GROUND COVER AND TREE GROWTH ON CALCAREOUS MINESOILS: GREATER INFLUENCE OF SOIL SURFACE THAN NITROGEN RATE OR SEED MIX[1]

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Abstract: Growth of ground cover and trees was evaluated for five growing seasons on calcareous coal minesoil surfaces (standard graded topsoil, graded and ripped topsoil, graded gray cast overburden) in southeastern Ohio. Soil surface plots were seeded in September 1987 with either a standard herbaceous seed mix [orchardgrass (Dactylis glomerata L.), timothy (Phleum pratense L.), perennial ryegrass (Lolium perenne L.), Kentucky bluegrass (Poa pratensis L.), Ranger alfalfa (Medicago sativa L.), Mammoth red clover (Trifolium pratense L.), Empire birdsfoot trefoil (Lotus corniculatus L.), and wheat (Triticum aestivum L.)], or a modified mix using no alfalfa and half the rate of orchardgrass. Nitrogen (45, 90, or 135 kg ha/N) was applied as ammonium nitrate in September 1987 and April 1989. White ash (Fraxinus americana L.), silver maple (Acer saccharinum L.), northern red oak (Quercus rubra L.), and eastern white pine (Pinus strobus L.) were planted in spring 1989 into 0.8 m-wide strips sprayed with glyphosate herbicide at 2.24 kg/ha in October 1988. Sethoxydim was applied at 0.54 kg/ha in June 1989 to control dense grass cover. Total herbaceous canopy cover and total aboveground live biomass were greater on standard topsoil than on gray cast overburden in 1989 and 1993, but the reverse was true in 1992. Legumes (canopy cover, aboveground live biomass, or fraction of total biomass) were generally more abundant on cast overburden than on the two topsoil surfaces until 1993. Total cover (84%) and total biomass (239 g/0.5 m^2) were highest in July 1989, following the last application of nitrogen fertilizer in April 1989. Total cover ranged from 44% to 56%, and total biomass ranged from 102 to 162 g/0.5 m^2 from 1990 to 1993. Total cover and total biomass were lower at the lowest nitrogen rate in 1989 only. Type of herbaceous seed mix did not affect growth of ground cover or trees. Overall tree survival was 82.0% the first year but declined to 40.6% after 5 yr. Survival varied significantly among all tree species (3.5% for pine, 22.2% for oak, 38.5% for maple, 98.1% for ash). White ash was taller on ripped topsoil (111 cm) than on cast overburden (94 cm). Silver maple survived better on standard topsoil (51.5%) and ripped topsoil (42.9%) than on cast overburden (21.0%). Red oak also survived better on both topsoil surfaces (33.4% or 23.9%) than on cast overburden (9.4%). Maple (43.8% versus 32.7%) and oak (33.6% versus 20.5%) survived better at the intermediate than at the low nitrogen rate. Survival was not reduced by the high nitrogen rate. The use of herbicides to control ground cover around the trees combined with above average rainfall during the one year in which nitrogen fertilizer increased ground cover probably explains the absence of detrimental effects on tree survival at the higher nitrogen rates.

Additional key words: standard graded topsoil, ripped topsoil, graded cast overburden, legume cover, legume biomass.

Introduction

Herbaceous ground cover competes with tree seedlings for water, nutrients, and light, and may also produce allelopathic chemicals that inhibit tree seedling growth. For these reasons, tree seedling survival and growth may be expected to increase with decreasing density and competitiveness of ground cover. Because nitrogen availability limits growth of ground cover on new minesoils, reducing the rate of nitrogen fertilizer may decrease ground cover density and increase tree survival and growth. Herbaceous seed mixes used in

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reclamation often contain a variety of grass and legume species with differing abilities to compete with trees. We believed that Ranger alfalfa and orchardgrass were the more competitive species in the standard seed mix on the Muskingum Mine and that a less competitive mix could be formulated by omitting alfalfa and decreasing the rate of orchardgrass.

This paper presents 5-yr results of the effects of soil surface, ground cover seed mix, and nitrogen fertilizer rate on yield of ground cover and trees. The study was part of a project testing various cultural practices to enhance tree survival and growth on calcareous minesoils.

