# ONE-YEAR RESPONSE OF AMERICAN SYCAMORE (*PLATANUS OCCIDENTALIS* L.) AND BLACK LOCUST (*ROBINIA PSEUDOACACIA* L.) TO GRANULAR FERTILIZER APPLICATIONS ON A RECLAIMED SURFACE MINE IN EASTERN KENTUCKY

**Josh Brinks, John Lhotka, and Chris Barton[1]**

**Abstract.**—The establishment of intensively managed woody energy crops on reclaimed surface mine lands provides an opportunity to diversify domestic biomass sources, while increasing the productivity and economic value of underutilized land. Our objective is to test the effect of fertilization on the growth and biomass accumulation of American sycamore (*Platanus occidentalis* L.) and black locust (*Robinia pseudoacacia* L.) planted on a reclaimed surface mine. In 2008, replicated plantings of sycamore and black locust were established on Big Elk Mine in eastern Kentucky. The treatments tested include a onetime granular fertilizer application of 37 kg N, 30 kg P, and 16 kg K $ha^{-1}$ and an unfertilized control. Following one growing season, American sycamore exhibited significantly ($p < 0.05$) greater stem biomass in the fertilizer treatment (48.98 g) than in the control (23.52 g). Stem biomass of black locust was also greater ($p < 0.01$) in the fertilizer treatment (32.36 g) than in the control (13.20 g). Mean diameter and height growth of black locust was significantly ($p < 0.05$) greater in fertilizer treatments (6.52 mm, 20.37 cm, respectively) compared to the control (2.27 mm; 9.38 cm). American sycamore also displayed significant ($p < 0.05$) differences in diameter and height growth between fertilizer (7.86 mm; 30.63 cm) and control (4.42 mm; 15.97 cm) treatments. Mean black locust survival was 79.25 percent in control treatments and 88.07 percent in fertilizer treatments. American sycamore survival did not differ between control (96.43 percent) and fertilizer (93.81 percent) treatments. Our findings indicate that fertilizer applications to 1-year-old seedlings on reclaimed mines in Appalachia increase height, diameter, and biomass accumulation.

## INTRODUCTION

Biofuel plantations provide an opportunity to diversify and increase domestic energy feedstocks (Johnson and others 2007). Currently, woody biomass is the leading domestic renewable energy supply and the U.S. Department of Energy forecasts an annual biomass supply of 1 billion tons by 2050 (English and Ewing 2002). Demand for woody biomass will be met through fuel reduction treatments, industrial waste residues, and reforestation projects (Perlack and others 2005). Woody crops intended for co-firing with coal for electricity generation will prolong coal supplies, reduce $NO_X$ and $SO_X$ emissions, and contribute to national woody feedstock supplies (Boylan 1996).

Feedstock plantations on reclaimed surface mines facilitate the restoration of previously forested lands. More than 90 percent of mined lands in Kentucky were forested prior to mining activities, but 98 percent of

[1]Graduate Research Assistant (JB), Assistant Professor (JL), Assistant Professor (CB), Department of Forestry, University of Kentucky, Lexington KY 40546; JB is corresponding author; to contact, call (616) 633-2037 or email at jbrinks@gmail.com.

reclaimed areas are restored as grasslands (Cole and others 2001). This considerable shift in land cover may be offset by planting woody biofuel plantations (Casselman and others 2006, Sperow 2006). In addition to the restitution of forested landscapes, woody crops sequester atmospheric carbon and can counteract anthropogenic emissions (Dickmann 2006). Sperow (2006) found that carbon sequestration was greatest in forests as opposed to cropland or grasslands on degraded lands in Indiana, Michigan, Ohio, Kentucky, West Virginia, Pennsylvania, and Maryland.

