Reforestation of Steep Reclaimed Slopes in Appalachia: Forest Establishment and Function

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Final Report

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Jennifer Franklin, David Buckley

Adam Klobucar and Elizabeth Aubuchon

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University of Tennessee, Department of Forestry, Wildlife and Fisheries,

274 Ellington Plant Science, Knoxville, TN 37996-4563

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Abstract

On the steep slopes of the Appalachian region, herbaceous ground covers are seeded soon after material placement on reclaimed coal mines. Herbaceous ground covers can help to reduce sediment movement but may also compete with planted tree seedlings, leading to mortality of planted seedlings. The goal of this technology transfer project was to improve our understanding of tree-compatible ground covers through scientific research, and to promote the use of tree-compatible ground covers for reforestation. Using field and greenhouse experiments we tested the compatibility of four ground cover species with hardwood tree seedlings. Alfalfa established well on field sites, had little negative effect on the growth of hardwoods to a minimal extent, and promoted the establishment of volunteer ground cover species. Switchgrass has a delayed establishment which gives the tree seedlings time to establish, and does not compete to any great extent with seedlings for water resources. However we found annual ryegrass to be highly competitive for water, and inhibited the growth of tree roots. The upper layers of soil can be dry enough to limit tree establishment, particularly on the upper portion of the slope. Black cherry and American chestnut were more negatively affected by ground cover than were northern red oak or shagbark hickory. Two workshops were given to promote the use of tree-compatible cover.

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Introduction

1.1 The Forestry Reclamation Approach

The overarching goal of the Appalachian Regional Reforestation Initiative (ARRI) is to re-establish productive forest ecosystems and all their amenities on mined lands, which will: 1) will promote the highest and best use of these lands, and 2) restore the pre-mining condition in many geographic locations. The working team of ARRI is comprised of Office of Surface Mining (OSM) personnel, representatives of state regulatory agencies, and scientists affiliated with universities and non-profit organizations (Angel et al. 2005). A predominant function of ARRI is to promote the Forestry Reclamation Approach (FRA), which involves five steps: 1) creation of a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material; 2) loosely grading the topsoil or topsoil substitute to create a non-compacted medium for root growth; 3) using ground covers that are compatible with growing trees; 4) planting both early successional trees for wildlife and soil stability and commercially valuable crop trees; and 5) using proper tree planting techniques.

1.2 Challenges in Implementing the FRA on Steep Slopes

The viability of FRA has been verified in several research studies and on a number of demonstration sites (Burger et al. 2011). In a few cases, however, there have been observations that have raised concern on the part of OSM officials, coal operators, and scientists alike. These observations include heavy rill formation and shallow slumping of the loosely graded growth medium on steep slopes. These occurrences have generated several questions including: 1) are these temporary occurrences that will self-resolve over time?; 2) will deeper, more widespread slope failure follow the minor slumping that is currently occurring?; 3) are these occurrences related to material types?; and 4) what reforestation and engineering options exist for addressing these challenges?

In addition to the actual risks that may be related to these occurrences, there is also the risk of the perception, on the part of coal operators and mine inspectors, that reforestation through the FRA is inappropriate on steep slopes. In fact, the greatest challenges in promoting reforestation and transferring technology such as the FRA have been cultural perceptions and traditions concerning reclamation techniques. Continued cases of heavy rill formation, sediment movement, and slumping are likely to push acceptance and implementation of the FRA on steep slopes several steps backward. As a result, additional research is needed to better understand the factors underlying these occurrences, and to develop reclamation and reforestation methods for addressing them.

1.3 Effects of Time

Processes such as vegetation and soil development occur over many years, and thus their impacts on hydrology, surface erosion, and mass slope failure can be expected to change over time. The likelihood of both surface erosion and mass slope failure is arguably highest immediately following placement of overburden materials, and the probability of each occurrence is likely to diminish at different rates over time. Surface erosion can be checked in as little as a few weeks with the sowing and fertilization of aggressive, herbaceous groundcovers, whereas substantial reductions in the likelihood of mass slope failures resulting from the root development of planted trees may require several years.

Dispersal of native and exotic plants into reclaimed areas from surrounding populations can bolster the effects of planted vegetation, and this process is likely to occur over time, whether any vegetation is planted, or not. Reconstruction of slopes with relatively sterile overburden materials will initiate primary succession, which also occurs in nature following sand dune formation, volcanic activity, and the retreat of glacial ice (Krebs 1985; Kimmins 1997). Pioneer species with special adaptations to harsh conditions such as unstable substrates, temperature and moisture extremes, and low amounts of nutrients and soil organic matter are often the first to arrive and successfully colonize new substrates. During their growth and development, these species moderate environmental extremes, and begin to increase soil fertility, which, in turn, facilitates colonization by other species. How rapidly these favorable changes occur depends on the particular pioneer species, the type of substrate, and the overall rigor of the environment. Similarly, the amount of time required for pioneering vegetation to significantly change the likelihood of surface erosion and mass slope failure also depends on these factors.

1.4 Solutions

Two viable approaches to reducing the risks of surface erosion and mass slope failure on steep slopes are application of engineering solutions during reclamation, and bioengineering after reclamation through careful selection of the best herbaceous and tree species for resisting surface erosion and mass slope failures. Immediate reduction in the risk of mass slope failures can be achieved through the inclusion of internal features that resist slippage during slope construction, management of surface and subsurface water flow, and strategic placement of materials with different characteristics. Surface erosion can also be controlled immediately through the application of natural and artificial mulches and fibrous mats.

Although immediate engineering solutions such as those described above exist, cost-effectiveness and logistics must also be considered in weighing their feasibility. Herbaceous groundcovers and tree seedlings can be planted at a relatively low cost per acre, and begin to control surface erosion within a reasonable period of time. Clearly, longer time periods will be required to realize reductions in the risk of mass slope failures through effects of herbaceous plants and trees on hydrology and soil strength. Due to the catastrophic consequences of significant mass slope failures and the amount of time required for vegetation to adequately reduce the risk of such failures, additional costs of certain engineering solutions implemented during slope construction may be warranted. A variety of engineering options exist, and can be studied to identify the most cost-effective solutions.

1.5 Addressing Surface Erosion and Mass Slope Failure: The Case for Reforestation

Forest vegetation on steep slopes in the U.S. and elsewhere around the world is critical for limiting surface erosion, reducing sediment yield, and reducing the risk of mass slope failures by increasing soil shear strength and maintaining favorable hydrology (Norris 2005; Abe and Ziemer 1991a). The loss of trees and other forest vegetation on steep slopes to fire, timber harvesting, and clearing to make way for activities such as agriculture, construction, and mining have been implicated time and again in cases of heavy surface erosion and catastrophic slope failures worldwide (Abe and Ziemer 1991b; Roberts et al. 2004; Restrepo and Alvarez 2006).

Classic studies of forest hydrology on steep watersheds summarized by Jackson et al. (2004) highlight the impact of forest trees on interception, transpiration, and ultimately water yield and quality.

Although dense grass cover can approach tree cover in terms of interception and transpiration, this has only been demonstrated with active management involving fertilization (Burt and Swank 2002). Investigations of root architecture and strength in herbaceous plants, shrubs and trees (Weaver 1926; Hruska et al. 1999; Jose et al. 2001; Di Iorio et al. 2005), field observations, and comparisons of soil shear resistance afforded by tree vs. herbaceous roots (Waldron et al. 1983) provide evidence that once fully developed, the positive impact of tree roots on soil shear strength is greater than those of shrub and herbaceous roots. Thus trees are particularly important among plant species for increasing shear strength deep in the soil profile, and for ameliorating hydrologic conditions that result in slope failure. These functions of trees add significantly to the impetus for successfully implementing the FRA on steep slopes, as opposed to heavy tracking in and the planting of less valuable cover types such as Kentucky 31 fescue and other agricultural grasses that can tolerate compaction.

1.6 Questions Concerning Reforestation on Steep Slopes

The menu of herbaceous groundcover and tree species from which to choose is quite large, and the characteristics of species such as rooting depth, growth rate, and competitive ability can differ substantially between species. Desirable characteristics in herbaceous groundcover and tree species for addressing surface erosion and mass slope failure include ample leaf area for absorbing raindrop impact, rapid production of roots as deep as possible in the soil profile, and the ability to survive rigorous environmental conditions at the start of primary succession. Native species are also preferable to exotic species in order to fulfill several of the long-term goals of reforestation, and compatibility between groundcover species and trees is also important for long-term success. Although aggressive growth characteristics are likely to maximize the utility of groundcovers in addressing surface erosion, detrimental effects of aggressive groundcovers on tree growth and survival have been well documented (Burger and Zipper 2002). Aggressive groundcovers may be feasible, however, in the case of groundcover species that quickly capture a site, but then decline rapidly within a year or less.

Certain native trees and native and exotic groundcovers possess the desirable characteristics listed above. Two native, herbaceous, pioneer species with promising characteristics are switchgrass and gray goldenrod. Both species are well-adapted to recently disturbed sites with harsh conditions, but differ with respect to leaf area, colonization patterns, and persistence. Switchgrass is a warm-season perennial grass native to oak savannas and tallgrass prairie, and occurred in the eastern two-thirds of the United States prior to European settlement (Hitchcock 1935). Today, Switchgrass occurs in all states except Alaska, Washington, Oregon, and California (USDA PLANTS Database). A notable characteristic of switchgrass for our purposes is its ability to produce roots more than 8 feet deep in the soil, but with few surface roots (Figure 1) (Weaver 1926). Switchgrass also exhibits high rates of productivity across a broad range of sites, which has led to considerable interest in this species as a perennial feedstock for biofuels production (Parrish and Fike 2005). Gray goldenrod is a broadleaf perennial, and the range of this species includes the eastern two-thirds of the United States (USDA PLANTS Database). Gray goldenrod produces deep root systems that resemble those of asters and other members of the composite family (Weaver 1926), but only attains half the above-ground stature (1-3 feet) of tall goldenrod and other similarly large goldenrods (Radford et al. 1968). Gray goldenrod commonly occurs at forest edges, in forest openings, and in old fields, and is tolerant of dry sites (Miller and Miller 1999).

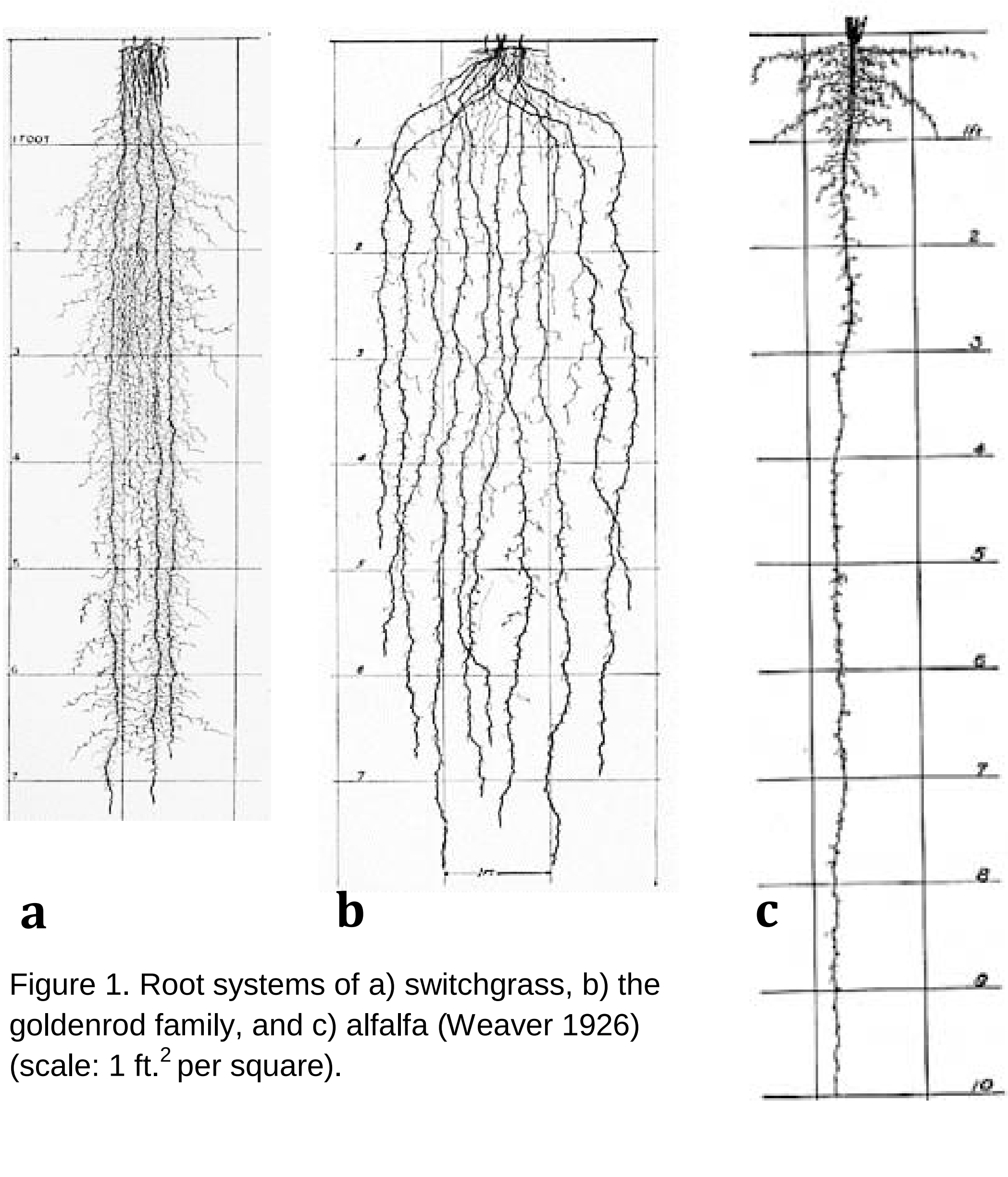


Figure 1. Root systems of a) switchgrass, b) the goldenrod family, and c) alfalfa (Weaver 1926) (scale: 1 ft.^{2} per square).

An exotic groundcover that is known to decline following initial establishment, but has tremendous rooting potential (Skousen and Zipper 1997; Weaver 1926), is alfalfa. This species is more readily available than the natives due to its importance in agriculture. Alfalfa fixes nitrogen, and has been reported to develop roots over 5 feet deep in one year on dry sites (Weaver 1926). Although it is an introduced species, it does not persist longer than a few years in the native ecosystem. Weeds often invade alfalfa in agricultural fields, suggesting that this species may allow colonization of the site by native species. Alfalfa contains the plant hormone Triacontanol, that has been found to promote root growth in a number of broad-leaved species. Although it establishes and grows rapidly, the species is prone to herbivory and root rot, and declines within several years. Even in healthy stands, alfalfa does not replace itself due to autotoxicity; a chemical is released by mature plants which prevents the establishment of new alfalfa seedlings.