Methods

The study used a split-split-split plot design testing three soil surfaces (standard topsoil, ripped topsoil, gray cast overburden), two herbaceous seed mixes (standard mix or modified mix), three nitrogen fertilizer rates (45, 90, or 135 kg/ha N applied on two occasions), and four tree species, with six replications. The study area is on Central Ohio Coal Co.'s Muskingum Mine, 5 km south of Cumberland in Noble County, OH. 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. Reconstructed soil surfaces consisted of graded gray cast overburden without topsoil, graded cast overburden with 30 cm of replaced topsoil (standard topsoil), and a similarly constructed topsoil surface that was ripped to 30-cm depth after topsoil grading and then disked (ripped topsoil). Four replications were on a gently sloping (2% to 10% slope) area facing northeast, and two were in a steep valley (29% slope) facing southwest. Main soil surface plots measured 21.9 by 40.2 m in four replications and 14.6 by 40.2 m in two replications.

Topsoil has 77% soil-sized (<2 mm) particles, clay loam texture, pH of 6.9, and 27.4 kg/ha Bray 1-extractable P. Ammonium acetate-extractable K was 245 kg/ha, Ca was 5,967 kg/ha, and Mg was 652 kg/ha. Gray cast overburden has 50% soil-sized particles, loam texture, pH of 7.3, and 7.3 kg/ha Bray 1-extractable P. Ammonium acetate-extractable K was 407 kg/ha, Ca was 12,443 kg/ha, and Mg was 1,558 kg/ha. Electrical conductivity (1:2 soil-water mix) of fresh gray cast overburden was 4.08 dS/m, indicating high soluble salts. Conductivity decreased to 1.15 dS/m after 5 yr of weathering.

Herbaceous ground covers were seeded in September 1987. The standard seed mix contained the following species and seeding rates (kg/ha): orchardgrass (13.4), timothy (11.2), perennial ryegrass (9.0), Kentucky bluegrass (5.6), Ranger alfalfa (5.6), Mammoth red clover (5.6), Empire birdsfoot trefoil (5.6), and wheat (1.3 hL/ha). The modified seed mix differed by containing no alfalfa and a lower rate (6.7 kg/ha) of orchardgrass. Plots were mulched with hay after seeding. Seed mix subplots measured 21.9 by 20.1 m in four replications and 14.6 by 20.1 m in two replications.

Nitrogen fertilizer (45, 90, or 135 kg/ha N) was hand broadcast using ammonium nitrate in September 1987 and April 1989. Fertilizer sub-subplots measured 7.3 by 20.1 m in four replications and 4.9 by 20.1 m in two replications. To promote uniform fertilizer distribution, each sub-subplot was divided into 2.4 by 20.1 m strips for fertilizer application. All plots had received 448 kg/ha of 8-32-16 (N-P-K) fertilizer in August 1987.

Each fertilizer sub-subplot was planted with two tree rows with half of each row assigned to a different tree species. Tree spacing was 2.4 m between rows in a sub-subplot and 1.2 m within rows. Each tree species sub-sub-subplot contained seven or eight trees and was the experimental unit for survival and height measurements. About 840 trees each of white ash, silver maple, northern red oak, and white pine were hand-planted in March-April 1989. Hardwood stock was 1 yr old and obtained from the Zanesville, OH state nursery. White pine stock was 2 yr old from the Vallonia, IN state nursery. Each species was graded and pruned to a relatively uniform stem caliper and height before planting.

In October 1988 glyphosate herbicide was applied in 0.8 m-wide strips at 2.24 kg/ha to kill vegetation in the tree rows before tree planting in spring 1989. Sethoxydim was applied at 0.54 kg/ha in June 1989 to control dense grass cover resulting from the nitrogen fertilization.

Tree survival was measured in June and October 1989 and August 1990. Tree survival and total height (nearest cm) were measured in July 1991 and August 1993.

Herbaceous percent cover and aboveground dry biomass were measured in 0.5 m^2 quadrats in June or July from 1989 through 1993. On each sampling date one sample was located systematically in each fertilizer treatment sub-subplot (total of 108 samples per date). Samples were taken between the tree rows in areas that had not been sprayed with herbicides. Previously sampled locations were avoided during successive years of sampling. Total canopy cover (projected onto the ground), mulch cover, rock cover, and bare soil were estimated as percentages to sum to 100 for each sample. Beginning in 1990, percent canopy cover due to legumes only was also estimated. In each sample, the presence or absence of alfalfa was recorded, and other legumes, grasses, or weedy plants were noted. Vegetation was clipped to 1 cm height, separated into nonlegume and legume components beginning in 1991, dried at 60 °C for at least 72 h, and weighed.

