Survival and Coverage by Several N_2-Fixing Trees and Shrubs on Lime-Amended Acid Mine Spoil

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Acid mine spoil was amended with agricultural-grade lime ($CaCO_3$) (0.0, 12.5, 25, and 39 tons per hectare) and planted with Alnus glutinosa *(European alder),* Caragana aborescens *(Siberian peashrub),* Elaeagnus umbellata *(autumn olive),* Myrica pensylvanica *(northern bayberry),* Robinia fertilis *'Arnot' (bristly locust),* Robinia pseudoacacia *(black locust), and* Shepherdia argentea *(silver buffaloberry). Addition of lime caused significant linear increases in soil pH. To maintain a pH above 5.5, 39 metric tons per hectare were required because of the acidic nature of the mine spoil. Survival of plant material was greatest at the highest lime addition, although responses of individual species varied*. Elaeagnus umbellata, R. pseudoacacía, R. fertilis *'Arnot', and* A. glutinosa *appeared more tolerant of the harsh conditions. Total coverage and growth (projected biomass) was proportional to the amount of added lime for all species except* R. pseudoacacia, R, fertilis *'Arnot', and* M. pensylvanica*. The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica*. The two* Robinia *species showed no response above 25 tons per hectare and* M. pensylvanica *performed best at lower pH.* Tree Planters' Notes 37(3):27-31; 1986.

Strip-mine spoil banks can be one of the most hostile environments for plant establishment and development, generally because of extremes in pH, texture, and slope (13). Soil temperature, low water-holding capacity, and nutrient status can also be limiting factors but are generally correctable.

In midwestern and eastern mine spoils, pH values as low as 2.2 have been recorded (1). Extreme acidity is generally the result of acid clays, sandstones, or shale or of the oxidation of pyrite to sulfuric acid (17, 18). Lime treatments may provide only short-term increases in pH because of the constant oxidation of sulfur-containing compounds (5, 19). Spoils with pH values less than 4.0 are generally considered toxic to most plants (18, 19).

Struthers and Vimmerstedt (15) believed that reclamation of mine sites would be more rapid and successful if methods were directed toward basic land improvement rather than superficial landscaping. They held little promise in the search for more tolerant plant species. A large number of species trials have been conducted on disturbed land over the years (7-9, 14, 15). Criteria for selecting plants for mine reclamation include suitability for drastic site conditions (pH, drought, low fertility, etc.) and the ability to rapidly develop long-term site cover. Additional considerations are soil enrichment, wildlife cover, and economic productivity (13, 14).

A number of woody nitrogen-fixing species have shown promise or are currently used for mine reclamation. These include *Alnus glutinosa* (L.) Gaertn. (3, 11, 13), *Elaeagnus angustifolia* L. (14), *E. commutata* Bernh. ex Rydb. (14), *E. umbellata* Thunb. (10, 13, 14), *Robinia fertilis* Ashe. (13, 16), and *R. pseudoacacia* L. (3, 4, 7-10, 12). Nitrogen-fixing trees and shrubs offer excellent possibilities for low maintenance and potentially productive perennial mineland cover. Some site amendment will be necessary to ensure survival of plants, and selection of species must be coordinated with site conditions. Organic matter has been shown to increase and surface temperatures to moderate as trees and shrubs increase in size (2).

This moderating effect favors establishment of other, less tolerant species. Nitrogen-fixing woody species could be combined with grass-legume cover crops and possibly other long-term forest crops to develop a total plant community on disturbed sites.

Materials and Methods

The site of the study was a surface coal mine in southwest Indiana that had been returned to original contour and was being revegetated. Several pH samples were taken to ensure as nearly a consistent pH as possible for the experimental areas. Lime requirements were determined using the SMP buffer pH method (6). Because of the extremely low initial pH (2.85) and the acid nature of mineland spoils, SMP lime rates were 0, 12.5 (low), 25 (medium), and 39 (high) metric tons of $CaCO_3$ (agricultural-grade limestone) per hectare. Treatments were spread by hand and disked to a depth of 15 to 20 centimeters in perpendicular directions. Each plot (11 by 5.8 meters) was replicated four times.