Oak, hickory, and American chestnut dominated the steep slopes of Appalachia at the time of European settlement, and oaks and hickories are known to survive well on recently reclaimed mine sites. Oak and hickory have high economic value due to their importance in the manufacture of furniture, cabinetry, and hardwood flooring, and the rot resistance, straight grain, and other characteristics of American chestnut made it economically important prior to arrival of the chestnut blight (Youngs 2000). All three species have high value as wildlife species, and one major impetus for restoring American chestnut is the particularly high nutritional value of chestnuts. Oaks and hickories are known to invest heavily in below-ground root growth during the seedling stage (Abrams 1990; Latham 1992). Working on a reclaimed mine site in Illinois, Ashby (1995) compared rooting depths of four oak species planted from seed on compacted topsoil that was subsequently chisel-plowed, and found rooting depths greater than 50 inches for all four species after three years of growth. In a comparison of the performance of hardwood tree seedlings under nine different combinations of light and fertility, Latham (1992) found that in all combinations, mockernut hickory allocated a substantially greater proportion of biomass to roots than northern red oak, American Chestnut, American beech, blackgum, and yellow-poplar. Although American chestnut had less root biomass in proportion to shoot biomass than hickory and oak, this species had the highest overall growth rate (Latham 1992). After several growing seasons, American chestnut grew 77% more in height and 140% more in diameter than northern red oak in a hardwood plantation in Wisconsin(Jacobs and Severeid 2004).

The species described above all hold promise for successful implementation of the FRA on steep slopes, but the following questions remain: 1) from the standpoint of competition, how do these groundcover and tree species compare in terms of compatibility?; 2) how rapidly will the root systems of each species develop on mine soils, and how deeply will their roots extend into the soil profile at different points in time after planting?; 3) how do the effects of different mixtures of these species on hydrology compare?; and 4) what mixtures result in the lowest sediment yields?

1.7 Executive Summary

The restoration of productive forest ecosystems on formerly mined land often represents the highest and best post-mining land use, and may be particularly important on steep slopes for long-term mass stability. The Forestry Reclamation Approach (FRA) has been developed and promoted by Core Team members of the Appalachian Regional Reforestation Initiative (ARRI) to ensure that reforestation efforts result in the establishment forest ecosystems having levels of productivity that are comparable to levels of productivity in native forest ecosystems.

The FRA consists of five basic steps: 1) creation of a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material; 2) loosely grading the topsoil or topsoil substitute to create a non-compacted medium for root growth; 3) using ground covers that are compatible with growing trees; 4) planting both early successional trees for wildlife and soil stability and commercially valuable crop trees; and 5) using proper tree planting techniques . Steps 1 and 2 are concerned with the types of materials used to create a rooting medium and their placement, whereas steps 3-5 address the selection of optimum species for planting, and planting methods.

The palette of herbaceous groundcover and tree species from which to choose from in selecting species for planting is very large. The composition of native trees in the vicinity of a mine site can offer a certain amount of information concerning appropriate choices for reforestation, but precisely which local species are optimum for a given slope position, type of rooting medium, or aspect remains poorly understood. The compatibility of different herbaceous groundcovers and tree species is also unknown in many cases due to the large number of possible combinations that exist. The ultimate herbaceous groundcover for reducing surface erosion would establish quickly and develop rapidly, but this type of species may be much too aggressive in competing with planted trees for both above-ground (light) and below-ground (soil moisture and nutrients) resources. Certain successful combinations of herbaceous groundcover and tree species have been identified largely by trial and error, but little research has been conducted on the physiological mechanisms underlying the outcome of competitive interactions between groundcovers and trees, particularly in the case of interactions occurring below-ground.
An increased understanding of the physiology underlying the success of different groundcover and tree species combinations would be very useful for identifying common characteristics of compatible species that could be used to select appropriate local species for planting across broad geographic regions.

To establish the best tree species/microsite combinations and effects of different potential groundcover species on the physiological status, growth, and survival of different tree species planted on steep

slopes, three reclaimed mine sites in Tennessee were selected for study and planted with different combinations of groundcover and tree species in March 2009. Establishment and development of groundcover species in 2009 was limited by a number of intense precipitation events and other factors, but planted groundcovers were successfully established on all three mine sites. Competitive interactions between groundcover and tree species were also investigated under controlled conditions in a greenhouse study conducted on the University of Tennessee Knoxville campus. Overall objectives of the research were to: 1) determine how different groundcover and tree species combinations compare in terms of compatibility; 2) document how rapidly the root systems of each species develop on mine soils, and how deeply their roots extend into the soil profile at different points in time after planting; 3) establish the effects of different mixtures of these species on hydrology; and 4) determine what mixtures result in the lowest sediment yields. Objective 4 was to be investigated utilizing erosion data collected by others on the same study sites for a related study of appropriate slope construction procedures, mass stability, and erosion on steep slopes reclaimed with the FRA.

The attached report contains the results obtained for this research project. Chapter 1 contains the introduction and background information on the state of the art in mine reforestation, challenges in the reforestation of steep slope, and research questions.

Chapter 2 contains the descriptions of the study sites, the experimental designs employed, and the techniques used in the establishment of plots on the study sites. Characteristics of the groundcover and tree species tested are described, along with the planting methods used in the field and greenhouse components of the study. Measurement techniques and instruments used to collect data are also covered in this chapter, along with the statistical techniques used for data analysis.

Chapter 3 contains the results for above-ground and below-ground performance and physiological status of planted trees in the greenhouse and field components of the study. Also included are results for measurements of above-ground resource levels resulting from the treatments.

EXPERIMENTAL

2.1 FIELD STUDY

2.1.1 STUDY SITES

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

Mountain (36º07'N 84º19'W elevation: 859 m). It was being mined by Premium Coal Company, Inc. and was located in Anderson County, Tennessee. Study plots were established at this site 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.

2.1.2 Field Study Experimental Design and Treatments

Each study site was subdivided into 4 plots. Each plot was assigned a groundcover treatment at random (Figure 2.1). Nine columns of seedlings spaced 2 m apart were established perpendicular to the slope within each plot (Figures 2.1, 2.2). 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 2.2).

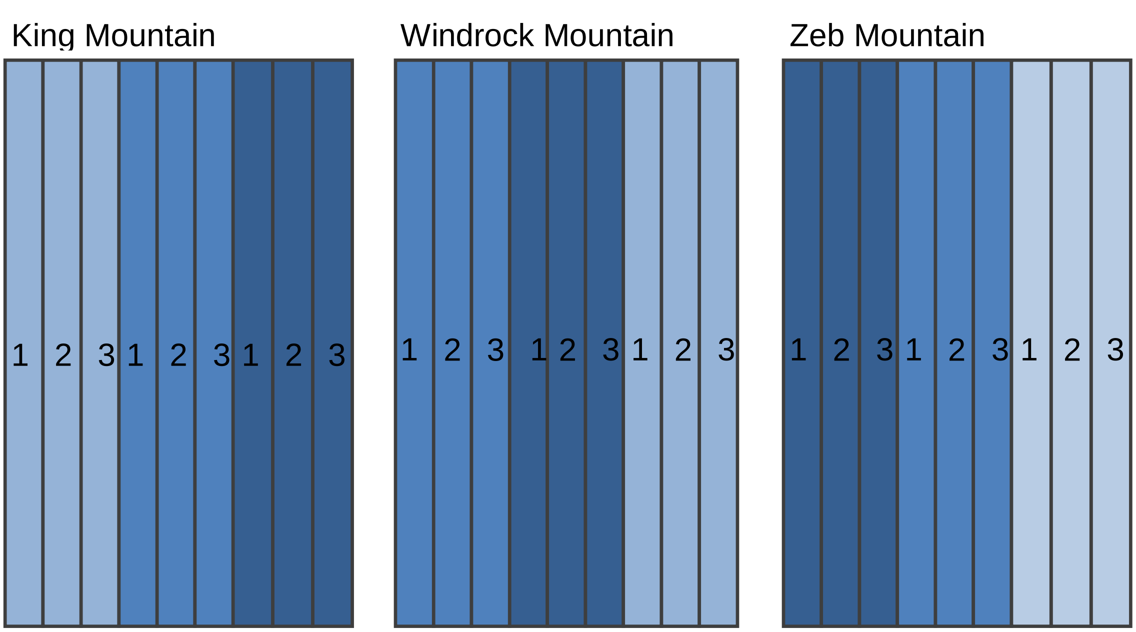


Figure 2.1. Groundcover and tree seedling treatments for each site.

2.1.3 GROUNDCOVERS STUDIED

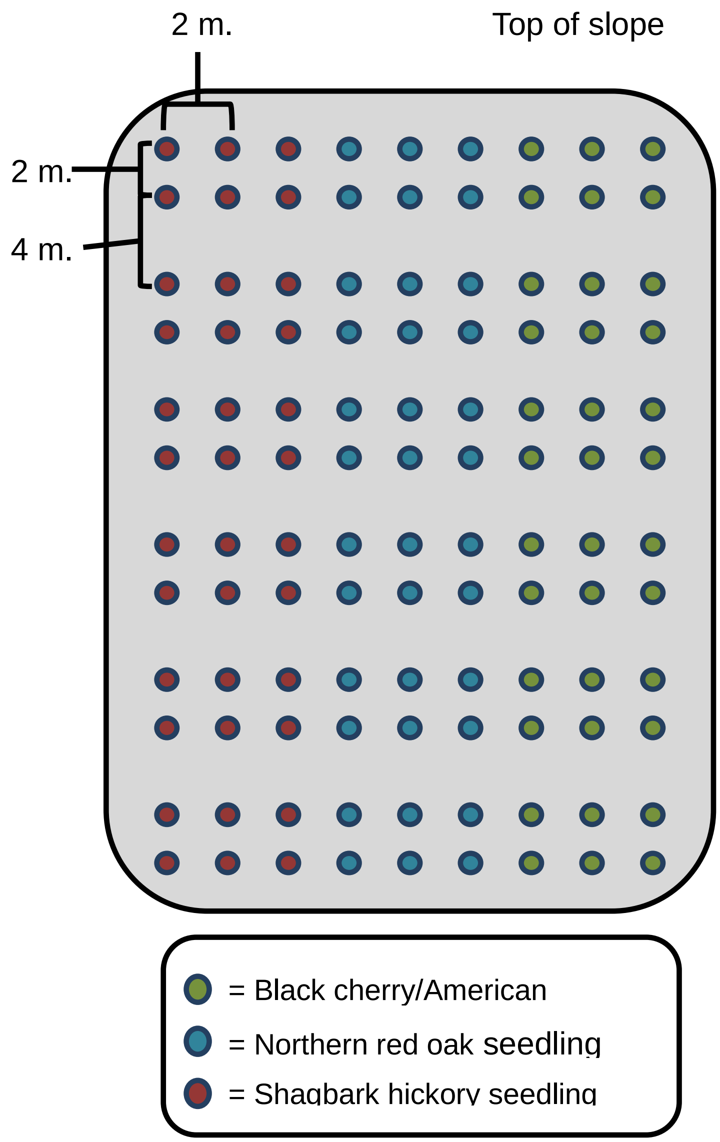


Figure 2.2. Spacing and species placement.

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 were switchgrass (*Panicum virgatum* Blackwell var.), and alfalfa (*Medicago sativa* Evermore var.). Annual ryegrass (*Lolium multiflorum*) was also planted on the sites in the second year of the study to provide for a quick-growing, but temporary, groundcover on the alfalfa and switchgrass treatments.

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 pH of 4.5-8 and establishes well when 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 ryegrass 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 ryegrass is being used for winter forage in Appalachia (Lacefield et al. 2003). Annual ryegrass 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 ryegrass 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).

2.1.4 Field Study Groundcover Planting Methods

Before groundcovers were planted, all plots were scarified by dragging a rake across the entire plot. Alfalfa and switchgrass were broadcast seeded May 20, 2009, and annual ryegrass was broadcast seeded June 18, 2009.

Alfalfa was planted at a rate of 6.8 kg pure live seeds (PLS) per acre. 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 ryegrass 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. Annual ryegrass 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 ryegrass 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 %.

2.1.5 Tree Species Studied

A large number of native tree species occur in Appalachian forests. Sites are often dominated by oaks, maples, hickories, and pines (Pijut 2005). The species of interest in this research project were 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.

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. 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. 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 seed fall is complete by early July.

2.1.6 Field Study Tree Planting Methods and Sources of Seedling Stock

Tree species were planted with tree planting spades and dibble bars between March 16 and May 8 of 2009. The University of Tennessee Tree Improvement Program supplied 1-0 American chestnut seedlings. The American chestnut seedlings were grown in Georgia from seed supplied by the American Chestnut Foundation. 1-0 Black cherry seedlings were 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 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. Oak that died in the first year of the study were replaced with 2-1 northern red oak seedlings from the same source.

2.1.7 Field Study 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.

2.1.8 Field Study Below-ground Measurements

Soil moisture and root growth data were collected with two polyacrylamide tubes installed 25 cm below a subset of planted northern red oak seedlings. The tubes were installed at the top, middle, and lower slope positions to address the effects of slope on soil moisture and root growth (Figure 2-3). These tubes were installed together so that soil moisture measurements could be related to root growth in the same vicinity. The two tubes differed in diameter: a 6.35 cm (2-½ inch) diameter tube for use with the root scanner (CI-600 CID Inc., Camas, WA) and a 1.91 cm (¾ inch) diameter tube for use with the soil moisture probe (Aqua Pro-Sensors LLC, Ducor, CA). The tubes are approximately 91 cm (3 feet) in length and installed 25 cm apart and 25 cm below the tree, and perpendicular to the slope.