Data were subjected to analysis of variance using the ANOVA or GLM procedures of Statistical Analysis Systems software (SAS Institute Inc. 1987). Survival and canopy cover percentages were transformed with the arcsine-square root function before analysis. When analysis of variance showed significant ($p=0.05$) effects, differences among means were tested at $p=0.05$ using Duncan's multiple range test.

Results

Herbaceous Cover and Aboveground Dry Biomass

There were no long-term relationships relating total canopy cover and total aboveground biomass to soil surface treatments. Total cover and total biomass (between herbicide-treated tree rows) were higher on standard topsoil than on gray cast overburden in 1989, were lower on standard topsoil than on the other two soil surfaces in 1992, and were higher on standard topsoil than on cast overburden in 1993 (tables 1 and 2).

The sum of total canopy cover plus dead mulch not under the canopy provides an indication of protection from soil erosion. In 1993 total cover plus mulch averaged 89% on cast overburden (range 45% to 100%), 94% on ripped topsoil (range 62% to 100%), and 96% on standard topsoil (range 75% to 100%).

The various measures of legume productivity (legume canopy cover, legume aboveground biomass, legume fraction of total biomass) were usually greater on cast overburden than on the two topsoil surfaces until 1993 (tables 1-3). Legumes increased on all soil surfaces from 1991 to 1992. There were additional increases on the two topsoils but not on cast overburden in 1993, with the result that legumes were no longer more abundant on cast overburden. Over the 5-yr period, birdsfoot trefoil and red clover were generally the most abundant legumes on the topsoil surfaces, and volunteer yellow sweetclover (Melilotus officinalis Lam.) was dominant on gray cast overburden.

Total canopy cover and total aboveground biomass were highest in July 1989 following the last application of nitrogen fertilizer in April 1989. Nitrogen fertilizer rate affected total cover and total biomass only in 1989, when cover and biomass were lower at the lowest nitrogen rate (tables 1-2). The response of total cover and total biomass to nitrogen fertilization was, therefore, very short-lived, possibly due to loss of excess nitrogen by leaching and/or volatilization.

Legume canopy cover was greater at the 45- than at the 135-kg/ha nitrogen rate in 1990 (table 1). Legume fraction of total biomass was greater for the lowest nitrogen rate in 1991 (table 3). These effects did not persist but are consistent with the idea that high rates of nitrogen fertilization favor nonlegumes over

Table 1. Total canopy cover and legume canopy cover as influenced by soil surface, seed mix, and nitrogen fertilization treatments.[1]

	Total live canopy cover, %					Legume live canopy cover, %			
	July 1989	July 1990	June 1991	July 1992	July 1993	July 1990	June 1991	July 1992	July 1993
Soil Surface:									
Standard topsoil...........	92 a	44	44	41 b	62	2 b	2 b	14 b	38
Ripped topsoil...............	84 ab	50	45	51 a	57	9 ab	4 ab	22 b	32
Gray cast overburden....	76 b	49	43	51 a	50	19 a	10 a	35 a	29
Seed mix:									
Standard.......................	86	46	43	49	56	8	5	25	32
Modified.......................	83	50	45	46	56	12	6	22	34
Nitrogen Rate:[2]									
45 kg/ha N...................	73 b	48	45	50	55	15 a	7	27	29
90 kg/ha N...................	88 a	50	44	48	59	9 ab	5	25	37
135 kg/ha N..................	92 a	46	43	46	55	6 b	4	20	33

[1]Within a column and factor, means followed by no letters or similar letters are not significantly different at p = 0.05 using Duncan's multiple range test for soil surface and nitrogen rate, and LSD test for seed mix.

[2]Applied in September 1987 and April 1989.

