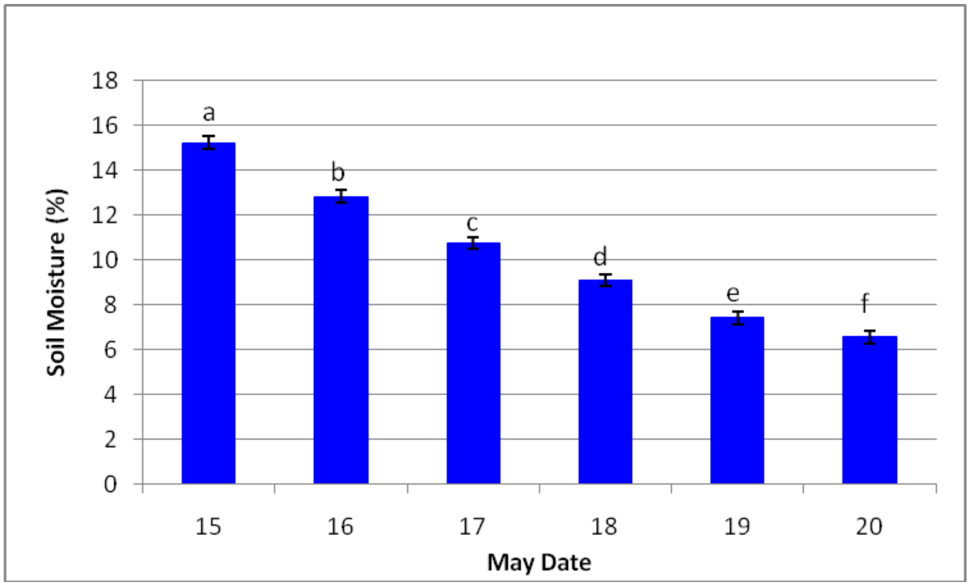

Figure 20: Mean percent soil moisture during the May dry-down period. Means ± standard errors are shown for treatment effects. Different letters represent statistically different means. Percent soil moisture was 15.2, 12.8, 10.7, 9.1, 7.4, and 6.6% on May 15, 16, 17, 18, 19, and 20, respectively.

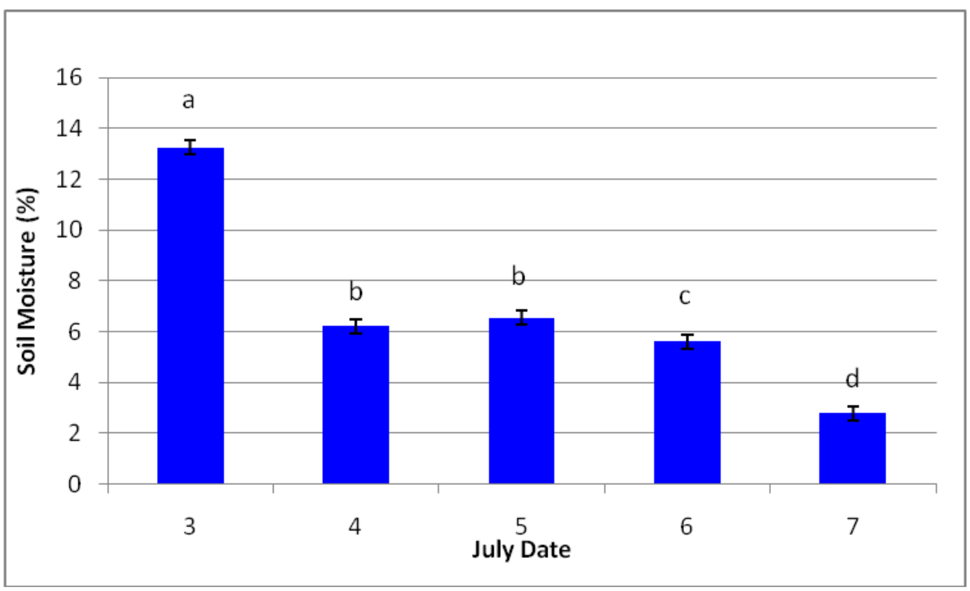

Figure 21: Mean percent soil moisture during the July dry-down period. Means ± standard errors are shown for treatment effects. Different letters represent statistically different means. Percent soil moisture was 13.3, 6.2, 6.5, 5.6, and 2.8% on July 3, 4, 5, 6, and 7, respectively.

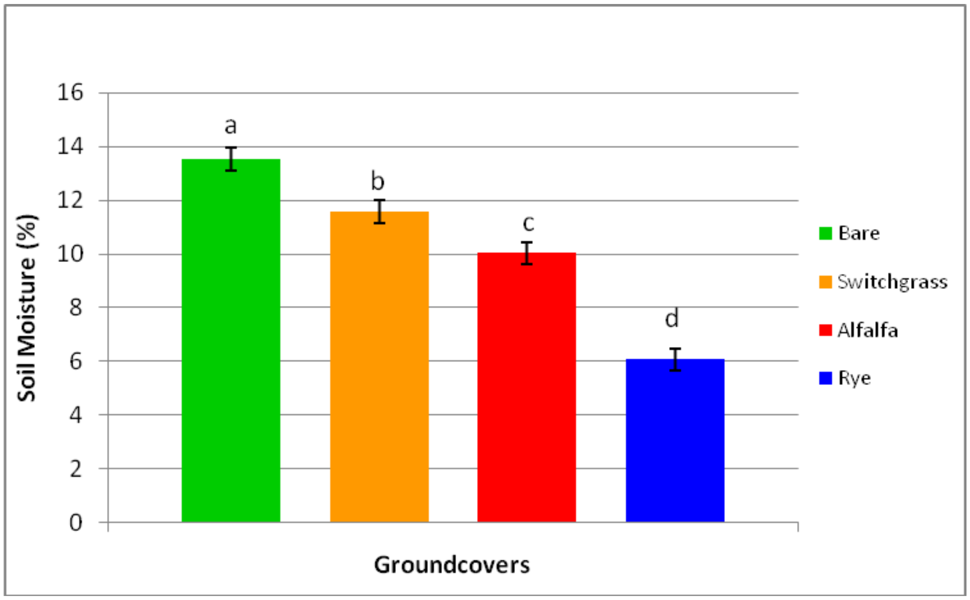

Figure 22: Mean percent soil moisture averaged over days between groundcover types during the May dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means. Percent soil moisture was 13.5, 11.6, 10.0, and 6.1% in the bare, switchgrass, alflalfa, and rye treatments , respectively.

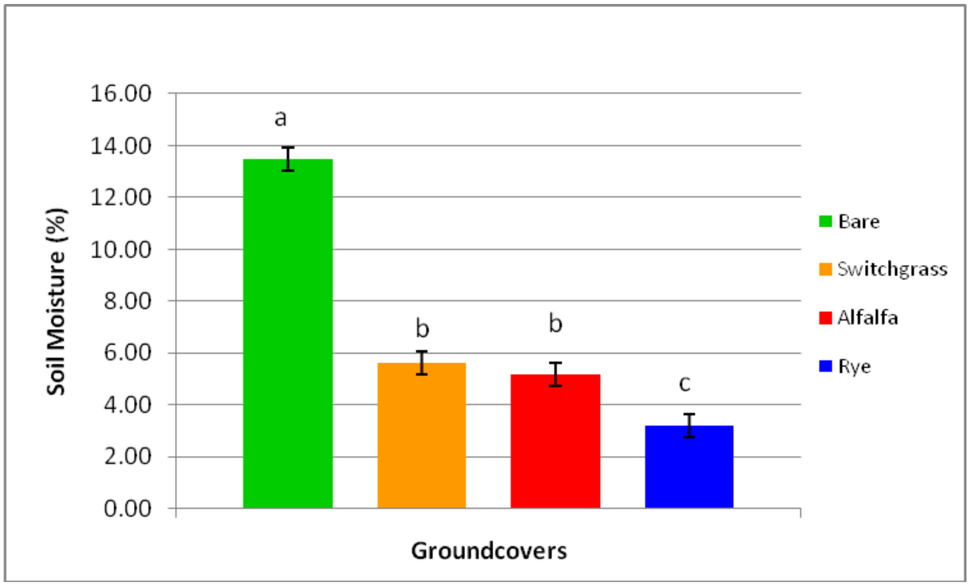

Figure 23: Mean percent soil moisture averaged over days between groundcovers during the July dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means. Percent soil moisture was 13.5, 5.6, 5.2, and 3.2% in the bare, switchgrass, alfalfa, and rye treatments, respectively.

treatment had the lowest. During the first dry-down period, the switchgrass treatment had the second highest percent soil moisture, followed by the alfalfa treatment. However, during the second dry-down period, percent soil moisture did not differ significantly between the alfalfa and switchgrass treatments.

For both dry-down periods, a significant interaction ($p<0.0001$ for both periods) was found between date and groundcover type in the analysis of soil moisture (Figures 24 and 25). Interactions occurred during the first dry-down period when the switchgrass treatment had a higher percent soil moisture than the bare treatment on May 16. All other days the bare treatment had higher soil moisture than switchgrass treatment. Interaction occurred during the second dry-down period when on July 6, 2010, the alfalfa treatment had higher percent soil moisture than the switchgrass treatment. The previous 3 days, the switchgrass treatment had slightly higher percent soil moisture than the alfalfa treatment.

2.5.2.2 Percent Full PAR

Percent full PAR at 14 cm above the surface was found to differ signficantly between groundcover treatments ($p<0.0001$). The bare treatment yielded the greatest perfect full PAR at 14 cm above the surface. Percent full PAR at 14 cm in the alfalfa treatment was slightly less, but did not differ from the bare treatment. Percent full PAR in the annual rye treatment was significantly less than the percent full PAR in the bare treatment at 14 cm above the surface.The lowest percent full PAR was found in the switchgrass treatment (Figure 26). In addition to the switchgrass having the lowest percent full PAR, it also had the greatest above ground biomass of the groundcover treatments (Figure 27).

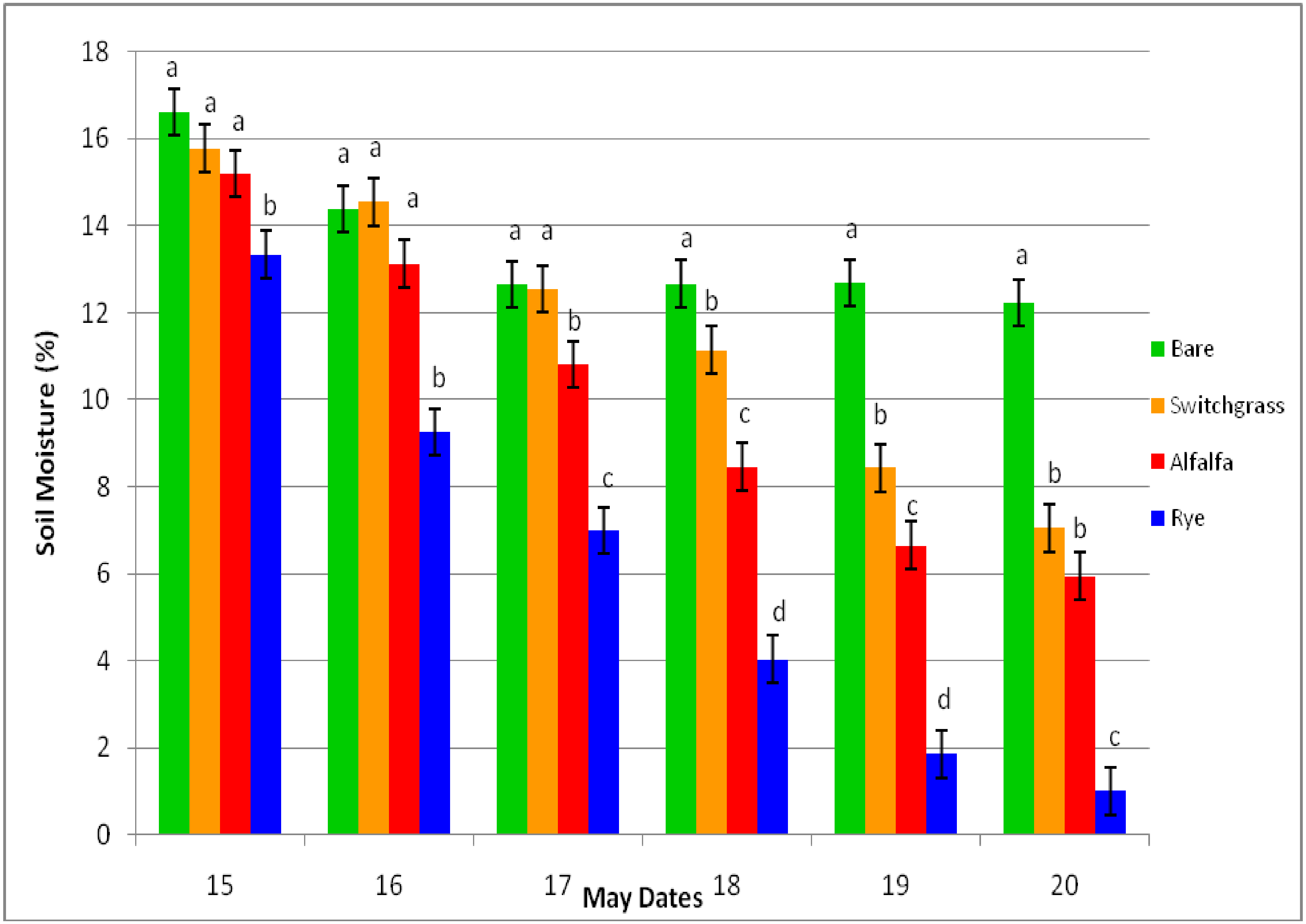

Figure 24: Mean percent soil moisture between groundcovers during days in the May dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means within individual days.

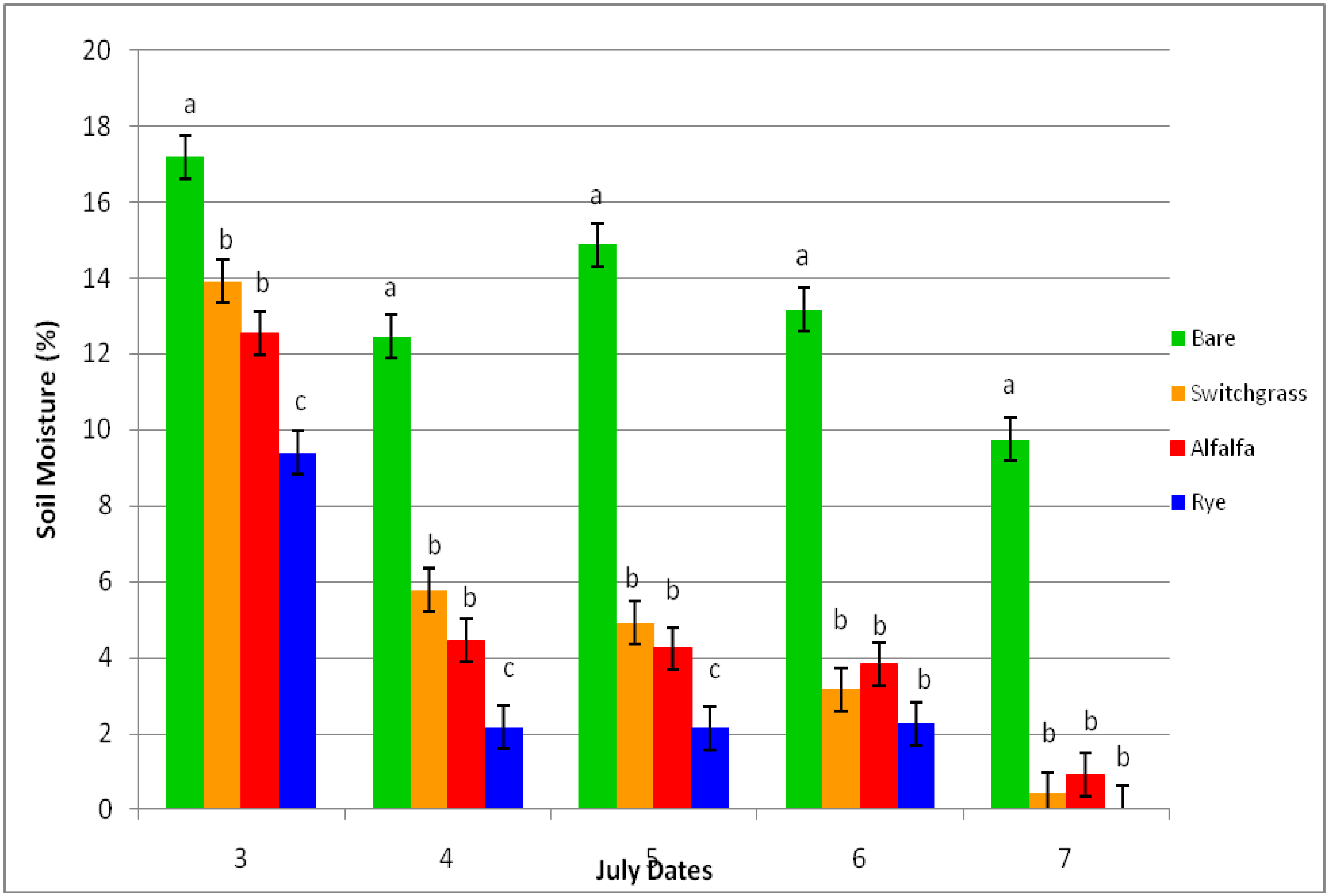

Figure 25: Mean percent soil moisture between groundcovers during days in the July dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means within individual days.

