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Evaluation of Reforestation Efforts on Two Reclaimed Surface Mines in West Virginia

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ABSTRACT

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Coal mining has disturbed approximately 2.4 million hectares (6 million acres) since 1930 in the United States. West Virginia is located in the Eastern Coal Region where surface mining has disturbed large areas of eastern deciduous forest. As coal operators and land owners are moving toward restoring forests on mined lands, techniques are being developed and tested to increase tree survival and growth to ensure disturbed land is converted back to forest in a timely fashion. To aid in successful reforestation, the Office of Surface Mining Reclamation and Enforcement adopted reclamation techniques called the Forestry Reclamation Approach which provides recommendations on substrate selection, grading, ground covers, tree species selection, and proper tree planting. This study was implemented to provide additional scientific data on the implementation of these techniques especially related to substrate selection. Studies were conducted at Catenary Coal's Samples mine in Kanawha County, WV and ICG Eastern, LLC's Birch River mine in Webster County, WV. Both of these sites have been surface mined for coal and reclaimed using either Commercial Forestry or Forestry post mining land uses. Following FRA guidelines, demonstration plots were constructed at both locations; 2005 at the Samples mine and 2007 at Birch River. Demonstration plots at the Samples mine had treatments of substrate (brown vs. gray), depth of substrate (1.2 m vs. 1.5 m), and compaction (compacted vs. noncompacted), while plots at Birch River had treatments of substrate (brown vs. gray), bark mulch (with vs. without), and hydroseeding (with vs. without). After final construction of the plots, a mixture of hardwood trees was planted at both sites. The objectives of this research were to assess physical and chemical properties of mine soils after three years at ICG and five years at Samples, and to determine tree volume and survival in various treatment combinations. Gray sandstone substrates at both sites had high pH ranging from 7.7 to 8.3 while brown substrates pH ranged from 4.4 to 5.4, which were consistent throughout the study at both sites. After five years at Samples, there were only a few significant changes in soil properties and extractable element concentrations. Electrical conductivity decreased in all treatment combinations with the exception of the 1.2 m brown sandstone noncompacted (4B-NC) with totals ranging from 0.10 to 0.53 dS m^{-1} and decreases ranging from 0.10 to 0.40 dS m^{-1}. Extractable potassium concentrations ranged from 0.17 to 0.20 $cmol_c$ kg^{-1} in 2005 and 0.05 to 0.10 $cmol_c$ kg^{-1} in 2009 with significant decreases in all treatment combinations. After five growing seasons at Samples, the average survival across all tree species was 66% with an average volume of 1328 cm^3. No significant differences were found for total tree survival between substrate, compaction and depth treatments. Survival by species ranged from 50% for white pine to 77% for black locust. Trees in the brown sandstone substrates had significantly greater volume at 1840 cm^3 compared to 176 cm^3 in the gray sandstone. Black locust significantly outperformed all other species with a volume of 7361 cm^3 while the species with the next closest volume was black cherry at 998 cm^3. After three years at Birch River, the gray sandstone treatments and treatments with bark mulch had a soil pH of 7.2 to 8.0, while brown sandstone treatments without bark mulch had a soil pH of 4.6 and 4.9. Electrical conductivity was significantly higher in treatments that received bark mulch. After three growing seasons at Birch River, average tree survival across all species was

69% and there were no tree survival differences between substrate, bark mulch, or hydroseeding. Average survival across all trees in all treatment combinations ranged from 41% for sycamore to 85% for sugar maple. Trees planted in brown sandstone had significantly greater volume of 313 cm^3 compared to gray sandstone at 100 cm^3. Black locust outperformed all other tree species with a volume of 806 cm^3 with the next closest species being tulip poplar at 319 cm^3.

In a separate study at Samples, four bulk density measurement techniques were used to determine bulk density in five substrates (four sandstone mine soils and one unmined native forest soil) and comparisons for accuracy and in-field efficiency were made among the four techniques. The techniques used were the frame apparatus, polyurethane foam, radiation, and sand-cone techniques. Bulk density measurements ranged from 1.35 to 1.76 g cm^{-3} for the four measurement techniques. Bulk density in the unmined native forest soil was significantly lower than the four sandstone substrates and no significant differences were found among the four sandstone substrates. The unmined native forest soil had a bulk density that was approximately 38 to 43% lower than the sandstone substrates. Bulk density ranged from 1.05 to 1.84 g cm^{-3} in the five substrates. The bulk density determined by the sand-cone technique was significantly lower than the other three determination techniques and no significant differences were found among the frame, polyurethane foam, and radiation techniques. The sand-cone technique produced a bulk density that was approximately 18 to 23% lower than the other techniques used. Significantly different in-field efficiency times were recorded for each of the four determination techniques. The radiation technique had the greatest in-field efficiency (345 s) while the frame had the lowest (1605 s) with the polyurethane foam and sand-cone techniques being intermediate between the two (612 and 837 s).

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CHAPTER 1. INTRODUCTION AND OBJECTIVES

Introduction

Two important industries in West Virginia are timber harvesting and coal mining. Both play vital roles in the economy, employment, and social and cultural history of the state. West Virginia is the third most forested state in the U.S., which allows timber harvesting and the production of wood products throughout much of the state. Forest related-industries employ over 30,000 individuals and contribute $3.2 billion dollars annually into the state economy (West Virginia Forestry Association, 2008). Mining for coal has been practiced commercially in West Virginia since the first commercial mine was established in 1834 (West Virginia Office of Miners' Health Safety and Training, 2010). In 2009, 144 million tons of coal were mined, and the coal industry employed over 30,000 workers through mining and supporting industries, with $3.5 billion dollars contributed to the state economy (West Virginia Office of Miners' Health, Safety and Training, 2010). Together coal mining and timber harvesting contribute substantially to the economic stability of the state by providing a combined $6.7 billion dollars to West Virginia's gross state product. This means that mining, forestry, and their supporting industries contributed an estimated 11% of West Virginia's 2008 gross state product of $61.6 billion dollars (Bureau of Economical Analysis, 2009). This reveals the importance of the two industries in the West Virginia economy.

Coal mining has disturbed approximately 2.4 million hectares (6 million acres) since 1930 in the United States (Skousen et al., 2006). Early surface mining disturbed large areas of land but left it in a condition that was favorable for natural invasion and reestablishment of forest species. This was because no laws existed for compaction of the surface or for seeding herbaceous species to cover the ground. Therefore, the resulting mine soils were deep, nontoxic, loose and porous (noncompacted), and void of dense herbaceous competition (Torbert and Burger, 2000). This began to change as regulations in the 1940's started to call for the reclamation of mined lands. From the 1940's to 1977, regulations evolved into requiring more grading of the surface to create smooth landscapes and the seeding of ground cover to control erosion. A federal mining law titled the Surface Mining Control and Reclamation Act (SMCRA, 1977) was eventually passed in 1977.

SMCRA regulations require coal operators to reclaim land in a timely manner to conditions that are capable of supporting the same uses or higher and better uses than were supported before any mining occurred (Sect. 816.133). SMCRA states that coal operators must establish a vegetative cover that is diverse, effective, and permanent, and capable of stabilizing the soil surface from erosion (Sect. 816.111). The interpretation of SMCRA by mine regulators and operators led to pasture and hayland being the dominant types of post mining land use and reclamation practices were developed to optimize forage production. However, in many areas of Appalachia, reclaimed surface mines are remote and these pastures and haylands go unmanaged and provide little economic benefit to the land owner (Torbert and Burger, 2000).

Starting in the late 1990's, operators at the insistence of landowners began to restore forest on lands that were disturbed by mining (Torbert and Burger, 2000). However, current reclamation practices and interpretations by regulators made reforestation on mined lands difficult due to heavy soil compaction and the seeding of aggressive herbaceous ground covers. With this knowledge in mind, the Appalachian Regional Reforestation Initiative (ARRI) was formed to encourage and support the restoration of high quality forests on reclaimed coal mines in the eastern United States (Angel et al., 2005). ARRI emphasized the Forestry Reclamation Approach (FRA), which is a method for reclaiming coal-mined land under SMCRA to forest and is based on knowledge gained from both scientific research and experience (Angel et al., 2005). The FRA consists of five steps and is achieved by:

1) creating a suitable rooting medium for good tree growth that is no less than 1.2 m deep and comprised of topsoil, weathered sandstone, and/or the best available material;

2) loosely grading the topsoil or topsoil substitutes to create a non-compacted growth medium;

3) using ground covers that are compatible with growing trees;

4) planting two types of trees (early succession species for wildlife and soil stability and commercially valuable crop trees) and;

5) using proper tree planting techniques (Burger et al., 2005a).

Utilizing the five steps of the FRA can lead to successful establishment and growth of trees on reclaimed surface mines.

Surface mining in West Virginia is regulated by the West Virginia Surface Mining Reclamation Rule (WVDEP, 2002). Under this rule, two types of post mining land use, Commercial Forestry and Forestry, focus on restoring forests after mining. Commercial Forestry and Forestry post mining land uses are defined in subsection 2.31 of the West Virginia Surface Mining Reclamation Rule. In subsection 2.31.a., Commercial Forestry is defined as a long-term post mining land use designed to:

1) achieve greater forest productivity than that found on the mine site before mining;

2) minimize erosion and/or sediment yield and serve the hydrologic functions of infiltrating, holding, and yielding water commonly found in undisturbed forests;

3) result in biodiversity by facilitating rapid recruitment of native species of plants and animals via the process of natural succession;

4) result in a premium forest that will thrive under stressful conditions and;

5) result in landscape, vegetation and water resources that create habitat for forest-dwelling wildlife.

In subsection 2.31.b., Forestry is defined as a long-term post mining land use for the production of wood or wood products designed to:

1) achieve forest productivity equal to that found on the mine site before mining;

2) minimize erosion and/or sediment yield and serve the hydrologic functions of infiltrating, holding, and yielding water commonly found in undisturbed forests;

3) result in biodiversity by facilitating rapid recruitment of native species of plants and animals via the process of natural succession and;

4) result in landscape, vegetation and water resources that create habitat for forest dwelling wildlife.

In order to achieve the intended outcome of Commercial Forestry and Forestry postmining land uses, certain steps for each must be followed. For Commercial Forestry, the final surface material used as the planting and growth medium shall consist of a minimum of 1.2 m, and an average of at least 1.5 m, of soil or a mixture of materials consisting of no less than one-third soil and two-thirds selected overburden materials or soil substitutes, and for forestry areas, the final surface material used as the planting and growth medium shall consist of a minimum of 1.2 m, or a mixture of soil and suitable soil substitutes (Section 7.4.b.1.D.8-9.) due to the limited depth of topsoil that is present before mining (WVDEP, 2002). This often means coal operators must use a soil substitute consisting of weathered brown sandstone which comes from within 5 to 10 m of the soil surface. The weathered brown sandstone must be removed from the surface at the beginning of the mining process and stock piled on the mine site out of the way of production. This equals added handling and labor costs that must be incurred by the coal operator. As a result, operators have preferred using the bottom most overburden layer (the material just above the lowest extracted coal seam) usually consisting of unweathered gray sandstone as the soil substitute.

There are a variety of overburden materials available when reclaiming surface mined land and the choice of material used for mine reclamation can often dictate the performance of the chosen post mining land use. SMCRA states that operators must demonstrate that the soil medium used is equal to or better than premining soil for sustaining vegetation, and is the best available material to support vegetation (Sect. 816.22 in SMCRA). Sandstone, siltstone, and shale are commonly present in overburdens on mined lands in West Virginia and are used as topsoil substitutes. Torbert et al. (1990) conducted a greenhouse study with sandstone, siltstone, and mixtures of both and found that pines planted in sandstone had five times greater volume than those planted in siltstone. They also found as siltstone proportion increased in the substrate, the growth of trees decreased. Similar results were also found by Casselman et al. (2006) in a field study across Virginia, West Virginia, and Ohio in which survival and growth were better on sites derived from sandstone as opposed to siltstone and shale. In West Virginia, there are two types of sandstone most commonly available for reclamation purposes, weathered brown sandstone and unweathered gray sandstone. In many research studies, weathered brown sandstone was shown to produce trees with significantly greater growth than unweathered gray sandstone (Emerson et al., 2009; Showalter et al., 2010). In an attempt to benefit from the availability of the unweathered gray sandstone and the favorable properties for growth found in the weathered brown sandstone, researchers have conducted studies by mixing the two substrates together. Angel et al. (2008) found that the survival of white oak, red oak, tulip poplar, and green ash were significantly lower in mixed sandstone than brown sandstone but found that the trees had significantly greater height and volume in weathered brown sandstone followed by the mixture and then unweathered gray sandstone. Opposite results for survival were found for American chestnut trees in which the highest survival (100%) was found in a mixture of weathered and unweathered sandstones (French et al., 2007).

The physical and chemical properties of the final planting substrate depend on the overburden material that is left at the surface after reclamation and those properties can vary widely across materials. Some commonly analyzed physical properties and the ranges that can be found in mine soils include: rock fragment content from 2 to 88%, pH from 3.2 to 8.5, electrical conductivity from 0.02 to 4.72 dS m^{-1}, bulk density from 0.61 to 1.94 g cm^{-3}, (Andrews et al., 1998; Emerson et al., 2009; Showalter et al., 2007). In addition, some commonly analyzed chemical properties and the ranges that can be found in mine soils include: elemental concentrations for P from 0.92 to 34.86 mg kg^{-1}, K from 2 to 161 mg kg^{-1}, Ca from 5 to 1426 mg kg^{-1}, Mn from 1.5 to 57.7 mg kg^{-1}, and Fe from 0.05 to 138.9 mg kg^{-1} (Andrews et al., 1998; Emerson et al., 2009; Showalter et al., 2007). These parameters are important in many aspects of establishing and growing trees on surface mined lands. Many of these factors can change rapidly after reclamation as the overburden material weathers over time and soil formation begins. The chemical properties of the materials can become equal to or better than native unmined soils (Bussler et al., 1984; Haering et al., 1993; Haering et al., 2004).

The weathered brown sandstone and unweathered gray sandstone overburden materials commonly used in reclamation of surface mines in West Virginia have some distinctly different characteristics. Weathered brown sandstone is often more acidic with a pH of 4.3 to 6.5 while unweathered gray sandstone typically has a pH of 7.6 to 8.5 (Angel et al., 2008; Emerson et al., 2009). This is important when looking at past research and the pH requirements of species found on mine sites and could be a predictive factor as to the species that will most likely colonize the site. Skousen et al. (2006) found that nonreclaimed mine sites with soil pH <5 were most commonly dominated by trees, while sites with pH >5 were dominated by herbaceous plants. This shows the importance of choosing a material with a pH that would be more favorable to trees to limit competition by herbaceous plants.

Percent rock fragments are also a parameter that is often different between brown and gray sandstone materials. Weathered brown sandstone has been shown to have rock fragment contents of 36 to 63% while unweathered gray sandstone if higher at 60 to 71% (Emerson et al., 2009). High rock fragment contents can produce mixed results on tree growth depending on the texture of the surrounding soil. High rock fragment contents in fine textured soils can increase the penetration of air and water to plant roots, but in coarse textured soils high rock fragment contents can result in a lower water holding and exchange capacity (Fisher and Binkley, 2000). Rodrigue and Burger (2004) found that the relationship of rock fragment content and water holding capacity to be the second and third most important factors in the productivity of mined lands planted with trees.

An additional parameter found to be important when discussing the productivity of these materials for trees is electrical conductivity (EC) (Andrews et al., 1998; Rodrigue and Burger, 2004). Electrical conductivity is used as a measure of the concentration of soluble salts found in the substrate material. Some research shows that EC is significantly different between weathered brown sandstone and unweathered gray sandstone; however, this varies greatly across studies. Electrical conductivity is important to the growth of trees though and levels of 2 dS m^{-1} are thought to be marginally detrimental and levels of 3 dS m^{-1} are considered toxic for plants on mined lands (Cummins et al., 1965).

After the passage of the Surface Mining Control and Reclamation Act of 1977, the majority of surface mined land in WV was reclaimed to pasture and hayland. For this type of reclamation, the land is often reclaimed by heavily compacting soils for stabilization, to minimize erosion, and to provide a good seed bed for pasture and hayland seeds. This heavy compaction has been referenced to be the most limiting factor in reclamation using trees on post SMCRA reclaimed lands (Larson and Vimmerstedt, 1983). Heavy soil compaction affects the tress mainly by impacting root growth. Compacted soils can lead to an increase in the soil resistance to penetration, poor aeration, slow movement of nutrients and water, and the buildup of toxic gases around the roots (Brady and Weil, 2002). Soil compaction can be limited if the soil is replaced by end-dumping the soil and minimizing travel of equipment over the soil surface at the start of reclamation (Sweigard et al., 2007a). Research has shown that by end-dumping the overburden material and minimizing grading, tree survival and growth is significantly better when compared to compacted sites (Angel et al., 2006; Michels et al., 2007; Torbert and Burger, 1990; Zeleznik and Skousen, 1996).

Another important aspect of reclamation with trees is the amount and type of ground cover on the site. State and federal regulations require coal operators to establish a vegetative cover that is diverse, effective, and permanent, and capable of stabilizing the soil surface from erosion (Sect. 816.111). Torbert and Burger (2000) state the use of dense herbaceous ground cover as being one of the main hindrances of tree establishment on mined lands. This effect of herbaceous ground cover on tree performance on surface mined lands has been extensively researched. Research has demonstrated that survival, height, and/or volume of trees show significant increases as competing vegetation is decreased through chemical control or by not being present (Ashby, 1997; Burger et al., 2005b; Burger et al., 2008; Chaney et al., 1995; Fields-Johnson et al., 2008; King and Skousen, 2003; Rizza et al., 2007; Skousen et al., 2006; Torbert et al., 1985; Torbert et al., 2000). Aggressive herbaceous ground cover such as K-31 tall fescue (*Festuca arundinacea* L.), red clover (*Trifolium pratense L.),* and sericea lespedeza (*Lespedeza cuneata L.)* impact trees by interfering with tree establishment, and by competing for light, nutrients, and water as well as providing cover for rodents that can girdle and kill young trees, or by attracting wildlife which can browse the trees (Torbert and Burger, 2000). The primary way to minimize these interactions from occurring is to plant tree compatible ground covers (Burger and Zipper, 2002; Burger et al., 2009; Skousen and Zipper, 2009). Species like birdsfoot trefoil (*Lotus corniculatus* L.*)*, ladino clover (*Trifolium repens* L.*)*, red top (*Agrostis gigantean* L.*)*, and perennial ryegrass (*Lolium perenne* L.) can be planted during initial reclamation and are less competitive but will still provide cover that meets regulations. Aside from the substrate present or the ground cover used, the suitability and productivity of mine soils for trees can be influenced with the addition of soil amendments.

Aside from the substrate material and ground cover used for reclamation, the suitability and productivity of mine soils for trees can be influenced with the addition of soil amendments. Bark mulch, or wood waste, is an organic mulch that can often be acquired from sawmills and timbering operations and used on mined land as an amendment (Falk, 1997; Norland, 2000). Research has shown that the surface application of bark mulch significantly increases the survival and height of trees planted in mine soils (Angel et al., 2006; Ringe, 1988; Ringe et al., 1989). Schoenholtz et al. (1992) found that incorporating wood chips into the mine soil also showed a significant increase in tree growth. The addition of bark mulch has also been shown to be effective in the control of erosion when applied to the soil surface at depths >2 cm, which can decrease the need for vegetative cover for erosion control (Demars et al., 2000). Bark mulch increases suitability and productivity of mine soils for trees but it does not significantly alter mine soil physical properties such as bulk density, maximum penetration depth, penetration resistance, and total pore space (Conrad et al., 2008; Plass, 1982). Overall, bark mulch can be used to (i) prevent the loss of water from evaporation, increase water-holding capacity of the soil, and increase surface wetness; (ii) aid in soil stabilization by reducing surface erosion; (iii) increase soil organic matter; (iv) reduce soil surface temperature extremes; (v) decrease surface crust formation; (vi) increase structural stability and permeability of soil; and (vii) reduce germination and growth of weeds (Norland, 2000). In addition to the substrate material, ground cover, and any amendments that are used during reclamation, certain species of trees must be included when reclaiming to Commercial Forestry or Forestry post mining land uses.

Section 7.4.b.1.H.1. of The West Virginia Surface Mining Reclamation Rule (WVDEP, 2002) outline the species requirements for Commercial Forestry and Forestry post mining land uses. Tree species selection shall be based on site-specific characteristics and long-term goals outlined in the forest management plan. For Commercial Forestry, all areas suitable for hardwoods must be planted with native hardwoods at a rate of 500 seedlings per acre in continuous mixtures across the permitted area with at least six species from the following list: white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.), northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), white ash(*Fraxinus americana* L.), tulip poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), cucumber magnolia (*Magnolia acuminata* L.), black walnut (*Juglans nigra* L.) , sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), or native hickories (*Carya spp.*). For Forestry all areas suitable for hardwoods must be planted with native hardwoods at a rate of 450 seedlings per acre in continuous mixtures across the permitted area with at least three or four species from the following list white oak, chestnut oak, northern red oak, black oak, white ash, tulip poplar, basswood, cucumber magnolia, black walnut, sugar maple, black cherry, or native hickories. Each of these species and many other species used for reclamation have varying growth habits and site requirements that are needed to achieve optimum performance.

Black cherry is a valuable timber species in West Virginia and the Appalachian region and is most often used for furniture and interior finishing (Fralish and Franklin, 2002; Hough, 1936). It's considered a medium-sized tree that commonly attains heights of 12 to 30 m with a diameter up to 1.5 m, depending on site quality and surrounding trees (Preston, 1989; Harlow, 1935a; Hough, 1936). Black cherry is a relatively shade intolerant species and grows rapidly through the seedling and pole stages, which generally leads to it overtopping surrounding species such as sugar maple or American beech (Fralish and Franklin, 2002; Marquis, 1990; Preston, 1989). It grows best on rich, moist sites but throughout its range it's found on sites that are strongly acid, relatively infertile, and have high coarse fragment content (Harlow, 1935a; Marquis, 1990).

Black locust (*Robinia pseudoacacia* L.) has been extensively planted on surfaced mined lands throughout Appalachia for erosion control, nitrogen fixation, and revegetation (Fralish and Franklin, 2002; Huntley, 1990). It's a medium-sized tree that commonly attains heights of 12 to 24 m with a diameter up to one meter (Core, 1959; Harlow 1953a). It's a shade intolerant species that grows best on rich, moist limestone soils (Huntley, 1990; Preston, 1989). In those rich, moist limestone soils, black locust can attain an increase in height of approximately one meter per year and an increase in diameter of 1.3 cm per year but the growth rate declines quickly after 20 to 30 years of age (Harlow, 1953a). However, black locust is capable of colonizing harsh sites with the exception of poorly drained, heavily compacted, and excessively dry sites (Hicks 1998; Huntley, 1990).

Dogwood (*Cornus racemosa* Lam.) is a species with some commercial value but it's chiefly planted on surface mines as a wildlife tree in which birds, squirrels, and other wildlife feed on its berries (Core, 1959). It's a small tree that commonly grows to heights of 5 to 13 m with a diameter of approximately 0.4 m (Core, 1959; Fralish and Franklin, 2002). It's considered a slow growing tree and is often found thriving in the shade of other trees (Core, 1959; Hough, 1936). It grows on deep moist soils along streams to well-drained upland soils but does not grow well on upper slopes and ridges (McLemore, 1990). Skousen et al. (2006) found that dogwood grows well on surface mined lands and will colonize as a volunteer. However, Skousen's (2006) study site was 22 years of age which could indicate that dogwood is more likely to move into an area and have success after a forest canopy is established and the site conditions are more favorable.

White oak, one of the most valuable American hardwoods, is common throughout West Virginia and is used in furniture, veneer, railroad ties, and many other products (Core, 1959; Harlow, 1935a). It's considered a large tree that attains heights of 18 to 30 m with a diameter up to 1.2 m (Core, 1959; Harlow, 1935a). White oak is an intermediately shade tolerate species that is slow growing and often found with other oaks, hickories, and tulip poplar (Hicks, 1998, Hough, 1936). It grows well on a variety of soils and does best on north or east slopes and coves and does poorly on dry, shallow ridges, poorly drained flats, and wet bottom lands (Rogers, 1990).

Red oak is another species of tree that is common in West Virginia and Appalachia and is highly valued for interior furnishings and for a wildlife tree that provides hard mast (Core, 1959;

Hicks, 1998). It's considered a medium sized tree that commonly attains heights of 18 to 33 m with a diameter up to 1.2 m (Core, 1959; Fralish and Franklin, 2002; Preston, 1989). Red oak is a moderate to fast growing species that is moderately shade intolerant (Hicks, 1998; Preston, 1989). It grows in a variety of soil types from clay to loamy sands and soils with high rock fragment contents and can be found in coves, well-drained slopes, and rich uplands (Fralish and Franklin, 2002; Hough, 1936). It prefers deep, fertile, well drained soils on lower and middle slopes with northerly or easterly aspects (Harlow, 1935a; Sander, 1990).

Chestnut oak is a very common tree in the hilly sections of West Virginia and is often harvested and used for the same purposes as similar upland white oaks (Core, 1959). It's considered a large tree that commonly attains heights of 30 m with a diameter up to 1.0 to 1.3 m (Core, 1959; Fralish and Franklin, 2002). Chestnut oak is a slow growing species that is intermediately shade intolerant (Hicks, 1998; Preston, 1989). It grows in best on well-drained fertile bottomlands but it is usually found on poorer sites on exposed upper slopes and ridges (Harlow, 1935a).

Redbud (*Cercis canadensis* L.), much like dogwood, has little commercial value and is chiefly planted on surface mines as a wildlife tree and to add diversity to the types of trees planted (Core, 1959). It is often a shrubby species but can attain a height of 12 to 15 m with a diameter of 0.6 m (Hough, 1936; Preston, 1989). Redbud is a shade tolerant species and is often found in the understory amongst taller trees (Hough, 1936; Preston, 1989). It shows good growth on moist well-drained sites with pH of 7.5 and is common along drainages, coves, and hollows (Dickson, 1990; Fralish and Franklin, 2002).

Sugar maple is one of West Virginia's best known and valuable trees and is highly prized as a timber species for the production of flooring and furniture (Core, 1959; Preston, 1989). It is considered a large tree that commonly attains heights of 18 to 33 m with a common diameter of 0.9 m (Godman et al., 1990; Harlow, 1935a). Sugar maple is a shade tolerant species and due to often developing under a closed canopy is slow growing (Godman et al., 1990; Preston, 1989). It grows on a variety of soils from strongly acid (pH 3.7) to slightly alkaline (pH 7.3) and in sands, loamy sands, sandy loams, loams and silt loams (Godman, 1965). However, best growth is seen on moist, rich, well-drained loam or sandy soils (Harlow, 1935a; Hicks, 1998

Tulip poplar, one of the tallest eastern hardwoods, is found throughout West Virginia and is a highly valued timber species used for furniture, exterior and interior trim, and in some cases high value veneer (Beck, 1990; Core, 1959). It is a large tree that commonly attains heights of 24 to 58 m with a diameter of 1 to 2 meters and greater (Hough, 1936; Preston, 1989). Tulip poplar is a fast growing, very shade intolerant species that is often found as a mixture with other hardwood species (Preston, 1989). It grows on a variety of soil types, with the exception of very wet or very dry soils, and grows best, showing a preference for, cool, deep, moist sites (Hicks, 1998; Hough, 1936).

White ash is the most common ash found in West Virginia and most often harvest as a timber tree for use as tool handles, baseball bats, and furniture (Core, 1959; Hough, 1936). It is a medium sized tree and commonly attains heights of 15 to 25 m with a diameter of 0.6 to 1.2 m and under exception conditions can grow to 37 m with a diameter of 1.8 m (Core, 1959; Hough, 1936; Preston, 1989). White ash is an intermediately shade tolerant species that is fast growing but can take as long as 15 years to reach a height of 1.5 m while its root system is becoming established (Hicks, 1998; Preston, 1989; Schlesinger, 1990). Once its roots are established it can often out grow many of the surrounding trees. It grows best on deep, moist soils on north slopes and is found less commonly in sandy soils (Harlow, 1935a; Fralish and Franklin, 2002;

Schlesinger, 1990). White ash has been found to have exceptional survival and growth on mine soils by Skousen et al. (2009) and performed as well in our study.

White pine (*Pinus strobus* L.), one of the largest eastern conifers, is distributed sporadically throughout West Virginia and is typically used for construction purposes, box boards, and many other products (Core, 1959; Harlow, 1935b). It’s considered a large tree that commonly attains heights of 18 to 30 m with a diameter of 0.6 to 1.2 meter and exceptional specimens attain heights of 50 to 60 m with diameters of 1.5 m (Core, 1959; Fralish and Franklin, 2002; Hough, 1936). White pine is fast growing species that is relatively shade tolerant when young but becomes shade intolerant as it matures (Hicks, 1998; Preston, 1989). It grows across a variety of soils and generally grows well on moist, well drained sandy soils and does not grow well on clay soils where it is often out competed by hardwood trees (Harlow, 1935b; Wendel and Smith, 1990). White pine is particularly important in Commercial Forestry post mining land use as a measure of successful reclamation. In order to meet bond release requirements, it must attain increases in height increments equal to or greater than 0.46 m on average for four or more consecutive years. This study was initiated to determine the suitability of brown and gray sandstone substrate material for the survival and growth of trees used for Commercial Forestry and Forestry post mining land uses in West Virginia.

Objectives

Chapter 2: Samples Mine

a. Determine growth and survival of trees growing in weathered brown and unweathered gray sandstone substrates in compacted and noncompacted conditions.
b. Assess the physical and chemical properties of mine soils five years after reclamation.