Once the tubes were installed in May and June 2009, bimonthly readings of volumetric soil moisture were taking using the soil moisture probe, and recorded on a PDA (HP iPAQ rxl 1950 series), using Aquapro software. Moisture at depths of 15, 23, 30, 46, 61, 76 cm (3, 6, 9, 12, 18, 24, and 30 inches) was measured. Data were transferred to a computer for further analysis. The initial root scans were taken during December 2009 and January 2010 at depths of 23, 46, and 76 cm (9, 18, ainches), then scans were made monthly from May 2010 through July 2010. The root scanner was connected via a USB port to a laptop with the corresponding software and lowered down the larger diameter tube (root scanning tubes) to the depths stated above. The image was saved as an image file that was analyzed using WinRHIZO TRON 2008 (Regent Instruments Inc., Canada) software to determine the amount of roots present by calculating the root length, root surface area and root volume. All root length measurements were based on a cubic meter soil volume. Root length was used for statistical analysis since it directly influenced the surface area and volume. Along with these data, the percentage of ground cover around the tube and tree were measured using a 1 m quadrat to estimate the percent cover of species planted, as well as the percent cover of species that naturally established. During these measurements, a soil temperature probe was pushed into the ground to a depth of 10 cm to

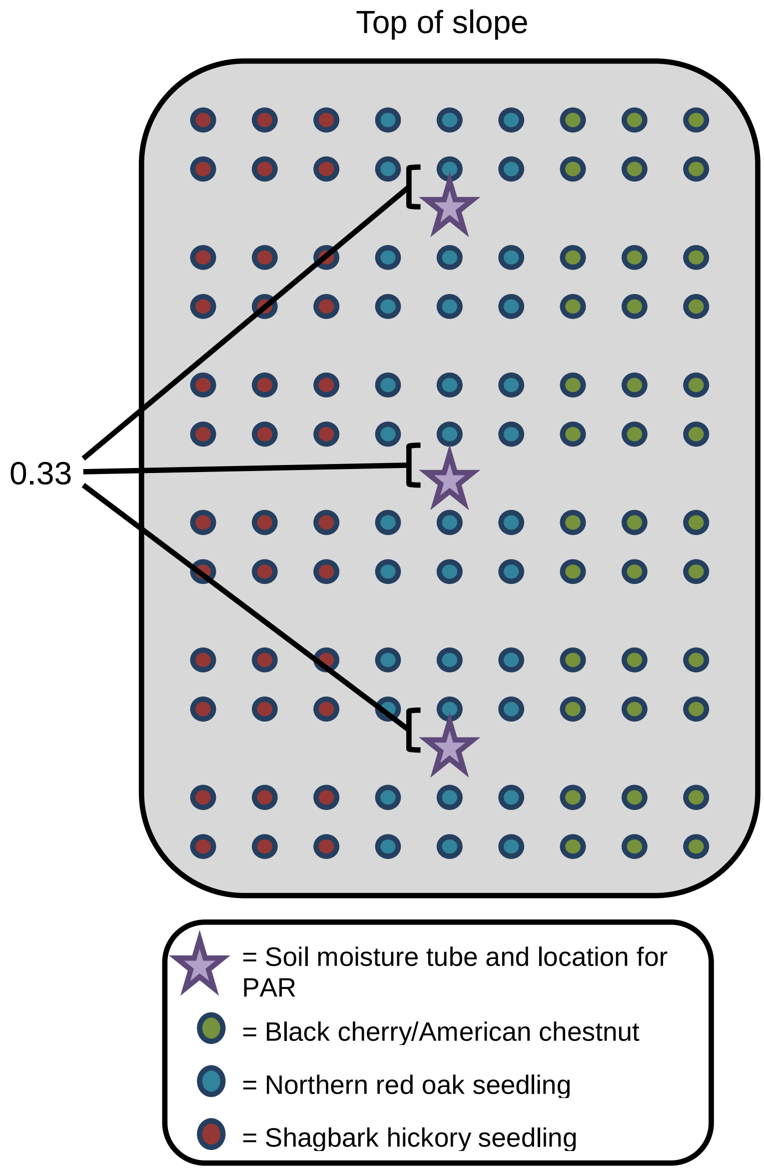


Figure 2.3 Locations of root and soil moisture sampling tubes.

measure the below-ground temperature. Soil temperature was measured monthly between May 2010 and August 2010.

2.1.9 Field Study Above-ground Measurements

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.

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.

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 percent soil moisture was measured. PAR was measured using a Li-Cor LI-190SA quantum sensor attached 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.

2.1.10 Field Study Below-ground Statistical Analyses

To investigate relationships between the site physical factors (slope position, soil moisture and soil temperature) a mixed model ANOVA was used. Soil moisture was tested for each month and at each depth against slope position. Soil moisture at the depth of 15 cm (6 inches) was tested against soil temperature for each month. Soil temperature was tested against slope position for each month. Sites were tested together, and then separately to determine whether there were any differences within sites. All analyses were done using SPSS software (SPSS Inc., Chicago, IL).
Relationships between the biotic factors (root growth and ground covers) were tested using correlation analyses. Root growth for each month was calculated by using changes in root length as an average and at each depth and this was compared to ground cover percentage for the preceding month. Each site was tested separately.

Relationships between root growth and soil moisture at depths of 23, 46, and 76 cm (9, 18, and 30 inches) were examined for each month: December, March, April, May, and June. A simple linear regression was used to test this relationship. Relationships between root growth and slope position were investigated at the 3 depths at each of the tube locations during the different months using simple linear regression. Finally, the relationship between root growth and soil temperature was examined, but only in the first depth, 23 cm (9 inches), for each month, May and June. Simple linear regression was also used to compare these variables. SPSS was used to run the regressions.

Relationships between groundcover percent cover and soil moisture, slope position, and soil temperature were investigated with linear regression for the months of May, June, and August. Soil moisture was averaged across depth at each sampling location, and within each treatment. Soil temperature was compared across ground cover treatments during the different dates, which were used as a covariate.

2.1.11 Field Study Above-ground Statistical Analyses

Mixed models analysis of variance and simple linear regression were used to analyze the data using SAS© Version 9.2 (SAS Institute, Cary NC). To analyze total height and root collar diameter growth, the model used was appropriate for a Randomized Block Design (RBD) with sampling and replication. Simple linear regression was used to investigate relationships between growth (total height and root collar diameter) and percent cover of all groundcover species combined. Foliar transpiration results were analyzed with a model 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).

2.2 Greenhouse Study

2.2.1 Experimental Design, Treatments, and Planting

Forty-eight dormant, bare-root, two-year-old northern red oak seedlings from the Kentucky Division of Forestry State Nursery (West Liberty, Kentucky) were planted in pots on March 13, 2010. The location of the greenhouse study was the University of Tennessee-Knoxville greenhouse (35º56’N 83º56’W) located in Knox County, Tennessee. The pots were 19 centimeters in diameter by 36 centimeters deep and contained a 1:1 ratio of sand and vermiculite. The mixture of sand and vermiculite provided a homogenous substrate and allowed for control over nutrient availability.

Each of four groundcover treatments were assigned to 12 of the 48 pots. The ground cover treatments were bare ground, alfalfa (*Medicago sativa*), switchgrass (*Panicum virgatum*), and annual ryegrass (*Lolium multiflorum*).

The Evermore variety of alfalfa was used for the greenhouse study. It was purchased from the Foothills Farmers Co-op in Maryville, TN. The seeds originated from Wyoming and have a germination rate of 85% with a rating of 65.8% pure live seed. The Alamo variety of switchgrass was planted in the greenhouse study. The seeds were purchased from the Bamert Seed Company in Muleshoe, Texas. Texas is also the seed source. The germination rate was listed as 81% with a rating of 88.77% pure live seed. Annual ryegrass seed for the study was purchased from Foothills Farmers Co-op in Maryville, TN. The seed source was Oregon, and the germination rate was listed as 89% with a rating of 93.74% pure live seed.

Groundcover seeds were planted in March of 2010 at the rate of 12 grams of seed per pot. This rate was chosen to ensure that a thick ground cover would be present which would force competitive interactions between the groundcover and the co-occuring northern red oak tree seedling.

2.2.2 Greenhouse Study Watering Regime and Dry-Down Periods

Over the course of the study, the pots were watered on Mondays and Wednesdays. One liter of nutrient solution was added to each pot on Fridays in addition to the normal watering. This solution was comprised of 50% deionized water and 50% Hoagland solution (Hoagland and Arnon 1939). The solution created a uniform amount of available nutrients to the plants within each pot. Two dry-down periods were administered during the study. During these periods no water or nutrient solution was added to the pots. 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.

2.2.3 Greenhouse Study Measurements of Oak Seedling and Groundcover Growth

Initial root collar diameter of the northern red oak seedlings 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 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.
Dried fine roots were removed from the tap root system by clipping off any roots that were smaller than 1.5 mm in diameter, and then weighed.

Biomass of herbaceous groundcover species was harvested on 7/13/10. 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.

2.2.4 Greenhouse Study Soil Moisture and Transpiration Measurements

Soil moisture and transpiration were measured daily during the two dry-down periods. Soil moisture was recorded as a volumetric percentage using a TRASE 6050X1 TDR Soil Moisture Probe

(Soil Moisture Equipment Corp. Santa Barbara, CA). 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 every day during the dry-down periods until the rate fell below 0.50 µg cm^{-2} s^{-1}.

2.2.5 Greenhouse Study Photosynthetically Active Radiation Measurements

PAR was 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.

2.2.6 Greenhouse Study Statistical Analyses

Data 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. Hypotheses 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 were investigated with an ANOVA model for appropriate for a Completely Random Design (CRD). Fine root mass was analyzed using a mixed model ANOVA. The model used to analyze the differences in foliar transpiration rates, soil moisture, and light was appropriate for a CRD with repeated measures. The relationship between soil moisture and foliar transpiration was investigated with linear regression. An alpha level of 0.05 was utilized in all analyses.

2.2.7 Ground Cover Transpiration Rates

To determine the range of ground cover transpiration rates, switchgrass, alfalfa, and annual ryegrass were grown from seed in the greenhouse. Seeds of each species were obtained from the Farmer's Co-op in Maryville, TN. Soil was collected from reclaimed sites on Zeb Mountain, near the field experiment site, and from a recently reclaimed quarry site in Oak Ridge, TN. A third inorganic soil substitute, consisting of quartz sand and vermiculite in a 1:1 by volume ratio, was used as a control.

Fifteen 4” diameter x 12” deep pots were filled with each soil type, and seeds were sown on the surface of each pot in sufficient quantity to cover the soil surface. Transpiration rates were measured weekly on 3 plants per pot, between 10:00 and 14:00 from weeks 8 to 12.

RESULTS

3.1 FIELD STUDY

3.1.1 SITE PHYSICAL FACTORS

Soil moisture and temperature were monitored to determine the extent to which these physical factors influenced ground cover establishment. Slope position was not related to soil moisture or soil temperature. Soil temperature was higher throughout the year on the Zeb mountain plots than on the other two sites. Mountainside, the northernmost site, had the lowest temperature in May and August. The only treatment that provided substantial ground cover in August of 2010, plots planted with alfalfa had soil surface temperatures 2-3°F lower than the other treatments. Soil moisture increased with depth (Fig. 3.1). Two of the three sites show a fairly consistent pattern over time with the lower three layers (46, 61, and 76 cm) having a greater soil moisture than the upper three layers (15, 23, and 30 cm). The Premium site had drier surface soils, and with less clearly defined patterns. This may be because the soil substrate is so heterogeneous that water does not move the same way through the soil as through soils with defined horizons. Matre et al. (2002) found that sandy soils had higher soil moisture than rocky soils. If there is a mixture of soil types in a small area then water may be held for longer in the upper layers compared to another area that may have a rockier matrix.

Table 3.1 Mean soil temperature (°F) in May, June, and August of 2001 at each of three sites, and mean soil temperature within each of three treatments.

Site	**May-10**	**Jun-10**	**Aug-10**
Mountainside	57.6	71.3	69.5
Premium	62.4	71.1	67.4
Zeb	66.2	73.6	85.8
Treatment			
alfalfa	60.8	71.4	72.3
bare	61.1	71.7	75.9
switchgrass	63.0	72.0	74.4

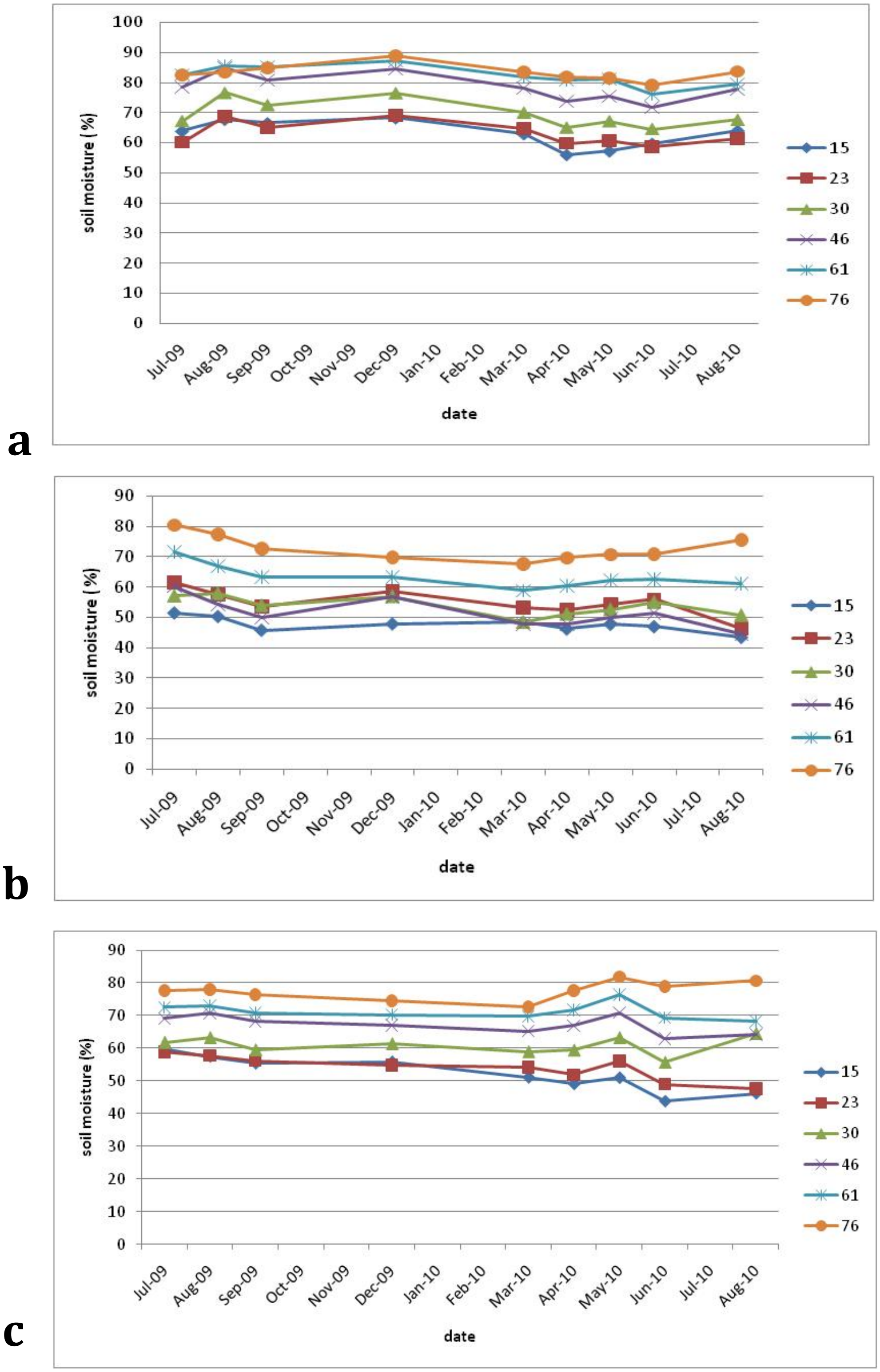


Figure 3.1 Average volumetric soil moisture in 6 depth zones over 14 months on Mountainside (a), Premium (b), and Zeb (c) plots. Depth zones are indicated in the legend, with 15 representing the mean moisture in the 0-15cm zone, 23 representing moisture in the 15-23 cm zone etc.

Table 3.2 Strength of relationship of soil depth to average soil moisture at each sampling date.