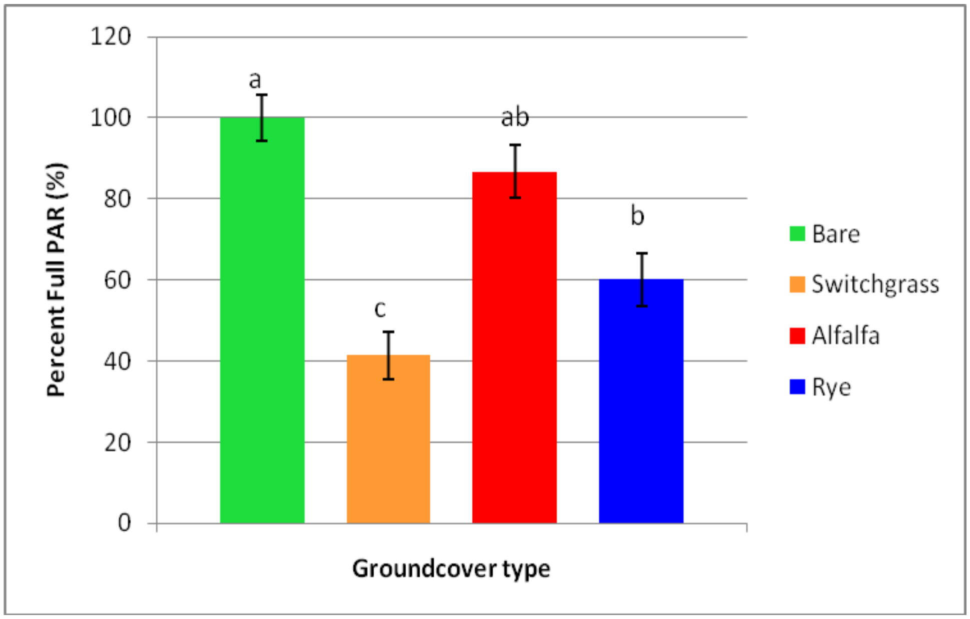

Figure 26: Percent full photosynthetically active radiation at 14 cm above the surface. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Percent full PAR was 100.00, 41.39, 86.71, and 69.09% in the bare, switchgrass, alfalfa, and rye treatments, respectively.

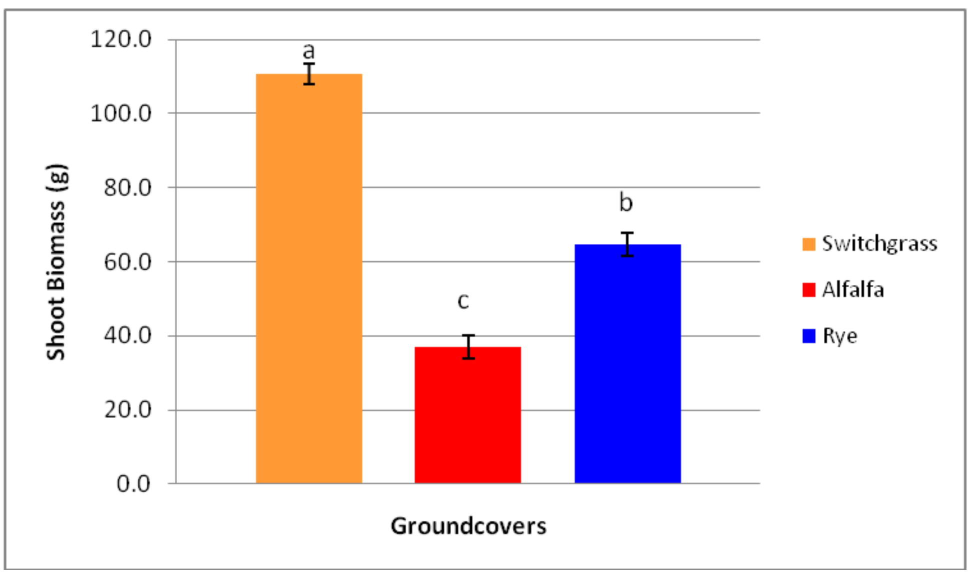

Figure 27: Mean shoot biomass of the groundcover treatments. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Shoot biomass was 110.7, 36.9, and 64.7g for the switchgrass, alfalfa, and rye treatments, respectively.

2.5.3 Objective 3

The significance of relationships between soil moisture and foliar transpiration changed as time progressed during the first dry-down period. On May 15, 16, and 17 of 2010, no significant relationship was found between soil moisture and foliar transpiration rates (p=0.1784, p=0.0574, p=0.0504, respectively). However, on the final 3 days, May 18, 19, and 20, a significant positive relationship was found between soil moisture and foliar transpiration rates (p=0.0016, p=0.0013, p=0.0001, respectively). R^2 values indicated relationships were moderate and increased in strength as time progressed (Table 3).

The second dry-down period yielded results that were similar to the first dry-down period. However, significant positive relationships between soil moisture and foliar transpiration rates were found (p=0.003, p=0.0061, p=0.0004, p<0.0001, and p=0.0044, respectively) on all 5 days (July 3, 4, 5, 6, and 7). R^2 values increased as time progressed until July 7. On this day, the R^2 value dropped to a value which was similar to those of July 3 (Table 3).

2.6 Discussion

2.6.1 Objective 1

2.6.1.1 New Growth of the Apical Meristem

Northern red oak seedlings did not show any significant differences in new growth of the apical meristem between the different treatments. The year prior to planting, the seedlings were all grown in optimal and similar conditions. Having been grown under these similar conditions prior to the experiment, seedlings may have had similar amounts of stored reserves that resulted in negligable differences in growth

Table 3: Regression equations for percent soil moisture and foliar transpiration rates of seedlings for each date during the first and second dry-down periods. Regression equations, standard error for the slope, R^2, and the model p-value are listed for each date. The red colored p-values were found to be significant ($P<0.05$). Percent soil moisture is the independent variable.

Date	Regression Equation	Standard Error for the Slope	R^2	Model P-value
5/15/10	1.02142+0.06772x	0.04896	0.0685	p=0.1784
5/16/10	2.77293+0.07123x	0.05662	0.0574	p=0.2196
5/17/10	2.64571+0.13766x	0.06701	0.1396	p=0.0504
5/18/10	2.58835+0.19931x	0.05667	0.3224	p=0.0016
5/19/10	2.32833+0.25729x	0.07141	0.3330	p=0.0013
5/20/10	1.54503+0.30267x	0.0673	0.4375	p=0.0001
7/3/10	2.10094+0.40560x	0.12574	0.2513	p=0.0030
7/4/10	6.01817+0.36497x	0.12361	0.2252	p=0.0061
7/5/10	6.16412+0.33177x	0.08392	0.3425	p=0.0004
7/6/10	5.44058+0.42279x	0.07893	0.4889	p<0.0001
7/7/10	6.31956+0.33780x	0.10925	0.2480	p=0.0044

during the time frame of the experiment, even though measured percent full PAR and soil moisture differed between groundcover treatments (Kozlowski et al. 1991). Other reasons for the lack of differences in new growth of the apical meristem may be the small sample size of the experiment, or the short duration of the experiment.

2.6.1.2 Root Collar Diameter Growth

Northern red oak seedlings in the greenhouse did not show any significant differences in root collar diameter growth between the different treatments. There are several reasons why this may have occurred. The first may be due to similar amounts of stored reserves accumulated under uniform conditions in the nursery the year before planting in the greenhouse. Another reason for the lack of differences is that root collar growth of the seedlings could have been too minute to measure accurately with calipers over the short time frame of the experiment. Also, the lack of differences in root collar diameter growth may be due to the small sample size of the experiment.

2.6.1.3 Seedling Root-to-Shoot Ratios

The root-to-shoot ratios of freshly harvested and dry seedlings were found to be the lowest in the alfalfa and rye treatments. The low root-to-shoot ratio of the seedlings planted in the alfalfa treatment may be explained by alfalfa's high demand for nutrients and water and rapid growth (McKenzie 1995). The alfalfa may have rapidly captured the space and other resources in the pots, thereby limiting the resources available for oak root growth. Another possible explanation for a lower root-to-shoot ratio for the seedlings in the alfalfa treatment may be due to the alfalfa fixing nitrogen for the seedlings to utilize for shoot growth. Research has found that when seedlings are planted in high nitrogen environments, more resources are allocated to shoot growth rather than root growth (Graca and Hamilton 1981; Bailian et al. 1991). Another potential reason for the seedlings in the alfalfa treatment having a low root-to-shoot ratio may be the greater number of leaves seedlings in the alfalfa treatment produced.

The low root-to-shoot ratio of the seedlings in the annual rye treatment may be due to the rapid establishment of annual rye and its heavy use of nitrogen and water during growth and development (USDA 1973). Similar to alfalfa, annual rye may have limited the amount of space and other resources available for oak seedling root growth. Fetene (2003) found decreases in root-to-shoot ratios of tree seedlings in the presence of increased competition from a perennial grass. Another possible explanation of the lower root-to-shoot ratio of the seedlings in the annual rye treatment may be the allelopathic effect members of the ryegrass family potentially exhibit. (Emeterio et al. 2004). These allelopathic effect could potentially inhibit root growth of the planted oak seedlings.

The seedlings in switchgrass treatments may have had greater root-to-shoot ratios than seedlings in the alfalfa and rye treatments and root-to-shoot ratios similar to those of seedlings in the bare treatment due to the delayed establishment and development of switchgrass that is often observed in the field (Sanderson and Reed 2000). The slow development described by Sanderson and Reed (2000) was observed in the switchgrass in the greenhouse. This may have given the tree seedlings more time to establish and develop a root system.

2.6.1.4 Number of Leaves and Leaf Weight

The number of leaves on the seedlings was found to be significantly different between groundcover treatments. The seedlings found in the alfalfa treatment had a significantly greater number of leaves than the other 3 treatments. This may be explained by the fact that alfalfa is a legume and is able to "fix" nitrogen. Cook (1985) found that the addition of nitrogen produced a 13 to 27 fold increase in the number of leaves in a grassland sward. In terms of tree species, Brix and Ebell (1969) found that the addition of nitrogen doubled the number of leaves in Douglas-fir. The larger total leaf weight of the seedlings within the alfalfa treatment can also be explained by the significantly greater amount of leaves and the mid-sized average leaf area on the seedlings.

Also, it was observed that seedlings planted in the alfalfa treatment produced more lateral branches than the seedlings planted in switchgrass, annual rye, and bare treatments, causing there to be a greater number of leaves. This may be explained by the balance of hormones in the trees in the different treatments. The production of auxins such as indoleacetic acid (IAA) has been found to inhibit lateral bud growth (Jankiewicz et al. 1972). However, Riera et al. (2004) found that the production of the plant hormone abscisic acid (ABA) is produced during times of drought. The production of ABA has been found to inhibit the production of the hormone IAA. This would allow the dormant lateral buds to activate causing seedlings in the alfalfa treatment to have more lateral branches and leaves. Seedlings planted in the switchgrass and annual rye treatments had similar numbers of lateral branches as seedlings planted in the bare treatment. Results indicate the seedlings planted in the switchgrass treatment established in an environment with percent soil moisture similar to that in the bare treatment, and with greater percent soil moisture than the seedlings planted in both the alfalfa and rye treatments.

2.6.1.5 Total Leaf Area and Area per Leaf

The seedlings in the alfalfa treatment were found to have the greatest total leaf area. This may be the result of greater number of leaves produced by the seedlings in the alfalfa treatment. Brix and Ebell (1969) obtained similar results after increasing nitrogen available to Douglas-fir, which increased the leaf area. This suggests that the alfalfa may have been “fixing” nitrogen, thereby increasing the nitrogen available to northern red oak.

Different results were obtained for area per leaf. The seedlings planted in the bare treatment had the greatest area per leaf, which was more than 3 times greater than area per leaf in the rye treatment. This may be explained by the fact that the bare pots had no competitors and there would have been less need for seedlings to conserve resources, especially water. The seedlings in the switchgrass treatment had a somewhat smaller, but not significantly different, area per leaf than those in the bare pots. This similarity may be due to the late development of the switchgrass, which did not hinder the establishment of the seedlings. Due to later establishment of the switchgrass and less utilization of water and nutrients in the early growing season, oaks could initially produce larger leaves without inhibition from competition. Smith (1978) found that smaller leaves were produced in perennial desert plants when under stress due to water and nutrient competition. He concluded the smaller leaves were produced to conserve water loss through transpiration. Dudley (1996) found evidence in her research to further support the conclusion of the production of smaller leaves during times of water and nutrients stress.

2.6.1.6 Specific Leaf Area (SLA)

SLA of the seedlings was found to be significantly lower in the rye treatment than in the bare, alfalfa, and switchgrass treatments. Sefton et al. (2002) state that a low SLA is common when the location is nutrient poor and where water conservation and nutrients must be efficiently utilized to ensure the success of the species. This was further supported by Poorter and Remkes (1990), Knops and Reinhart (2000), and Liu and Stutzel (2004). As stated previously, rye is a fast growing, quick establishing groundcover that requires large amounts of water and nitrogen. These characteristics of annual rye may be the reason that seedlings planted in the rye treatment exhibited the lowest SLA.

2.6.1.7 Foliar Transpiration Rates over Time and between Treatments

Foliar transpiration rates of the seedlings were found to vary between days. Many factors affect foliar transpiration rates such as soil moisture, relative humidity, and temperature (Feldhake and Boyer 1986; Zhang et al. 2008). During the dry-down periods, temperature and relative humidity fluctuated and soil moisture decreased. This may have caused the foliar transpiration rates of the seedlings to vary between days.

During the first dry-down period, seedlings in the bare and switchgrass treatments were found to have the greatest foliar transpiration rates, and the alfalfa and rye treatments were found to have the lowest foliar transpiration rates. The seedlings in the switchgrass treatment may have had statistically similar foliar transpiration rates to the seedlings in the bare treatment because of the proportionally greater development late in the growing season that switchgrass exhibits in the field (Smart and Moser 1997; Sanderson and Reed 2000; Lee and Boe 2005). The later development of switchgrass in the greenhouse may have caused more soil moisture to be available for the seedlings to take up and transpire. The seedlings in the alfalfa and rye treatment may have had lesser foliar transpiration rates because these groundcover species have a high demand for water and nutrients, leaving the seedlings less water to take up and transpire (USDA 1973; McKenzie 1995).

During the second dry-down period, the seedlings in the bare treatment had the greatest foliar transpiration rates. Foliar transpiration in the switchgrass treatment was significantly lower than transpiration in the bare treatment and statistically similar to transpiration in the alfalfa treatment. This change in foliar transpiration rates may be due to the increased development of the switchgrass by this time period (Sanderson and Reed 2000).

