SUGAR MAPLE RESPONSE TO WEED CONTROL, LIMING AND FERTILIZATION ON A RECLAIMED MINE SOIL IN SOUTHWESTERN VIRGINIA

A. M. Salzberg[1] and J. A. Burger

Abstract

Landowners are interested in the potential of reforesting the large expanse of disturbed mine lands in southwestern Virginia with high-valued hardwoods such as sugar maple (*Acer saccharum* Marsh.). Much is known about the nutrient requirements and preferred soil types for optimal sugar maple growth due to extensive studies surrounding the recent decline of this species in various regions. However, little is known about the growth potential of sugar maples on mine soils. The purpose of this study was to determine the productivity and nutrient status of sugar maples on mine soils, and to evaluate their response to three treatments: control; an herbicide (Brushmaster® 2% solution) application to control competing woody vegetation; and an herbicide, fertilizer (N-P-K), and lime treatment. A 2-ha study site was planted with sugar maple seedlings (2-0 transplants) three years after mine reclamation in 1988. The treatments began 12 years after planting. Nine plots were established, three replications for each treatment, in a randomized block design. For this study, eight randomly located soil samples and five foliage samples from randomly selected trees were collected for nutrient analysis from each plot. Height and diameter of each tree were measured prior to treatment and three years thereafter. Growth rates among treatments were compared based on a volume index (diameter^2 x height) equation, which showed a trend of increased growth rates on the fert/herb/lime plots ($p = 0.06$). There were also statistical differences in foliar N levels among treatments ($p < 0.001$), and a positive correlation between higher foliar N and greater growth in the fert/herb/lime plots. Except for a slight deficiency in foliar N in the control plots, nutrient levels compared favorably to both published foliar ranges of healthy sugar maples and nutrient levels of sugar maples at other study sites across the region. Site index, based on regional site index values, was highest on herb/fert/lime plots ($p = 0.00$). Site index values ranged from 22 to 23 m (age 50) across treatments, indicating Class II levels of productivity. We suggest further studies to evaluate an herbicide treatment to control competing herbaceous vegetation as well as the application of fertilizers in the initial years following the planting of sugar maples. The growth and health of sugar maples on this study site indicate that this species could be planted on mine soils in southwestern Virginia as part of a mix of valuable hardwood species, or in plantations for sugar maple syrup production.

[1] A. M. Salzberg is M.F. student and J. A. Burger is Professor of Forest Soil Science, Department of Forestry, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Introduction

In the past 60 years, surface mining for coal has disturbed more than 80,000 acres of mountainous land throughout southwestern Virginia (Daniels and Zipper 1997). Federal law mandates that mined lands be reclaimed to a permanent vegetative cover "capable of self-regeneration and plant succession" (Surface Mining Control and Reclamation Act, Public Law 95-87, Federal Register 3 Aug 1977, 455-532). One example of reclamation for these once-forested lands is the planting of native tree species on the mine soils constructed from the overburden produced during mining operations.

Historically, mined lands have been planted to early successional species such as black locust (*Robinia pseudoacacia* L.), white pine (*Pinus strobus* L.) or shrubs to establish a woody cover (Vogel and Berg 1973). There has been little emphasis on the commercial value of the planted species. Today, there are more landowners interested in planting higher-valued species on this large expanse of disturbed land. Along with reclaiming these sites by planting oaks (*Quercus* sp.) or other important timber species, another possibility is planting parts of these areas to sugar maple (*Acer saccharum* Marsh.). Sugar maple offers a viable alternative compared to traditional timber species by providing either a highly coveted timber for cabinetry and flooring or maple syrup.