Chapter 3: Birch River Mine

a. Determine growth and survival of trees growing in weathered brown and unweathered gray sandstone substrates with and without treatments of herbaceous ground cover and bark mulch.
b. Assess the physical and chemical properties of mine soils three years after reclamation.

Chapter 4: Bulk Density at Samples

a. Determine soil bulk density in mine soils composed of weathered brown sandstone and unweathered gray sandstone and to compare these to unmined native forest.
b. Compare four soil bulk density measurement techniques and evaluate their in-field-efficiency.

CHAPTER 2. SUBSTRATE AND COMPACTION EFFECTS ON TREE SURVIVAL AND VOLUME ON A RECLAIMED SURFACE MINE IN WEST VIRGINIA

Objectives

a. Determine tree growth and survival of weathered brown and unweathered gray sandstone substrates in compacted and noncompacted conditions.

b. Assess the physical and chemical properties of mine soils five years after reclamation.

Materials and Methods

This study was conducted at Catenary Coal's Samples mine (38°26′27′′ N, 80°36′33′′ W) near the town of Eskdale, in Kanawha County, West Virginia. In January 2005, Catenary Coal constructed three demonstration plots totaling 8.5 hectares. Each plot was constructed by end-dumping either weathered brown or unweathered gray sandstone overburden material in closely adjacent piles. The three plots consisted of weathered brown sandstone with a depth of 1.5 m, weathered brown sandstone with a depth of 1.2 m, and unweathered gray sandstone with a depth of 1.5 m. After placement, one half of each plot was compacted by using a bulldozer to completely cover the surface with tracks (requiring three to four passes). The other half of the plot was graded with only one or two passes of the bulldozer to minimize compaction. Overall there were six soil treatment combinations (Table 2-1).

Table 2-1. Soil treatment combinations at Catenary Coal's Samples mine operation in Mine in Kanawha County, West Virginia

Treatment	Abbreviation
1.2-m weathered brown sandstone compacted	4B-C
1.2-m weathered brown sandstone noncompacted	4B-NC
1.5-m weathered brown sandstone compacted	5B-C
1.5-m weathered brown sandstone noncompacted	5B-NC
1.5-m unweathered gray sandstone compacted	5G-C
1.5-m unweathered gray sandstone noncompacted	5G-NC

In March of 2005, after final grading, eleven species of trees were manually planted by a tree planting company in a random fashion across the 8.5 hectare demonstration plots (Table 2-

2). The trees were planted on a 2.4 by 2.4 m spacing equaling an initial density of 1680 trees per hectare across the three plots. In fall 2007, the three demonstration plots were hydroseeded with a seed mixture at 15.4 kg/ha (Table 2-3).

Table 2-2. Species and number of trees planted at Catenary Coal's Samples mine operation in Kanawha County, West Virginia

Species	No. Planted	% of trees planted
Black cherry	465	3
Black locust	465	3
Chestnut oak	1,250	8
Eastern redbud	465	3
Gray dogwood	465	3
Northern red oak	3,400	22
Sugar maple	1,500	10
Tulip poplar	1,250	8
White ash	2,500	16
White oak	2,500	16
White pine	1,250	8
Total	15,510	100

Table 2-3. Species and rate of ground cover hydroseeded at Catenary Coal's Samples mine operation in Kanawha County, West Virginia

Species	Rate
	kg ha-1
Birdsfoot trefoil	11.0
Perennial ryegrass	2.2
Redtop	2.2
Total	15.4

All data collected (soil, cover, and trees) was taken from within two 2.7-m wide and 195-m long permanent transects that were arranged in an X pattern across each treatment. During August of each year (2005-2009), trees located inside the transect were identified to species, measured for height to the highest point of live growth, and measured for diameter 2.5 cm above the soil surface. Volume for each tree was determined by HD^2 where H = height and D = diameter.

A vigor rating was also assigned to each tree sampled during 2008 and 2009. Vigor was based on a visual assessment and ranged from 1 to 5 with 1 being trees with >75% leaves discolored and extensive dieback present and 5 being trees with <25% leaves discolored and no visible dieback (Table 2-4).

Table 2-4. Vigor rating criteria used at Catenary Coal's Samples mine operation in Kanawha County, West Virginia

Rating	Modifier	Vigor criteria
1	very poor	>75% leaves discolored; extensive dieback
2	poor	50%-75% discoloration; dieback present
3	moderate	25 - 50% leaves discolored; dieback present
4	good	25 - 50% leaves discolored; no dieback present
5	very good	< 25% leaf discolored; no dieback present

During August 2008 and 2009, herbaceous ground cover was determined using 1-m^2 quadrats. Twenty randomly placed quadrat locations were sampled within the transect boundaries for each soil treatment combination for a total of 120 measurements. Percent plant cover, percent litter cover, and rock/bare ground were estimated within each quadrat.

Soil samples were collected during July-August 2005-2009. Soil sampling locations were randomly selected inside the transect boundaries and five samples were taken from each soil treatment combination for a total of 30 samples each year. Soil samples were collected from the top 15 cm with a trowel, placed in labeled bags, and transported from the field to the lab for air drying. After each sample was air dried, it was sieved through a #10 U.S. standard (2mm) sieve. Each sample was separated into a <2 mm portion (fines) and a >2 mm portion (rock fragments), the data collected from 2005-2007 was separated into a <2 mm portion and sandstone >2 mm. Percent fines and percent rock fragments were determined on a per weight basis by dividing the weight of the individual portion by the weight of the whole soil sample. The fines portion of the soil samples were used to determine pH, electrical conductivity, and extractable elements.

Soil pH was determined by mixing soil and distilled deionized water at a 1:1 ratio. Samples were mixed at 180 oscillations per minute for approximately 50 minutes. The soil pH was then determined using a Beckman 43 pH meter. Electrical conductivity (EC) was used to determine the presence of soluble salts (Bower and Wilcox, 1965). Soil samples were mixed on a 2:1 ratio with distilled deionized water, mixed at 180 oscillations per minute for 15 minutes, and then allowed to equilibrate over night. After equilibrating, samples were measured with a handheld Milwaukee C65 EC Meter. A Mehlich 1 solution composed of 0.05N HCl and 0.025N $H_2SO_4$was used to obtain the extractable elements found in the soil (Mehlich, 1953). The leachate from each sample was analyzed for aluminum, calcium, iron, magnesium, manganese, phosphorus, potassium, and zinc using a Perkin Elmer Plasma 400 emission spectrometer.

Soil data were analyzed by one-way ANOVA by treatment combinations within year for pH, percent fines, percent rock, EC, and extractable elements. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$. Soil data were also analyzed by t-test among years within treatment combinations.

Ground cover data were analyzed by one-way ANOVA to compare cover types (herbaceous, litter, tree, bare ground/rock, water, and total cover) by soil treatment combinations for 2009. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$.

Tree data were analyzed using Proc GLM by substrate, compaction, depth, interactions, and species. Due to issues in the field from transitioning between students and unequal number of trees sampled, analysis of tree data was based on means for each treatment by species instead of measurements taken for each tree. Survival for 2008 and 2009 was calculated from estimated survival between 2005 and 2007 data. Significant differences for survival and volume were determined at $P < 0.05$.

Results and Discussion

Soil

The gray sandstone plots, 1.5 m gray compact (5G-C) and 1.5 m gray noncompacted (5G-NC), had significantly greater pH levels in 2005 (7.6 and 8.3) and 2009 (7.7 and 8.1) compared to the brown sandstone treatments (Table 2-5). The brown sandstone treatments had pH levels ranging from 4.7 to 6.0 in 2005 and 4.6 to 6.1 in 2009. These pH levels are similar to Showalter at al. (2010) who found mine soils sampled in Virginia to have pH levels of 5.53 for weathered brown sandstone mine soil and 8.86 for unweathered gray sandstone mine soil. There were no significant differences in pH within each treatment combination between 2005 and 2009. No decrease in the soil pH was found by Haering et al. (1993) who showed an initial decrease in pH after three years but then pH levels rebounded to near initial levels due to continued carbonate weathering and exposure to additional climatic factors.

The 5G-C and 5G-NC treatment combinations had significantly lower percent fines in 2005 (40 and 36%) and 2009 (37% for both) than all the brown sandstone treatments with the exception of the 1.2 m brown noncompacted (4B-NC) treatment in 2005 and the 1.5 m brown noncompacted (5B-NC) treatment in 2009 (Table 2-5). The 1.5 m brown compacted (5B-C) treatment showed a significant increase in percent fines of 51 to 60% from 2005 to 2009. The greater amount of fines found in the brown sandstone treatments was expected due to the presence of some native topsoil and a higher level of weathering of the brown sandstone substrates before being placed at the surface during reclamation. Both brown and gray sandstone substrates are expected to weather rapidly after being placed on the surface and a greater amount of change was expected between 2005 and 2009 since a freeze-thaw study conducted by Angel et al. (2008) found that brown sandstone samples lost 64% of its mass compared to 35% for gray sandstone. However, due to climatic variation and differences in sandstone material, these results may be seen in the future as this study continues. Results for percent rock fragments are the exact opposite of those found for percent fines.

There were no significant differences for EC values within treatments in both 2005 and 2009 (Table 2-5). However, EC decreased significantly from 2005 to 2009 in all treatments but the 4B-NC. Decreases ranged from 0.10 to 0.40 dS m^{-1} across the six treatment combinations. All EC values were less than 1.0 dS m^{-1} which is considered acceptable for trees since EC values of 2.0 dS m^{-1} are thought to be marginally detrimental and values > 3.0 dS m^{-1} are considered toxic for plants on mined lands (Cummins et al., 1965).

Table 2-5. 2005 and 2009 soil properties in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†					
Properties	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**
pH						
2005	$4.7^{c‡}$	5.2^{bc}	6.0^{b}	4.7^{c}	7.6^{a}	8.3^{a}
2009	4.7^{cd}	4.6^{d}	6.1^{b}	5.8^{bc}	7.7^{a}	8.1^{a}
Percent fines						
2005	50^{ab}	48^{ab}	$^{*}51^{a}$	54^{a}	40^{bc}	36^{c}
2009	56^{ab}	55^{ab}	60^{a}	47^{bc}	37^{c}	37^{c}
Percent rock						
2005	50^{bc}	52^{bc}	$^{*}49^{c}$	46^{c}	60^{ab}	64^{a}
2009	44^{bc}	45^{bc}	40^{ab}	53^{ab}	63^{a}	63^{a}
Electrical conductivity (dS m^{-1})						
2005	*0.53	0.28	*0.40	*0.43	*0.21	*0.20
2009	0.13	0.17	0.09	0.16	0.10	0.10

†see Table 2-1 for treatment descriptions
‡means for each property within rows with the same letter are not significantly different at $P < 0.05$
* denotes significantly different within that soil property between 2005 and 2009

Concentrations of extractable elements varied across treatment combinations and some significant differences were found among treatments and among years. The most notable difference was for K in which extractable potassium concentrations ranged from 0.17 to 0.20 $cmol_c\ kg^{-1}$ in 2005 and 0.05 to 0.10 $cmol_c\ kg^{-1}$ in 2009 with significant decreases in all treatment combinations that ranged from 0.07 to 0.12 $cmol_c$ kg^{-1} from 2005 to 2009. This could be due to K being absorbed by plants in larger amounts than any other nutrient except N or due to leaching since K leaching is common in coarse-texture soils in humid regions (Havlin et al., 2005). Another notable difference was for P, which was significantly higher in the gray sandstone treatments in 2005 (59 and 63 mg kg^{-1}) and in 2009 (109 and 108 mg kg^{-1}) when compared to the brown sandstone treatments, which ranged from 20 to 36 mg kg^{-1} in 2005 to 12 to 48 mg kg^{-1} in 2009. The concentration of P in the gray sandstone treatments also significantly increased from 59 and 63 mg kg^{-1} in 2005 to 109 and 108 mg kg^{-1} in 2009. Even though there was a large increase in extractable P in some treatments from 2005 to 2009, the P may not be plant available which is shown by sequential leaching studies conducted by Skousen and Emerson (2010). Extractable Mg and Zn showed no differences among years by treatment but there were some significant differences between treatments in 2009. The most notable difference being that Zn was significantly higher in the gray sandstone treatments (4.1 and 4.0 mg kg^{-1}) compared to the brown sandstone treatments (1.5 to 2.3 mg kg^{-1}) in 2009.

Table 2-6. 2005 and 2009 Elemental concentrations in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

		Treatments†					
Element	**Year**	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**
		---------------------------$cmol_c\ kg^{-1}$	-----------------------------				
Mg							
	2005	1.9	1.5	2.1	1.4	1.6	1.5
	2009	0.9^{ab}‡	0.9^{b}	1.2^{ab}	1.2^{ab}	1.2^{ab}	1.4^{a}
K							
	2005	*0.20	*0.19	*0.17	*0.18	*0.17	*0.17
	2009	0.09	0.07	0.09	0.10	0.10	0.05
Ca							
	2005	*2.3	*2.3	*2.9	1.8	3.2	2.8
	2009	1.1^{b}	1.1^{b}	1.7^{ab}	1.6^{b}	1.8^{ab}	2.7^{a}
		-----------------------------$mg\ kg^{-1}$	-----------------------------				
Al							
	2005	142^{a}	125^{ab}	*90^{ab}	*119^{ab}	61^{ab}	*40^{b}
	2009	79^{ab}	81^{a}	43^{cd}	49^{bc}	16^{d}	18^{d}
P							
	2005	22^{c}	*23^{c}	36^{b}	20^{c}	*59^{a}	*63^{a}
	2009	17^{c}	12^{c}	48^{b}	36^{bc}	109^{a}	108^{a}
Mn							
	2005	*123^{a}	71^{ab}	*75^{ab}	*82^{ab}	51^{b}	*23^{b}
	2009	27^{b}	28^{b}	28^{b}	26^{b}	34^{ab}	51^{a}
Fe							
	2005	*86	175	*64	*71	123	*211
	2009	33^{b}	33^{b}	21^{b}	23^{b}	41^{b}	88^{a}
Zn							
	2005	2.6	3.7	2.5	2.5	4.4	5.7
	2009	1.5^{b}	2.0^{b}	2.3^{ab}	1.5^{b}	4.1^{a}	4.0^{a}

†see Table 2-1 for treatment descriptions
‡means for each element within rows with the same letter are not significantly different at $P < 0.05$
* denotes significantly different within that element between 2005 and 2009

Ground cover

The 5B-C treatment combination had significantly greater herbaceous ground cover at 80% while the remaining treatment combinations ranged from 3 to 47% (Table 2-7). Due to the higher pH found in the gray sandstone treatments which is more favorable to herbaceous plants, the low amount of herbaceous ground cover was unexpected. It's possible that these treatments did not receive a hydroseed application like the brown treatment combinations. Few significant differences were found for litter cover and ranged from 0 to 2% across the six treatment combinations. No significant differences were found for the percentage of tree cover (0.3 to 7%) across the six soil treatment combinations. Total ground cover was significantly greater on the 5B-C treatment combination (84%) while the 5G-C and 5G-NC treatment combinations were significantly less than the other brown treatment combinations. Results for the percentage of bare ground or rock were exact opposites of the total cover found in each treatment combination. The 5B-NC treatment combination had a significant amount of standing water covering the soil surface (5%) which was greater than all other treatments.

Table 2-7. 2009 ground cover on six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†						
Cover	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**	**Avg.**
	--------------------------------------%--------------------------------						
Herbaceous	44[b]	32[b]	80[a]	47[b]	3[c]	5[c]	38
Litter	0.4[ab]	2[a]	0[b]	0.3[b]	0[b]	0.2[b]	0.5
Tree	6[a]	7[a]	4[a]	7[a]	1[a]	0.3[a]	4
Total	50[b]	41[b]	84[a]	54[b]	3[c]	5[c]	43
Bare/rock	48[b]	59[b]	16[c]	40[b]	97[a]	95[a]	56
Water	0[b]	0.3[ab]	0[b]	5[a]	0[b]	0[b]	1

†see Table 2-1 for treatment descriptions
‡means for each cover within rows with the same letter are not significantly different at $P < 0.05$

Tree survival and volume

After five growing seasons, there were 424 trees sampled across all species and soil treatment combinations (Table 2-8). This translates into an estimated 1342 trees per hectare but does not include volunteer species that have become established on the site. Trees sampled by species across treatment combinations ranged from 7 for black cherry to 179 for three combined oak species and by treatment across species with 58 for both the 5G-C and 5G-NC treatments to 87 for the 4B-NC treatment. Trees sampled by species and treatment combination ranged from zero for black cherry and redbud in the 5G-C treatment to 44 for the three combined oak species in the 4B-NC treatment.

Table 2-8. Total number of trees sampled after five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†						
Species	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**	**Total**
Black cherry	1	1	2	2	0	1	7
Black locust	3	10	10	3	2	3	31
Dogwood	1	3	1	3	6	1	15
Oak	22	44	27	37	21	28	179
Redbud	1	5	2	2	0	2	12
Sugar maple	3	7	8	6	7	2	33
Tulip poplar	7	2	5	7	6	4	31
White ash	20	11	15	15	9	10	80
White pine	5	4	9	4	7	7	36
Total	63	87	79	79	58	58	424

†see Table 2-1 for treatment descriptions

There were no significant differences found for survival by substrate, compaction, or depth of treatments and few significant differences were found by interactions and by species (Table 2-9). The survival in the 4B-NC treatment combination (79%) was significantly greater than the 5B-NC treatment (50%), while the remaining interactions showed no significant difference. Black locust had significantly greater survival (77%) than white pine (50%) and no significant differences were found for the remaining tree species. Volume was significantly greater in brown sandstone treatments at 1840 cm^3 when compared to the gray sandstone treatments at 176 cm^3. There were no significant differences for volume by compaction or depth of treatments. There were significant differences for volume by treatment interactions with brown and gray main treatments being significantly different. Black locust had significantly greater volume (7361 cm^3) than all other species which had volumes ranging from 111 cm^3 to 998 cm^3.

Table 2-9 Treatment effects for volume and survival after five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

		Survival	Volume
Substrate		%	cm3
	Brown	66[a]	1840[a]
	Gray	68[a]	176[b]
Compaction			
	Compacted	66[a]	1095[a]
	Noncompacted	66[a]	1544[a]
Depth			
	1.2 m depth	72[a]	1555[a]
	1.5 m depth	63[a]	1208[a]
Interactions			
	4B-C	66[ab]	1052[a]
	4B-NC	79[a]	2058[a]
	5B-C	67[ab]	1842[a]
	5B-NC	50[b]	2409[a]
	5G-C	65[ab]	191[b]
	5G-NC	70[ab]	165[b]
Species			
	Black cherry	53[ab]	998[b]
	Black locust	77[a]	7361[a]
	Dogwood	71[ab]	867[b]
	Oak	68[ab]	638[b]
	Redbud	71[ab]	638[b]
	sugar maple	73[ab]	111[b]
	Tulip poplar	57[ab]	627[b]
	White ash	76[ab]	518[b]
	White pine	50[b]	211[b]
	Average	66	1328

The average tree survival, volume, and vigor rating for all species across the six soil treatment combinations was 67%, 1309 cm^3, and good to very good (4.2) after five growing seasons (Table 2-10, 2-11, 2-12). The average survival across the six treatment combinations ranged from 50% for white pine to 77% for black locust, average volume ranged from 111 cm^3 for sugar maple to 7361 cm^3 for black locust, and average vigor rating ranged from moderate (3.0) for sugar maple to good to very good (4.7) for black cherry. The average survival for trees across species ranged from 56% in the 5B-NC treatment to 79% in the 4B-NC, average volume ranged from 165 cm^3 in the 5G-NC treatment to 2409 cm^3 in the5B-NC, and the average vigor rating ranged from moderate to good (3.9) in the 5G-NC treatment to good to very good (4.7) in the 5B-C.

Table 2-10. Average survival of tree species after five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†						
Species	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**	**Avg.**
	%						
Black cherry	67	100	50	50	0	50	53
Black locust	60	63	91	50	100	100	77
Dogwood	100	86	33	63	86	60	71
Oaks	54	85	69	58	70	74	68
Redbud	83	100	100	44	0	100	71
Sugar maple	75	93	69	43	88	67	73
Tulip poplar	22	56	55	53	82	73	57
White ash	79	77	80	60	100	60	76
White pine	50	51	60	33	63	42	50
Avg.	66	79	67	56	65	70	66

†see Table 2-1 for treatment descriptions

Table 2-11. Average volume of tree species after five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†						
Species	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**	**Avg.**
	cm^3						
Black cherry	812	2718	945	395	.	120	998
Black locust	4082	9866	12565	17157	24	469	7361
Dogwood	596	1664	1060	1372	494	14	867
Oaks	694	961	414	454	124	71	453
Redbud	1423	959	412	388	.	7	638
Sugar maple	145	136	191	123	40	28	111
Tulip poplar	475	1129	148	1043	322	646	627
White ash	680	863	633	563	283	85	518
White pine	560	225	210	183	47	42	211
Avg.	1052	2058	1842	2409	191	165	1328

†see Table 2-1 for treatment descriptions

Table 2-12. Average vigor rating of tree species after five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

	Treatments†						
Species	**4B-C**	**4B-NC**	**5B-C**	**5B-NC**	**5G-C**	**5G-NC**	**Avg.**
Black cherry	4.0	5.0	5.0	4.5	.	5.0	4.7
Black locust	3.7	4.7	4.9	4.7	5.0	4.3	4.5
Dogwood	4.0	4.7	5.0	5.0	4.2	3.0	4.3
Oaks	4.6	5.0	4.7	4.8	3.6	2.9	4.3
Redbud	5.0	3.6	5.0	4.0	.	4.5	4.4
Sugar maple	2.7	3.1	3.6	3.2	2.6	3.0	3.0
Tulip poplar	3.1	3.5	4.2	4.1	3.8	3.5	3.7
White ash	4.0	4.5	4.7	4.0	4.2	3.8	4.2
White pine	5.0	5.0	5.0	5.0	4.9	4.7	4.9
Avg.	4.0	4.3	4.7	4.4	4.0	3.9	4.2

†see Table 2-1 for treatment descriptions

Black cherry had the third lowest average survival across the six soil treatment combinations at 61% with an average volume of 998 cm^3 and a good to very good vigor rating of 4.7. The highest average survival (100%) was recorded in the 4B-NC treatment while the lowest (0%) was recorded in the 5G-C treatment. The greatest volume (2718 cm^3) was recorded in the 4B-NC treatment while the lowest (120 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (5.0) was recorded in the 4B-NC, 5B-C, and the 5G-NC treatments while the lowest (4.0) was recorded in the 4B-C treatment. Species survival, height, diameter, and volume for five growing seasons can be seen in Figures 2-1a through 2-1d. Black cherry had mixed results for tree performance which could be to the low number of trees that were sampled in each treatment. The low number of trees may have confounded the results so that survival and growth trends for this species are unclear.

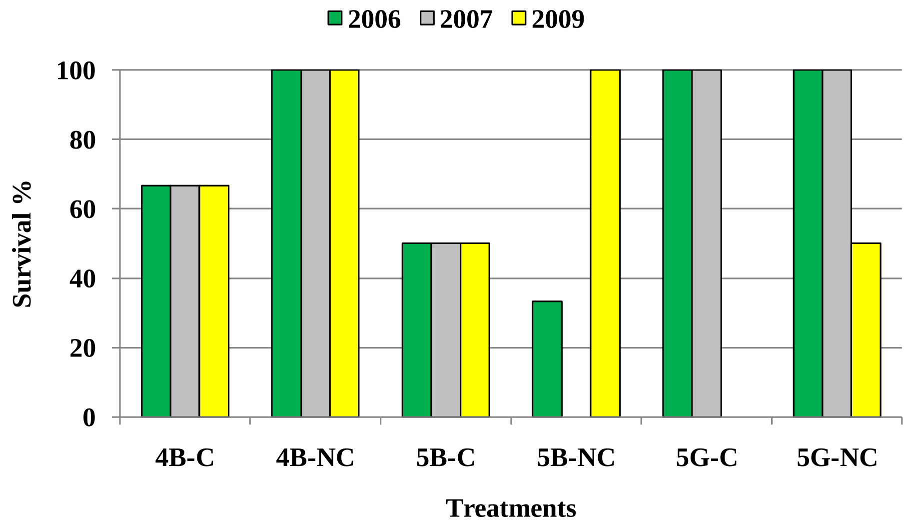

Figure 2-1a. Average survival of black cherry for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

4B-C = 1.2 m brown sandstone compacted, 4B-NC = 1.2 m brown sandstone noncompacted, 1.5 m brown sandstone compacted, 5B-NC = 1.5 m brown sandstone noncompacted, 5G-C = 1.5 m gray sandstone compacted, 5G-NC = 1.5 m gray noncompacted

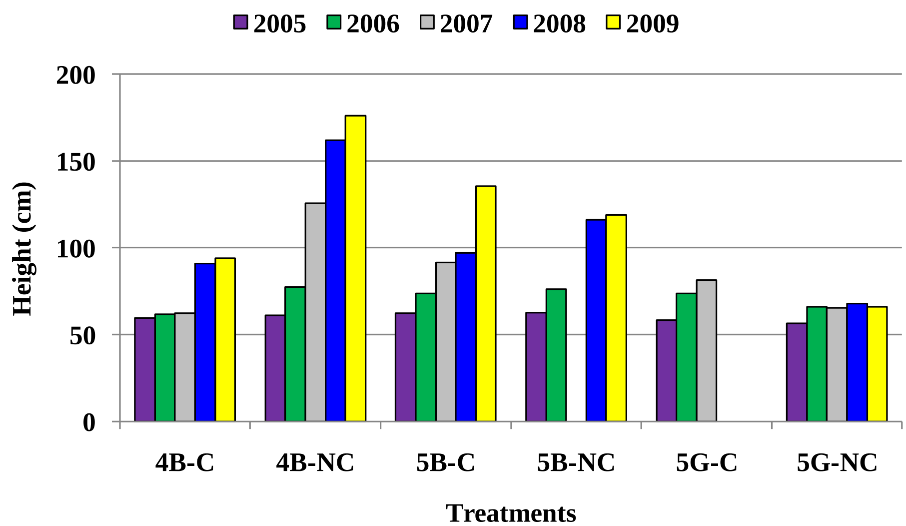

Figure 2-1b. Average height of black cherry for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

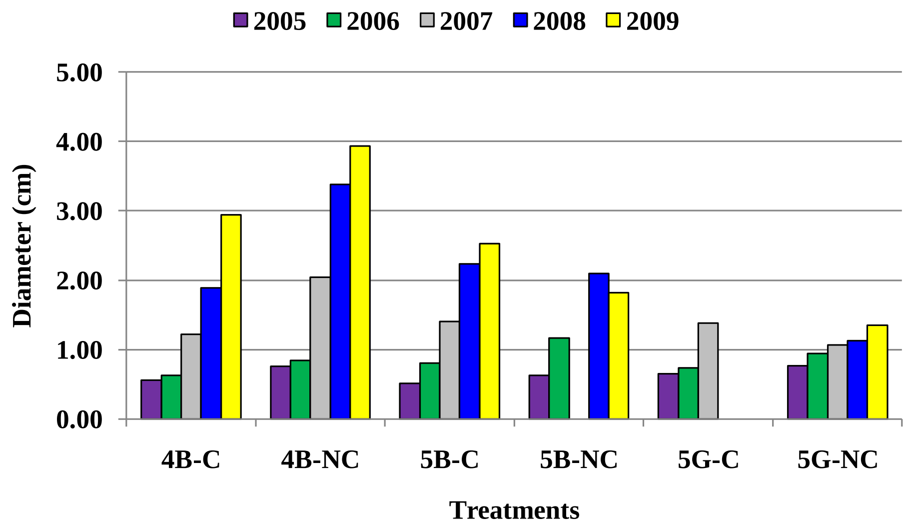

Figure 2-1c. Average diameter of black cherry for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

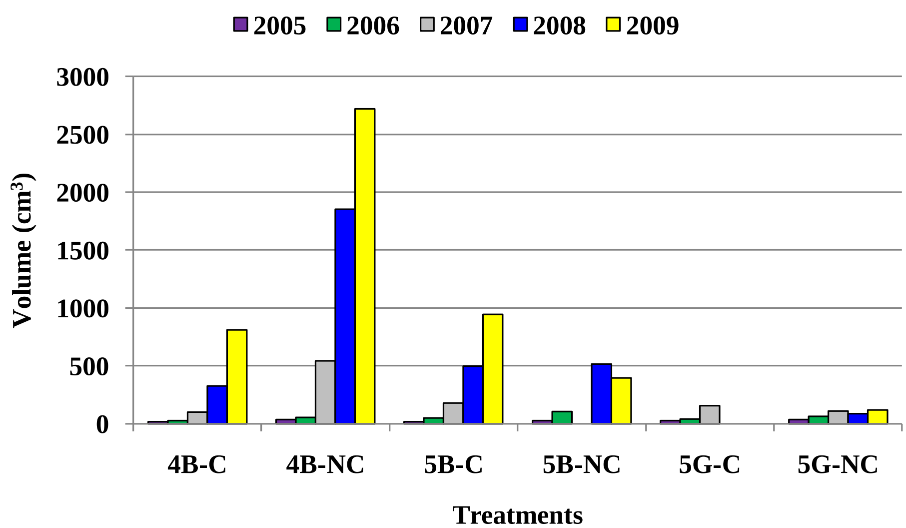

Figure 2-1d. Average volume of black cherry for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Black locust had the highest average survival across the six soil treatment combinations at 77% with an average volume of 7361 cm^3 and a good to very good vigor rating of 4.5. The highest average survival (100%) was recorded in the 5G-C and 5G-NC treatments while the lowest (50%) was recorded in the 5B-C. The greatest average volume (17157 cm^3) was recorded in the 5B-NC while the lowest (24 cm^3) was recorded in the 5G-C treatment. The highest average vigor rating (5.0) was recorded in the 5G-C treatment while the lowest (3.7) was recorded in the 4B-C treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-2a through 2-2d. This species grew by far the best of the species planted on this site. Growth was especially impressive during 2008 and 2009 (Figure 2-2d), and volume increased three times from between 2008 and 2009.