Plots were planted with ten 1- to 2-year-old seedlings of *A. glutinosa*, *Caragana arborescens* L., *E. umbellata*, *M. pensylvanica* Lois., *R. fertilis* 'Arnot'. *R. pseudoacacia*, and *Shepherdia argentea*. Plants were nodulated at the time of planting, and legumes were reinoculated with commercial *Rhizobium* preparations. Seedlings were planted at a spacing of 90 by 120 centimeters on April 26, 1977. Soil was tested and plant survival observations were taken on May 19, June 14, August 23, and September 21, 1977, and May 5, and July 7, 1978. Soil pH was determined using 2.5:1 (water/soil).

Projected biomass was determined by multiplying the average dry weight of plant tops from a maximum of five representatives from each replicate by the number of survivors in a given species. Dry weights of tops were measured after drying at 80 °C for 5 days.

Results and Discussion

The addition of lime ($CaCO_3$) to acid strip-mine spoil raised the pH markedly, with the highest pH being achieved within 30 days of application (fig. 1). It required 39 tons per hectare to achieve a pH of 6.5 and maintain a pH of approximately 5.75 at 15 months after application. The medium and low lime treatments resulted in an increase in pH up to 6.1 and 5.0 initially, but these pH values declined to 4.8 and 3.5 after 15 months. Without lime, pH remained low (2.9).

Additions of lime maintained a relatively steady pH on acid mine spoils when amounts were adequate to overcome the constant

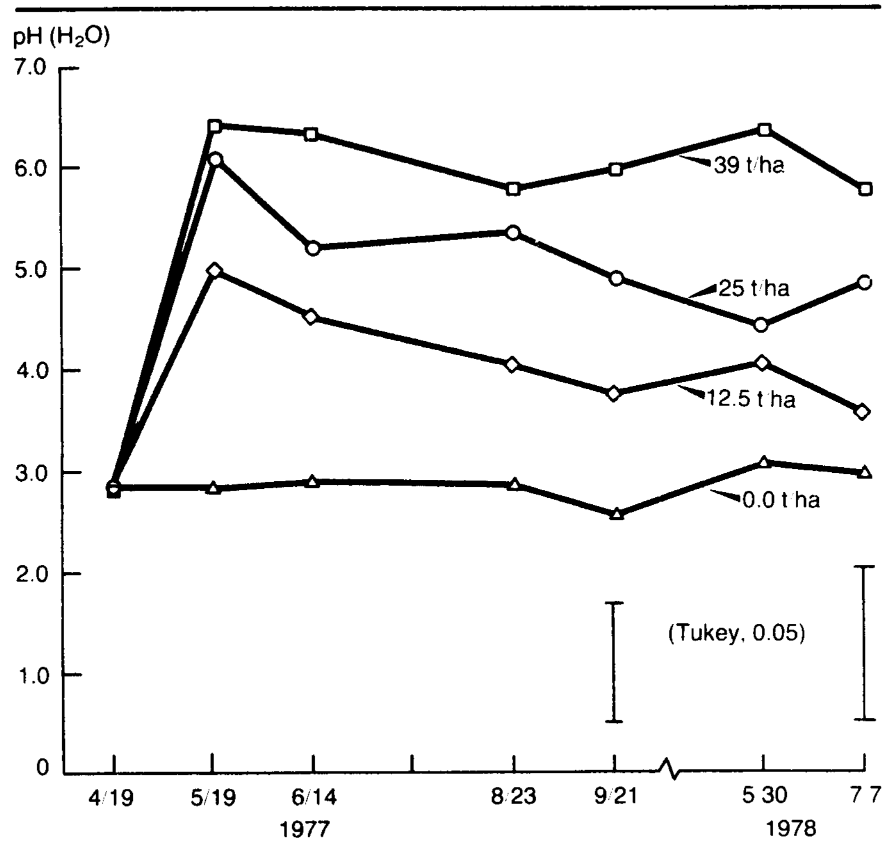

Figure 1—*Increased soil pH as a result of lime ($CaCO_3$) addition. $CaCO_3$ amendment is given to metric tons per hectare. Vertical bar represents significant mean separations (Tukey-hsd, 5%).*

leaching of acid from the parent material. Lime applications that would be adequate for normal soils were able to provide only short-term pH adjustment against the constant acid leaching as indicated by the decline in pH values of low and medium lime treatments (fig. 1). The pH of 5.75 resulting from the high lime treatment is adequate for growth of most plants. Although pH might be expected to decline somewhat over time, additions of organic matter by the plants would aid the soil's buffering capacity.