Sugar maples are a slow-growing species distributed throughout the Appalachian Mountains from northern Georgia to Maine, and onwards through the Maritime Provinces of Canada. In the southern part of their range, such as Virginia, sugar maples are typically found growing at higher elevations due to the milder summer temperatures (Hicks 1998). Sugar maples tolerate a variety of soil conditions but prefer a deep, well-drained sandy or loamy soil (Hicks 1998). In addition, sugar maples grow on soils with a range of pH values, from 3.7 to 7.3, but growth is poor when soil pH and levels of calcium and magnesium are low (Coughlan et al. 2000; Lovett and Myron 2004). Also important to the health and productivity of sugar maples is the symbiotic relationship with arbuscular mycorrhizal fungi (AMF). AMF act as a bioprotectant against soil pathogens and toxic stresses and play an important role in the mineral nutrition and water uptake of sugar maples (Coughlan et al. 2000, Jeffries et al. 2003). AMF also increase survivability of sugar maple in acid soils (Klironomos 1995).

Throughout the past several decades, sugar maple decline, as indicated by characteristic symptoms such as crown dieback, foliar chlorosis, and early leaf abscission, has been noted in various regions across the northeast and Canada (Horsley et al. 2002; McLaughlin et al. 1985; and Payette et al. 1996). Although the direct cause of the deteriorating health of the trees is unknown, studies suggest that the decline is linked to various environmental and biological stresses (Kolb and McCormick 1993). Furthermore, the differing causes of sugar maple decline appear to be site-specific (Mohamed et al. 1997).

Bauce and Allen (1991) found that sugar maples in central New York were more prone to decline due to the severe interspecies competition found in dense stands of second-growth forest. A study in Quebec by Duchesne et al. (2000) suggests that the decline in sugar maple health results, in part, from acid rain. Acid deposition can lead to an acidification of the soil environment, causing either the leaching of base cations (particularly Ca and Mg) from the upper soil horizons or soil acidity levels unfavorable for root growth or nutrient uptake by the trees (Morrison et al. 1992, Watmough 2002). Studies also suggest that the effect of acid deposition in lowering soil pH is amplified on non-calcareous soils (Drohan and Sharpe 1997, Lynch et al 1997).

Likewise, there is evidence that liming and fertilizing the soil can help to ameliorate the effects of soil acidification and improve nutrient availability, providing favorable site conditions for sugar maple growth. Ouimet and Fortin (1992) found that applying the appropriate fertilizers produced an improvement in foliar nutrient status, which led to increased stem radial growth of declining sugar maples in southern Quebec. On study sites in northern Vermont, Wilmot et al. (1996) found that fertilization with base cations supplemented with lime improved nutrient availability, enhancing crown condition of stressed sugar maples over a three-year period. Similar results were reported by Long et al. (1997) regarding the effects of liming on the growth and crown vigor of declining sugar maples growing on the Allegheny plateau. Lastly, Coughlan et al. (2000) and St. Clair and Lynch (2005) found that amending acidic soils (pH 4.2) with base cation fertilizers increased mycorrhizal colonization of sugar maple roots.

Haering et al. (1993) showed that mine soils in southwestern Virginia initially exhibit high levels of Ca and Mg, and a soil pH between 5 and 7. Rapid weathering of the sandstone mine spoil leads to leaching of the base cations in the first few years of mine soil development. But levels return to ones similar to those found initially due to bioaccumulation of calcium and the buffering capacity of increasing amounts of soil organic matter (Haering et al, 1993). In earlier studies, Daniels and Amos (1982) concluded that mine soils have the potential to be of equal or greater productivity than the steep, infertile soils naturally found in the mined regions of southwestern Virginia.

The productivity of mine soils depends on properties such as nutrient status, depth, composition, and placement of the hard rock mine spoil (Rodrigue and Burger 2004). Newly constructed mine soils are deficient in nitrogen and can lack available phosphorous (Li and Daniels 1994, Daniels and Zipper 1997). Phosphorous deficiencies are caused by Fe oxide fixation; therefore, Fe oxide-rich strata should be avoided when placing the final layer of mine spoil (Howard et al. 1988). Fertilizing mine soils with these elements is essential for the newly planted vegetation to thrive on these sites. Once vegetation is established, pools of these nutrients begin to accumulate with increasing amounts of organic matter (Li and Daniels 1994). Bendfelt et al. (2001) found that fertilizer inputs are critical for tree establishment, but vegetation growth and decay will maintain soil organic matter and total N without further inputs.