Nutrient amendments are shown to improve feedstock yields and enhance reforestation efforts in non-mined lands (Coyle and Coleman 2005, Cobb and others 2008). Fertilizer treatments increase leaf area which enhances carbon assimilation and whole plant growth (Samuelson and others 2001). Maximizing yields will be essential as rising global populations place increasing pressures on forest resources and energy supplies. Despite elevated biomass and carbon sequestration, fertilizer applications may negatively impact on-site carbon budgets and release $N_2O$, which has a greater global warming potential than $CO_2$ (Crutzen and others 2007).

Numerous studies have quantified the impact of nutrient applications on plantation growth and survival (Coleman and others 2004, Coyle and Coleman 2005); however, more research is needed to better understand the effects of fertilizer treatments on reclaimed surface mines (Coleman and others 2004, Coyle and Coleman 2005). Moreover, an accurate assessment of the atmospheric carbon sequestration potential of reclaimed mine lands and their suitability as biofuel feedstock production sites are needed on all landscapes (Dickmann and others 1985, Rae and others 2004, Coyle and Coleman 2005, Casselman and others 2006, Cobb and others 2008). Furthermore, past studies questioned the impacts of increased resource availability on relationships among diameter, height, and biomass, but recent findings suggest nutrient amendments only accelerate ontogenetic stages and do not alter allometric relationships (Coyle and Coleman 2005). This study may further our understanding of these relationships.

The objective of this study is to test the effect of annual fertilizer application on biomass production and survival for black locust (*Robinia pseudoacacia* L.) and American sycamore (*Platanus occidentalis* L.) planted on a reclaimed surface coal mine. This paper presents the 1-year response of tree height growth, diameter growth, survival, and aboveground leafless biomass accumulation in fertilizer and control treatments.

## STUDY SITE

The study is located on a reclaimed surface mine in the Cumberland Plateau at Big Elk Mine near Hazard, KY, in Knott County. The region is characterized by warm, humid summers and cool winters. The yearly rainfall average is 127 cm. The average July high temperature is 30 °C and the average January low is –5 °C. Upland oak-hickory hardwood forests dominated the site prior to being cleared for mining. The soil profile is undeveloped, compacted, and derived from shale and sandstone. Large rocks pervade the soil matrix (Conrad 2002).

The study site was previously reclaimed using smooth grading. The site was ripped parallel to future planting with a single-blade ripping shank on a D-11 bulldozer in February 2008 to alleviate compaction. Six 0.209-ha experimental plots were established following ripping. In March 2008, half of each plot was planted with American sycamore, while the other half was planted with black locust. 1-0 bare root seedlings were used. Boulders and rough topography prevented uniform seedling plantings. Mean seedling density across all plots was 1,842 stems ha$^{-1}$. Following surface ripping and planting, the vegetation community was populated by old-field and other early successional plants reported at other reclaimed surface mines in the region (Bell and Ungar 1981, Holl and Cairns 1994, Holl 2002). Dominant genera are *Rubus*, *Lespedeza*, *Ambrosia*, *Oxalis*, *Cirsium*, *Vernonia*, *Leucanthemum*, *Rudbeckia*, *Festuca*, and *Coronilla*.

# METHODS

## FIELD METHODOLOGY

Height and basal diameter were tracked in two centrally located 0.019-ha measurement subplots containing tagged seedlings within each experimental unit (Fig. 1). Ten destructive samples (n = 60) were harvested from four 0.008-ha destructive subplots within each experimental unit. Control (C) and fertilization (F) treatments were replicated three times and randomly assigned to the six 0.209-ha experimental units. At least three border rows were present between all experimental units and subplots. All fertilized plots received 36 kg of nitrogen, 30 kg of phosphorus, and 16 kg of potassium ha$^{-1}$ on June 3, 2008. Glyphosate was applied to all treatments at a rate of 0.871 l ha$^{-1}$ with backpack sprayers during June 2008.

