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

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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

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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

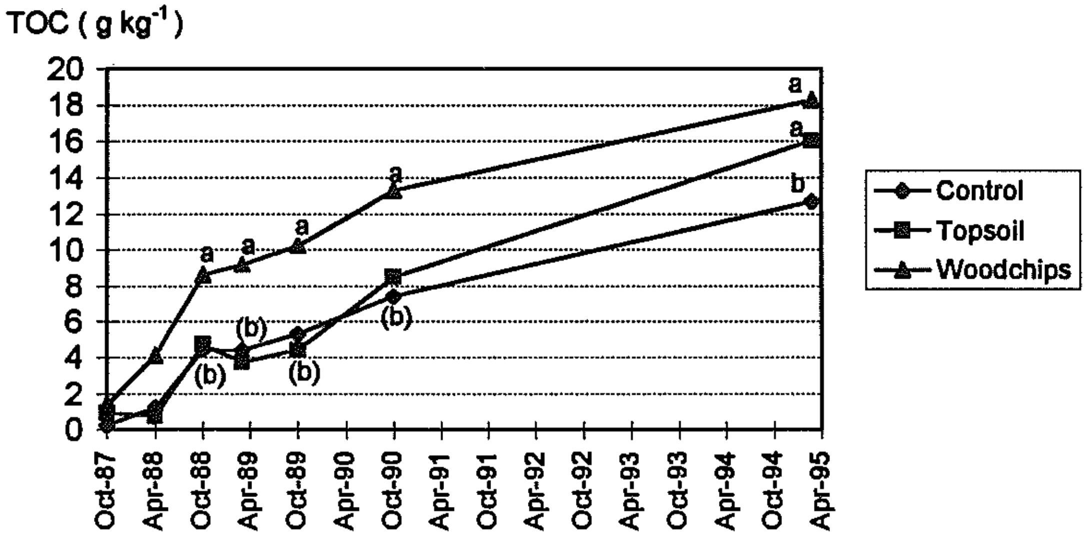

Figure 1. Effect of organic amendment on TOC accumulation in an Appalachian minesoil. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

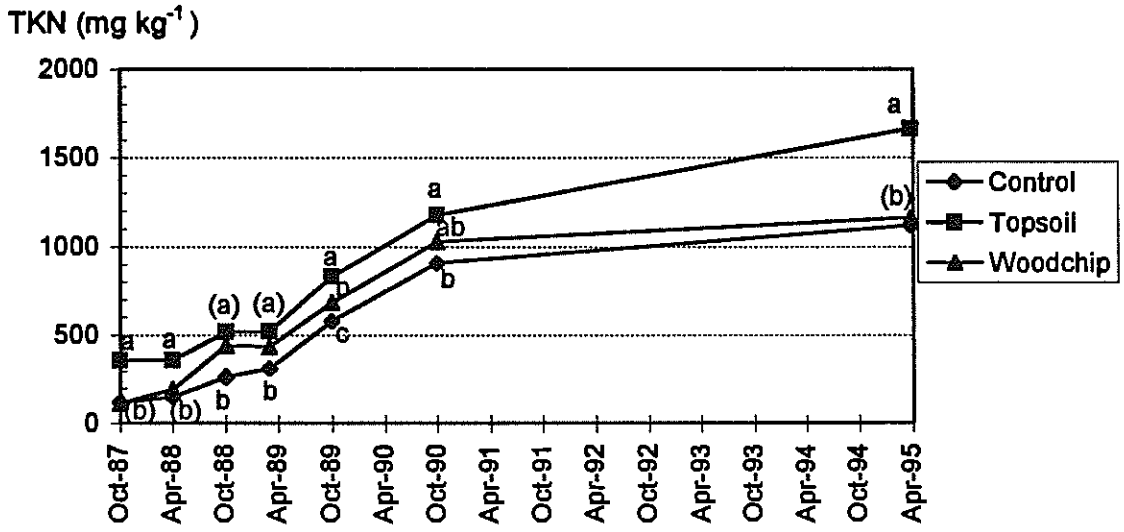

Figure 2. Effect of organic amendment on Total Kjeldahl N (TKN) in an Appalachian minesoil. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

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.

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

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.

