INFLUENCE OF REFORESTATION RECLAMATION TREATMENTS ON NITROGEN DYNAMICS IN MINESOILS[1]

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Abstract. Reforestation of surface-mined land in the Appalachian region of the United States offers an environmentally and economically attractive reclamation alternative. However, reestablishment of productive forest ecosystems may be limited by minesoil nutrient deficiencies. Reclamation treatments which promote nutrient cycling are required to overcome these limitations. A tank lysimeter study was established to simulate field conditions for evaluation of reforestation reclamation treatments on nitrogen cycling in a minesoil from southwestern Virginia. The treatments were replacement of natural topsoil, yellow-poplar whole-tree chip amendment, and no amendment; each had 0 or 100 kg nitrogen ha^{-1} applied. Lysimeters were then seeded with grass-legume reforestation groundcover mixtures in July 1987, and one-year-old pitch x loblolly hybrid pine seedlings were planted in March 1988. Results after three growing seasons suggest that inorganic nitrogen fertilizer effects on soil, leachate, and plant nitrogen cycling dynamics are rapid but temporary. In contrast, the topsoil and wood-chip organic amendments have provided sources of organic nitrogen and carbon which should influence the nitrogen dynamics of this minesoil system in a slower, more effective and longer lasting manner.

Additional Key Words: organic amendments, southwestern Virginia, lysimeters, ecosystem restoration, *Pinus rigida* x *taeda*.

Introduction

The overall objective of most surface-mine reclamation is restoration of a stable, self-sustaining ecosystem that will minimize long-term environmental degradation and support the desired post-mining land use. Reforestation of surface-mined land in the Appalachian region of the United States is one land use that offers an environmentally and economically attractive reclamation alternative.

Restoration of productive forest ecosystems may be limited by minesoil nutrient deficiencies, particularly nitrogen (N). Mays and Bengtson (1978) reported that an inspection of revegetated surface mines in the eastern United States revealed the need for maintenance N fertilization in addition to the initial application at establishment. A lack of N in minesoils reported by others, including Czapowskyj (1973), Plass and Vogel (1973), Vogel (1981), Schoenholtz and Burger (1984), Reeder (1988), and Roberts et al. (1988), suggests that current reclamation programs do not always meet the goal of reestablishing an adequate N cycling capacity which would promote N accumulation, biomass production, and ecosystem stability.

Heavy applications of soluble fertilizers to recently exposed overburden materials are often used to overcome low N levels and to promote establishment of vegetation. However, in contrast to intact terrestrial ecosystems which have evolved stable nutrient cycling mechanisms, minesoils may not retain adequate amounts of the applied fertilizer, resulting in low use efficiency and in the potential for rapid N movement into adjacent surface water and groundwater. Stabilization of reclaimed mine sites with a desirable plant community that requires no long-term fertilizer inputs to maintain a satisfactory level of productivity is

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a major reclamation goal. The development of an active biological N cycle is necessary to realize this goal.

One of the first priorities in reestablishing N cycling in minesoil is the development of an organic-N reservoir through the establishment of an organic-matter pool. This has been accomplished by using organic amendments such as sawdust, wood residues, and sewage sludge (Moss et al., 1985, Schuman and Sedbrook 1984, Seaker and Sopper 1984). The establishment and maintenance of an organic-matter pool should provide an initial immobilization sink for fertilizer N via microbial uptake followed by slow release of inorganic N until an equilibrium between N immobilization and mineralization is reached.

Soil microbial activity is an intricate component of N cycling. Numbers and diversity of microorganisms are lower in minesoils than in most native soils (Wilson 1965, Stroo and Jencks 1982). Topsoil replacement is one means by which microbial populations can be reestablished. Furthermore, topsoil can provide a good rooting medium, improved infiltration, decreased runoff, increased vegetation species diversity, and a source of mineralizable N to the system.

Although mine operators in the Appalachian coalfields commonly stockpile and replace native topsoil as required by reclamation regulations, the value of this procedure has been questioned in steeply sloped areas with thin, infertile soils. At many sites, replacing native topsoil is time consuming and expensive. Improved mining techniques which isolate substitute overburden materials have been implemented and may provide equal or superior productivity compared with some native soils (Daniels and Amos 1985). Additional observations and quantification of the effect of topsoil additions on N dynamics would help assess the usefulness of this reclamation alternative.