Table 2. Total aboveground live biomass and legume aboveground live biomass as influenced by soil surface, seed mix, and nitrogen fertilization treatments.[1]

	Total aboveground live biomass, g/0.5m²					Legume live biomass, g/0.5m²		
	July 1989	July 1990	June 1991	July 1992	July 1993	June 1991	July 1992	July 1993
Soil surface								
Standard topsoil............	277.8 a	92.4	107.5	119.8 b	188.9 a	3.9 b	14.2 b	84.8
Ripped topsoil...............	240.6 ab	108.5	101.5	152.7 a	156.8 ab	3.8 b	36.9 b	62.0
Gray cast overburden....	199.1 b	118.0	95.3	149.4 a	139.7 b	18.2 a	79.9 a	55.9
Seed mix:								
Standard.......................	239.9	105.7	98.5	133.8	158.5	9.9	37.2	64.7
Modified.......................	238.3	106.9	104.4	147.5	165.1	7.4	50.1	70.5
Nitrogen rate:[2]								
45 kg/ha N....................	177.0 b	112.0	102.7	152.7	162.2	13.0	55.4	64.6
90 kg/ha N....................	260.5 a	105.3	100.8	131.6	162.8	7.5	37.0	70.1
135 kg/ha N..................	280.0 a	101.6	100.8	137.5	160.3	5.4	38.4	68.0

[1]Within a column and factor, means followed by no letters or similar letters are not significantly different at $p = 0.05$ using Duncan's multiple range test for soil surface and nitrogen rate, and LSD test for seed mix.

[2]Applied in September 1987 and April 1989.

Table 3. Legume aboveground biomass as a percentage of total aboveground biomass as influenced by soil surface, seed mix, and nitrogen fertilization treatments.[1]

	June 1991	July 1992	July 1993
Soil surface			
Standard topsoil....................	3.0 b	10.1 b	39.2
Ripped topsoil.......................	3.8 b	19.0 b	33.4
Gray cast overburden...........	16.5 a	44.8 a	37.4
Seed mix:			
Standard..............................	8.7	23.3	35.4
Modified..............................	6.9	26.0	37.9
Nitrogen rate:[2]			
45 kg/ha N............................	13.0 a	28.1	34.7
90 kg/ha N............................	6.5 b	24.3	37.9
135 kg/ha N..........................	3.9 b	21.5	37.4

[1]Within a column and factor, means followed by no letters or similar letters are not significantly different at $p = 0.05$ using Duncan's multiple range test for soil surface and nitrogen rate, and LSD test for seed mix.

[2]Applied in September 1987 and April 1989.

legumes.

Type of herbaceous seed mix did not affect total canopy cover, legume canopy cover, total aboveground biomass, legume aboveground biomass, or legume fraction of total biomass on any sampling date (tables 1-3). From 1989 through 1993 alfalfa was present in 15.9% (43 of 270) of samples on subplots seeded with the standard mix and in 4.4% (12 of 270) of samples on subplots seeded with the modified mix. Omitting alfalfa from the modified seed mix, therefore, reduced but did not eliminate the presence of alfalfa in the ground cover. For the standard seed mix, alfalfa was present in 4.4% (4 of 90) of samples on standard topsoil, 5.6% (5 of 90) of samples on ripped topsoil, and 37.8% (34 of 90) of samples on cast overburden. For the modified seed mix, alfalfa was present in 1.1% (1 of 90) of samples on standard topsoil, 0.0% (0 of 90) samples on ripped topsoil, and 12.2% (11 of 90) samples on cast overburden. Sparse occurrence of alfalfa on standard or ripped topsoil indicates that alfalfa is not likely to be an important competitor with trees on these soils. From 1991 through 1993 orchardgrass was found in 54.3% (88 of 162) of samples on standard mix subplots and in 48.8% (79 of 162) of samples on modified mix subplots. Reducing the rate of orchardgrass in the modified seed mix thus had little effect on the presence of orchardgrass, possibly because orchardgrass seed was present in the hay used for mulching the plots.

<u>Tree Survival and Growth</u>

Overall tree survival was 82.0% the first year (1989), decreased to 48.8% following a drought in the third year (1991), and was 40.6% after 5 yr (1993). Type of seed mix did not affect survival or height of any tree species. Nitrogen rate affected survival of silver maple and red oak but not height of any species.

White ash survived well (greater than 97%) on all treatments during the study. White ash was 29% taller on standard topsoil (79.1 cm) and ripped topsoil (79.8 cm) than on cast overburden (61.4 cm) in 1991. From 1991 to 1993 height increased 23.1 cm on standard topsoil, 31.6 cm on ripped topsoil, and 33.0 cm on cast overburden. By 1993 only trees on ripped topsoil (111.4 cm) were taller (18%) than those on cast overburden (94.4 cm), and trees on standard topsoil (102.2 cm) were intermediate. For the seed mix or nitrogen rate treatments, white ash height ranged from 72.4 cm to 74.8 cm in 1991 and from 101.2 cm to 104.2 cm in 1993.