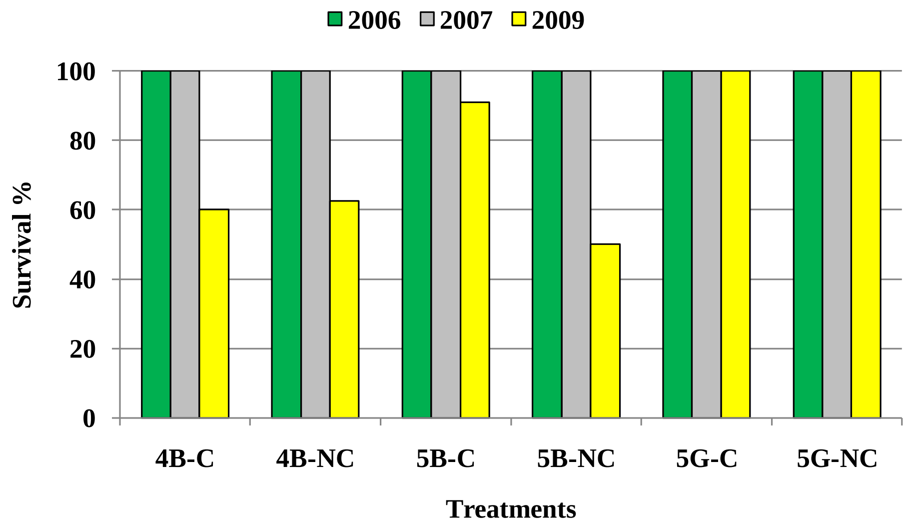

Figure 2-2a. Average survival of black locust for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

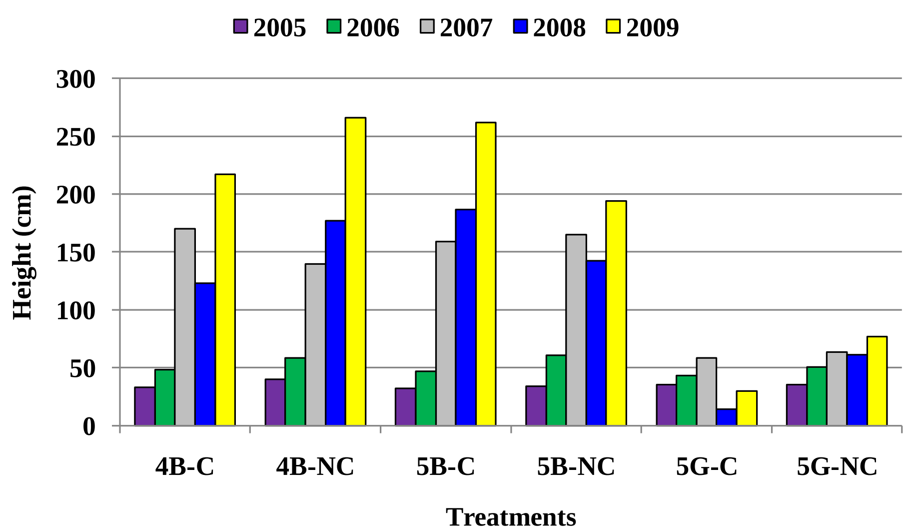

Figure 2-2b. Average height of black locust for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

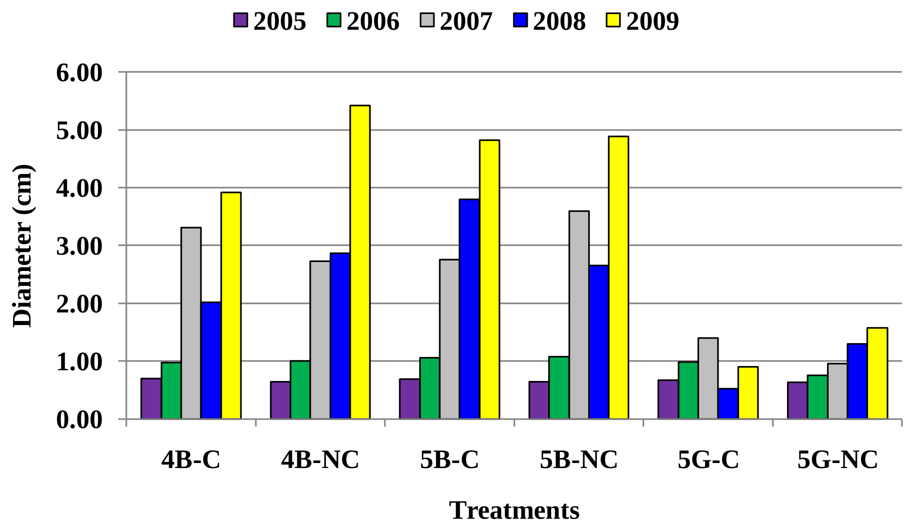

Figure 2-2c. Average diameter of black locust for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

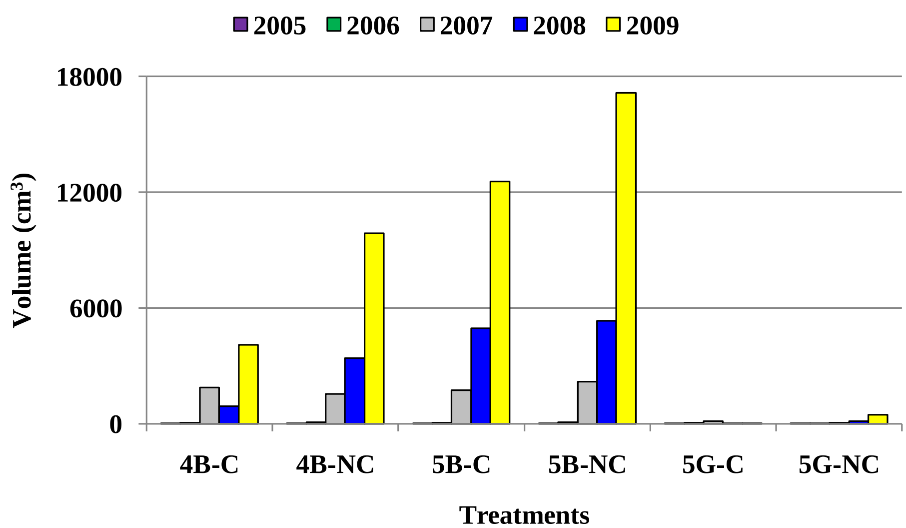

Figure 2-2d. Average volume of black locust for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Dogwood had the fourth highest average survival across the six treatment combinations at 71% with an average volume of 867 cm^3 and good to very good vigor rating of 4.3. The highest average survival (100%) was recorded in the 4B-C treatment while the lowest (33%) was recorded in the 5B-C treatment. The greatest average volume (1664 cm^3) was recorded in the 4B-NC treatment while the lowest (14 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (5.0) was recorded in the 5B-C and 5B-NCtreatments while the lowest (3.0) was recorded in the 5G-NC treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-3a through 2-3d. Increases in volume for dogwood were remarkably good from 2008 to 2009 especially in the brown sandstone plots (Figure 2-3d). Dogwood had greater growth in the noncompacted plots in both brown sandstone treatments but not in the gray sandstone treatments.

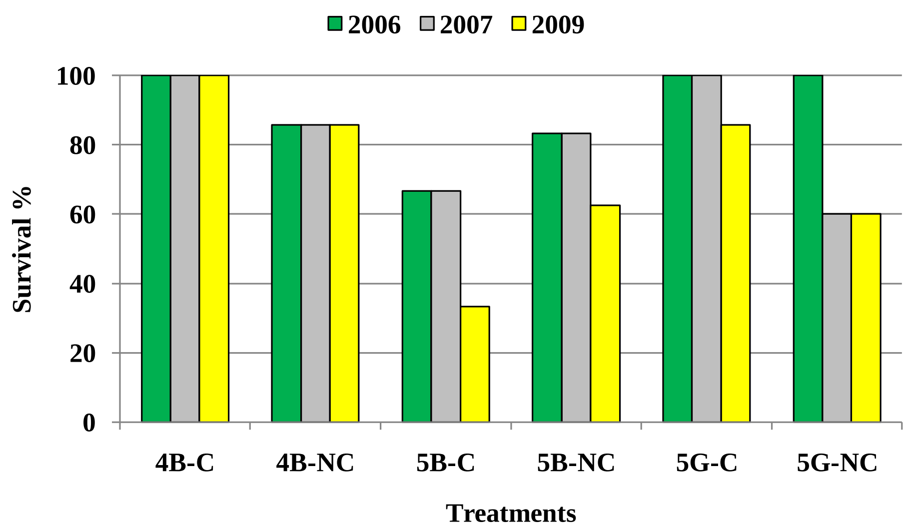

Figure 2-3a. Average survival of dogwood for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

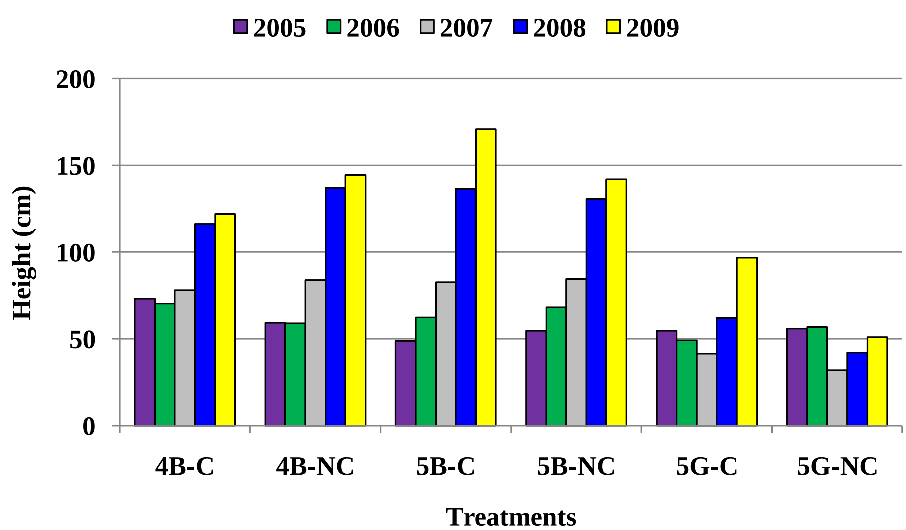

Figure 2-3b. Average height of dogwood for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

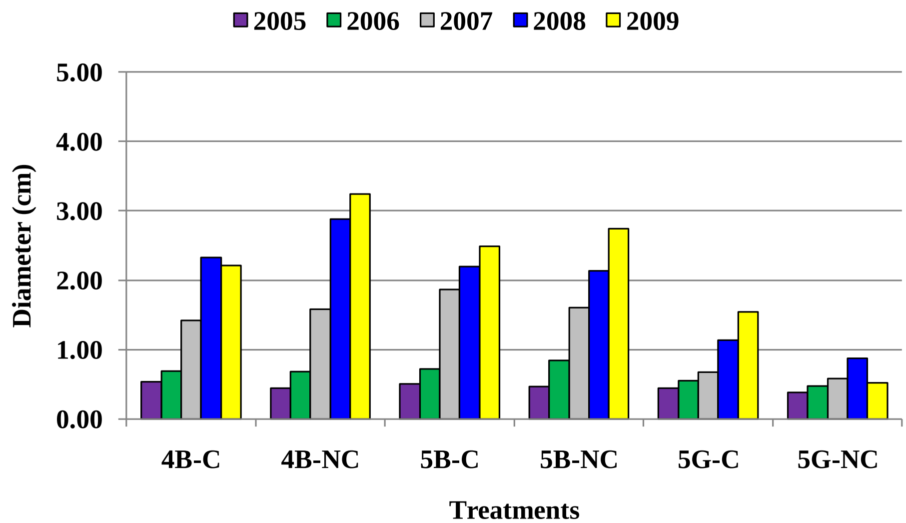

Figure 2-3c. Average diameter of dogwood for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

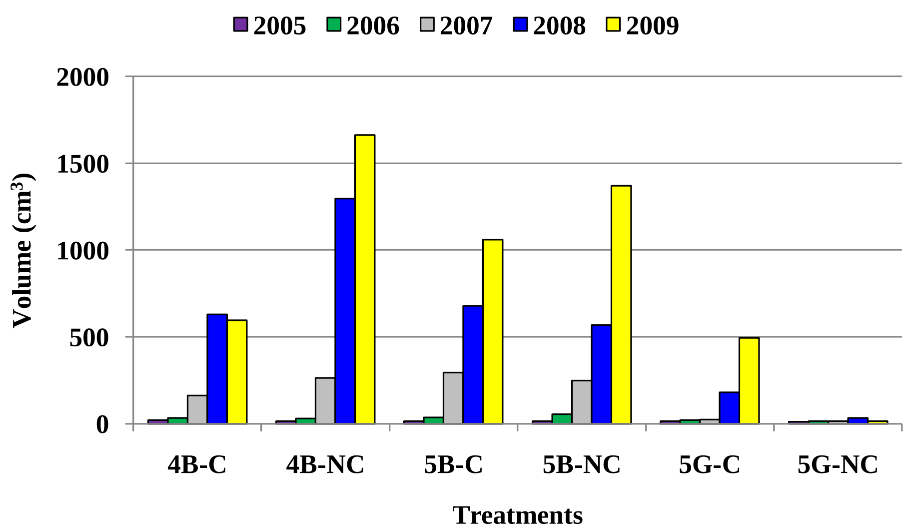

Figure 2-3d. Average volume of dogwood for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

The three oak species (chestnut, red, and white), as well as redbud, had the fourth lowest survival across the six soil treatment combinations with an average volume of 453 cm^3 and a good to very good vigor rating of 4.3. The highest average survival (85%) was recorded in the 4B-NC treatment while the lowest (54%) was recorded in the 4B-C treatment. The greatest average volume (961 cm^3) was recorded in the 4B-NC treatment while the lowest (71 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (5.0) was recorded in the 4B-

NC treatment while the lowest (2.9) was recorded in the 5G-NC treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-4a through 2-4d. The three oak species showed greater volume in the brown sandstone plots and the noncompacted plots indicating possible limiting factors of moisture, compaction, and pH.

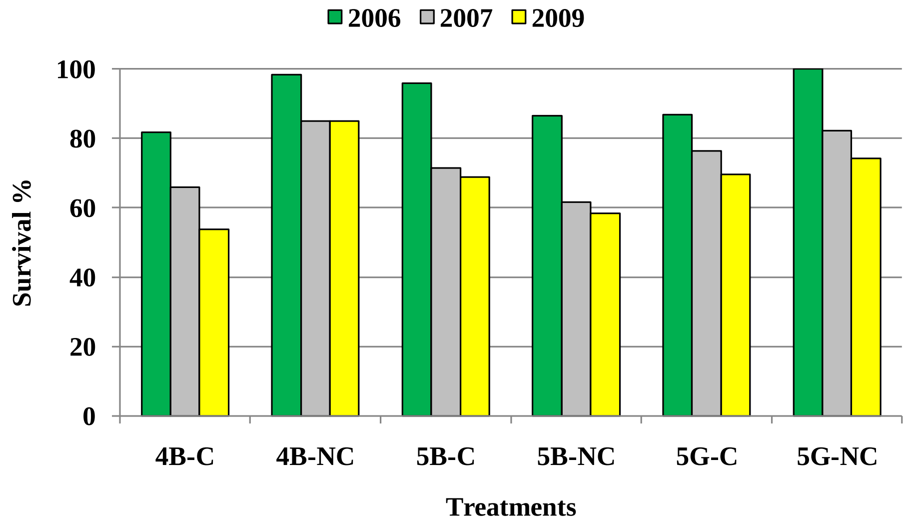

Figure 2-4a. Average survival of oak for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

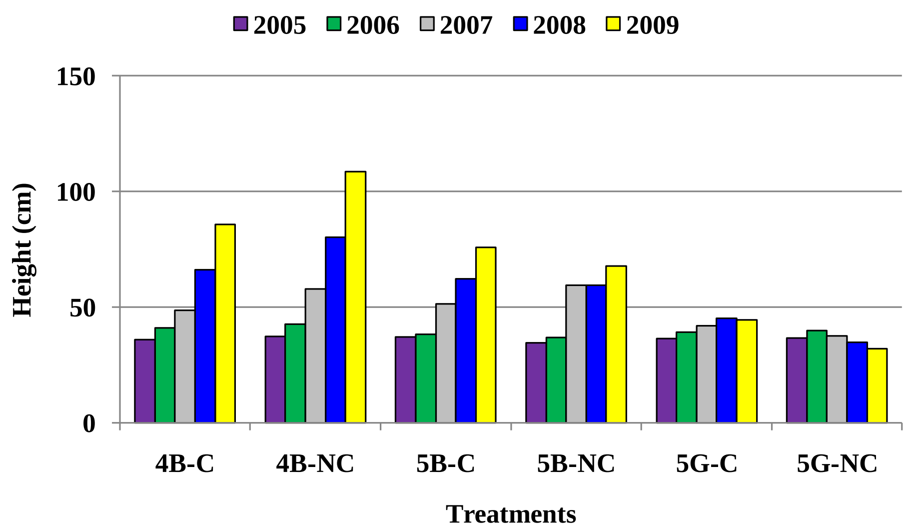

Figure 2-4b. Average height of oak for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

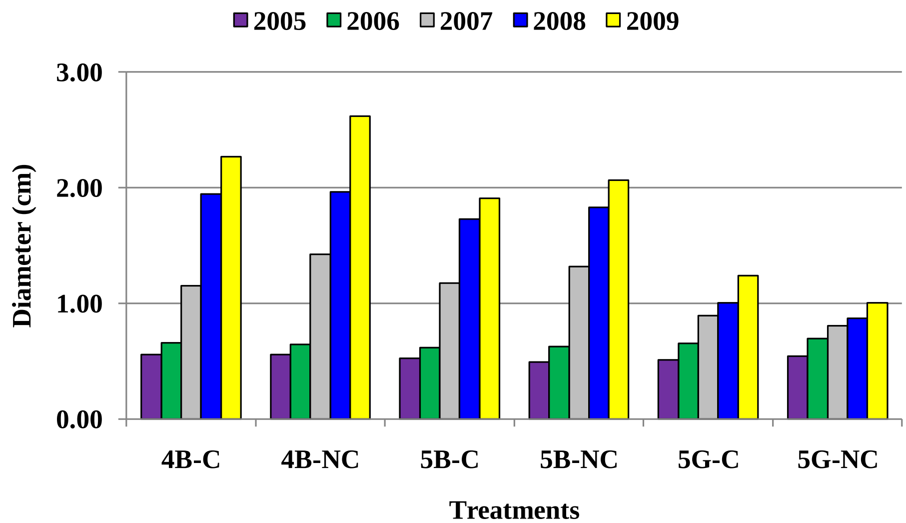

Figure 2-4c. Average diameter of oak for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

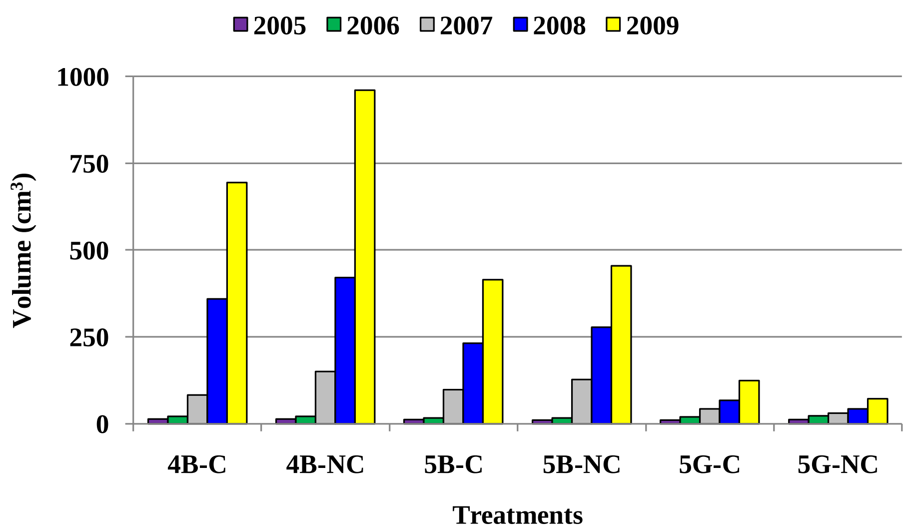

Figure 2-4d. Average volume of oak for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Redbud, along with the three oak species (chestnut, red, and white), had the fourth highest average survival across the six soil treatment combinations at 71% with an average volume of 453 cm^3 and a good to very good vigor rating of 4.3. The highest average survival (100%) was recorded in the 4B-NC, 5B-C, and 5G-NC treatments while the lowest (0%) was recorded in the 5G-C treatment. The greatest average volume (1423 cm^3) was recorded in the 4B-C treatment while the lowest (7 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (5.0) was recorded in the 4B-C and 5B-C treatments while the lowest (3.6) was recorded in the 5B-NC treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-5a through 2-5d. Due to the higher pH found in the gray sandstone treatments, redbud performance was expected to be higher but the lower percentage of fines and thus decreased water holding capacity could indicate that moisture is a limiting factor for this species.

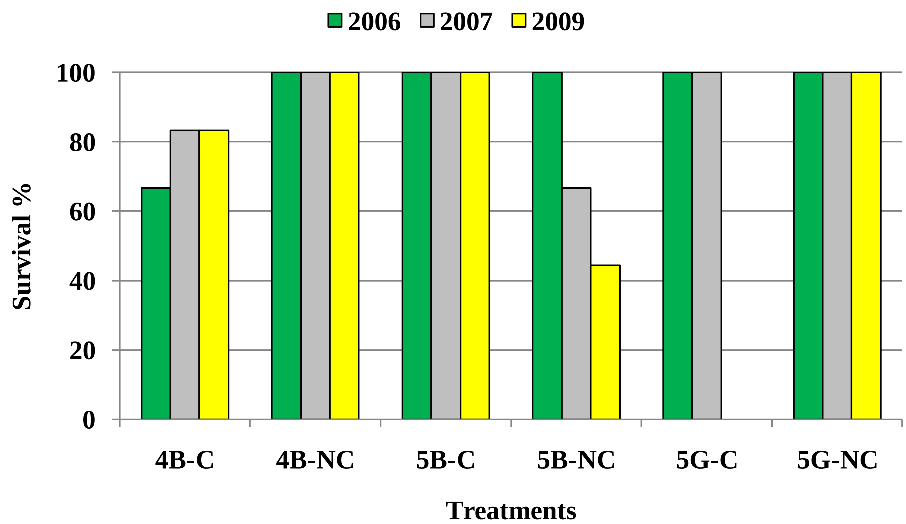

Figure 2-5a. Average survival of redbud for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV

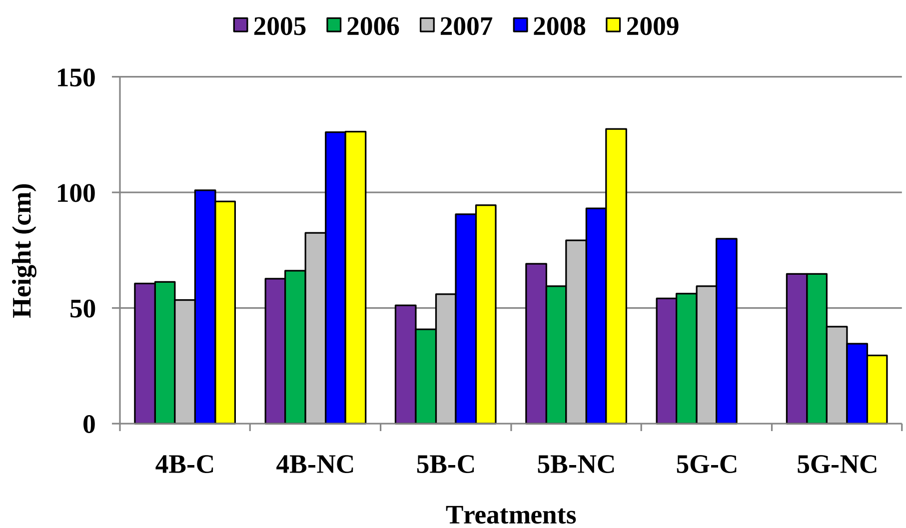

Figure 2-5b. Average height of redbud for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

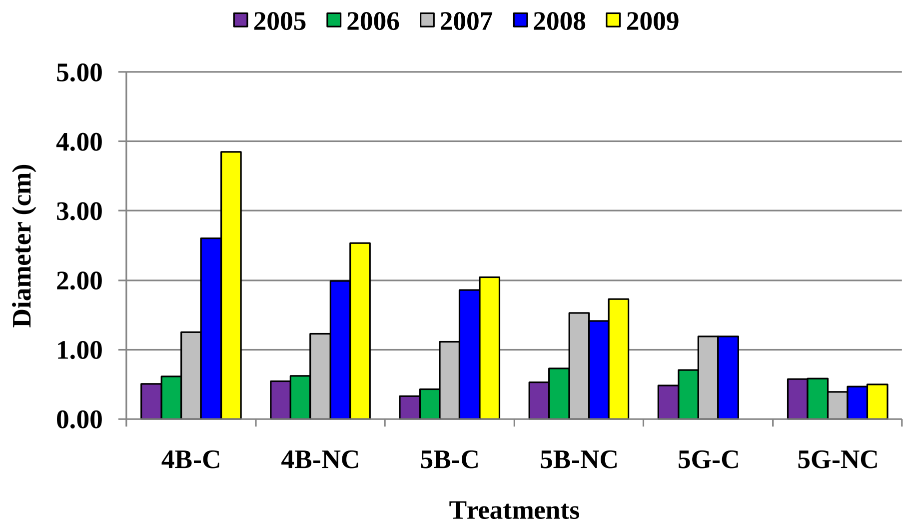

Figure 2-5c. Average diameter of redbud for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

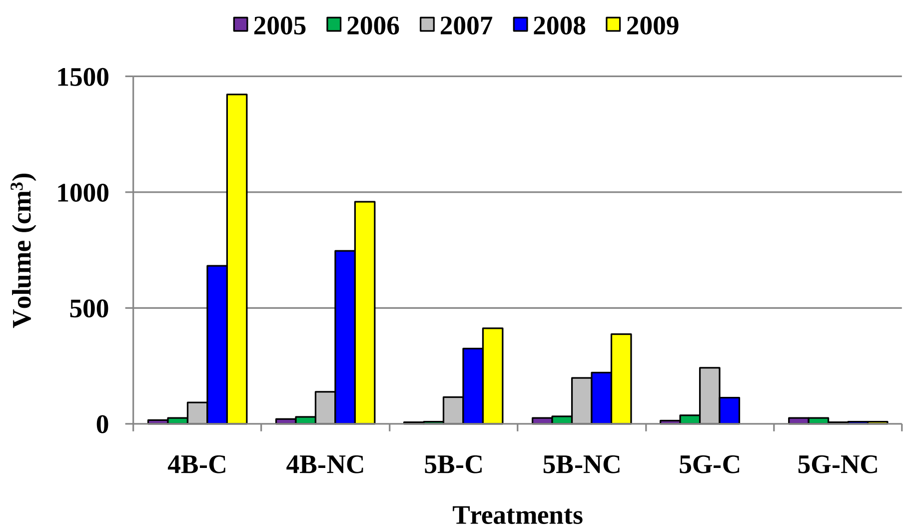

Figure 2-5d. Average volume of redbud for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Sugar maple had the third highest average survival across the six soil treatment combinations at 72% with an average volume of 111 cm^3 and a moderate vigor rating of 3.0. The highest average survival (93%) was recorded in the 4B-NC treatment while the lowest (43%) was recorded in the 5B-NC treatment. The greatest average volume (191 cm^3) was recorded in the 5B-C treatment while the lowest (28 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (3.6) was recorded in the 5B-C treatment while the lowest (2.6) was recorded in the 5G-C treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-6a through 2-6d. Sugar maple showed much greater volume in the brown sandstone plots indicating that the greater amount of fines (moist soil conditions) of the brown sandstone promoted its growth.