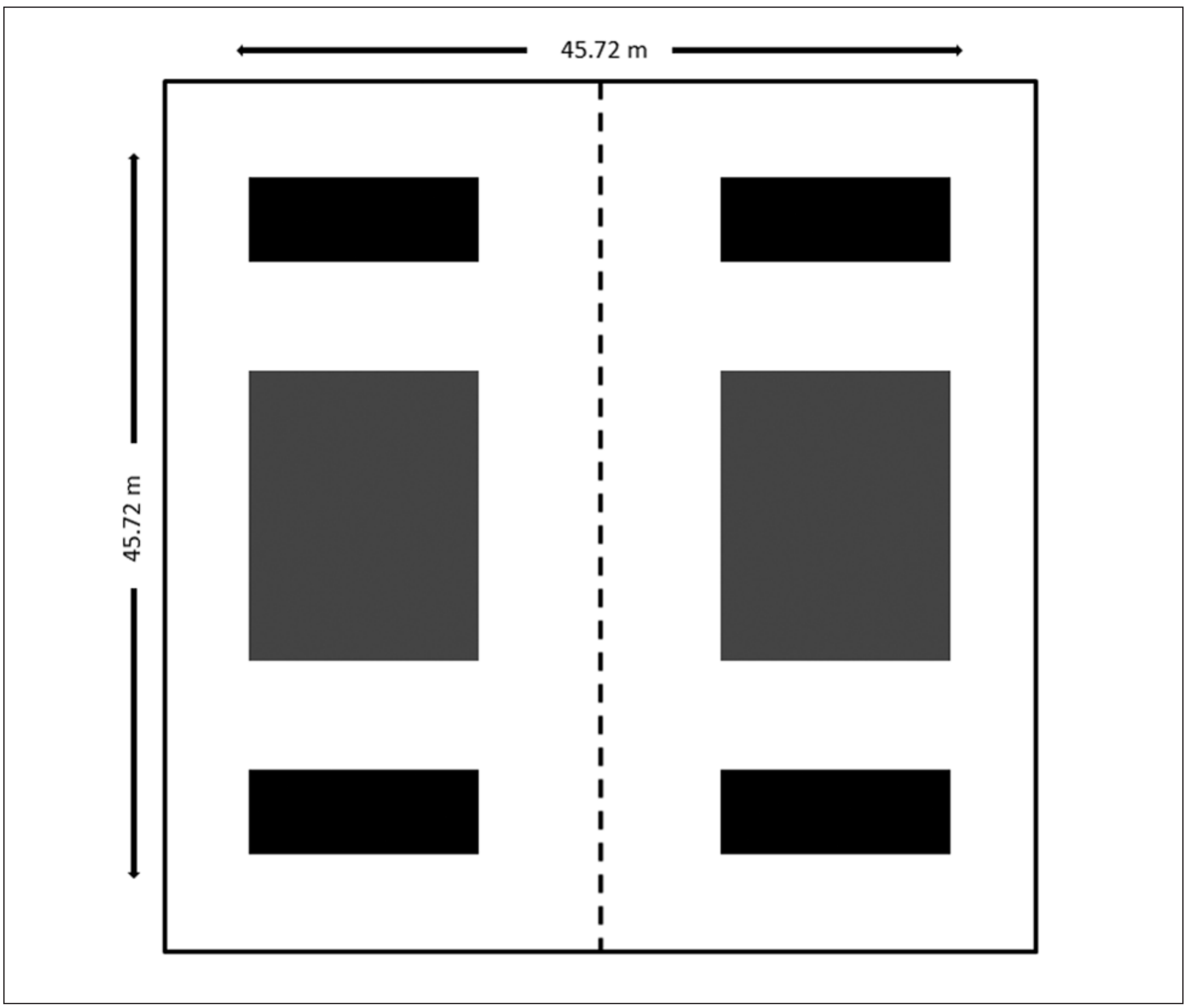


Figure 1.—Layout of individual 0.209-ha experimental unit. Dashed line represents species divide. Light-gray areas are seedling-measurement subplots for tagged and tracked trees. Black areas are destructive-harvest subplots.