Measured foliar transpiration rates were much greater during the second dry-down period than during the first period (Figures 18 and 19). It is important to note the temperature differences between the first dry-down period and the second period. The first dry-down period had an average mean temperature of 20.39 degrees Celsius and the second had an average mean temperature of 27.56 degrees Celsius. Temperatures were higher during the second dry-down period, and it has been found that, to a certain point, higher temperatures can result in greater transpiration rates due to water loss (Feldhake and Boyer 1986). Another important factor that may have affected transpiration is the level of establishment of the seedlings. During the first dry-down period, the seedlings were not as well established as during the second period. Cui and Smith (1991) found that transpiration rates also increase once trees become more established in their environment.

2.6.2 Objective 2

2.6.2.1 Percent Soil Moisture over Time and between Groundcover Treatments

It was found that percent soil moisture steadily dropped as time progressed during the dry-down periods. Many other researchers have studied the effect of dry periods on soil moisture and obtained similar results (Hosty and Mulqueen 1996; Niklaus et al. 1998; Kumusch 1998). Water may have been pulled from the pots via evaporation, by seedling and groundcover transpiration, and by gravity pulling soil moisture down through the pot.

The groundcover treatment that averaged the lowest percent soil moisture was the rye treatment. This may have been due to the aggressive, dense establishment of the rye mentioned previously (USDA 1973). The bare treatment had the greatest average percent soil moisture. This was likely due to the lack of groundcover roots that would take up water. During the first dry-down period, percent soil moisture in the switchgrass treatment was significantly greater than the alfalfa treatment, but during the second dry-down period, the percent soil moisture of the alfalfa and switchgrass treatments were not significantly different. This may have been due to the development of the switchgrass later in the experiment that was mentioned previously compared to the alfalfa and annual rye treatments (Smart and Moser 1997; Sanderson and Reed 2000; Lee and Boe 2005).

As mentioned previously, it is important to note the difference in temperature between the first and second dry-down periods. The first dry-down period had greater soil moisture percentages than the second period. This may have been due to the effects of the higher greenhouse and soil temperatures (Kumusch 1998). It has been found that increasing temperatures can cause increased rates of evaporation from soils and transpiration from the seedlings and groundcovers. This results in loss of water from the soil (Feldhake and Boyer 1986).

2.6.2.2 Photosynthetically Active Radiation between Groundcover Treatments

The bare treatment was found to have the greatest percent full PAR at 14 cm above the surface. It is expected that a bare plot would have greater percent full PAR than one that was seeded with a groundcover treatment. The alfalfa and rye treatments were found to have a significantly greater percent full PAR than the switchgrass treatment. Due to PAR being measured later in the growing season, percent full PAR at 14 cm above the tube surface may have been less in the switchgrass treatment due to the proportionally greater development of switchgrass later in the experiment (Smart and Moser 1997; Sanderson and Reed 2000; Lee and Boe 2005) and taller height of switchgrass (USDA NRCS Plant Materials Program 2006) relative to alfalfa and annual rye, which exhibit rapid and early development (Volesky and Anderson 2010;USDA 1973) and short heights (USDA NRCS Plant Materials Program 2006; USDA NRCS Plant Materials Program 2002). This was further supported by the greater amount of above ground biomass groundcovers in the switchgrass treatment compared to the alfalfa and annual rye treatments. If PAR had been measured earlier in the growing season, it may have been lower in the switchgrass treatment.

2.6.3 Objective 3

2.6.3.1 Relationship between Foliar Transpiration Rates and Soil Moisture

In 8 of the 11 days, soil moisture and foliar transpiration rates of the seedlings showed significant, linear relationships with one another. These trends are positive and moderately strong and show that as percent soil moisture increased, foliar transpiration rates also increased. With greater percent soil moisture, more water may be available for the plant to utilize for transpiration and conservation of the water resource becomes less vital for the seedling. Many other studies have yielded similar results when examining other species (Schneider and Childers 1941; Andrews and Newman 1967; Lassoie et al. 1977; Wetzel and Chang 1987).

2.7 Conclusion

Results of this study suggest that northern red oak seedlings demonstrate varying responses when grown within different groundcovers. Planting rye with seedlings resulted in several negative outcomes for the seedlings. Seedlings in the rye treatment exhibited the lowest root-to-shoot ratios, total leaf area, leaf area average, SLA, and foliar transpiration rates. Percent soil moisture was found to be lowest in the rye treatments, further supporting the possibility that there was a lack of soil moisture available to the northern red oak seedlings. Due to the aggressive growth and rapidly establishing cover and high demand for water that rye exhibits, growth and establishment of the northern red oak seedlings may be inhibited. Results of this study suggest that the planting of annual rye as a tree-compatible groundcover for northern red oaks may not be appropriate.

The seedlings planted in the alfalfa treatment exhibited both positive and negative responses to their interactions with alfalfa. The seedlings in the alfalfa treatment were found to have lower root-to-shoot ratios, average leaf area, and foliar transpiration rates than seedlings in the switchgrass and bare treatments, suggesting poorer performance and less soil moisture available to these seedlings than those in the switchgrass and bare treatments. Measured percent soil moisture in the alfalfa treatment was found to be lower than in the switchgrass and bare treatments, which provides further evidence for an overall lack of available soil moisture. However, the total leaf area was found to be the greatest among the groundcover treatments, and SLA was found to be similar to the bare and switchgrass treatments, which suggest the seedlings in the alfalfa performed similarly to the bare and switchgrass treatments. Like annual rye, alfalfa exhibits rapid growth and establishment and has a high demand for resources. This may inhibit the growth and establishment of northern red oak seedlings. More research is needed to determine if alfalfa should be considered a compatible groundcover with 2-year old northern red oak seedlings.

It was found that seedlings planted within the switchgrass treatment exhibited results most similar to the bare treatments. The seedlings were found to have similar total leaf area, leaf area averages, SLA, and root-to-shoot ratios as the seedlings planted within the bare treatments. Foliar transpiration rate of the seedlings and soil moisture percent were also similar to those found in the bare treatment during the first dry-down period. However, in the second dry-down period, it was found that the seedlings planted within the switchgrass treatment had slightly lower foliar transpiration rates suggesting the amount of available soil moisture was lower than in the bare plots.

This was further supported by results for percent soil moisture during the second dry-down period, which was found to be lower in the switchgrass treatment than in the bare treatments. During the measurement of PAR in July, the percent full PAR at 14 cm above the surface of the tube of the switchgrass treatment was found to be the lowest of all the treatments. This may be explained by greater amount of above-ground biomass switchgrass produced. Both the percent soil moisture and the percent full PAR results may be explained by the delayed development of the switchgrass described by Sanderson and Reed (2000).

With respect to species characteristics, switchgrass grows later in the growing season, even after the first year of establishment (Smart and Moser 1997; Sanderson and Reed 2000; Lee and Boe 2005). By the time the development and growth of switchgrass occurs, it may be late enough in the growing season that growth of northern red oak seedlings is mostly complete. This indicates a possible reduction in the competition between seedlings and switchgrass for resources early in the growing season, which is further supported in this study because northern red oak seedlings planted in the switchgrass treatment performed similarly in all facets of this experiment to seedlings in the bare treatment. Therefore, of the groundcover species studied, switchgrass may be the most compatible with co-occurring 2-year old northern red oak seedlings.

References

Andrews, R.E. and Newman, E.I. 1967. The influence of root pruning on the growth and transpiration of wheat under different soil moisture conditions. *New Phytologist* 67(3):617-630.

Bailian, L., S.E. McKeand, and H.L. Allen (1991) Seedling shoot growth of loblolly pine families under two nitrogen levels as related to 12-year height. *Canadian Journal of Forest Research* 21(6): 842-847.

Beck, D. E. (1970) Effect of competition on survival and height growth of red oak seedlings. United States Department of Agriculture Forest Service, Research Paper SE-56. Southeastern Forest Experiment Station.

Belt, S. (2009) USDA Plant Data Sheet: Gray Goldenrod (*Solidago nemoralis*). United States Department of Agriculture.

Bradshaw, L. and D.E. Goldberg (1989) Resource levels in undisturbed vegetation and mole mounds in old fields. *American Midland naturalist* 121:176-183.

Brix, H. and L.F. Ebell (1969) Effects of Nitrogen Fixation on Growth, Leaf Area, and Photosynthesis Rate in Douglas- Fir. *Forest Science* 15(2):189-196.

Burger, J.A., and C.E. Zipper (2002) How to Restore Forests on Surface Mined Lands. Virginia Cooperative Extension.

Burger, J., C.E. Zipper, and J. Skousen (2009) Establishing Ground Cover for Forested Post-Mining Land Uses. Publication Number 460-124.

Cater, Timothy C. and Chapin, F.S. (2000) Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. *Ecology* 81(4):1086-1099.

Collin, P., P.M. Badot, and B. Millet (1996) Croissonce rythmique et developpement du chene rouge d' Amerique, *Quercus rubra* L. cultive en condiflons controlees. *Journal of Ann. Science* 53: 1059-1069.

Cook, S.J. (1985) Effect of nutrient application and herbicides on root competition between green panic seedlings and a *Heteropogon* grassland sward. *Grass and Forage Science* (40) 171-175.

Cui, M. and W.K. Smith (1991) Photosynthesis, water relations and mortality in *Abies lasiocarpa* seedlings during natural establishment. *Tree Physiology* 8:37-46.

Davis, M.A., Wrage, K.J., Reich, P.B., Tjoelker M.G., Schaeffer, T. and Muermann, C. (1999) Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology* 145: 341–350.

Dudley, S.A. (1996) The Response of Differing Selection on Plant Physiological Traits: Evidence for Local Adaptation. *Journal of Evolution* 50(1):103-110.

Feldhake, C.M. and D.G. Boyer (1986) Effect of soil temperature on evapotranspiration by C3 and C4 grasses. *Journal of Agricultural and Forest Meteorology* 37(4):309-318.

Fetene, M. (2003) Intra- and inter-specific competition between seedlings of *Acacia etbaica* and a perennial grass (*Hyparrenia hirta*). *Journal of Arid Environments* 55:441-451.

Graca, M.E.C. and D.F. Hamilton (1981) Effects of nitrogen and phosphorus on oot and shoot growth of *Cotoneaser divaricata* Reud & Wils. *Scientia Horticulturae* 15(1): 77-85.

Guehl, J.M., C. Fort, and A. Fehri (1995) Differential response of leaf conductance, carbon isotope discrimination and water-use efficiency to nitrogen deficiency in maritime pine and pedunculate oak plants. *New Phytologist* 131:149-157.

Harmer, R. and M. Robertson (2003) Seedling root growth of six broadleaf species grown in competition with grass under irrigated nursery conditions. *Ann. For. Sci.* 60:601-608.

Harrington, G.H. (1991) Effects of soil moisture on shrub seedling survival in a semi-arid grassland. *Ecology* 72(3):1138-1149.

Hoagland, D. R. and D. I. Arnon. 1938. The water-culture method for growing plants without soil. University of Calif. College of Agriculture Experimental Station Circulation 347. University of California, Davis.

Hosty, M. and J. Mulqueen (1996) Soil Moisture and Groundwater Drawdown in a Dry Grassland Soil. *Irish Journal of Agricultural Food and Research* 35(1):17-24.

Jankiewics, L.S., H Plich, B. Borkowska, and A. Moraszczyk (1972) Growth Correations and the Shape of Young Trees and Shrubs. *Acta Horticulturae 34: Symposium on Growth Regulators in Fruit Production*:107-116.

Karl, M.G. and P.S. Doescher (1993) Regulating competition on conifer plantations with preregulating competition on conifer plantations with prescribed cow grazsing. *Forest Science* 39: 405-418.

Knops, J.M.H. and K. Reinhart (2000) Specific Leaf Area along a Nitrogen Fertilization Gradient. *American Midland Naturalist* 144(2): 265-272.

Kozlowski, T.T., P.J. Kramer, P.J., and S.G. Pallardy (1991) The Physiological Ecology of Woody Plants. Academic Press, Inc. San Deigo, CA.

Kumusch, A.U. (1998) Implications of Climate Change for Soil Moisture Availability in Turkey's Southeastern Anatolia Project Region. *Drought Network News* 10(2):9-13.

Landsburg, J. J. and S.T. Gower (1997) Applications of Physiological Ecology to Forest Management. Academic Press. San Diego.

Lassoie, J.P., D.R.M. Scott, and L.J. Fritschen (1977) Transpiration Studies in Douglas-fir Using the Heat Pulse Technique. *Forest Science* 23(3):377-390.

Lee, D.K. and A. Boe (2005) Biomass Production of Switchgrass in Central South Dakota. *Crop Science* 45: 2583-2590.

Liu, F. and H. Stutzel (2004) Biomass partitioning, specific leaf area, and water use efficiency of vegetable amaranth (*Amaranthus spp*.) in response to drought stress. Scientia Horticulturae 102 (1) 15-27.

McKenzie, R.H. (2005) Soil and Nutrient Management of Alfalfa: Agri-facts. Agdex 121/531-5. Alberta Agriculture, Food, and Rural Development.

Mitchell, R.J., B.R. Zutter, T.H. Green, M.A. Perry D.H. Gjerstad, and G.R. Glover (1993) Spatial and temporal variation in competitive effects on soil moisture and pine response. *Ecological Applications* 3(1):167-174.

Niklaus, P.A., D. Spinnler, and C. Korner (1998) Soil moisture dynamics of calcareous grassland under elevated CO_2. *Oecologia* 117(1-2):201-208.

Poorter, H and C. Remkes (1990) Leaf area and net assimilation rate of 24 wild species differing in relative growth rate. *Oecologia* 83 (4): 553–559.

Richards, J.H. and M.M. Caldwell (1987) Hydraulic lift: Substantial nocturnal water transport between soil layers by *Artemisia tridentata* roots. *Oecologia* 73: 486-489.

Riera, M., M Figueras, C. Lopez, A. Goday, and M. Pages (2004) Protein kinase CK2 modulates developmental functions of the acscisic acid reponsitive protein Rab17 from maize. *Proceedings from the National Academy of Science of the United States of America* 101:9879-9884.

Samra, J.S., M.K. Vishwanatham, and A.R. Sharma (1999) Biomass production of trees and grasses in a silvopasture system on marginal lands of Doon Valley of north-west India. *Agroforestry Systems* 46: 197–212.

San Emeterio, A. Arroyo, and R.M. Canals (2004) Allelopathic potential of *Lolium rigidum* Gaud. On the early growth of three associated pasture species. *Grass and Forage Science* 59(2): 107-112.

Sander, I.L. (1990) Quercus rubra (Northern red oak). Silvics of North America. U.S. Department of Agriculture Forest Service, Washington D.C.

Sanderson, M.A. and R.H. Reed (2000) Switchgrass Growth and Development: Water, Nitrogen, and Plant Density Effects. *Journal of Range Management* 53(2): 221-227.

Schneider, G.W. and Childers, N.F (1941) Influence of soil moisture on photosynthesis, respiration, and transpiration of apple leaves. *Plant Physiology* 16:565-583.

Sefton, C.A., K.D. Montagu, B.J. Atwell, and J.P. Conroy (2002) Anatomical variation in juvenile eucalypt leaves accounts for differences in specific leaf area and CO2 assimilation rates. *Australian Journal of Botany* 50:301-310.

Seidel, K. (1972) Drought resistance and internal water balance of oak seedlings. *Forest Science* 18:34-40.

Smart, A.J. and L.E. Moser (1997) Morphological development of switchgrass as affected by planting date. *Agronomy Journal* 89:958-966.

Smith, W.K. 1978. Temperatures of Desert Plants: Another Perspective on the Adaptability of Leaf Size. *Journal of Science* 20(4356):614-616.

Tirmenstein, D.A (1991) Quercus rubra. In: Fire Effects Information System. U.S. Department of Agriculture, Rocky Mountain Research Station, Fire Sciences Labortory.

USDA NRCS Plant Materials Program. (2006) USDA Plant Data Sheet: Alfalfa (*Medicago sativa).*

USDA NRCS Plant Materials Program (2002) USDA Plant Data Sheet: Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot).

USDA NRCS Plant Materials Program (2006) USDA Plant Data Sheet: Switchgrass (*Panicum virgatum).*

Vories, K.C. Unknown Date Published. The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines. United States Department of Interior: Office of Surface Mining.

Weaver, J.E. (1926) Root Development of Field Crops, 1st ed. McGraw-Hill Inc., NY.

Wetzel, P.J. and J.T. Chang (1987) Concerning the Relationship between Evapotranspiration and Soil Moisture. *American Meteorological Society* 26:18-27.

