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Nutrient concentrations in tree leaves on brown and gray reclaimed mine soils in West Virginia

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HIGHLIGHTS

- Tree leaf nutrient concentrations growing in four mine soils were lower than those in native forests.
- Phosphorus and potassium were lower in all three tree species.
- Brown mine soil had similar foliar and soil nutrient values as those in native soils.
- After 6 yrs, amended and Brown mine soils supported healthy tree growth.

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ABSTRACT

Surface mining in Appalachia disrupts large areas of forested land. Federal and state laws require disturbed lands be reclaimed by re-constructing the landscape and replacing soil materials to provide a rooting medium. If insufficient quantities of native topsoil are available, substitute materials derived from the overburden may be used as soil media. This study examined soil and foliar nutrient concentrations of three hardwood tree species on areas where brown and gray sandstone overburden were applied as substitute growth media at the Birch River mine in West Virginia. Soil and foliar nutrient concentrations found in four experimental plots were compared to soil and foliar nutrient concentrations found in a nearby native Appalachian forest. Many foliar nutrients such as phosphorus and potassium were lower in all three tree species on most mine soils compared to trees growing in nearby native forest soils and to tree nutrient concentrations from the literature. Foliar and soil nutrient concentrations in the Brown mine soil were similar to those found in native forest soil, while the Gray mine soil provided significantly lower levels of nutrients. Overall, low nutrient availability in mine soils translates into generally lower foliar nutrient concentrations in trees growing on mine soils. After six years, amended topsoil substitutes and Brown mine soil produced higher foliar nutrient concentrations than Gray mine soil.

1. Introduction

The Appalachian region of the eastern USA is home to some of the most ecologically diverse temperate deciduous forests in the world (Showalter et al., 2007; Riitters et al., 2000). Every year more than 10,000 ha of land in Appalachia are disturbed for the purpose of surface coal mining (Zipper et al., 2011). In the USA, West Virginia is the second largest coal producing state. In 2012, West Virginia produced 126,483,400 tonnes of coal from both underground and surface mining operations. Currently, there are 232 active surface mines in West Virginia which produced 43,599,824 tonnes of coal in 2012 (West Virginia Coal Association, 2012).

In 1977 the U.S. government passed the Surface Mining Control and Reclamation Act (SMCRA) due to growing concerns about environmental and safety issues with surface mining. SMCRA mandates performance standards for coal operators to meet before, during, and after mining operations including restoring the land to its approximate original contour, minimizing disturbances to the hydrologic system, reclaiming the land in a timely manner, and establishing a permanent vegetative cover (Public Law 95-87, 1977). In an effort to quickly and economically establish a permanent vegetative cover as mandated by SMCRA, coal operators frequently planted a variety of rapidly establishing grasses and legumes. However, aggressive non-native forage species such as red clover (*Trifolium pretense* L.), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb), and sericea lespedeza (*Lespedeza cuneata* L.) impede the re-colonization of native herbaceous and tree species by outcompeting them for nutrients, water, and solar energy (Franklin et al., 2012; Emerson et al., 2009).

Recently however, there has been a shift in reclamation philosophy in the Appalachian region. The U.S. Office of Surface Mining (US OSM) launched the Appalachian Regional Reforestation Initiative (ARRI)

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with assistance from several state regulatory agencies and university researchers to encourage mine operators to re-establish native hardwood tree species. Reforestation of mined land enhances wildlife habitat, supports ecosystem diversity, promotes soil and water conservation, aids in the sequestration of atmospheric CO_2, and eventually provides an economically valuable post-mining land use for the landowner (Burger, 2009; Amichev et al., 2008; Larkin et al., 2008). ARRI recommends using Forestry Reclamation Approach (FRA) technology. The five FRA steps are (Burger et al., 2005): 1) create a suitable rooting medium for tree growth; 2) loosely grade the topsoil or topsoil substitute; 3) seed a tree compatible ground cover; 4) plant early successional tree species and commercially valuable crop trees; and 5) use proper tree planting techniques. Research has shown that these techniques foster natural succession of native plant species, increases the survival and growth of trees, and promotes the re-colonization of wildlife communities (ARRI, 2012; Zipper et al., 2011).

The designation of forestry post-mining land uses in West Virginia requires the placement of 1.2 m of soil material. This performance standard was established in the West Virginia surface mining regulations to optimize the growth of commercially valuable trees and to re-establish a sustainable forest ecosystem on mined lands. Steep topography and thin native soils characterize the coal mining regions of southern West Virginia and make topsoil salvage extremely hazardous and expensive. Therefore, regulations allow coal operators to use topsoil substitutes derived from weathered and unweathered geologic strata from the overburden to achieve required depths of soil material (Emerson et al., 2009). In West Virginia, the predominant overburden rock type is sandstone; as either brown sandstone, which is weathered and moderately acidic, or gray sandstone, which is unweathered and slightly- to moderately-alkaline (Emerson et al., 2009).

Several studies conducted in the Appalachian coal fields have shown that selecting the appropriate material from the overburden to create mine soils suitable for reforestation is imperative for proper tree growth and survival. Angel et al. (2008) found that average tree height on brown sandstone was significantly greater (66 cm) than average tree height on gray sandstone (35 cm) after three years. Skousen et al. (2013) reported that the average height of chestnut (*Castanea* spp.) seedlings was 90 cm on brown mine soil compared to 62 cm on gray mine soil after the third year. Eight years after reclamation, Wilson-Kokes et al. (2013) found that average tree volume index (diameter^2 × height) was significantly greater on brown mine soils (3853 cm^3) than on gray mine soils (407 cm^3). In a greenhouse study, Showalter et al. (2010) attributed better tree performance on brown sandstone overburden to lower pH and a higher percentage of fine soil material (<2 mm).