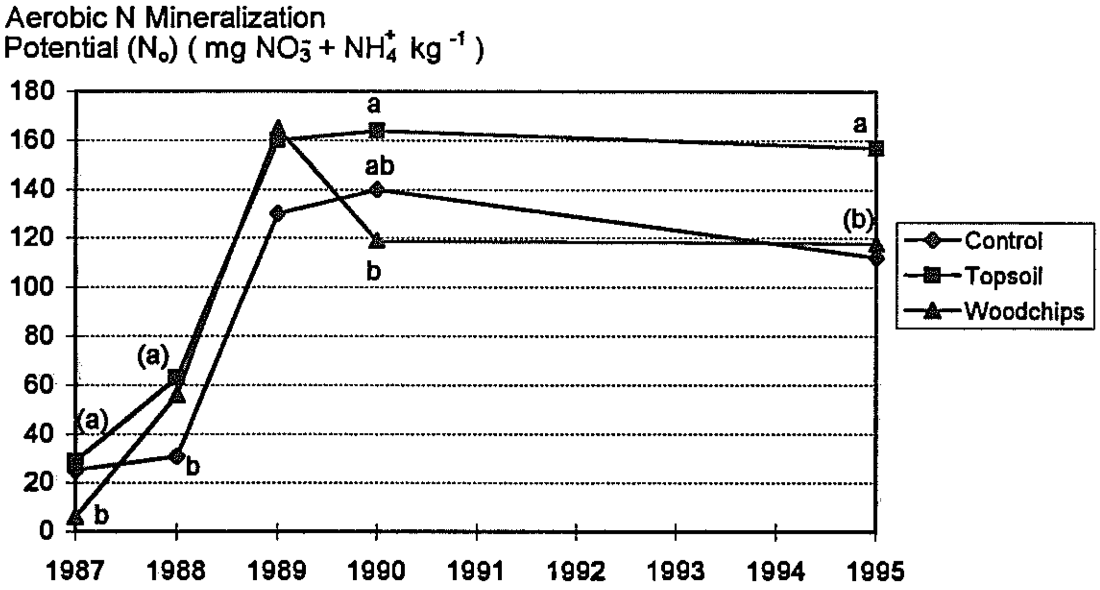

Figure 3. Effect of organic amendments on the N mineralization potential (N_o) of an Appalachian minesoil. A letter in () applies to the two closest data points. For each date, different letters represent statistical differences at the $\alpha = 0.05$ level.

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

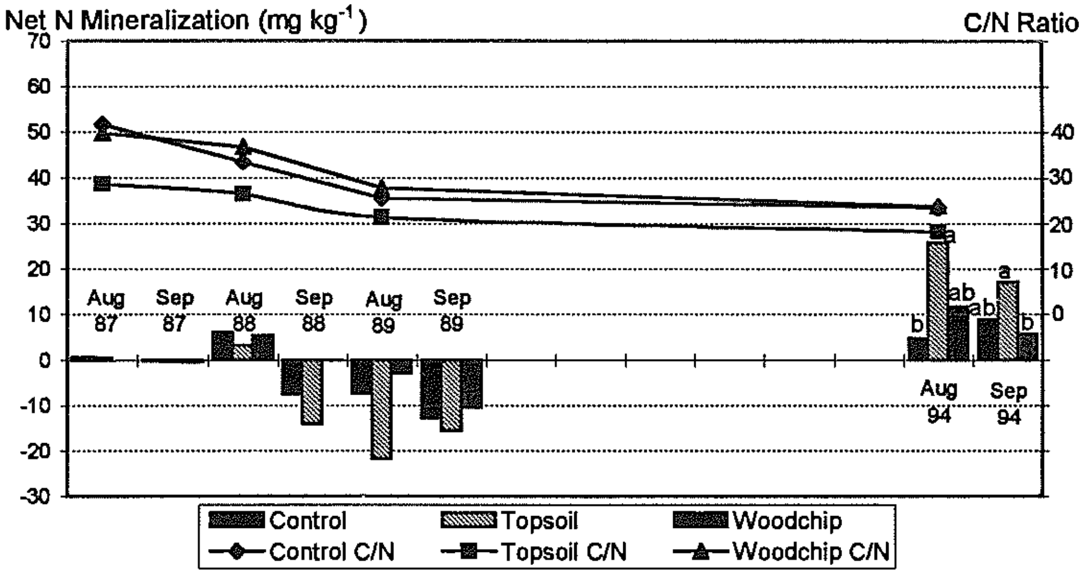

Figure 4. Effect of organic amendments on net N mineralization and C/N ratio in an Appalachian minesoil. Statistical means separation was not performed for mineralization data from the first three years or for the C/N ratio data. For each date, different letters represent statistical differences at the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

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