To insure adequate rooting depth and sufficient water holding capacity, the final layer of spread mine spoil needs to be ≥ 1 m and without excessive coarse fragments (Burger and Zipper 2002). Care should be taken to avoid excessive machine traffic and grading the final layer of mine spoil when wet (Daniels and Zipper 1997). This will help limit soil compaction and a corresponding increase in soil bulk density. High bulk density inhibits root growth and decreases water infiltration and retention (Ashby 1997).

Weathered sandstone overburden can provide a soil parent material suitable for the growth of native hardwoods such as sugar maple, due to sufficient levels of base cations, adequate drainage, and a slightly acidic pH (Torbert 1990). As stated in the preceding paragraph, satisfactory rooting depth and drainage are dependent on limiting compaction in the final grading of the mine soils. Lastly, sugar maples prefer a moist soil and therefore are most likely to thrive on slopes with a northwest- to northeastern-facing aspect (Burger and Zipper 2002).

On a 1-ha test site at the Powell River Project Research and Education Center in Wise County, Virginia, sugar maples were planted in 1991 to determine the potential for this highly-valued timber species for mine land reforestation. After age 8 there was considerable woody plant competition, and a mild chlorosis was observed in the foliage.

The objectives of this study were to: (i) determine the nutrient status and growth rates of sugar maples as influenced by woody weed control, liming, and fertilization; (ii) compare the foliage nutrient levels to those of sugar maples growing in a number of study sites across the eastern United States; and (iii) evaluate site quality of the test site based on regional site index values for sugar maples.

Methods and Procedures

Site Description and Classification

The study site is located in Wise County, Virginia (37°00'N, 82°41'W) at the Powell River Project Research and Education Center. The average annual precipitation is 1180 mm, relatively evenly distributed throughout the year. Annual mean temperature is 11°C, with a low of -0.1°C in January and a high of 21.3°C in July (National Climatic Data Center, Asheville, NC). The soils are acidic, naturally low in fertility, and derived from sandstones, siltstones, and shales. The mine soils are classified as loamy-skeletal mixed, mesic Typic Udorthents (Daniels and Amos 1982, Roberts 1986).

The study site was mined and reclaimed in 1988, three years before the trees were planted. The mine soil was a 2:1 sandstone:siltstone mixture that was sown with tall fescue (*Festuca arundinaceae* Schreb.), redtop (*Argostis alba* L.), and red clover (*Trifolium pratense* L.) after the site was reclaimed. The 2:1 sandstone:siltsone mixture yields a mine soil with a loamy texture, good water holding capacity, and a fairly high cation excnage capacity (Daniels and Amos 1982). Additionally, mine soils constructed after passage of the Surface Mining Control and Reclamation Act typically have a bulk density of 1.3 g cm^{-1} (Torbert et al. 2000).

The north- to northwest-facing site was planted in the spring of 1991 with sugar maples. Seedlings were 2-0 obtained from the Virginia Department of Forestry Nursery. Trees were planted on a 4.5 x 4.5 m spacing for a sugar bush trial and demonstration. No further treatments of any kind were applied until 2003, age 12, when this study was installed. Survivability of sugar maples at age 12 was greater than 90 percent.

In the spring of 2003, nine plots were established on the 1-ha site in a randomized complete block design with three replications. Three treatments were applied consisting of (i) control, (ii) herbicide treatment (Brushmaster® 2 % solution, active ingredients 2, 4-D and dicamba) to reduce competing woody vegetation, and (iii) an herbicide/fertilize/lime treatment. The herbicide/fertilize/liming treatment consisted of Brushmaster® 2% solution, liming, and fertilization with nitrogen, phosphorous, and potassium (Table 1). Herbicide was applied via backpack sprayer as a spot treatment to control woody vegetation each summer from 2003 to 2005. Fertilizer and lime were applied via cyclone spreader each spring from 2003 to 2005.