Wilson, P.J. (1999) Specific leaf area and leaf dry matter content as alternative predictors of plant strategies. *New Phytologist* 143:155-162.

Zhang, W., Y.Wang, H. Kangning, Y. Zhou, and X. Gan (2008) Factors affecting transpiration of *Pinus tabulaeformis* in a semiarid region of the loess plateau. *Frontiers of Forestry in China* 3(2):194-199.

Zutter, B.R., G.R. Glover, and D.H. Gjerstad (1986) Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. *Forest Science* 32: 882-899.

3 Chapter 3: Initial Competitive Interactions among Planted Appalachian Hardwoods and Different Groundcover Species on Reclaimed Mine Sites with Steep Slopes

3.1 Abstract

Coal mining is an important industry in Appalachia. Environmental challenges associated with mining include the potential for reduced water quality, soil erosion, and mass slope failure. Herbaceous groundcovers are commonly planted to reduce soil erosion and protect water quality, but many groundcovers may be too competitive to be compatible with trees during reforestation.

The objectives of this research were to: 1) investigate the competitive effects of different groundcover species on northern red oak, American chestnut, black cherry, and shagbark hickory seedlings; 2) compare differences in percent cover of groundcover species between treatments and assess how percent cover changed as the season progressed; 3) and investigate the effect of these groundcovers on resource availability, specifically soil moisture and light. Seedlings of the 4 different tree species were planted on 3 different reclaimed mine sites in Tennessee located on the Cumberland Plateau in 3 different treatments: bare, switchgrass, and alfalfa.

Tree seedling root collar diameter growth, height growth, and foliar transpiration rates were measured for objective 1. To investigate objective 2, quadrats were used to measure percent cover of all groundcover species in each treatment within the 1 m^2 area around selected seedlings. Photosynthetically active radiation and percent soil moisture were measured to investigate the third objective.

Total height and root collar diameter growth of northern red oak, American chestnut, black cherry, and shagbark hickory did not differ between treatments. However, relationships were found between percent cover of all groundcover species combined and growth of black cherry, northern red oak, and American chestnut

seedlings. Mean foliar transpiration rates of seedlings did not differ between groundcover treatments.

Percent cover of groundcover species did not change within treatments over time. However, total percent cover of all groundcover species within treatments was found to differ between treatments. The alfalfa treatment had greater percent cover than the bare and switchgrass treatments.

Mean percent soil moisture was greatest in the bare treatment, followed by the switchgrass treatment. Mean percent soil moisture was lowest in the Alfalfa treatment. Photosynthetically active radiation at 14 cm above the soil surface was found to be greatest in the bare and switchgrass treatments, and lowest in the alfalfa treatment.

The lack of differences in seedling performance between treatments in this study may have been due to the low percent cover of groundcover species established on some replicate sites, large variability between planting locations in substrate characteristics, and perhaps other micro-site factors which may have reduced the development of differences among treatments.

3.2 Introduction

3.2.1 History of Coal Mining in Tennessee

Tennessee has a long history of coal mining. Coal mining started in the state in the late 1700’s, but was not a large-scale industry until the mid-1800’s. Tennessee was the tenth of 19 states that became involved in bituminous coal production (Fickle 1998), and 22nd of 26 states in total coal production (Office of Surface Mining Reclamation and Enforcement 2008). Bituminous coal is a soft coal that contains bitumen. It is a lower quality coal than anthracite coal but higher quality than lignite coal. Bituminous coal is also known as “steam coal” (American Coal Foundation 2002). The growth of the coal industry was quickly followed by a large expansion of the railroad industry, which in turn, aided coal mining and transport.

By the early 1900’s “steam coal” was the largest mining industry in Tennessee. Other industries included mining of lead, iron, zinc, and quarrying of marble. Until 1940, underground mining was the predominant method of mining coal. This was due to a lack of technology needed to access coal on steep mountain slopes. However, as technology improved, strip and other forms of mining began to prevail (Fickle 1998).

Currently, 22 counties in Tennessee contain coal resources. Mining primarily occurs in the Cumberland Mountains and the Cumberland Plateau, and is mainly surface mining. The total recoverable coal reserves in Tennessee amount to 60.7 million short tons. These reserves exist in beds up to 1.2 m thick, and can be found as deep as 305 m underground (Office of Surface Mining Reclamation and Enforcement 2008).

3.2.2 Impacts and Regulations

When surface mining is completed, there are substantial environmental changes that must be addressed. Mountainsides are left with no vegetation, little or no topsoil, and little or no organic matter. These conditions can lead to problems such as reduced water quality, soil erosion, and mass slope failure. Before 1977, there were no laws and regulations in place that enforced the reclamation of coal mining operations. This changed in 1977, when the Surface Mining Control and Reclamation Act (SMCRA) was passed. This act established a program for the regulation of surface mining activities and the reclamation of coal mined lands. The Office of Surface Mining (OSM) was created simultaneously to enforce this act (Vories Unknown date).

3.2.3 Post-SMCRA Reclamation Efforts

The passing of SMCRA resulted in a large increase in efforts to reclaim mined land in the Appalachian Mountains. Initial efforts to reclaim mines focused on heavily compacting the soil, and the seeding of herbaceous groundcovers. These herbaceous plants were commonly Kentucky 31 fescue (*Festuca arundinacea*), sericea lespedeza (*Lespedeza cuneata),* and several others. These plants were successful in controlling erosion, but had detrimental effects when inter-cropped with trees. Many groundcover species grew tall and very dense, which hindered the ability of trees to grow from seeds. They also competed very heavily for resources. Along with the practice of heavily compacting the soil, this competition limited tree seedling growth and survival. Although early reclamation efforts following the passing of SMCRA were successful in protecting water quality and reducing surface erosion and mass slope failures, they resulted in levels of compaction and competition with groundcovers that were essentially incompatible with the restoration of forests on mined land (Burger et al. 2005).

3.2.4 Forestry Reclamation Approach

The Appalachian Regional Reforestation Initiative (ARRI) was created in 2004 to address problems associated with reclamation and reforestation techniques. This group is a conglomerate of agencies, organizations, and institutions, including the University of Tennessee. Members of ARRI have forwarded the Forestry Reclamation Approach (FRA). The FRA is a cost-effective method of reclaiming coal-mined land to forest under the SMRCA, which results in development of forest wildlife habitat, watershed protection, and many other environmental services (Burger et al. 2005). The FRA consists of a 5 step approach which is described in Burger et al. (2005).

The first step in the 5-step approach is to create a suitable rooting medium for good tree growth that is no less than 1.3 m deep and comprised of topsoil, weathered sandstone and/or the best available material. The second step is to loosely grade the topsoil or topsoil substitute established in the first step to create a non-compacted growth medium. The third step is to use groundcovers that are compatible with growing trees. In the fourth step, 2 types of trees are planted: early successional species for wildlife and soil stability, and commercially valuable crop trees. The final step is to use proper tree planting techniques (Burger et al. 2005).

There are many reasons why non-compacted growth mediums are so important for plant growth and survival. Loosely graded soil allows rainfall to penetrate the soil, the soil to hold greater amounts of air and water, and roots to have the ability to grow without restraint (Sweigard et al. 2007). There are many studies that confirm the value of this approach. Torbert and Burger (1992) performed a study that demonstrated greater growth and survivorship of various hardwood species as compaction decreased. Results of a study located on Starfire mine in Kentucky, suggested that trees planted on plots with loosely graded soils demonstrated exceptional growth and survival when compared to trees planted in plots with conventionally graded soils (Angel et al. 2006).

Surface erosion is a concern in any type of reclamation, and the planting of grasses or other groundcover species along with the seedlings is warranted on many sites. Burger and Zipper (2002) state that tree-compatible groundcovers are often sparse the first year and become denser in the following years. This allows for the tree seedlings to emerge above the groundcover and increases their survival. According to Burger et al. (2009), some compatible grasses of choice for groundcover include orchardgrass (*Dactylis glomerata*), Timothy (*Phleum pratense*), winter rye (*Secale cereale*), foxtail millet (*Setaria italica*), redtop (*Agrostis gigantea*), and perennial ryegrass (*Lolium perenne*). The legumes of choice are Kobe lespedeza (*Lespedeza striata var. Kobe*), birdsfoot trefoil (*Lotus corniculatus*), and white clover (*Trifolium repens*). These species are often short in stature.

Burger et al. (2009) have argued that these groundcovers are advantageous because they allow more sunlight to reach planted tree seedlings. These groundcovers also withdraw water and nutrients from the soil more slowly than faster-growing agricultural grasses and legumes, leaving more of these below-ground resources for the planted trees. These groundcovers also do not cover the ground as rapidly or completely. This results in more open micro-sites for wind and wildlife dispersed seeds to germinate and become successfully established. In Appalachian coal-mining areas, most of the seeds planted are generally native forest species. The tree-compatible species are also less attractive to animals such as deer and rodents (Burger and Zipper 2002).

The groundcovers listed above have shown promise in forestry reclamation, but problems have occurred with some of the existing pool of groundcover species. Some can persist for many years and become aggressive competitors under certain conditions. Most also prefer a soil pH of 6-7, whereas trees are typically adapted to a soil pH of 4.5-6. A very large number of potential herbaceous groundcover species exists, but many of these species have not been thoroughly tested for use in forestry reclamation.

In addition to the need for testing of an expanded set of groundcover species, there has been little research performed on steep slopes. A steep slope is defined as a 20 – 45% slope (Hungr et al. 2001). Sites located on steep slopes are more likely to have problems such as surface erosion and mass slope failure than more level sites. A simple solution to reduce surface erosion is to plant dense and aggressive groundcovers, but unfortunately these aggressive groundcovers severely hinder the survival and growth of trees needed to reduce the chances of mass slope failure.

3.3 Objectives

There are 3 objectives in this study. The first objective was to compare the growth and transpiration of seedlings planted in different groundcover treatments. The second objective was to compare differences in percent cover of groundcover species between groundcover treatments and assess how percent cover changed as the seasons progressed. The third objective was to determine the influence of each groundcover on light and moisture availability.

The null hypothesis for the first objective was that the different groundcovers would not affect the growth (height and root collar diameter) and foliar transpiration rates of planted seedlings. The two null hypotheses for objective 2 were that the total percent cover of groundcover species would not differ between groundcover species, and that percent cover of all groundcover species combined within each groundcover treatment would not change over time as the growing season progressed. The null hypothesis under the third objective is that percent soil moisture and percent full photosynthetically active radiation (PAR) would not differ between groundcover treatments.

3.4 Materials and Methods

3.4.1 Site Descriptions

Three field study sites were selected in active coal mining operations run by different coal companies. The first of these sites is located on King Mountain (36º37'N 83º56'W elevation: 594 m). It is being mined by Mountainside Coal Company and located in Claiborne County, Tennessee. The study is on a west-facing slope (287º azimuth). The second of these sites is located on Zeb Mountain (36º30'N 84º16'W elevation: 701 m). It is being mined by National Coal Company and located in Campbell County, Tennessee. The elevation of this site is approximately 701 m. The study site is on a southeast-facing slope (151º azimuth). The third site is located on Windrock Mountain (36º07'N 84º19'W elevation: 859 m). It is being mined by Premium Coal

Company, Inc. and located in Anderson County, Tennessee. The study site is on a west-facing slope (290º azimuth).

Each site was selected to ensure slopes were consistent with the definition of a steep slope (Hungr et al. 2001). A steep slope is defined as a slope that falls between 20% and 45%. After the mining operation was completed, original material was placed back on all slopes using the Forestry Reclamation Approach that is recommended by ARRI. Substrates were comprised of sandstone and shale.

3.4.2. Experimental Design

Each slope was subdivided into 4 plots. Each plot was assigned a groundcover treatment at random (Figure 28). Nine columns of seedlings spaced 2 m apart were established perpendicular to the slope within each plot (Figures 28, 29). Shagbark hickory seedlings were planted in the first 3 columns, northern red oak seedlings were planted in the next 3 columns, and American chestnut and black cherry seedlings were planted in an alternating manner in the last 3 columns. For example, in the first row an American chestnut seedling, a black cherry seedling, and then an American chestnut seedling were planted. In the second row a black cherry, an American chestnut, and then a black cherry seedling were planted. This planting order was carried out down the entirety of the slope. Rows were planted in an alternating 2 m and 4 m spacing pattern so the number of seedlings available for planting would fit in the allotted space on the slopes. The first row was planted 4 m from the top of the plot, the second row was planted 2 m below this, and the third row was planted 4 m below the second row, and so on. Twelve rows of seedlings were established in each plot (Figure 29).