Reliable guidelines for effective reforestation reclamation practices require a detailed understanding of the fundamental ecological processes occurring within the minesoil system. Assessments are not available comparing the effects of N fertilization, native topsoil replacement, and whole-tree wood-chip amendment on N cycling dynamics in Appalachian minesoils. The objective of this study was to evaluate the effects of these reclamation alternatives on selected N cycling dynamics in a minesoil from southwestern Virginia.

Materials and Methods

To simulate field conditions, 18 concrete lysimeters (2.4 by 1.2 by 0.8 m deep) were set into native soil at the Reynolds Homestead Agricultural Experiment Station in Patrick County, Virginia. The lysimeters were designed to insure drainage and leachate collection. New minesoil from sandstone and siltstone overburden strata of the Wise formation in Wise County, Virginia was weighed and placed in the lysimeters. Minesoil bulk density within each lysimeter was calculated based on lysimeter volume and minesoil weight.

The reclamation treatments were the replacement of 5 cm of native topsoil, the addition of 8 cm of yellow-poplar whole-tree chips, and no organic amendment; each had 0 or 100 kg N ha^{-1} applied as NH_4NO_3. All lysimeters also received 100 kg phosphorus (P) ha^{-1} and 60 kg potassium (K) ha^{-1}. Selected properties of these organic amendments are presented in Table 1. Prior to fertilization and seeding, organic amendments were tilled into the minesoil to a depth of approximately 25 cm. Selected properties of the minesoil after tilling are presented in Table 2.

Treatments were in place by early July 1987. At this time, a mixture of grass and legume species was broadcast over the surface of each lysimeter (Table 3).This mixture was selected for its compatability with tree establishment (Torbert et al., 1986). Ten 1-0 pitch x loblolly hybrid (<u>Pinus rigida</u> x <u>taeda</u>) pine seedlings were planted in each lysimeter in March 1988. Pitch x loblolly pine was selected because of its desirable growth habit and wood quality.

Composite minesoil samples from 20 randomly located subsamples were collected from 0-15 cm depth in each lysimeter at intervals for the duration of the study. Total Kjeldahl N and KCl-extractable NH_4+NO_3 representing total soil N and plant-available inorganic soil N pools, respectively, were analyzed. Available P was extracted with 0.5 <u>N</u> $NaHCO_3$ (pH 8.5). Available K, calcium Ca), and magnesium (Mg) were extracted with 1 <u>N</u> NH_4OAc (pH 7.0).The volume and inorganic-N (NH_4+NO_3) content of leachate draining from each lysimeter was measured after each precipitation event.

Herbaceous vegetation was sampled at the end of each growing season using two randomly located 0.10 m^2 clip-plots in each lysimeter for dry-weight yield and N content. Survival, height, and ground-line diameter of the pine seedlings were measured after each growing season. A pine stem-volume index calculated from height x $diameter^2$ was also derived.

The study was a completely randomized design with three types of organic amendment (control, topsoil, and wood chips) and two levels of fertilizer (control and 100 kg N ha^{-1}). The six possible treatment combinations were replicated three times. Analysis of variance followed by Duncan's multiple range tests for mean separations were used to compare treatment effects on response variables. Percent survival values were statisically compared following an arcsine transformation.

Results and Discussion

Total Soil N

Total soil N levels were not affected by the fertilizer treatment. However, the topsoil amendment significantly increased this N pool

Table 1. Selected properties of the organic amendments.

Amendment	pH	%C	%N	C/N	Dry wt. added	C added	N added
					kg ha^{-1}		
Topsoil[1]	5.0	3	.20	15/1	500,000	15,000	1,000
Wood Chips	-	47	.18	261/1	50,000	23,500	90

[1]Predominately A horizon of Jefferson series, loamy typic hapludult.

Table 2. Selected chemical and physical properties of the upper 15 cm of minesoil following addition of organic amendments.

Amendment	Total N	Available P	Available K	Available Ca	Available Mg	Bulk Density
	mg kg^{-1}					Mg m^{-3}
Control	565	2.7	52	654	211	1.84
Topsoil	838	3.6	73	768	234	1.88
Wood Chips	568	2.0	59	625	208	1.64

Table 3. Reforestation groundcover seed mixture.

