SESSION 10: MINED LAND REFORESTATION

Page No.

The Use of Leguminous Trees in Reclamation of Tropical Mined Soils.
Luiz E. Dias, Avílio A. Franco, Eduardo F.C. Campello, Sérgio M. de Faria 601

Organic Amendment Effects on Nitrogen and Carbon Mineralization in an Appalachian Minesoil.
R.D. Faulconer, J.A. Burger, S.H. Schoenholtz, R.E. Kreh 613

Tree Shelter and Interplanted N-Fixing Shrub Effects on Crop Tree Growth on a Calcareous Minesoil.
David A. Kost, Merlyn M. Larson, John P. Vimmerstedt 621

Evaluation of Natural Succession on Reclaimed Coal Mine Land in Western Kentucky.
Dan L. Williamson, R. Brent Gray 629

Influence of Grading Intensity on Herbaceous Ground Cover, Erosion, and Tree Establishment in the Southern Appalachians.
John L. Torbert, James A. Burger 637

AMERICAN SOCIETY • SURFACE MINING and RECLAMATION •

THE USE OF LEGUMINOUS TREES IN RECLAMATION OF TROPICAL MINED SOILS[1]

by

Luiz E. Dias[2]; Avílio A. Franco[3]; Eduardo F.C. Campello[3] and Sérgio M. de Faria[3]

Abstract

Characterized as vigorous pioneer species which produce large amounts of biomass, forest leguminous trees have shown promise in studies of degraded soil rehabilitation. When associated with atmospheric nitrogen-fixing bacteria and mycorrhizal fungi, these species show superior utilization of nutrients and growth under adverse soil conditions. The objective of this paper is to present the principal results obtained from the Research Program for Use of Nodulated and Mycorrhizal Tree Legume Species in Rehabilitation of Degraded Areas, developed by National Research Center for Agrobiology-CNPAB/EMBRAPA in conjunction with the Federal University of Viçosa, Brazil. The program has been developed in four subprograms: 1. Field surveys to collect and identify native leguminous tree species with potential for land reclamation; 2. Selection to identify more efficient nitrogen-fixing bacteria for each potential species; 3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils; and 4. Field experiments in lands degraded by mining.

Additional Key Words: leguminous trees; nitrogen fixation; bauxite mining; land reclamation

Introduction

Brazil is the world's leading producer of iron ore and a major exporter of aluminum, gold, niobium and tin. Totaling U.S.$6.6 billion, its mining output constitutes almost a third of Latin America's mineral-derived revenue (Project Survey 1993). A large part of these minerals, such as iron, gold, tin, bauxite, manganese, copper and kaolin, lies under biologically diverse forests in the Amazon Region, (Griffith et al. 1996).

Human activities such as surface mining have resulted in great disturbance to original soils. Among the different aspects of degradation, loss of soil organic matter is one of the most important (Franco et al. 1995a). The absence of organic matter contributes to low nutrients levels, low water holding capacity, and compaction problems. These situations may cause great difficulties when attempting to rehabilitate these areas. Nitrogen, sulphur and phosphorus are the main factors affecting soil fertility if organic material is lacking. Therefore both biological

---

[1] Paper presented at the 13th Annual Meeting of American Society for Surface Mining and Reclamation, Knoxville, TN. May 19-25, 1996

[2] Luiz Eduardo Dias. Associate Professor and CNPq Researcher (Brazilian National Research Council), Federal Univ. of Viçosa, Viçosa, MG, 36571-000. Brazil E-mail DPSXLED@BRUFV.BITNET

[3] Avílio Antônio Franco, Eduardo Francia C. Campello and Sergio Miana de Faria. Researcher from CNAPB/EMBRAPA, Itaguaí, RJ, 23851-970. Brazil

nitrogen fixation and mycorrhizal associations play very important roles in plant growth in such situations (Franco et al. 1991).

Characterized as vigorous pioneer species which produce large amounts of biomass, forest legumes have shown exceptional qualities in studies of rehabilitation of degraded soils (Franco et al. 1994, Dias et al. 1995 and Franco et al 1995a). Estimates from Brazil's arid "caatinga" region indicate that the "sabiá" tree (*Mimosa caesalpinifolia*) returns 5.8 $t.ha^{-1}.year^{-1}$ of vegetative material to the soil (Suassuna, 1982). Others researchs carried out in Central America with *Erythrina* (Glover & Beer, 1986) and in India with *Leucaena leucocephala* (Sandhu et al. 1990) showed contributions from 13 and 10 $t.ha^{-1}.year^{-1}$, respectively.

When associated with atmospheric nitrogen-fixing bacteria and mycorrhizal fungi, forest legumes present superior utilization of nutrients and growth under adverse soil conditions. For the last thirteen years, several large surveys of nodulation for native legume trees have been conducted in many acidic soils of Brazil (Magalhães et al. 1982, Faria et al. 1984, 1987, 1989, Moreira et al. 1992, 1993). Several experiments have been conducted to screen rhizobial strains for the most promising species (Franco & Silva, 1985 and Faria & Franco, 1993). Tropical legume trees have shown great dependence on VA-mycorrhizae (Mendes Filho, 1985 and Monteiro, 1990). Therefore, after inoculation with these microorganism the leguminous trees could absorb more water and nutrients such as phosphorus and zinc (Lambert et al. 1979).

The objective of this paper is to present the principal results obtained from the Research Program for Use of Nodulated and Mycorrhizal Leguminous Tree Species in Rehabilitation of Degraded Areas, developed by the National Research Center for Agrobiology-CNPAB-EMBRAPA in conjunction with the Federal University of Viçosa, Brazil.

Research Program for use of Nodulated and Mycorrhizal Leguminous Tree Species in Rehabilitation of Degraded Areas

This research program basically is divided into four subprograms:

1. Field surveys to collect and identify native species of tree legumes with potential for land reclamation;
2. Selection to identify more efficient nitrogen-fixing bacteria for each potential species;
3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils;
4. Field experiments in lands degraded by mining.

1. Collection and identification of native tree legumes.

In the last twelve years, researchers of CNPAB/EMBRAPA have examined more than 600 legume species for nodulation ability (Faria & Franco, 1993). The surveys were done in differents parts of the country, especially in the "cerrado", and other phytogeographic regions in the North, Northeast and Southeast. The surveys consist in observation of young plants to

identify the presence or absence of nodules. Later, the nodules are evaluated by acetylene reduction to verify activity.

Nodulation was observed in 392 of 688 species that were studied. The species belong to different subfamilies. Nodulation was most prevalent in the *Mimosoideae* (147 of 192 species) and *Papillionoideae* (158 of 219 species) and least prevalent in the *Caesalpinioideae* (38 of 183 species) and other subfamilies (49 of 94 species). This was the first report of nodulation for 172 species in 17 genera, and no-nodulated for 118 species in 18 genera.

Nodules obtained by the surveys were isolated, purified and, after liofilization, 1417 strains of rhizobia were added to CNPAB's culture collection. At present, the strains bank at CNPAB/EMBRAPA contains over 1,800 strains.

2. Selection to identify more efficient nitrogen fixing bacteria for each potential species.

For species with more economical and ecological potential, greenhouse experiments have been conducted by CNPAB/EMBRAPA using "Leonard" jars to select more efficient strains of rhizobia. Experiments with more promising strains were carried out in soil conditions. Efficient strains were selected for more than 45 leguminous tree species including *Acacia mangium, A. auriculiformis, A. holosericea, A. angustissima, Albizia guachapele, A. saman, Paraserianthes falcataria, Gliricidia sepium, Leucaena leucochepala, Mimosa caesalpiniifolia, M. scabrella, Enterolobium contortisiliquum, Stryphnodendrum guianensis* and *Prosopis juliflora.*

Many of these species have shown good growth in adverse substrates such as acid and high density soils, which are common in lands degraded by mining.

3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils.

Promising species were evaluated for mineral nutrition requirements and capacity for growth in high density soils. These experiments provided important information for choosing species with the best potential to grow in each kind of substrate, and indicated the minimum necessary requirements for good establishment. The main results, obtained from the experiments carried out with *Acacia mangium, A. holosericea, Sclerolobium paniculatum* and *Mimosa tenuiflora* in the Soils Department of the Federal University of Viçosa, follow.

3.1 Response to liming and phosphorus fertilization.

Absence of topsoil is a common condition for surface-mined soil. In the tropics, the lack of topsoil exposes soil horizons with high acidity and phosphorus adsorption capacity. Different studies evaluated the plants response to liming and phosphorus fertilization in the B horizon of

acidic soil (pH = 4.6; P and K by Mehlich-1 = 0.4 and 5.0 mg/dm^3, respectively; Ca^{2+}, Mg^{2+} and Al^{3+} by KCl 0,01 Mol/L = 0.04, 0.02 and 0.9 cmol$_c$/dm^3, respectively).

Only *M. tenuiflora* responded to lime application (Paredes F. et al. 1995). This result confirms field observations that this species is capable of growing in soils with approximately neutral pH. For the other species, liming did not significantly affect dry matter production, height or stem diameter (Dias et al., 1990; Dias et al. 1991a and Balieiro et al. 1995). The lack of response to lime application in soil with low exchangeable calcium shows the low demand for this nutrient and the capacity of the other species to grow in poor substrates. In other greenhouse experiments with a nutrient solution, the low Ca requirement by *A. mangium* was also shown by high dry matter production over the long term despite deprivation of Ca after an initial short contact period with calcium in the original planting solution (Dias et al. 1994a).

All species responded to phosphorus fertilization. The obtained regression equations for dry matter production as a function of the different doses of applied P are shown in Table 1. These data agree with the thesis that leguminous species when fixing nitrogen by symbiotic association have high P uptake to supply the high demand of ATP by the fixation process (Siqueira & Franco, 1988).

The critical levels of P for the different species are found in Table 1. These values ranged from 18 to 32 mg/dm^3 of available Mehlich-1 P and confirm the high demand for this nutrient by fast-growing tree seedlings.

3.2 Response to sulfur and potassium fertilization

Only *M. tenuiflora* (Paredes F. et al. 1995) responded to sulfur fertilization (sulfur rates varyed from 0 to 120 mg/dm^3) which characterized this species as more demanding of soil fertility. The lack of response for other species may be related to the level of organic matter (2.8 %) of the subsoil used and the action of the liming on providing organic-S mineralization (Dias et al. 1991b and Dias et al. 1992).

Although the S requirement is low, in solution deprivation tests S was the second most important limiting factor, after N, in dry matter production for *A. mangium*, (Dias et al. 1994a).

Given the responses of *Acacia holosericea* (Balieiro et al. 1995) and *Mimosa tenuiflora* (Paredes F. et al. 1995) to potassium fertilization, it was not possible obtain good models by regression analysis. Table 2 shows the obtained equations, which indicate the negative response of *A. mangium* and positive response of *S. paniculatum.*

3.3 Capacity to grow in high density soils

Intense movment of machines over mined susbtrate can induce soil compaction which causes nutritional and water availability problems. Studies on the capacity of the plants to grow in high density soils therefore have great importance.

Fernandez et al. (1994) studied the capacity of seven leguminous woody plants to grow in columns containing compacted subsurface soil samples. The study used 0.91 and 1.14 g/cm^3 of bulk density to fill PVC columns.

Of the seven species evaluated, *Mimosa tenuiflora* and *Leucaena leucocephala* were the most sensitive to high substrate density. Observed effects were reduction in height and dry matter production at 140 days. The other five species (*Enterolobium contortisiliquum, Acacia holocericea, Mimosa caesalpinifolia, Acacia mangium and Acacia auriculiformis*) showed good tolerance to compaction. An interesting effect of compaction was the reduction of root dry matter for *A. mangium* (Figure 1). This species grew better than the others in the different mine substrates, including compacted ones. The exceptional ability of this species to produce high amounts of biomass even in harsh ambiental conditions is shown in Figure 2. *A. mangium* in compacted substrate produced the same amounts of foliar and stem dry matter as in non-compacted tests. The same behavior was observed in field conditions when *A. mangium* was grown in compacted bauxite residue ponds and developed shallow but extensive lateral root systems (Franco et al. 1995b).

4. Field experiments in lands degraded by mining.

Dias et al. (1994a) studied the recuperative capacity of nine-year old *Eucalyptus pellita* versus *Acacia mangium* trees planted on soils degraded by bauxite mining in Porto Trombetas, Pará State, Brazil. Each species was planted in plots wich conteined 36 plants each (3 x 2 m). Litter (layers L and H) and soils (depths 0 to 2.5 cm, 2.5 to 7.5 cm and 7.5 to 20 cm) were sampled at the onset of the rainy season (November 1992), midway through the dry season (June 1993) and at the end of the rainy season (April 1994).

Greatest accumulation of organic material occurred on *A. mangium* plots at 7.5 cm depth and for all three sampling times. Similar behavior occurred for soil sum of bases and effective cation exchange capacity (CEC). Plots with *A. mangium* had more litter with smaller C/N ratio and greater quantites of P, K, Mg and N. These results reinforce the importance of including leguminous trees in land rehabilitation programs.

We also conducted two other experiments at Porto Trombetas, Pará State, Brazil (Franco et al. 1994, Franco et al. 1995a and Franco et al. 1995b). For both we used concentrated sulphuric acid to scarify seeds as required, and nodulating species were inoculated with effective rhizobial strains. All species were also inoculated both with inoculum of *Gigaspora margarita* and with soil plus roots of *Brachiaria decumbes* collected in the region to provide inoculum of introduced and local vesicular-arbuscular mycorrhiza fungi.

The first test was conducted in subsoil, without topsoil, exposed by bauxite mining (pH = 4.6; P and K by Mehlich-1 = 0.1 and 9.0 mg/dm^3, respectively; Ca^{2+}+Mg^{2+} and Al^{3+} by KCl 0,01 Mol/L = 2.0 and 0.3 cmol$_c$/dm^3, respectively). We tested five nodulating (nod+) leguminous species (*Sclerolobium paniculatum, Acacia mangium, A. auriculiformis, Enterolobium contortisiliquum, Strypnodendrum guianensis*); two non-nodulating (nod-) leguminous species (*Cassia leiandra and Senna siamea*) and three pioneer but non-legume (no-leg) species (*Didimopanax morototoni*, *Byrsonima crassicarpa* and *Goupia glaba*). One year

after planting, *A. mangium* and *A. auriculiformis* had grown more than any other species. Among the nod- and no-leg species *Didimopanax morototoni* and *Byrsonima crassicarpa* showed reasonable but less growth than the nodulating legume (Table 3).

The second experiment was planted on bauxite mining residue (pH = 4.6; P and K by Mehlich-1 = 0.0 and 3.0 mg/dm^3, respectively; Ca^{2+} + Mg^{2+} and Al^{3+} by KCl 0,01 Mol/L = 0.4 and 0.2 cmol$_c$/dm^3, respectively). We tested nine nod+ species (1. *A. mangium,* 2. *A. angustissima,* 3. *A. holocericea,* 4. *Albizia saman,* 5. *A. guachapelle,* 6. *Enterolobium contortisiliquum,* 7. *Clitoria fairchiladiana,* 8. *Sclerolobium paniculatum and* 9. *Stryphnodendrum guianensis*); five nod- *species (*10. *Senna siamea,* 11. *Parkia pendula,* 12. *Dinizia excelsa,* 13. *Cassia leiandra* and 14. *Adenanthera pavonina*) and two no-leg species (15. *Cecropia sp,* and 16. *Eucalyptus terenticornis*). At planting time two of the four replications received two liters of compost (cattle manure waste) in the planting hole each and two none.

Plant heights measured at 9, 13 and 22 months after transplanting showed similar trends except that *S. paniculatum* and *S. guianensis* were growing best despite a slow start, while *A. angustissima* showed the opposite behaviour. For the nod+ species, the differences observed with compost added at planting decreased up to the last evaluation. *Acacia mangium* plants showed values above 7 m of height at last measurement. Figure 3 shows total biomass recovered in the plants 22 months after transplanting. *Acacia mangium and A. holocericea* showed highest value for shoot dry matter. These results comfirm the great potential of leguminous trees in reclamation of tropical mined lands.