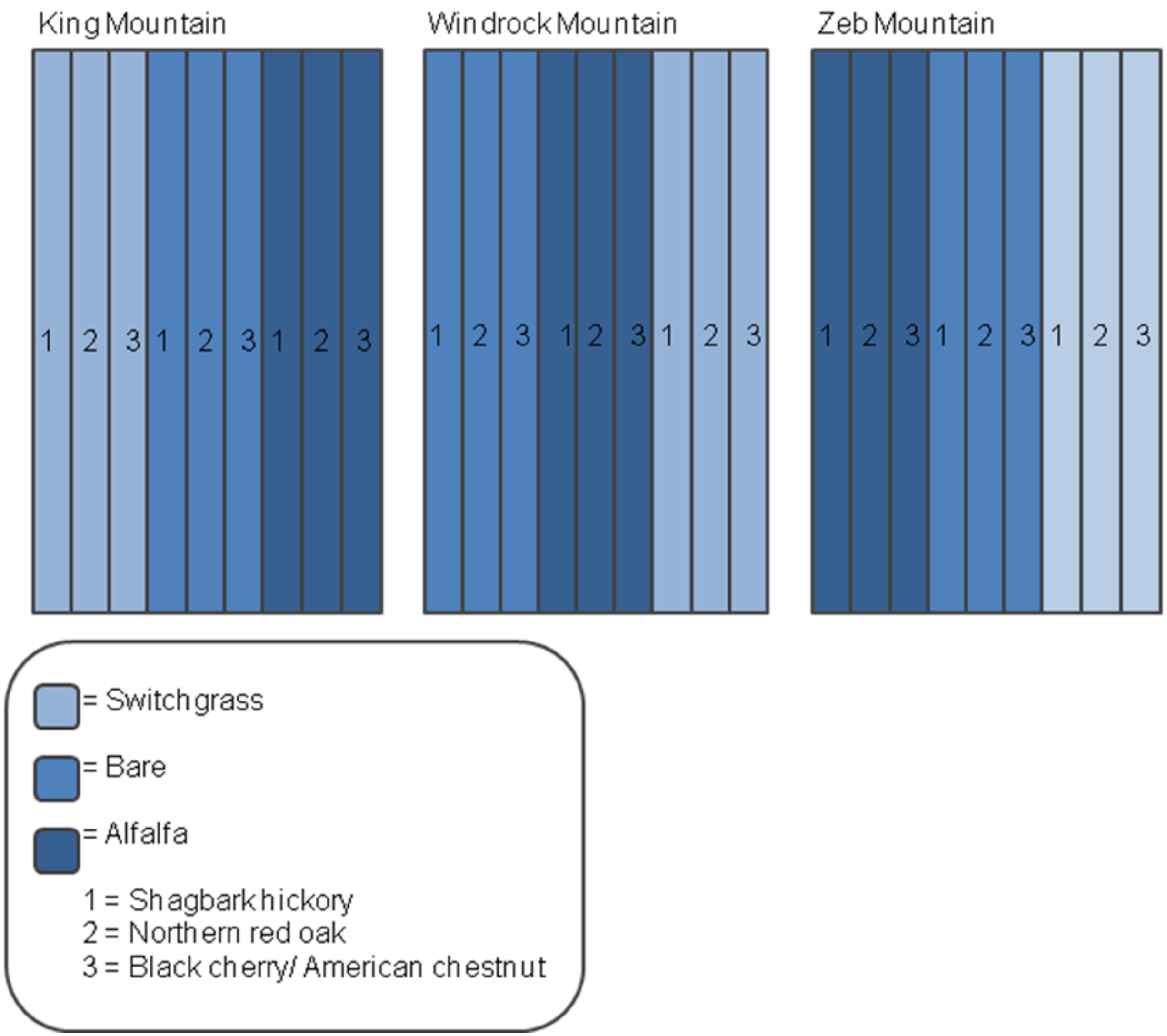

Figure 28: Groundcover and seedling treatments for each site

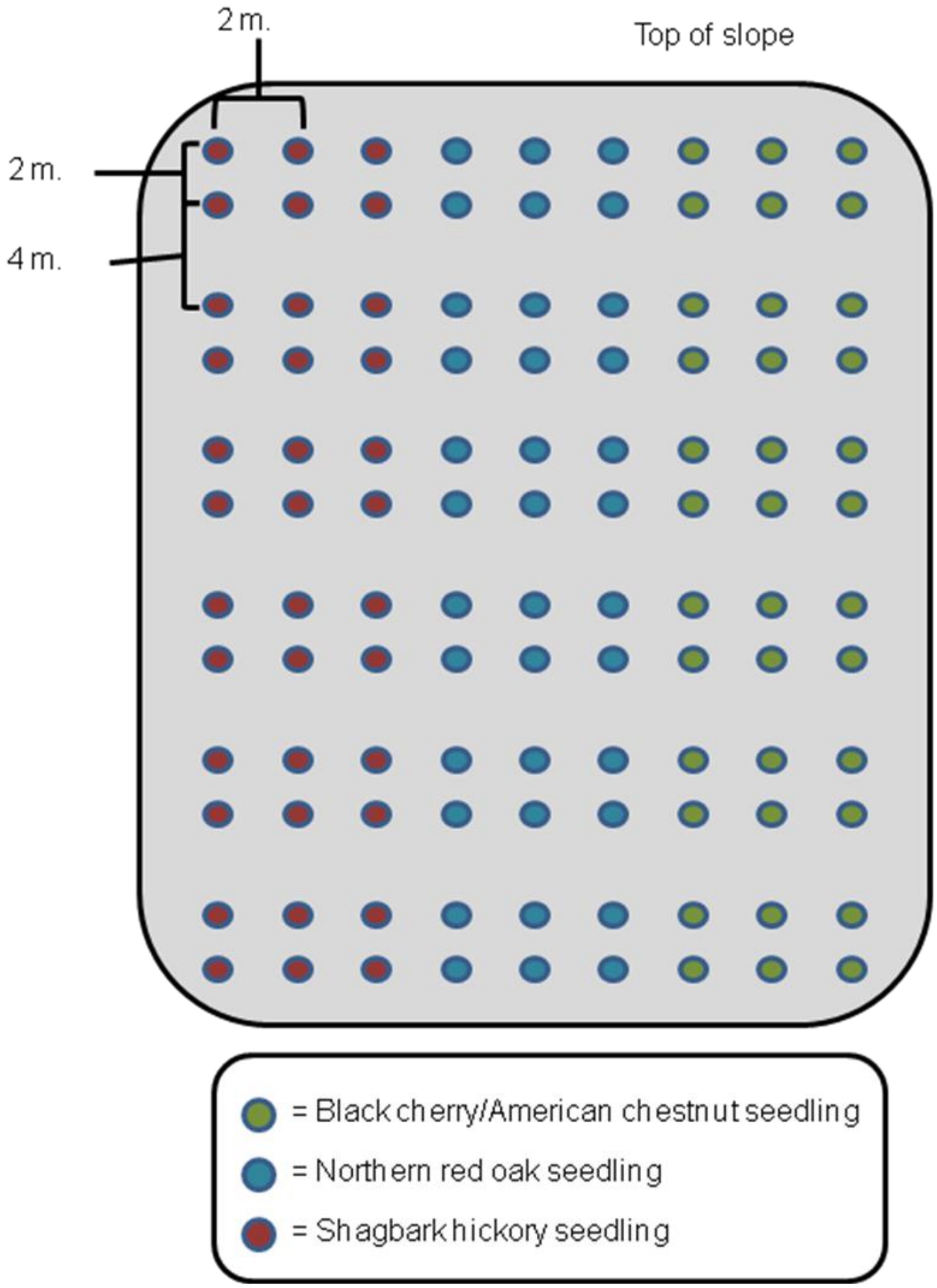

Figure 29: Spacing and species arrangement of trees on each site.

3.4.2 Groundcovers studied

In this research project, effects of 2 potentially tree-compatible groundcovers with different rooting characteristics on tree growth and survival were compared, along with their potential as future selections to be used for forestry reclamation after mining. These two groundcovers are switchgrass (*Panicum virgatum* Blackwell var.), and alfalfa (*Medicago sativa* Evermore var.). Annual rye (*Lolium multiflorum*) was also planted on the sites to provide for a quick-growing, but temporary, groundcover on the alfalfa and switchgrass treatments. Before groundcovers were applied, all plots were scarified by dragging a rake across the entire plot. Alfalfa and switchgrass were broadcast seeded May 20, 2009, and annual rye was broadcast seeded June 18, 2009.

Switchgrass is a perennial, warm season grass that is native to the United States. Switchgrass can be found in all of the lower 48 states except for Washington, Oregon, and California. Switchgrass exhibits rapid growth according to the USDA NRCS Plant Materials Program (2006). It can have a root system with roots extending up to 3 m deep in the soil profile. Along with the potential for growing deep in the soil, the roots are also very fibrous. Switchgrass can grow 1-3 m tall and will have a spreading top. Switchgrass has a long lifespan and grows best in soils with a 4.5-8 pH and when it is drill seeded (USDA NRCS Plant Materials Program 2006).

Alfalfa is an exotic groundcover that now has a range that encompasses all of the United States. It was introduced to North America for agricultural uses. Alfalfa is able to fix atmospheric nitrogen. It also contains the chemical Triacontanol, which has been found to promote the growth of roots in some broadleaf plants. Mature alfalfa plants release a chemical to prevent the establishment of new alfalfa seedlings. This phenomenon is known as autotoxicity (USDA NRCS Plant Materials Program 2006). Alfalfa is a perennial that exhibits a rapid growth rate and grows best in soils with a pH of 6.0-8.5. It can grow to be 1 m tall and has a spreading form with a single crown. Weaver (1926) stated that alfalfa root systems on some sites have been documented to grow more than 2 m.

Annual rye is an exotic plant which is native to Europe. It is also very widespread in North America. It is closely related to perennial ryegrass but is a cool-season or winter annual. It does not withstand excessive hot and dry weather or severe cold weather. Due to varieties being modified to make them exhibit winter hardiness, annual rye is being used for winter forage in Appalachia (Lacefield et al. 2003). Annual rye exhibits a rapid growth rate which provides for a quick cover. It grows in soils that have a pH range of 6-7 (Riewe et al. 1985). Annual rye has a fibrous root system. When mature, it can attain a height of 1 meter. It has a bunchy form with many long, thin leaves forming at the base (USDA NRCS Plant Materials Program 2002).

Alfalfa and switchgrass were planted on the field study sites in May of 2009. Alfalfa was planted at a rate of 6.8 kg pure live seeds (PLS) per acre (Bates 1998). The seeds came from a Wyoming seed source and were purchased from the Foothills Farmers Coop in Maryville, Tennessee. The germination rate for this variety was 85% with 65.80 % purity. As recommended by Teel et al. (2003), switchgrass was planted at a rate of 2.27 kg pure live seed per acre on the field study sites. The seeds were purchased from Stock Seed Farms and came from a Nebraska seed source. The germination rate for this variety was 74%, with 92.38 % purity.

Due to high initial erosion rates that were experienced, annual rye was overseeded on each of the sites within the alfalfa and switchgrass treatments to provide a quick establishing short lived groundcover to minimize soil erosion until the alfalfa and switchgrass established (USDA Plant Fact Sheet 2002). Annual rye was planted at a rate of 1.91 kg pure live seed per acre on all treatments but the bare. Lacefield et al. (2003) suggests applying 9.07 to 13.61 kg pure live seed per acre for agricultural use. However, approximately a quarter of the recommended seeding rate was used because a low percent cover of annual rye was desired. The seeds were purchased from Tennessee Farmers Coop and came from an Oregon seed source. The germination rate was predicted to be 90% and purity was 94.09 %.

3.4.3 Tree Species Studied

There are many native tree species that can be found in the Appalachian Mountain forests. Sites are often dominated by oaks, maples, hickories, and pines (Pijut 2005). The species of interest in this research project are northern red oak (*Quercus rubra*), American chestnut (*Castanea dentata*), black cherry (*Prunus serotina*), and shagbark hickory (*Carya ovata*). Each of these species exhibits different growing characteristics and is native to the Appalachian Mountains. Tree species were planted between March 16 and May 8 of 2009.

Northern red oak can be found in most of the eastern United States. It is in the *Fagaceae* family. Northern red oak is considered a mid-successional species (Tirmenstein 1991). It was reported that northern red oak does not colonize aggressively like most early successional species do, and it is not shade tolerant like late successional species (Sander 1990). Northern red oak seedlings often do not grow fast enough to compete with the other woody vegetation or groundcover (Beck 1970). This includes oak seedlings that were established naturally or planted just following a clearcut. In order for northern red oak seedlings to compete in new stands, the seedlings must be of sufficient size, and the root system must be well established (Sander 1990).

The range of shagbark hickory also encompasses most of the eastern United States. Shagbark hickory is within the *Juglandaceae* family. Shagbark hickory is considered intermediate in shade tolerance (Graney 1990, Nelson 1965), and is a climax species in the oak-hickory forest type. Hickories, in general, exhibit a slow shoot growth habit during early stages of development. This puts hickories at a disadvantage when competing with other tree species in a stand for light resources. However, shagbark hickory seedlings typically develop a large and deep taproot and will not have many lateral roots. The main taproot may penetrate to a depth of 0.6-0.9 m in the first 3 years, with a correspondingly slow growth of seedling shoots (Graney 1990). In a study conducted in the Ohio River valley, 1-year-old seedlings produced an average root length of 30 cm and a top height of 7 cm. By age 3, the taproot extended to about 0.8 m, while the top increased only to 19.8 cm (Graney 1990, Nelson 1965). This study suggested that primary growth of the roots is much greater than that of the stems.

At one time, American chestnut had a range that extended from Maine to Georgia (Figure 10). However, this was before the exotic disease known as the chestnut blight (*Cryphonectria parasitica*) came to North America and decimated the American chestnut population. There has been much research focused on creating a hybrid that is tolerant to this disease. American chestnut is monoecious. The fruit is a nut, and 2-3 nuts are enclosed by a spiny husk. American chestnut can be regenerated from both stump sprouts and seeds. In this project, this species was planted as a seedling. According to Saucier (1973), the growth of sprouts is relatively rapid. Sprouts can reach up to 4 m tall by age 5. It has been reported that before the blight kills them, American chestnut sprouts can reach 12.8 m in height and 17.27 cm in diameter (Saucier 1973). Similar to many oak species, American chestnut seedlings can persist in the absence of disturbance. However, growth is stimulated by increased light (Clark et al. 2006). Jacobs (2007) states that chestnut is a broad generalist and a strong competitor for resources.

Black cherry has a large range that spans the eastern United States as well as coastal Mexico and parts of Texas and Nevada (Figure 11). Black cherry is in the *Roseaceae* family. Black cherry is considered to be intolerant of shade. Black cherry seedlings are found in the understory of natural stands and can survive up to 5 years in these conditions. However, they cannot live for extended periods or move into more mature classes without a disturbance that causes an opening in the overstory canopy that allows full sunlight to reach the seedling. The root system of black cherry initially has a distinct taproot with many laterals. As time progresses, a shallow, spreading root system develops where there is no apparent taproot (Marquis 1990). Black cherry grows quickly in the seedling, sapling, and pole stages. It will generally outgrow and overtop many hardwood competitors such as sugar maple and American beech. In the first few years after planting, it has been recorded that juvenile height growth of black cherry can average 46 cm. Black cherry seedlings grow best in full sunlight (Marquis 1990). Black cherry flowers are perfect and are insect pollinated (Grisez 1974). The fruit is a small, one-seeded drupe. It has a bony stone or pit and is black in color when ripe. In the southeastern United States, where this research project occurred, the fruit of the black cherry will ripen in late June, and the seedfall is complete by early July.

Seedlings of all tree species were planted on the project area during the spring of 2009. The University of Tennessee Tree Improvement Program supplied 1-0 American chestnut seedlings. The UT Tree Improvement Program obtained the seeds from the American Chestnut Foundation, and the seedlings were grown in Georgia. 1-0 Black cherry was purchased from the Indiana Division of Forestry State Nursery. The seedlings were grown from seeds in the state nursery in Pulaski, Indiana. Each site received a total of 72 American chestnut and 72 black cherry seedlings, which amounted to a total of 216 American chestnut and 216 black cherry seedlings planted for this research.

1-0 northern red oak seedlings were purchased from the Tennessee Division of Forestry State Nursery and planted onto the project areas. The seedlings were grown from seeds in the state nursery located in Delano, Tennessee. 1-0 Shagbark hickory seedlings were grown and purchased from a private nursery in Michigan. The seeds originated from Pennsylvania. A total of 432 northern red oak and 432 shagbark hickory seedlings were planted for this project, with each site receiving 144 northern red oak and 144 shagbark hickory seedlings.

3.4.4 Fertilizer application

A 10-10-10 granular fertilizer was applied on all plots on June 16-17, 2009 at a rate of 0.91 kg per acre.

3.4.5 Measurements

3.4.5.1 Objective 1

Due to an unequal distribution of groundcover growth during the 2009 growing season and the desire to maximize the time period for interaction between the planted trees and groundcover species prior to measuring tree performance, seedlings of all 4 tree species were measured for growth and transpiration during the 2010 growing season. In the spring of 2010, seedlings were selected for measurement based on 2 criteria. The first was that the seedling was alive. The second was that the seedling was surrounded by the planted groundcover with less than 5 percent of the cover in the 1 m^2 area around the seedling comprised of volunteer species.

Total shoot height and root collar diameter growth were also measured at the end of the 2009 growing season on 12/15/09 and 12/16/09. These data were used as a baseline for calculating 2010 growth. Total height and root collar diameter of the selected seedlings on the field study sites were measured between 8/11/10 and 8/13/10. Root collar diameter of each seedling was measured with calipers to the nearest 0.1 mm and total height growth was measured to the nearest 1 cm with a meter stick. To obtain growth of each tree species during the 2010 growing season, total height and root collar diameter measured at the end of the 2009 growing season were subtracted from August 2010 measurements.

Foliar transpiration rates were measured during 3 intervals throughout the 2010 growing season. The first measurement period occurred between 5/3/10 and 5/5/10, the second occurred between 6/1/10 and 6/3/10, and the last measurement period was scheduled between 7/16/10 and 7/22/10. Foliar transpiration rates were measured between 9:00 a.m. and 12:00 noon Eastern Daylight Savings Time. Foliar transpiration was measured on only one given site per day during each sampling period. Multiple sites could not be feasibly measured in a single day due to the geographic locations of the sites. Foliar transpiration rates were measured using a Li-Cor LI-1600 Steady State Porometer (Li-Cor, Inc., Lincoln, NE) and the sensor head aperture was attached to the uppermost leaf that was fully expanded, undamaged, and mature.

3.4.5.2 Objective 2

One m^2 quadrats were centered on all planted tree seedlings selected for growth measurements in order to sample percent cover of groundcover species. Percent cover of planted groundcover species, percent cover of volunteer plants that had seeded in, and percent cover of all species that were located within the quadrat combined were recorded on the same day that foliar transpiration rates were measured.

3.4.5.3 Objective 3

For the third objective, percent soil moisture was measured twice a month from March to July 2010 using an AquaPro Soil Moisture Probe (AquaPro, Ducor, CA) at 3 locations per groundcover treatment on all sites (Figure 30). Measurements were taken 15.25 cm below the surface.