Table 1. Fertilizer and lime rate and annual source.

Element	Rate (kg/ha)	Source
N	224	urea (45-0-0)
P	56	DAP(18-46-0)
K	112	muriate of potash (0-0-60)
lime	1120	ground rock dolomitic limestone

Field and Laboratory Methods

Soil samples were taken prior to treatment in 2003, and in April 2005 after three years of treatment. Eight random samples were collected from each plot to a 15-cm depth. The samples from each plot were combined on site for one composite sample. Samples were dried and sieved through a 2-mm sieve. Soil reaction was determined in a 2:1 water:soil suspension using a pH meter. Total nitrogen and carbon were found using an Elementar VarioMAX CN analyzer (Mt. Laurel, NJ). Available nutrients (Ca, Mg, K) were found using the Mehlich I test, and available P was measured using the sodium bicarbonate method (Olsen and Sommers 1982).

Foliage sampling took place in mid-August 2005, when the trees were 15 years old. Using a pole pruner, foliage was sampled from five randomly-selected trees within each plot. From each of the five trees within the plot, two branches from the upper portion of the crown were cut towards the tip to collect six leaves. The leaves were combined to form one composite sample per plot. Foliage samples were dried at 46°C for seven days and then ground using a Wiley mill to pass a 1-mm screen. Samples were further dried at 65°C for 48 hours and analyzed for total foliar C and N using an Elementar VarioMAX CN analyzer (Mt.Laurel, NJ). Foliar Ca, Mg, K, P, and Mn were determined after dry ashing and digesting with 6*N* HCl. Height and diameter at breast height (dbh) were measured during the winters of 2003 through 2006 with a height pole and diameter tape, respectively.

Data Analysis

Statistical analyses were performed using the SAS System for Windows V8 Software Program (SAS 2004). Treatment responses for soil and foliage chemistry were tested using an analysis of variance (ANOVA) test for a completely randomized block design. Treatment responses for tree growth, including annual diameter and height measurements and mean annual increment, were determined using a covariate analysis of variance test for a completely randomized block design. Treatment means were compared using the Fisher's LSD test. Treatments were considered different when the ANOVA was significant at the 0.10 probability level.

Relative tree growth among treatments over the four-year period was compared and tested by calculating a volume index (d^2h) and then using regression analysis of volume index as a function of time to determine and test growth rates by comparing the regression slope values. ANOVA for a completely randomized block design was used to test for differences in slope values. If slopes were different at the $p < 0.1$ level, tree growth was considered different.

Results

Baseline (April 2003) mine soil chemistry was the same among treatment plots prior to application of treatments (Table 2). After three years of treatment (2005), mine soil carbon ($p = 0.06$) and total nitrogen ($p = 0.07$) were significantly higher compared to the control (Table 3). Exchangeable potassium ($p = 0.09$) and calcium ($p = 0.01$) were higher in the herb/fert/lime treated plots compared to the control, but these nutrient elements in the herbicide plots were not different from the control or different from the herb/fert/lime treatments. Phosphorous ($p = 0.08$) and magnesium ($p = 0.04$) were significantly higher on the herb/fert/lime plots compared to other treatments. An increasing trend in pH occurred, but plot values were highly variable thus averages were not significant.

Table 2. Comparison of mean soil chemistry for control, herbicide, and herb/fert/lime plots prior to application of the treatments (April 2003).

Treatment	pH	C	N	P	K	Ca	Mg
		----- % -----		----------- ppm -----------			
Control	5.6	1.5	0.08	17	119	430	242
Herbicide	5.7	2.0	0.33	22	135	547	270
Herb/Fert/Lime	5.7	1.9	0.10	18	142	515	261
P-value[1]	0.34	0.41	0.50	0.40	0.29	0.31	0.39

[1] Probability that the means are not significantly different.