Conclusions

Many leguminous trees fix atmospheric nitrogen when they occur in symbiosis with rhizobia and form mycorrhizal associations which improve efficiency of absorption of water and mineral nutrients from the soil. Such improved efficiency especially affects phosphorus, the most important and frequently limiting nutrient in tropical soils. These species, when associated with microsymbionts, are suitable for revegetation of mined tropical lands when the deficiencies of major nutrients (other than nitrogen, unnecessary because of fixation capability) have been corrected. The addition of a large amount of organic matter (litter) with low C/N ratio besides protects the soil from the direct impact of raindrops and erosion, accelerates the cycling of soil nutrients, and favors the return of life to the soil.

The slow growth of native species means, however, that we must identify native nodulating species that can provide better ecological conditions for soil rehabilitation. Griffith et al. (1994) emphasized the importance of using an ecological approach in mined land reclamation, and indicated that one way to do so is to use nodulated and mycorrhizal legume trees.

The current focus of our research program is to understand the natural evolution of areas undergoing rehabilitation so as to identify opportune moments to intervene in the revegetation process and thereby guarantee its sustainability.

Acknowledgments

We appreciate assistance and comments by Dr. James J. Griffith from the Forestry Department of Federal University of Viçosa. Part of the research was supported by Mineração Rio do Norte S.A., Porto Trombetas, PA, Brazil and by CNPq (Brazilian National Research Council).

Table 1. Regression equations adjusted for dry matter production for selected species, in function of levels of P applied to substrate and critical level values in soil, so as to obtain 90% of maximum production

Species	Dosage	Model	R^2	Crit. Level
	mg/dm^3	g/pot		mg/dm^3
A. mangium	0 - 570	$Y = 7.3714 + 0.0139\ P$	0.850	1/
A. holosericea	0 - 480	$Y = 0.466 + 0.036\ P - 0.00006\ P^2$	0.968	18.55
M. tenuiflora	0 - 480	$Y = 0.1952 + 0.0119\ P - 0.00002\ P^2$	0.947	31.95
S. paniculatum	0 -570	$Y = 3.717 + 0.0513\ P - 0.00006\ P^2$	0.944	26.10

1/ The linear response to P applied did not allow obtaining the critical level

Table 2. Regression equations adjusted for dry matter production for selected species, in function of levels of K applied to substrate and critical level values in soil, so as to obtain 90% of maximum production

Species	Dosage	Model	R^2	Crit. Level
	mg/dm^3	g/pot		mg/dm^3
A. mangium	0 - 200	$Y = 15.041 - 0.561\ X^{0.5} + 0.026\ X$	0.985	1/
S. paniculatum	0 -300	$Y = 9.920 + 0.046\ X - 0.0001\ X^2$	0.909	27.4
M. tenuiflora	0 - 160	$Y = 1.563 + 0.053\ X^{0.5} - 0.004\ X$	0.886	16.61

1/ The negative response to applied K did not allow obtaining the critical level.

Table 3. Height at 13 months for 10 species cultivated in subsoil (topsoil absent) exposed by bauxite mining

Species	height
	--- cm ---
Sclerolobium paniculatum	56.9
Acacia mangium	258.8
Acacia auriculiformis	163.9
Enterolobium contortisiliquum[1]	76.1
Strypnodendrum guianensis	83.4
Cassia leiandra[1]	78.9
Senna siamea	97.4
Didimopanax morototoni	14.8
Byrsonima crassicarpa	75.2
Goupia glaba	33.1

1/ Plants browsed by deer

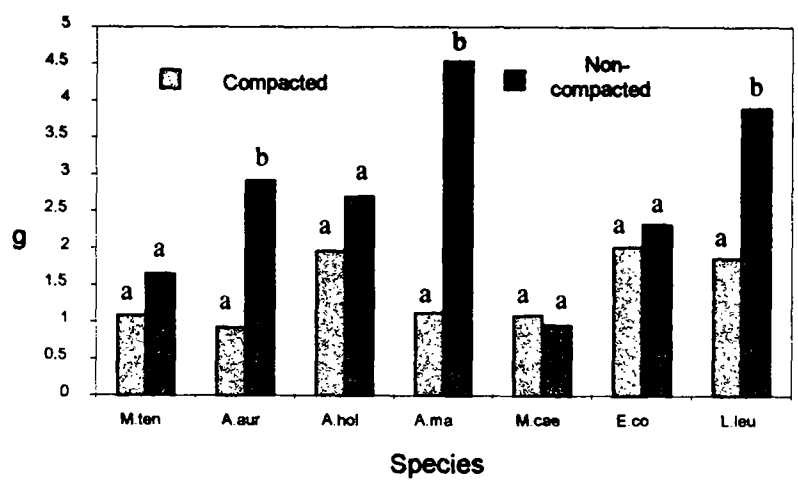


Figure 1. Root dry matter for seven forest leguminous plants grown in compacted and non-compacted soil. M.ten = *Mimosa tenuiflora,* A. aur = *Acacia auriculiformis,* A. hol = *Acacia holocericea,* A. man = *Acacia mangium,* M. cae = *Mimosa caesalpinifolia,* E. co = *Enterolobium contotisiliquum,* and L. leu = *Leucaena leucocephala.* The letters indicate differences between compacted and non-compacted soil within a species.

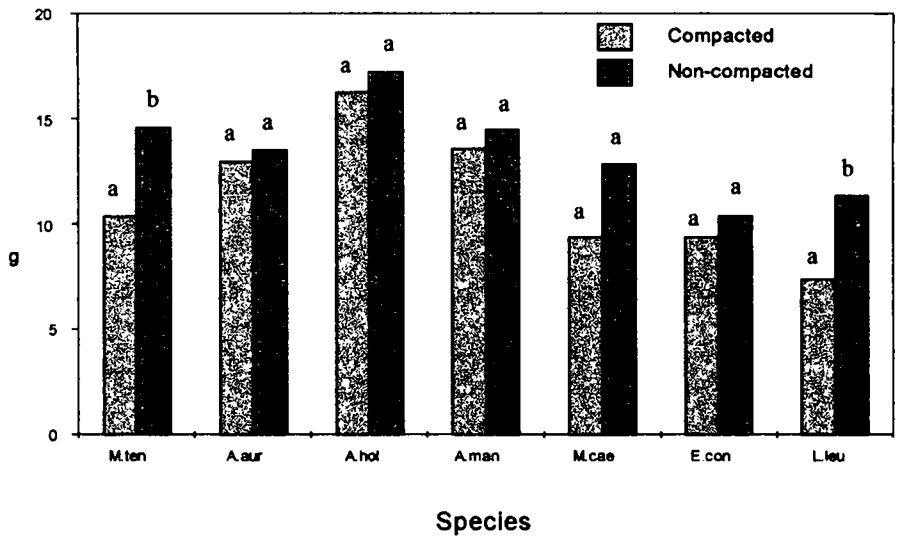


Figure 2. Total dry matter of seven forest leguminous species grown in compacted and non-compacted soil. M.ten = *Mimosa tenuiflora,* A. aur = *Acacia auriculiformis,* A. hol = *Acacia holocericea,* A. man = *Acacia mangium,* M. cae = *Mimosa caesalpinifolia,* E. co = *Enterolobium contotisiliquum,* and L. leu = *Leucaena leucocephala.* The letters indicate differences between compacted and non-compacted soil within a species.

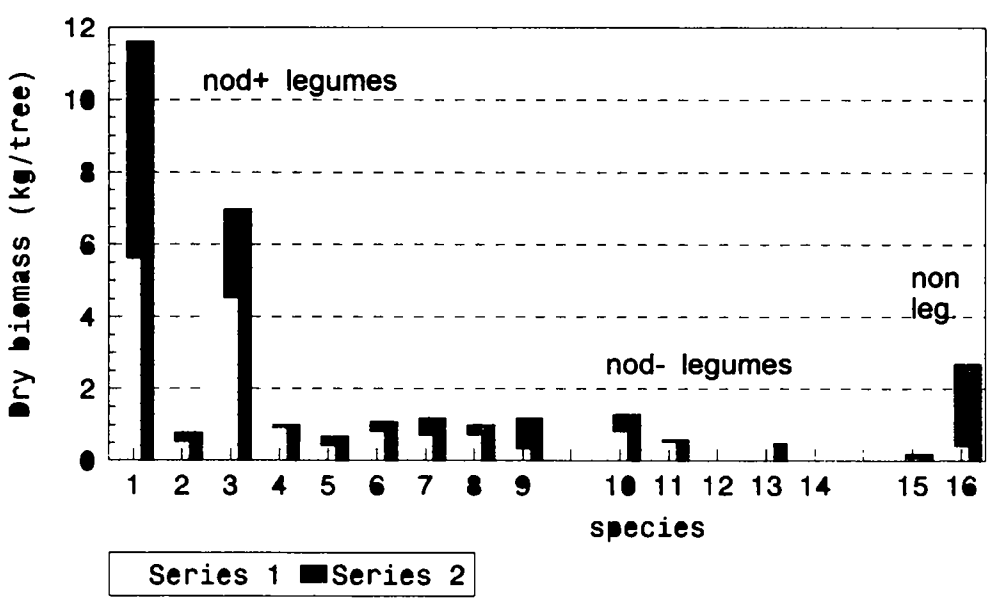


Figure 3. Biomass of 16 forest leguminous species production,22 months after transplanting to the field. Series 1 without compost and series 2 with compost.

References

BALIEIRO, F. de C.; OLIVEIRA, I.G. de and DIAS, L.E. 1995. Formação de mudas de *Acacia holocericea* : Resposta à calagem, fósforo e enxofre. In: Congresso Brasileiro de Ciência do Solo, XXV. Viçosa-MG. 1995. Resumos Expandidos. Vol. II, p. 830-832.

DIAS, L.E.; ALVAREZ V., V.H. and BRIENZA Jr, S. 1990. Formação de mudas de Acacia mangium. I. Resposta à calcário e fósforo. In: Anais do VI Congresso Florestal Brasileiro - Sociedade Brasileira de Silvicultura e Sociedade Brasileira de Eng. Florestais. Campos do Jordão-SP. 1990, p.449-453.

DIAS, L.E.; ALVAREZ V., V.H.; JUCKSCH, I.; BARROS, N.F. de and BRIENZA Jr., S. 1991a. Formação de mudas de taxi-branco (Sclerolobium paniculatum Voguel). I Resposta à calcário e fósforo. Pesq.agrop.bras., Brasília, 26(1):69-76.

DIAS, L.E.; ALVAREZ V., V.H. and BRIENZA Jr, S. 1991b. Formação de mudas de Acacia mangium. II. Resposta à nitrogênio e potássio. Rev.árv., Viçosa, 16(2):135-143.

DIAS, L.E.; ALVAREZ V., V.H.; JUCKSCH, I.; BARROS, N.F. and BRIENZA, S. 1992. Formação de mudas de taxi-branco (Sclerolobium paniculatum Voguel): Resposta a nitrogênio, potássio e enxofre. *Rev. Árvore*, 16(2):135-143.

DIAS, L.E.; FRANCO, A.A. e CAMPELLO, E.F.C. 1994a. Dinâmica de matéria orgânica e de nutrientes em solo degradado pela extração de bauxita e cultivado com eucalyptus pellita e Acacia mangium. In: simpósio Sul-americano I e Simpósio Nacional II sobre Recuperação de Áreas Degradadas. Fóz do Iguaçú, Paraná.1994. Anais, p.515-25.

DIAS, L.E.; FARIA, S.M. and FRANCO, A.A. 1994b. Crescimento de mudas de Acacia mangium Willd em resposta à omissão de macronutrientes. *Rev. Árvore*, 18(2):123-131.

DIAS, L.E.; FRANCO, AA.; CAMPELLO, E.F.C. and FARIA, S.M. and FARIAS, S.M de 1995. The use of nodulated and mycorrhized legume trees to rehabilitate of degraded soils: One technological model used in Porto Trombetas-PA. In: Kanashiro, M. and Parrotta, J.A. (eds.), Management and Rehabilitation of Degraded Lands and Secondary Forests in Amazonia, An International Symposium/Workshop, 1992. Proceedings... International Institute of Tropical Forestry USDA-Forest Service. Rio Piedras, Puerto Rico, USA. p.224-229.

FARIA, S.M.de; FRANCO, A.A.; JESUS, R.M.; MENANDRO, M.S.; BAITELLO, J.B.; MUCCI, E.S.F.; DOBERAINER, J. and SPRENT, J.I. 1984. New nodulating legume trees from Southeast Brazil. New Phytol. 98:317-328.

FARIA, S.M. de; LIMA, H.C. de; FRANCO, A.A. and SPRENT, J.I. 1987. Nodulation legumes from Southeast Brazil, Plant and S 99:347-356,

FARIA, S.M. de; LEWIS, G.P.; SPRENT, J.I. and SUTHERLAND, J.M. 1989. Occurrence of nodulation in the Leguminosae. New Phytol., 111:607-619.

FARIA, S.M. and FRANCO, A.A. 1993. Levantamento e seleção de estirpes de rizóbio para leguminosas arbóreas. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, XXIV, Goiânia - GO. 1993. Resumo..., Sociedade Bras. de Ciência do Solo. p. 335-336.

FERNANDEZ, J.Q.P.; MACHADO, M.C.; DIAS. L.E. and RUIZ, H.A. 1994. Crescimento de sete espécies leguminosas florestais em colunas de solo compactado. In: Reunião Brasileira de Manejo e Conservação do Solo e da Água, 10. Florianópolis, SC. Resumos p.242-243.

FRANCO, A.A.; CAMPOS NETO, D.; CUNHA, C.O.; CAMPELLO, E.F.C.; MONTEIRO, E.M. da S.; SANTOS, C.J.F.; FONTES, A.M.; FARIA, S.M. de. 1991. Revegetação de solos degradados. In: Workshop sobre recuperação de áreas degradadas, jan. 1990, Itaguaí, Anais... UFRRJ/Dep. de Ciências Ambientais, p. 133-137.

FRANCO, A.A. and SILVA, G.G. 1985. Potential of the *Rhizobium* symbiosis in tree legumes. Presented at the workshop on *Rhizobium*/legume inoculants, Porto Alegre, RS., Oct. Mimeo.

FRANCO, A.A.; CAMPELLO, E.F.C.; DIAS, L.E. and FARIA, S.M. 1994. Revegetation of acidic residues from bauxite mining in Porto Trombetas-PA using nodulated and micorrhizal legume trees. In: Simpósio Sul-americano I e Simpósio Nacional II sobre Recuperação de Áreas Degradadas.1994. Fóz do Iguaçú, Paraná. Anais, p.145-153.

FRANCO. A.A.; DIAS, L.E.; FARIA, S.M.de; CAMPELLO, E.F.C. and SILVA, E.M.R.da 1995a. Uso de leguminosas florestais noduladas e micorrizadas como agentes de recuperação e manutenção da vida do solo: um modelo tecnológico. In: Estrutura, Funcionamento e Manejo de Ecossistemas Brasileiros. Oecologia Brasiliensis Vol I. Esteves, F.A. (ed.). Instituto de Biologia-UFRJ, Rio de Janeiro-RJ. p. 459-467.

FRANCO. A.A.; CAMPELLO, E.F.C. DIAS, L.E. and FARIA, S.M.de 1995b Use of Nodulated and Mycorrhizal Legume Trees for Revegetation of Residues from Bauxite Mining. In: International Symposium on Sustainable Agriculture for the Tropics: the Role of Biological Nitrogen Fixation- Angra do Reis, RJ. Brasil. Abstracts.

GLOVER, N. and BEER, G. 1986. Nutrient cycling in two traditional Central American agroforestry systems. Agraforestry Systems, 4:77-87.

GRIFFITH, J.J.; DIAS, L.E. and JUCKSCH, I. 1994. Novas estratégias ecológicas para a revegetação de áreas mineradas no Brasil. In: Simpósio Sul-americano I e Simpósio Nacional, II sobre Recuperação de Áreas Degradadas.1994. Fóz do Iguaçú, Paraná. Anais, p.31-43.

GRIFFITH, J.J.; DIAS, L.E. and JUCKSCH, I. 1996. Rehabilitation of mine sites in Brazil using native vegetation. In: Majumdar, S.K.; Miller, E.W. and Brenner, F.J. (eds.) *Forests - A Global Perspective*. The Pennsylvania Academy of Science, Pennsylvania, USA. (Cap. 31) p.470-488.

LAMBERT, D.H.; BAKER, D.E. and COLE JR., H. 1979. The role of mycorrhize in the interactions of phosphorus with zinc, copper and other elements. Soil Sci. Soc. Am. J., Madison, 43:976-980,

MAGALHÃES, F.M.M.; MAGALHÃES, L.M.S.; OLIVEIRA, L.A. and DOBEREINER, J. 1982. Ocorrência de nodulaçãso em leguminosas nativas da região de Manaus-AM. Acta Amaz.. 12:509-514.