Silver maple survived well on all treatments for the first two growing seasons and then declined sharply during the 1991 drought (table 4). After five growing seasons survival was greater (1) on both topsoil surfaces than on cast overburden and (2) at the intermediate than at the low nitrogen rate. Silver maple was taller on the two topsoil surfaces than on cast overburden in 1991 and 1993 (table 4). There was no increase in height from 1991 to 1993 owing primarily to deer browsing and rabbit cutting.

Red oak had lower first-year survival (table 5) than white ash or silver maple (table 4). Survival decreased substantially the second year and further the third year (table 5). After five growing seasons survival was low but was greater on both topsoil surfaces than on cast overburden. Beginning in 1990, red oak survived better at the intermediate (90 kg/ha N) than the low (45 kg/ha N) nitrogen rate. Red oak height was not affected by soil surface (table 5). Although we did not measure height at planting, we pruned the trees before planting to an initial height around 15 cm. The small height increases by 1993 reflect poor growth and

Table 4. Silver maple survival and height as influenced by soil surface, seed mix, and nitrogen fertilization treatments.[1]

	Survival, %				Total height, cm	
	1989 (yr 1)	1990 (yr 2)	1991 (yr 3)	1993 (yr 5)	1991 (yr 3)	1993 (yr 5)
Soil surface:						
Standard topsoil..................	97.6	97.6	73.1 a	51.5 a	36.6 a	35.0 a
Ripped topsoil.....................	97.6	98.3	57.8 ab	42.9 a	41.3 a	36.3 a
Gray cast overburden.........	99.3	99.3	45.3 b	21.0 b	28.5 b	27.6 b
Seed mix:						
Standard.............................	98.1	98.6	59.5	39.1	35.9	33.3
Modified.............................	98.1	98.1	57.9	37.8	35.0	33.8
Nitrogen rate:[2]						
45 kg/ha N...........................	99.0	99.3	46.5 b	32.7 b	34.4 ab	32.8
90 kg/ha N...........................	97.2	97.9	69.6 a	43.8 a	38.4 a	35.5
135 kg/ha N..........................	98.2	97.9	60.1 a	38.8 ab	33.3 b	32.1

[1]Within a column and factor, means followed by no letters or similar letters are not significantly different at p = 0.05 using Duncan's multiple-range test.

[2]Applied in September 1987 and April 1989.

Table 5. Red oak survival and height as influenced by soil surface, seed mix, and nitrogen fertilization treatments.[1]

	Survival, %				Total height, cm	
	1989 (yr 1)	1990 (yr 2)	1991 (yr 3)	1993 (yr 5)	1991 (yr 3)	1993 (yr 5)
Soil surface:						
Standard topsoil..................	79.0	55.1 a	40.8 a	33.4 a	15.4	20.4
Ripped topsoil.....................	74.4	43.3 ab	29.9 a	23.9 a	18.4	19.4
Gray cast overburden.........	70.1	28.9 b	11.9 b	9.4 b	NA	NA
Seed mix:						
Standard..............................	76.6	47.3	29.6	23.9	[3]16.6	[3]22.3
Modified.............................	72.4	37.6	25.5	20.6	18.8	20.5
Nitrogen rate:[2]						
45 kg/ha N...........................	75.4	37.2 b	20.5 b	15.6 b	[3]15.6	[3]19.7
90 kg/ha N...........................	73.8	48.8 a	33.6 a	27.2 a	17.2	21.6
135 kg/ha N.........................	74.3	41.3 ab	28.4 ab	23.8 ab	18.3	18.3

NA indicates not available because of low survival.

[1]Within a column and factor, means followed by no letters or similar letters are not significantly different at p = 0.05 using Duncan's multiple range test.

[2]Applied in September 1987 and April 1989.

[3]Means for standard topsoil and ripped topsoil.

extensive damage by rabbits.

White pine had lower first-year survival (56.0%) than any other species. Survival declined moderately in 1990 (40.0 % survival) and sharply during the 1991 drought (10.5% survival). White pine survived better on standard topsoil than on cast overburden in 1989 (69.1% on standard topsoil versus 39.6% on cast overburden) and 1990 (56.0% on standard topsoil versus 24.8% on cast overburden). After 5 yr it had failed (less than 10% survival) on all soil surfaces.