## FIELD AND LABORATORY MEASUREMENTS

We recorded initial basal diameters and heights in measurement subplots after planting in May 2008. Basal diameter was taken to the nearest tenth of a mm with digital calipers at two locations, 90° apart from one another, and then averaged. Measurements taken following the first growing season were recorded in January 2009. We severed five trees from each treatment and species combination at the base with loppers and harvested them in January 2009. Diameters and heights were recorded before specimens were oven-dried for 48 hours at 60 °C, and then weighed to the nearest hundredth of a gram.

## STATISTICAL METHODS

Harvested trees were used to develop regression equations for predicting aboveground leafless biomass (SAS 9.1; SAS Institute Inc., Cary, NC). Stem biomass was predicted using a linearized version of a power function with seedling height and basal diameter as independent variables. Equations were then used to predict aboveground leafless biomass of trees being tracked in measurement subplots. Plot means were used in one-tailed t-tests to evaluate the effect of fertilization on height growth, diameter growth, and biomass accumulation for each species following one growing season. For analysis of biomass accumulation, we used average stem biomass as a dependent variable. Stem averages were used because area-based calculations would have differed due to varying plot densities, not disparate growth patterns. A generalized linear model was used for the ANOVA that tested for differences in seedling survival among treatment and species. The generalized linear model utilized a binomial distribution and a logit link function to account for the binomial nature of survival data (Littell and others 2002).

# RESULTS

## GROWTH MEASUREMENTS

Both species responded positively to granular fertilizer treatments (Table 1). Mean black locust basal diameter growth was greater in fertilizer treatments (6.52 mm) than controls (2.27 mm). American sycamore exhibited similar results (7.86 mm [F]; 4.42 mm [C]). Mean height growth of black locust was greatest in fertilizer (20.37cm) treatments compared to controls (9.38 cm). American sycamore also displayed considerable ($p < 0.05$) height differences between fertilizer (30.63 cm) and control (15.97 cm) treatments. Fertilizer applications had no significant effect on survival. However, overall survival was significantly higher for American sycamore compared to black locust. Survival of American sycamore was greater than 90 percent in both treatments following one growing season, and ranged from 79-88 percent for black locust.

**Table 1.—Mean* seedling survial, growth, and stem biomass accumlation by treatment and species one growing season after planting on a reclaimed surface mine in Knott County, KY.**

| | Survival (%) | Diameter growth (mm) | Height growth (cm) | Stem biomass (g) |
|---|---|---|---|---|
| Black locust | | | | |
| Control | 79.25Aa | 2.27a | 9.38a | 13.20a |
| Fertilizer | 88.07Aa | 6.52b | 20.37b | 32.36b |
| American sycamore | | | | |
| Control | 96.43Bb | 4.42a | 15.97a | 23.52a |
| Fertilizer | 93.81Bb | 7.86b | 30.63b | 48.98b |

*Uppercase letters indicate significant ($p<0.05$) differences across treatment and species, and lowercase letters indicate significant ($p<0.05$) differences across intra-species treatments .

## REGRESSION EQUATIONS AND BIOMASS PREDICTIONS

Stem biomass was predicted from seedling diameter and height using a linearized version of a power function. No significant interactions between treatments or species with diameter or height were present. Regression equations were as follows:

Black locust: $\ln(\text{Weight}) = -4.15 + 0.74*\ln(\text{Height}) + 1.86*\ln(\text{Diameter})$

Sycamore: $\ln(\text{Weight}) = -4.48 + 0.74*\ln(\text{Height}) + 1.86*\ln(\text{Diameter})$

where weight is listed in grams stem$^{-1}$, height in centimeters, and basal diameter in millimeters ($n = 60$; $r^2 = 0.97$).

Stem biomass means for fertilizer treatments were more than double that of controls in both species (Table 1). American sycamore exhibited greater stem biomass (48.98 g [F]; 23.52 g [C]; $p < 0.05$) than black locust (32.36 g [F]; 13.20 g [C]; $p < 0.01$) during the first growing season.