MENDES FILHO, P.F. 1985. Efeito da interação *Rhizobium*, micorrizas VA e fosfatos no desenvolvimento de mudas de sabiá *Mimosa caesalpinifolia* Benth. Fortaleza, M. Sc. Thesis, UFCe. 51p.

MONTEIRO, E.M. da S. 1990. Resposta de leguminosas arbóreas à inoculação com rizóbio e fungos micorrízicos vesículo-arbusculares em solo ácido. Tese de Doutorado. UFRRJ. 221p.

MOREIRA, F.M.S.; SILVA, M.F. and FARIA, S.M. de 1992. Occurrence of nodulation in legume species in the Amazon Region of Brazil. New Phitol. 121:563-570.

MOREIRA, F.M.S.; GILLIS, M.; POT, B.; KERSTERS, K. and FRANCO, A.A. 1993. Characterization of rhizobia isolated from different devergence groups of tropical Leguminosae by comparative polyacrylamide gel electrophoresis of their proteins. Applied and Env. Microb.

PAREDES F., J.Q.; R.R.; DIAS, L.E. and BARROS, N.F.de 1995. Formação de mudas de Mimosa tenuiflora.In: Congresso Brasileiro de Ciência do Solo, XXV. Viçosa-MG. 1995. Resumos Expandidos. Vol. II, p. 813-815.

PROJECT SURVEY 1993. Latin America Calling. 1993. Engineering and Mining Journal. 194(1):20-26.

SANDHU, J. SINHA, M. and AMBASHT, R.S. 1990. Nitrogen release from decomposing litter of leucaena leucocephala in the dry tropics. Soil Biol.Biochem., 22(6):859-863.

SIQUEIRA, J.O. and FRANCO, A.A. 1988. Biotecnologia do solo; fundamentos e perspectivas. Brasília: MEC/ABEAS: Lavras: ESAL/FAEPE, 235p.

SUASSUNA, J. 1982. Efeitos da associação do sabiá (Mimosa caesalpiniifolia, Benth) no comortamento do jacarandá (Dalbergia nigra, FR. Allen) e da peroba branca (Tabebuia stenocalyx, Sprague and Stapf) na zona da mata de Pernambuco, Recife, UFPE. 179p. (Tese M.S.).

ORGANIC AMENDMENT EFFECTS ON NITROGEN AND CARBON MINERALIZATION IN AN APPALACHIAN MINESOIL[1,2]

R.D. Faulconer, J.A. Burger, S.H. Schoenholtz, and R.E. Kreh [3]

Abstract: The use of blasted rock overburden as a topsoil substitute during surface-mined land reclamation is practiced in areas with thin, unrecoverable topsoil. The long-term productivity of topsoil substitutes has often been difficult to maintain under forage and row crops. The objective of this project was to evaluate the effectiveness of an unamended topsoil substitute as a tree growth medium compared to both topsoil and organic matter amended minesoils based on the accumulation and mineralization of C and N pools. A factorial experiment was established in 1987; treatments (5 cm of a Jefferson series topsoil, 8 cm of whole-tree woodchips, and an unamended control) were assigned to lysimeters filled with blasted overburden. All lysimeters were planted with a tree-compatible ground cover of grasses and legumes and 10 pitch pine *x* loblolly pine hybrid seedlings (*Pinus rigida* L. *x P. taeda* L.). Net accumulated Total Organic C in 1989 was 4.4, 3.7, and 9.2 g kg^{-1} for the control, topsoil, and woodchip treatments, respectively; in 1995, concentrations were 12.7, 16.0, and 18.2 g kg^{-1} . Aerobic N mineralization potential in 1988 was 31, 63, and 56 mg kg^{-1} for the control, topsoil, and woodchip treatments and increased to 112, 157, and 118 mg kg^{-1} by 1995. These and other results show that within 8 years, N and C accumulation and cycling in the unamended control have reached levels comparable to the amended minesoils. This suggests the potential for reclamation cost savings through the use of unamended topsoil substitutes without compromising long-term forest productivity.

Additional Key Words: Topsoil substitute; Aerobic nitrogen mineralization; Reclamation forestry.

Introduction

Coal operators are required by law (SMCRA: P.L. 95-87) to reclaim surface-mined lands to a level of productivity equal to or greater than the productivity of the land before mining occurred. The coal operator is responsible for meeting all legal reclamation requirements and must post performance bonds that are released in stages as requirements are met. When the coal operator leases the mined area from a separate landowner, a conflict can occur between the short-term goals of the coal operator (to perform the most cost effective reclamation that meets legal obligations) and the long-term goals of the landowner (which may be to achieve and maintain productivity necessary for forest management). The post-mining land use chosen as a reclamation goal has often been hay lands or pasture lands because a grass cover crop is relatively easy to establish. These hay or pasture lands often represent a missed economic opportunity for the landowner because the long-term productivity of reclaimed lands is difficult to maintain under nutrient-intensive forage crops. Failing hay and pasture lands in remote, rugged areas often create erosion hazards and liabilities and will eventually revert to native forest cover. However, this forest will probably be slow growing and unproductive unless forestry is specifically planned for before and during reclamation. Re-establishment of trees can improve minesoil properties, provide food and habitat for wildlife, and provide an additional source of income through timber harvests or tree crops. Reclamation

[1] Paper presented at the 1996 National Meeting of the American Society for Surface Mining and Reclamation, Knoxville, Tennessee, May, 1996.

[2] Publication in this proceedings does not prevent authors from publishing their manuscripts, whole or in part, in other publication outlets.

[3] R.D. Faulconer, Buchanan Consultants, Ltd., 220 W Main St., Farmington NM 87401; J.A. Burger, Professor, Virginia Polytechnic Institute and State University; S.H. Schoenholtz, Associate Professor, Mississippi State University; R.E. Kreh, Director, Reynolds Homestead Forest Resources Research Center, Critz, VA.

forestry can provide long-term benefits for landowners and environmental and aesthetic benefits for local communities. For reforestation to be a viable alternative for landowners and coal operators, reclaimed mine land must be capable of supporting productive forests and reclamation forestry must be cost effective. Consequently, a great deal of research has focused on the forest productivity of minesoils created during the reclamation process (Moss et al. 1989; Torbert et al. 1988, Bengtson and Mays 1978).

Long-term growth and maintenance of forest vegetation in large part depends on accumulating pools of C and N and establishment of nutrient cycles associated with these pools. Freshly reclaimed minesoils contain little or no organic matter and little C or N in plant-available forms (Bradshaw et al. 1982). Fertilizer applied at the time of seeding provides enough N and other nutrients to aid in the establishment of a plant community; however, this nutrient supply is transitory and high nutrient demanding forages often show deficiency symptoms after only a few years (Reeder and Sabey 1987; Woodmansee et al. 1978). Traditionally, the approach to establishing pools of C and N has been to replace native topsoil, when available. Since Appalachian topsoils are frequently thin and difficult to recover, there has been some interest in amending minesoils with organic materials such as sawdust or sewage sludge (Moss et al. 1989; Roberts et al. 1988). In contrast to these methods which involve the placement of a substrate which already includes C and N, another option is to stimulate the establishment of a soil/plant system which builds the C and N pools by natural processes. The gradually increasing resource needs of trees more closely matches the supply of C and N from gradually increasing pools. It is hypothesized that the C and N cycles can develop naturally if coal operators will select an appropriate spoil type, place it in an uncompacted fashion, establish a tree-compatible ground cover of grasses and legumes, and plant or seed selected tree species. Under the right conditions, this last approach saves the cost of topsoil or organic matter amendments and creates a growth medium where C and N accumulate and cycle and trees and ground cover survive and grow.

The objective of this research project was to evaluate the effectiveness of an unamended topsoil substitute as a growth medium compared to both topsoil and organic matter amended minesoils and N fertilized minesoils. This evaluation was based on the accumulation of C and N pools and the mineralization capacity of these pools over the eight years since the minesoils were created.

Materials and Methods

This project was initiated at the Reynolds Homestead Forest Resources Research Center in Critz, Virginia in 1987 and was fully described by Schoenholtz (1990). Large concrete lysimeters (2.6 m^3) were used as replications in a 2 by 3 factorial experiment testing the effects of two levels of N fertilization and three levels of organic amendment on C and N cycling in minesoil.

In July, 1987, eighteen concrete lysimeters were filled with a pre-weighed amount of fresh mine spoil associated with the Middle Wise Formation obtained from Wise County, Virginia. The mine spoil consisted mainly of sandstone and siltstone with traces of shale. An attempt was made to fill each lysimeter with the same percentage of the different size fragments present ranging from sand-sized particles to large rocks. Each lysimeter has a surface area of 2.9 m^2 and a depth of 0.8 m.

Six of the lysimeters received 5 cm of topsoil found in the area where the spoil was removed. The topsoil consisted of the A horizon from a Jefferson series soil (loamy, mixed, mesic Typic Hapludult) also from Wise County, Virginia. Six lysimeters received 8 cm of fresh, yellow-poplar (*Liriodendron tulipifera* L.), whole-tree wood chips; and the remaining six lysimeters received no organic amendments. Within the three treatments, half received 100 kg ha^{-1} N applied as NH_4NO_3 and half got no N fertilization. Results from the first three years of this experiment show that the fertilizer treatment effects on N and C parameters ceased to be important after the first year (Schoenholtz 1992). All lysimeters were initially fertilized with 100 kg ha^{-1} P and 60 kg ha^{-1} K. The wood chips had a C/N ratio of 261:1 and were used to provide a source of organic N and a C source for heterotrophic bacteria. The topsoil had a C/N ratio of 17:1 and was used to evaluate the potential of topsoil as a source of organic N and as a microbial innoculum to promote N cycling. The wood chips and topsoil were tilled into the top 25 cm of the mine spoil prior to seeding and tree planting.

In July 1987, a tree-compatible mixture of the following grass and legume species was sown in each lysimeter: foxtail millet [*Setaria italica* (L.) Beauv.], perennial ryegrass (*Lolium perenne* L.), annual ryegrass (*Lolium multiflorum* Lam.), redtop (*Agrostis gigantea* Roth), birdsfoot trefoil (*Lotus corniculatus* L. var. *corniculatus*), Korean lespedeza (*Lespedeza stipulacea* Maxim.), and 'Appalow' sericea lespedeza [*Lespedeza cuneata* (Dum.-Cours.) G. Don]. Ten 1-0 bareroot pitch *x* loblolly hybrid pine (*Pinus rigida* L. *x* *P. taeda* L.) seedlings were planted in each lysimeter in March 1988. The legumes accounted for over 80 percent of the ground cover after three years, and tree survival was 60 percent in the topsoil treatment, 83 percent in the control, and 98 percent in the woodchip treatment (Schoenholtz 1992).

Soil Analyses

A composite soil sample was collected from the 0 to 10 cm layer of each tank using a 2 cm push tube and used for the following analyses.

- Total organic carbon (TOC) was determined by dry combustion (Nelson and Sommers 1982).
- Total Kjeldahl nitrogen (TKN) was determined by a modified micro-Kjeldahl digestion procedure (Bremner and Mulvaney 1982).
- N mineralization potential (N_o) was determined from composite samples using the aerobic incubation procedure of Stanford and Smith (1972) as modified by Burger and Pritchett (1984).
- An in-situ buried-bag procedure was used to determine the monthly rate of net N mineralization. Net mineralized N was calculated as the difference in 2M KCl-extractable N between unincubated and incubated samples.
- In-situ CO_2 was monitored over a 24 hour period using the alkali trapping method described by Anderson (1982).

Foliar N concentration was determined by Kjeldahl digestion of dried and ground samples (Bremner and Mulvaney 1982). All soil and foliar N concentrations were determined colorimetrically using a Technicon Autoanalyzer II.

Since there were no significant differences between N fertilizer treatments on vegetation and soil variables by 1989, the treatment was disregarded and data were analyzed using a one-factor analysis of variance with three levels of amendment (control, topsoil, and wood chips) and six replications. Duncan's Multiple Range Test (α level of 0.05) was used to test for differences among treatment means. Non-linear, least-squares regression (NLLSR) was used to estimate N_o from aerobic incubation data. NLLSR was also used to determine the accumulation rates (k) of TOC and TKN.

Results and Discussion

C and N Accumulation

The values for TOC and TKN that follow are amounts that have accumulated since the start of the project. All three treatments had accumulated between 1.2 to 1.8 percent TOC or roughly 2 to 3 percent organic matter after eight years (Figure 1). The woodchip treatment had the highest TOC over 8 years, though not significantly different from the topsoil treatment in the eighth year. The control treatment TOC was not significantly different from the topsoil treatment except in the eighth year (Figure 1). The TOC accumulation rate for the woodchip treatment (0.033 $month^{-1}$) was significantly higher than both the topsoil (0.008 $month^{-1}$) and control (0.013 $month^{-1}$) treatments which were not significantly different from each other.

TKN was highest in the topsoil treatment over 8 years (Figure 2). The TKN values for the woodchip and control treatments were not significantly different from each other after 8 years. The TKN accumulation rates were not significantly different among the three treatments, but the rate of TKN accumulation in the woodchip and control treatment appears to have slowed by year 8. This may be attributable to a difference in the number of trees per tank which, in turn, affected shading and ground cover. Seedling survivability was an initial part of this research, and, as a result, seedlings that died were not replaced. After 8 years, there were an average of 9.7 trees per tank in the woodchip treatment, 7.3 trees per tank in the control, and 5.2 trees per tank in the topsoil treatment. The higher number of trees in the woodchip and control treatments caused total ground cover, including the legume component, to decrease after the third growing season. Therefore, the decrease in the rate of

TKN accumulation that occurred after the third growing season in the woodchip and control treatments may be largely the result of tree-ground cover interactions.

The TOC and TKN concentrations were converted to a weight-per-unit-area basis using the fine-soil bulk density and the fine-earth fraction of the 0 to 10 cm layer (Table 1). After 8 years, TOC in the control and woodchip treatments was not significantly

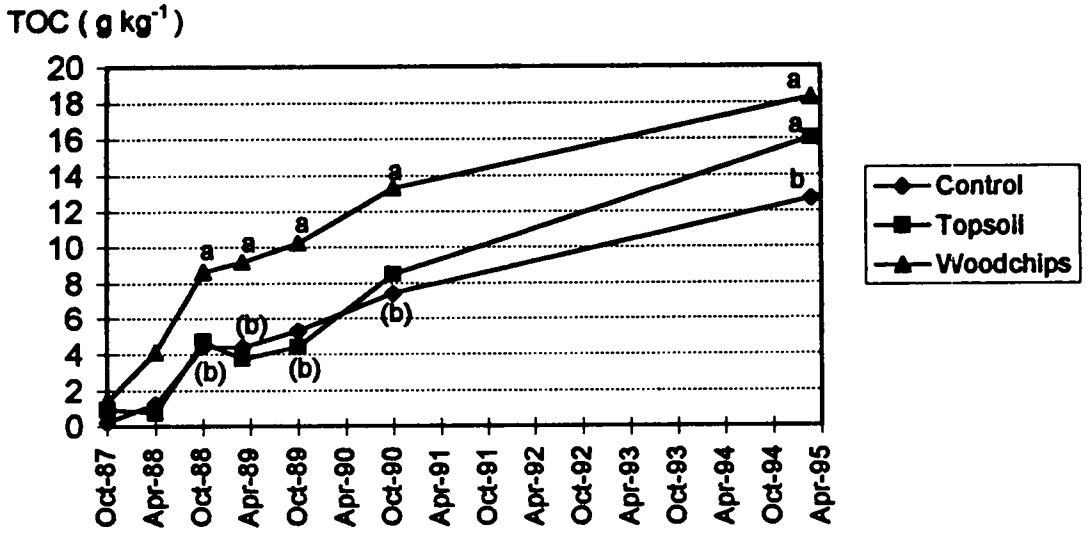


Figure 1. Effect of organic amendment on TOC accumulation in an Appalachian minesoil. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

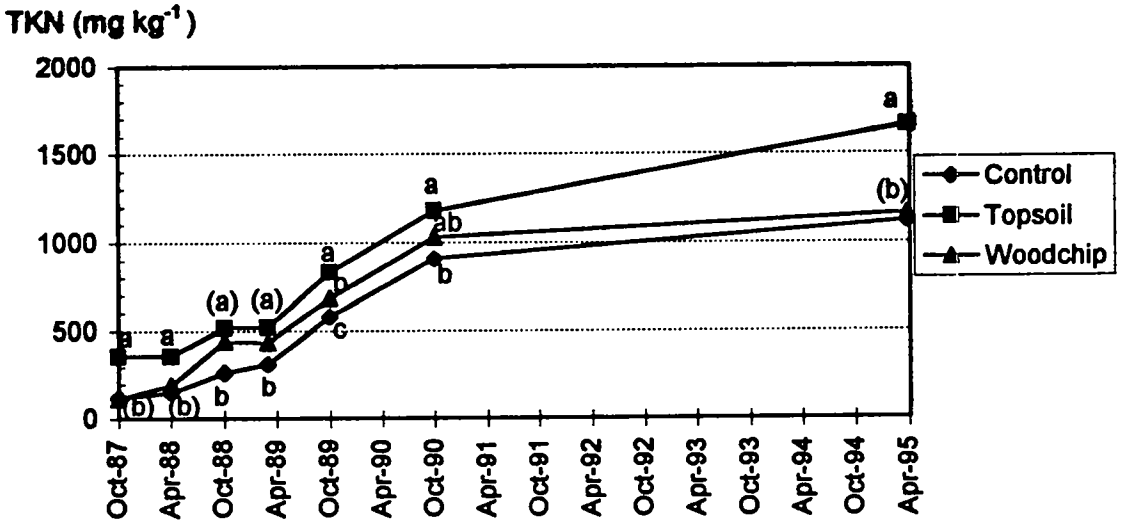


Figure 2. Effect of organic amendment on Total Kjeldahl N (TKN) in an Appalachian minesoil. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

different, and TKN in the control and topsoil treatments was not significantly different (Table 1). Wells and Jorgensen (1975) reported that a 16-year-old loblolly pine stand in North Carolina on undisturbed soils had 1,753 kg N ha^{-1} in the mineral soil, 74 percent of the total N in the system. These 8-year-old minesoils have accumulated roughly half of the N found in a natural soil several thousands of years old.