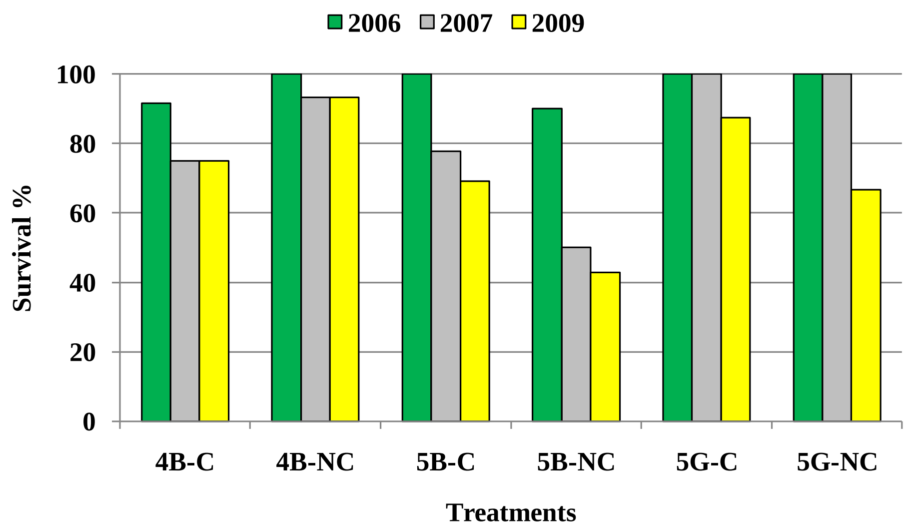

Figure 2-6a. Average survival of sugar maple for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

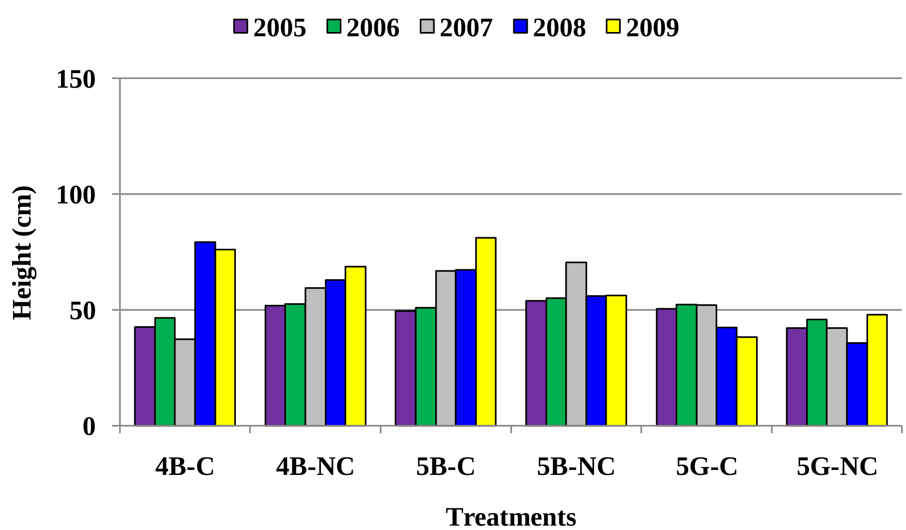

Figure 2-6b. Average height of sugar maple for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

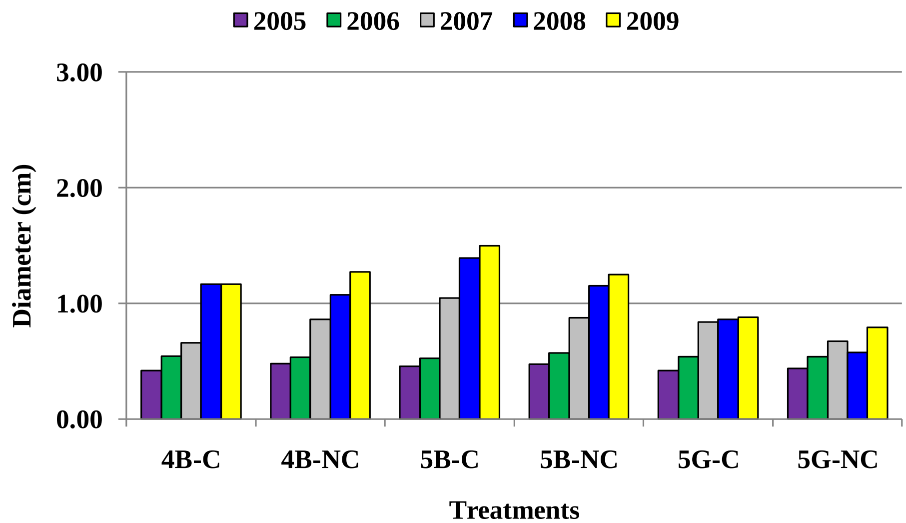

Figure 2-6c. Average diameter of sugar maple for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

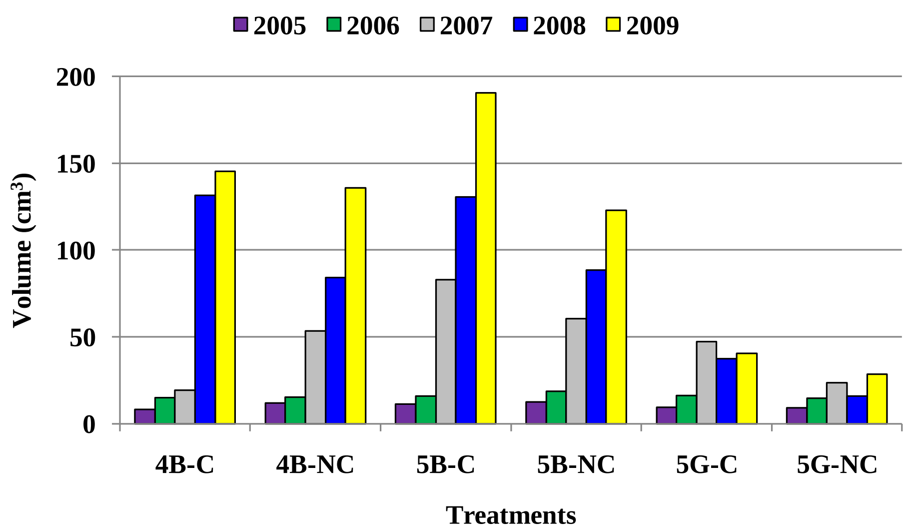

Figure 2-6d. Average volume of sugar maple for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Tulip poplar had the second lowest average survival across the six soil treatment combinations at 57% with an average volume of 627 cm^3 and a moderate to good vigor rating of 3.7. The highest average survival (82%) was recorded in the 5G-C treatment while the lowest (22%) was recorded in the 4B-C treatment. The greatest average volume (1129 cm^3) was recorded in the 4B-NC treatment while the lowest (148 cm^3) was recorded in the 5B-C treatment. The highest average vigor rating (4.2) was recorded in the 5B-C treatment while the lowest (3.1) was recorded in the 4B-C treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-7a through 2-7d. Tulip poplar showed a trend of greater volume in the noncompacted plots in both brown and gray sandstone treatments suggesting this species to be more sensitive to soil compaction.

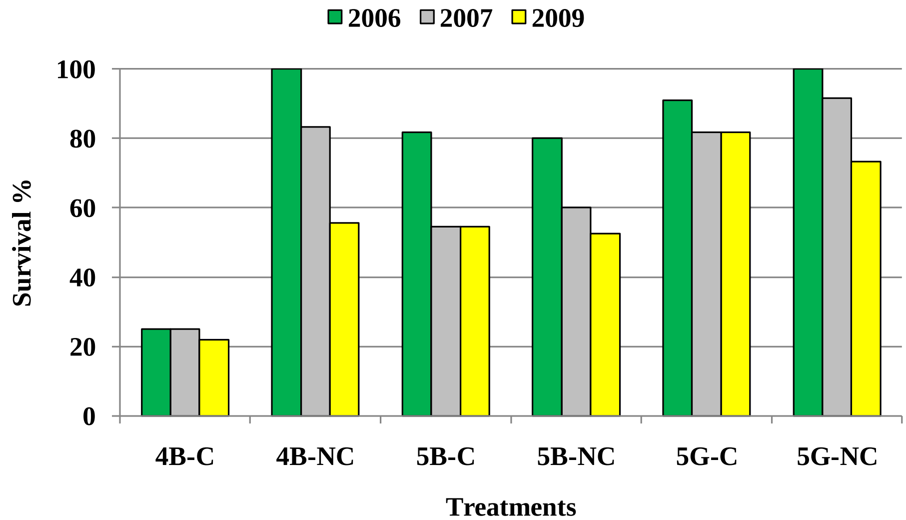

Figure 2-7a. Average survival of tulip poplar for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

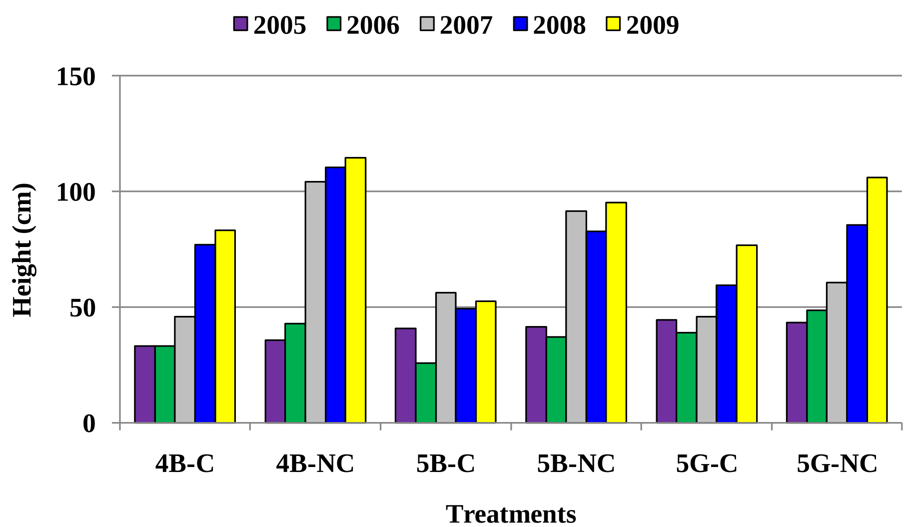

Figure 2-7b. Average height of tulip poplar for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

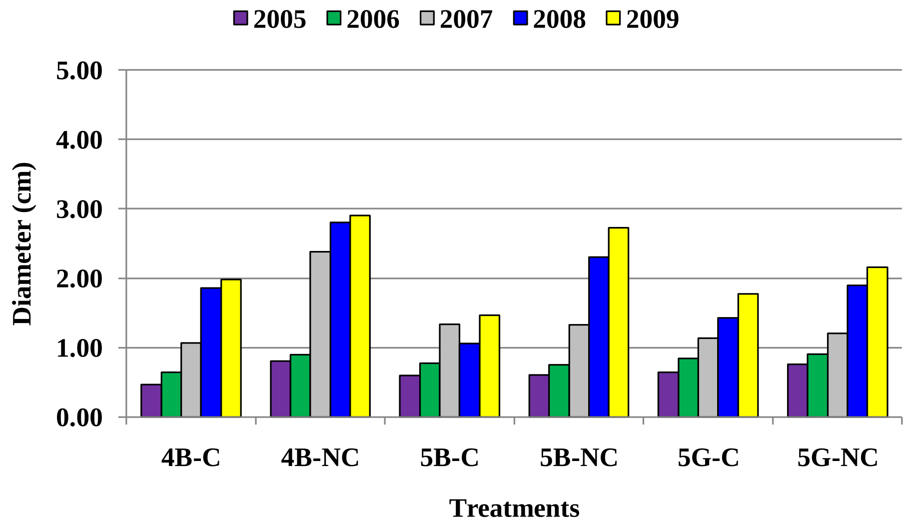

Figure 2-7c. Average diameter of tulip poplar for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

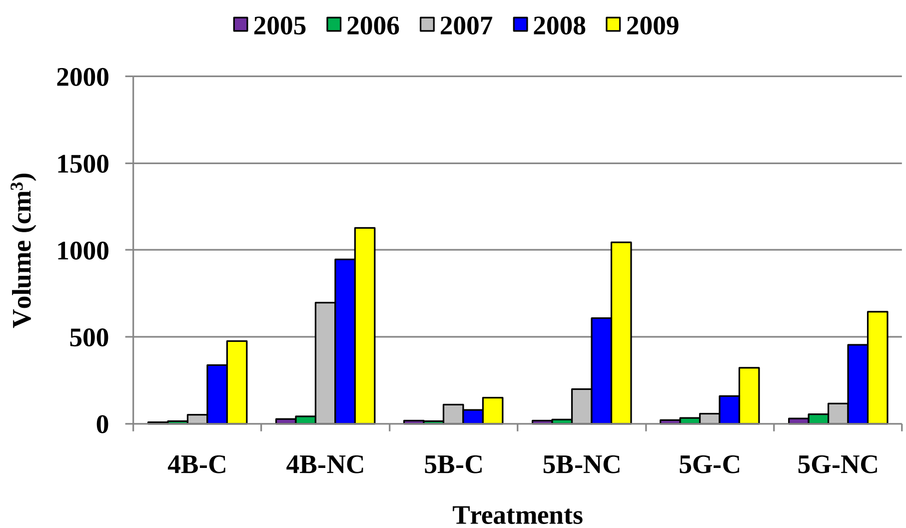

Figure 2-7d. Average volume of tulip poplar for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

White ash had the second highest survival across the six soil treatment combinations at 76% with an average volume of 518 cm^3 and a good to very good vigor rating of 4.2. The highest average survival (100%) was recorded in the 5G-C treatment while the lowest (60%) was recorded in the 5B-NC and 5G-NC treatments. The greatest average volume (863 cm^3) was recorded in the 4B-NC treatment while the lowest (85 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (4.7) was recorded in the 5B-C treatment while the lowest (3.8) was recorded in the 5G-NC treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-8a through 2-8d. White ash has been found to have exceptional survival and growth on mine soils by Skousen et al. (2009) and performed as well in our study with an average survival across treatments of 76%.

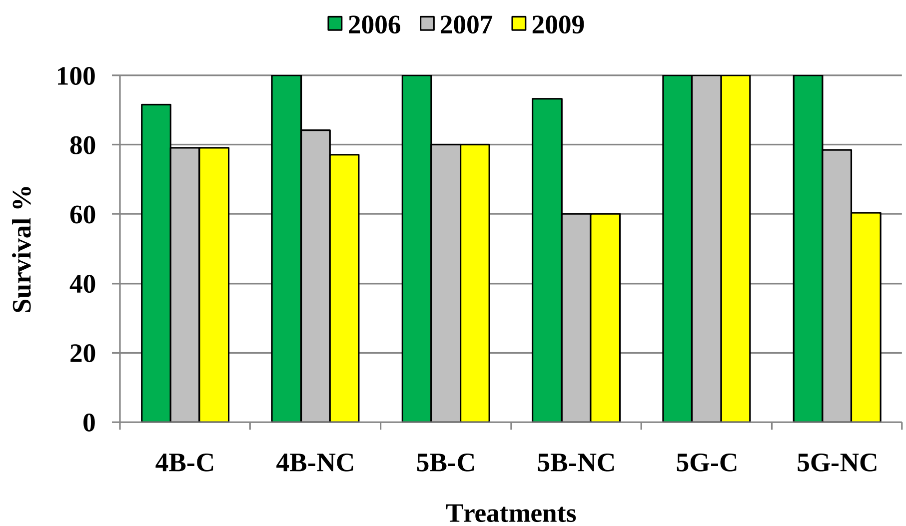

Figure 2-8a. Average survival of white ash for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

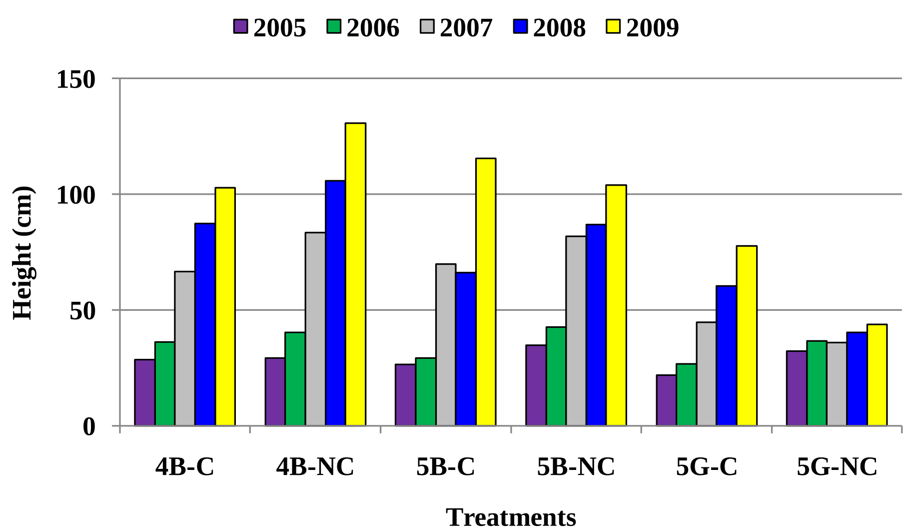

Figure 2-8b. Average height of white ash for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

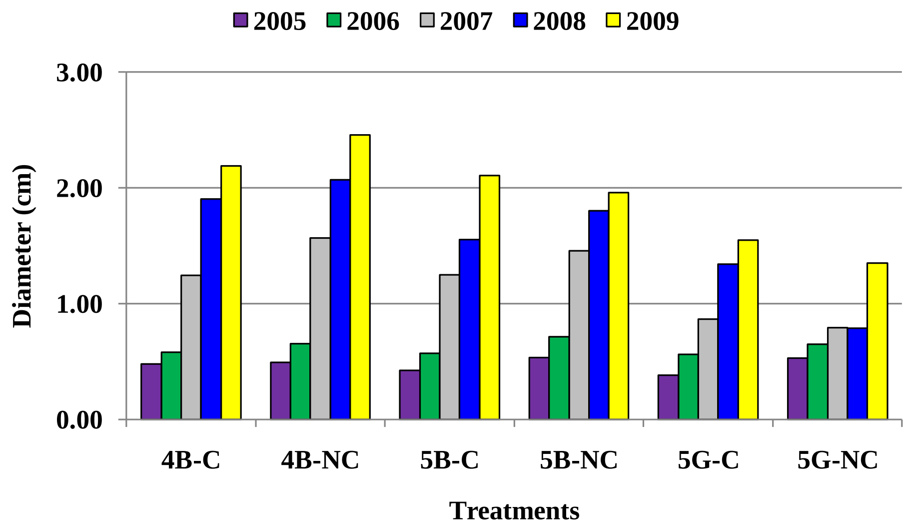

Figure 2-8c. Average diameter of white ash for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

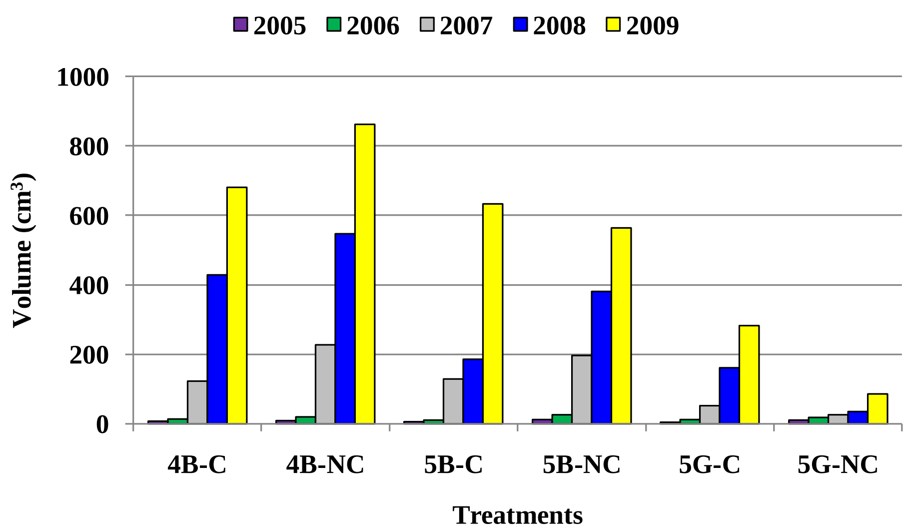

Figure 2-8d. Average volume of white ash for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

White pine had the lowest survival across the six soil treatment combinations at 50% with an average volume of 211 cm^3 and a good to very good vigor rating of 4.9. The highest average survival (63%) was recorded in the 5G-C treatment while the lowest (33%) was recorded in the 5B-NC treatment. The greatest average volume (560 cm^3) was recorded in the 4B-C treatment while the lowest (42 cm^3) was recorded in the 5G-NC treatment. The highest average vigor rating (5.0) was recorded in the 4B-C, 4B-NC, 5B-C, and 5B-NC treatments while the lowest

(4.7) was recorded in the 5G-NC treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 2-9a through 2-9d. White pine is particularly important in this study since this species is used as an indicator of the success of tree planting for Commercial Forestry post mining land uses. In order to meet bond release requirements, it must attain height growth increments equal to or greater than 0.46 m on average for four or more consecutive years. After five growing seasons, it is starting to show increases in height growth on the brown sandstone that would qualify the site for bond release (Figure 2-9b).

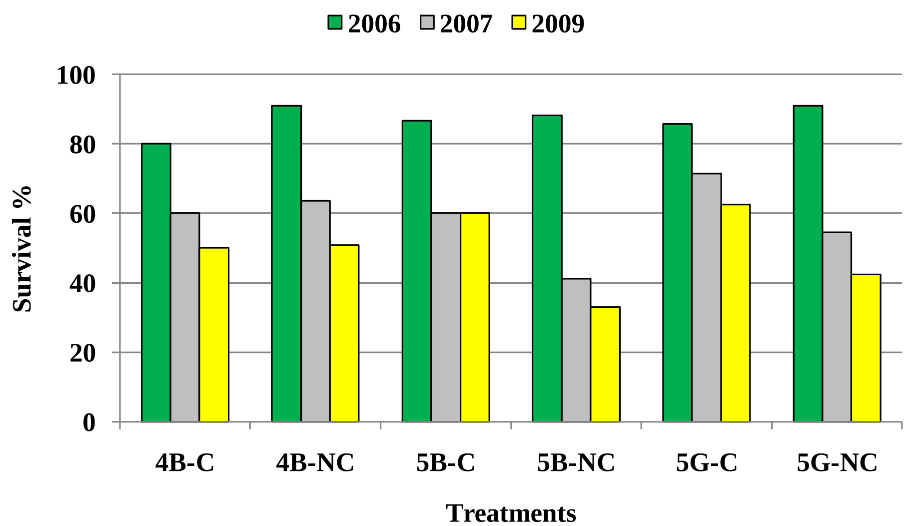

Figure 2-9a. Average survival of white pine for three growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

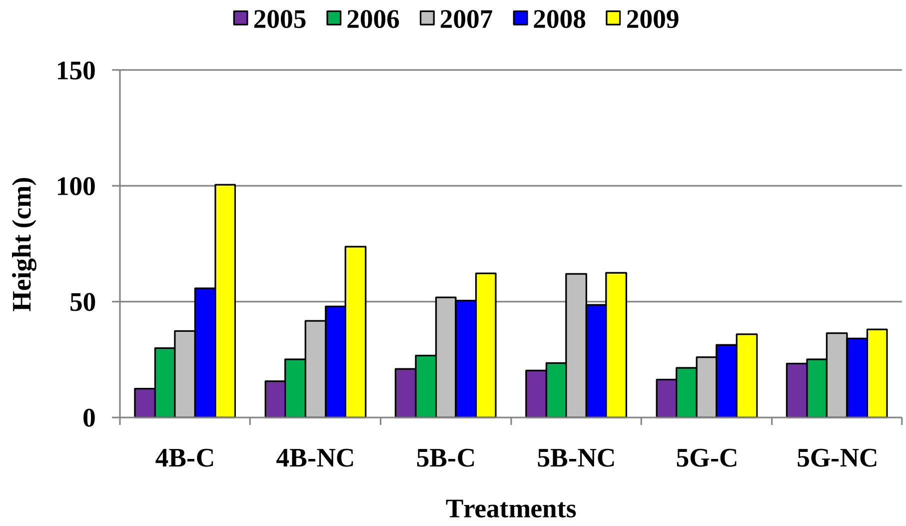

Figure 2-9b. Average height of white pine for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

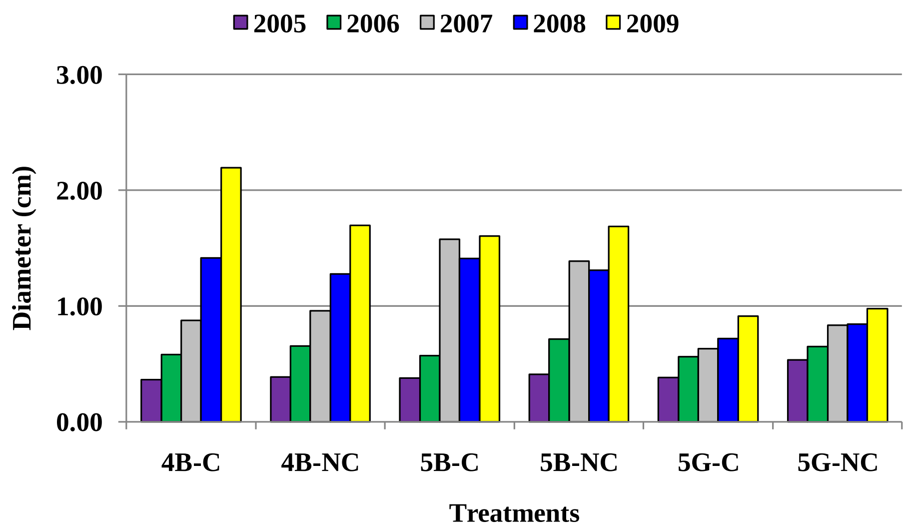

Figure 2-9c. Average diameter of white pine for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

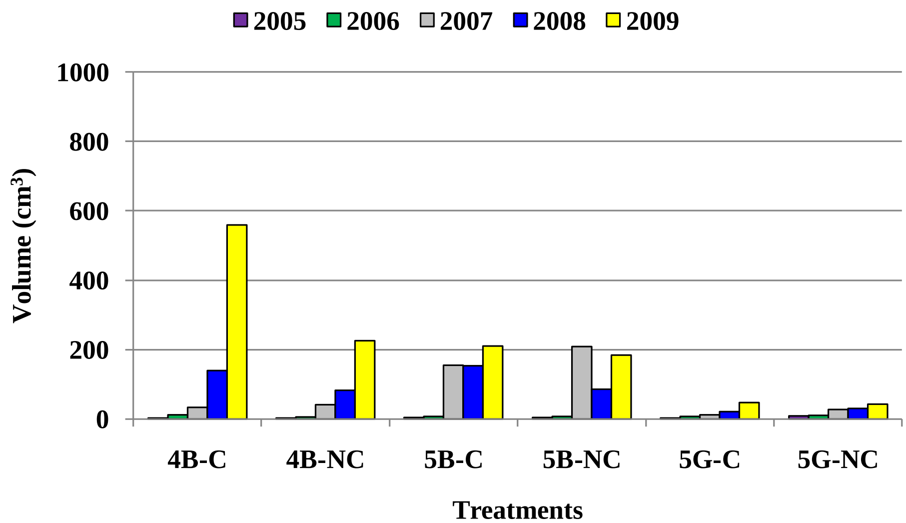

Figure 2-9d. Average volume of white pine for five growing seasons in six soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

<u>Summary and Conclusions</u>

Few changes were found for soil properties after five years. The most notable change was found for EC which decreased significantly in all treatment combinations with the exception of the 4B-NC treatment. There were no significant changes for soil pH among years and after five years soil pH was still significantly greater for gray sandstone treatments compared to the brown sandstone. Extractable element concentrations continued to vary greatly among treatment combinations after five years. Potassium decreased significantly after five years across all treatment combinations and Ca, Al, P, and Fe showed varying changes from 2005 to 2009.

No significant differences for survival were found when comparing sandstone (brown vs. gray), compaction (compacted vs. noncompacted), and depth of substrate (1.2 m vs. 1.5 m) across all tree species planted in this study. However, volume was significantly greater in brown sandstone vs. gray sandstone and although not significantly different volume does seem to be affected by compaction of the substrate with trees in noncompacted treatments having greater volume than those in compacted treatments. Interactions by substrate, compaction, and depth showed little difference for survival but showed great differences for volume between gray sandstone treatments with volumes of 165 cm^3 and 191 cm^3 compared to brown sandstone treatments which had volumes that ranged from 1052 cm^3 to 2409 cm^3. Survival of tree species was fairly uniform across trees sampled in this study and ranged from 50% for white pine to 77% for black locust. Black locust had significantly greater volume at 7361 cm^3 than all over species sampled in this study.

CHAPTER 3. SUBSTRATE, HYDROSEEDING, AND BARK MULCH EFFECTS ON TREE SURVIVAL AND VOLUME ON A RECLAIMED SURFACE MINE IN WEST VIRGINIA

Objectives

a. Determine tree growth and survival of weathered brown and unweathered gray sandstone substrates with and without treatments of herbaceous ground cover and bark mulch.

b. Assess the physical and chemical properties of mine soils three years after reclamation.

Materials and Methods

This study was conducted at ICG Eastern, LLC's Birch River surface mine (38°2′43′′ N, 81°30′29′′ W) near the town of Cowen in Webster County, West Virginia. In October 2006, ICG Eastern constructed a 2.8 ha forestry demonstration plot. The demonstration plot was constructed by end-dumping overburden material in closely adjacent piles and using one to two passes of a bulldozer to knock the tops off of the piles. One-half of the demonstration plot was constructed using weathered brown sandstone while the other half was unweathered gray sandstone. After the overburden material was placed, a 15-cm-layer of bark mulch and a hydroseeding treatment were applied to a portion of each sandstone type. Overall there were eight soil treatments including combinations of substrate, mulch, and hydroseeding (Table 3-1).

Table 3-1. Soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Treatment	Abbreviation
weathered brown sandstone	Bss
weathered brown sandstone w/bark mulch	BssB
weathered brown sandstone w/hydroseeding	BssH
weathered brown sandstone w/bark mulch and w/hydroseeding	BssBH
unweathered gray sandstone	Gss
unweathered gray sandstone w/bark mulch	GssB
unweathered gray sandstone w/hydroseeding	GssH
unweathered gray sandstone w/bark mulch and w/hydroseeding	GssBH

In Spring 2007, twelve species of trees were manually planted by a tree planting company in a semi-random fashion across the 2.8-ha demonstration plot (Table 3-2). The trees were planted on 2.4-m centers equaling an initial density of 1,680 trees per ha across the demonstration plot. The hydroseeding mixture was applied in September 2007 at a rate of 35.8 kg/ha (Table 3-3).