Mountainside

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
depth	Jul-09	4871.475	5	974.295	2.377	0.053
	Aug-09	3598.419	5	719.684	4.191	0.003
	Sep-10	4305.336	5	861.067	4.617	0.002
	Dec-10	4042.973	5	808.595	3.749	0.006
	Mar-10	4043.765	5	808.753	3.999	0.004
	Apr-10	6493.658	5	1298.732	8.3	<0.001
	May-10	5738.638	5	1147.728	5.867	<0.001
	Jun-10	3699.105	5	739.821	3.576	0.008
	Aug-10	3915.317	5	783.063	3.09	0.017

Premium

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
depth	Jul-09	6978.913	5	1395.783	4.178	0.003
	Aug-09	5702.374	5	1140.475	3.232	0.013
	Sep-09	5528.87	5	1105.774	3.325	0.012
	Dec-09	3262.386	5	652.477	2.177	0.072
	Mar-10	3335.826	5	667.165	2.159	0.074
	Apr-10	4036.372	5	807.274	2.742	0.029
	May-10	3878.1	5	775.62	2.539	0.04
	Jun-10	3867.947	5	773.589	2.747	0.029
	Aug-10	8564.576	5	1712.915	4.456	0.002

Zeb mountain

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
depth	Jul-09	2985.22	5	597.044	2.23	0.066
	Aug-09	3832.325	5	766.465	2.615	0.036
	Sep-09	3860.803	5	772.161	2.856	0.025
	Dec-09	3151.819	5	630.364	2.587	0.038
	Mar-10	3304.377	5	660.875	2.787	0.027
	Apr-10	5475.658	5	1095.132	4.402	0.002
	May-10	6552.708	5	1310.542	4.96	0.001
	Jun-10	7506.887	5	1501.377	5.499	<0.001
	Aug-10	7611.513	5	1522.303	13.585	<0.001

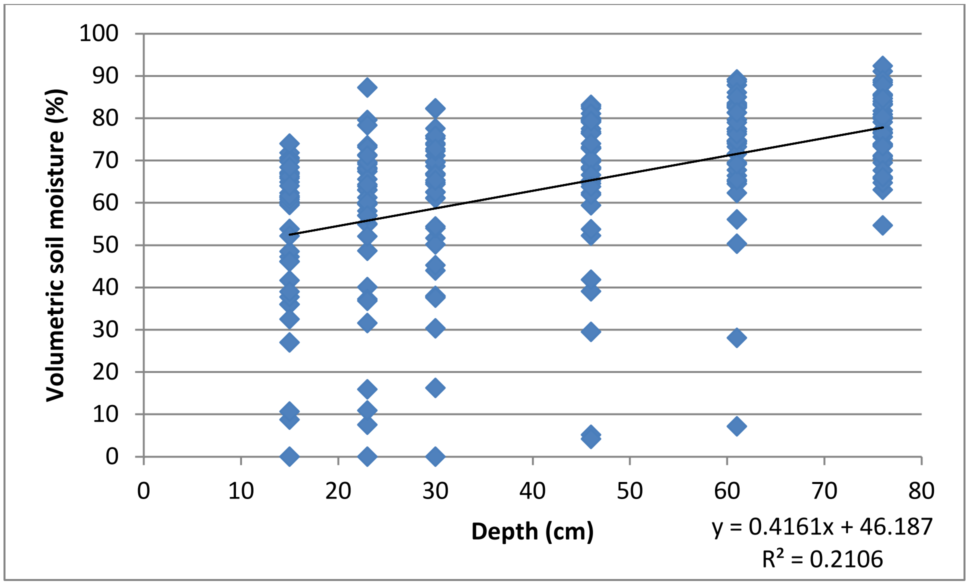


Figure 3.2 Relationship between depth and volumetric soil moisture across sites and sampling dates. The regression line and equation are given for the strongest relationship, which is linear.

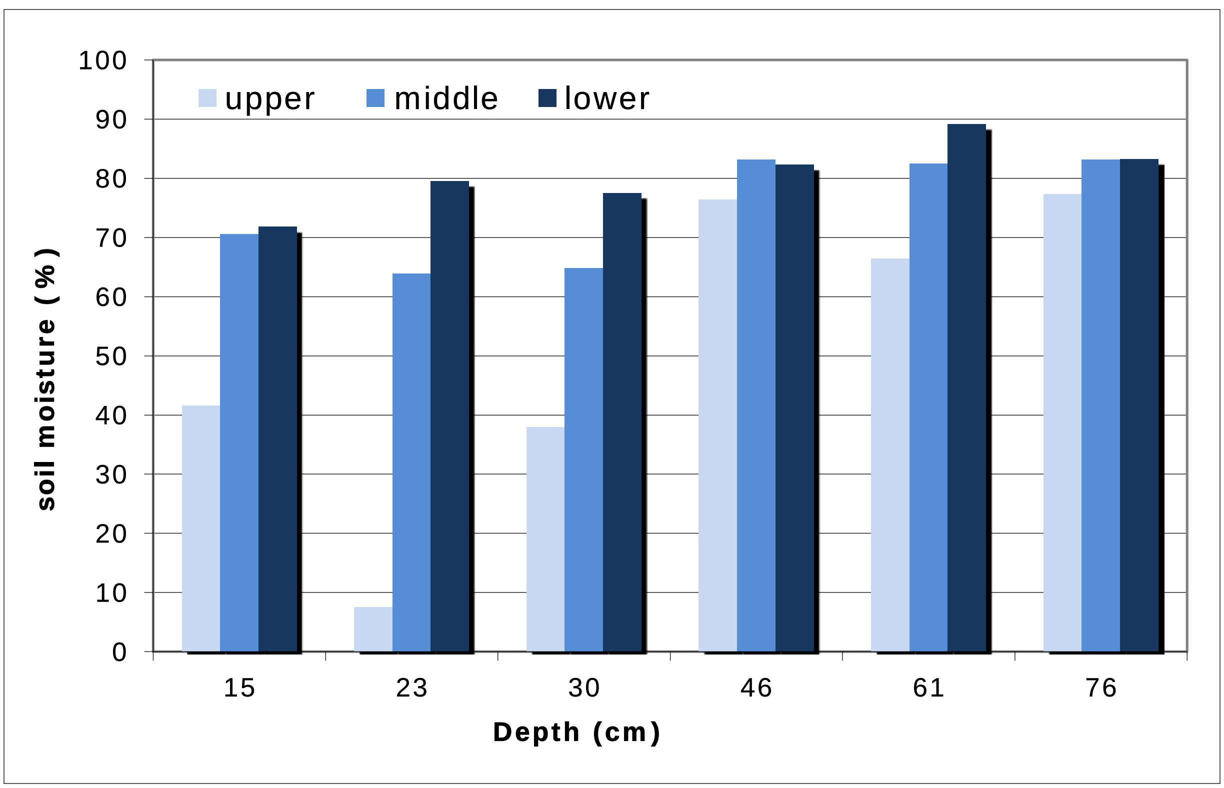


Figure 3.3 Mean volumetric soil moisture by depth on upper, middle, and lower portions of the slope across all sites in June 2010.

Volumetric soil moisture content was strongly related to depth on most sampling dates (Table 3.2). The equation that best explained this relationship was linear, declining in a predictable manner from the 61-76 cm soil layer to the 0-15 cm soil layer:

$$\text{Volumetric soil moisture} = 0.4161 * \text{depth in cm} + 46.187$$

Variability was high in the upper layers of soil, as expected. There was some variability in soil moisture between upper and lower portions of the slope (Figure 3.3). Below 30 cm there was little difference in soil moisture between slope positions. In the upper 30 cm of soil, moisture content varied considerably, being lowest on the upper slope and highest on the lower portion of the slope. Surface soils on the upper part of the slope were dry enough to inhibit the growth of roots. Sites differed in slope construction, slope length, and relative contents of rocks and clay. Zeb, the site with the most rocks and even slope angle, showed the expected decrease in surface soil moisture from bottom to top of the slope (Figure 3.4). Premium, which had a very steep slope constructed in a series of rough terraces, did not follow this pattern (Figure 3.5), suggesting that the slope construction method altered the surface hydrology.

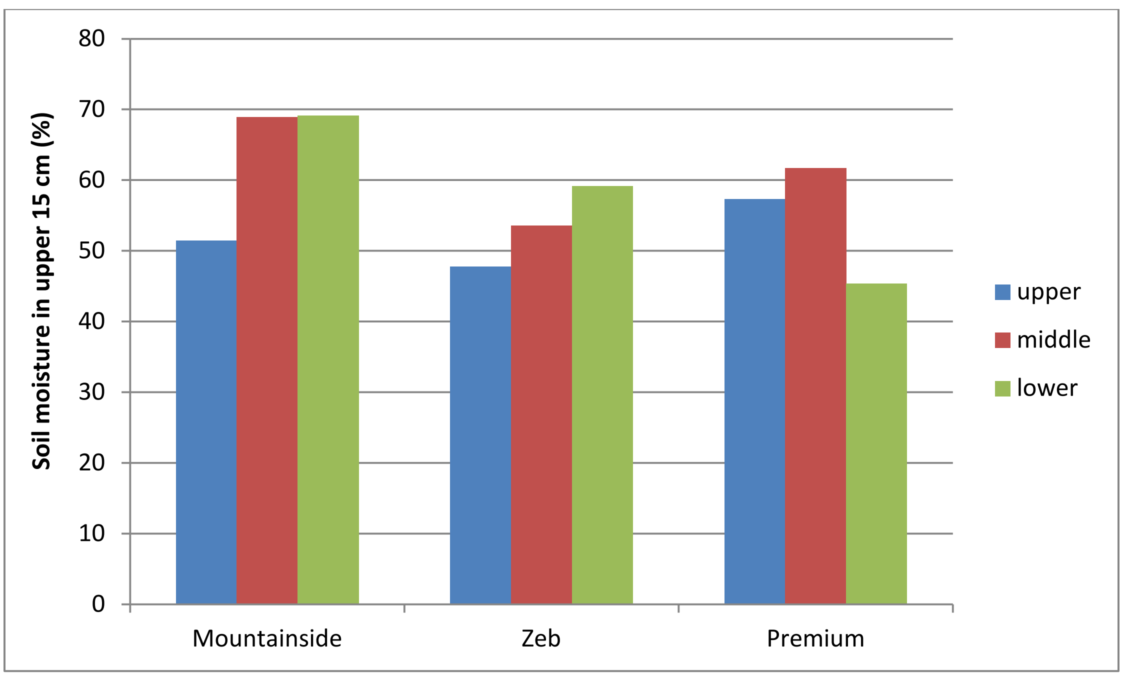
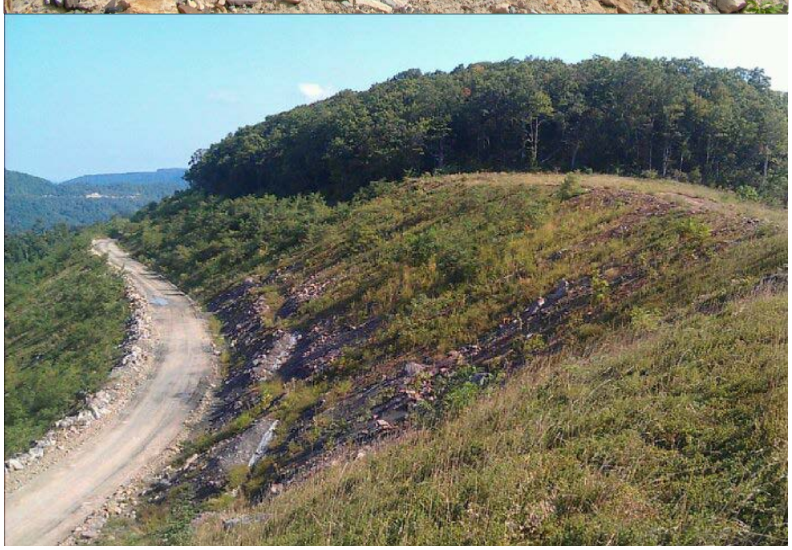


Figure 3.4 Mean volumetric soil moisture in the upper 15 cm of soil, at upper, middle, and lower slope positions, on three study sites.

Mountainside

Zeb Mountain



Premium

Figure 3.5 Study sites showing differences in slope construction. Slopes at Zeb Mountain were the longest, had the most rocks, and were less steep than other sites. The slope at Premium was the shortest and steepest, with a couple of shallow terraces in the middle of the slope.

3.1.2 Above-ground development of ground cover

In the first year of the study, establishment of the perennial ground cover was very slow. Concern over heavy rill development due to an unusually wet growing season prompted the seeding of an annual cover at the end of the first growing season. This was concentrated along the bottom of the plots, and seeded very lightly within plots, to minimize any effect of ryegrass, and was not seeded on bare ground control plots. In the 2010 growing season, the alfalfa treatment was found to have greater percent cover than the bare and the switchgrass treatments. 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 3.6). 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.

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 been exacerbated due to consistent, windy conditions on the field sites. An unusually high rainfall and notable sediment movement may also have contributed to the movement of lightweight switchgrass seeds off of the steeply sloped sites.

Figure 3.6 Picture of King Mountain (Mountainside) 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.

Despite the low percent cover of groundcover species found on the sites in 2010, and the lack of differences in cover between dates, the tendency for switchgrass to develop later in the growing season 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. By the end of the 2011 growing season, ground cover had increased substantially, primarily due to the establishment of volunteer cover. There was no difference between sites in the development of vegetation (Table 3.2), but there was a difference between treatments, with ground cover greater than 80% on sites planted with alfalfa (Figure 3.7).

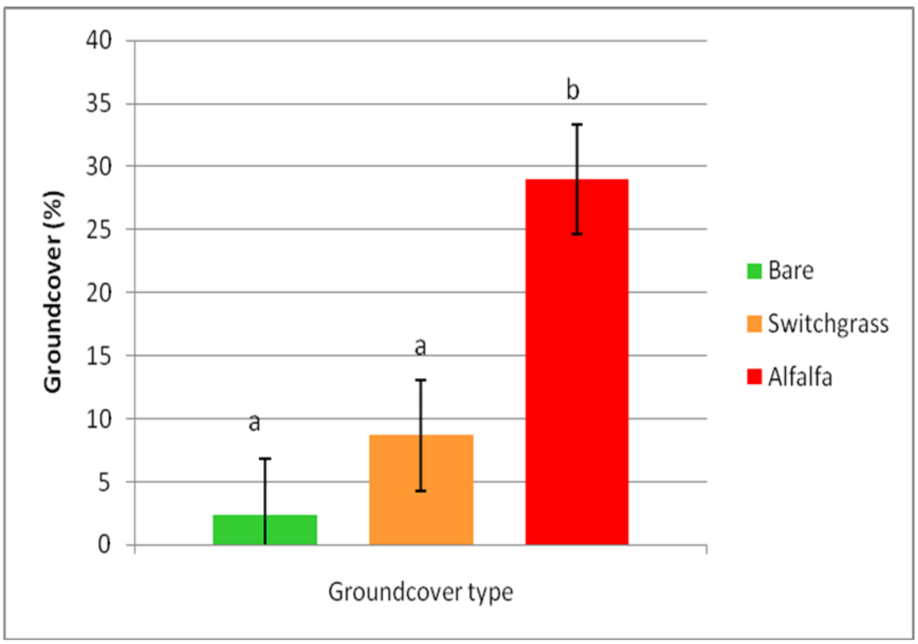


Figure 3.7 Total percentage of groundcover by treatment at the end of the second growing season in 2010. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$). Percent groundcover was 2.4, 8.7, and 29.0% in the bare, switchgrass, and alfalfa treatments, respectively.