Table 3. Comparison of mean soil chemistry for control, herbicide, and herb/fert/lime plots after three annual applications of the treatments (April 2005).

Treatment	pH	C	N	P	K	Ca	Mg
		----- % -----		----------- mg/kg -----------			
Control	5.6	1.9[a]	0.11[a]	16[a]	89[a]	442[a]	195[a]
Herbicide	5.9	2.5[b]	0.14[b]	16[a]	112[ab]	577[ab]	215[a]
Herb/Fert/Lime	6.3	2.4[b]	0.15[b]	26[b]	138[b]	744[b]	284[b]
P-value[1]	0.30	0.06	0.07	0.08	0.09	0.01	0.04

[1] Probability that the means are not significantly different.
Mean values not sharing a letter differ significantly at $p < 0.10$.

Tree diameter (dbh) and height were significantly higher in the herb/fert/lime plots compared to the herbicide and control for each growing season after treatment applications began in the spring of 2003 (Table 4). Height and diameter of trees in 2002, the year before treatments were applied, were used as co-variates in the ANOVA to account for initial differences in height and diameter among plots.

Table 4. Sugar maple mean height and diameter measurements over a three-year period. Treatments were applied each spring season beginning with year 2003.

	2003		2004		2005	
Treatment	**Ht (m)**	**dbh (cm)**	**Ht (m)**	**dbh (cm)**	**Ht (m)**	**dbh (cm)**
Control	5.99[a]	8.2[a]	6.61[a]	9.35[a]	6.97[a]	10.21[a]
Herbicide	5.97[a]	8.2[a]	6.71[a]	9.63[a]	7.04[a]	10.41[a]
Herb/Fert/Lime	6.43[b]	8.57[b]	7.06[b]	10.48[b]	7.44[b]	11.59[b]
P-value[1]	0.03	0.01	0.00	0.01	0.01	0.01

[1] Probability that the means are not significantly different.
Mean values not sharing a letter differ significantly at $p < 0.10$.

The mean tree growth rates (shown as volume index [VI] through time) of the herb/fert/lime plots was higher ($p = 0.06$) compared to the rates (slope values) for the other treatments (Fig. 1A). The mean annual increment (MAI) was not different among treatments for the years 2003 ($p = 0.27$) and 2005 ($p = 0.26$) (Fig. 1B). MAI was higher on the herb/fert/lime plots for the year 2004 ($p = 0.02$) compared to the other treatments.