Table 3-2. Species and number of trees planted at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Species	No. Planted	% of trees planted
Black cherry	850	11
Black locust	800	10
Eastern redbud	350	4
Gray dogwood	350	4
Northern red oak	850	11
Pitch X loblolly pine (*Pinus rigida* × *P. taeda*)	800	10
Sugar maple	850	11
Sycamore	450	6
Tulip poplar	600	8
White ash	850	11
White oak	850	11
White pine	400	5
Total	8,000	100

Table 3-3. Species and rate of ground cover hydroseeded at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Species	Rate
	kg ha-1
Birdsfoot trefoil	11.2
Kobe lespedeza (*Kummerowia stipulaceea* Maxim.)	5.6
Ladino clover	3.4
Orchard grass (*Dactylis dglomerata* L.)	5.6
Perennial ryegrass	5.6
Red top	2.2
Weeping lovegrass (*Egrostis curvula* Schra.)	2.2
Total	35.8

Soil, ground cover, and tree data collected were collected from within eleven 3-m wide permanent transects of varying length that were arranged in a parallel fashion across the demonstration plot. The transects were arranged in a fashion to cover at least 10 percent of each soil treatment combination within the demonstration plot (Table 3-4).

Table 3-4. Area and transect coverage for each soil treatment combination at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Treatment	Treatment area	Transect area	Coverage by transect
	m^2	m^2	%
Bss†	5,489	551	10
BssH	9,319	1,053	11
BssB	1,650	197	12
BssBH	1,303	165	13
Gss	5,874	728	12
GssH	2,324	269	12
GssB	1,021	139	14
GssBH	648	80	12
Total	27,628	3,183	12

† See table 3-1 for treatment descriptions

During August 2007, 2008 and 2009, trees located inside the transects were identified to species, measured for height to the highest point of live growth, and measured for diameter 2.5 cm above the soil surface. Volume for each tree was determined by HD^2 where H = height and D = diameter. A vigor rating was also assigned to each tree sampled in 2008 and 2009. Vigor was based on a visual assessment and ranged from 1 to 5 with 1 being trees with >75% leaves discolored and extensive dieback present and 5 being trees with <25% leaves discolored and no visible dieback (Table 3-5).

Table 3-5. Vigor rating criteria used at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Rating	Modifier	Vigor criteria
1	very poor	>75% leaves discolored; extensive dieback
2	poor	50%-75% discoloration; dieback present
3	moderate	25 - 50% leaves discolored; dieback present
4	good	25 - 50% leaves discolored; no dieback present
5	very good	< 25% leaf discolored; no dieback present

During August 2008 and 2009, the percentage of ground cover and ground cover composition was determined using 1-m^2 quadrats. Fifteen randomly placed quadrat locations were sampled within the transect boundaries for each soil treatment combination, 120 measurements total. Percent plant cover, percent litter cover and rock/bare ground were estimated within each quadrat.

Soil samples were collected during July 2007, 2008, and 2009. Soil sampling locations were randomly selected inside the transect boundaries and four samples were taken from each soil treatment combination, 32 samples total for each year. Soil samples were collected from the top 15 cm with a trowel, placed in labeled bags, and transported from the field to the lab for air drying. For samples collected within bark mulch treatment combinations, the bark mulch was scraped away from the soil surface prior to excavating each sample. After each sample was air dried, it was sieved through a #10 U.S. standard (2mm) sieve. Each sample was separated into a <2mm portion (fines) and a >2mm portion (rock fragments). Percent fines and percent rock fragments were determined on a per weight basis by dividing the weight of the individual portion by the weight of the whole soil sample. The fines portion of the soil samples were used to determine pH, electrical conductivity, and extractable elements.

Soil pH was determined by mixing soil and distilled deionized water at a 1:1 ratio. Samples were mixed at 180 oscillations per minute for approximately 50 minutes. The soil pH was then determined using a Beckman 43 pH meter. Electrical conductivity (EC) was used to determine the presence of soluble salts (Bower and Wilcox, 1965). Soil samples were mixed on a 2:1 ratio with distilled deionized water, mixed at 180 oscillations per minute for 15 minutes, and then allowed to equilibrate over night. After equilibrating, samples were measured with a handheld Milwaukee C65 EC Meter. A Mehlich 1 solution composed of 0.05N HCl and 0.025N $H_2SO_4$was used to obtain the extractable elements found in the soil (Mehlich, 1953). The leachate from each sample was analyzed for aluminum, barium, calcium, iron, magnesium, manganese, phosphorus, potassium, and zinc using a Perkin Elmer Plasma 400 emission spectrometer.

Soil data were analyzed by General Linear Model to compare soil properties (pH, fines, rock fragments, and EC) and extractable elements (Mg, K, Ca, AL, P, Mn, Fe, and Zn) by year and soil treatment combination. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$ level. Few significant differences were observed for soil properties and extractable elements within soil treatment combination by year. Thus, soil data from 2007 through 2009 are presented but significant differences are only indicated on means across the three years of data.

Ground cover data were analyzed by one-way ANOVA to compare cover types (herbaceous, bark/litter, tree, bare ground/rock, and total cover) by soil treatment combination for 2009. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$ level.

Due to unequal sample numbers, Proc GLM was used to analyze the tree data and significant differences were determined at the $P < 0.10$ level. Only selected populations of trees were used in the statistical analysis where sample numbers were adequate for analyses. Species of trees with < 2 trees represented in a treatment combination were not included in the statistical analysis. Also due to low sample numbers, interactions among treatment combinations for each species were not determined.

<u>Results and Discussion</u>

<u>Soil</u>

The brown sandstone alone and brown sandstone with hydroseeding treatment combinations had significantly lower pH values (4.6 and 4.9) across the three years while no significant difference was found among the other six treatment combinations, which varied between pH 7.7 to 8.2 (Table 3-6). After three years, pH values showed a decreasing trend in all treatment combinations with the exception of brown sandstone alone (pH 4.4 increased to 4.8) and brown sandstone with hydroseeding (pH 4.5 increased to 5.4) and gray sandstone with hydroseeding which was the same as sampled in 2007 (pH 7.7). Decreased pH was found for the remaining treatment combinations ranging from 0.2 to 0.8 units. The pH values for the brown and gray sandstone substrates were similar to Emerson et al. (2009) who found mean pH values of 4.8 to 6.1 in brown sandstone and 8.1 and 8.2 in gray sandstone substrates across three years. The trend of decreasing pH was also similar to Haering et al. (1993) in which pH values decreased over the first three years of the study. Haering et al. (1993) also found that after the first three years the pH level rebounded to near initial levels due to continued carbonate weathering and exposure to additional climatic factors.

The greater amount of fines found in the brown sandstone alone was expected due to the presence of native topsoil and increased weathering of the brown sandstone substrates before being placed at the surface during reclamation. As so, these results were similar to Emerson et al. (2009) who found the percentage of fines to be 49 to 53% in brown sandstone substrates and 34% in gray sandstone after a three year period. Haering et al. (2004) also found that weathered brown sandstone substrates had a greater percentage of fines than unweathered gray sandstone when comparing pre- and post-SMCRA mines sites in southwestern Virginia. Both brown and gray sandstone substrates are expected to weather rapidly after being placed on the surface. However, a freeze-thaw study conducted by Angel et al. (2008) found that brown sandstone samples lost 64% of its mass compared to 35% for gray sandstone. This demonstrates that as these materials continue to weather, further increases in fine material are expected but could occur at significantly different rates.

The treatment combinations with bark mulch had significantly greater EC values (0.40 to 0.47 dS m^{-1}) than treatment combinations that did not receive a bark mulch application (0.11 to

0.16 dS m^{-1}) (Table 3-6). Overall the mean EC values across the eight treatment combinations ranged from 0.11 to 0.47 dS m^{-1}. After three years, five of the eight treatment combinations showed a decrease in EC from 2007 to 2008 as well as 2008 to 2009. Three combinations (brown sandstone with bark mulch, brown sandstone with hydroseeding, and gray sandstone with bark mulch) showed a slight increase from 2008 to 2009. Decreases from 2007 to 2009 across the eight treatment combinations ranged from 0.11 to 0.44 dS m^{-1}. All EC values were less than 1.0 dS m^{-1}, which is considered acceptable for trees since EC values of 2.0 dS m^{-1} are thought to be marginally detrimental and values > 3.0 dS m^{-1} are considered toxic for plants on mined lands (Cummins et al., 1965).

Table 3-6. 2007-2009 soil properties in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†							
Properties	**Bss**	**BssB**	**BssH**	**BssBH**	**Gss**	**GssB**	**GssH**	**GssBH**
pH								
2007	4.4	7.8	4.5	7.9	8.2	7.8	7.7	7.8
2008	4.7	7.1	4.8	8.1	7.9	7.0	7.4	6.9
2009	4.8	7.5	5.4	7.7	7.8	7.5	7.7	7.0
Avg.	4.6^{c‡}	7.5^{ab}	4.9^{c}	7.9^{ab}	8.0^{a}	7.4^{ab}	7.6^{ab}	7.2^{b}
Percent fines								
2007	42	35	42	41	28	28	26	49
2008	57	24	47	27	42	34	34	32
2009	52	37	49	41	40	42	36	35
Avg.	51^{a}	33^{c}	46^{ab}	36^{bc}	37^{bc}	35^{bc}	32^{c}	39^{bc}
Percent rock								
2007	58	65	58	59	72	72	74	51
2008	43	76	53	73	58	66	66	68
2009	48	63	51	59	60	58	64	65
Avg.	49^{c}	68^{a}	54^{bc}	64^{ab}	63^{ab}	65^{ab}	68^{a}	62^{ab}
Electrical conductivity dS m^{-1}								
2007	0.16	0.61	0.34	0.70	0.12	0.57	0.22	0.73
2008	0.12	0.28	0.06	0.39	0.11	0.28	0.12	0.40
2009	0.05	0.31	0.07	0.30	0.08	0.33	0.11	0.29
Avg.	0.11^{b}	0.41^{a}	0.16^{b}	0.47^{a}	0.11^{b}	0.40^{a}	0.15^{b}	0.47^{a}

† See table 3-1 for treatment descriptions

‡means for each property across treatments with the same letter are not significantly different at $P < 0.05$

Concentrations of extractable elements varied across treatment combinations and some significant differences were found. Treatments that received an application of bark mulch (with bark mulch; with bark mulch and hydroseeding) had higher concentrations of Ca, K, Mg, and Mn and had lower concentrations of P and Zn (Table 3-7). This suggests that bark mulch is adding nutrients to the sandstone substrates for a few elements but the mulch could also be adsorbing elements like P and Zn and decreasing their availability. Both P and Zn have a high affinity for binding to organic matter in soils (Havlin et al., 2005). Extractable P concentrations were significantly higher in gray sandstone alone and gray sandstone with hydroseeding treatment combinations when compared to brown sandstone treatments. This finding is similar to Emerson et al. (2009) who found P concentrations to be almost four times higher in gray vs. brown sandstone substrates. However, a subsequent study by Skousen and Emerson (2010) showed that the Mehlich I extractable P may not be plant available since it was not found in greater abundance in sequential extractions experiments, and therefore the higher P concentrations in gray sandstone do not translate into higher soluble soil P concentrations. Most extractable elements showed no change or slightly decreasing trends in concentration from 2007 to 2009. Both Al and Fe had considerable increases in concentration for brown and gray sandstone substrates from 2007 to 2008 and then returned to near initial levels in 2009. Manganese was found to be similar to Al and Fe but the considerable increases were only found in the gray sandstone treatment combinations.

Table 3-7. 2007-2009 Elemental concentrations in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

		Treatments†							
Element	Year	Bss	BssB	BssH	BssBH	Gss	GssB	GssH	GssBH
		---- $cmol_c$ kg-1 ----							
Mg	2007	1.4	2.6	0.9	2.5	1.0	3.2	1.2	1.8
	2008	1.5	1.5	0.5	2.9	1.2	3.8	2.0	4.9
	2009	0.7	2.6	0.8	2.5	1.0	2.4	1.0	1.9
	Avg.	1.2[bc‡]	2.1[ab]	0.7[c]	2.6[a]	1.0[bc]	2.8[a]	1.4[bc]	2.9[a]
K	2007	0.18	0.29	0.14	0.33	0.12	0.24	0.17	0.23
	2008	0.13	0.18	0.15	0.28	0.14	0.20	0.18	0.28
	2009	0.07	0.13	0.09	0.13	0.06	0.11	0.08	0.12
	Avg.	0.13[c]	0.20[abc]	0.13[c]	0.25[a]	0.11[c]	0.18[bc]	0.14[bc]	0.21[ab]
Ca	2007	1.4	28.1	0.8	27.6	2.2	26.8	1.8	23.4
	2008	1.1	5.1	0.4	16.3	1.5	11.4	2.6	18.3
	2009	0.7	18.9	1.1	18.2	1.5	20.7	1.7	15.3
	Avg.	1.1[b]	16.9[a]	0.8[b]	20.7[a]	1.8[b]	18.7[a]	2.0[b]	19.0[a]
		---- mg kg^{-1} ----							
Al	2007	55	2	205	5	22	20	23	4
	2008	150	83	437	3	36	130	135	573
	2009	36	48	170	29	17	41	17	145
	Avg.	80[b]	44[b]	271[a]	12[b]	25[b]	64[b]	58[b]	241[a]
P	2007	12	1	7	2	12	2	22	3
	2008	4	6	3	1	19	8	20	2
	2009	3	3	13	6	28	4	40	2
	Avg.	7[b]	4[b]	7[b]	3[b]	20[a]	4[b]	28[a]	2[b]
Mn	2007	30	47	47	45	39	64	43	35
	2008	29	43	34	55	67	118	102	175
	2009	16	62	34	68	43	55	39	64
	Avg.	25[d]	51[c]	38[cd]	56[bc]	50[c]	79[ab]	61[bc]	91[a]
Fe	2007	89	1	87	2	141	8	119	1
	2008	77	63	99	7	322	207	654	91
	2009	18	16	52	28	75	13	72	37
	Avg.	61[c]	27[c]	79[c]	13[c]	179[b]	76[c]	282[a]	43[c]
Zn	2007	16.6	0.7	4.4	0.5	4.9	1.8	5.1	0.5
	2008	4.1	6.7	3.1	1.8	5.2	5.7	6.0	2.0
	2009	4.5	2.7	4.7	2.9	4.2	3.5	4.6	2.4
	Avg.	8.4[a]	3.3[bcd]	4.1[bcd]	1.8[cd]	4.8[b]	3.7[bcd]	5.2[b]	1.7[d]

† See table 3-1 for treatment descriptions
‡ means for each element across treatments with the same letter are not significantly different at $P < 0.05$

Ground cover

The gray sandstone with bark mulch and with hydroseeding treatment combination had significantly greater herbaceous ground cover at 34% while the remaining treatment combinations ranged from 0 to 19% (Table 3-8). The greater amount of herbaceous ground cover could be attributed to the higher pH of the gray sandstone material, which is more favorable for herbaceous plants, and the added moisture that could be retained by the bark mulch. The bark mulch or litter was significantly greater in the brown and gray sandstone with bark mulch treatment combinations (81 and 82%) compared to the brown and gray sandstone with bark mulch and with hydroseeding (58 and 51%), while the brown and gray sandstone alone were significantly lower. The brown and gray sandstone with bark mulch and with hydroseeding had lower amounts of bark or litter recorded due to the herbaceous cover that was also recorded in those treatment combinations. No significant differences were found for the percentage of tree cover (1 to 4%) across the eight treatment combinations. Total ground cover was significantly greater on brown and gray substrates that had bark mulch and bark mulch and hydroseeding applications and ranged from 78 to 88%, while treatment combinations of brown and gray sandstone alone and brown and gray sandstone with hydroseeding ranged from 1 to 16%. Results for the percentage of bare ground or rock were exact opposites of the total cover found in each treatment combination.

Table 3-8. Ground cover on eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†								
Cover	**Bss**	**BssB**	**BssH**	**BssBH**	**Gss**	**GssB**	**GssH**	**GssBH**	**Avg.**
					%				
Herbaceous	$2^{c‡}$	1^{c}	12^{bc}	19^{b}	0^{c}	1^{c}	8^{bc}	34^{a}	10
Bark/litter	0^{c}	81^{a}	0^{c}	58^{b}	0^{c}	82^{a}	0^{c}	51^{b}	34
Tree	4^{a}	3^{a}	4^{a}	1^{a}	1^{a}	2^{a}	1^{a}	3^{a}	2
Total	7^{bc}	85^{a}	16^{b}	78^{a}	1^{c}	86^{a}	9^{bc}	88^{a}	46
Bare/rock	93^{ab}	15^{c}	84^{b}	22^{c}	99^{a}	14^{c}	91^{ab}	12^{c}	54

† See table 3-1 for treatment descriptions
‡means for each cover type across treatments with the same letter are not significantly different at $P < 0.05$

Tree survival and volume

After three growing seasons, there were 319 total trees sampled across the eleven tree species and eight treatment combinations (Table 3-9). This translates into an estimated 1002 trees sampled per ha but does not include volunteer species that have become established on the site. Trees sampled by species across treatment combinations ranged from two for dogwood to 49 for red oak. Trees sampled by treatment including all trees were 16 for brown sandstone with bark mulch to 107 for brown sandstone with hydroseeding. Trees sampled by species and treatment combination ranged from zero for several species to 26 for red oak in the brown sandstone with hydroseeding treatment combination.

Table 3-9 Number of trees sampled after two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†								
Species	**Bss**	**BssB**	**BssH**	**BssBH**	**Gss**	**GssB**	**GssH**	**GssBH**	**Total**
Black cherry	4	2	10	.	7	2	1	2	28
Black locust	7	4	13	6	6	4	3	.	43
Dogwood	0	.	1	0	0	1	0	0	2
Redbud	2	1	0	.	2	0	.	.	5
Red oak	5	1	26	.	8	4	2	3	49
Sugar maple	6	1	12	2	5	3	4	4	37
Sycamore	9	.	6	2	1	.	0	2	20
Tulip poplar	5	1	4	2	5	3	1	1	22
White ash	8	2	12	3	4	5	0	1	35
White oak	11	1	13	3	4	1	2	2	37
White pine	12	3	10	2	9	1	3	1	41
Total	69	16	107	20	51	24	16	16	319

† See table 3-1 for treatment descriptions
- no trees were planted and/or recorded in the first year of sampling
0 all trees planted had died after three growing seasons

For the populations of trees which had a sufficient n number for statistical analysis, there were no significant differences in tree survival by substrate, bark mulch, or hydroseeding with ranges of 74 to 80% (Table 3-10). This is somewhat surprising when such large differences were found for pH and percent fines among substrate treatments. There were also no significant differences in volume for bark mulch or hydroseeding, which ranged from 184 cm^3 to 309 cm^3. However, there were significant differences in volume in brown vs. gray sandstone substrates. Trees in the brown sandstone had a volume of 313 cm^3 compared to 100 cm^3 in the gray. This is similar to results found by Emerson et al. (2009) and Angel et al. (2008) who found no differences in survival in brown vs. gray sandstone substrates, but did find that trees in brown sandstone substrates had greater volume than trees in gray sandstone. Survival by species across treatments was fairly uniform ranging from 56 to 85%, and an overall average of 76% survival across all species. Sycamore had significantly lower survival (56%) of all the species with the exception of sugar maple (67%). Species volume varied greatly across species ranging from 13 cm^3 for sugar maple to 1086 cm^3 black locust. Black locust had significantly greater volume (1086 cm^3) than all other species and no additional volume differences were found between species.

Table 3-10 Main treatment effects (substrate, bark, hydro) and species survival and volume after two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

		Survival	Volume
Treatment		%	cm^3
	Brown	76^a	313^a
	Gray	78^a	100^b
	w/ bark	80^a	309^a
	w/o bark	76^a	228^a
	w/ hydroseeding	74^a	306^a
	w/o hydroseeding	80^a	184^a
Species			
	Black cherry	83^a	216^b
	Black locust	83^a	1086^a
	Red oak	79^{ab}	100^b
	Sugar maple	67^{bc}	13^b
	Sycamore	56^c	81^b
	Tulip poplar	76^{ab}	220^b
	White ash	73^{ab}	122^b
	White oak	85^a	58^b
	White pine	85^a	102^b
	Average	76	222

‡means for each treatment and species with the same letter are not significantly different at $P < 0.10$

The average tree survival, volume, and vigor rating for all eleven species across the eight treatment combinations was 69%, 178 cm^3, and good to very good (4.1) after three growing seasons (Tables 3-11, 3-12, 3-13). The average survival for trees across treatment combinations ranged from 85% for sugar maple to 16% for dogwood, average volume ranged from 806 cm^3 for black locust to 3 cm^3 for dogwood, and vigor rating ranged from good to very good (4.8) for white pine to poor to moderate (2.9) for sugar maple. The average survival of trees across species ranged from 84% in the brown sandstone with bark mulch to 50% in the gray sandstone with hydroseeding, average volume ranged from 283 cm^3 in the brown sandstone with hydroseeding to 30 cm^3 in the gray sandstone alone, and the average vigor rating ranged from good to very good (4.5) in the brown sandstone with bark mulch to moderate to good (3.1) in the gray sandstone alone treatment combinations.

Table 3-11 Survival of eleven species of trees after two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†								
Species	**Bss**	**BssB**	**BssH**	**BssBH**	**Gss**	**GssB**	**GssH**	**GssBH**	**Avg.**
				%					
Black cherry	57	100	91	.	88	100	100	50	84
Black locust	78	80	87	75	86	100	75	.	83
Dogwood	0	.‡	14	0	0	100	0	0	16
Redbud	40	50	0	.	100	0	.	.	38
Red oak	100	100	81	.	80	67	50	75	79
Sugar maple	43	100	57	100	83	100	100	100	85
Sycamore	75	.	46	50	33	.	0	40	41
Tulip poplar	83	50	50	67	100	100	33	100	73
White ash	89	100	80	100	44	83	0	100	75
White oak	100	100	81	100	67	50	67	100	83
White pine	100	75	91	50	82	50	75	100	78
Avg.	70	84	62	68	69	75	50	74	69

† See table 3-1 for treatment descriptions
‡ Indicated no trees were sampled in that treatment

Table 3-12 Volume of eleven species of trees after two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†								
Species	Bss	BssB	BssH	BssBH	Gss	GssB	GssH	GssBH	Avg.
				cm^3					
Black cherry	375	485	199	.	31	314	4	65	211
Black locust	1143	499	2001	1324	83	477	113	.	806
Dogwood	.	.	2	.	.	4	.	.	3
Redbud	47	37	.	.	4	.	.	.	29
Red oak	113	104	139	.	20	84	27	24	73
Sugar maple	30	18	12	26	9	12	3	3	14
Sycamore	89	.	62	82	23	.	.	102	71
Tulip poplar	87	963	128	91	56	923	65	237	319
White ash	142	77	126	98	37	180	.	36	99
White oak	63	6	67	32	14	7	5	159	44
White pine	189	31	89	186	23	27	49	60	82
Avg.	228	247	283	263	30	225	38	86	178

† See table 3-1 for treatment descriptions

Table 3-13 Vigor of eleven species of trees after two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

	Treatments†								
Species	Bss	BssB	BssH	BssBH	Gss	GssB	GssH	GssBH	Avg.
Black Cherry	5.0	5.0	4.5	.	3.9	4.5	3.0	4.0	4.3
Black Locust	4.7	4.5	5.0	5.0	1.8	5.0	5.0	.	4.4
Dogwood	.	.	2.0	.	.	4.0	.	.	3.0
Redbud	5.0	5.0	.	.	2.0	.	.	.	4.0
Red Oak	4.8	4.0	4.5	.	3.0	4.5	3.0	3.0	3.8
Sugar Maple	3.3	3.0	3.0	2.5	3.0	3.3	2.5	2.5	2.9
Sycamore	4.2	.	4.2	5.0	3.0	.	.	5.0	4.3
Tulip Poplar	4.0	5.0	4.8	4.5	3.6	4.3	4.0	5.0	4.4
White Ash	4.8	5.0	4.5	5.0	4.0	4.6	.	5.0	4.7
White Oak	4.6	4.0	4.1	3.7	2.5	4.0	3.5	5.0	3.9
White Pine	5.0	4.7	4.6	5.0	4.3	5.0	4.7	5.0	4.8
Avg.	4.5	4.5	4.1	4.4	3.1	4.4	3.7	4.3	4.1

† See table 3-1 for treatment descriptions

Black cherry had the second highest average survival across the eight soil treatment combinations at 84% with an average volume of 211 cm^3 and a good to very good vigor rating of 4.3. The highest average survival (100%) was recorded in the brown sandstone with bark mulch, gray sandstone with bark mulch, and gray sandstone with hydroseeding treatments while the lowest (50%) was recorded in the gray sandstone with bark mulch and with hydroseeding. The greatest volume (485 cm^3) was recorded in the brown sandstone with bark mulch while the least

(4 cm^3) was recorded in the gray sandstone with hydroseeding. The highest average vigor rating (5.0) was recorded in the brown sandstone alone and brown sandstone with bark mulch treatments while the lowest (3.0) was recorded in the gray sandstone with hydroseeding treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-1a through 3-1d. Black cherry had greater volume in the brown sandstone treatments compared to the gray sandstone and the addition of bark mulch could have improved site conditions to be similar to preferred conditions of rich, moist sites mentioned in Chapter 1.

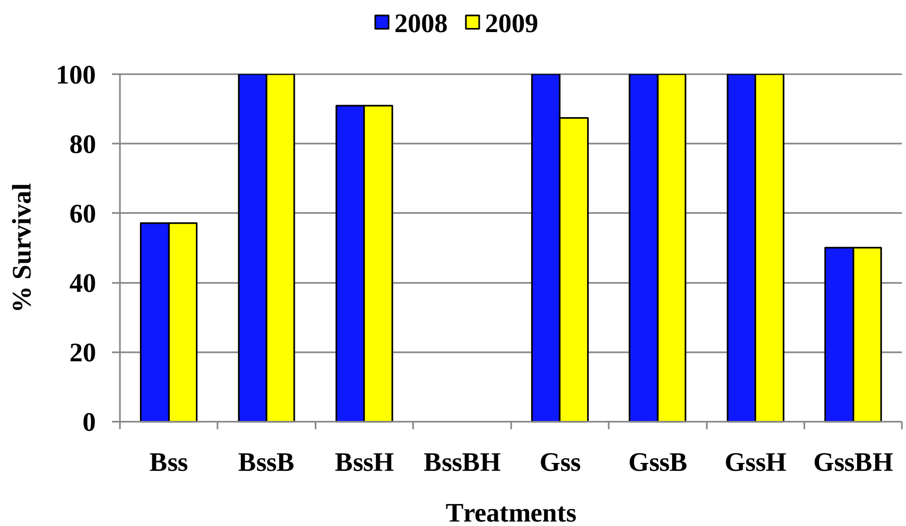

Figure 3-1a. Average survival of black cherry for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV
Bss=brown sandstone, BssB=brown sandstone bark mulch, BssH=brown sandstone hydroseeded, BssBH= brown sandstone hydroseeded and bark mulch, Gss=gray sandstone, GssB=gray sandstone bark mulch, GssH=gray sandstone hydroseeded, GssBH=gray sandstone hydroseeded and bark mulch

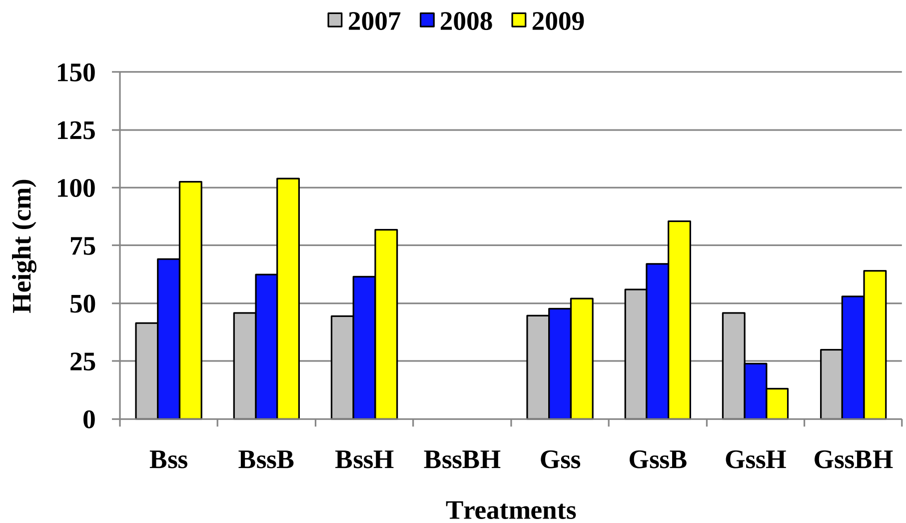

Figure 3-1b. Average height of black cherry for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

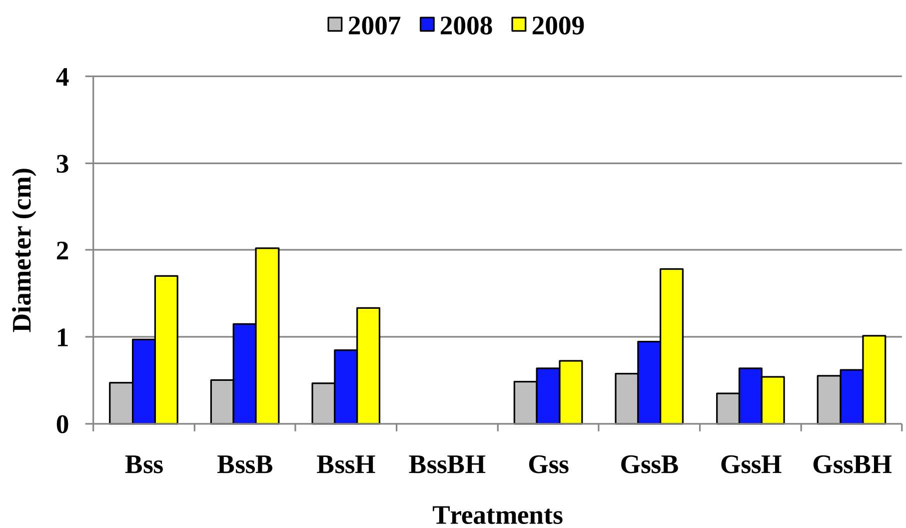

Figure 3-1c. Average diameter of black cherry for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

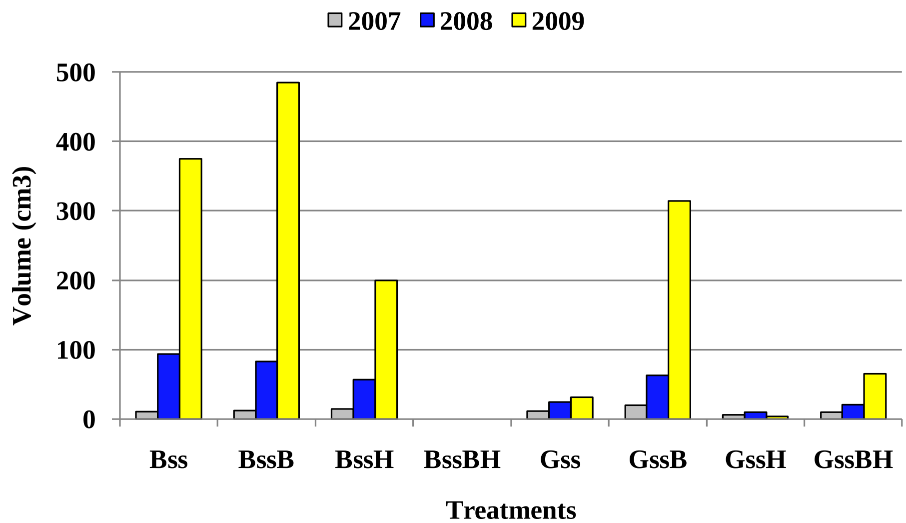

Figure 3-1d. Average volume of black cherry for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Black locust had the third highest average survival across the eight soil treatment combinations at 83% with an average volume of 806 cm^3 and a good to very good vigor rating of 4.4. The highest average survival (100%) was recorded in the gray sandstone with bark mulch treatment while the lowest (75%) was recorded in the brown sandstone with bark mulch and with hydroseeding and the gray sandstone with hydroseeding treatments. The greatest average volume (2001 cm^3) was recorded in the brown sandstone with hydroseeding treatment while the least (83 cm^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (5.0) was recorded in the brown sandstone with hydroseeding, brown sandstone with bark mulch and with hydroseeding, gray sandstone with bark mulch, and gray sandstone with hydroseeding treatments while the lowest (1.8) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-2a through 3-2d. Black locust performance was similar to the study by Emerson et al. (2009) in which average volume was significantly greater than all other species used for reclamation on the site. The bark mulch application increased volume in the gray sandstone treatments but did not show an increase in volume for the brown sandstone treatments. Growth between 2008 and 2009 was especially impressive on most of the sites.