C Mineralization

Organic C quality is an important determinant of C and N cycling. A C source that is highly resistant to decomposition will provide very little available N due to low C mineralization rates. Quality of organic matter can be evaluated by studying the activity of heterotrophic microbes that are responsible for decomposing and mineralizing organic matter, and microbial activity is reflected by the amount of CO_2 evolved from the system. During the first two years of the study, the woodchip treatment showed significantly higher in-situ CO_2 evolution than both the topsoil and control treatments (Table 2). However, by the seventh year, differences in CO_2 evolution rates were much smaller among the three treatments. Over 7 years, the control and topsoil treatments had accumulated more readily mineralizable forms of C, while the CO_2 evolution rates in the woodchip treatment remained essentially unchanged (Table 2).

Nitrogen Mineralization

N is the nutrient that plants require in the largest amount and that is often the most limiting in young minesoils (Woodmansee et al. 1978). The accumulation and mineralization of C in a minesoil are important factors in determining N mineralization, but it may not be the determining factor. While the woodchip treatment had the highest TOC concentration and the highest C mineralization values at year 8, the topsoil treatment had the highest N_o at year 8 (Figure 3). In a survey of 11 minesoils and two native soils, Stroo and Jencks (1982) found that microbial respiration was not significantly correlated with Total N or Mineralizable N.

The N_o for the woodchip treatment was not significantly different than the topsoil treatment in the first and second years; but, as the readily mineralizable forms of C were decomposed, the N_o of the woodchip treatment dropped to the same level as the control by the eighth year (Figure 3). The N_o was not significantly different among the three treatments in the third year. The N_o for the topsoil treatment was significantly higher than the N_o for the control throughout the 8 years of the study except for the third year. The decline of N_o in the woodchip and control treatments follows the decline in the rate of TKN accumulation in both treatments (Figure 2), and again may be linked to the drop in legume ground cover caused by the higher number of trees in the woodchip and control treatments.

Table 1. Effect of organic amendment on TOC and TKN (kg ha^{-1}) in an eight-year-old Appalachian minesoil.[1]

Treatment	Total Organic C	Total Kjeldahl N
	kg ha^{-1}	
Control	8893b	784ab
Topsoil	10923a	1132a
Woodchips	10698ab	679b

[1] Fine-soil bulk densities were 1.46, 1.42, and 1.33 for the control, topsoil, and woodchip treatments. Fine-earth fraction was 48, 48, and 44 percent for same.

Table 2. Effects of organic amendment on in-situ CO_2 evolution in an Appalachian minesoil.

Treatment	Evolved CO_2
	-- mg CO_2 m^{-2} $hour^{-1}$ --
October 1987	
Control	108b
Topsoil	125b
Woodchip	220a
October 1988	
Control	102b
Topsoil	110b
Woodchip	202a
October 1994	
Control	196b
Topsoil	211ab
Woodchip	221a

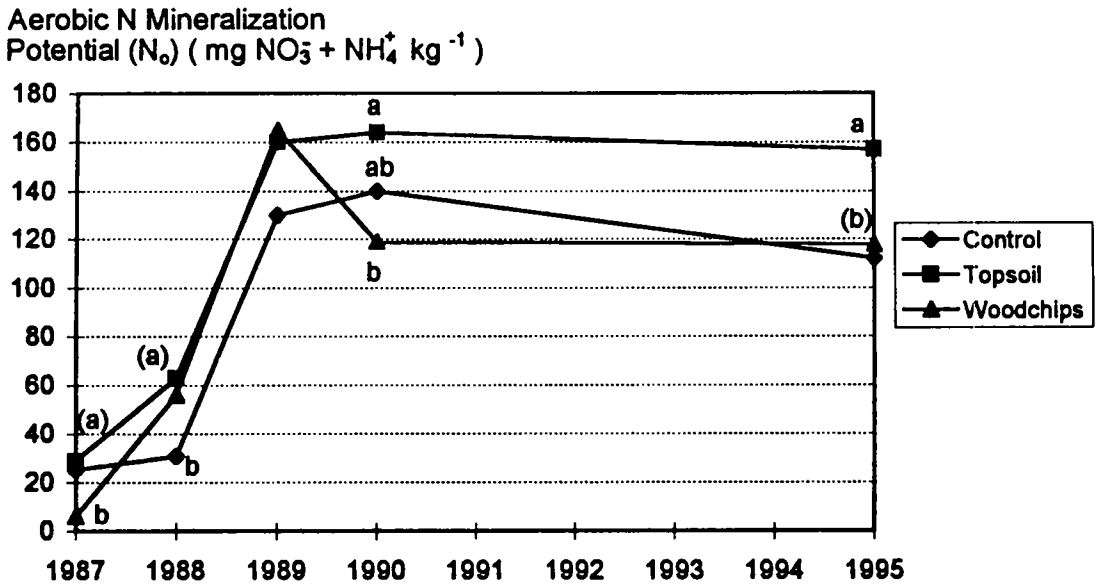


Figure 3. Effect of organic amendments on the N mineralization potential (N_o) of an Appalachian minesoil. A letter in () applies to the two closest data points. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

The buried-bag data were collected monthly for the first three years of the experiment (Figure 4). This data showed that the lowest net N mineralization (or the highest net N immobilization) of the year occurred during August and September in each of the first three years. By the eighth year, all three treatments had net N mineralization during August and September (Figure 4). Net N mineralization in the control treatment was not significantly different from that of the woodchip treatment in August and was not significantly different from that of the topsoil treatment in September (Figure 4). Over eight years, the C/N ratio declined from about 50 in the control and woodchip treatments to about 23 and from about 39 to 19 in the topsoil treatment (Figure 4).

If N limitation is one of the primary problems in minesoils, then research must determine how much N is required to ensure short and long-term forest productivity and which treatments in this study met the requirements. A loblolly pine stand, at its most active growth stage, needs about 100 kg N ha^{-1} yr^{-1}. Most of this annual requirement is met by internal recycling, throughfall, and litterfall; atmospheric deposition and leaching losses roughly equal each other (Bormann et al. 1977; Keeney 1980). There is a demand, unmet by these sources, of from 5 to 25 kg N ha^{-1} yr^{-1} that is supplied mostly by the mineral soil (Keeney 1980). The best estimate of this N-supplying ability comes from the buried bag data which represents the closest approximation to field conditions.

Using the 1994 two month average of 7 mg N kg^{-1} $month^{-1}$ for the control treatment (Figure 4) and converting to a yearly rate, the control treatment had an in-situ N mineralization rate of at least 59 kg N ha^{-1} yr^{-1}. This is an indication that the control treatment can meet the 5 to 25 kg N ha^{-1} yr^{-1} required. These results also indicate that all three treatments had the ability to supply inorganic N in the amounts necessary to support trees, given that the woodchip and topsoil treatments had higher average N mineralization rates than the control (Figure 4). The foliar N concentration of the trees in all three treatments was higher than the 1.1 percent critical level reported by Allen (1987). Foliar N concentrations were 1.46, 1.40, and 1.35 percent for the control, topsoil, and woodchip treatments respectively and none were significantly

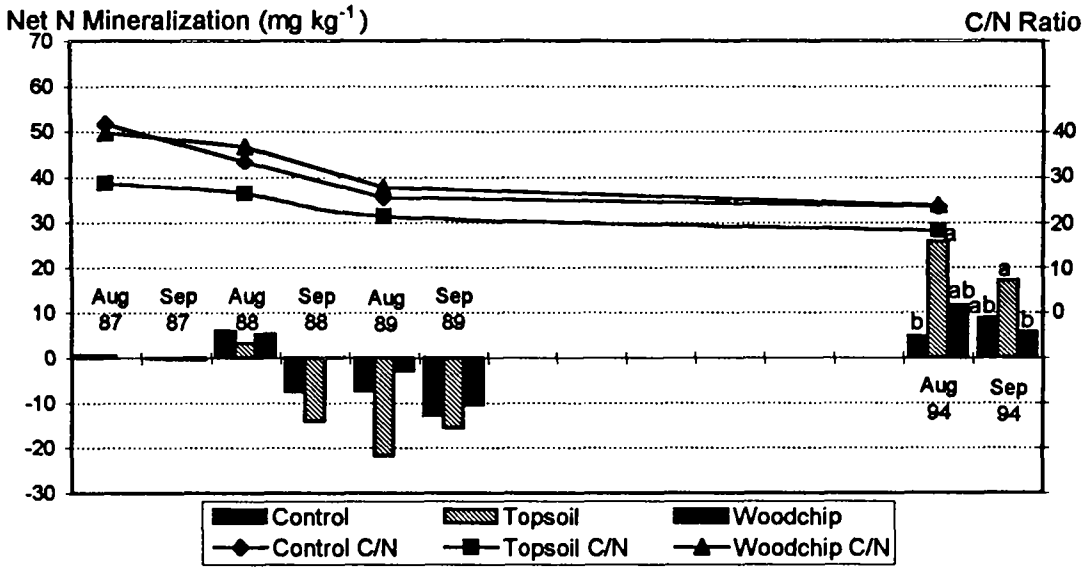


Figure 4. Effect of organic amendments on net N mineralization and C/N ratio in an Appalachian minesoil. Statistical means separation was not performed for mineralization data from the first three years or for the C/N ratio data. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

different. The foliar N concentration data provide further evidence that the use of tree-compatible legumes has established sufficient N to support tree growth.

These young minesoils may not have the buffering ability with regard to total N supply that would allow them to withstand significant N removals at first rotation. However, the replacement of the N removed by sustainable harvesting methods, either through fertilization or reseeding with a tree-compatible legume cover crop at the time of replanting, should return these minesoils to a productive level until they have accumulated enough N to buffer natural or managed disturbances.

Conclusions

This research project showed that uncompacted, unamended topsoil substitutes of favorable material, planted with tree-compatible grasses and legumes, can provide the necessary conditions for trees and ground cover to survive and grow, and C and N to accumulate and cycle. Topsoil substitutes so treated can create the conditions necessary to support and sustain forests for the long-term, meet the reclamation requirements for bond release, and save coal operators grading costs and costs associated with topsoil or organic matter amendments. When minesoils are created following the reclamation forestry design, as described in this research, the problem of N limitation can be removed.

Literature Cited

Anderson, J. P. E. 1982. Soil Respiration. *In* A. L. Page et al. (ed.) *Methods of Soil Analysis*. Part 2. 2nd ed. Agronomy 9: 831-901.

Bormann, F. H., G. E. Likens, and J. M. Melillo. 1977. Nitrogen budget for an aggrading northern forest ecosystem. Science 196: 981-983.

Bengtson, G. W., and D. A. Mays. 1978. Growth and nutrition of loblolly pine on coal mine spoil as affected by nitrogen and phosphorus fertilizer and cover crops. Forest Sci. v.24 n.3, pp.398-409.

Bradshaw, A. D., R. H. Marrs, R. D. Roberts, and R. A. Skeffington. 1982. The creation of nitrogen

cycles in derelict land. Phil. Trans. R. Soc. Lond. B. 296: 557-561.

Bremner, J. A., and C. S. Mulvaney. 1982. Nitrogen-total. *In* A. L. Page et al. (ed.) *Methods of Soil Analysis*. Part 2. 2nd ed. Agronomy 9: 595-624.

Burger, J. A., and W. L. Pritchett. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. Soil Sci. Soc. Am. J. 48: 1432-1437.

Keeney, D. R. 1980. Prediction of soil nitrogen availability in forest ecosystems: a literature review. Forest Sci. 26: 1. pp 159-171.

Moss, S. A., J. A. Burger, and W. L. Daniels. 1989. Pitch x loblolly pine growth in organically amended mine soils. J. Environ. Qual. 18: 110-115.

Nelson, D. W., and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. *In* A. L. Page et al. (ed.) *Methods of Soil Analysis*. Part 2. 2nd ed. Agronomy 9: 539-579.

Reeder, J. D. and B. Sabey. 1987. Nitrogen. pp. 155-184. *In* R. D. Williams and G. E. Schuman (eds.) Reclaiming mine soils and overburden in the western United States; analytical parameters and procedures. Soil Water Conserv. Soc., Ankeny, IA.

Roberts, J. A., W. L. Daniels, J. C. Bell, and J. A. Burger. 1988. Early stages of mine soil genesis as affected by topsoiling and organic amendments. Soil Sci. Soc. Am. J. 52: 730-738.

Schoenholtz, S. H. 1990. Restoration of nitrogen and carbon cycling in an Appalachian mine spoil. Ph.D. dissertation. Virginia Polytechnic Institute and State University. Blacksburg, VA. 174p.

Schoenholtz, S. H., J. A. Burger, and R. E. Kreh. 1992. Fertilizer and organic amendment effects on mine soil properties and revegetation success. Soil Sci. Soc. Am. J. 56: 1177-1184.

Stanford, G., and S. J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36: 465-472.

Stroo, H. F., and E. M. Jencks. 1982. Enzyme activity and respiration in minesoils. Soil Sci. Soc. Am. J. 46: 548-553.

Torbert, J. L., A. R. Tuladhar, J. A. Burger, and J. C. Bell. 1988. Minesoil property effects on the height of ten-year-old white pine. J. Environ. Qual. 17: 189-192.

Wells, C. G., and J. R. Jorgensen. 1975. Nutrient cycling in loblolly pine plantations. In Forest soils and land management (B. Bernier and C. H. Winget, eds) pp 137-158. Proc. 4th North American Forest Soils Conference, Les Presses de l'Universite Laval, Quebec.

Woodmansee, R. G., J. D. Reeder, and W. A. Berg. 1978. Nitrogen in drastically disturbed lands. pp. 376-392. *In* C. T. Youngberg (ed.) Forest and soil land use. Dept. of Forest and Wood Sci., Colorado St. Univ., Ft. Collins, CO.