Photosynthetically active radiation (PAR) was measured in May and June during the 2010 growing season. PAR was simultaneously measured at 14 cm above the surface of the ground and nearby at an ambient station at approximately 80 cm above the ground that received full sunlight. PAR measured at 14 cm above the surface of the ground was measured at the same locations within sites and treatments at which soil moisture percent was measured. PAR was measured using a Li-Cor LI-190SA attached

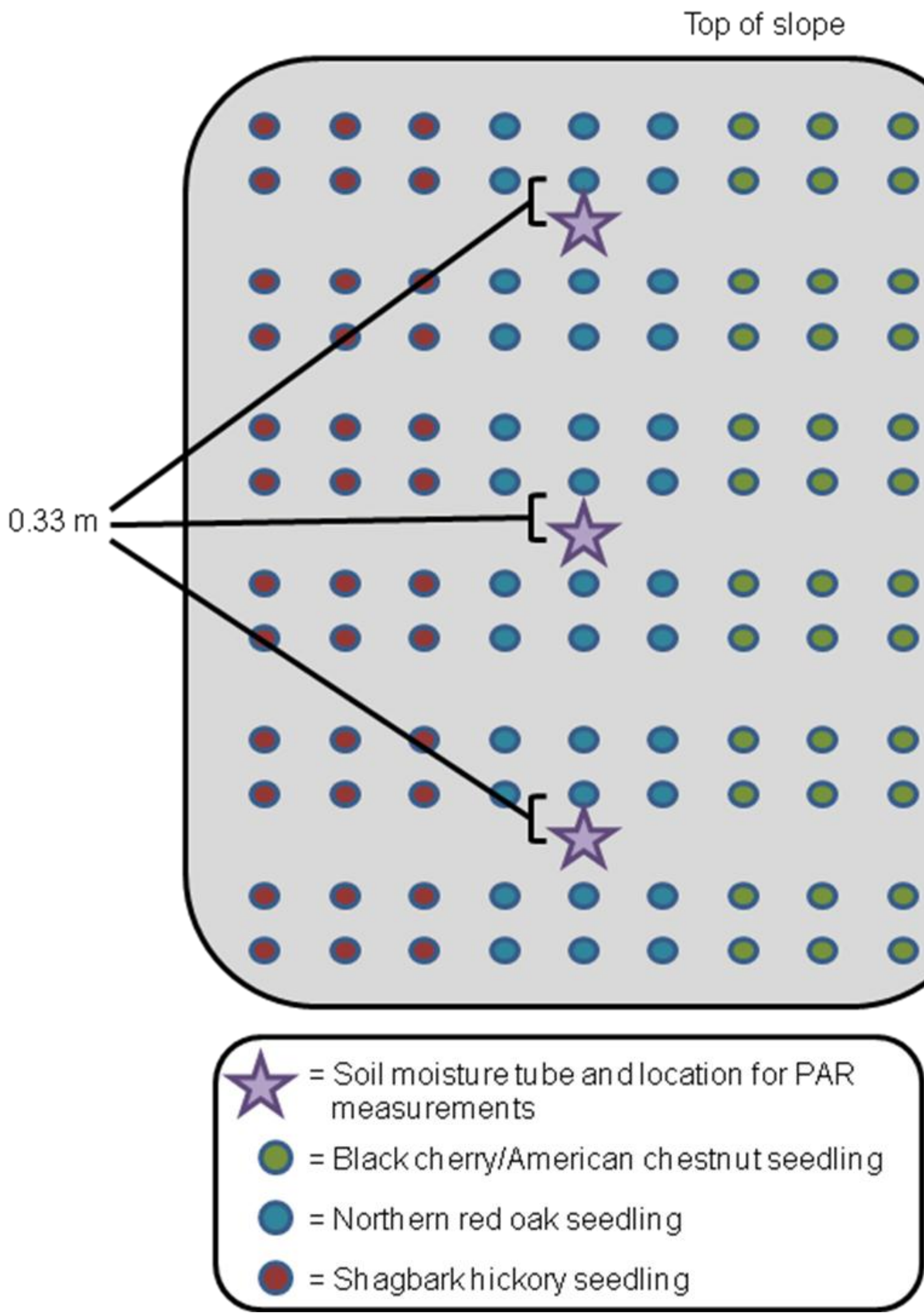

Figure 30: Placement of tubes for measuring percent soil moisture and locations for PAR measurements within each groundcover treatment

to the sensor head aperture on the Li-Cor LI-1600 Steady state Porometer. Ambient PAR was measured using a Li-Cor LI-190SA Quantum Sensor and a LI-1400 Data Logger. All measurements of PAR were collected within 30 minutes of solar noon. To obtain percent full PAR, synchronous PAR measurements from the ambient station were divided by PAR measurements obtained 14 cm above the surface of the ground.

3.4.6 Statistical Analysis

Data for this project were analyzed using SAS© Version 9.2 (SAS Institute, Cary NC). Mixed models analysis of variance and simple linear regression were used to analyze the data. There were 3 models used under the first objective. To analyze total height and root collar diameter growth, the model used was appropriate for a Randomized Block Design (RBD) with sampling and replication, the second was a simple linear regression for growth (total height and root collar diameter) and percent cover of all groundcover species combined, and to analyze foliar transpirations, the model used was appropriate for a RBD with sampling, replication, and repeated measures using time of day as a covariate. The model used under for analyzing percent cover of groundcover was appropriate for a RBD with replication, sampling, and repeated measures. The model used to analyze the effects of groundcover species on soil moisture and light was appropriate for a RBD with replication, sampling, and repeated measures. An alpha level of 0.05 was utilized in all analyses. Differences between treatments were determined by the post-hoc technique of Least Significant Difference (LSD).

3.5 Results

3.5.1 Objective 1

Over the 2010 growing season, no significant differences in height growth occurred between groundcover treatments in any of the 4 tree species planted (Table 4). Similarly, no differences in 2010 root collar diameter growth occurred between groundcover treatments in any of the tree species planted (Table 4).

Height growth of northern red oak, American chestnut, and shagbark hickory seedlings during the 2010 growing season did not have a significant relationship with total percent cover of all groundcover species. However, height growth in black cherry did have a significant linear relationship with total percent cover of all groundcover species. Root collar diameter growth of northern red oak, American chestnut, and black cherry seedlings had a significant linear relationship with percent cover of all groundcover species combined, whereas root collar diameter growth of shagbark hickory seedlings did not. All statistically significant regression relationships were weak and negative (Table 5).

Overall mean foliar transpiration rates of northern red oak, American chestnut, black cherry, and shagbark hickory seedlings did not differ significantly between groundcover treatments ($p= 0.4218$, 0.5568, 0.6413, and 0.8647 respectively). The interaction between groundcover and date in the analysis of northern red oak foliar transpiration rates was found to be significant, but not consistent ($p=0.0055$). No interactions between foliar transpiration rate and date were found during the analysis of foliar transpiration in shagbark hickory, black cherry, and American chestnut ($p=0.5393$, 0.5546, and 0.5445, respectively).

Table 4: 2010 seedling mean total height growth and root collar diameter growth within different groundcover treatments. Groundcover treatment, mean growth, standard error, and p-value are listed for tree species.

	Tree Species	Groundcover Treatment	Mean Growth	Standard Error	Letter Group	P-value
Total Height Growth (cm)	Northern Red Oak	Alfalfa	9.3	3.4994	a	0.4966
		Switchgrass	7.7	3.3005	a	
		Bare	13.0	3.2687	a	
	American Chestnut	Alfalfa	12.1	4.3711	a	0.3065
		Switchgrass	17.3	4.0697	a	
		Bare	20.52	4.0461	a	
	Black Cherry	Alfalfa	8.2	5.8782	a	0.2667
		Switchgrass	22.3	5.1862	a	
		Bare	18.6	5.7632	a	
	Shagbark Hickory	Alfalfa	2.6	0.8113	a	0.6168
		Switchgrass	2.4	0.6047	a	
		Bare	3.3	0.5031	a	
Root Collar Diameter Growth (mm)	Northern Red Oak	Alfalfa	2.2	0.8501	a	0.6612
		Switchgrass	2.3	0.8247	a	
		Bare	4.0	0.8208	a	
	American Chestnut	Alfalfa	2.4	1.2761	a	0.2924
		Switchgrass	3.0	1.2442	a	
		Bare	4.7	1.2342	a	
	Black Cherry	Alfalfa	2.8	1.1812	a	0.4494
		Switchgrass	4.2	1.0811	a	
		Bare	3.8	1.1612	a	
	Shagbark Hickory	Alfalfa	1.4	0.4325	a	0.7115
		Switchgrass	1.6	0.3687	a	
		Bare	1.3	0.3469	a	

Table 5: Regression equations for growth of seedlings and total percent cover of all groundcover species for each species of seedling planted. Regression equations, standard error for the slope, R^2, and the model p-value are listed for tree species. P-values in red indicate statistically significant regression relationships ($P<0.05$).

	Tree Species	Regression Equation	Standard Error for the Slope	R^2	Model P-value
Height Growth Vs. Groundcover Percent	Northern Red Oak	12.39045-0.16516x	0.09585	0.0367	0.0888
	American Chestnut	18.99417-0.18781x	0.11164	0.0516	0.0985
	Black Cherry	22.97886-0.48405x	0.20766	0.0930	0.0236
	Shagbark Hickory	3.17463-0.01668x	0.01668	0.0195	0.3136
Root Collar Diameter Growth Vs. Groundcover Percent	Northern Red Oak	3.384999-0.05008x	0.01813	0.0590	0.0300
	American Chestnut	4.25728-0.06347x	0.02229	0.1349	0.0063
	Black Cherry	4.94527-0.09824x	0.35666	0.1252	0.0080
	Shagbark Hickory	1.4081-0.00359x	0.00668	0.0055	0.5931

3.5.2 Objective 2

Although total percent cover did not differ between treatments during the 2009 growing season (p=0.1729), total percent cover of all species combined differed significantly (p=0.0115) between groundcover treatments when averaged over the 2010 season (Figure 31). The alfalfa treatment yielded the greatest percent cover of groundcover species. Total percent cover of all species combined in the switchgrass treatment was slightly higher, but statistically similar to percent cover of all species combined in the bare treatment.

Total percent cover of all groundcover species did not significantly change over the sampling periods in the 2010 growing season (p=0.7088). Percent cover of all species combined averaged approximately 13 percent in each set of measurements.

The interaction of total groundcover percent and time of measurement throughout the growing season was not significant (p=0.7274). Percent cover of all species in the alfalfa treatment averaged approximately 29 percent for each set of measurements. Total percent cover of all species in the switchgrass treatment averaged approximately 9 percent for each set of measurements. Total percent cover of all species found in the bare treatment increased slightly each month, but differences were not significant. Percent cover of all species in the bare treatment averaged approximately 1.75 percent in the first measurement period and 3.21 percent in the second and third periods.

3.5.3 Objective 3

Mean percent full PAR measured at 14 cm above the surface in May and June 2010 differed significantly between groundcover treatments (p>0.0001). Percent full

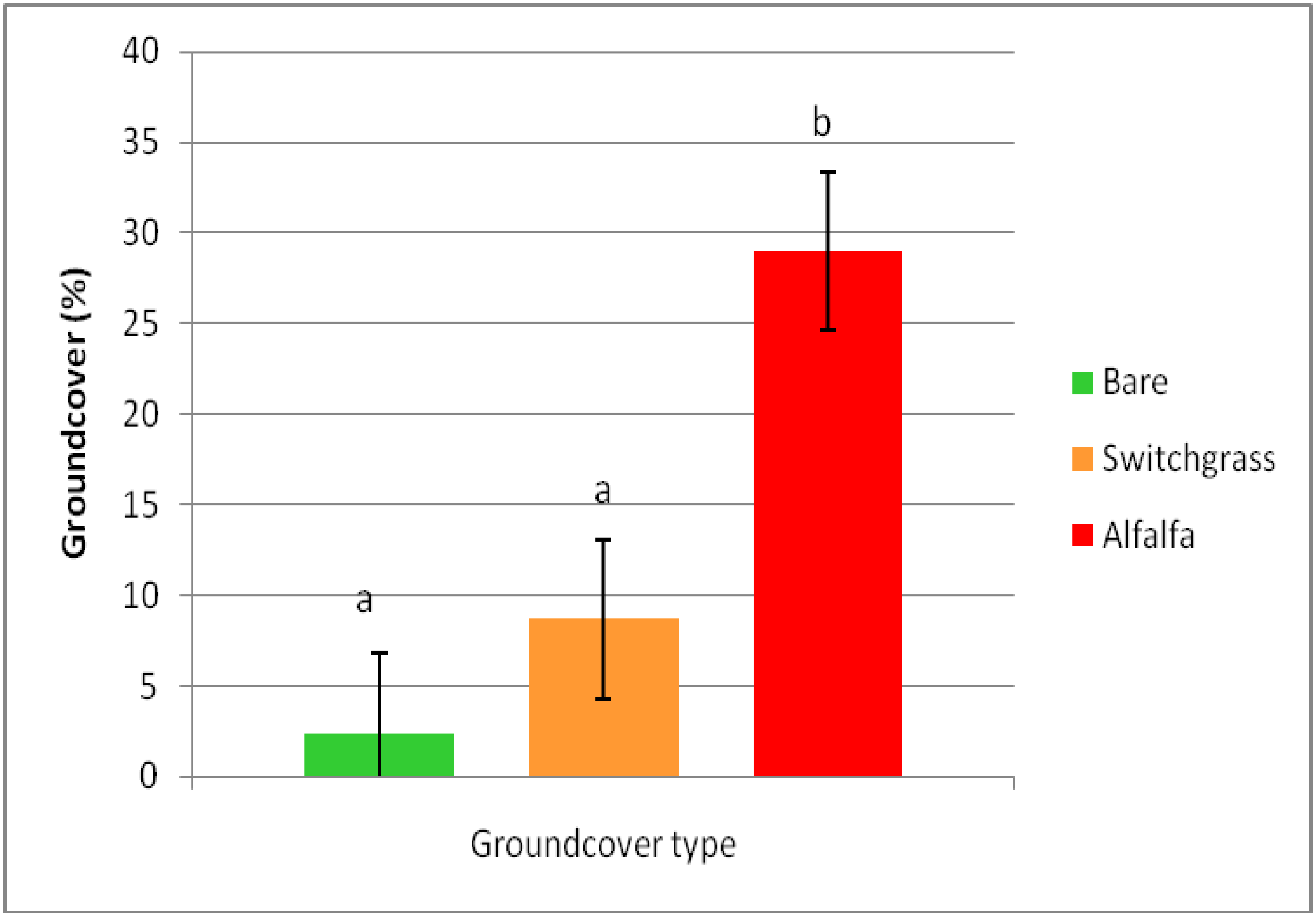

Figure 31: Total percentage of groundcover by treatment. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means (P<0.05). Percent groundcover was 2.4, 8.7, and 29.0% in the bare switchgrass, and alfalfa treatments, respectively.

PAR was lowest in the alfalfa treatment, greatest in the bare treatment, and intermediate in the switchgrass treatment (Figure 32). The date measured and the date by groundcover treatment interaction did not differ, suggesting the differences between days were negligible (p= 0.5351 and p=4182, respectively).

Percent soil moisture 15.25 cm below the surface differed significantly between groundcover treatments (p=0.0226). Mean percent soil moisture 15.25 cm below the surface was significantly lower in the alfalfa treatment than in the switchgrass and bare treatments (Figure 33). The date by groundcover treatment interaction was found not to be significant (p=0.8809).