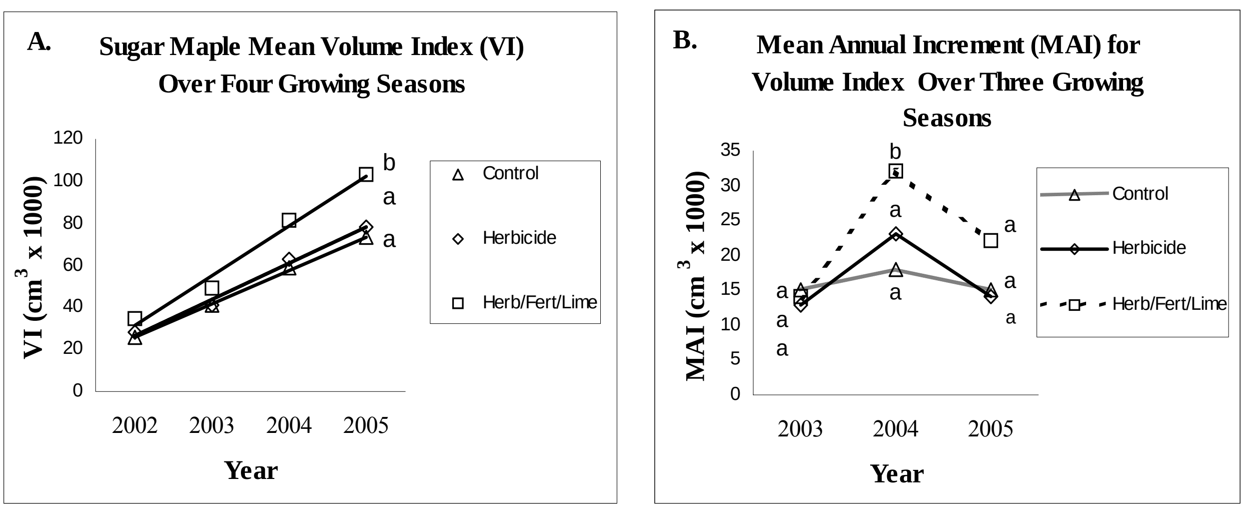

Fig. 1. Sugar maple volume index (d^2h) over a four-year period and mean annual growth increment for a three-year period following woody plant control and fertilization and liming. Mean values not sharing the same letter are significantly different at $p < 0.1$. The regression equations for volume index as a function of time are: control, $y = 158.72x + 101.4$; herbicide, $y = 171.25x + 36.47$; and herb/fert//lime, $y = 238.38x + 77.311$.

Mean foliar nutrient levels among treatments were the same except for levels of nitrogen ($p = 0.00$) in the plots that received annual applications of the fertilizer treatment (Table 5). Mean foliar N level for the herb/fert/lime plots was 2.31%, compared to 1.66% and 1.57% on the herbicide/fertilized and control plots, respectively. The fertilized plots had foliar N concentrations on the upper end of the literature-based range in concentration. The published foliar nutrient ranges for "healthy" sugar maples indicate that the trees in the unfertilized plots were probably nitrogen-deficient (Table 5) (Kolb and McCormick 1993).

Table 5. Comparisons of sugar maple mean foliage chemistry for control, herbicide, and herb/fert/lime plots in 2005.

Treatments	C	N	P	K	Ca	Mg	Mn
	---------------------------	---	---	%	---	---------------------------	
Control	55.23	1.57[a]	0.16	0.64	0.96	0.21	0.06
Herbicide	54.55	1.66[a]	0.18	0.65	1.13	0.25	0.06
Herb/Fert/Lime	55.05	2.31[b]	0.18	0.61	1.1	0.26	0.07
Low†	*	1.60	0.08	0.55	0.50	0.11	0.06
Midpoint†	*	1.96	0.13	0.80	1.35	0.26	0.85
High†	*	2.32	0.18	1.04	2.19	0.40	1.63
P-value[1]	0.83	0.00	0.89	0.43	0.46	0.2	0.98

† Literature ranges for N, P, K, Ca, Mg, and Mn of "healthy" sugar maples as reported by Kolb and McCormick (1993)
[1] Probability that the means are not significantly different.
Mean values not sharing a letter differ significantly at $p < 0.10$.

The concentrations of elements found in the foliage of the sugar maples at the study site are, for the most part, comparable to the nutrient levels found in sugar maples across eastern North America (Table 6). One notable exception is the mean level of nitrogen (2.31%) found in the fertilized stand, which exceeded the range of N values (1.66%-2.19%) at the sites across the northeast. K values ranging from 0.61 to 0.65 (Table 5) were much lower than the literature reference values, but our trees did not respond to K added in the herb/fert/lime treatment.

Table 6. Element concentrations in the foliage of sugar maple in eastern North America (Bernier and Brazeau 1988).

Region and Soil or Parent Material	N	P	K	Ca	Mg	Reference
	-------------------	---	%	---	-------------------	
Kentucky, limestone	1.88	0.24	0.99	1.92	0.35	McHargue and Roy 1932
Massachusetts, glacial till	2.13	0.11	1.00	1.24	0.15	Mader and Thompson 1969
New Hampshire, till derived from gneiss and quartz monzonite	2.19	0.18	1.01	0.60	0.12	Likens and Bormann 1970
New Hampshire, till derived from gneiss and quartz monzonite	2.13	0.15	0.82	0.62	0.18	Pletscher 1982
New York, glacial till derived from shales and sandstones	1.66	0.15	1.01	1.43	---	Bard 1946
New York, Gloucester stonyloam	1.87	0.24	0.80	1.17	---	Mitchell 1936