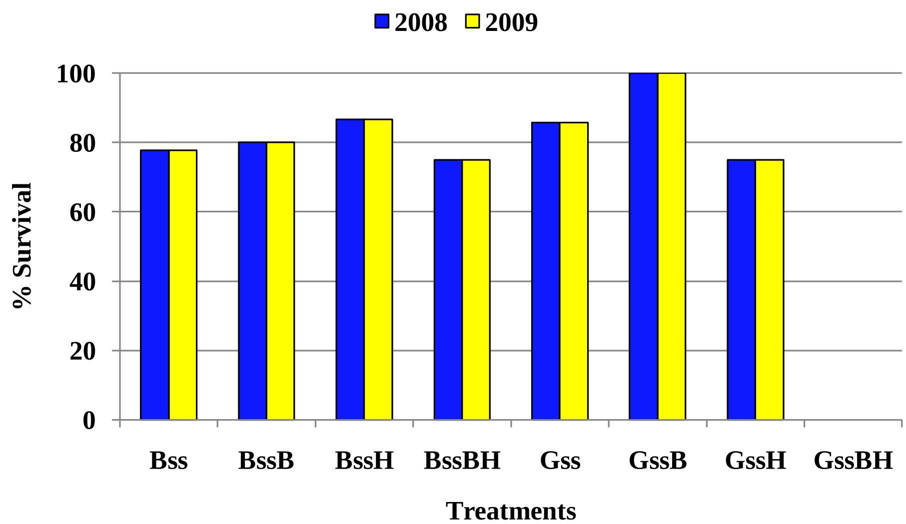

Figure 3-2a. Average survival of black locust for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

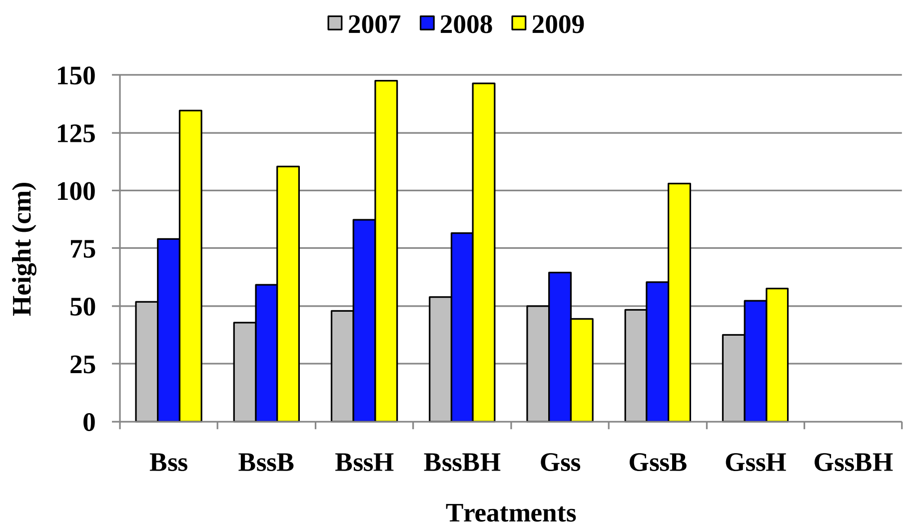

Figure 3-2b. Average height of black locust for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

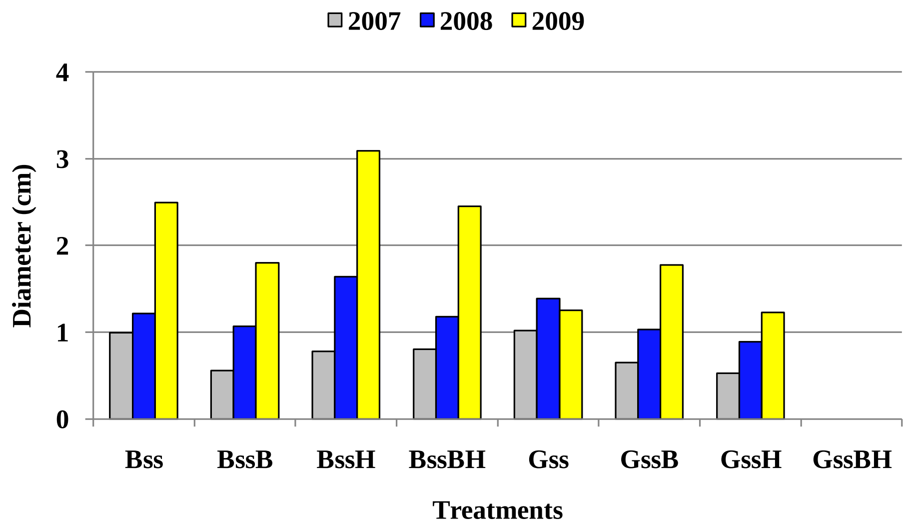

Figure 3-2c. Average diameter of black locust for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

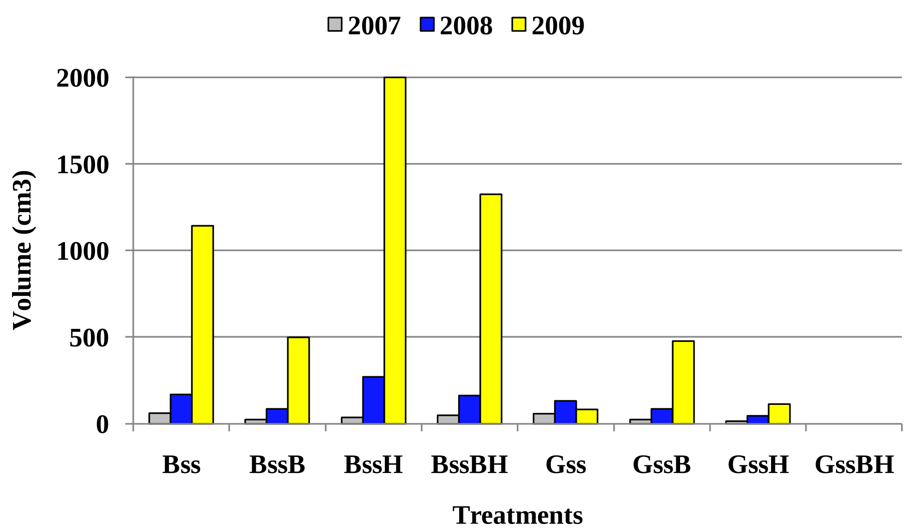

Figure 3-2d. Average volume of black locust for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Dogwood had the lowest average survival across the eight soil treatment combinations at 16% with an average volume of 3 cm^3 and a moderate vigor rating of 3.0. The highest average survival (100%) was recorded in the gray sandstone with bark mulch treatment while the lowest (0%) was recorded in the brown sandstone alone, brown sandstone with hydroseeding, gray sandstone alone, gray sandstone with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments. The greatest average volume (4 cm^3) was recorded in the gray sandstone alone treatment while the least (2 cm^3) was recorded in the brown sandstone with hydroseeding treatment. The highest average vigor rating (4.0) was recorded in the gray sandstone alone while the lowest (2.0) was recorded in the brown sandstone with hydroseeding treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-3a through 3-3d. Skousen et al. (2006) found that dogwood will grow on surface mined lands and will colonize as a volunteer. However, the site in the study by Skousen et al. (2006) was 22 years of age which could indicate that dogwood is more likely to move into an area and have success after a forest canopy is established and the site conditions, detailed in Chapter 1, are more favorable.

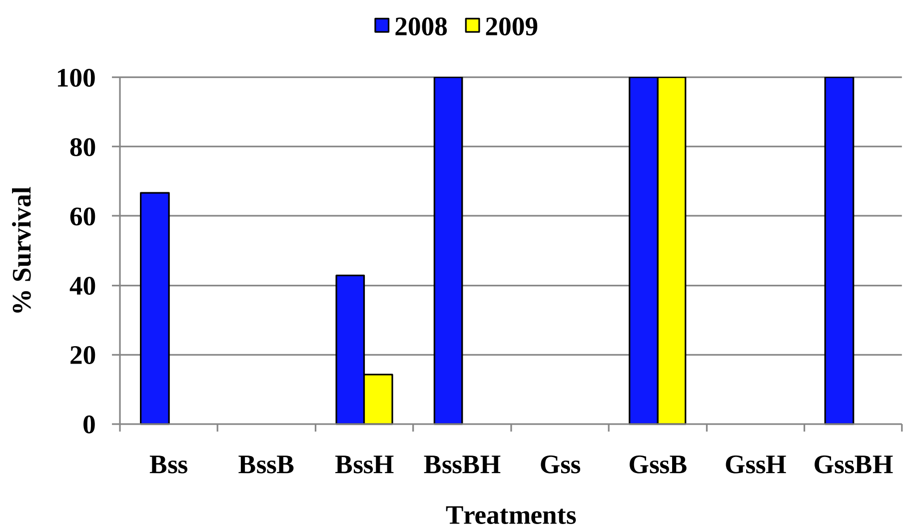

Figure 3-3a. Average survival of dogwood for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

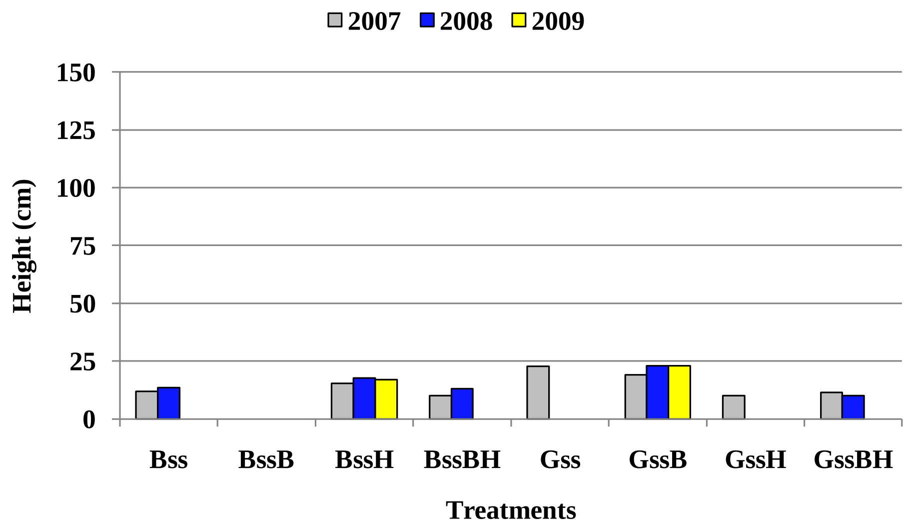

Figure 3-3b. Average height of dogwood for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

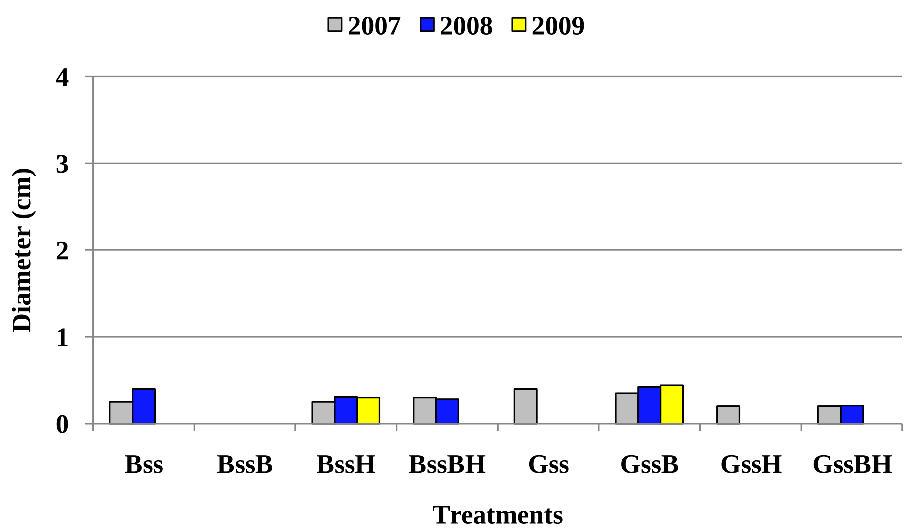

Figure 3-3c. Average diameter of dogwood for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

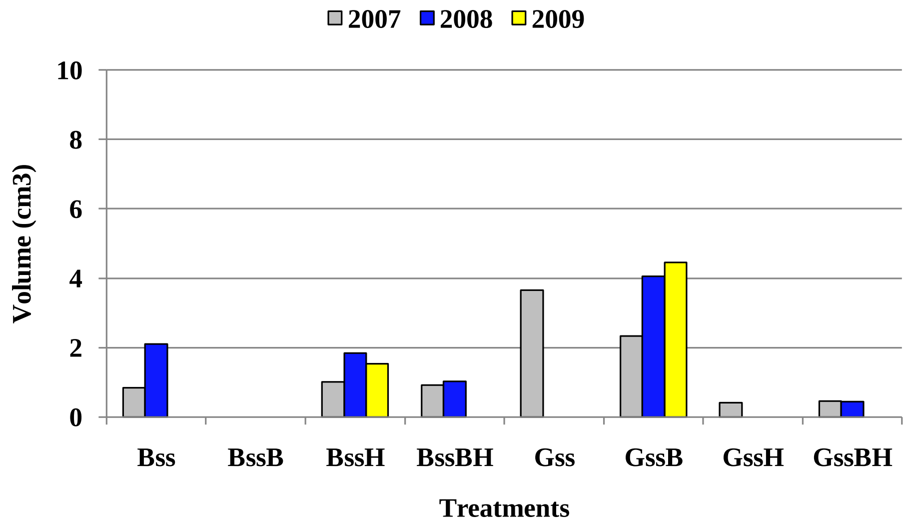

Figure 3-3d. Average volume of dogwood for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Redbud had the second lowest average survival across the eight soil treatment combinations at 38% with an average volume of 20 cm^3 and a good vigor rating of 4.0. The highest average survival (100%) was recorded in the gray sandstone alone treatment while the lowest (0%) was recorded in the brown sandstone with hydroseeding and gray sandstone with bark mulch treatments. The greatest average volume (47 cm^3) was recorded in the brown sandstone alone treatment while the least (4 cm^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (5.0) was recorded in the brown sandstone alone and brown sandstone with bark mulch treatments while the lowest (2.0) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-4a through 3-4d. Redbud performance in this study was relatively poor and fits with its intolerance of sunny conditions and harsh soils. Growth would be expected to increase as the tree canopy increases and provides shade and cooler conditions more favorable for growth.

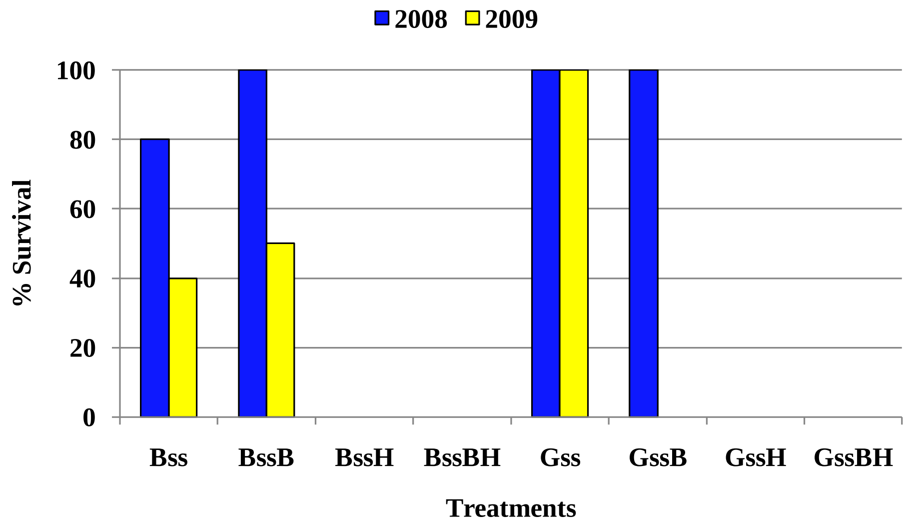

Figure 3-4a. Average survival of redbud for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

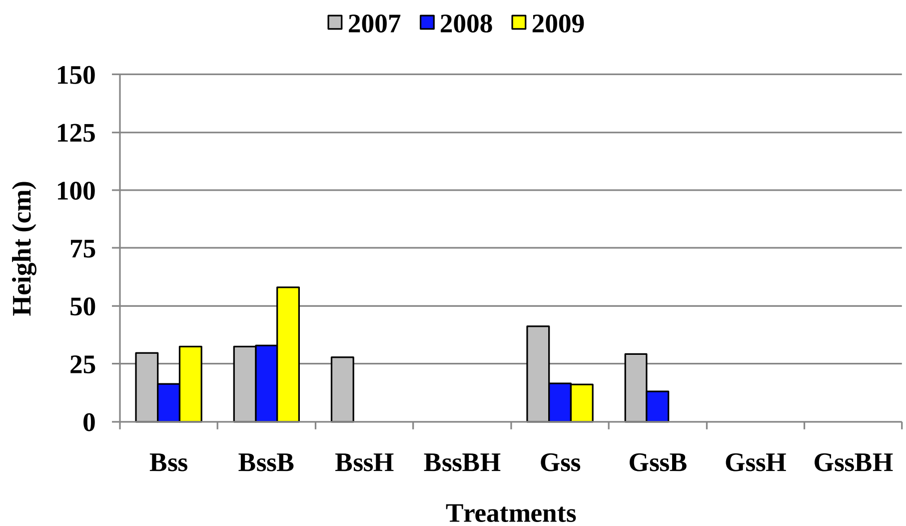

Figure 3-4b. Average height of redbud for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

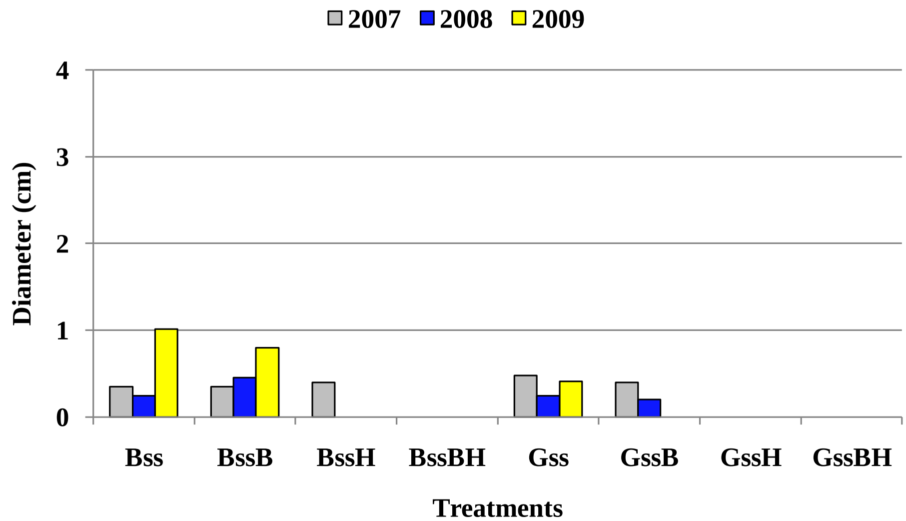

Figure 3-4c. Average diameter of redbud for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

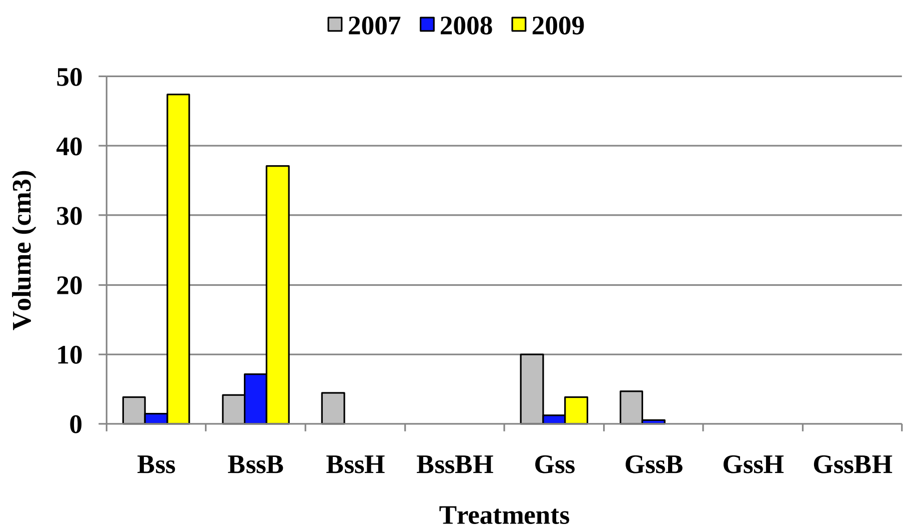

Figure 3-4d. Average volume of redbud for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Red oak had the fifth highest average survival across the eight soil treatment combinations at 79% with an average volume of 73 cm^3 and a moderate to good vigor rating of 3.8. The highest average survival (100%) was recorded in the brown sandstone alone and brown sandstone with bark mulch treatments while the lowest (50%) was recorded in the gray sandstone with hydroseeding treatment. The greatest average volume (139 cm^3) was recorded in the brown sandstone with hydroseeding treatment while the least (20 cm^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (4.8) was recorded in the brown sandstone alone treatment while the lowest (3.0) was recorded in the gray sandstone alone, gray sandstone with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-5a through 3-5d. Its performance in this study on these harsh rocky soils was expected and amending these mine soils with bark and fertilizer (in the hydroseed mixture) showed improved growth and volume (Burger et al., 2007). Increases in volume were especially good between 2008 and 2009 (Figure 3-5d).

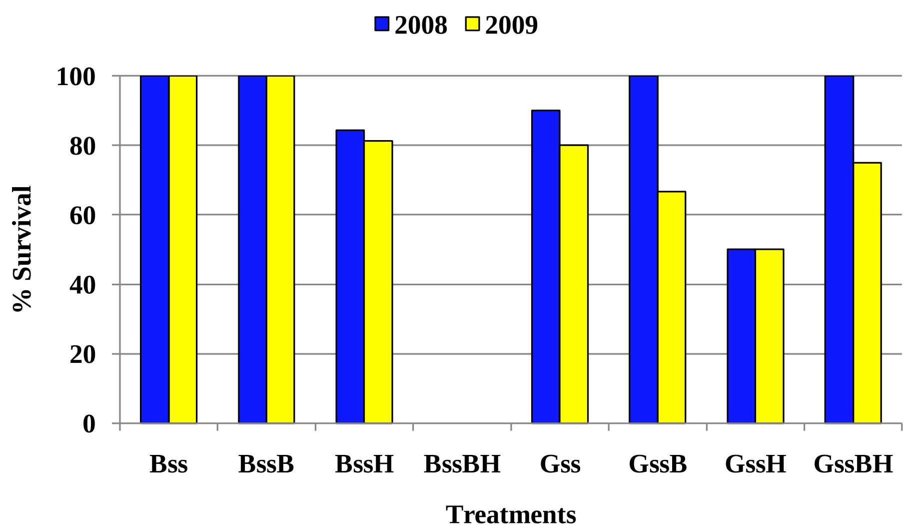

Figure 3-5a. Average survival of red oak for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

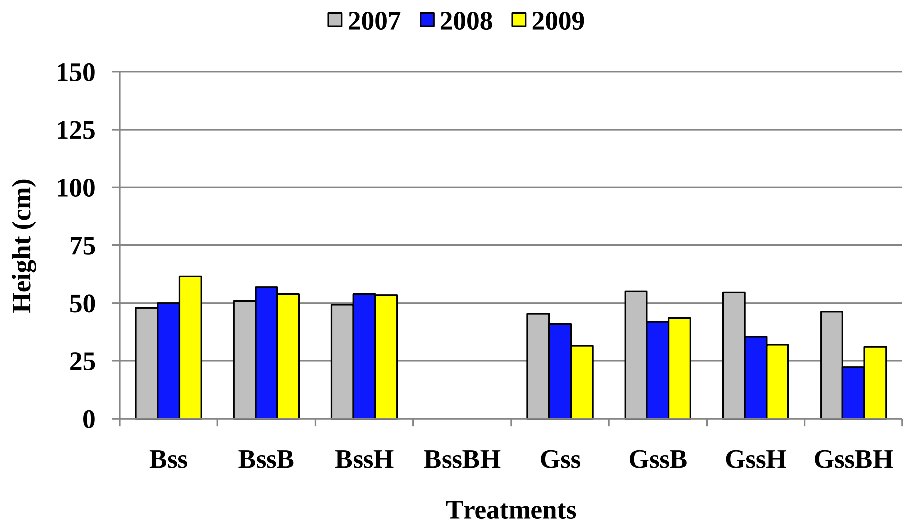

Figure 3-5b. Average height of red oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

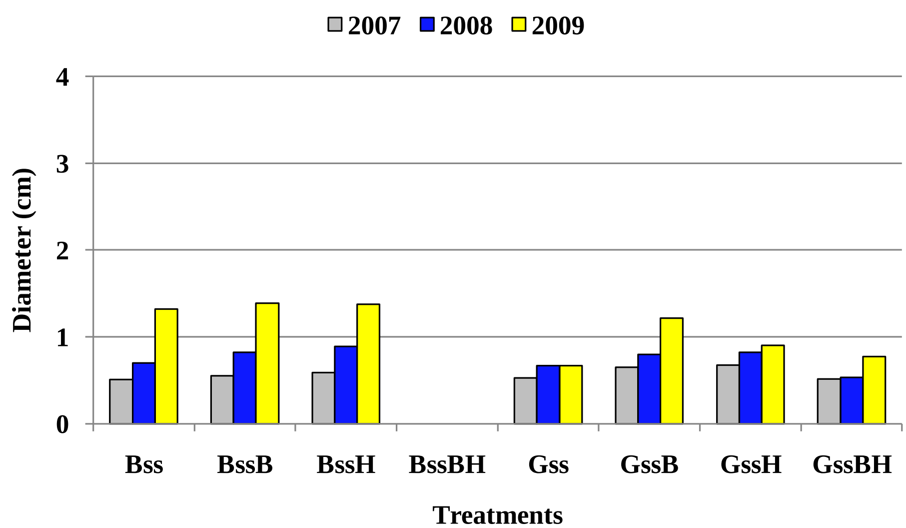

Figure 3-5c. Average diameter of red oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

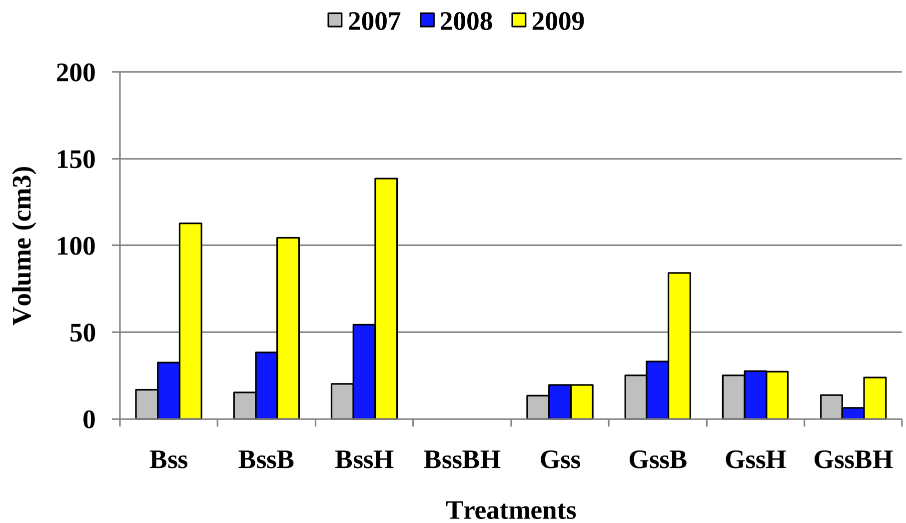

Figure 3-5d. Average volume of red oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Sugar maple had the highest average survival across the eight soil treatment combinations at 85% with an average volume of 14 cm^3 with a poor to moderate vigor rating of 2.9. The highest average survival (100%) was recorded in the brown sandstone with bark mulch, brown sandstone with bark mulch and hydroseeding, gray sandstone with bark mulch, gray sandstone with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (43%) was recorded in the brown sandstone alone treatment. The greatest average volume (30 cm^3) was recorded in the brown sandstone with hydroseeding treatment while the least (3 cm^3) was recorded in the gray sandstone with hydroseeding and gray sandstone with bark mulch and with hydroseeding treatments. The highest average vigor rating (3.3) was recorded in the brown sandstone alone and gray sandstone with bark mulch treatments while the lowest (2.5) was recorded in the brown sandstone with bark mulch and with hydroseeding, gray sandstone with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-6a through 3-6d. The good survival of sugar maple in this study is somewhat surprising since it prefers shaded and moist environments, neither of which are found on this site. As the trees continue to grow and a canopy forms, sugar maple would be expected to show increased performance as the conditions are more favorable to growth for this species.