3.6 Discussion

3.6.1 Objective 1

3.6.1.1 Growth of Seedlings in Groundcover Treatments

Total height and root collar diameter growth of all tree species did not differ significantly between groundcover treatments. The lack of statistically significant differences in height and root collar diameter growth across treatments may be due to the large variation found in the data. This variation may have come from differences in micro-sites across the study areas. Micro-site effects on tree performance have been well researched (Vetaas 1992; Nyberg and Hogberg 1995; Blood and Titus 2010). It has been found that micro-sites have a large influence on the performance of plants. When mine overburden is put back onto a site, soil is mixed, causing an unequal distribution of any nutrients, topsoil, and other soil components that may be left. This causes soil found on reclaimed mine sites to be extremely variable. This variability causes the creation of many different micro-sites causing micro-site to play an important role in how

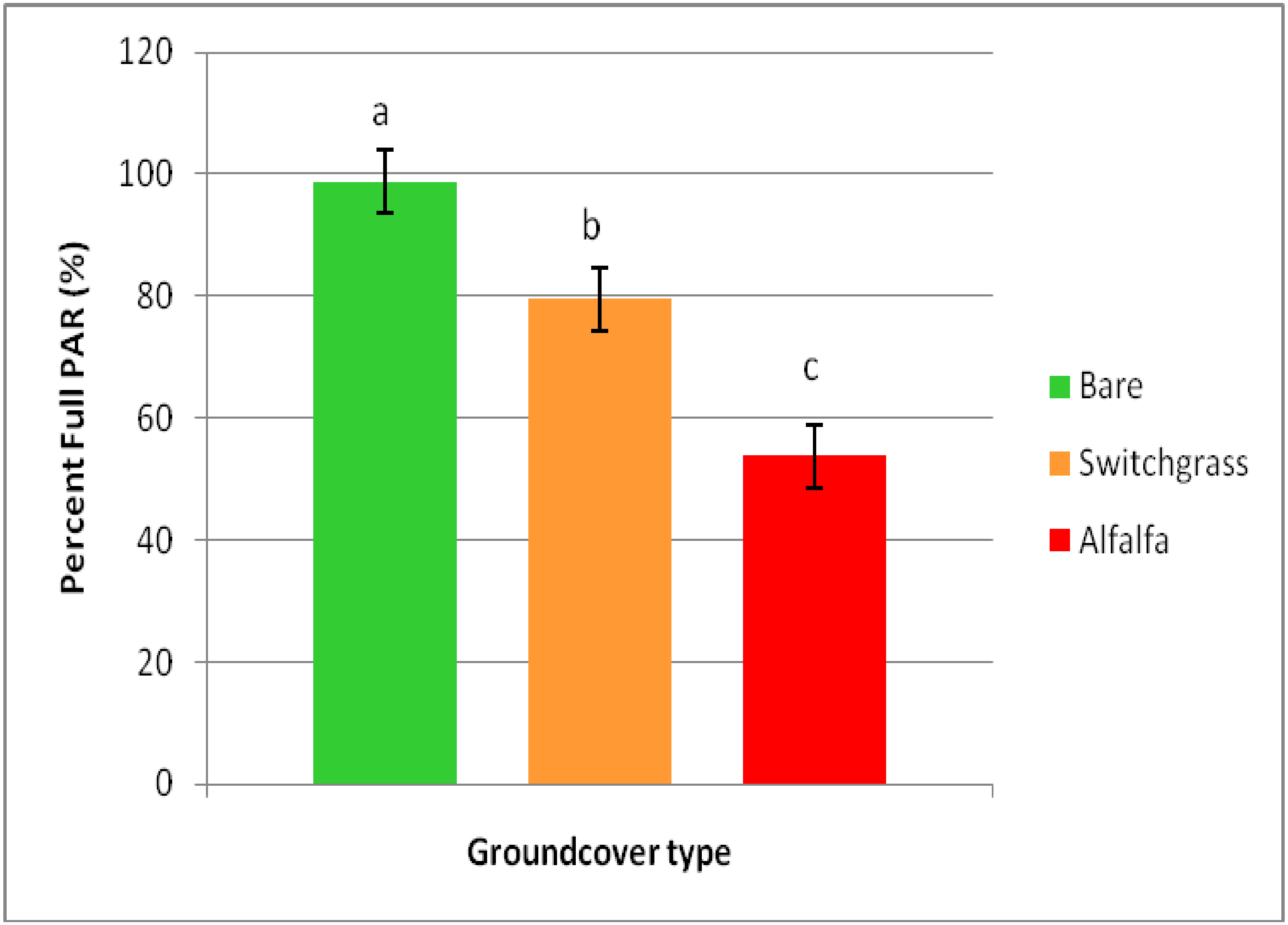

Figure 32: Percent full PAR by groundcover treatment in May and June 2010. Means ± standard errors are shown for treatment main effects. Means with the same letter are not significantly different (P<0.05). Percent full PAR was 98.79, 79.48, and 52.82% in the bare, switchgrass, and alfalfa treatments, respectively.

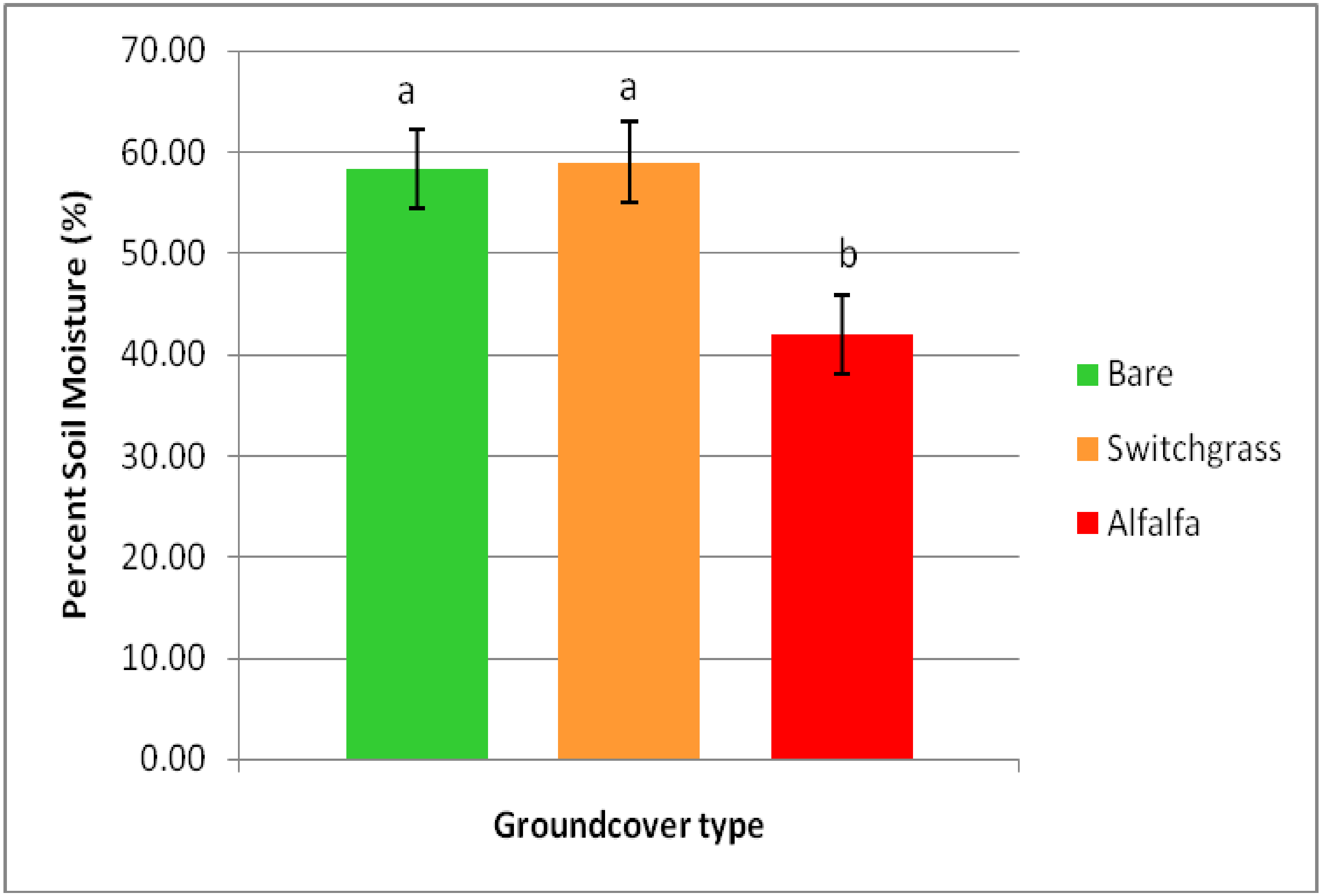

Figure 33: Percent soil moisture by groundcover treatments. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means. Percent soil moisture was 58.4, 59.0, and 42.0% in the bare, switchgrass, and alfalfa treatments, respectively.

a tree performs. The lack of differences in growth between tree seedlings and groundcover treatment may have also been due to a low total percent cover of all groundcover species within each treatment. Percent cover of the groundcover species may have been too low to result in levels of competition for resources that would affect the growth of the seedlings planted. Another possible explanation for the lack of differences in the growth of seedlings between groundcover treatments may be the low sample size of tree seedlings measured in each groundcover treatment. This low sample size may have contributed to high variability in the data due to outside factors such as low percent cover and micro-site influence. Another reason for lack of significant differences in diameter growth between treatments may be measurement error. Diameter changes in tree seedlings are subtle, and the slightest movement of the calipers up or down the stem of the seedling may cause a large difference in the accuracy of root collar diameter measurements.

3.6.1.2 Total Groundcover Percent and Growth of Seedlings

Percent cover of all species was found to have a significant negative relationship with total height growth of black cherry, but not with northern red oak, American chestnut, or shagbark hickory seedlings. The significant relationship between black cherry total height growth and percent cover of all species may have been due to rapid growth rate of the shoots of black cherry compared to the other 3 species of seedlings planted (Wilson 2000).

The lack of relationships between northern red oak and American chestnut total height growth and groundcover percent may be due to a low total percent cover of all groundcover species within each treatment, the variability of micro-sites on the mines, and the slower height growth compared to black cherry.

Significant negative relationships were found between total percent groundcover and root collar diameter growth of black cherry, American chestnut, and northern red oak. Many studies have compared differences in secondary growth between open grown trees and trees in competition. Trees often allocate more resources to secondary growth in open grown conditions with low competition (Makela and Sievanen 1992; O'Connell and Kelty 1994).

3.6.1.3 Foliar Transpiration Rates of Seedlings between Groundcover Treatments

Differences in overall foliar transpiration rates between different groundcover treatments were not significant in any of the tree species. Interactions between day and groundcover type of transpiration rate for all tree species except northern red oak were also not significant. The interactions between day and groundcover type of transpiration rates for northern red oak were significant, but were not consistent, suggesting outside sources causing variation.

There are many factors on a site that can affect transpiration rates of plants. As mentioned previously, micro-site can have a profound effect on tree performance. Other effects that may have caused a lack of significant results are the low percent total groundcover and the low sample size of tree seedlings within each groundcover treatment.

Another effect that may have influenced foliar transpiration rates is relative humidity. Relative humidity has been found to have a profound impact on transpiration (Kozlowski et al. 1991). On the mine sites, it was observed that relative humidity fluctuated as the day progressed. Relative humidity and transpiration have been found to have an inverse relationship. When relative humidity is greater, transpiration rates are less (Thut 1938). This relationship has been well documented (Wallace and Stout 1962; Allen et al. 1998; Tanner and Beever 2001). By having this relationship, rapid fluctuations in relative humidity throughout the day could lead to insignificant differences in foliar transpiration rates between treatments.

3.6.2 Objective 2

In the 2010 growing season, the alfalfa treatment was found to have greater percent cover than the bare and the switchgrass treatments. It is expected that a seeded plot would have a greater total percent cover of vegetation than a bare plot. The switchgrass treatment produced significantly less percent cover of all species than the alfalfa treatment, and a percent cover of vegetation similar to that for the bare treatment (Figure 34). This may be partially due to the proportionally greater development of switchgrass later in the growing season (Sanderson and Reed 2000) compared to the more rapid and early development of alfalfa (Volesky and Anderson 2010).

Throughout the sampling period, the total percent cover of all species in the switchgrass treatment was always found to be less than the alfalfa treatment. The small percentage of total groundcover the switchgrass treatment produced may also have been due to adverse conditions for switchgrass establishment on the field sites. Previous research suggests switchgrass does best planted 1 cm deep in the soil and when not in competition with other groundcovers. The seeds are more easily blown by the wind due to their low relative mass (Douglas et al. 2009) compared to alfalfa (Gjuric and Smith 1997). The problem of the seeds of switchgrass being blown away may have


Figure 34: Picture of King Mountain in May 2010. The groundcover treatment to the far left is switchgrass, the groundcover treatment in the center is bare, and the groundcover treatment to the right is alfalfa.

been exacerbated due to consistent, windy conditions on the field sites.

Despite the low percent cover of groundcover species found on the sites and the lack of differences in cover between dates, the tendency for switchgrass to develop later in the growing season (Smart and Moser 1997; Lee and Boe 2005) may be important. Once established, switchgrass may make a more compatible groundcover species during mine reclamation because it essentially develops late in the growing season when the growth of many tree species is nearly complete.

3.6.3 Objective 3

3.6.3.1 Percent Full PAR

The bare treatment was found to have the greatest percent full PAR at 14 cm above the surface. It is expected that a bare plot would have greater percent full PAR than one that was seeded with a groundcover treatment. The switchgrass treatment had greater percent full PAR at 14 cm above the surface than the alfalfa treatment. Greater percent full PAR at 14 cm above the surface in the switchgrass treatment may have been due to the smaller percentage of total groundcover the switchgrass treatment produced in comparison to the alfalfa treatment. The lesser cover in the switchgrass treatment may have intercepted less light than the greater amounts of cover in the alfalfa treatment. Greater cover in the alfalfa treatment was due to the greater development of alfalfa, and also greater percent cover of other volunteer species in the alfalfa treatment compared to the switchgrass and bare treatments.

3.6.3.2 Percent Soil Moisture

Percent soil moisture at 15.25 cm below the surface was lower in the alfalfa treatment than in the switchgrass and bare treatments. The bare and switchgrass treatment were statistically similar. The difference in soil moisture may be due to the greater percent total cover of all species in the alfalfa treatment than in the switchgrass and bare treatments. Past research has found that an increase in competition between plants can lead to a decrease in soil moisture (Zutter et al. 1986; Davis et al. 1999). An increase in plant cover has also been found to decrease soil moisture (Hoorman 2009).

3.7 Conclusion

Although there were some weak relationships between total percent cover of all groundcover species combined and the height growth and root collar diameter growth of some planted tree species, the results suggest a lack of differences in tree seedling height growth, root collar diameter growth, and transpiration between groundcover treatments. This may have been due to variation in micro-sites and the low total percent cover of all groundcover species within each treatment, which may have been too low to affect the growth of the seedlings planted.

It was found that the percent cover between the treatments was significantly different: the alfalfa treatment having significantly more total groundcover than the switchgrass and the bare treatments, indicating that alfalfa was easier to establish and more successful. However, no groundcover treatment provided an average percent cover that was close to 100%. The greatest percent cover was associated with the alfalfa treatment. At 29%, it was still a low value. At these mean groundcover percentages and amount of variability found, it may not matter what groundcover is planted on the mine sites because competitive effects of the groundcovers may not be strong enough to affect the performance of the tree seedlings.

In general, alfalfa is a nitrogen fixing legume which may have beneficial effects on soil nutrients (USDA NRCS Plant Materials Program 2006). However, alfalfa also has a high demand for water and nutrients, which may limit the availability of resources for tree seedling growth and establishment during mine sites reforestation (McKenzie 1995).

Switchgrass has been documented to have proportionally greater development later in the growing season (Smart and Moser 1997; Sanderson and Reed 2000; Lee and Boe 2005). To further support the use of switchgrass on reclaimed mine sites, it has also been well documented that without prescribed fires in prairies seeded with switchgrass, hardwood encroachment occurs as time passes. In time, succession will cause these prairies to convert forest land. This suggests switchgrass produces an environment that is suitable for tree seedling establishment (Lewis and Harshbarger 1976; Schacht and Stubbendieck 1985; Hartnett et al. 1996). However, switchgrass has also been found to be difficult to establish in non-agricultural settings (Sanderson and Reed 2000). Results from the study showed low total percent cover of all species in the switchgrass treatment and that there was no significant increase of switchgrass throughout the growing season. The difficulty of establishment of switchgrass may decrease its utility when reclaiming mine sites because reasonably dense groundcover is needed for soil erosion control.

Percent full PAR at 14 cm above the surface and percent soil moisture were found to be significantly different between groundcover treatments. As expected, the bare treatment yielded the greatest percent full PAR at 14 cm above the surface followed by the switchgrass treatment. Percent soil moisture in the switchgrass and bare treatments was found to be statistically greater than that in the alfalfa treatment. Both percent soil moisture and percent full PAR at 14 cm above the surface were lowest in the alfalfa treatment. These results may be due to the alfalfa treatment having a greater percent cover and greater establishment than the switchgrass treatment, rather than alfalfa being a strong competitor.

Greater seedling sample sizes within each treatment would be useful in future work. This should reduce the effect of variation in the data due to factors such as micro-site influence, relative humidity fluctuations, and non-uniform growth of groundcover species.

References

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith (1998) Crop evapotranspiration-Guidelines for computing crop water requirement. *FAO Irrigation and drainage* Paper 56.