For the first 2 yr white pine survival responded strongly to slope and drainage conditions. In 1989 survival averaged 45.3% on the four gently sloping replications versus 77.3% on the two steeply sloping replications. Survival on cast overburden alone was almost four times less on the gently sloping replications (20.2%) than on the steeply sloping replications (78.6%). In 1990 survival averaged 28.8% on the four gently sloping replications versus 62.2% on the two steeply sloping replications. Survival on cast overburden alone was 6.2% on the level area versus 62.2% on the steep area. Rainfall (for the April-August growing season) was 77% above average in 1989 and 41% above average in 1990. These results indicate that excessive soil moisture or compaction, particularly on cast overburden, affected white pine survival on the level site.

Discussion and Conclusions

Effects of the experimental treatments on herbaceous ground cover development can be considered from two viewpoints. Mining regulations require a ground cover density that will control erosion, and any treatment that failed to produce the required density would not be acceptable. In contrast, treatments that result in excessively dense ground covers should be avoided if tree establishment is the goal of reclamation.

Our 5-yr results indicate that topsoil replacement is not necessary for ground cover establishment on the Muskingum Mine. There was year-to-year variation in the relative productivity of ground cover on standard topsoil and cast overburden, but ground cover on cast overburden was adequate for erosion control.

The relatively large fraction of legumes in the ground cover after 5 yr has important implications for both persistence of the ground cover and tree survival and growth. Legumes are an important source of the nitrogen capital needed for continued growth of the ground cover in a developing ecosystem (Bradshaw 1983), and some of the N fixed by legumes is available to trees in the short term. On the negative side, some legumes have allelopathic effects on tree growth. Larson and Patel (1992) reported that adding birdsfoot trefoil litter to the growing medium strongly inhibited growth of white ash seedlings in the greenhouse. Birdsfoot trefoil was a dominant species on the topsoils in this study.

Modifying the herbaceous seed mix or varying the rate of nitrogen fertilizer did not strongly affect ground cover competitiveness with trees. The differences in composition of the two seed mixes were not great enough to produce important differences in ground cover. Alfalfa's presence was reduced by using the modified mix, but this would be important only on cast overburden because alfalfa was rare on the topsoils regardless of seed mix. Further research on alternative seed mixes should use mixes that have major differences in species composition. Eliminating rather than reducing the rate of orchardgrass would be a good starting point in formulating an alternative mix. Torbert and Burger (1990) reported success in developing tree compatible ground covers in Virginia. In other studies on the Muskingum Mine we have had poor tree survival associated with dense stands of volunteer tall fescue on topsoil and volunteer sweetclover or seeded legumes on cast overburden. In this study nitrogen fertilizer affected ground cover only during the year in which fertilizer was applied.

The responses of tree survival and height to the various experimental treatments varied with tree species. Silver maple and red oak survived better on the two topsoil surfaces than on cast overburden. The same was true for white ash and silver maple height. These results indicate that this topsoil is better than this cast overburden as a tree growth medium. The pH and soluble salt levels in cast overburden are higher than most trees prefer.

Increased silver maple and red oak survival at the intermediate nitrogen rate may be related to the extensive animal damage suffered by these species. At the intermediate N rate trees may have developed larger root systems that facilitated sprouting in response to continuing rabbit cutting. Lack of a growth response to N by white ash is puzzling. This species has a high N requirement (Mitchell and Chandler 1939) and so would be expected to respond to increasing N. Two factors reduced any harmful effects of increased nitrogen supply on ground cover competitiveness with trees. We used herbicides to control ground cover in strips around the trees, and therefore our results probably do not apply to conditions where herbicides are not used. Because we had above average rainfall during the year in which ground cover varied with nitrogen rate, competition between ground cover and trees for soil moisture probably was not important.

Although early white pine survival was affected more by slope and drainage conditions than by the experimental treatments, continued decline on both the gently and the steeply sloping sites indicates that white pine is not adapted to these soils. Because of poor height growth and continuing mortality associated with animal damage, it is questionable how many of the surviving silver maple and red oak will persist. These two species would probably benefit from tree shelters. White ash is the only tree species that is definitely established after 5 yr.

In summary, trees responded more to soil surface type than to nitrogen rate or seed mix. Whether topsoil replacement is economically justified will depend on continuation of the greater tree productivity on topsoil. Information from other studies in the project that includes this study will help to answer this question.

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