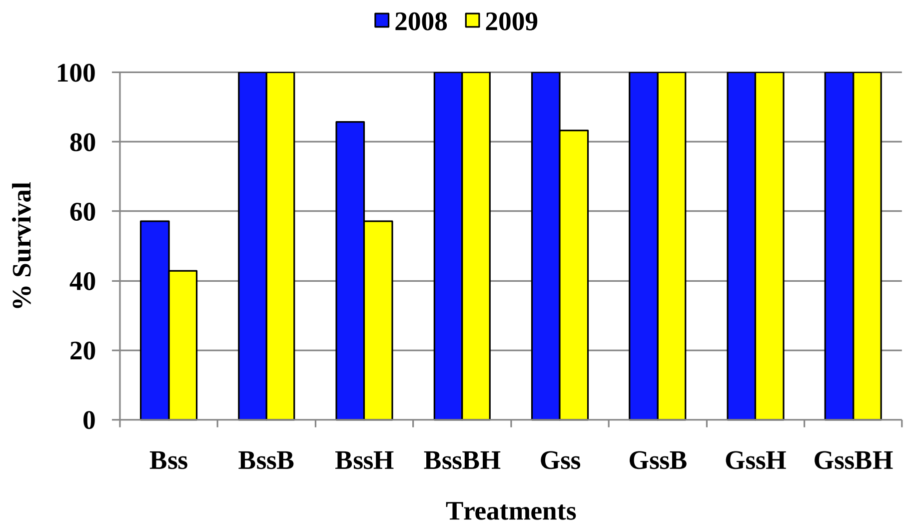

Figure 3-6a. Average survival of sugar maple for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

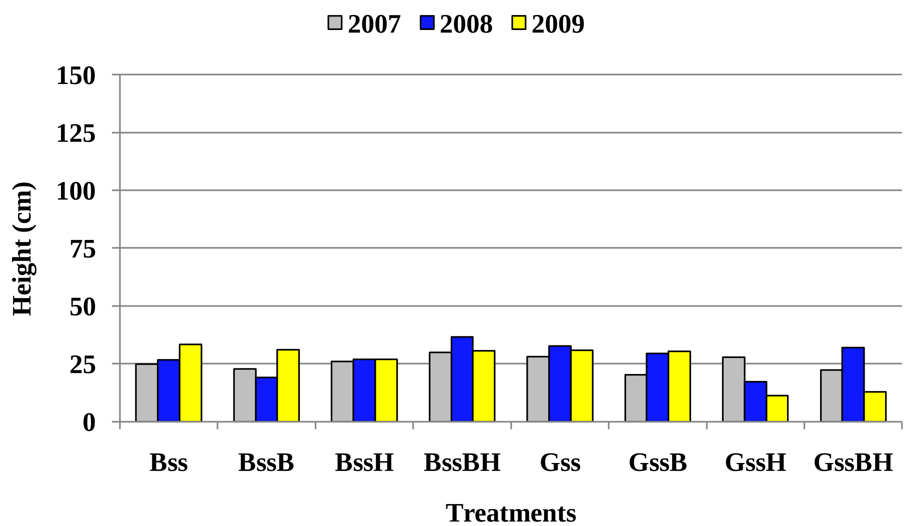

Figure 3-6b. Average height of sugar maple for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

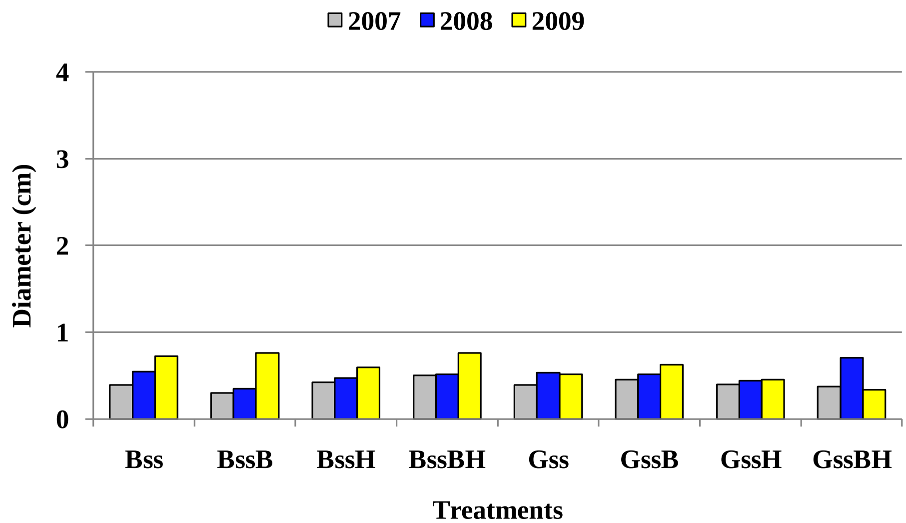

Figure 3-6c. Average diameter of sugar maple for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

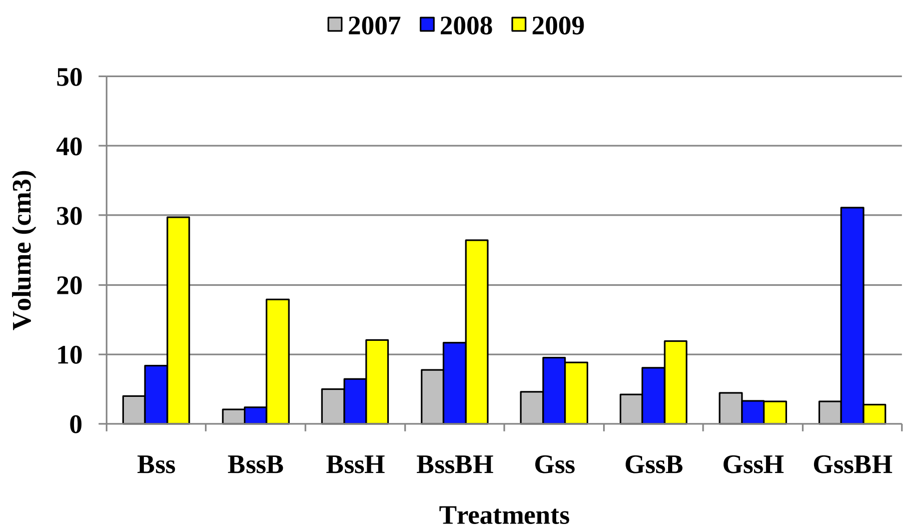

Figure 3-6d. Average volume of sugar maple for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Sycamore had the third lowest average survival across the eight soil treatment combinations at 41% with an average volume of 71 cm^3 and a good to very good vigor rating of 4.3. The highest average survival (75%) was recorded in the brown sandstone alone treatment while the lowest (0%) was recorded in the gray sandstone with hydroseeding treatment. The greatest average volume (102 cm^3) was recorded in the gray sandstone with bark mulch and with hydroseeding treatment while the least (23 m^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (5.0) was recorded in the brown sandstone with bark mulch and with hydroseeding and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (3.0) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-7a through 3-7d. Its lower survival and slower growth on this site matches its intolerance of coarse-textured, dry mine soils and as the rocky soils mature and as the tree canopy forms, sycamore could show increases as the site becomes more favorable for growth.

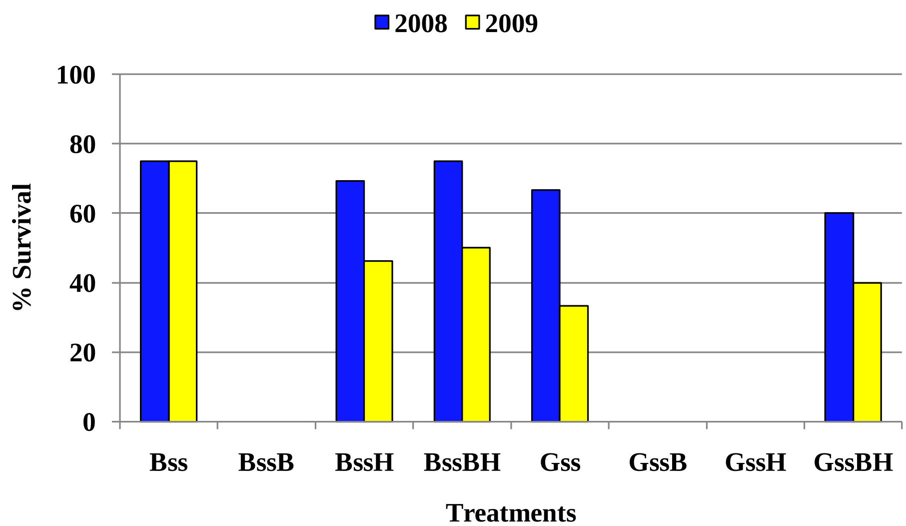

Figure 3-7a. Average survival of sycamore for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

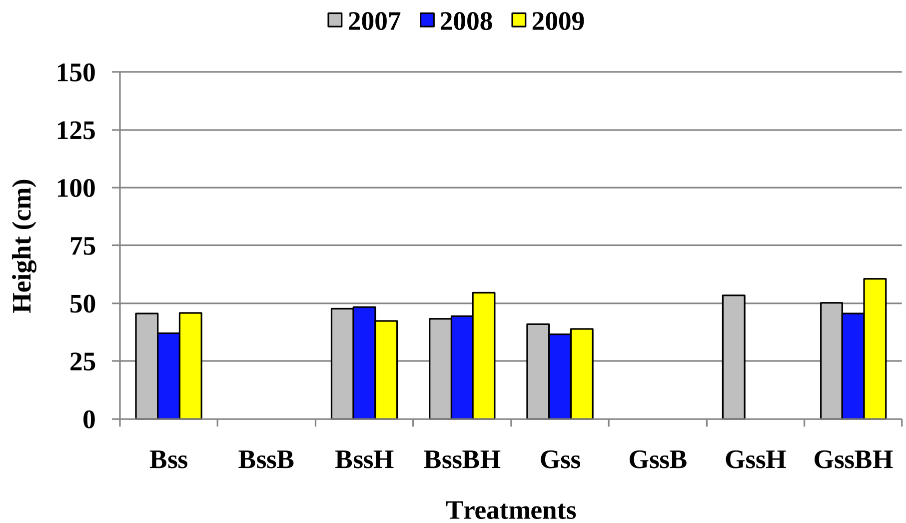

Figure 3-7b. Average height of sycamore for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

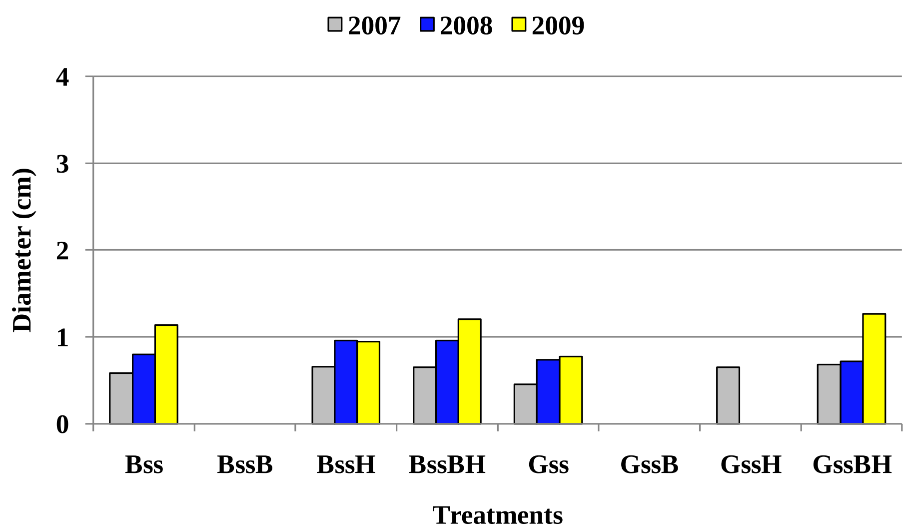

Figure 3-7c. Average diameter of sycamore for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

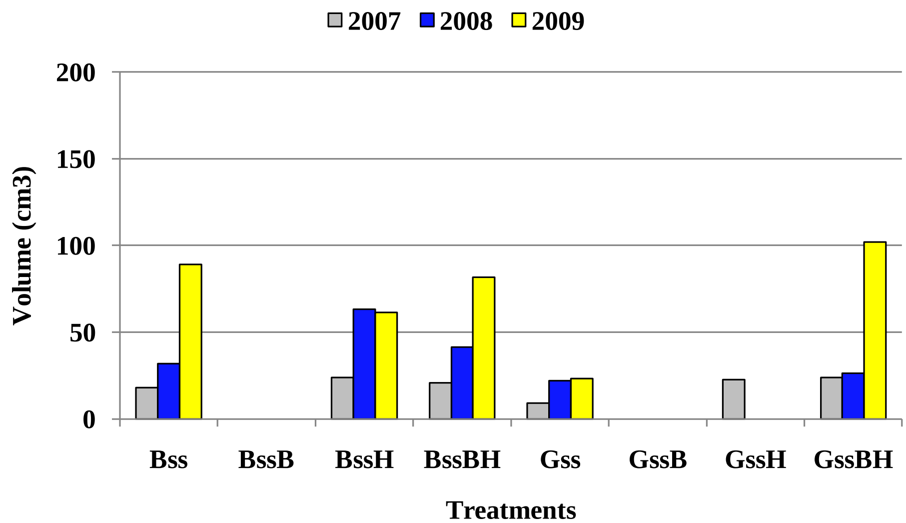

Figure 3-7d. Average volume of sycamore for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Tulip poplar had the fourth lowest average survival across the eight soil treatment combinations at 73% with an average volume of 319 cm^3 and a good to very good vigor rating of 4.4. The highest average survival (100%) was recorded in the gray sandstone alone, gray sandstone with bark mulch, and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (33%) was recorded in the gray sandstone with hydroseeding treatment. The greatest average volume (963 cm^3) was recorded in the brown sandstone with bark mulch treatment while the least (56 cm^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (5.0) was recorded in the brown sandstone with bark mulch treatment while the lowest (3.6) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-8a through 3-8d. Its performance in this study shows that the bark mulch treatment helped in producing a much greater volume than in treatments without bark mulch. The lower volume in the brown and gray sandstone with bark mulch and with hydroseeding as compared to the brown and gray sandstone with bark mulch could show that tulip poplar is experiencing competition with herbaceous ground covers which are hampering growth.

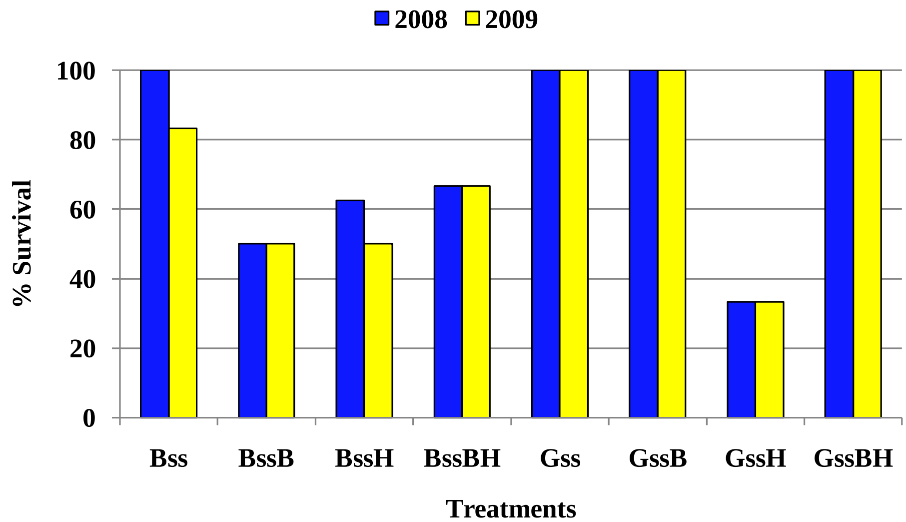

Figure 3-8a. Average survival of tulip poplar for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

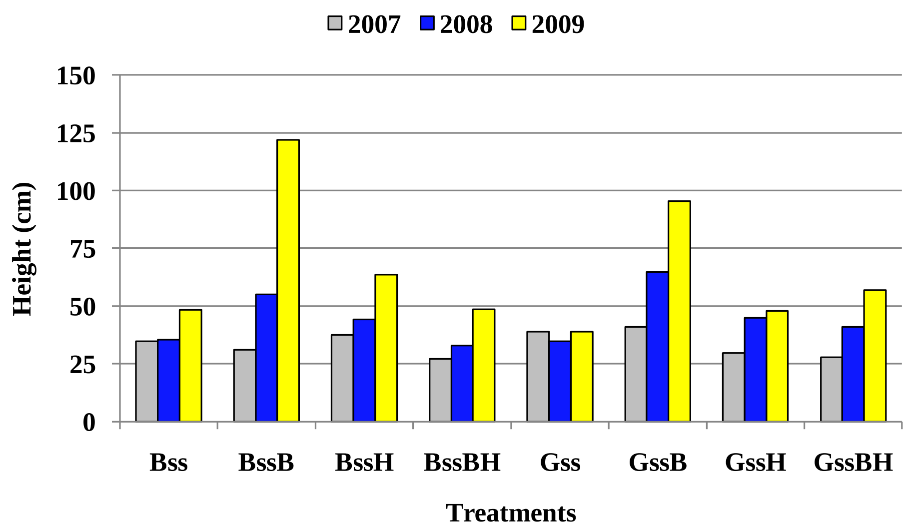

Figure 3-8b. Average height of tulip poplar for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

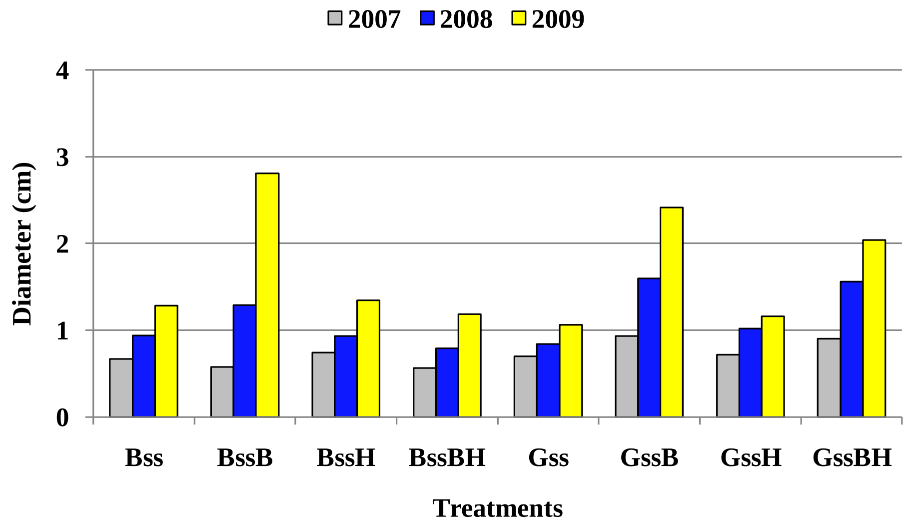

Figure 3-8c. Average diameter of tulip poplar for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

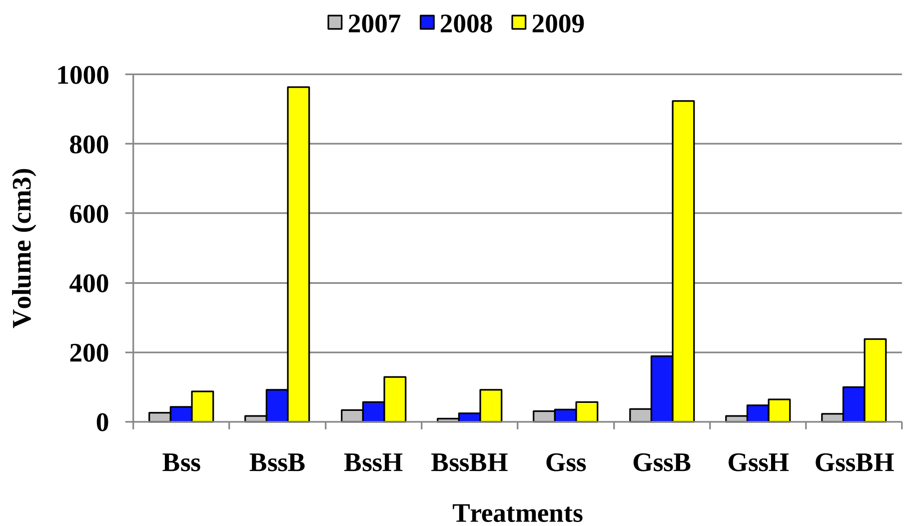

Figure 3-8d. Average volume of tulip poplar for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

White ash had the fifth lowest average survival across the eight soil treatment combinations at 75% with an average volume of 99 cm^3 and a good to very good vigor rating of 4.7. The highest average survival (100%) was recorded in the brown sandstone with bark mulch, brown sandstone with bark mulch and with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (0%) was recorded in the gray sandstone with hydroseeding treatment. The greatest average volume (180 cm^3) was recorded in the gray sandstone with bark mulch treatment while the least (36 cm^3) was recorded in the gray sandstone with bark mulch and with hydroseeding. The highest average vigor rating (5.0) was recorded in the brown sandstone with bark mulch, brown sandstone with bark mulch and with hydroseeding, and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (4.0) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-9a through 3-9d. Skousen et al. (2009) found white ash to have exceptional survival and growth on mine soils, and white ash also performed well in this study as other reports by Zeleznik and Skousen (1996) and Skousen et al. (2006). The addition of bark mulch increased volume in the gray sandstone substrate making it comparable to the brown sandstone treatment combinations. Increases in volume from 2008 to 2009 were exceptional for all the brown sandstone treatments and for the gray sandstone with bark (Figure 3-9d).

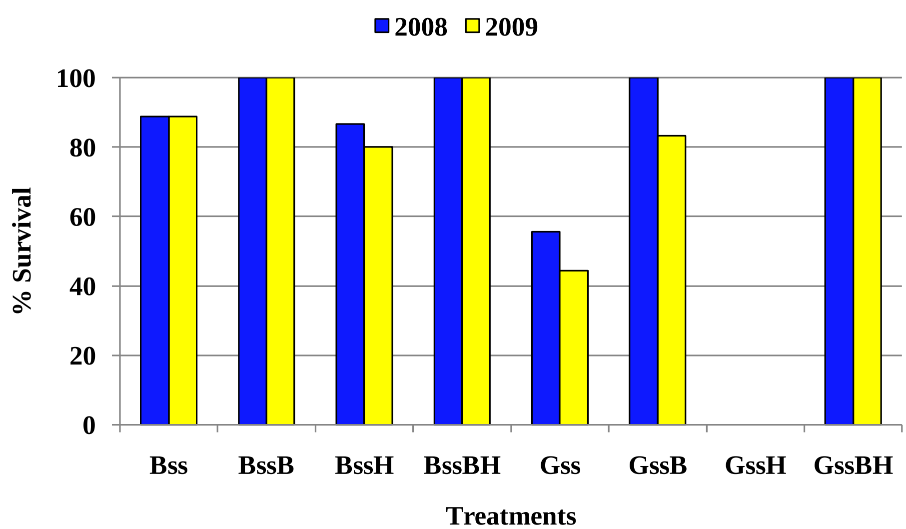

Figure 3-9a. Average survival of white ash for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

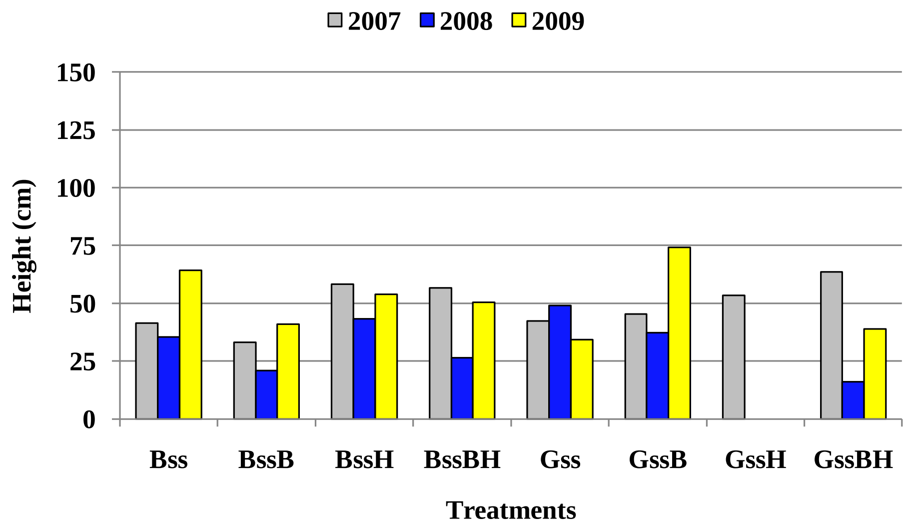

Figure 3-9b. Average height of white ash for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

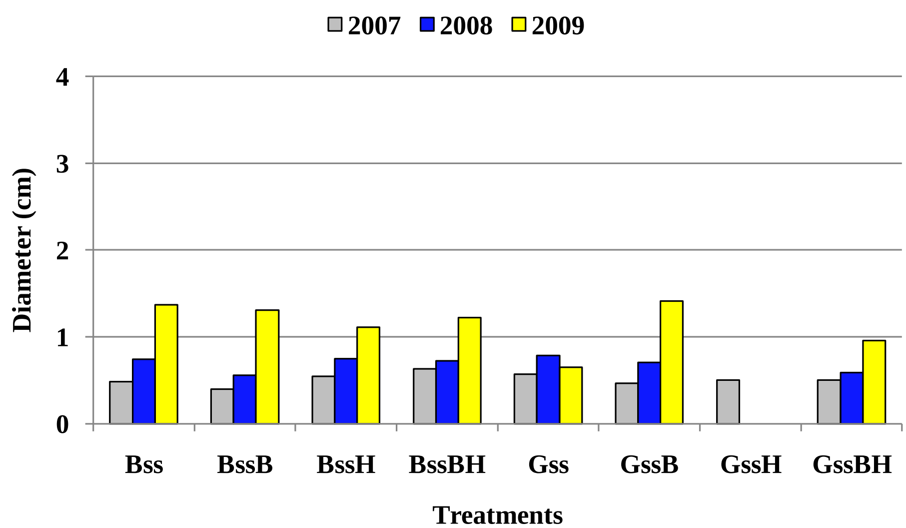

Figure 3-9c. Average diameter of white ash for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

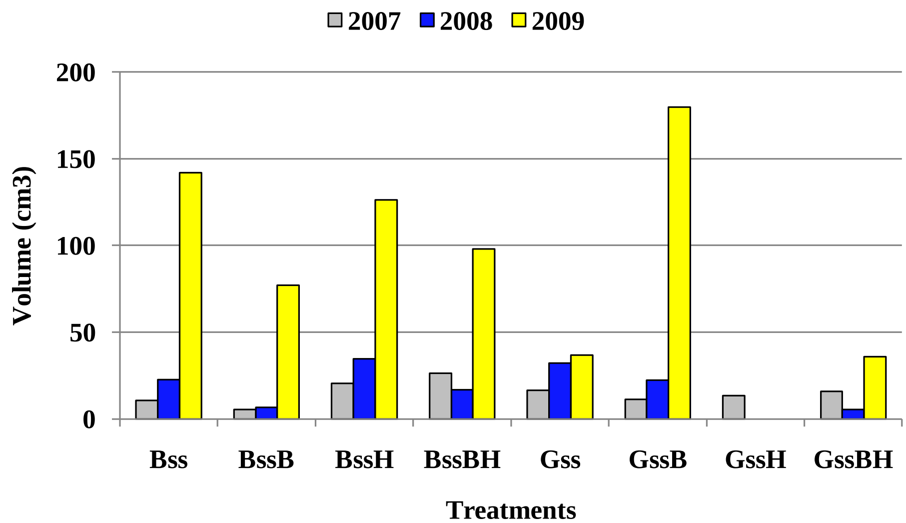

Figure 3-9d. Average volume of white ash for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

White oak had the third best average survival across the eight soil treatment combinations at 83% with an average volume of 44 cm^3 and a moderate to good vigor rating of 3.9. The highest average survival (100%) was recorded in the brown sandstone alone, brown sandstone with bark mulch, brown sandstone with bark mulch and with hydroseeding, and gray sandstone with bark mulch and with hydroseeding while the lowest (50%) was recorded in the gray sandstone with bark mulch treatment. The greatest average volume (159 cm^3) was recorded in the gray sandstone with bark mulch and with hydroseeding treatment while the least (67 cm^3) was recorded in the brown sandstone with hydroseeding treatment. The highest average vigor rating (5.0) was recorded in the gray sandstone with bark mulch and with hydroseeding treatment while the lowest (2.5) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-10a through 3-10d. Due to white oak being a slow growing species, as mentioned in Chapter 1, the lower volume recorded in this study was expected and as trees become established their volume would be expected to be similar to other species that grow to dominate forest canopies. It is noteworthy that volume increased more so on the gray sandstone with bark and with hydroseeding than any other treatment.