Table 3.2 Percentage of volunteer ground cover and total ground cover (volunteer +planted) on 3 sites at the end of the 2010 and 2011 growing seasons.

	August 2010		September 2011	
Site	volunteer %	total cover %	volunteer %	total cover %
Mountainside	3.54	16.33	35.6	43.5
Premium	11.33	22.58	44.1	51.3
Zeb	5.75	9.17	49.3	59.7

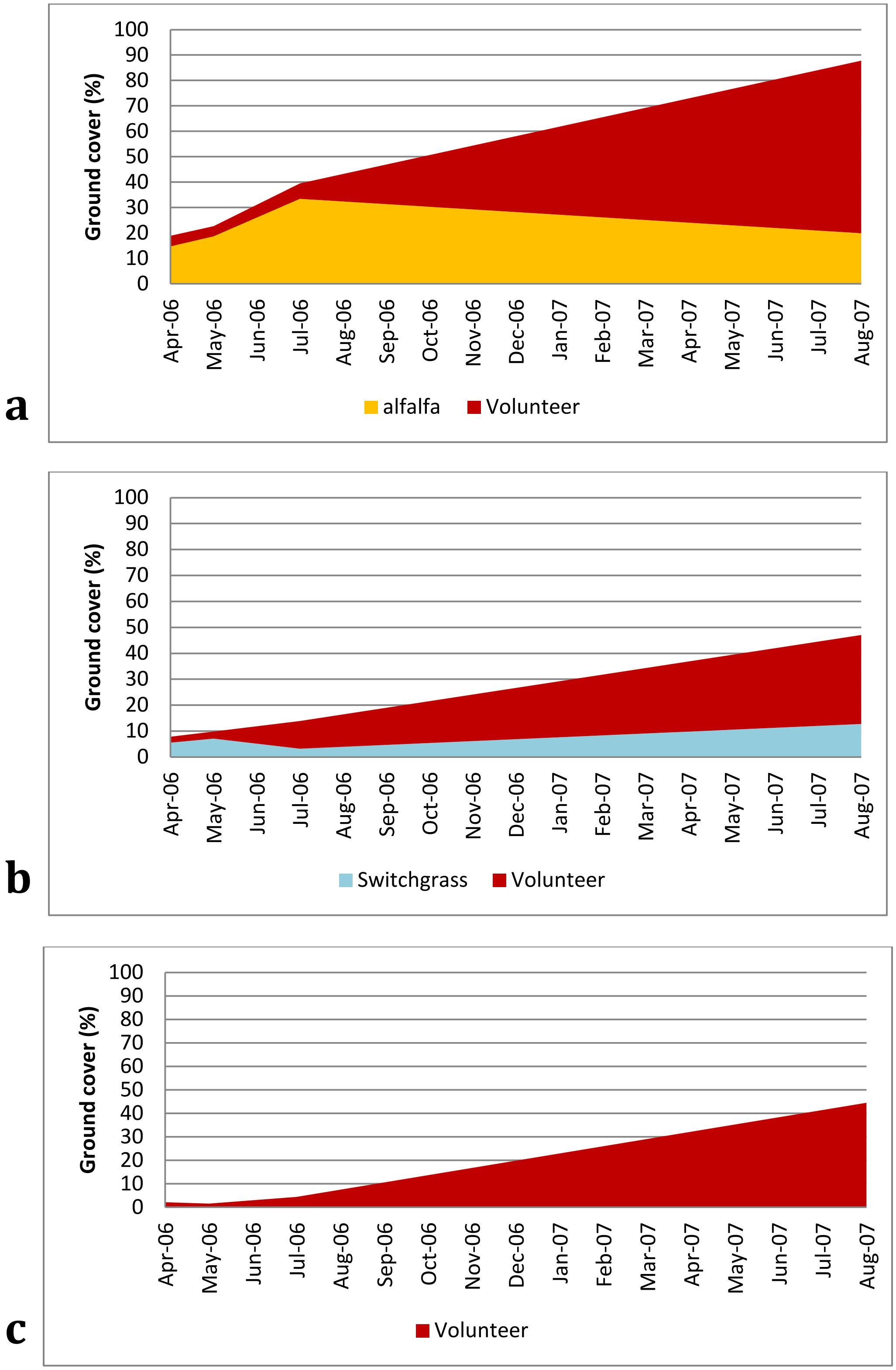


Figure 3.8 Development of ground cover over the second (2010) and third (2011) growing seasons, across all three sites, in plots planted with alfalfa (a), switchgrass (b), and unplanted plots (c).

3.1.3 BELOW-GROUND DEVELOPMENT OF GROUND COVER

Root growth began earliest in plots planted with alfalfa, but was highly variable in these plots throughout the growing season. Root growth in the switchgrass plots increased through the spring, reaching a peak in May (Figure 3.9). Root growth and ground cover treatment/ percent cover were not related to one another at any of the three sites. We expected above-ground biomass to be closely correlated with below-ground biomass. Our failure to find this relationship could be due to the small sample size that failed to capture a representative sample of below ground growth, or it may be due to heterogeneity of root distribution. Within each ground cover type, the change in root length over each month was not related to the percentage of ground cover that had been recorded in the previous month. Ground cover type and ground cover percentage also did not have a significant relationship. Figure 3.9 shows the seasonality of root growth over the measured soil profile in the four different ground cover treatments, when averaged across all sites.

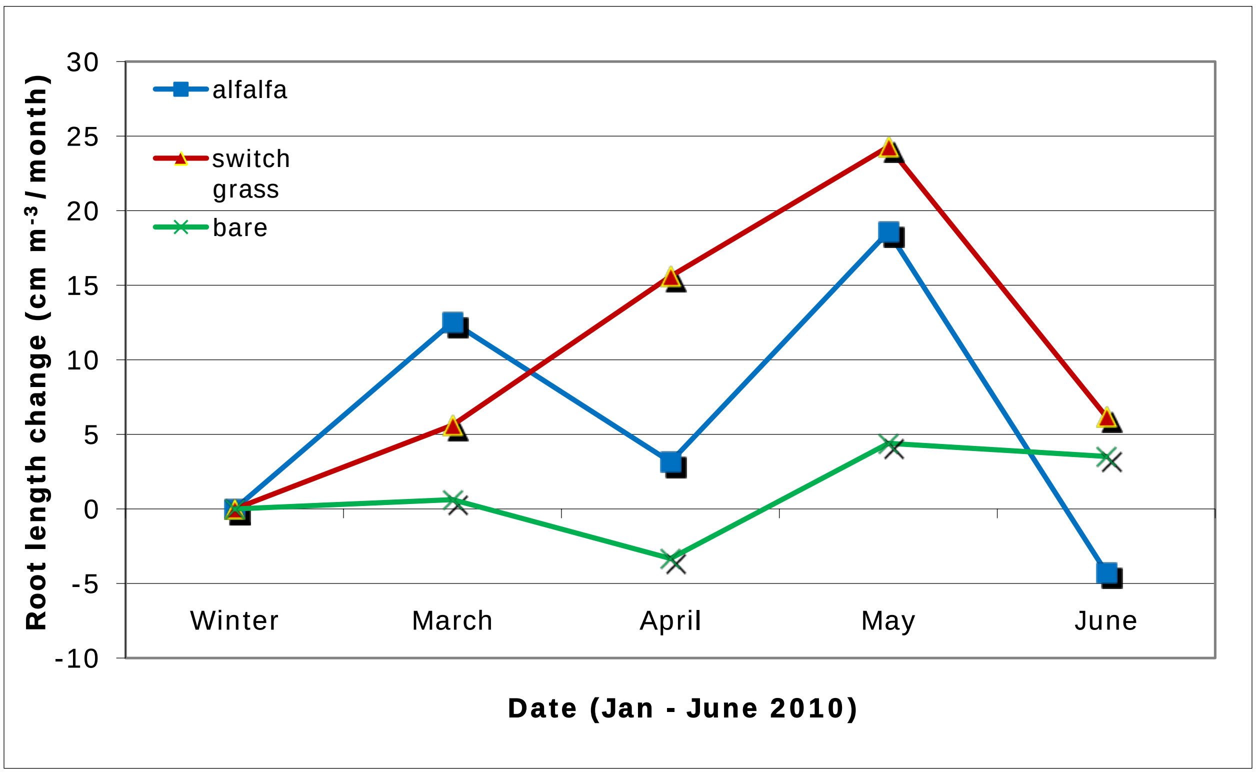
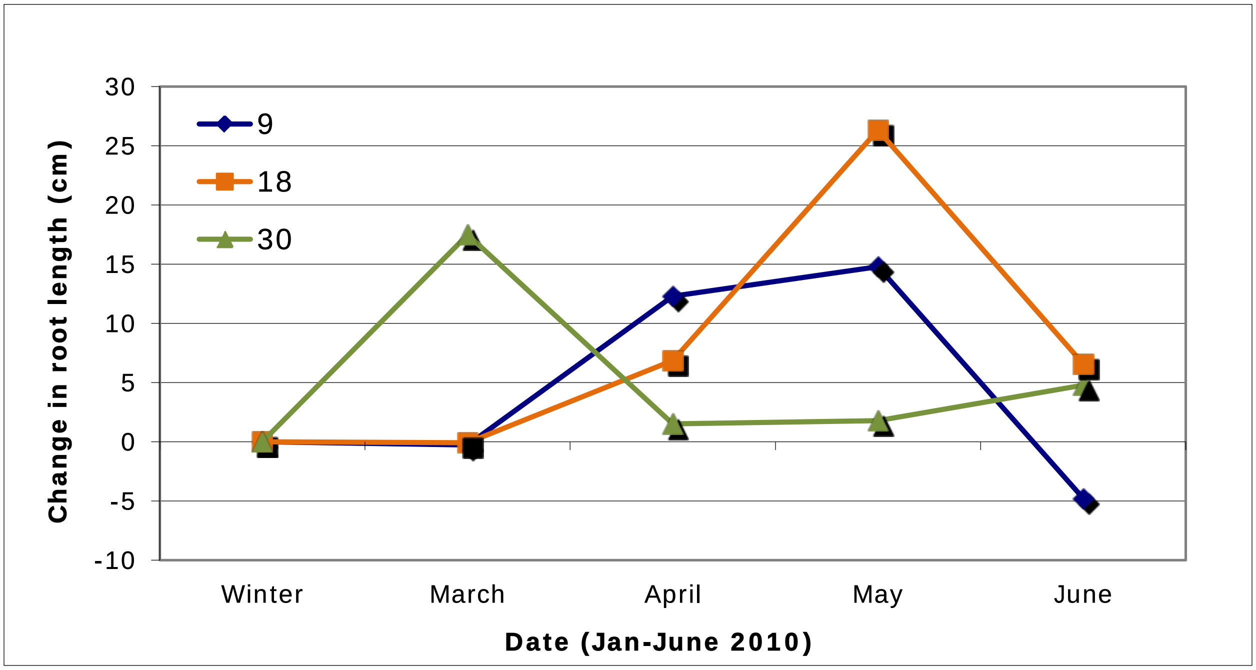


Figure 3.9 Mean growth rate of roots between January and June 2010 in plots seeded with alfalfa or switchgrass, and unseeded bare ground control plots.



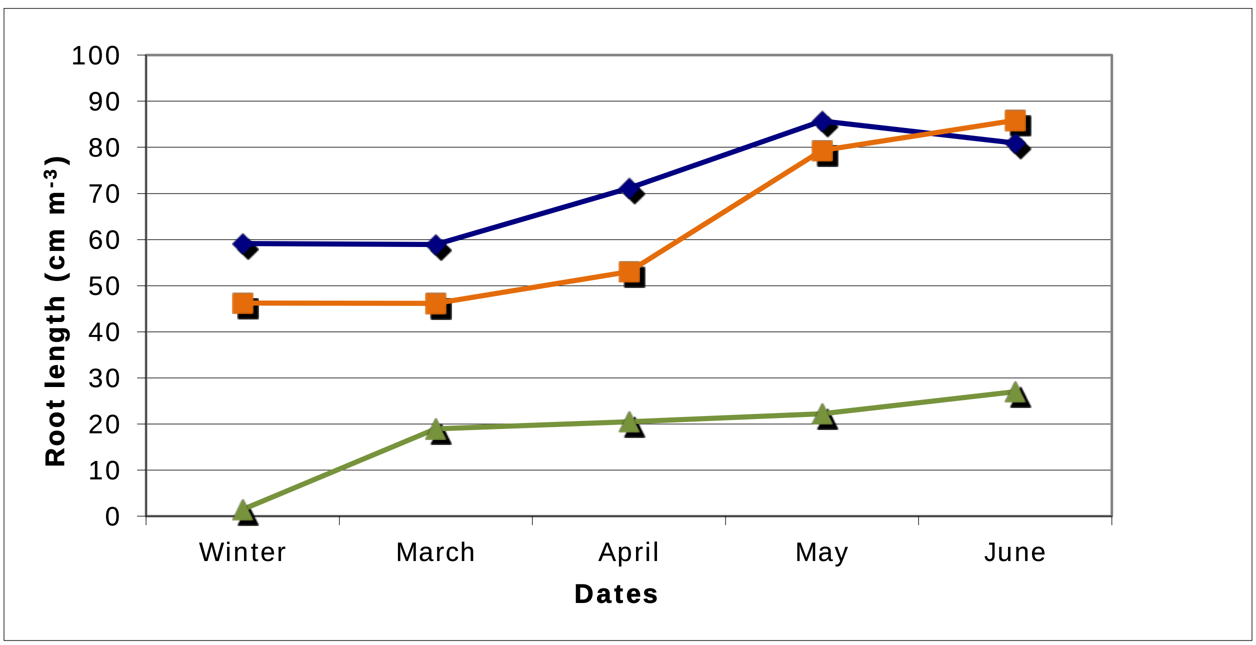


Figure 3.10 Mean growth rate (top) and cumulative biomass (bottom), shown as root length per unit soil volume, across all treatments and sites, between January and June 2010 at depths of 0-9 inches (9), 9-18 inches (18), and 18-30 inches (30).