American Coal Foundation (2002) Coal: Ancient Gift Serving Modern Man. American Blacksmith Association.

Beck, D. E. (1970) Effect of competition on survival and height growth of red oak seedlings. United States Department of Agriculture Forest Service, Research Paper SE-56. Southeastern Forest Experiment Station.

Blood, L.E. and J.H. Titus (2010) Micro-site effects on forest regeneration in a bottomland swamp in western New York. *Journal of Torrey Botanical Society* 137(1): 88-102.

Burger, J.A., and C.E. Zipper (2002) How to Restore Forests on Surface Mined Lands. Virginia Cooperative Extension.

Burger, J., C.E. Zipper, and J. Skousen (2009) Establishing Ground Cover for Forested Post-Mining Land Uses. Publication Number 460-124.

Burger, J., P. Angel, V. Davis, D. Graves, and C. Zipper (2005) The Appalachian Reforestation Initiative. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 1.

Burger, J., P. Angel, V. Davis, D. Graves, C. Zipper (2005) The Forestry Reclamation Approach. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 2.

Burger, J., V. Davis, J. Franklin, C.E. Zipper, J. Skousen, C. Barton, and P. Angel, (2009) Tree-Compatible Ground Covers For Reforestation and Erosion Control. The Appalachian Reforestation Initiative. U.S. Office of Surface Mining. Forest Reclamation Advisory No. 6.

Cater, Timothy C. and Chapin, F.S. (2000) Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. *Ecology* 81(4):1086-1099.

Davis, M.A., K.J. Wrage, P.B. Reich, M.G. Tjoelker , T. Schaeffer, and C. Muermann (1999) Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology* 145: 341–350.

Doulgas, J., J. Lemunyon, W. Richard, and P. Salon (2009) Planting and managing Switchgrass as a Biomass Energy Crop. USDA NRCS. *Technical Note No. 3.* 15 pp.

Fickle, J. (1998) "Mining." The Tennessee Encyclopedia of History and Culture.

Gjuric, R. and S.R. Smith Jr. (1997) Inheritance in seed size of alfalfa: Quantitative analysis and response t selection. *Plant Breeding* 116:337-340.

Grisez, T.J. (1974) *Prunus* L. Cherry, peach, and plum. Seeds of woody plants in the United States: 658-673. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

Graney, D.L. (1990) Carya ovata (Shagbark hickory). Silvics of North America. United States Department of Agriculture Forest Service, Washington D.C.

Guehl, J.M., C. Fort, and A. Fehri (1995) Differential response of leaf conductance, carbon isotope discrimination and water-use efficiency to nitrogen deficiency in maritime pine and pedunculate oak plants. *New Phytologist* 131:149-157.

Harmer, R. and M. Robertson (2003) Seedling root growth of six broadleaf species grown in competition with grass under irrigated nursery conditions. *Ann. For. Sci.* 60:601-608.

Hartnett, D.C., K.R. Hickman, and L.E. Fischer-Waller (1996) Effects of Bison Grazing, Fire, Topography on Floristic Diversity in Tallgrass Prairie. *Journal of Range Management* 49(5): 413-420.

Hoorman, J.J. (2009) Using Cover Crops to Improve Soil Waters Quality. The Ohio State University Extension Publication.

Hungr, O, S.G. Evans, M. Bovis, and J.N. Hutchinson (2001) Review of the classification of landslides of the flow type. *Environmental and Engineering Geoscience* 7: 221-238.

Jacobs, D.F. (2007) Toward development of silvical strategies for forest restoration of American chestnut (Castanea dentata) using blight-resistant hybrids. *Biological Conservation* 137(4): 497-506.

Karl, M.G. and P.S. Doescher (1993) Regulating competition on conifer plantations with preregulating competition on conifer plantations with prescribed cow grazing. *Forest Science* 39: 405-418

Kozlowski, T.T., P.J. Kramer, P.J., and S.G. Pallardy (1991) The Physiological Ecology of Woody Plants. Academic Press, Inc. San Deigo, CA.

Lacefield, G., M. Collins, J. Henning, T. Phillips, M. Rasnake, R. Spitaleri, D. Grigson, , and K. Turner (2003) Annual Ryegrass. Cooperative Extension Service, University of Kentucky. College of Agriculture.

Landsburg, J. J. and S.T. Gower (1997) Applications of Physiological Ecology to Forest Management. Academic Press. San Diego.

Lee, D.K. and A. Boe (2005) Biomass Production of Switchgrass in Central South Dakota. *Crop Science* 45: 2583-2590.

Lewis, C.E. and T.J. Harshbarger (1976) Shrub and Herbaceous Vegetation 20 Years of Prescribed Burning in South Carolina Coastal Plain. *Journal of Range Management* 29(1): 13-18.

Little Jr., E.L. (1977) Atlas of United States Trees: Minor Eastern Hardwoods, Vol. 4. USDA Misc. Pub. No.1342.

Makela, A. and R. Sievanen (1992) Height growth strategies in open-grown trees. *Journal of Theoretical Biology* 159(4) 443-467.

Marquis, D. A. (1990) Black Cherry (Prunus serotina). Silvis of North America. United States Department of Agriculture Forest Serivice, Washington D.C.

McCormick, L.H. and T.W. Bowersox (1997) Grass or fern competition reduce growth and survival of planted tree seedlings. United States Department of Agriculture Forest Service, Washington D.C.

McKenzie, R.H. (2005) Soil and Nutrient Management of Alfalfa: Agri-facts. Agdex 121/531-5. Alberta Agriculture, Food, and Rural Development.

Nelson, T.C. (1965) Silvical characteristics of shagbark hickory (Carya ovata (Mill.) K Koch). Silvics of forest trees of the United States: 128-131. U.S. Department of Agriculture, Agriculture Handbook 271. Washington, DC.

Nyberg, G. and P. Hogberg (1995) Effects of young agroforestry trees on soils in on-farm situations in western Kenya. *Agroforestry systems* 32: 45-52.

O'Connell, B.M. and M.J. Kelty (1994) Crown architecture of understory and open grown white pine (*Pinus strobus* L.) saplings. *Tree Physiology* 14:89-102.

Office of Surface Mining Reclamation and Enforcement. (2008) Annual Evaluation Summary Report for the Regulatory Program Administered by the Knoxville Field Office of Tennessee for Evaluation Year 2008 (October 1, 2007, to September 30, 2008).

Pijut, P. M. (2005) Native Hardwood Trees of the Central Hardwood Region. Research Paper FNR-218. United States Department of Agriculture Forest Service, North Central Research Station.

Riewe, M. E., R.F. Barnes, and D.S. Metcalfe (1985). Forages: The Science of Grassland Agriculture. Iowa State University Press, Ames, Iowa.

Samra, J.S., M.K. Vishwanatham, and A.R. Sharma (1999) Biomass production of trees and grasses in a silvopasture system on marginal lands of Doon Valley of north-west India. *Agroforestry Systems* 46: 197–212.

Samson, R., S. Mani, R. Boddey, S. Sokhansanj, D. Quesada, S. Urquiaga, V. Reis, and C. Ho Lem (2005) The Potential of C4 Perennial Grasses for Developing a Global Bioheat Industry. *Critical Reviews in Plant Sciences* 24: 461-495.

Sander, I.L. (1990) Quercus rubra (Northern red oak). Silvics of North America. U.S. Department of Agriculture Forest Service, Washington D.C.

Sanderson, M.A. and R.H. Reed (2000) Switchgrass Growth and Development: Water, Nitrogen, and Plant Density Effects. *Journal of Range Management* 53(2): 221-227.

Saucier, J.R. (1973) American Chestnut... An American Wood(*Castanea dentata* (Marsh.) Borkh.). United States Department of Agriculture Forest Service. FS-230.

Schatcht, W. and J. Stubbendieck (1985) Prescribed Burning in Loess Hills Mixed Prairie of Southern Nebraska. *Journal of Range Management* 38(1): 47-51.

Seidel, K. (1972) Drought resistance and internal water balance of oak seedlings. *Forest Science* 18:34-40.

Smart, A.J. and L.E. Moser (1997) Morphological development of switchgrass as affected by planting date. *Agronomy Journal* 89:958-966.

Tanner, W. and H. Beever (2001) Transpiration, a prerequisite for long-distance transport of minteals in plants. Proceedings from the *National Science Academy of the United States of America* 98(16): 9443-9447.

Thut, H.F. (1938) Relative Humidity Variations Affecting Transpiration. *American Journal of Botany* 25(8): 589-595.

Tirmenstein, D.A (1991) Quercus rubra. In: Fire Effects Information System. U.S. Department of Agriculture, Rocky Mountain Research Station, Fire Sciences Labortory.

USDA NRCS Plant Materials Program. (2006) USDA Plant Data Sheet: Alfalfa (*Medicago sativa).*

USDA NRCS Plant Materials Program (2002) USDA Plant Data Sheet: Italian ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot).

USDA NRCS Plant Materials Program (2006) USDA Plant Data Sheet: Switchgrass (*Panicum virgatum).*

Vetaas, O.E. (1992) Mirco-site effects of trees and shrubs in dry savannas. *Journal of Vegetation Science* 3(3) 337-344.

Volesky, J.D., and B.E. Anderson (2010) Grazing Alfalfa. University of Nebraska-Lincoln. *Technical Guide G2030*.

Vories, K.C. Unknown Date Published. The Surface Mining Control and Reclamation Act: A Response to Concerns about Placement of Coal Combustion By-Products at Coal Mines. United States Department of Interior: Office of Surface Mining.

Wallace, A.M. and N.B. Stout (1962) Transpiration rates under controlled environment: species, humidity, and available water as variables. *The Ohio Journal of Science* 62(1):18-26.

Weaver, J.E. (1926) Root Development of Field Crops, 1st ed. McGraw-Hill Inc., NY.

Wilson, B.F. (2000) Apical control of branch growth and angel in woody plants. *American Journal of Botany 87*: 601-607.

Zutter, B.R., G.R. Glover, and D.H. Gjerstad (1986) Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. *Forest Science,* 32: 882-899.

Thesis Conclusion

The two main objectives of this work were: 1) to establish the effects of groundcover treatments on tree seedling performance and 2) to study the effects of groundcover treatments on resource availability, specifically sunlight and soil moisture.

Both the greenhouse and the field studies showed significant and non-significant results in relation to performance. Root collar diameter and total height growth of seedlings between groundcover treatments did not differ in the greenhouse or the field. This may be due to the potential variability of micro-sites, low sample size of seedlings within each groundcover treatment, and low total percent cover. The greenhouse study yielded differences in root-to-shoot ratios of freshly harvested and dried seedlings between treatments. Northern red oak seedlings in the annual rye treatment had the lowest root-to-shoot ratio followed by seedlings in the alfalfa treatment. This may be explained by the high levels of water and nutrients required by annual rye. It was found that seedlings in the switchgrass treatment yielded similar root-to-shoot ratios as seedlings planted in the bare treatment. Northern red oak seedlings were also found to have a lower SLA in the annual rye treatment compared to seedlings planted in the bare, alfalfa, and switchgrass treatment. Results for root-to-shoot ratios and SLA of the seedlings suggest that annual rye is more competitive than the other 3 groundcovers.

Results for the field study suggest root collar diameter growth of all the species of seedlings except shagbark hickory and total height growth of black cherry had an inverse relationship with total percent groundcover. However, differences in height and root collar diameter growth between groundcover treatments were not found. This may be due to low number of observations within each groundcover. Results from this study suggest that as competition increases, growth will decrease. Many studies have demonstrated similar relationships (Davis et al.1999; Cater and Chapin 2000; Harmer and Robertson 2003).

Results indicate that foliar transpiration rates of seedlings planted within different groundcover treatments in the greenhouse and field were different. The greenhouse study suggested that foliar transpiration rates of the seedlings planted in the greenhouse differed between groundcover treatments. Seedlings planted in the bare treatment always had the greatest foliar transpiration rates, and seedlings planted in the annual rye treatment always had the lowest foliar transpiration rates. Greater foliar transpiration rates in the switchgrass treatment earlier in the growing season suggests that the northern red oak seedlings are performing more similarly to the bare treatment than the alfalfa and annual rye treatments. However, results in the field indicated that differences in foliar transpiration rates were not significant among groundcovers in any tree species.

There are many reasons the seedlings in the greenhouse yielded consistently different foliar transpiration rates, whereas transpiration rates in seedlings in the field did not differ. Seedlings in the greenhouse were planted within 100 percent total groundcover percent unlike seedlings planted in the field, which could have resulted in more intense competition in the greenhouse study. Groundcover percentages in the field were highly variable. Different results may have been observed if there were greater and more uniform percent cover in the field. Seedlings in the greenhouse were planted and grown in uniform growing conditions. Each seedling was planted in similar soils, received similar applications of nutrients, and received similar amounts of water. Seedlings in the field were planted on sites that are highly variable and may have been affected by many factors. Some of these factors may have been soil type and other micro-site factors such as relative humidity.

Percent full photosynthetically active radiation (PAR) at 14 cm above the surface and soil moisture percent both differed significantly between treatments. PAR for the bare treatments was significantly greater than in the other treatments in both the greenhouse and field study. Percent full PAR in the switchgrass treatment was lower than the other two groundcover species in the greenhouse study, but percent full PAR was lowest in the alfalfa treatment in the field, which suggests conflicting results. This was likely due to low establishment rates of switchgrass in the field due to external factors such as wind and rain. A low percent full PAR at 14 cm may not have an effect on larger tree seedlings planted. However, if trees are being grown from seeds, a low percent full PAR at 14 cm may have a very negative effect on growth and survival of small seedlings.

Soil moisture was greatest in the switchgrass and bare treatments in the field and in the greenhouse. In the greenhouse, the annual rye treatment had the lowest percent soil moisture. However, percent soil moisture in the alfalfa treatment was the next lowest. Percent soil moisture in the alfalfa treatment in the field was found to be the lowest. These results suggest that the alfalfa treatment utilizes more water than the bare and switchgrass treatments. However, greater percent cover in the alfalfa treatment in the field may have also contributed to these results.

According to both studies, switchgrass was the groundcover species that appeared to be most compatible with tree seedlings. Performance of seedlings planted in the switchgrass treatment was not significantly different than seedlings planted in the bare treatments. In both the field and the greenhouse, percent soil moisture was lower in the alfalfa treatment than in the switchgrass and bare treatments which indicated less available water, and in the field, percent full PAR was lower in the alfalfa treatment than the switchgrass and bare treatments which indicated less light available for smaller seedling to utilize. The impact of alfalfa on resource availability makes it less compatible with tree seedlings when compared to the switchgrass treatment. The groundcover found to have the most profound impact on the performance of tree seedling and the impact on resource availability was annual rye. In the greenhouse, percent soil moisture, the SLA, and the root-to-shoot ratios were the lowest of all the treatments. These findings indicate that annual rye is the least compatible of the groundcovers utilized in this experiment.

References

Cater, Timothy C. and Chapin, F.S. (2000) Differential effects of competition or microenvironment on boreal tree seedling establishment after fire. *Ecology* 81(4):1086-1099.

Davis, M.A., K.J. Wrage, P.B. Reich, M.G. Tjoelker, T. Schaeffer, and C. Muermann (1999) Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient. *Plant Ecology* 145: 341–350.

Harmer, R. and M. Robertson (2003) Seedling root growth of six broadleaf species grown in competition with grass under irrigated nursery conditions. *Ann. For. Sci.* 60:601-608.

VITA

Adam Klobucar is a native of Baton Rouge, Louisiana. In fall of 2008, he graduated Cum Laude with a Bachelor of Science in Forestry with a concentration in Forest Resource Management from Louisiana State University and Agricultural and Mechanical College. While at LSU, Adam was an active member of the Society of American Foresters and The Wildlife Society. He was also President of LSU's chapter of Xi Sigma Pi. Adam worked in the Forestry Division at the Louisiana Department of Wildlife and Fisheries as a student intern while attending LSU.

In January 2009, he accepted a graduate research assistantship at the University of Tennessee-Knoxville under the direction of Dr. David S. Buckley. While at the University of Tennessee he performed research on reforestation and reclamation of the steep slopes of strip mines. In the fall of 2010, he received his Master of Science in Forestry with a concentration in Forest Biology.