TREE SHELTER AND INTERPLANTED N-FIXING SHRUB EFFECTS ON CROP TREE GROWTH ON A CALCAREOUS MINESOIL[1]

by

David A. Kost, Merlyn M. Larson, and John P. Vimmerstedt[2]

Abstract. In southeastern Ohio, we installed three studies to test the effects of plastic tube tree shelters and interplanted N-fixing shrubs on crop tree survival and growth. Study 1 on graded gray cast overburden used white ash (*Fraxinus americana* L.) and a hybrid willow (*Salix matsudana* x *alba*, or Austree) as crop trees. These were tested in factorial combination with 1.2 m tall tree shelters (present or absent) and N-fixing shrubs [none, bristly locust (*Robinia fertilis* Ashe), or Siberian peashrub (*Caragana arborescens* Lam.)]. Study 2 evaluated growth of bur oak (*Quercus macrocarpa* Michx.) as affected by soil surface (graded cast overburden or ripped topsoil), presence of tree shelters, and presence of interplanted Siberian peashrub. Study 3 tested Austree growth as affected by soil surface and presence of tree shelters. After four or five growing seasons, overall crop tree survivals were white ash (80%), bur oak (52%), and Austree (10% in study 1 and 25% in study 3). All crop tree species tended to survive better with tree shelters but only Austree in study 3 (36% with shelter vs. 14% without shelter) showed a significant difference. Tree shelters increased heights of white ash (102 cm with shelter vs. 21 cm without shelter) and bur oak (84 cm vs. 27 cm). Crop tree survival and growth were not affected significantly by interplanted N-fixing shrubs or by soil surface. In study 1 (cast overburden only), peashrub (64%) survived better than bristly locust (31%) but locust was taller (74 cm vs. 45 cm). In study 2, peashrub survived better on ripped topsoil (53%) than cast overburden (17%), but height was not impressive on either soil (41 ± 11 cm).

Additional Key Words: *Fraxinus americana* L., *Quercus macrocarpa* Michx., *Salix matsudana* x *alba*, *Robinia fertilis* Ashe, *Caragana arborescens* Lam.

Introduction

A variety of cultural techniques, such as fertilizing, herbiciding, soil ripping, spraying animal repellents, or planting containerized stock, can be used to improve tree survival and growth on surface mines. One of the newer practices is the use of tree shelters. Tree shelters are translucent plastic tubes available in various lengths up to 1.8 m that are installed over individual trees and supported by a stake. The shelter modifies the microenvironment around the tree seedling (increases humidity, decreases wind and light intensity) and promotes rapid height growth. The shelter also protects the seedling from vertebrate animal damage until it emerges from the tube. After the terminal bud emerges from the tube, additional growth may carry it beyond the reach of deer, although Ward and Stephens (1995) reported browse damage on trees that had emerged from 1.2 m tubes. Tree shelters show great promise for improving tree establishment but are expensive in terms of initial cost ($3.75 per 1.2 m tall shelter) and labor for installation and maintenance.

Tree growth on new minesoils, which are almost always deficient in nitrogen, may be improved by interplanting nitrogen-fixing shrubs. Although the primary expected benefit from the shrubs is an increase in available soil nitrogen, other possible benefits are the increased accumulation of organic matter and the reduction of wind.

There are a variety of N-fixing shrub species that can be interplanted with trees (Vogel,1981). Bristly locust is a native species that is well adapted to acid minesoils but also grows well on calcareous soils. It spreads by root suckers to form dense stands but is not considered a potential "pest" species

[1]Paper presented at the 1996 National Meeting of the American Society for Surface Mining and Reclamation, Knoxville, TN, May 19-25, 1996.

[2]David A. Kost, Senior Research Associate, Merlyn M. Larson, Professor Emeritus, and John P. Vimmerstedt, Associate Professor Emeritus, School of Natural Resources, The Ohio State University and Ohio Agricultural Research and Development Center, Wooster, OH 44691.

(Vogel,1981). Root suckering is reduced where ground cover is dense. Siberian peashrub is native to Siberia and Manchuria but has been planted widely for windbreaks on farms and for hedges and outdoor screening in towns of the upper midwest United States (Dietz and Slabaugh,1974). It is adapted to sandy, alkaline soil and open, unshaded sites. Carpenter and Hensley (1979) evaluated seven species of N-fixing shrubs, including bristly locust and Siberian peashrub, for adaptation to an extremely acid minesoil amended with lime. These two species have also been planted on alkaline iron and copper tailings in Michigan (Shetron and Carroll, 1977).

These studies used bur oak, white ash, and Austree as crop tree species. Bur oak and both white and green ash have shown good to excellent survival in other studies on the Muskingum Mine. White ash has a high N requirement for best growth (Mitchell and Chandler, 1939) and so may show a strong response to the interplanted N-fixing shrubs. Austree is a hybrid between Salix matsudana Koidz (native to Korea) and Salix alba L. (white willow; native to Europe and north Africa). It has potential for rapid growth and use in windbreaks and its leaves are an excellent source of animal fodder.

These studies evaluated effects of tree shelters and interplanted N-fixing shrubs on survival and growth of white ash, bur oak, and Austree. Two of the studies also compared tree and shrub growth on ripped topsoil versus graded cast overburden.

Methods

The studies are on Central Ohio Coal Company's Muskingum Mine, 5 km south of Cumberland, Ohio. Study 1 is west of State Route 83 in Muskingum County, and studies 2 and 3 are east of State Route 83 in Noble County. The area was mined using pan scrapers to remove and stockpile the topsoil, followed by draglines to uncover the Meigs Creek No. 9 coal seam. The overburden is predominately gray shale and limestone, with lesser amounts of sandstone and claystone.

Reconstructed soil surfaces consisted of graded gray cast overburden without topsoil, and graded cast overburden with 30 cm of replaced topsoil. The topsoil was ripped to 30-cm depth at 30-cm spacing after grading and then disked (ripped topsoil). Ripped topsoil is classified as Morristown silty clay loam, a loamy-skeletal, mixed (calcareous), mesic Typic Udorthent (Waters and Roth,1990). Soil physical and chemical characteristics are listed in Table 1. Cast overburden has greater sand content but lower levels of extractable nutrients in study 1 relative to studies 2 and 3.

All study areas received 448 kg/ha of 8-32-16 (N-P-K) fertilizer, plus ammonium nitrate at 224 kg/ha for study 1 and at 112 kg/ha for studies 2 and 3. The areas were seeded with an herbaceous mix containing the following species and seeding rates (kg/ha): orchardgrass-Dactylis glomerata L. (6.7), timothy-Phleum pratense L. (11.2), perennial ryegrass-Lolium perenne L. (9.0), Kentucky bluegrass-Poa pratensis L. (5.6), Mammoth red clover-Trifolium pratense L. (5.6), and Empire birdsfoot trefoil-Lotus corniculatus L. (5.6). Wheat (Triticum aestivum L.) at 1.3 hL/ha was included as a cover crop for studies 2 and 3. Plots were mulched with hay after seeding. Fertilizing, seeding, and mulching were done in spring 1988 for study 1 and in late summer 1987 for studies 2 and 3.

Tree rows were sprayed with glyphosate herbicide (2.24 kg active ingredient/ha) in 0.8 m-wide strips in April 1991, and trees and shrubs (except Austree) were planted within two weeks. Austree planting was delayed until 1992. All tree rows were sprayed with oryzalin herbicide (4.48 kg active ingredient/ha) in 0.8 m-wide strips in May 1991.

All studies used the same subplot design. Each subplot (5.5 m by 7.3 m) was planted with six crop trees (either white ash, Austree, or bur oak) arranged in two rows at 1.8 m by 1.8 m spacing. Crop trees were also planted on the borders at the ends of all plots. Plots interplanted with bristly locust contained eight locust, so that each crop tree was flanked by two locust planted in the tree row. Plots interplanted with Siberian peashrub contained 24 peashrubs, with each crop tree flanked by two groups of peashrubs planted in the tree row. Each peashrub group contained three plants spaced about 0.3 m apart. Brown plastic tube tree shelters were installed on all six crop trees in those plots that received shelters.

All studies had three

Table 1. Soil physical and chemical characteristics for study areas on the Muskingum Mine.

	Cast Overburden		Ripped Topsoil
	Study 1	Studies 2 and 3	Studies 2 and 3
Sieve Analysis	% by weight		
> 4 mm	41	30	18
2 - 4 mm	7	14	7
< 2 mm	52	56	75
Texture Analysis[1]	%		
Sand	66	36	28
Silt	23	41	40
Clay	11	23	32
pH	7.7	7.0	7.0
Extractable Nutrients[2]	kg/ha		
P	4	13	16
K	211	377	285
Ca	9442	14381	5824
Mg	606	1157	877
	meq/100g		
Cation Exchange Capacity	24	37	17

[1] < 2 mm fraction
[2] P by Bray-1 extraction. K, Ca, and Mg by ammonium acetate (1 mole/L) extraction.

replications. Study 1 used a randomized complete block design to test three interplanted N-fixing shrub treatments (no shrub, bristly locust, or Siberian peashrub), two tree shelter treatments (no shelter or 1.2 m tube shelter), and two crop tree species (white ash or Austree) in a 3 x 2 x 2 factorial experiment. The soil surface is graded cast overburden. Each replication measured 21.9 m by 21.9 m.

Studies 2 and 3 were separate but contiguous experiments using split-plot designs with soil surface (graded cast overburden or ripped topsoil) as main plots. Main plots measured 11.0 m by 14.6 m in Study 2 and 5.5 m by 14.6 m in Study 3. Study 2 (bur oak crop tree) had factorial combinations of two tree shelter treatments (no shelter or 1.2 m tube shelter) with two interplanted shrub treatments (no shrub, or Siberian peashrub) as subplots. Study 3 (Austree crop tree) had two tree shelter treatments (no shelter or 1.2 m tube shelter) as subplots. European alder [Alnus glutinosa (L.) Gaertn.] was planted in all subplots of the Austree study so presence of alder was not an experimental factor in the study. Each subplot contained eight alder, with each Austree flanked by two alder in the tree row.

In 1991, white ash was a mixture of seedlings from three half-sib sources grown at the Marietta, OH state nursery and was relatively small one-year-old stock. Bristly locust and European alder (Vallonia, IN state nursery), Siberian peashrub (Lincoln-Oakes, Bismarck, ND nursery) and bur oak (General Andrews Nursery, Willow River,

MN) were purchased in 1990 and held as transplants in the OARDC nursery until 1991.

Because of considerable mortality due to a drought in 1991, all trees and shrubs that died, except European alder, were replanted in April 1992. Austree was also planted then. White ash and bur oak (Zanesville, OH state nursery), peashrub (Lincoln-Oakes nursery), and bristly locust (Augusta Forestry Center, Crimora, VA) were purchased new in 1992. Austree obtained from Austree, Inc. (Pescadero, CA) was received too late for outplanting in 1991 and so was held in the OARDC nursery until planting in 1992. Thus, Austree stock was stout, rooted cuttings about 30 cm long and 2-3 cm in diameter.

Tree shelters were installed on appropriate crop trees on April 27 and May 1, 1992.

We measured tree and shrub survival in May 1991, June 1992, and in September or October from 1991 through 1995. Crop tree heights (nearest cm) were measured in September 1992. Heights of all tree and shrub species were measured in September or October from 1993 through 1995. Survival and height of bristly locust were based upon the eight planted seedlings per subplot (sprouts not counted).

Data analysis used the ANOVA or GLM procedures of Statistical Analysis System (SAS) software (SAS Institute Inc.,1987). Survival percentages were transformed with the arcsine-square root function before analysis. If analysis of variance indicated significant ($p=0.05$) effects, we tested differences among means at $p=0.05$ using the LSD test.

Results

Crop Tree Survival and Growth

Study 1. Overall white ash survival was 57% the first year, increased to 86% after replanting the second year, and stabilized at 80% after five years. Tree shelters did not significantly affect ash survival but did produce a fivefold increase in height (Table 2). Height of ash without shelters showed little increase compared to the initial planting height of 15 to 20 cm.

Overall Austree survival was 55% the first year but decreased to 10% the second year (1993) presumably because of low rainfall (1.2 cm) from July 22 to September 1. Survival remained stable through the fourth growing season, but only 6 of 18 Austree plots had surviving Austree. First-year heights were significantly greater with shelters (95 cm) versus without shelters (35 cm). After four years, tree shelter effects on Austree survival and height were not statistically significant (Table 2).

Survival and height of ash or Austree were not affected by presence of interplanted shrubs (Table 2), or by significant interaction of shelter treatments with interplanted shrub treatments.

Study 2. Overall bur oak survival was 52% the first year (67% on ripped topsoil, 38% on cast overburden), increased to 75% after replanting the second year, and appeared to stabilize at 52% after five years. Bur oak tended to survive better on ripped topsoil and with tree shelters but the differences were not significant (Table 3). Tree shelters produced a threefold increase in height (Table 3). Heights of oak without shelters showed little increase compared to the initial planting height of 20 to 25 cm. Oak survival and height were not affected by interplanted Siberian peashrub (Table 3), or by significant interactions of the soil surface, shelter, and interplanted peashrub treatments.

Study 3. Overall Austree survival was 72% the first year (86% on ripped topsoil, 58% on cast overburden), decreased to 22% the second year (1993) because of low rainfall in August, and appeared to stabilize at 25% after four years. First-year heights were significantly greater with shelters (107 cm) versus without shelters (31 cm). After four years, Austree survived better with tree shelters and tended to survive better on ripped topsoil than on cast overburden (Table 3). Survival on cast overburden was similar in Study 3 (11%) and Study 1 (10%). Austree tended to be taller with tree shelters (Table 3).

Survival and Height of Interplanted N-fixing Shrubs and Trees - All Studies

In study 1 (graded cast overburden only) Siberian peashrub survived better than bristly locust but locust was taller (Table 4). Peashrub survival in individual plots ranged from 46% to 79%.

Table 2. Tree survival and height on graded cast overburden (Study 1) after four or five growing seasons as affected by tree shelters and interplanted N-fixing shrubs.

	Survival		Total Height	
	White Ash (yr 5)	Austree (yr 4)	White Ash (yr 5)	Austree (yr 4)
	--------- % --------		-------- cm --------	
Tree Shelter[1]				
Yes	87.0[2]	16.7	102 a	275
No	72.2	3.7	21 b	128
Interplanted Shrub				
None	77.8	5.6	65	250
Bristly locust	80.6	19.4	59	227
Siberian peashrub	80.6	5.6	62	212

[1]Tree shelters were installed on white ash at beginning of second growing season.
[2]Within a column and factor, means followed by different letters are significantly different at p = 0.05 using the LSD test.

Bristly locust survival in individual plots varied from 0% to 75%. Locust survival is based on the planted locust only (8 per plot). Several plots had volunteer locust from root sprouts, including one plot and adjoining area with 65 stems.

In study 2, peashrub survived better on ripped topsoil than on cast overburden (Table 4). Peashrub survival appeared lower in study 2 than study 1 (Table 4), with survival on cast overburden in study 2 being less than one-third that in study 1.

European alder in study 3 had excellent initial survival (97%) in June 1991. Survival decreased to 9% in September 1991 following the drought and stabilized at 7% after five growing seasons. The few surviving alder were on ripped topsoil (Table 4). European alder also showed a sharp decrease in survival (from 87% to 14%) during the 1991 drought in a herbicide study that benefited from two years of above average rainfall before the drought (Kost et al,1992).

Discussion

Tree shelters had a greater effect on tree survival and growth than interplanted N-fixing shrubs. Heights of white ash and bur oak and survival of Austree were increased by tree shelters. White ash and bur oak without tree shelters showed little height increase after five years, due in part to damage by rabbits and deer. These studies used relatively small plots (6 crop trees per plot) and tree shelters may have concentrated the animal damage on the unprotected trees.

Lack of height growth on unprotected trees in these studies does not agree with results from all other ongoing studies on the Muskingum mine. In a nitrogen fertilization study (Kost and Vimmerstedt,1994), white ash without shelters had similar survival (97%) and height (94 cm) after five years as trees with shelters in study 1 (Table 2). Thus, fertilized trees without shelters may grow as well as trees with shelters. In a species trial (unpublished data), white ash without shelters had similar survival (79%) but lesser height (34 cm) after four years compared to trees with shelters (74 cm) in study 1. In another study (unpublished data), bur oak without shelters had similar survival (56%) but lesser height (25 cm) after five years as trees with shelters in

Table 3. Tree survival and height after four or five growing seasons as affected by soil surface, tree shelters, and interplanted Siberian peashrub.[1]

	Bur oak (Study 2, yr 5)		Austree (Study 3, yr 4)	
	Survival	Total Height	Survival	Total Height
	---%---	-----cm-----	---%---	-----cm-----
Soil Surface				
Ripped topsoil	63.9[2]	72	38.9	219
Graded cast overburden	40.3	40	11.1	163
Tree Shelter[3]				
Yes	59.7	84 a	36.1 a	214
No	44.4	27 b	13.9 b	74
Interplanted peashrub				
Yes	52.8	53	---	---
No	51.4	60	---	---

[1]Interplanted peashrub was not a factor in Study 3 with Austree.
[2]Within a column and factor, means followed by different letters are significantly different at p = 0.05 using the LSD test.
[3]Tree shelters were installed on bur oak at beginning of second growing season.