# DISCUSSION

## SURVIVAL

The survival trend between species may be a function of ungulate browsing. The study site (Big Elk Mine) is home to the highest densities of elk throughout all of the Eastern Kentucky elk reintroduction zone (Dahl 2008), and numerous black locust trees were heavily browsed. Furthermore, despite herbicide treatments, weedy competition from *Lespedeza* spp. and *Ambrosia* spp. may have reduced seedling survival (Fortson and others 1996) and could have compounded the impacts of browsing on black locust. Fertilizer amendments may also have exacerbated weedy competition at our site.

These findings fall within ranges established by studies of sycamore in western Kentucky (Witter 1980) that reported 90-percent first-year survival in control plots and 80 percent in fertilized plots, and on a reclaimed agricultural field in South Carolina (Davis and Trettin 2006) that reported an 84-percent survival rate. Therefore, despite a heavily disturbed landscape, survival at our site was similar to other studies.

## GROWTH AND BIOMASS

Response to fertilizer treatments at our site was similar to other studies. Casselman and others (2006) reported similar heights for hybrid poplars, but lower heights and diameters for mixed planted hardwoods with nutrient amendments on reclaimed surface mines in Virginia, West Virginia, and Ohio. Control mean total heights were 50.3 cm, 60.2 cm, and 65.4 cm at three reclaimed mines. Their respective heights in fertilized plots were 50.8 cm, 57.6 cm, and 126.6 cm. These findings are similar to those in our study.

Studies established on higher-quality sites in the eastern United States outperformed our plantings in total height and diameter after one growing season. A reclaimed agricultural field in South Carolina planted with American sycamore reported heights nearly three times greater than our control and fertilizer treatments (Coleman and others 2004). Van den Driessche and others (2003) witnessed negligible impacts of fertilizer treatments in aspen (*Populus tremuloides*) plantations, but heights under control, fertilizer, and irrigation treatments following 2 years were roughly 27 cm higher than our best-performing species and treatment combination (fertilized American sycamore). Growth response at our site did not compare favorably to plantations established on reclaimed agricultural fields and bottomlands. Impeded growth on reclaimed surface mines is commonly reported on sites composed primarily of shale and sandstone overburden (Fortson and others 1996, Kost and others 1998). Despite ripping prior to planting, soil compaction may still be high relative to non-mined forested lands (Conrad 2002). Moreover, the positive impacts of surface ripping have been touted by numerous studies (Cleveland and Kjelgren 1994, Ashby 1997), but they have been questioned in some research (Kost and others 1998). Excessive soil compaction hinders root growth, nutrient uptake, and soil drainage (Andersen and others 1989). Additionally, large rocks permeate the soil matrix and inhibit root growth (Fortson and others 1996).

Aboveground leafless biomass displayed considerable gains for both species in response to fertilizer applications. Black locust increased per-stem biomass production by 145 percent while American sycamore leafless biomass rose by 108 percent. Our findings are similar to hybrid poplar plantations established on reclaimed surface mines in Ohio, Virginia, and West Virginia that exhibited a per-stem biomass of approximately 22 g $stem^{-1}$ in control and 50 g $stem^{-1}$ in fertilized plots (Casselman and others 2006). Both species at our site exceed per-stem biomass accumulation found in mixed hardwood plantations in the same study.

Establishment of woody bioenergy plantations on reclaimed mined lands may help transform underutilized, low-value lands into a biomass source that helps diversify the domestic feedstock supply. Our results indicate that the application of granular fertilizer may increase biomass accumulation of black locust and American sycamore planted on reclaimed surface mines. Increased height growth associated with fertilization may also benefit ongoing reforestation efforts in the Appalachian region by accelerating the development of young seedlings in restoration projects (Angel and others 2005, Groninger and others 2007). While our initial results appear promising, it remains to be seen whether long-term biomass production will reflect our preliminary results and whether annual fertilization can make the production of bioenergy feedstocks on reclaimed surface mines more economically feasible. Continued monitoring of the study will help address these questions.

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