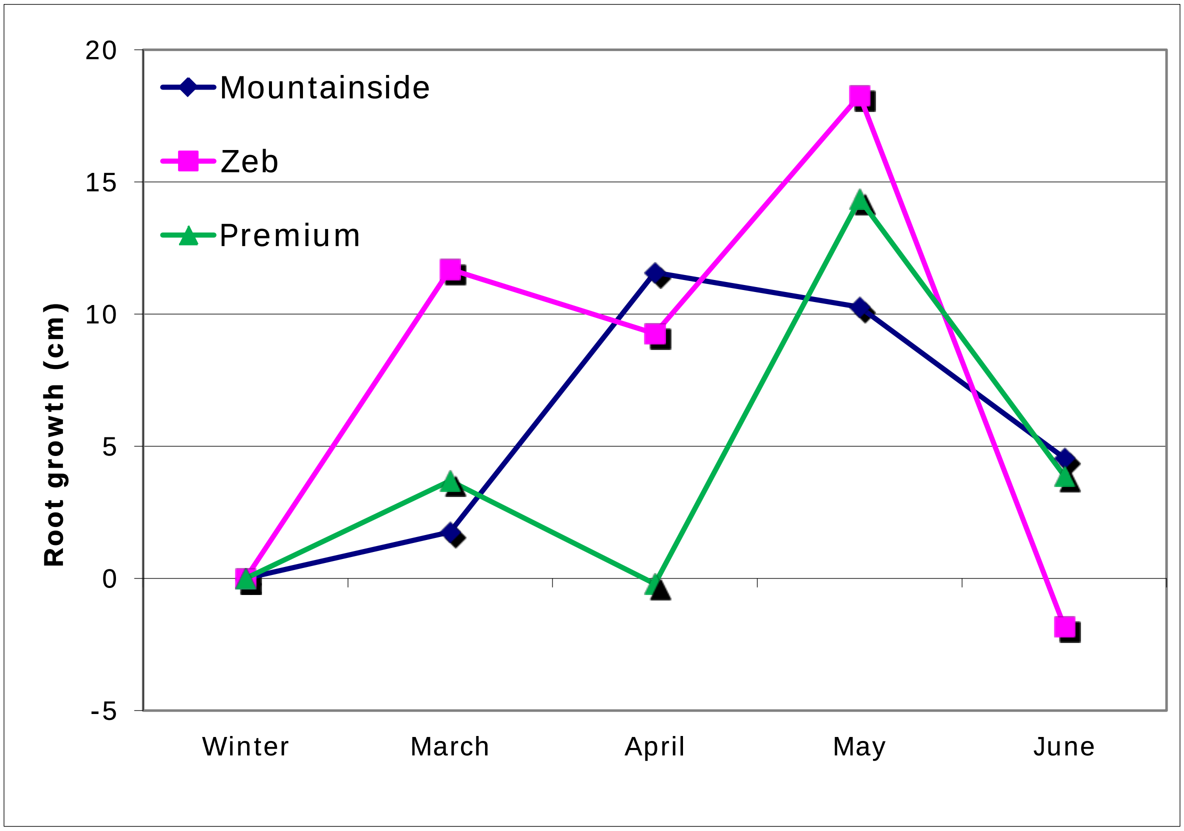


Figure 3.11 Mean root growth in cm per m^3 between January and June 2010, on three study sites.

Root growth was not related to soil moisture, slope position, or soil temperature but was related to depth. The upper two layers (0-18 inches) had much greater root biomass than the lower layer (18-30 inches). Lyford (1980) explained that in young northern red oak trees most of the root system would be found in the upper layers of soil, since the root system is composed of a deep tap root with many spreading, fine laterals. Growth early in the year occurred in the deepest soil layer, and may have been the growth of oak seedling roots. However in this experiment it was difficult to distinguish tree roots and ground cover roots from one another due to discoloration from the soil. Root growth and soil moisture were not related, possibly because of the heterogeneity of the soil. Even if one area has greater soil moisture than another area, roots may not be able to reach the resource if there is a rocky substance hindering its growth. Also, root systems may not be developed enough to show a relationship between these two variables. Soil temperature and root growth did not show a relationship, which could mean that temperatures are not outside of an optimum range within which fluctuations did not hinder or help growth.

3.1.4 Growth of trees

The growth of tree seedlings was affected by the total percentage of ground cover, but tree species were affected differently by ground cover treatments. American Chestnut and black cherry had lower growth and survival at higher levels of ground cover that occurred in the alfalfa treatment, oak had reduced growth, but not survival as ground cover increased, while ground cover had a positive influence on hickory survival, and no effect on growth.

Over the 2010 growing season, no significant differences in height growth occurred between groundcover treatments in any of the 4 tree species planted (Table 3.3). Similarly, no differences in 2010 root collar diameter growth occurred between groundcover treatments in any of the tree species. 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 ground cover. 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 3.4).

Table 3.3 Mean 2010 height growth and root collar diameter growth of seedlings 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	P-value
Total Height Growth (cm)	Northern Red Oak	Alfalfa	9.3	3.4994	0.4966
		Switchgrass	7.7	3.3005	
		Bare	13.0	3.2687	
	American Chestnut	Alfalfa	12.1	4.3711	0.3065
		Switchgrass	17.3	4.0697	
		Bare	20.52	4.0461	
	Black Cherry	Alfalfa	8.2	5.8782	0.2667
		Switchgrass	22.3	5.1862	
		Bare	18.6	5.7632	
	Shagbark Hickory	Alfalfa	2.6	0.8113	0.6168
		Switchgrass	2.4	0.6047	
		Bare	3.3	0.5031	
Root Collar Diameter Growth (mm)	Northern Red Oak	Alfalfa	2.2	0.8501	0.6612
		Switchgrass	2.3	0.8247	
		Bare	4.0	0.8208	
	American Chestnut	Alfalfa	2.4	1.2761	0.2924
		Switchgrass	3.0	1.2442	
		Bare	4.7	1.2342	
	Black Cherry	Alfalfa	2.8	1.1812	0.4494
		Switchgrass	4.2	1.0811	
		Bare	3.8	1.1612	
	Shagbark Hickory	Alfalfa	1.4	0.4325	0.7115
		Switchgrass	1.6	0.3687	
		Bare	1.3	0.3469	

Table 3.4 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

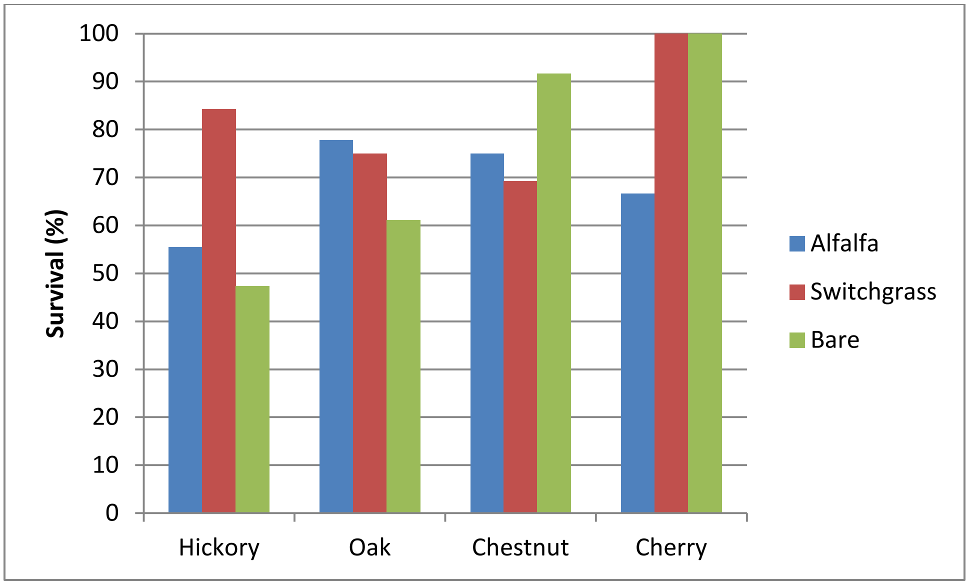


Figure 3.12 Survival of planted tree seedlings in Sept. 2011, in plots planted with alfalfa or switchgrass, and unplanted bare ground control plots.

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; Blood and Titus 2010; Nyberg and Hogberg 1995). 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 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.

Ignoring the effects of treatment, to examine the effects of percent cover of all herbaceous species, there was 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).

By the end of the third growing season in 2011, survival of all tree species was 72%. Although ground cover in the alfalfa treatment was greater than 85%, the influence on survival rates was negative for chestnut and cherry, both species known to prefer open, disturbed sites, but positive for oak and hickory which have intermediate shade tolerance (Figure 3.12). Although plots planted with switchgrass had a total ground cover of less than 50%, over a three-year period this treatment did affect tree survival. A strong positive influence on hickory and oak survival was found, and unlike the alfalfa treatment, there was no influence of the ground cover on black cherry survival. Only chestnut survival was negatively influenced by the switchgrass planting treatment.

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), indicating that ground cover treatments did not differ in the degree of water stress imposed on tree seedlings. 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).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.

3.2 Greenhouse Study

3.2.1 *Growth of oak seedlings*

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 ryegrass 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 3.5). 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. 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 ryegrass 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 ryegrass 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. 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 ryegrass and alfalfa treatments had the lowest root-to-shoot ratio.

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 ryegrass treatment yielded the lowest weight of freshly harvested leaves (Table 3.6). 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 ryegrass treatments were found to be statisically similar, although the switchgrass treatment had the largest average and the ryegrass had the lowest average dry

Table 3.5 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	
	Ryegrass	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	
	Ryegrass	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	
	Ryegrass	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	
	Ryegrass	0.61	0.0773	b	

Table 3.6: 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	
	Ryegrass	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	
	Ryegrass	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	
	Ryegrass	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	
	Ryegrass	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	
	Ryegrass	9.36	4.23	c	

weight of leaves. 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. 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 ryegrass treatment produced the lowest average leaf area, but were statistically similar to the alfalfa treatment.

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

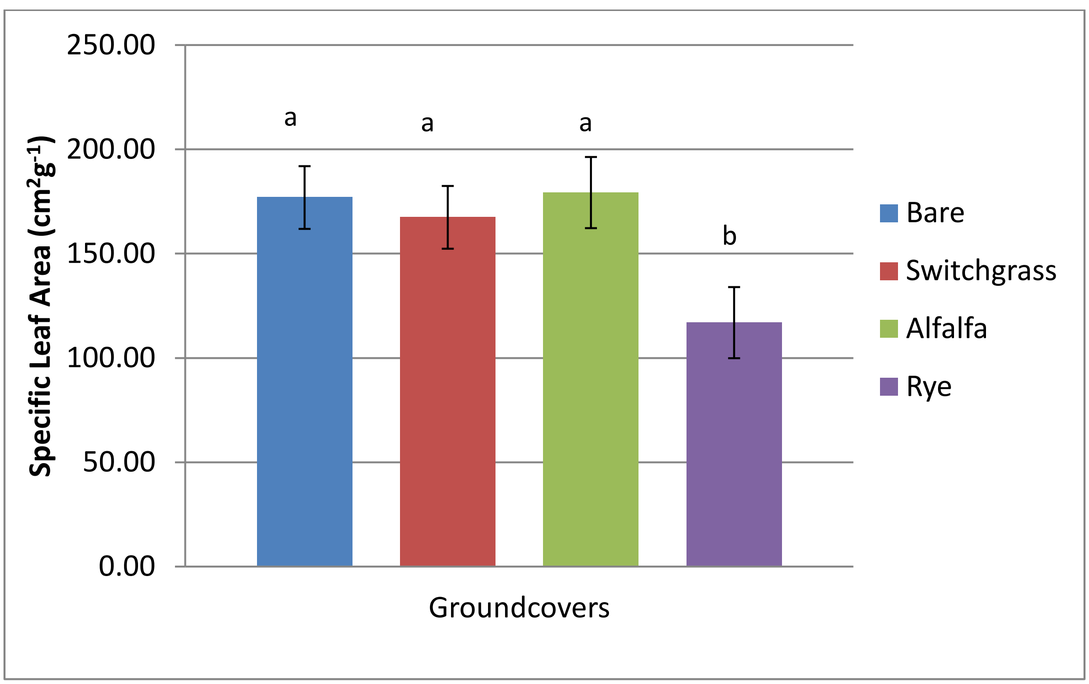


Figure 3.13 Mean specific leaf area of oak seedlings grown with a dense cover of switchgrass, alfalfa, annual ryegrass, or a bare ground control.

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 (Figure 3.14). During both dry-down periods, as time progressed foliar transpiration rates increased to a peak point and then decreased. The date peak foliar transpiration rates occurred for both dry-down periods was found in the middle of the period. Foliar transpiration rates of the seedlings varied ($p<0.0001$ for both periods) between groundcover types during both dry-down periods (Figure 3.15). 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 ryegrass treatments had the lowest foliar transpiration rates. During the second dry-down period, seedlings in the bare treatment had the highest foliar transpiration rates. For both dry-down periods, a significant interaction ($p<0.0001$ and 0.0084, respectively) was found between date and groundcover type (Figures 3.16 and 3.17). During the first dry-down period, foliar transpiration rates were either greater in the alfalfa than in the ryegrass 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 rate of seedlings in the switchgrass treatment fell below those in the alfalfa treatment for the first time.

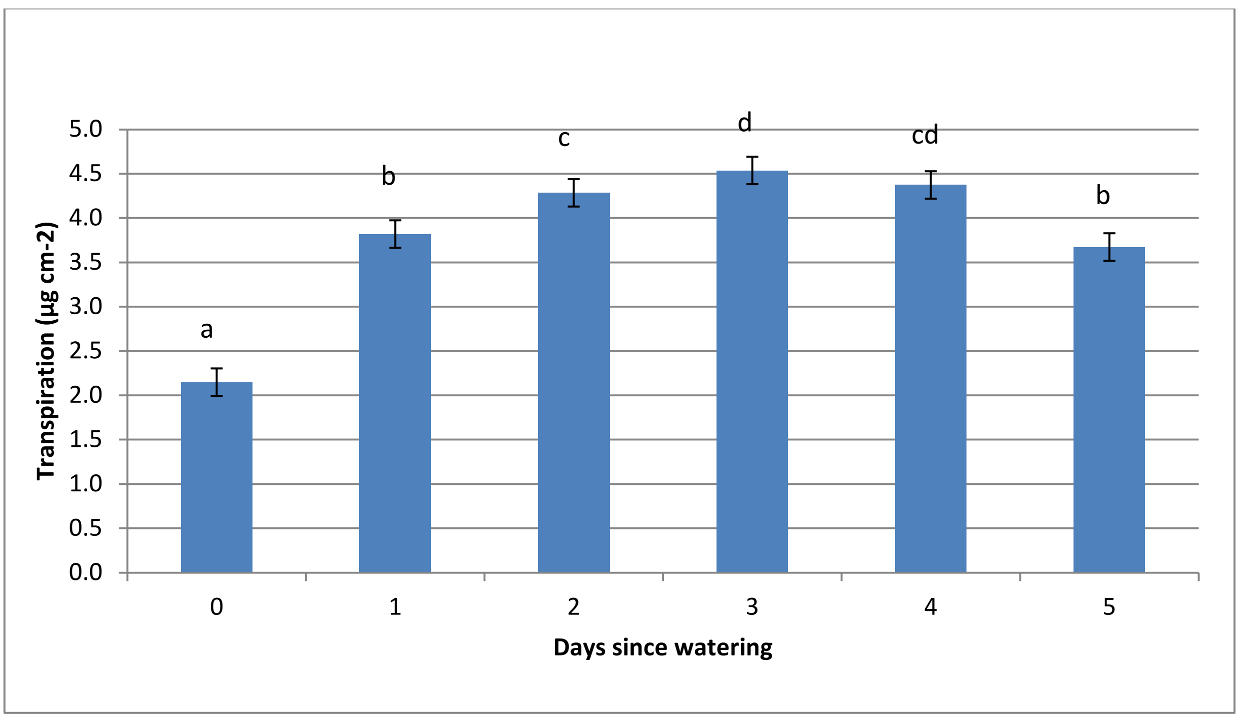
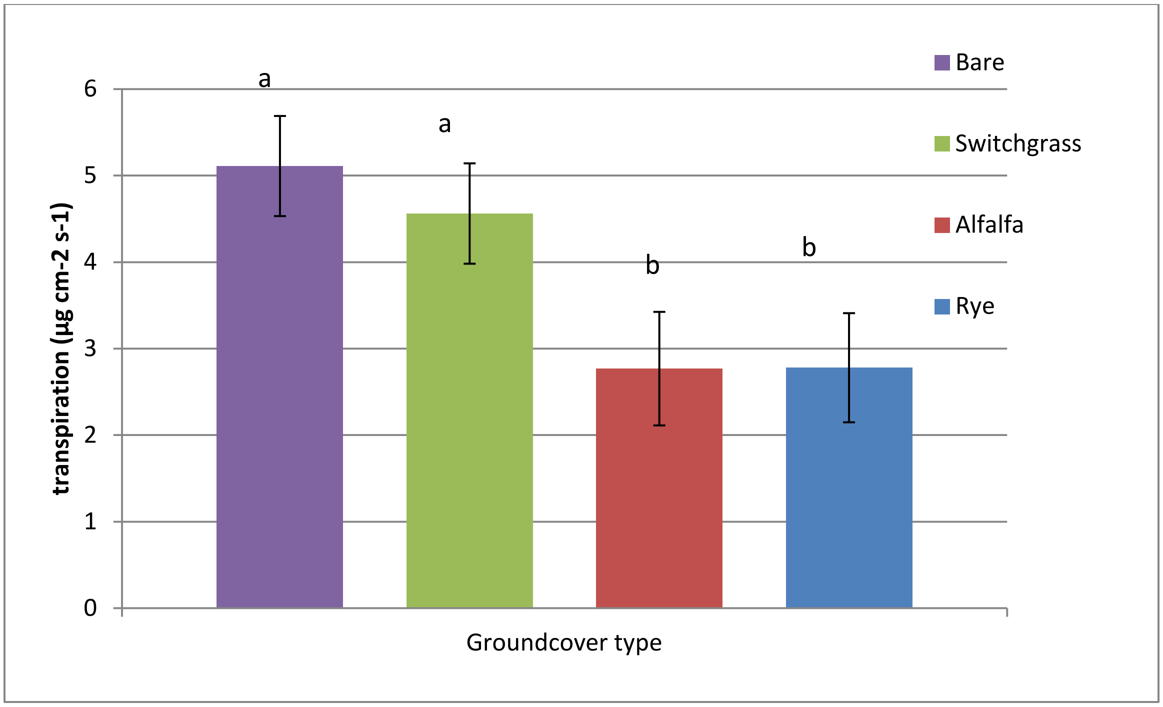