Site productivity was estimated using the following regional site index (SI) equation for sugar maples at base age 50 (Carmean et al. 1989):

$$SI = 0.1984H^{1.2089}(1-e^{-0.0110A})^{-2.4917H^{-0.2542}}$$

The mean height for each of the three treatments and the current age of the stand (15 yrs) were used in the equation. The herb/fert/lime treatment increased site index over that of the control (p = 0.01) (Table 7). The range of site index among treatments (22-23 m) shows an overall moderate level of site productivity (Class II) for the eastern United States (Fox 2005).

Table 7. Mean site index for three treatments.

Treatment	Site Index (m)
Control	22.0[a]
Herbicide	22.2[a]
Herb/Fert/Lime	23.0[b]
P-value[1]	0.00

[1] Probability that the means are not significantly different.
Mean values not sharing a letter differ significantly at p<0.10.

Discussion

The herbicide treatment used to control woody competition did not have a significant effect on the growth of the sugar maples. There appeared to be a positive response on sugar maple mean annual increment for the 2004 growing season when rainfall was normal (Fig. 1B), but there was clearly no response during 2005, which was an unusually dry growing season. Because of erosion risk, we did not control herbaceous vegetation. The herbaceous ground cover was a dense, uniform stand of tall fescue that appeared to benefit from woody competition control. Tall fescue is a very competitive grass in mined land environments (Burger and Zipper 2002), with a deep root system and relatively high rates of evapotranspiration in comparison to other cool season grasses (Zhang et al. 2005). At least partial control of this vigorous ground cover would likely be beneficial to tree growth.

The combined herb/fert/lime treatments had the predicted effect on the soil, competing woody vegetation, and sugar maple trees. The growth trajectory of the maples during the four-year measurement period was higher than the herbicide and control treatments (Fig. 1A). The mean annual increment for the 2004 growing season was also greater, but the droughty 2005 season also confounded the benefits of this combined treatment (Fig. 1B). Additionally, the site index value was highest for the herb/fert/lime plots (Table 7).

The soil pH prior to treatment was 5.6, a level that is quite common in native forest soils unaffected by acid precipitation. The limed plots had an average pH of 6.3, although this value was not significantly different from non-limed plots due to high variation among plots. Limed plot pH ranged from 6.2 to 6.5. There was no direct evidence that the sugar maples responded to liming, perhaps due to agricultural lime having low solubility in forest soil (Marschner et al. 1992, Fyles et al.Wilmot et al. 1996).

Soil Ca and Mg levels were both higher in the limed plots due to the addition of the dolomitic limestone, but foliar Ca and Mg levels were unaffected. We believe sugar maple will thrive on mine soils with pH levels at or above 5.4, and that liming is needed on lower pH soils. A study by Long et al. (1997) in the Alleghany Plateau of northwestern Pennsylvania found that raising soil pH from 3.7 to 5.4 through the application of dolomitic limestone increased vigor and crown health of declining sugar maples. They attribute this response to improved Ca and Mg nutrition from the applied lime.

Rodrigue and Burger (2004), in a study of 14 mature forest stands growing on mine soils in a seven-state region, found that mixed native hardwoods grew normally within a pH range of 5 to 7. Sugar maple reportedly has an affinity for high base levels (Morrison et al. 1992, Duchesne et al.), which is why we limed our study site to achieve a pH of 6.0. Even though foliar Ca and Mg levels were unaffected, liming may have had a positive affect on other soil chemical and biological processes that could affect sugar maple growth. For example, liming has been shown to increase arbuscular mycorrhizal fungi (AMF) colonization of sugar maple roots as a result of applying lime to acidic soils (St. Clair and Lynch 2005). The symbiotic relationship with AMF improves the health of sugar maples through increased mineral and water uptake, and protection from soil pathogens (Coughlan et al. 2000, Jeffries et al. 2003). A study of the impact of liming on sugar maples growing in the Susquehannock State Forest in Pennsylvania also found that liming improved the health of sugar maples, enabling the trees to resist attack from the pathogen *Armillaria calvescens* (Marcais and Wargo 2000).