Table 1—*Effects of lime ($CaCO_3$) supplementation on survival nitrogen-fixing species planted on acid mine spoil*[1]

	Percent survival				
Species	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	Average
Elaeagnus umbellata	0 c	53 b z	55 ab z	82 a z	48 z
Robinia fertilis 'Arnot'	21 b	37 ab z	60 a z	63 a yz	46 z
Shepherdia argentea	0 c	26 bc z	53 ab z	87 a z	42 yz
Alnus glutinosa	0 c	43 ab z	28 bc yz	77 a z	37 yz
Robinia pseudoacacia	9 b	30 ab z	38 ab z	63 a yz	35 yz
Caragana arborescens	0 c	17 bc z	30 b yz	60 a yz	27 yz
Myrica pensylvanica	0 a	33 a z	13 a y	27 a y	18 y

[1] Data collected on July 7, 1978. Mean separations by Tukey-hsd, 5%. Values within a row (a, b, c) or column (z or y) followed by different letters differ significantly.

Plant survival. Addition of increasing amounts of limestone to acidic mine spoil had a 97.2 percent linear correlation to survival of all species approximately 1 year after planting. This concurs with the suggestion by Struthers and Vimmerstedt (15) that reclaimed mineland spoils be modified to obtain good plant survival rates. However, some species appear more tolerant of the harsh conditions than others.

Robinia fertilis 'Arnot' and *R. pseudoacacia* were the only species to survive without the addition of lime (table 1); however, the individuals failed to grow and were essentially the same size as when planted. Survival rates of *R. fertilis* 'Arnot' and *R. pseudoacacia* (table 1), as with all species, were significantly increased with the addition of lime, but there was no statistical difference between higher and lower levels.

Survival of *E. umbellata* was high at all levels of lime addition (table 1). The 82 percent at the high lime treatment was greater than the 53 and 55 percent at the medium and low lime treatments, but not statistically because of variation within the replicates. Survival of *A. glutinosa* was greater at the high lime treatments (table 1) but was not statistically distinguishable from that at low lime treatments. The percent survival at the medium lime treatments was significantly less than at high but not at low lime treatment. *Caragana arborescens* and *S. argentea* responded to the high lime treatment with significantly greater survival (table 1). The low and medium lime treatments resulted statistically in the same low survival rates.

Survival of *M. pensylvanica was* poor at all lime additions (less than 50 percent) and was best, although not statistically, at the low lime treatment (table 1).

There was significant difference in the combined survival of all species at all lime levels (table 1). Poorest overall performance was by *M. pensylvanica* and best overall survival was by *E. umbellata*, *R. fertilis* 'Arnot', and *S. argentea*. Response of individual species varied with lime additions as demonstrated by the individual survival data. The highest lime application rate (pH 5.75) resulted in the highest survival rates for all species but *M. pensylvanica* (table 1). Survival of *S. argentea* was greatest but not statistically better than that of other species except *M. pensylvanica.*

*Robinia f*ertilis 'Arnot', *E.* umbellata, and *S. argentea* survived best at the medium lime treatment (pH 4.8) (table 1) but were not significantly different from other species, except *M. pensylvanica.*

Regardless of the care taken to find homogeneous sites for the study, some variation with the replicates prevented detection of discrete statistical differences among the majority of the species at given treatment levels or differences within the responses of individual species to lime additions. *Elaeagnus umbellata*, *R. fertilis* 'Arnot', and *R. pseudoacacia* performed well at all amended pH levels. Insect infestation was noted on *R. pseudoacacia* the first season after planting and was more severe during the second season. There was no insect damage evident on any other surviving species in the study.

Projected biomass. Projected biomass is meant to provide an index of growth and ground cover associated with species and treatments within this study. It was calculated from actual dry matter data for species within a replicate and/ or top dry weights of representative samples multiplied by the number of individuals surviving within the replicate. It is expressed as grams per square meter.