Figure 3.14 Mean transpiration rates of oak seedlings over the first of two dry-down periods. Bars indicate standard error. Different letters indicate significant differences between dates.



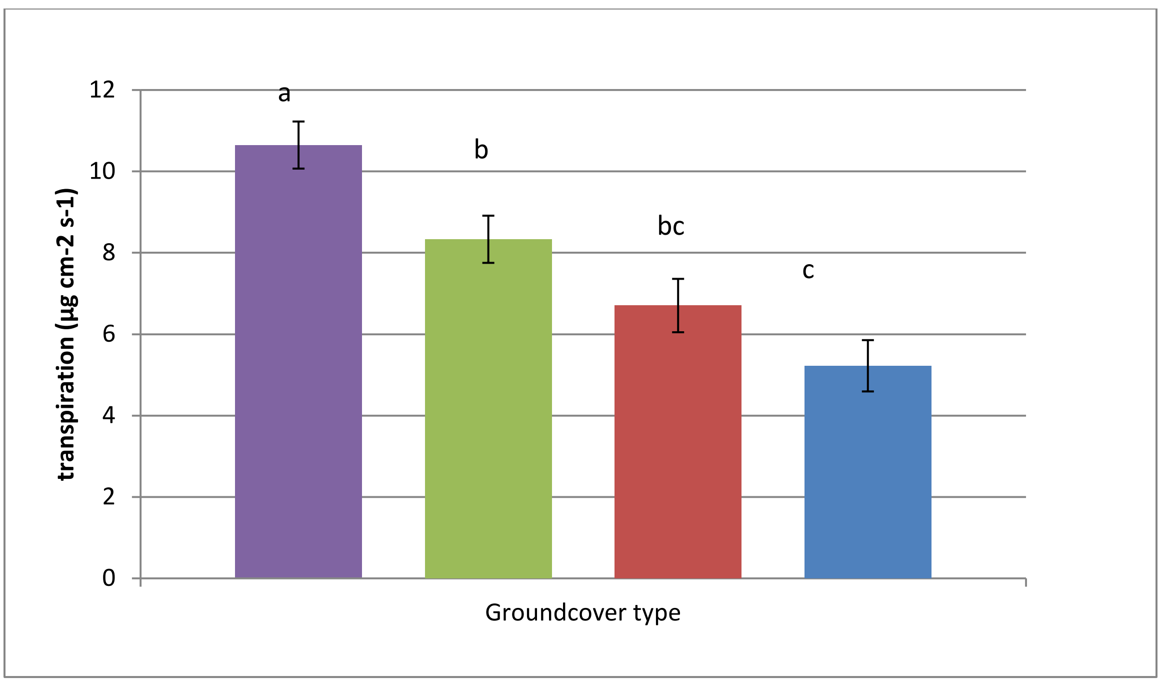


Figure 3.15 Mean foliar transpiration rates of seedlings between groundcover types during the first (top) and second (bottom) dry-down period. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means ($P<0.05$).

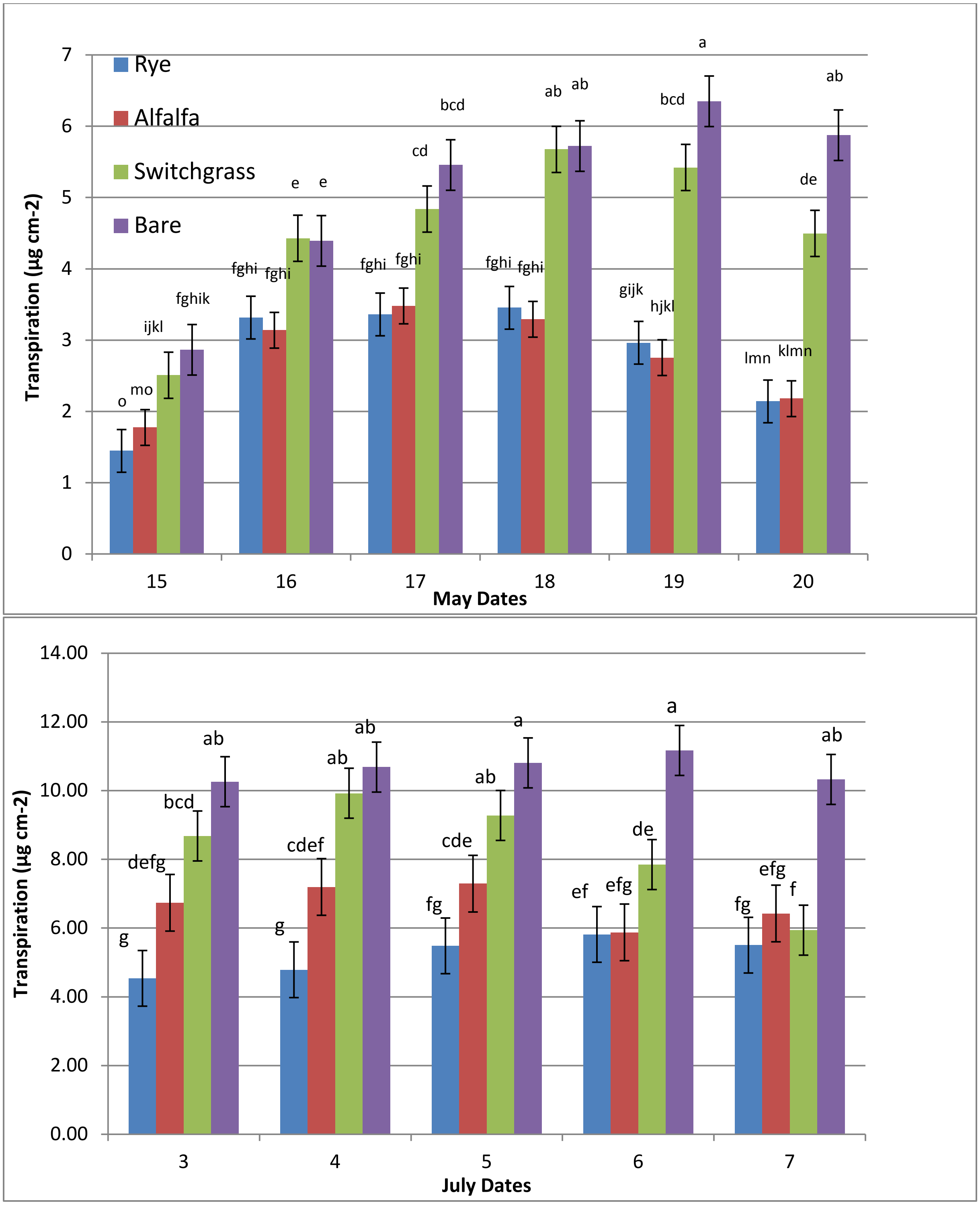


Figure 3.16 Mean foliar transpiration rates of seedlings between groundcovers during days in the May (top) and July (bottom) dry-down periods. Means ± standard errors are shown for treatment main effects. Different letters represent statistically different means within individual days ($P<0.05$). The first date shown is the first day of the dry-down period.

3.2.2 Ground cover effects on Soil Moisture

Differences in oak transpiration rate between ground cover treatments were primarily the result of soil moisture differences. 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 (Figure 3.17).

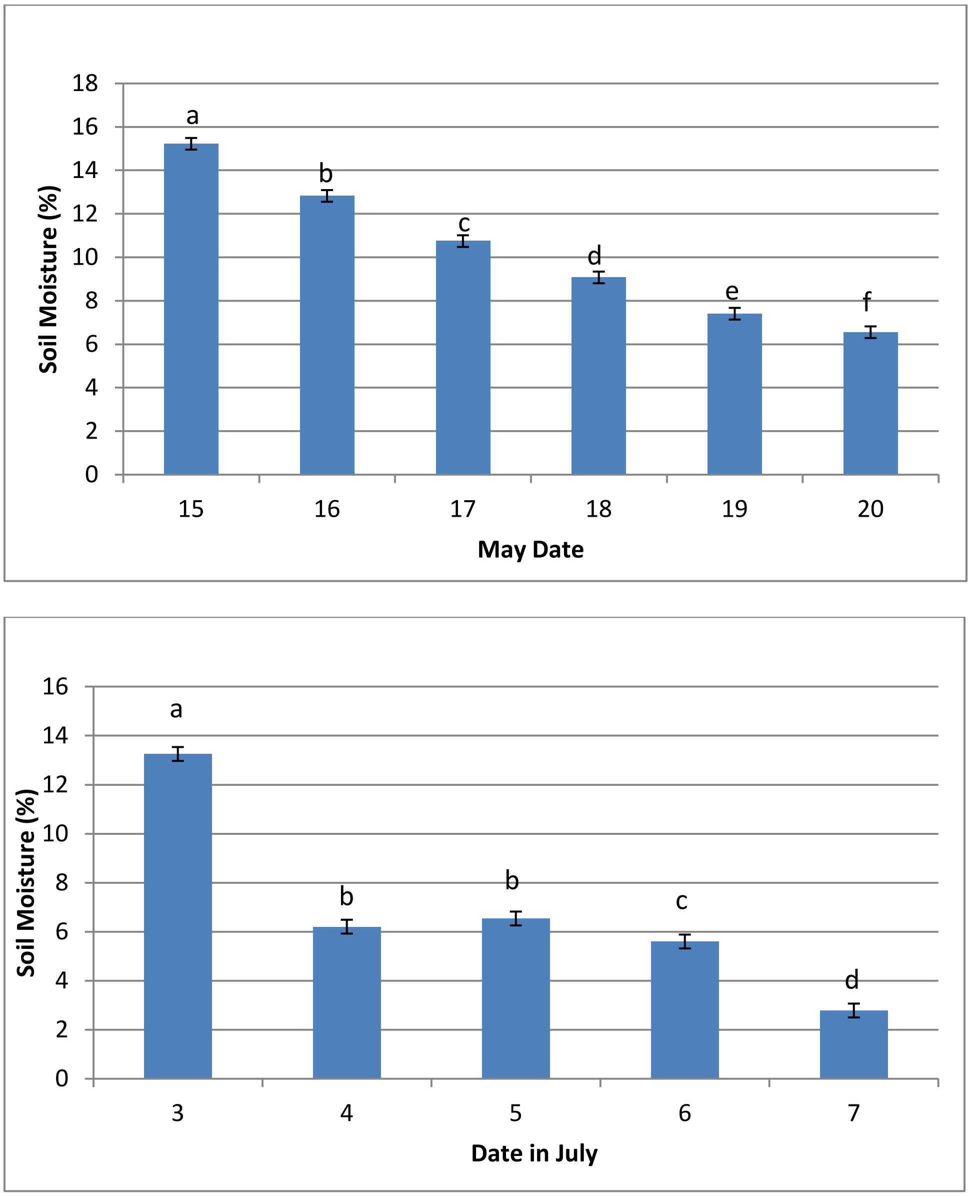


Figure 3.16 Mean soil moisture across all groundcovers during days in the May (top) and July (bottom) dry-down periods. Different letters represent statistically different means within individual days (P<0.05). The first date shown is the first day of the dry-down period.

Soil moisture also varied significantly ($p<0.0001$ for both periods) between groundcover types during both dry-down periods (Figure 3.17). During both dry-down periods, the bare treatment had the highest percent soil moisture, and the ryegrass 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.