Mine soil N and C values (2005) on the herbicide and herb/fert/lime plots were higher than on the control plots. Soil carbon is usually higher under grass than under woody vegetation on mined sites (Akala and Lal 2001). We observed that woody competition control increased the vigor and biomass of the predominantly tall fescue sward, which might have caused higher cycling rates and accumulation of soil Ca and N in the treated plots. Higher levels of P, K, Ca, Mg, and were also evident in soils of the herb/fert/lime plots compared to the control soils, due to the application of fertilizer and lime.

The sugar maples clearly responded to the herb/fert/lime treatment. Higher growth rates, as seen in the yearly height and diameter measurements and the volume index, likely resulted from the annual application of N. Given the range of published foliar nutrient values for "healthy" sugar maples, and as evident on the herb/fert/lime plots, a response to N-P-K fertilizer would be expected; however, the growth response appeared to be due primarily to the considerably higher concentrations of N in trees on fertilized plots.

There is other evidence for the influence of N on sugar maple growth. For instance, Liu et al. (1997), in a study of two sugar maple stands in northwestern Vermont, found correlations among concentrations of foliar N, leaf area, and rates of photosynthesis in sugar maples. Wilmot et al. (1995) hypothesized that a deficiency in carbohydrates caused by a reduction in N-dependent photosynthesis rates led to a decrease in basal area growth of sugar maples. Nitrogen is clearly an important element needed for optimum sugar maple growth, and without a nitrogen-fixing legume ground cover, N fertilization will be necessary to meet demand for this nutrient.

Foliar K levels were low, but this may be related to the month (August) when foliage samples were collected. For example, Bernier and Brazeau (1988) measured a 6-25% reduction in foliar K of mature sugar maples in August due to retranslocation of K from foliage prior to sampling. Burke and Raynal (1998) found in a study of 2-year-old sugar maple seedlings that surface-applied lime reduced K uptake, as opposed to incorporating lime into the surface soil, which did not affect the uptake of this nutrient.

Several steps could be taken to possibly improve the productivity of sugar maples on mine soils. For instance, it would probably be beneficial to apply fertilizer in tree rows at time of planting. Burger and Zipper (2002) recommend rates of 56 to 84 kg/ha of nitrogen and 90 to 112 kg/ha of phosphorous. They also recommend planting tree-compatible ground covers such as foxtail millet and annual ryegrass and legumes such as ladino or white clover and birdsfoot trefoil for longer term nitrogen fixation and reduced competition from grasses. Another option is to leave unseeded strips to plant with trees (Halofsky and McCormick 2005). Ashby (1997) found that ripping compacted sites also enhanced the growth of trees on mine soils.

Conclusions

The reclaiming of large acreages of disturbed mined lands to productive, native forest is both a feasible and desirable goal. As shown by this study, commercially valuable tree species such as sugar maple can be productive on mine soils. For instance, we found that the mine soils provide adequate nutrition for sugar maples as indicated by concentrations of foliar nutrients all within the range for reasonably healthy sugar maples, except for a slight deficiency in N. This study showed that the N deficiency was remedied with the application of fertilizer, and when combined with lime and woody weed control, increased growth rates occurred.

Our study also showed that this mine soil had a Class II level of productivity based on regional site index values. Similar mine soils should be of equal quality. The potential for even greater productivity should be possible through proactive management when reforesting these drastically disturbed landscapes. Practices such as carefully constructing mine soils to ensure an adequate depth for root growth, planting tree-compatible ground covers instead of aggressive tall fescue, and early applications of fertilizer and lime when needed, will likely increase the success of sugar maples on reclaimed mine lands. Lastly, well-managed sugar maples should provide landowners satisfactory financial returns due to the value of the timber and maple syrup.

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