The mean biomass for all species had a *97* percent linear correlation with lime additions (table *2). Elaeagnus umbellata* achieved the greatest projected biomass of any species at all lime additions and showed a linear correlation of *95* percent for increased growth with increasing lime level (table *2).*

Shepherdia argentea and *A. glutinosa* showed *99* and *97* percent linear correlations, respectively, between projected biomass accumulation and lime additions (table *2). Alnus glutinosa* responded dramatically to the high lime treatment *(39* tons per hectare).

*Robinia p*seudoacacia and *R. fer tills* 'Arnot' (table *2)* responded nearly identically in projected biomass development with lime additions. Both provided minimal cover on unamended sites, responded dramatically to the medium lime treatment, and declined slightly in the high lime treatment.

Myrica pensylvanica provided greater growth and cover at the lowest lime additions *(12.5* tons per hectare) (table *2).* However, there was statistically no difference between treatment means.

Table 2—*Effects of lime supplementation on mean projected biomass of nitrogen-fixing species planted on acid mine spoil*[1]

	Mean projected biomass (g/m^2)				
Species	0.0	Low lime (12.5 t/ha)	Medium lime (25.0 t/ha)	High lime (39.0 t/ha)	*r*
Elaeagnus umbellata	—	16.9 b	73.0 a	79.0 a	0.95
Robinia fertilis 'Arnot'	3.0 b	4.3 b	36.0 a	30.2 a	—
Robinia pseudoacacia	0.1 b	3.0 b	38.4 a	32.7 a	.86
Alnus glutinosa	—	8.8 b	10.4 b	23.7 a	.97
Caragana arborescens	—	4.2 c	6.2 b	18.7 a	.94
Shepherdia argentea	—	8.2 a	11.8 a	19.4 a	.99
Myrica pensylvanica	—	11.2 a	2.0 a	2.9 a	—
All species	0.41 b	8.1 b	25.4 a	29.5 a	.97

[1] Mean separation by Tukey-hsd, 5%. Values within a row followed by different letters differ significantly. Correlation coefficients (*r*) less than 0.90 are not listed.

Conclusions

Applications of agricultural-grade limestone had significant effects on the pH of acid strip-mine spoil and on the survival and projected biomass of the legume and nonlegume nitrogen-fixing species tested. Liming is the minimum site modifica-tion necessary for plant survival and growth. The pH of the spoil after all lime treatments dropped steadily, and only the *39* tons per hectare treatment maintained the pH above *5.0.* Constant acid leaching from the parent material necessitates the use of massive quantities of neutralizing materials. Split or additional applications may prove necessary, if feasible, to maintain pH within plant tolerance ranges on some sites.

Lime applications or pH increases were required for the survival of most and the growth of all species. Survival was greatest at the highest lime applications; however, response of individual species varied. *Elaeagnus umbellata*, *R. pseudoacacia*, *R. fertilis* 'Arnot', and *A. glutinosa* appeared to be more tolerant of the harsh conditions. Survival was generally good to fair, even at the lowest lime treatment, which resulted in spoil with a pH below the 4.0 considered toxic for most species. *Caragana arborescens* and *S. argentea* appeared to survive best if pH can be maintained near 6.0. *Myrica pensylvanica* survived better at lower lime applications, but its survival rate was generally poor at all treatment levels.

Total coverage and growth, as measured by projected biomass, was proportional to lime applications in all species except *R. pseudoacacia*, *R. fertilis* 'Arnot', and *M. pensylvanica*. *Myrica pensylvanica* performed best at lower pH and the two *Robinia* species showed no response at applications above 25 tons per hectare (pH 4.8).

Elaeagnus umbellata seemed to be a superior plant for the amended study site. *Robinia pseudoacacia*, *R. fertilis* 'Arnot', and *A. glutinosa* performed admirably and warrant inclusion in a total plant community. *Shepherdia argentea* and *C. arborescens would* appear more suitable on more extensively amended or less severe sites. Although survival of *M. pensylvanica* was low, its growth at low pH may warrant consideration in certain situations.

Although *R. pseudoacacia* is the most frequent nitrogen-fixing member of current plant communities on disturbed sites, it is not necessarily an ideal plant. Insect infestation had weakened the growth habit of the plants. While tolerance and survival may warrant continued usage, certain limitations for long-term and economic considerations should be weighed in comparison to other species.

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