Table 4. Survival and height of N-fixing woody plants after five growing seasons.

	Survival	Total Height
	-----%-----	-----cm----
Study 1- Graded cast overburden		
Bristly locust	30.8 b[1]	74 a
Siberian peashrub	64.2 a	45 b
Study 2- Siberian Peashrub		
Ripped topsoil	53.4 a	47
Graded cast overburden	17.2 b	34
Study 3- European alder		
Ripped topsoil	14.6	184
Graded cast overburden	0.0	--

[1]Within a study and column, means followed by different letters are significantly different at p = 0.05 using the LSD test.

study 2 (Table 3). In contrast to the tree shelter experiments, other ongoing studies were planted in 1989 or 1990 and had one or two years of above average rainfall before the drought in 1991. Thus, for species such as white ash and bur oak that survive well without shelters, the main benefit of shelters is increased height growth. Height growth may slow after seedlings emerge from the shelters (Lantagne,1995). By 1995, 33% of bur oak and 36% of white ash had emerged from shelters.

Austree survival was good on ripped topsoil but mediocre on cast overburden during the first growing season with adequate rainfall. The sharp decline in survival that probably resulted from the dry period in the second growing season suggests Austree, like other willows, requires abundant soil moisture. It will not be possible to monitor the long-term effects of the interplanted shrubs on Austree in study 1 because most plots do not have surviving Austree.

There are probably several reasons why the interplanted N-fixing shrubs have not affected crop tree growth. Nitrogen fixation by herbaceous legumes, which were present in all studies, may have nullified the effects of nitrogen fixation by the N-fixing shrubs. Although we did not measure the abundance of herbaceous legumes, we noticed that volunteer sweetclover (Melilotus officinalis Lam.) was prominent in the herbicide-treated tree rows in study 1 during the second season. The seeded birdsfoot trefoil was abundant in studies 1 and 2 in 1995. It is possible that the interplanted shrubs will contribute available N after herbaceous legumes are shaded out by crop trees. Long term studies would be required to test this.

Poor survival of bristly locust in some plots and overall poor growth of peashrub have reduced nitrogen fixation by these shrubs. We do not think that the nitrogen applied during ground cover establishment has prevented a crop tree response to nitrogen fixation by the shrubs. For example, in a study on the same site as study 1 (unpublished data), green ash grew taller with 168 or 336 kg N/ha in addition to N applied when ground cover was seeded.

Survival of bristly locust was variable in study 1 and in an adjacent study (unpublished data) on the same site. In the adjacent study, locust survived best in plots with the least ground cover when locust was planted. There were no obvious differences in ground cover in study 1 that would have contributed to the variation in locust survival. Although sprouting may allow one surviving locust to spread over a large area (Davidson,1979), several plots in study 1 had no surviving locust and thus no possibility of spreading by sprouting. Low initial survival for locust may not be a problem in routine reclamation plantings where locust is planted uniformly over a large area instead of being separated in research plots. To insure locust establishment it may be necessary for plantings to be spaced closer than the 1.8 m by 1.8 m used in study 1. Locust grew vigorously in several plots with abundant sprouts.

Siberian peashrub survived better than bristly locust, but peashrub growth was unimpressive due in part to animal damage. In northern Michigan peashrub survived better than bristly locust on alkaline iron tailings but neither species survived on alkaline copper tailings after five years (Shetron and Carroll,1977). On an acid minesoil in Kentucky, peashrub had 44% survival after four years but did not persist after 18 years (Wade et al,1985).

Conclusions

Tree heights were increased dramatically by tree shelters but it is too early to speculate if the increased growth would offset the costs of installing shelters. Bristly locust does not survive as well as Siberian peashrub but shows more potential for vigorous growth with concomitant nitrogen fixation.

Acknowledgements

The financial support and assistance of Central Ohio Coal Co. (American Electric Power Service Corp.) in plot construction, tree planting, and tree shelter installation is appreciated. Clay Dygert, Tim Huffman, Mark Klies, Bob McConnell, and Charles Vrotney provided valuable field assistance.

Literature Cited

Carpenter, P.L., and D.L. Hensley. 1979. Utilizing N_2-fixing woody plant species for distressed soils and the effect of lime on survival.

Botanical Gazette 140(Suppl.):S76-S81.

Davidson, W.H. 1979. Results of tree and shrub plantings on low pH strip-mine banks. USDA Forest Service Research Note NE-285. 5 p.

Dietz, D.R., and P.E. Slabaugh. 1974. Caragana arborescens Lam. (Siberian peashrub). p. 262-264. In Seeds of woody plants in the United States. USDA Forest Service Agriculture Handbook 450.

Kost, D.A., J.H. Brown, and J.P. Vimmerstedt. 1992. Effects of coal minesoil surface and herbicide applications on early tree survival and growth. p. 130-145. In Proc. of 9th Annual National Meeting of the Amer. Soc. for Surface Mining and Reclamation. (Duluth, Minn. June 14-18, 1992). Amer. Soc. for Surface Mining and Reclamation, Princeton, West Virginia.

Kost, D.A., and J.P. Vimmerstedt. 1994. Ground cover and tree growth on calcareous minesoils: greater influence of soil surface than nitrogen rate or seed mix. p. 295-304. In Inter. Land Reclamation and Mine Drainage Conf. and Third Inter. Conf. on the Abatement of Acidic Drainage. (Pittsburgh, Penn. April 24-29, 1994). Vol. 3. USDI Bur. of Mines Special Publication SP 06C-94, 353 p. Washington, D.C.

Lantagne, D.O. 1995. Effects of tree shelters on planted red oaks after six growing seasons. p. 515-521. In Proc. 10th central hardwood forest conference. (Morgantown, West Virginia. March 5-8, 1995). USDA Forest Service General Technical Report NE-197. 577 p. Northeastern Forest Experiment Station.

Mitchell, H.L., and R.F. Chandler. 1939. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock Forest Bulletin 11. Cornwall-on-the-Hudson, NY. 94 p.

SAS Institute Inc. 1987. SAS/STAT guide for personal computers, version 6 edition. SAS Institute Inc., Cary, NC. 1028 p.

Shetron, S.G., and D.A. Carroll. 1977. Performance of trees and shrubs on metallic mine mill wastes. Journal of Soil and Water Conservation 32:222-225.

Vogel, W.G. 1981. A guide for revegetating coal minesoils in the eastern United States. USDA Forest Service General Technical Report NE-68. 190 p.

Wade, G.L., R.L. Thompson, and W.G. Vogel. 1985. Success of trees and shrubs in an 18-year-old planting on mine spoil. USDA Forest Service Research Paper NE-567. 10 p.

Ward, J.S., and G.R. Stephens. 1995. Protection of tree seedlings from deer browsing. p. 507-514. In Proc. 10th central hardwood forest conference. (Morgantown, West Virginia. March 5-8, 1995). USDA Forest Service General Technical Report NE-197. 577 p. Northeastern Forest Experiment Station.

Waters, D.D., and L.E. Roth. 1990. Soil survey of Noble County, Ohio. USDA-SCS. Washington, D.C.

[1]EVALUATION OF NATURAL SUCCESSION OF RECLAIMED COAL MINE LAND IN WESTERN KENTUCKY

by

Dan L. Williamson and R. Brent Gray[2]

ABSTRACT: In 1989 Peabody Coal Company began a comprehensive inventory program on roughly 2000 acres of reclaimed land in various stages of reforestation. Although the information gathered was intended for in-house use, accurate maps and records were created.

Since the inception of public law 95-87, reclamation managers have discussed their observations that compaction and ground cover requirements make the establishment of tree seedlings extremely difficult and the role that this has played in natural regeneration. To examine this situation more closely an isolated area that had been seeded in 1987 to a tree compatible grass\legume ground cover was selected. The area was tree planted in the spring of 1988 and again in the spring of 1989. The area is approximately 250 acres and is surrounded by unmined remnants of upland forest and cast overburden areas planted to trees in the late 1950's. Trees observed in the unmined area included Red oak (*Quercus rubra*), White ash (*Fraxinus americana*) and Sugar maple (*Acer saccharum*). Trees observed on the previously mined area include Loblolly pine (*Pinus taeda*), White pine (*Pinus strobus*), Sycamore (*Platanus occidentalis*), Black locust (*Robinia pseudoacacia*) and various other reclamation type species planted in the late 1950's.

In August of 1990, 22 plots were run in a random method to determine tree survival. Plots were circular and 50 feet in diameter. Results from this inventory indicated that stocking was 388 trees per acre. Using the map from the 1990 survey the area was resurveyed in July 1995. The 1995 survey indicated an increase in stocking to 427 trees per acre. However, Winged sumac (*Rhus copallina*) and Eastern red cedar (*Juniperus virginiana*) were the only 2 tree species that have regenerated and accounted for the increase in stocking.

Ground cover changed greatly; Redtop grass (*Agrostis alba*) was the only component of the original grass\legume mix present to any extent. Serecia lespedeza (*Lespedeza cuneata*) was present on 17 of the 22 plots and was the dominant vegetation on 8 plots; only 1 plot was free of Serecia lespedeza.

It is our summation that this area will lag far behind pre-law areas in the amount of time required to regenerate to woodland.

---

[1] Paper presented at the 13th Annual Meeting of the American Society for Surface Mining and Reclamation, Knoxville, Tennessee, May 22, 1996.

[2] Dan L. Williamson is a Registered Forester and the Field Director for Kentucky Reclamation Association, Inc.,Madisonville, Kentucky 42431. R. Brent Gray is the Reclamation Manager for Peabody Coal Company, Graham, Kentucky 42344.

Additional Key Words: natural regeneration, compaction, ground cover.

Introduction

With the implementation of approximate original contour (A.O.C.) grading in the late 1960's as required by Kentucky state law and the subsequent passage of public law 95-87, the contour of post mining land has changed dramatically in Western Kentucky. Obviously, topography is significantly different. Adherence to approximate original contour (A.O.C.) grading requirements has achieved the desired effect of blending mining areas into the surrounding unmined landscape. Along with the change in topography there is a pronounced change in vegetation cover.

As a rule, pre-law ungraded or strike-off graded sites are in some sort of tree cover, either planted or naturally regenerated. Conversely, graded sites are dominated by herbaceous plants or remnants of tree and shrub plantings and herbaceous plants.

Difficulty with establishing trees on graded sites has been well documented. As early as 1951 concerns were raised that grading could be detrimental to reforestation. In 1954 Kentucky adopted strike-off grading of spoil ridges and it soon became evident to foresters that even limited grading of sites produced a negative effect on reforestation. There have been numerous research studies since public law 95-87 to the substantiate compaction problems associated with grading and ground cover requirements (Vogel and Gray 1987), (Cunningham and Allen 1989), (Hutnik and Hughes 1990) and (Probert 1990). Also, numerous unpublished research studies exist in the Mid-west coal fields.

Reforestation of surface mine sites in Western Kentucky has dwindled since the enactment of public law 95-87. In reviewing Kentucky Reclamation Association, Inc., archives, we compiled a comparison of the total acres that have been revegetated to pasture hayland versus reforestation for the period 1980 through 1995. Since 1980 Kentucky Reclamation Association, Inc., has revegetated approximately 86,000 acres. Less than 1500 acres of this total were reforested and less that 4000 acres of the total received any wildlife plantings. Kentucky Reclamation Association, Inc., was founded in 1948 and has planted nearly 67,000,000 tree and seedlings since its inception. Only 10,000,000 trees and/or shrubs have been planted since 1980, mostly on Peabody Coal Company lands (Table #1).

Erosion control became the primary responsibility of reclamation managers when it became apparent that these graded, highly compacted sites were subject to severe erosion; especially those areas where topsoil was replaced. In order to control erosion, a dense grass\legume ground cover has to be established. The combination of compaction and ground cover made reforestation nearly unattainable for post mining land use. To compound the problem of reforestation, pasture hayland acreage was considered a higher priority for land use than reforestation by the public law 95-87.

Concern that (A.O.C.) and it's associated problems had effectively regulated reforestation out of existence was negated by the assumptions that eventually these lands would return to forest by natural succession. The mining industry and regulatory agencies assumed that land use change to pasture/hayland was only temporary. This assumption was based upon the natural regeneration that had occurred on ungraded pre-law mined areas.

In the early 1980's we began to notice some disturbing problems associated with graded spoil and graded spoil with replaced topsoil. A stand of grass and legumes could be established using proper tillage and soil amendments. The stand would maintain itself for a few growing seasons and then the legume component would die out. Coarse weeds began to replace the legumes and eventually the grasses. What has continued to surprise us is the relative absence of invasion by trees. We are finding that large tracts of reclaimed lands in Western Kentucky are not regenerating to forest but are being invaded and dominated by Serecia lespedeza.

Methods

To examine this situation in more detail we selected a unique site in Ohio County, Kentucky. The site at Peabody Coal Company's Ken mine is an isolated tract approximately 250 acres in size. All reclamation at the site was done under the regulations in Public law 95-87. The site is surrounded by cast overburden spoil ridges that were reforested in the 1950's (Table #2).

The mining area had a pre-mining vegetation survey performed by Dan Williamson in December 1982. The findings were as follows: This area has been extensively cut over within the last 5 years. Because such a large volume of timber was removed, there is not enough residual overstory present to constitute a logical size class ranking. The area is characterized by clumps of 8"-18" diameter at breast height Pignut hickory (*Carya pallida*), Mockernut hickory (*Carya tomentosa*), Shagbark hickory (*Carya ovata*) and Sugar maple with some White oak (*Quercus alba*), Blackgum (*Nyssa sylvatica*) and Sassafras (*Sassafras albidum*). These clumps of residuals are heavily fire scared or of poor form. Surrounding these clumps are large, relatively open sections with dense seedling and sapling size White oak, Red oak, Black oak (*Quercus velutina*), Southern red oak (*Quercus falcata*), Flowering dogwood (*Cornus florida*), Sugar maple, American beech (*Fagus grandifolia*), White ash, and Sassafras with Devils walking stick (*Aralia spinosa*), Greenbriar species (*Smilax sp.*) and Sumac (*Rhus*).

Soils present were predominantly Frondorf-Wellston-Rosine silt loams, 12-20% slopes on the side slopes and Zanesville 2-12% slopes along the ridges.

The area was mined using the "area" method. Topsoil was removed by dozer and scrapers before mining; overburden was removed by a dragline. The number 11 and 13 seams of coal were removed. After the coal was removed the spoil was graded to (A.O.C.) using dozers. Topsoil

was redistributed over the area by dozers and scrapers.

Final grading and seeding of permanent ground cover was completed in the fall of 1987. Soil amendments included 7 tons of agricultural lime per acre incoporated with a disc-harrow to a depth of 6 inches. The fertilizer used was a combination of 400 pounds of 18-46-0 and 200 pounds of 0-0-60 per acre. Seed mixture was a grass and legume mixture comprised of:

Species	**lbs.per acre**
Timothy (*Phleum pratense*)	5 lbs.
Orchard grass(*Dactylis glomerata*)	15 lbs.
Perennial ryegrass(*Lolium perenne*)	15 lbs.
Redtop (*Agrostis alba*)	5 lbs.
Korean lesp.(*Lespedezastipulocea*)	5 lbs.
Red clover (*Trifolium pratense*)	10 lbs.
White clover (*Trifolium repens*)	5 lbs.

In the spring of 1988 the site was planted with approximately 150,000 tree and shrub seedlings. Tree species planted included Loblolly pine, White pine, Virginia pine (*Pinus virginiana*), Eastern redbud (*Cercis canadensis*), Autumn olive (*Elaeagnus umbellata*), Crabapple (*Malus sp.*), Persimmon (*Diospyros virginiana*), Flowering dogwood, Shrub lespedeza (*Lespedeza bicolor*), Bayberry (*Myricaceae*), Silver maple (*Acer saccharinum*), Yellow-poplar (*Liridendron tulipifera*), Green ash (*Fraxinus pennsylvanica*), River birch (*Betula nigra*), Pin oak (*Quercus prinus*), Pecan (*Carya illinoensis*), Black walnut (*Juglano nigra*) and Willow oak (*Quercus phellos*). Planting was done by hand, using dibble bars. No site preparation was implemented. We assumed that the ground cover seeded was very compatible for reforestation and less competitive that a typical fescue\alfalfa mix.