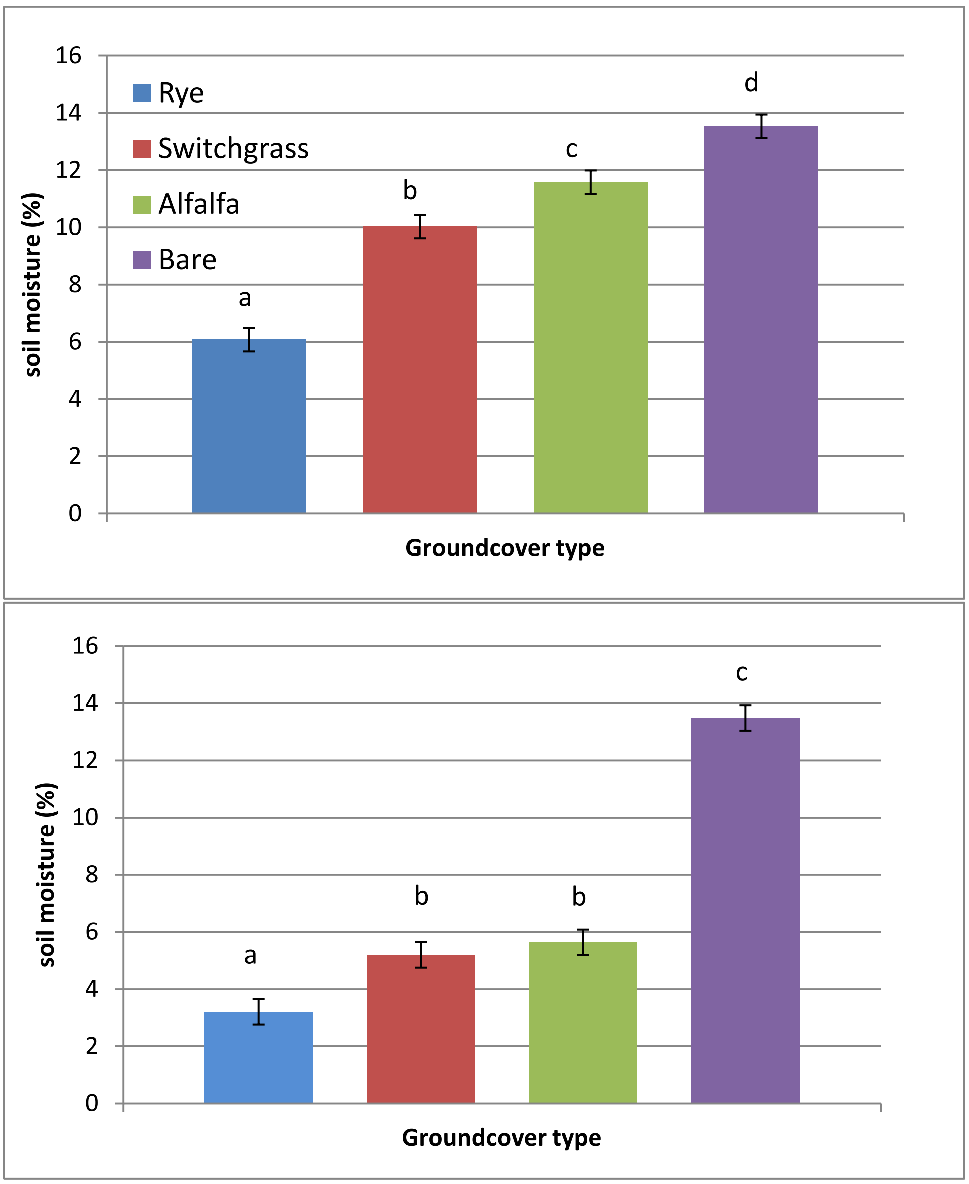


Figure 3.16 Mean soil moisture in pots containing an oak seedling with one of four groundcover treatments during dry-down periods. Different letters represent statistically different means within individual days ($P<0.05$).

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 ryegrass treatments (Smart and Moser 1997)). 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. Increasing temperatures can cause increased rates of evaporation from soils and transpiration from the seedlings and groundcovers, resulting in loss of water from the soil.

3.2.3 Ground cover effects on oak roots

Fine root mass of northern red oak trees was significantly different between the various ground cover treatments (p=0.0215) (Figure 3.17). Trees in the alfalfa and bare treatments had the greatest dry weight of fine roots. The two treatments were not statistically different from each other but were different from the annual ryegrass treatments. Trees in the switchgrass treatment were not significantly different from any of the other treatments. Annual ryegrass treated trees had the lowest mass of fine roots.

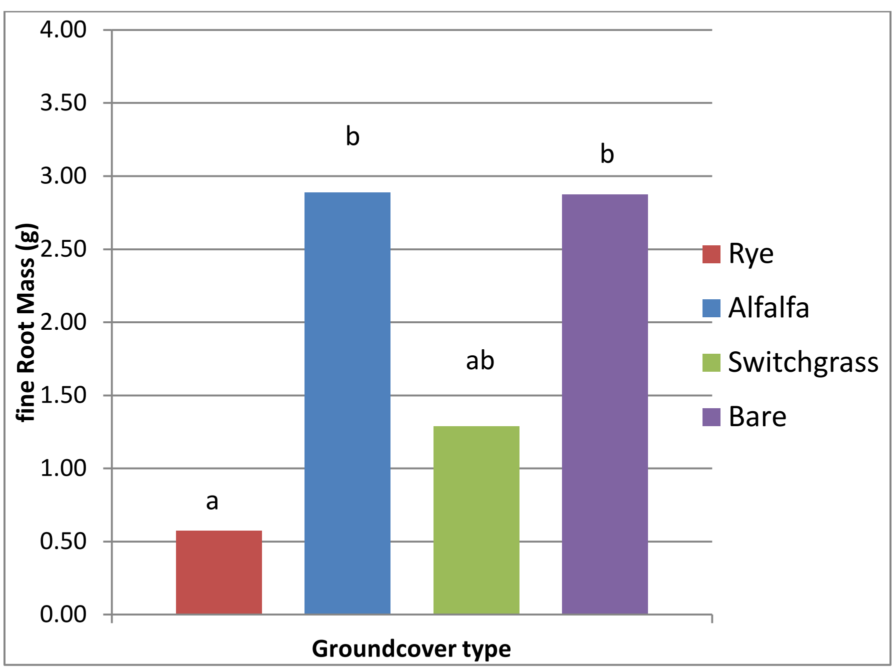
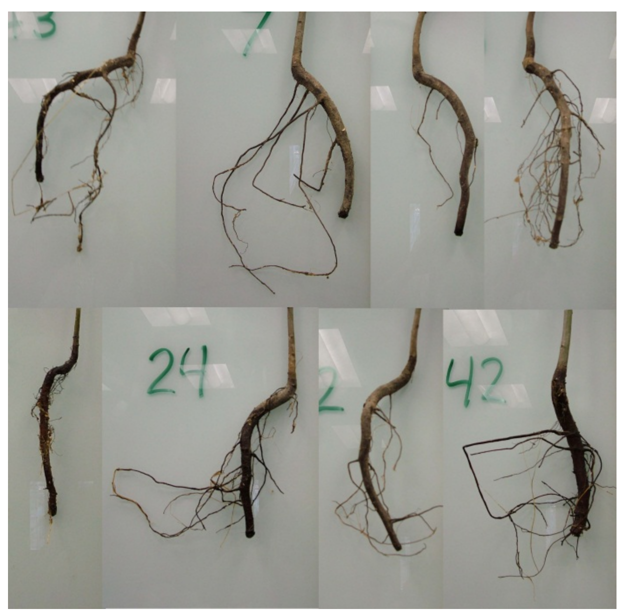


Figure 3.17 Mean fresh fine root mass of oak seedlings grown in one of four ground cover treatments. Different letters indicate a significant difference between treatments.

Bare ground

Switchgrass

Alfalfa



Annual Ryegrass

Figure 3.18 Root systems of oak seedlings grown in four different ground cover treatments.

When planted the bare-root seedlings had very few fine roots, therefore the mass of fine roots is thought to approximate root biomass production over the course of the experiment. Fine root mass of northern red oak was highest in the alfalfa and the bare ground treatments which shows that alfalfa may not be competing heavily with the tree for below-ground resources. Annual ryegrass-treated trees had the lowest fine root mass, and showed little to no development of fine roots over the growth period. A lack of fine roots inhibits the tree's ability to absorb nutrients (Chang et al. 2002). The lack of root growth may have been due to soil resources being limited. Annual ryegrass has been noted to establish quickly and grow rapidly, with heavy use of nitrogen and water. Kolb et al. (1990) found a reduction in root growth in northern red oak seedlings exposed to lower soil moisture and nutrient availability. This is supported by the soil moisture results.

Fine root mass, soil moisture, and transpiration are all inter-related. Water is pulled up from the pots by evaporation or by the plants. It is then released through the leaves during transpiration. Transpiration is a function of a plant that impacts growth since it relates to the creation of energy in a plant. Schenk and Jackson (2002) found that root system size decreased with increasing potential evapotranspiration. This study showed a clear relationship between these factors. Trees grown with annual ryegrass had lower fine root mass, lower soil moisture, and lower transpiration indicating that annual ryegrass is highly competitive with northern red oaks for water resources. Switchgrass and alfalfa showed few differences. Trees grown with alfalfa had a greater mass of fine roots, but had lower transpiration and soil moisture compared to trees grown with switchgrass.

CONCLUSION

Based on the results of field and greenhouse studies, both alfalfa and switchgrass appears to be compatible ground cover species for reforestation, while annual ryegrass is not. Alfalfa established well, and proved to inhibit the growth of hardwoods to a minimal extent, even when ground cover was dense. Alfalfa was also found to promote the establishment of volunteer ground cover species, and so seeding at a low rate may be sufficient to facilitate the process of natural succession. Switchgrass was also found to be a tree-compatible ground cover. It has a delayed establishment which gives the tree time to establish. Because switchgrass does not compete to any great extent for water resources, it is recommended as a cover species for reforestation on fairly dry sites. Neither of these perennial species establishes quickly enough to control sediment movement in the first year of reclamation, and an annual cover crop should be seeded along with the perennial species. However we found annual ryegrass to be highly competitive for water, and inhibited the growth of tree roots. Further research is needed to identify an annual ground cover species that is more compatible with tree seedlings. The upper layers of soil can be dry enough to limit tree establishment, particularly on the upper portion of the slope. At high densities, shallowly-rooted ground covers such as annual ryegrass will decrease soil moisture, and increase the likelihood of seedling mortality. Tree species that are intermediate in shade tolerance may perform better than shade-intolerant species where moderate levels of ground cover are desired.

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APPENDIX 1: Fact sheet

Reforestation of Steep Reclaimed Slopes in Appalachia: Forest Establishment and Function

J.A. Franklin, D.S. Buckley, A. Klobucar, E. Aubuchon

Department of Forestry, Wildlife and Fisheries, University of Tennessee

Project Description and Objectives: The goal of this technology transfer project was to improve our understanding of tree-compatible ground covers through field and greenhouse tests, and to promote the use of tree-compatible ground covers for reforestation. On the steep slopes of the Appalachian region, herbaceous ground covers are seeded during reclamation of coal mines, but these can hinder establishment of planted tree seedlings. This project identified two tree-compatible ground cover species, and documented the effect of ground covers on soil moisture and on tree seedling establishment. The results presented will help reclamation experts to select appropriate ground covers for sites with a land-use goal of forestry.

Applicability to Mining and Reclamation:

The short-term goal of reclamation to a land use of forestry is to establish vegetation that will control erosion, and jump-start succession toward a productive forest ecosystem capable of supporting multiple land uses. The selection of ground cover species may be important for ecosystem development, but prior to this project there was little information available on the influence of ground cover species on tree establishment. Recommended ground cover mixtures have been based on experience and observation. The need for less aggressive ground covers for reforestation has been expressed by researchers and regulatory agencies, along with a desire to base recommendations on scientific evidence. This study is among the first to clearly demonstrate that the choice of ground cover species has significant effects on tree establishment, soil moisture profiles, and the speed of natural succession on reclaimed mine sites. This knowledge, and the potential of alfalfa and switchgrass for reforestation, can be applied across the region and should be tested in other areas of the country in which these species grow. Information on species establishment can be applied regionally. This will allow reclamationists to better match tree species to site and slope position, improving reforestation success.

Methodology:

Northern red oak, black cherry, shagbark hickory and American chestnut were planted on plots without seeded ground cover, or seeded with switchgrass or alfalfa, on 3 reclaimed mine sites. In the greenhouse, northern red oak seedlings were grown with switchgrass, alfalfa, or annual ryegrass. Tree growth, root growth, soil moisture, and the density of planted and volunteer species were measured.

HIGHLIGHTS:

Results/Findings:

Ryegrass had the most negative influence on the growth of oak roots, and on soil moisture, while alfalfa had the least influence. In the field, survival of the two shade-intolerant tree species was reduced by ground cover, while the survival of seedlings of intermediate tolerance was improved by the presence of ground cover. The development of herbaceous ground cover was more rapid in plots seeded with alfalfa.

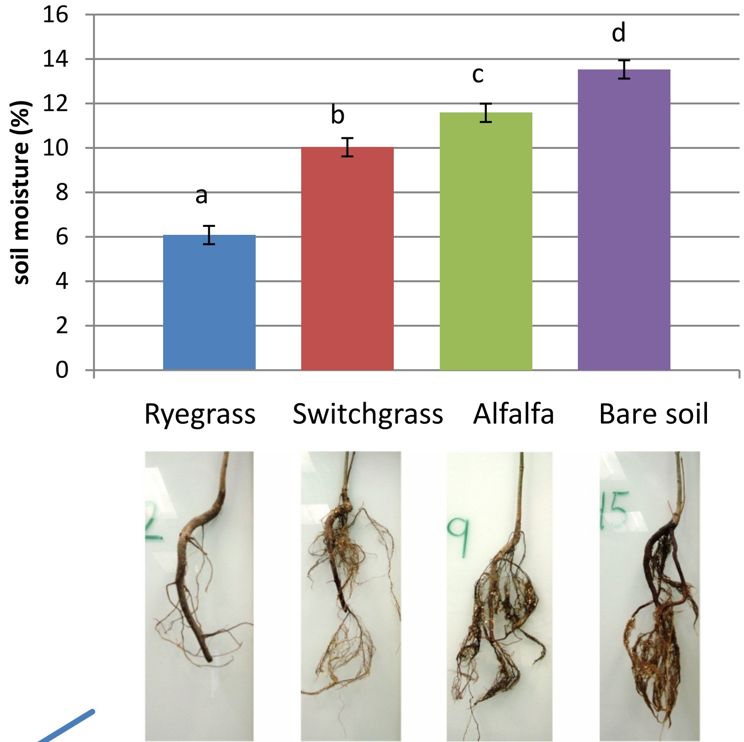

Figure 1. A comparison of soil moisture (top) and the growth of oak roots (photos) in three herbaceous covers and in bare ground.

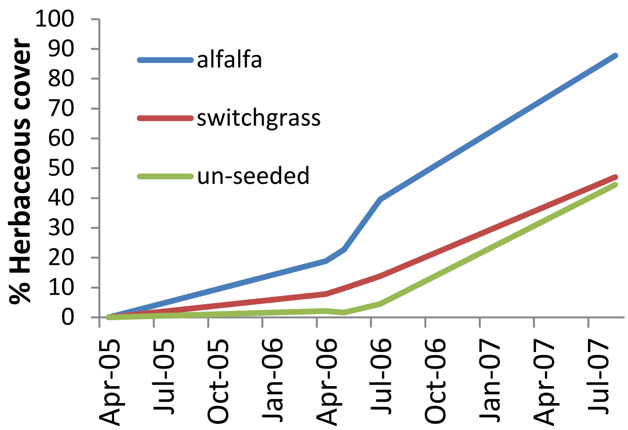

Figure 2. Development of ground cover on field plots, which includes both seeded and volunteer species.

Website
http://fwf.ag.utk.edu/physlab/index.html

Information: The final project report can be found at http://www.techtransfer.osmre.gov

Principal Investigator: Jennifer Franklin and David Buckley **Location/affiliation** University of Tennessee, Knoxville, TN 865-974-2724, 865-974-7978 **jafranklin@utk.edu**, **dbuckley@utk.edu**	*OSM* Project Technical Representative: **Victor Davis** Phone number: (865) 545-4103 Email address: vdavis@osmre.gov