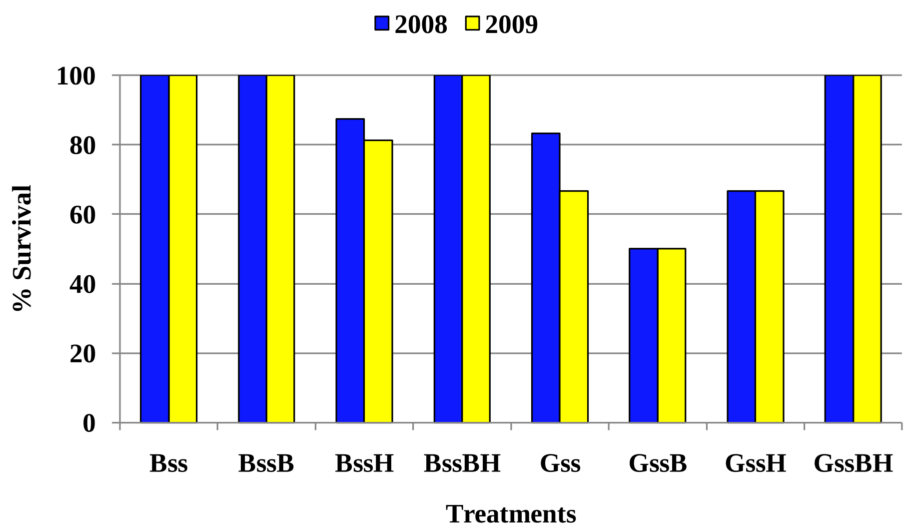

Figure 3-10a. Average survival of white oak for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

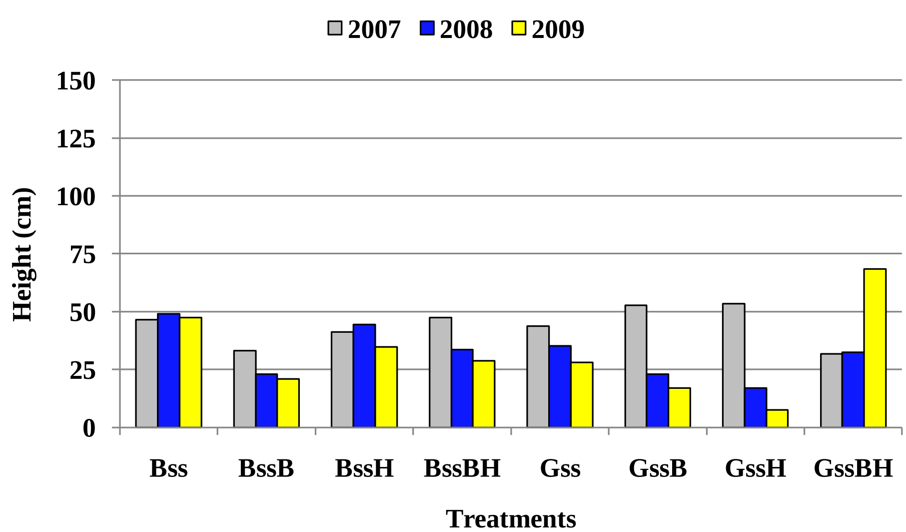

Figure 3-10b. Average height of white oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

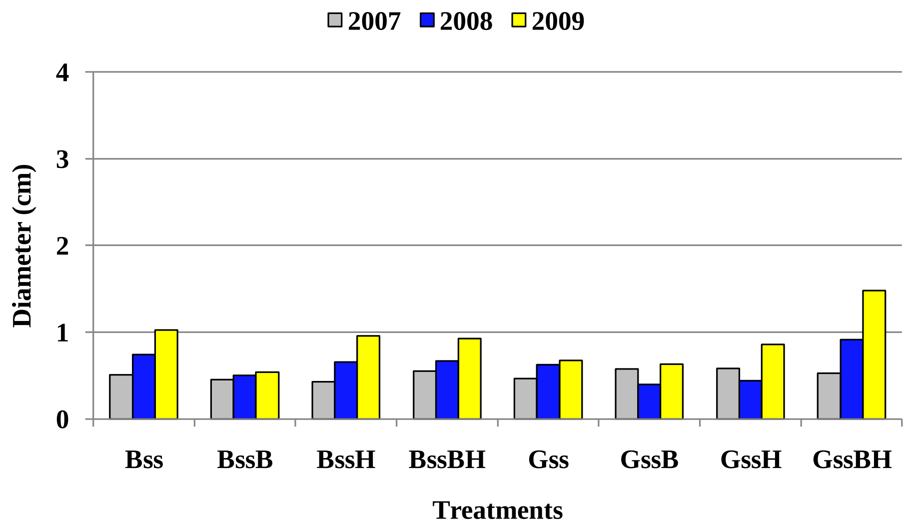

Figure 3-10c. Average diameter of white oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

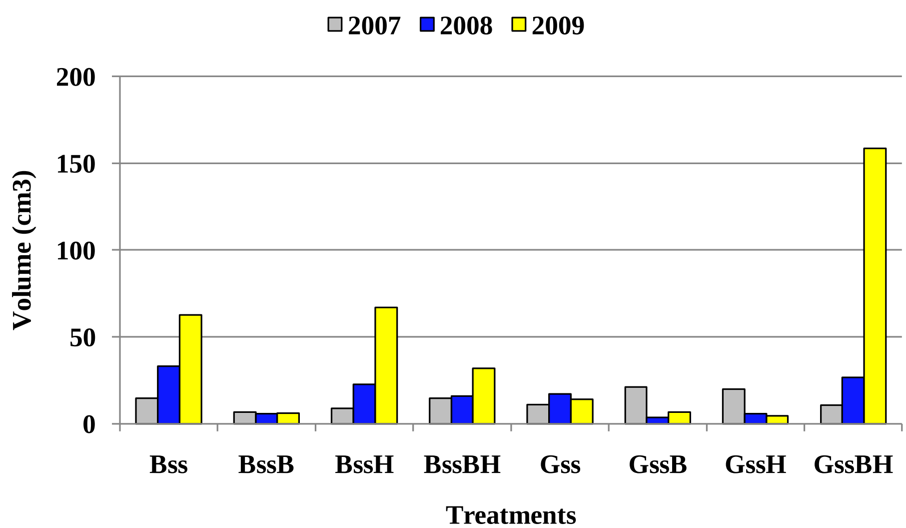

Figure 3-10d. Average volume of white oak for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

White pine had the sixth highest average survival across the eight soil treatment combinations at 78% with an average volume of 82 cm^3 and a good to very good vigor rating of 4.8. The highest average survival (100%) was recorded in the brown sandstone alone and gray sandstone with bark mulch and with hydroseeding treatments while the lowest (50%) was recorded in the brown sandstone with bark mulch and with hydroseeding and gray sandstone with bark mulch treatments. The greatest average volume (189 cm^3) was recorded in the brown sandstone alone treatment while the least (23 cm^3) was recorded in the gray sandstone alone treatment. The highest average vigor rating (5.0) was recorded in the brown sandstone alone, brown sandstone with bark mulch and with hydroseeding, gray sandstone with bark mulch, and gray sandstone with bark mulch and with hydroseeding while the lowest (4.3) was recorded in the gray sandstone alone treatment. Species survival, height, diameter, and volume for the length of the study can be seen in Figures 3-11a through 3-11d. The performance of white pine in this study is similar to Emerson et al. (2009) who showed white pine to have an average survival of 65% and an average volume of 58 cm^3 after three growing seasons. The addition of hydroseeding in the gray sandstone treatment combinations increased volume making it similar to the results found in the brown sandstone treatment combinations (Figure 3-11d).

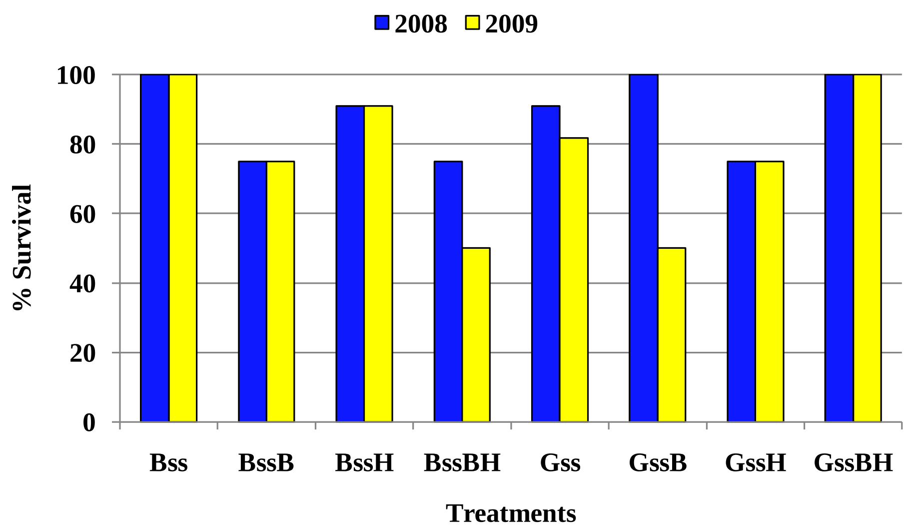

Figure 3-11a. Average survival of white pine for two growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

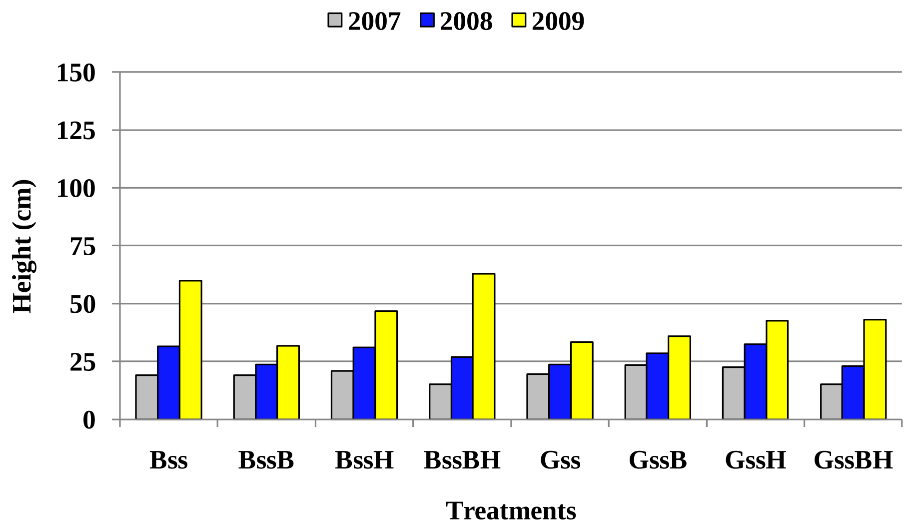

Figure 3-11b. Average height of white pine for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

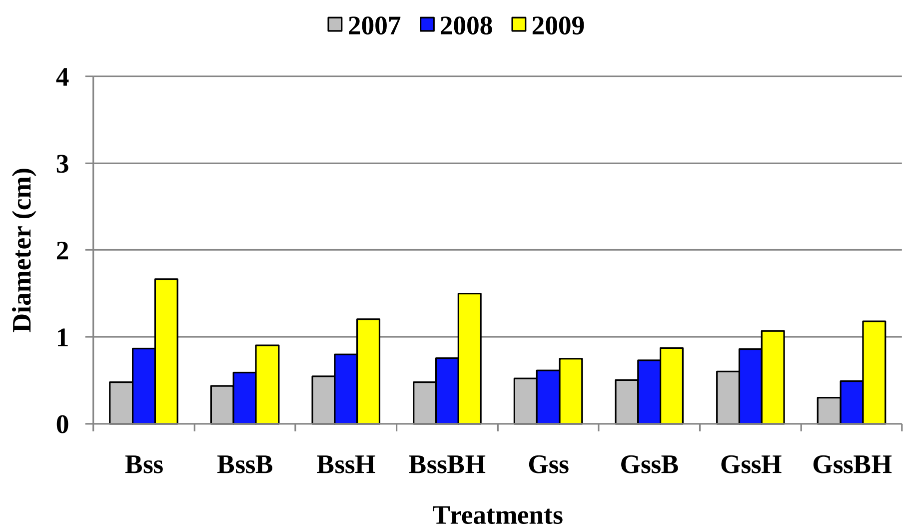

Figure 3-11c. Average diameter of white pine for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

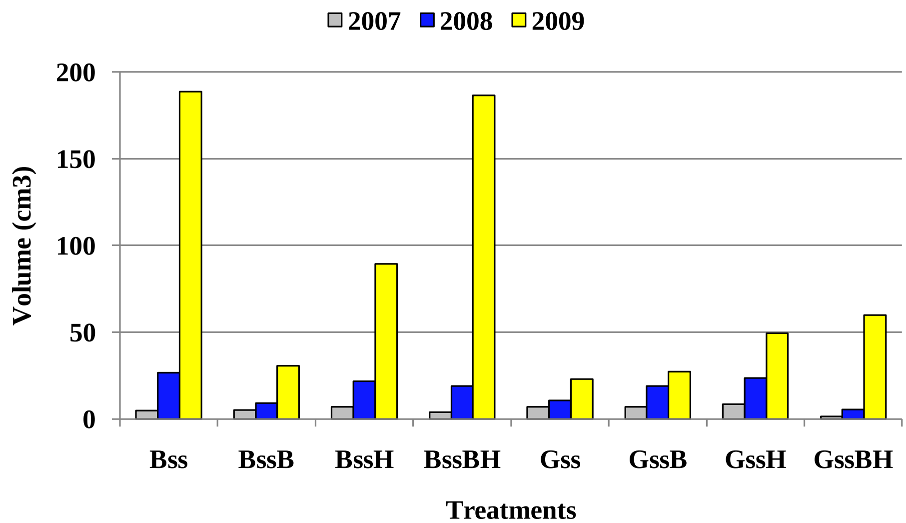

Figure 3-11d. Average volume of white pine for three growing seasons in eight soil treatment combinations at ICG Eastern, LLC's Birch River Operation in Webster County, WV

Summary and Conclusions

Treatments of gray sandstone and treatments with bark mulch had soil pH levels that were significantly greater than the brown sandstone treatments that did not have bark mulch applied. Bark mulch, which was taken from log landings at sawmills, has ground up limestone from aggregate spread on the site for traction, which gives it a high pH. Therefore, bark mulch has soil and limestone as well as organic matter from trees and mud. Electrical conductivity in treatments that received a bark mulch application was higher than their counterparts. Extractable element concentrations varied greatly across treatments. Overall there were few significant differences among treatments but treatments with bark mulch showed higher concentrations of Mg, K, and Ca and lower concentrations of Zn and P.

Survival among species across all treatment combinations was not significantly different. However, treatments of brown sandstone had significantly greater volume than treatments of gray sandstone. The addition of bark mulch and hydroseeding increased volume but the increases we not significantly greater than the treatments without bark mulch or hydroseeding. Black locust was clearly the best performing tree on this site while the other trees showed no significant difference for volume.

CHAPTER 4. DETERMINATION OF MINE SOIL BULK DENSITY AND COMPARISON OF BULK DENSITY MEASUREMENT TECHNIQUES

Introduction

Since the late 1970's, mined lands have commonly been reclaimed using smooth grading followed by the establishment of dense grasses and legumes (Groninger et al., 2007). Using this type of reclamation, the land is often reclaimed by heavily compacting soils for stabilization, to minimize erosion, and to provide a good seed bed for pasture and hayland crops. However, in the early 1990's land owners began to show an increasing interest in reclaiming mined land to forest (Torbert and Burger, 2000). Even though the post mining land use chosen for the land was different, the practice of heavily compacting the soils was still being done. In return, this heavy soil compaction is thought to be the number one problem associated with sites being reclaimed with trees on post-SMCRA mine lands (Larson and Vimmerstedt, 1983). Heavy soil compaction affects the trees mainly by impacting root growth. Compacted soils can lead to an increase in the soil resistance to penetration, poor aeration, slow movement of nutrients and water, and the buildup of toxic gases around the roots (Brady and Weil, 2002). One way to avoid this would be to limit compaction of the surface during the reclamation process. This can be achieved by using low compaction grading of the mine soil during reclamation (Sweigard et al., 2007a). Angel et al. (2006) showed that by minimizing compaction through decreased grading, the height and survival of white oak, eastern white pine, northern red oak, black walnut, and yellow poplar were all significantly greater than in compacted mine soils. Zeleznik and Skousen (1996) found that leaving mine soil unleveled (noncompacted) increased the survival and height of white pine and yellow poplar. Knowing that decreased compaction increases tree growth and survival is important, but being able to quantitatively measure the level of compaction is key to showing the differences in compaction levels.

Soil compaction can be measured in many ways. The common practice is by measuring soil bulk density. Soil bulk density is defined as the mass of a unit volume of dry soil in which both solids and pore space are included in the volume measurement (Brady and Weil, 2002). Measurement is achieved in one of three ways. The first and most common way of sampling soil bulk density is by collecting an intact soil core of known volume (Blake and Hartge, 1986). A second way is by excavating the soil and then measuring the physical dimension of the excavated cavity using rulers. A third way is by excavating the soil and filling the excavated cavity with a medium of known density such as sand or with a substance such as polyurethane foam in which the volume of the polyurethane foam filling the cavity can be determined. In mine soils, it's often difficult to extract soil by means of a container with a known volume due to the high amount of rock fragments. Thus excavation methods are more commonly used to determine bulk density in mine soils. A radiation technique using a moisture-density gauge can also be used for bulk density determination (American Society for Testing and Materials, 1999). However, a certified technician is required to conduct the readings due to the ^{137}Cs found in the moisture-density gauge.

Objectives

a. Determine soil bulk density in mine soils composed of weathered brown sandstone and unweathered gray sandstone and to compare these to unmined native forest.
b. Compare four soil bulk density determination methods and evaluate their in-field efficiency.

Methods and Materials

This study was conducted at Catenary Coal's Samples mine (38°26′27′′ N, 80°36′33′′ W) near the town of Eskdale, in Kanawha County, West Virginia. Five substrates were chosen for the bulk density determination. Four of the substrates were reforestation demonstration plots and the fifth was adjacent unmined native forest (Table 4-1). In January 2005, Catenary Coal constructed the demonstration plots consisting of weathered brown sandstone to a depth of 1.5 m and unweathered gray sandstone to a depth of 1.5 m. Plots were constructed by end-dumping the overburden material in closely adjacent piles and then one half of each plot was compacted by using a bulldozer to completely cover the surface with tracks while the other half of the plot was graded with only one or two passes of the bulldozer to minimize compaction. The unmined native forest substrate (Dekalb-Pineville-Guyandotte association) was located adjacent to the demonstration plots on the permitted area.

Table 4-1. Substrates used for bulk density determination at Catenary Coal's Samples mine operation in Mine in Kanawha County, West Virginia

Substrate	Abbreviation
1.5 m weathered brown sandstone compacted	5B-C
1.5 m weathered brown sandstone noncompacted	5B-NC
1.5 m unweathered gray sandstone compacted	5G-C
1.5 m unweathered gray sandstone noncompacted	5G-NC
Unmined native forest	UNF

In July 2009, three excavation techniques (polyurethane foam, frame apparatus, and sand-cone) and one radiation technique were used for determining soil bulk density. For the polyurethane foam technique, a hole with a square surface area of about 225 cm^2 (15 cm x 15 cm) and depth of approximately 15 cm was excavated using a hand trowel and the substrate material was collected and saved for weight determination. The excavated area was then filled with polyurethane foam (Mueller and Hamilton, 1992). The foam was applied by starting at the deepest part of the hole and working upwards in a circular fashion leaving a small excess when finished. A piece of cardboard was then placed over the hole and weighted to push the foam into crevices in the hole. After curing and hardening over night, the foam was trimmed off flush with the soil surface, carefully removed, and excess soil was brushed and picked from the surface of the foam form. The foam form was labeled and returned to the laboratory where its volume was measured by water displacement. The excavated soil was air dried for a period of seven days in the West Virginia University (WVU) green house and then weighed to determine the mass of each sample.

For the sand-cone technique, a metal template was placed on the soil surface and soil was excavated in a 15-cm diameter hole to a depth of 15 cm through the center of the template (Blake and Hartge, 1986). The hole was then filled with sand and the weight of the sand used to fill the hole was recorded and later used to calculate the volume of the hole using the density of the sand used (sand density = 1.43 g cm^3). The excavated soil was air dried for a period of seven days in the WVU green house and then weighed to determine the mass of each sample.

For the frame apparatus method, a wooden frame measuring 1225 cm^2 (35 cm by 35 cm square) with a plexi-glass cover plate, containing 40 evenly placed holes, was placed on the soil surface and secured with four metal rods (Grossman and Reinsch, 2002). The distance to the soil surface from the plastic plate was then measured in the 40 holes. After initial measurements, the plexi-glass plate was removed (the wooden frame being left in place) and the soil was excavated to a depth of about 15 cm. After excavation, the plastic cover plate was replaced and the distance to the bottom of the excavated area to the soil surface was again measured in the 40 holes to determine the volume of soil removed. The differences in height was determined and multiplied by 1000 cm^2 to obtain the volume measurement.

$$\text{Volume} = [\ \sum (H_1 - H_0) / 40\ ) \text{ X } 1000 \text{ cm}^2$$

Where: H_0 equals initial height measurement, H_1 equals height measurement after excavation, and 1000 cm^2 equals area covered by the frame. The excavated soil was air dried for a period of seven days in the WVU green house and then weighed to determine the mass of each sample.

The radiation method (American Society for Testing and Materials, 1999) required contracting a private firm to conduct the soil bulk density sampling since a registered nuclear radiation technician must operate the device. The substrate surface was prepared by removing any loose materials that would have prevented adequate contact between the testing device and the substrate. A hole was then formed in the substrate by pounding a 2.5 cm steel rod approximately 20 cm into the soil for the insertion of the testing probe. The testing probe was then placed in the hole to a depth of 15 cm and a one-minute reading was taken at each sampling point. Bulk substrate samples were then collected at the 15 cm depth by the technician so density calculations could be determined after correction for soil moisture.

Bulk density measurements were taken in each treatment from five randomly located points. The four sampling techniques were conducted from within a 4-m^2 area at each of the randomly selected locations. Five replications of each technique were conducted in each treatment (five replications and four techniques equaling 20 measurements per treatment for a total n=100). The in-field efficiency of the techniques used was determined by the amount of time it took to complete each technique in the field. The statistical analysis was performed by a General Linear Model by substrate and technique and Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$ level for soil bulk density and in-field efficiency.

Results and Discussion

The bulk density determined with the sand-cone technique was significantly lower than the other three determination techniques, giving results that were 18 to 23% lower than the other techniques. No significant differences were found among the frame, polyurethane foam, or radiation techniques (Table 4-2). Bulk density measurements by technique ranged from 1.35 to

1.76 g cm^{-3}. The significantly lower bulk density for the sand-cone technique compared to the others was not expected. Muller and Hamilton (1992) found that there was no significant difference between the sand-cone and polyurethane techniques when compared in two compacted mine soil substrates. However, the polyurethane foam and radiation techniques produced similar results to Page-Dumroese et al. (1999) who found little to no significant difference between the two techniques when compared in a rocky forest soil.

The bulk density in the unmined native forest substrate was significantly lower than the four sandstone substrates and there were no significant differences among the four sandstone substrates (Table 4-2). The unmined native forest substrate had a bulk density that was approximately 38 to 43% lower than the sandstone substrates.

Bulk density by substrate ranged from 1.05 to 1.84 g cm^{-3}. The bulk densities for the four sandstone substrates and the unmined native forest were comparable to other studies conducted on similar sites. Michels et al. (2007) found bulk densities of 1.66 and 1.72 g cm^{-3} in compacted sandstone substrates and 1.60 and 1.61 g cm^{-3} in noncompacted sandstone substrates at a depth of 15 cm. The unmined native forest bulk densities were similar to and slightly lower than Page-Dumroese et al. (1999) for the polyurethane foam and radiation techniques in which the authors found the bulk densities to be 1.10 and 1.24 g cm^{-3} at 0-10 cm and 1.11 to 1.21 g cm^{-3} at 10-20 cm.

Table 4-2. Soil bulk density and in-field efficiency for four soil bulk density determination techniques in five substrates at Catenary Coal's Samples mine operation in Kanawha County, West Virginia

		Bulk Density	In-field efficiency
Technique		g cm^{-3}	s
	Frame	1.69[a]	1605[a]
	Polyurethane foam	1.76[a]	612[c]
	Radiation	1.64[a]	345[d]
	Sand-cone	1.35[b]	837[b]
Substrate			
	5B-C	1.76[a]	1032[a]
	5B-NC	1.84[a]	939[ab]
	5G-C	1.72[a]	750[c]
	5G-NC	1.70[a]	714[c]
	UNF	1.05[b]	816[bc]
Interactions[†]			
	F-5 B-C	1.92[ab]	2016[a]
	F-5B-NC	1.90[ab]	1632[ab]
	F-5G-C	1.79[abc]	1356[bc]
	F-5G-NC	1.74[abc]	1368[bc]
	F-UNF	1.12[de]	1656[ab]
	P-5B-C	1.97[a]	780[de]
	P-5B-NC	1.87[abc]	720[def]
	P-5G-C	2.12[a]	516[efg]
	P-5G-NC	1.86[abc]	468[efg]
	P-UNF	0.99[de]	576[efg]
	R-5B-C	1.78[abc]	264[g]
	R-5B-NC	1.82[abc]	384[efg]
	R-5G-C	1.78[abc]	408[efg]
	R-5G-NC	1.74[abc]	312[fg]
	R-UNF	1.10[de]	360[efg]
	S-5B-C	1.38[cde]	1068[cd]
	S-5B-NC	1.76[abc]	1020[cd]
	S-5G-C	1.18[de]	720[def]
	S-5G-NC	1.46[bcd]	708[def]
	S-UNF	0.97[e]	672[defg]

[†]F-5B-C = frame 1.5 m brown compacted, P-5B-NC = polyurethane foam 1.5 m brown noncompacted, R-5G-C = radiation 1.5 m gray compacted, S-UNF = sand-cone unmined native forest

Significantly different in-field efficiency times were recorded for each of the four determination techniques (Table 4-2). The radiation technique had the greatest in-field efficiency (6 minutes per sample) while the frame was the lowest at 27 minutes per sample with the polyurethane foam and sand-cone techniques being intermediate between the two. Overall the in-field efficiency ranged from 345 to 1605 seconds for the four determination techniques. The in-field efficiency for the weathered brown sandstone substrates was significantly lower than the unweathered gray sandstone substrates while the unmined native forest was not significantly different than both sandstone substrates (Table 4-2). This was due to the more rocky nature of the gray sandstone compared to brown sandstone. The unmined native forest soil had rocks and roots which slowed the measurements.

Summary and Conclusion

The frame, polyurethane foam, and radiation determination techniques all produced similar results in the sandstone substrates and unmined native forest, and showed comparable results to other studies suggesting that all three techniques would provide accurate measurements of bulk density. The significantly lower bulk density results for the sand-cone technique could have been due to rock fragment content (40 to 50% in the brown sandstone and 63% in the gray) and an uneven surface found in the sandstone substrates. This could have allowed a greater volume of sand to fill the excavated area and the void space between the base of the sand-cone metal template and the ground surface. This discrepancy would have increased the volume of sand used to fill the hole which would have resulted in a greater volume of material than what was excavated, which would lead to lower bulk density measurements. As expected, the unmined native forest substrate had a lower bulk density than the four sandstone substrates.

Each determination technique was significantly different in respect to in-field efficiency and each technique has its own benefits and drawbacks. The frame technique allows the sampling of a large volume of material which could lower the amount of error associated with sampling, but that larger sample requires a greater amount of time to collect while in the field. Although the polyurethane foam technique in-field efficiency was intermediate in time recorded, the foam must cure for eight hours or be left over night and collected the following day. The added versatility of being able to use the polyurethane foam on sloping and uneven areas is a benefit but additional time to return and collect the foam molds is necessary. The sand-cone technique is fairly efficient in the field and can be completed all at one time, but it cannot be used on sloping areas nor on areas with great amounts of rock fragments protruding from the ground surface since the metal base plate must be flush with the soil surface to get accurate results. The radiation technique required the shortest time of the four techniques and allows for a greater number of samples to be measured in a set period of time. It, however, requires expensive equipment, training, and certification to properly execute the technique.

CHAPTER 5. LITERATURE CITED

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