Drought in the summer of 1988 led to poor seedling survival. The area was completely replanted in the Spring of 1989 using tree species similar to those planted in 1988.

Concern for tree survival and regeneration on this area began in 1989. In May 1989, 3, 1 acre observation plots were established. The plots were monitored monthly to determine when planted seedlings were dying; all natural regeneration was also recorded. During the summer of 1989 3 Winged sumac became established by natural regeneration on this study area.

In August 1990 a tree survival inventory was conducted using 22, 50' diameter circular plots. This inventory ascertained that only 3 Winged sumac had become established through natural regeneration and that the stocking rate for planting seedlings was 388 trees per acre.

During the summer of 1991 new observation plots were established to continue our investigation into tree survival. Based upon the finding of the 1990 inventory we determined that 5, 50' diameter circular plots would provide a commensurate example. During the summer of 1991 it was detected that no regeneration had occurred on the 5 plots with the exception of 1 Winged sumac.

We discontinued our observation plots in 1991. We had determined when seedling mortality was occurring and concluded that natural regeneration was not occurring

quickly enough to offset the loss of the planted seedlings.

In August 1995 we reinventoried the area utilizing the same 22, 50' diameter circular plots established in 1990. Stocking had increased to 427 trees per acre; Winged sumac and Eastern red cedar accounted for the increase in stocking. However, of the 22 plots only 10 plots had any natural regeneration. Four of these plots accounted for 85% of the natural regeneration. It was also discovered that seedling mortality was continuing to occur. Stocking for planted trees dropped from 338 seedling to 330 seedlings per acre. Summary as follows:

SUMMARY OF 1995 INVENTORY
(22 50' diameter plots)

plot #	Number & Species
1	1 Winged sumac
2	1 Eastern red ceder
5	8 Winged sumac
6	1 Winged sumac
12	1 Winged sumac
14	23 Winged sumac
15	30 Winged sumac
16	17 Winged sumac
19	1 Winged sumac
20	13 Eastern red cedar

Serecia lespedeza was never seeded on this site. The 1995 inventory found Serecia lespedeza was present on 17 of the 22 plots and was the dominant vegetation of 8 plots and only 1 plot was free of this species. Redtop grass was the only component of the original ground cover still well represented.

Soil samples were taken in 1995 to determine if soil chemistry was responsible for loss of ground cover; water p.H. results were between 6.2 and 6.4.

Conclusion

In our opinion the assumption that natural regeneration of the original pre-mining tree species will readily occur on compacted soil lands reclaimed under Public law 95-87 is inaccurate. High mortality with artificial regeneration on these sites is well documented. Reduced water capacity and impervious rooting zones are the result of unnecessary compaction; ground cover and soil chemistry also limit the chances for tree establishment. Colonization of these sites by highly competitive herbaceous plants like Serecia lespedeza will slow the return of pre-mined tree species.

Acknowledgments

This work was supported by Peabody Coal Company and Kentucky Reclamation Association, Inc. We also acknowledge the years of commitment to reforestation and expertise that Jimmy Dean, Clark Ashby, Willis Vogel and Jim Burger have shared with us.

References

Vogel, W.G., and B. Gray 1987. Will trees survive on topsoil surface mines? Pages 302-305. In Proceedings of the National symposium on mining, hydrology, sedimentology and reclamation. University of Kentucky, Lexington. 728 pp.

Hutnik,R.J., & H.G. Hughes. 1990. Revegetation of abandoned mine lands in Pennsylvania with containerized seedlings and amendments. Pages 555-561. In Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. West Virginia University, Morgantown. 615 pp.

Cunningham, H., & M. Allen. 1989. Mine soil and ground vegetation effect success of reforestation of surface mines in Northern Appalachia. Unpublished Report. USDI, Office of Surface Mining, Eastern Service Center, Pittsburgh, Pennsylvania, 16 pp.

Probert,T.,R.E. Gallimore, J.L. Torbert, & J.A. Burger. 1990. Results of Eastern white pine establishment in southern West Virginia after four years. Pages 299-305. In Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. West Virginia University, Morgantown. 615 pp.

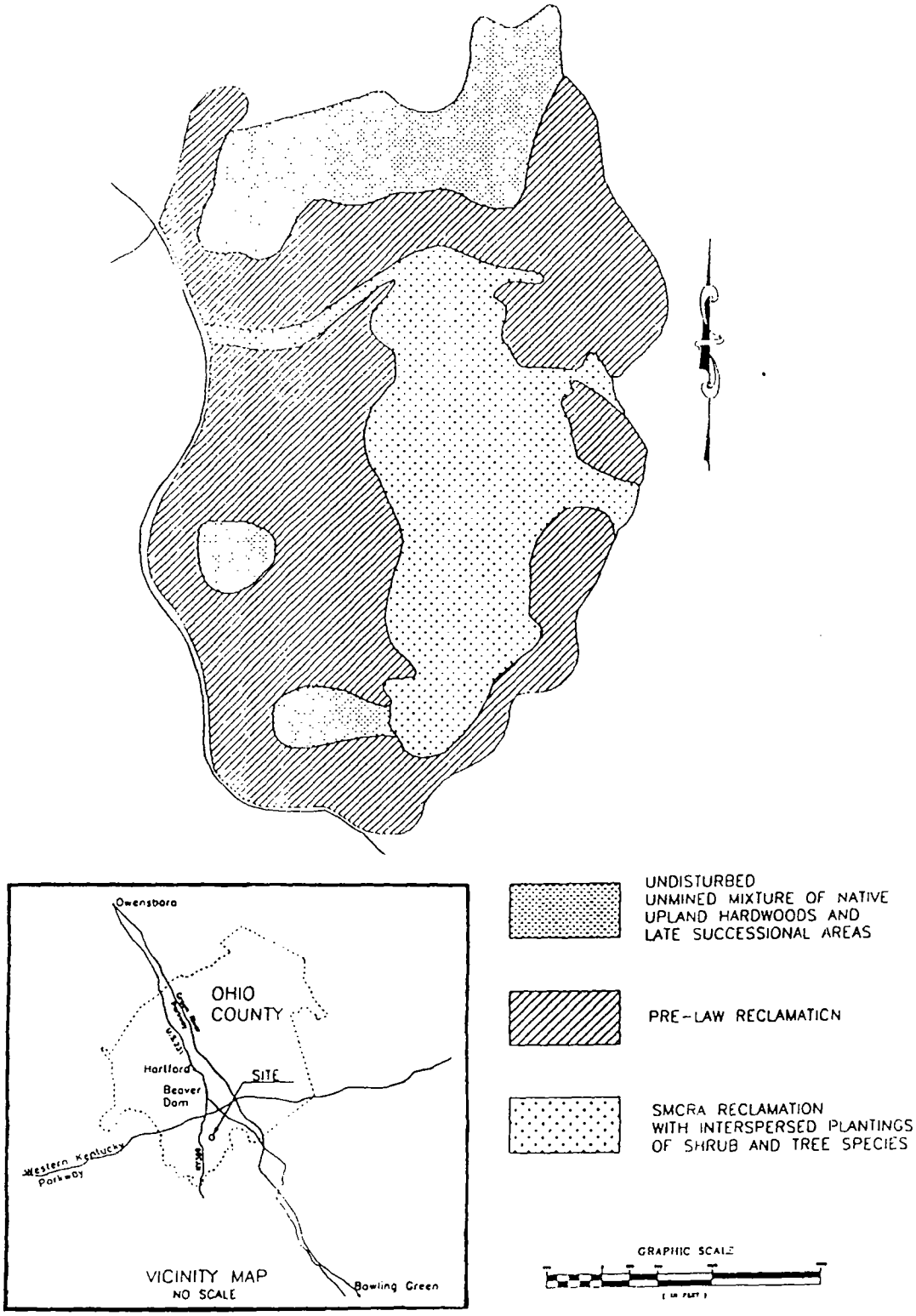
Table #1

Kentucky Reclamation Association, Inc.
Cumulative Summary
1994

Trees and Game Food 1948-1994 Inclusive	Western Kentucky	Eastern Kentucky	Total
Trees and Game Food	65,120,819	2,610,645	67,731,464
Estimated Acres	77,206	3,372	80,578
Forage Crop Seed - Lbs.	7,821,947	1,239,354	9,061,301
Estimated Acres	142,242	28,752	170,994
Estimated Total Acreage Planted and/or Seeded Since 1948*	186,228	31,749	217,977

* Acres reclaimed (planted to trees, planted and seeded both or seeded only).

Table #2


Owensboro
OHIO
COUNTY
Hartford
Beaver
Dam
SITE
Western Kentucky
Parkway
VICINITY MAP
NO SCALE
Bowling Green
UNDISTURBED
UNMINED MIXTURE OF NATIVE
UPLAND HARDWOODS AND
LATE SUCCESSIONAL AREAS
PRE-LAW RECLAMATION
SMCRA RECLAMATION
WITH INTERSPERSED PLANTINGS
OF SHRUB AND TREE SPECIES
GRAPHIC SCALE

INFLUENCE OF GRADING INTENSITY ON HERBACEOUS GROUND COVER, EROSION, AND TREE ESTABLISHMENT IN THE SOUTHERN APPALACHIANS [1]

John L. Torbert and James A.Burger [2]

Abstract: In the southern Appalachian coalfields of Virginia, southern West Virginia and eastern Kentucky, the opportunity exists to create productive forests capable of providing good timber management opportunities on surface mined land. Unfortunately, this opportunity is seldom realized, in part because minesoil compaction caused by excessive surface grading hinders tree establishment and long-term tree growth. This five-year study was established in eastern Kentucky to evaluate the effect of several surface grading treatments on minesoil erosion, herbaceous ground cover development, and tree survival and growth. Three grading treatments were each replicated three times on a 40% slope. The treatments were 1) the operational "intensive" grading practice used by the operator, 2) a more "moderate" grading, and 3) a "ripped" treatment that created a rough surface. During the course of the study, the intensive graded treatment had the greatest erosion and the poorest ground cover development and tree growth. This traditional practice of intensive surface grading to create a smooth surface is not only unnecessarily expensive but, as this study clearly indicates, compaction caused by grading can have detrimental effects for environmental quality (erosion) and forest productivity. When forestry is the post-mining land use, grading practices should be minimized to leave minesoil in a loose condition to reduce erosion and increase tree growth.

Additional Key Words: compaction, minesoils, reclamation, productivity.

Introduction

Since passage of the Surface Mining Control and Reclamation Act (SMCRA), reclamation throughout the southern Appalachians has been conducted in a fashion that creates a "golf course appearance" by making a smooth landscape covered with lush grass. This reclamation scenario has become standard operating practice for most coal operators, and regulators have come to expect smoothly finished surfaces with dense vegetation, regardless of the designated post-mining land use. These practices may be desirable for creating a "hayland/pasture" land use, but they are counter-productive for a forestry land use, an important land use in the southern Appalachians.

Following a 30-year assessment of tree plantings on graded and ungraded spoil in Ohio, Larsen and Vimmerstedt (1983) concluded that spoil compaction was the most important SMCRA-related problem in need of solution for forest-land reclamation. Other researchers have voiced concern that SMCRA encourages excessive spoil grading that results in growth-limiting levels of compaction. Soil compaction increases soil strength, decreases soil aeration and water infiltration, and increases surface runoff. Compacted soils are difficult to plant, seedling mortality is often high, and surviving trees have slower growth rates.

---

[1] Paper presented at the 1996 National Meeting of the American Society for Surface Mining and Reclamation, Knoxville, Tennessee, May 1996.

[2] J.L. Torbert, Soil Scientist, Mead Coated Board, Box 9908, Columbus GA 31908; J.A. Burger, Professor Forest Soils, Virginia Polytechnic Institute and State University, Blacksburg VA 24061.

Minesoil compaction seems most detrimental to tree growth on level areas. After the landforming stage is finished, operators typically do a "*final grading*" to smooth the surface and remove any protruding boulders, large roots, or any other debris that may be included in the spoil material. Finally, before the site is seeded, it is "*walked-in*", "*tracked-in*", or "*trammed*" using a bulldozer to cover the entire surface with indentations from the bulldozer treads. This practice breaks the surface crust that may have developed between the time of grading and seeding, removes any rills or gullies that formed, and creates a uniform distribution of small microsites to capture grass seed and produce a uniform ground cover.

SMCRA does not explicitly require the intensive surface grading that has become so common. Section 816.102 pertains to general requirements for backfilling and grading, and states that "*Disturbed areas shall be backfilled and graded to: 1) achieve the approximate original contour ..., 2) eliminate all highwalls ..., 3) achieve a post-mining slope that does not exceed the angle of repose ..., 4) minimize erosion ..., and 5) support the approved post-mining land use.*" This underlined requirement suggests that grading practices should be land-use specific. We contend that, when forestry is the post-mining land use, level and gently sloping land (where erosion hazard is slight) should be "rough-graded" and left in a loose condition. It should be acceptable for some rocks, depressions, and woody debris to remain on the surface of reclaimed land that will be used for growing trees.

Minesoil compaction effects on tree growth

Early reports on the adverse effects of spoil grading on tree growth were presented by Limstrom (1952) and Chapman (1967). In Ohio, Larsen and Vimmerstedt (1983) found that yellow-poplar height and diameter were 142% and 67% greater after 30 years on ungraded versus graded spoil banks. White pine height and diameter were 32% and 23% greater in the ungraded spoil.

In Illinois, Josiah and Philo (1985) contrasted the physical properties of unmined soil, ungraded spoil, and graded spoil. The bulk density of the ungraded spoil and unmined soil were both 1.3 Mg m^{-3}, whereas the bulk density of the graded spoil was 1.8 Mg m^{-3}. Four years after planting, black walnut (*Juglans nigra*) trees were 35% taller and stem diameter was 31% greater in the ungraded spoil compared to the graded spoil. Where graded spoil was loosened by ripping, height and diameter were increased 38% and 55%.

Torbert and Burger (1990) compared the survival and growth of six commercially important tree species planted on two adjacent slopes, each comprised of the same spoil material. One was operationally regraded and tracked-in, and the other was left in a rough-graded condition. After two years, tree survival averaged 42% on the conventionally regraded site and 70% on the rough-graded slope. For some species, average height growth was almost doubled by eliminating the compacting process.

Surface grading effects on erosion

Rough graded sites are less prone to erosion since the loose soil has a higher infiltration rate (Merz and Finn, 1951). In a discussion about mined land shaping and grading, Glover et al. (1978) listed five practices to reduce or detain surface runoff. First on the list was "roughening and loosening the soil" (followed by mulching and revegetation, topsoiling and use of soil amendments, reduction of slope length or gradient, and use of concave slopes). Minesoil that is left in a loose condition, either as a result of rough grading to avoid compaction, or by ripping to ameliorate compaction, has a greater infiltration rate that decreases overland flow and erosion. Furthermore, the lower strength of uncompacted soils is more conducive to root growth for trees and other plants and ensures that better vegetative cover will be capable of further protecting the soil.

Despite the common-sense knowledge

that loose soils have a greater infiltration rate and less runoff than compacted soils, there is a common belief among some reclamation contractors and inspectors that intensive grading is necessary to reduce erosion. To dispel the belief that intensive grading is necessary to prevent erosion, a research/demonstration project was established in eastern Kentucky to evaluate the effect of surface roughness on ground cover establishment, erosion, and tree growth.

Objectives

The specific objectives of this study were to:

1) compare the influence of three surface grading treatments on erosion. The treatments are i) standard intensive grading, ii) a moderate level of grading, and iii) intensive grading followed by ripping.

2) compare the influence of these three surface grading treatments on herbaceous ground cover development.

3) compare the influence of these three surface grading treatments on survival and growth of five tree species: white pine (*Pinus strobus*), loblolly pine (*Pinus taeda*), sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*).

Methods

Site Selection and Treatments

The study is located on land mined by Martiki Coal Corp. near Lovely, KY. A slope, approximately 50 m (upslope) by 500 m (along the contour) had been reconstructed and moderately graded to its final contour (40% slope). The site was not topsoiled. The topsoil substitute was an alkaline spoil derived primarily from gray siltstone with a minor component of gray and oxidized sandstone. Spoil pH before hydroseeding ranged from 7.7 to 8.8. The site was awaiting final surface grading and hydroseeding when it was selected for study in January 1991.