As a consequence to coal mining, many surface-mined sites lack sufficient organic matter to support optimum soil function (Bendfeldt et al., 2001). Several studies have shown that mine soils exhibit limited nitrogen and phosphorus availability, micronutrient imbalances, high electrical conductivity, and low water holding capacity (Daniels and Zipper, 1988; Torbert et al., 1989, 1988), all of which are influenced by the low amount of organic matter in these soils.

The application of soil amendments to reclaimed surface mines can improve tree growth by alleviating the problems mentioned above. Bark mulch helps to deter erosion, provides soil nutrients, protects tree seeds and seedlings, and helps retain moisture for plant uptake (Conrad et al., 2008). Angel et al. (2006) found the addition of organic soil supplements (hardwood bark mulch and composted straw and manure) to a shale and sandstone topsoil substitute improved tree growth by adding nutrients to the soil. Showalter et al. (2010) found the addition of forest topsoil to unweathered shale topsoil substitute improved the growth of native hardwood trees. It was reported that the addition of forest topsoil significantly increased mineralizable nitrogen from 0.35 to 4.24 mg kg^{-1} compared with non-amended unweathered shale. In addition to providing soil nutrients, the application of soil amendments such as bark mulch to mine soils may reduce levels of iron or other heavy metals by forming metal complexes with the organic matter (Harman et al., 2007).

Past research involving tree growth on mined lands primarily focused on the physical and chemical properties of mine soils which affect tree growth and development. Often these studies focused on compaction, electrical conductivity, pH, and available nutrients (Rodrigue and Burger, 2004; Emerson et al., 2009; Conrad et al., 2008). Only a few studies have been conducted which examine mine soil nutrient concentrations and the foliar nutrient concentrations in trees grown on the reclaimed mine sites. Torbert et al. (1990) found nutrient availability in the soil varied with pH of overburden materials, which influenced the overall tree volume of pitch × loblolly hybrid pine (*Pinus* × *rigitaeda*). They reported that mine soil pH had the greatest effect on available manganese. Manganese availability decreased as soil pH increased, resulting in low concentrations in the soil and foliage. This deficiency directly affected tree volume (Torbert et al., 1990). Showalter et al. (2007) found a correlation between nutrient availability in mine soil and foliar nutrient concentration of white oak (*Quercus alba* L.). The researchers reported that mine soil nitrogen levels were deficient, consequently resulting in reduced foliar nitrogen levels. Foliar nitrogen concentrations found in the mine soil were significantly lower than foliar nitrogen concentrations of white oak from a nearby native Appalachian hardwood forest.

The objectives of this study were to determine the effects of topsoil substitute (brown vs. gray sandstone topsoil substitutes) and amendment (bark mulch vs. no bark mulch) on nutrient concentrations in soil and leaves of three deciduous hardwood tree species at the Birch River mine in Webster County, West Virginia. We compared these soil and foliar nutrient concentrations in mine soils to trees growing in a nearby native Appalachian forest and to foliar nutrient concentrations in the literature.

2. Methods

The location of this study was Arch Coal's Birch River mine (approximately 1620 ha) located near Cowen in Webster County, West Virginia (38° 26′ 31.4154″ N 080° 36′ 39.9594″ W). In November 2006, a 2.8-ha experimental plot was established using two different topsoil substitutes. Half of the plot was constructed with approximately 1.5 m of weathered brown sandstone and the other half with approximately 1.5 m of unweathered gray sandstone. Measures were taken to limit compaction by allowing only one or two passes of the bulldozer to level the area, which resulted in a 1.2-m depth of roughly graded material throughout the plot. The following spring, a 15-cm layer of hardwood bark mulch was applied to an area over the top of both mine soil types. The hardwood bark was obtained from a local sawmill which had accumulated at the log landing. The material included soil, bark and other woody debris, and ground up limestone (added as aggregate for traction), all of which was scraped up and hauled to the mine site. Seedlings (2/0 bare root) of twelve tree species were then planted on 2.4-m centers by a professional planting crew for a stocking rate of about 1450 trees per ha. The tree seedlings were purchased from commercial growers. Four topsoil substitute treatments were used in this study: Brown mine soil, Brown mine soil with bark mulch, Gray mine soil, and Gray mine soil with bark mulch (B, BM, G, and GM). A native Appalachian hardwood forest (FOR) located within the permitted boundaries of the Birch River mine was used as a control site for collection of soil and foliar samples for nutrient analyses (38° 25′ 22.48″ N 080° 40′ 04.44″ W). Fig. 1 illustrates the location of the forest in relation to the experimental plot. The predominant soil type in the forested area sampled is Dekalb channery sandy loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) with naturally low fertility and extremely acid to strongly acid. However, the potential productivity for trees on this soil is considered moderately high (Carpenter, 1992).

Black cherry (*Prunus serotina* Ehrh.), tulip-poplar (*Liriodendron tulipifera* L.), and red oak (*Quercus rubra* L.) were three of the twelve