The slope was divided into nine plots (50 x 50 m) that were used for three replications of three grading treatments. The three grading treatments, installed on March 26, 1991 were:

Intensive grading. This treatment was the standard operational practice used by Martiki and other operators in the region. Bulldozers (D-9 Caterpillars) smoothed the slopes by backblading (dragging their blades as they backed downhill), afterwhich the surface was tracked-in by running the bulldozer up and down the slope until the entire surface was covered with indentations from cleats on the bulldozer treads.

Moderate grading. For this treatment, no further grading was applied. Grading already completed when the study site was selected resulted in a fairly smooth surface, although some rocks and rills were present. A hard crust was present at the surface since six months elapsed between the time of grading and seeding.

Ripped. This was an ameliorative treatment intended to mimic the surface conditions that might be created by rough-grading. The initial study design called for a rough grading treatment where the slope would be returned to its approximate original contour with a minimal amount of grading, leaving some boulders, depressions, and loose soil at the surface. Unfortunately, when selected, the study site was already graded to the moderate level. The decision was made to backblade and track-in these plots to the intensive level of treatment, and then ameliorate the compaction by ripping with a 1-m deep subsoiling shank pulled directly downslope by the D-9 bulldozers. Rips were created at 3-m (10 ft) intervals. Ripping created a very rough surface in the immediate vicinity of the rips. Some large boulders (> 1 meter) were pulled to the surface and some deep holes were opened. This treatment did not loosen the entire soil; approximately 1.5 m between the rips remained compacted and unaffected by ripping.

Tree Planting

Trees were planted on April 1-2 1991, less than one week after installation of the grading treatments. Five species of trees were planted: white pine, loblolly pine, yellow-poplar, sweetgum, and sycamore. Approximately 40 of each pine species and 20 of each hardwood were planted in each plot on a 3 m x 3 m (10 ft x 10 ft) spacing. Two rows of each hardwood species and four rows of each pine species were planted. All species were 1-year-old seedlings except white pine which were 2-years-old. Trees in the ripped plots were planted in or very near the rip. After the fifth growing season, tree heights were measured and survival was determined.

Ground Cover Establishment

On April 16, two weeks after tree planting, a "tree-compatible" ground cover (Table 1) was established by hydroseeding. After the first and fifth growing seasons, three 30 m (100 ft) transects were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. At 0.6 m (2 ft) intervals along the transect, a 2.5 cm sighting tube was used to assess ground cover. If more than half the area observed through the tube consisted of bare soil, the point was tallied as such. If more than half the area was vegetated, the vegetation was tallied as grass or legume. This was done at 150 points per plot.

Erosion Measurements

Soil movement from the slope and deposition at the toe of the slope were monitored by measuring the changes in the distance between the soil surface and the top of metal rods installed in each plot. Three rows of metal rods were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. Ten rods were installed in each row, 3 m (10 ft) apart from each other. The above-mentioned vegetation transect was conducted along these rows of rods. A row of measurement rods was also placed at the toe of each plot on the level area. Rods were measured in October 1991, and October 1993, after the first and third growing season.

Results

The study was conceived with the goal of quantifying the amount of erosion and the response of herbaceous and woody vegetation to rough grading on a minesoil with desirable chemical properties for tree growth. Unfortunately, the ripped treatment did not accurately imitate rough grading because the area between rips was still compacted and the area within the rip was rougher than desired. The objective of rough grading is to leave an uncompacted surface that is similar to the surface of natural forest land with respect to undulations of the surface and the presence of rocks and boulders on the ground.

The ripped treatment in this study represented what many people would consider to be a worst-case scenario. If rough grading were likely to increase erosion, then deep ripping directly up and down a steep slope would surely represent a worst case opportunity for erosion to occur. Although the authors believe oxidized (brown) sandstone spoil is the best medium for tree growth in the southern Appalachians (Burger and Torbert 1990), and oxidized sandstone existed at this mining site, it was not possible to locate experimental plots where oxidized sandstone was placed at the surface. Unlike most coal operators in the southern Appalachians, Martiki's spoil handling is mostly done with a dragline. As such, the spoil that exists closest to the surface (oxidized sandstone) is placed immediately at the bottom of the adjacent, previously mined pit. In this situation, the best overburden for trees is buried about 20 m below the surface, and the spoil that exists immediately above the last coal seam will almost always end up on the final surface. For operations such as this, where the desired overburden material for forest productivity is not

economically available, a research challenge exists to develop alternative reforestation strategies. The hardwood species used in this experiment were selected to evaluate their performance on near-neutral pH minesoils.

Ground Cover Establishment

All plots had a southerly aspect, which resulted in high surface temperatures on the dark gray spoil during the summer in the first year. The site received no rainfall from July to September in the first year, and rainfall in June occurred as short thunderstorms. As a result, ground cover was very sparse during the first year. Average ground cover after the first year was only 44% and unaffected by grading treatment. After five years, average ground cover increased to 86% and was still unaffected by treatment (Table 2). Most of the ground cover during the first three years was provided by weeping lovegrass (*Eragrostis curvula*), a heat-tolerant species. On some of the moderate and intensively graded plots, weeping lovegrass was almost the only species at the end of the first growing season. Although it is generally considered to be an acid-tolerant species (Vogel 1981) it survived very well on this dark, droughty, alkaline spoil.

Average legume cover was only 12% after the first year and 61% after three years. Birdsfoot trefoil (*Lotus corniculatus*) was the predominant legume species during the first three years, but crownvetch (*Coronilla varia*) was the most common after the fifth year. For the most part, ground cover on the moderately and intensively graded treatments was uniformly distributed across the plot. On ripped plots, however, values in Table 2 are a weighted average of the relatively sparse vegetation that existed in the area between rips, and the relatively vigorous vegetation that existed within the loose soil of the rips. Within a 1-meter band up the rip, ground cover was 100%.

Minesoil erosion

Compaction on intensively graded plots increased surface runoff. During a thunderstorm in June of the first year, surface runoff was observed flowing off the slope at the base of the intensively graded plots. On the ripped plots, there was overland flow occurring on the compacted soil between individual rips, but within the rips and the soil immediately adjacent to the rip, water was absorbed into the soil and no overland flow occurred. No water flowed from the rips at the bottom of the slope. Rips did not develop into gullies during the course of this study. The surface roughness created by ripping diminished as soil next to the rip moved into the rip and collected.

Erosion was quantified by two approaches: 1) as the average depth of spoil lost from the 30 erosion rods on each plot, and 2) by the average deposition at the erosion rods at the base of the plot (Table 3).

After the first growing season, erosion, based on measurements from erosion rods in the treatment plots, was 18 times greater in the intensively graded treatment than in the ripped treatment, and almost twice as high as the moderate-graded treatment. Variability among treatment replicates was so high that these differences were not statistically different, based on an analysis of variance and a probability level of 0.1.

Erosion results from third year measurements are confusing and probably unreliable. They indicate that no erosion occurred during the course of the study and that soil accumulated on the slope since year one. Measurements of the rods indicate a net deposition of approximately 0.4 cm on the slope in the ripped and moderate graded plots and no deposition or erosion from the intensively graded plots. Perhaps some loosening or swelling of the soil occurred as a result of disintegration of rock fragments or freezing in the winter.

Erosion appraisal based on a

measurement of deposition at the base of the slope seems to be a more meaningful assessment, although there are still some unexplainable effects between the first and third years. If soil freezing and expansion confounded results on the slope, it would also affect results at the base of the slope. After the first growing season, deposition at the base of the intensively graded plots was about 130% greater than the ripped treatment, and almost 600% greater than the moderately graded treatment. After three years, deposition at the base of the intensively graded plots was about 20% greater than the ripped treatment, and 118% greater than the moderately graded treatment.

Our method of measuring erosion does not provide an opportunity to calculate the Mg ha^{-1} of soil movement from the slope with any definitive level of confidence. Results are still valid however for accomplishing the fundamental purpose of this study: to compare the relative advantage or disadvantage of intensive grading to other treatments which leave the surface in a looser condition. It is reasonable to conclude that intensive grading did not prevent or decrease the amount of erosion compared to the treatments with looser soil. It's obvious that the intensively graded treatment had as much or more erosion than the moderate or ripped treatments. These results should help dispel the idea that intensive grading is beneficial for reducing erosion.

Tree survival and growth

The study included two species of pines (white and loblolly) and three hardwoods (sycamore, sweetgum, and yellow-poplar). It was known beforehand that the pH would be undesirable for pine growth, and thus the hardwood species were included. They were selected because of their reported ability to tolerate neutral-pH to slightly alkaline soils (Vogel 1981).

As anticipated, the pine species suffered on this minesoil (Table 4). Only 3% of the white pines survived to the fifth year. Almost all of the loblolly pines appeared dead within two months of planting, but by age five, 29% were still alive. The surviving loblolly pines were healthier than white pines, but still not vigorous. Foliage on loblolly pines was yellow, and some trees displayed reddish coloration at the tips of needles suggesting high soluble salt concentrations. The overall poor general health of these trees did not provide a good opportunity to evaluate the effect of these grading treatments on pine growth. Nonetheless, the height of loblolly pines was significantly lower on the intensively graded treatment than the moderate graded and ripped treatments (64, 120, and 99 cm, respectively).

Sycamore performed better in this study than any other species, and because it was relatively tolerant of the minesoil chemical conditions, it provides the best demonstration of compaction effects on survival and growth. In the ripped and moderate graded treatments, sycamore survival averaged 70%, but in the intensively graded treatment, survival was only 50%. Growth followed the compaction gradient created by treatment with the best growth occurring on the ripped treatment. Compared to the intensively graded treatment, average height was about 34% greater in the moderate treatment, and 74% greater in the ripped treatment.

Survival of sweetgum and yellow-poplar was significantly greater in the ripped versus intensively graded treatment. Only 3% of yellow-poplar survived in the intensively graded plots whereas almost 70% survived in the ripped plots. Growth of yellow-poplar was improved about 78% by ripping, but even in the ripped treatment, growth was not good for yellow-poplar or sweetgum. Overall poor growth was attributed to chemical properties of the minesoil. Even though these species are tolerant of a high pH, they would grow better in minesoils with a pH more typical of natural forest soils.

Conclusions

The study was established to compare the traditional intensive grading treatment with a less intensive "rough grading" treatment with respect to erosion, ground cover development, and tree performance. The experiment did not include a treatment that fairly represented rough grading conditions. The ripped treatment was an ameliorative treatment that mimicked rough grading to some extent. Ripping did not loosen soil between the rips, and the loose soil in and immediately adjacent to the rip was much rougher than would result from rough grading. The ripping process pulled some boulders (more than one meter in diameter) to the surface, creating huge depressions and open chasms that could be hazardous to people walking on the site.

Even though this study did not provide the opportunity to quantify the beneficial effect of a rough-graded oxidized sandstone, it is useful for concluding that the intensively graded treatment, which represents the standard operating practice for most coal operators in the Appalachians, did not provide any improvements in erosion control, ground cover establishment or tree survival and growth. All measures of performance were lowest on the intensively graded treatment. In some respects, the ripping treatment provides the opportunity to assess what many would consider a worst-case scenario: ripping a steep slope (where erosion potential was high) with rips oriented directly up and down the slope. The fact that ripping did not result in gullies or any observable increase in erosion provides evidence that the presence of loose soil does not necessarily lead to increased erosion.

Other researchers have found ripping to be beneficial to improving tree rooting and growth, and have recommended ripping as a standard practice where trees are planted on minesoils (Josiah and Philo 1985, Berry 1985). Although ripping can ameliorate compacted soils, the wiser approach would be to avoid the compaction in the first place. Ripping is an expensive operation which, if necessary to achieve decent tree survival and growth, could discourage operators from selecting forestry as a post-mining land use. Furthermore, ripping can create hazards by uplifting large boulders and creating holes that could be dangerous for anyone walking on the site.

We believe all aspects of reclamation, including final surface grading, should be land-use specific. In order for operators to satisfactorially reclaim surface-mined forest land to a level of productivity at least as high as prior to mining (as required by SMCRA) and to reduce erosion caused by surface runoff, operators should reduce the intensity of bulldozer activity when preparing the final soil surface. Reduced grading will not only decrease the operator's reclamation costs, but it will result in a looser, more productive soil which improves the success of tree planting, long term growth, and environmental protection.

CITATIONS

Andrews, J.A. 1992. Soil Productivity Model to Assess Forest Site Quality of Reclaimed Surface Mines. M.S. Thesis, College of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg VA.

Berry, C.R. 1985. Subsoiling and sewage sludge aid loblolly pine establishment on adverse sites. Reclam Reveg Res. 3:301-311.

Burger, J.A. and J.L. Torbert. 1990. Restoring forests on surface-mined land. Virginia Coop. Ext. Serv. Publ. 460-123. Blacksburg VA.

Chapman, A.G. 1967. How strip-land grading effects tree survival and growth. So. Illinois Univ., School of Agric. Publ. 29.

Glover, F., M. Augustine, and M. Clar. 1978. Grading and shaping for erosion control

and rapid vegetative establishment in humid regions. pp 271-284. In F.W. Schaller and P. Sutton (eds) Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Madison WI.

Josiah, S.J., and G. Philo. 1985. Minesoil construction and ripping affects long term black walnut growth. pp 209-221. In C.Kolar (ed) Proc. Fifth Better Reclamation with Trees Conference. June 5-7 1985. So. Illinois Univ. Carbondale IL.

Larsen, M.M., and J.P. Vimmerstedt. 1983. Evaluation of 30-year-old plantations on stripmined land in east central Ohio. Ohio Agric. Res. and Dev. Center. Res. Bull. 1149. Ohio State University, Wooster OH.

Limstrom, G.A. 1952. Effects of grading strip-mined lands on the early survival and growth of planted trees. USDA For. Serv. Tech. Pap. NC-130.

Merz, R.W., and R.F. Finn. 1951. Differences in infiltration rates on graded and ungraded strip-mine lands. USDA For. Serv. Central States Exp. Sta. Note 65.

Torbert, J.L, and J.A. Burger. 1990. Tree survival and growth on graded and ungraded minesoil. Tree Planters Notes. 41(2):3-5.

Torbert, J.L., J.A. Burger, and J.E. Johnson. 1994. Commercial forestry as a post-mining land-use. Virginia Cooperative Extension Serv. Pub. No. 460-136. Blacksburg VA.

Vogel, W.G. 1981. A guide for revegetationg coal minesoils in the eastern United States. USDA Forest Service Gen. Tech. Rep. NE-68.

Table 1. Ground cover species and seeding rates used in experiment.

Species	Application Rate (kg ha^{-1})
Winter rye (*Secale cereale*)	10
Perennial ryegrass (*Lolium perenne*)	5
Orchard grass (*Dactylis glomerata*)	5
Weeping lovegrass (*Eragrostis curvula*)	3
Redtop (*Agrostis gigantea*)	3
Kobe lespedeza (*Lespedeza striata* var Kobe)	5
Appalow lespedeza (*Lespedeza cuneata* var Appalow)	5
Birdsfoot trefoil (*Lotus corniculatus*)	5
Ladino clover (*Trifolium repens*)	3
Crownvetch (*Coronilla varia*)	1

Table 2. Ground cover (%) after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	Total Cover (%)		Legume Cover (%)	
	average	range	average	range
Moderate	90	71-100	68	42-92
Intensive	85	62-97	61	33-81
Ripped	83	68-95	54	36-82

Table 3. Average soil loss and deposition after the first and third growing seasons on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	Soil Loss from Slope (cm)		Soil Deposition at Base (cm)	
	Year 1	Year 3	Year 1	Year 3
Moderate	.44	-.39	0.50 b	0.85
Intensive	.72	0.0	3.48 a	2.21
Ripped	.04	-.38	1.51 ab	1.84

Values within a column followed by different letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.

Table 4. Survival and height of five tree species after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Tree Species	Ripped		Moderately Graded		Intensively Graded	
	Survival - % -	Height - cm -	Survival - % -	Height - cm -	Survival - % -	Height - cm -
White pine	2	42	7	51	0	--
Loblolly pine	43	99 ab	32	120 a	15	64 b
Sweetgum	74 c	61	41 b	83	39 b	52
Yellow-poplar	69 a	79 ab	38 b	99 a	3 c	44 b
Sycamore	77 a	142 a	63 ab	109 ab	50 b	82 b

Values for survival and height within a species/grading treatment combination followed by different letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.