Species	Scientific Name	Rate
		kg ha^{-1}
Foxtail millet	Setaria italica	8.4
Perennial ryegrass	Lolium perenne	8.4
Annual ryegrass	Lolium multiflorum	8.4
Redtop	Agrostis gigantea	5.1
Birdsfoot trefoil	Lotus corniculatus	8.4
Korean lespedeza	Lespedeza stipulacea	8.4
'Appalow' Sericea lespedeza	Lespedeza cuneata cv. "appalow"	16.8

throughout the course of the study (Figure 1). The decrease in total soil N which occurred with the wood-chip amendment at the start of the study was a result of decreased bulk density under this treatment and not a function of lower N concentration (Table 2). By the end of the first growing season (October 1987) the wood-chip treatment total N value was comparable to the control. These results indicated that a single fertilizer application had no effect on total N in the soil during the first three years. In contrast, topsoil replacement increased this pool and may provide a long-term source of N for ecosystem restoration.

Extractable Inorganic N

Potassium chloride-extractable inorganic N provides an index of N available for plant uptake. Fertilization significantly increased extractable inorganic N during the first three months of the study (Figure 2). This increase in extractable inorganic N was beneficial during the critical period of plant establishment when promotion of groundcover was a primary objective. Fertilization did not result in an increase in extractable inorganic N beyond this initial period.

The topsoil amendment also significantly increased extractable inorganic N levels during the initial groundcover-establishment stage (Figure 3). The lack of a wood-chip effect on extractable inorganic N suggests that immobilization of fertilizer N was not a significant process under this treatment. This may be a function of rapid fertilizer loss in leachate N or rapid plant uptake of fertilizer N.

Leachate N

High levels of available N during the initial vegetation-establishment stage of reclamation can result in degradation of off-site water quality if this N is not retained in the plant-soil system. Inorganic N levels measured in the leachate indicate that N loss totaled 17.5 and 1.9 kg N ha^{-1} for fertilizer and control, respectively, during the first growing season (Table 4). In contrast, leachate N loss during the second growing season was not affected by fertilization. The initial difference between the two fertilizer treatments illustrates the potential risk to off-site water quality when a single fertilizer application is used prior to vegetation establishment.

The quantity of inorganic N in the leachate was not significantly affected by the organic amendments. This suggests that any short-term effects of these treatments on net N mineralization were probably precluded by rapid plant uptake and by rapid initial fertilizer N leaching.

Aboveground Biomass

The development of abundant, high-quality aboveground biomass for site protection, nutrient retention, and post-mining land use is the primary concern of reclamation programs. Fertilization increased the dry-weight yield and total N of the aboveground herbaceous biomass after the first growing season (Table 5). This supports the hypothesis that fertilizer N dynamics were strongly influenced by both plant uptake and leaching during the first growing season. However, by the second growing season, fertilization effects on herbaceous biomass were absent.

The wood-chip amendment decreased dry-weight yield and total biomass N after the first and third growing seasons (Table 5). This treatment caused an initial phytotoxicity to the grass species in the revegetation mix resulting in only legume establishment during the first growing season. The topsoil amendment increased total biomass N after the first growing season, but did not differ from the control in subsequent years. The relatively stable nature of the organic carbon (C) and organic N provided by the two organic amendments may provide a long-term treatment effect on N cycling dynamics.

Tree Performance

First- and second-year pitch x loblolly hybrid pine survival were highest in the fertilized treatments (Table 6). However, stem-volume index was not significantly affected by this treatment.

After two growing seasons, pine survival and stem-volume index were highest with the wood-chip amendment (Table 6 and Figure 4). This may be directly related to the lower level of herbaceous competition and improved soil moisture relationships resulting from this treatment. Aboveground herbaceous biomass development was slowest and competitive grasses were minimal with the wood-chip amendment.

Conclusions

Early results of this long-term minesoil reclamation study suggest that inorganic N fertilizer effects on soil, leachate, and plant N cycling dynamics are rapid but temporary. In contrast, the topsoil and wood-chip organic amendments have provided sources of organic N and C which should influence the N dynamics of this minesoil system in a slower, more effective, and longer lasting manner.

The two organic amendments used in this study are often available in the southern Appalachian coalfields. If productive post-mining ecosystem restoration is a reclamation objective, then amendments which produce more stable changes in N cycling dynamics than inorganic N applications may be required.

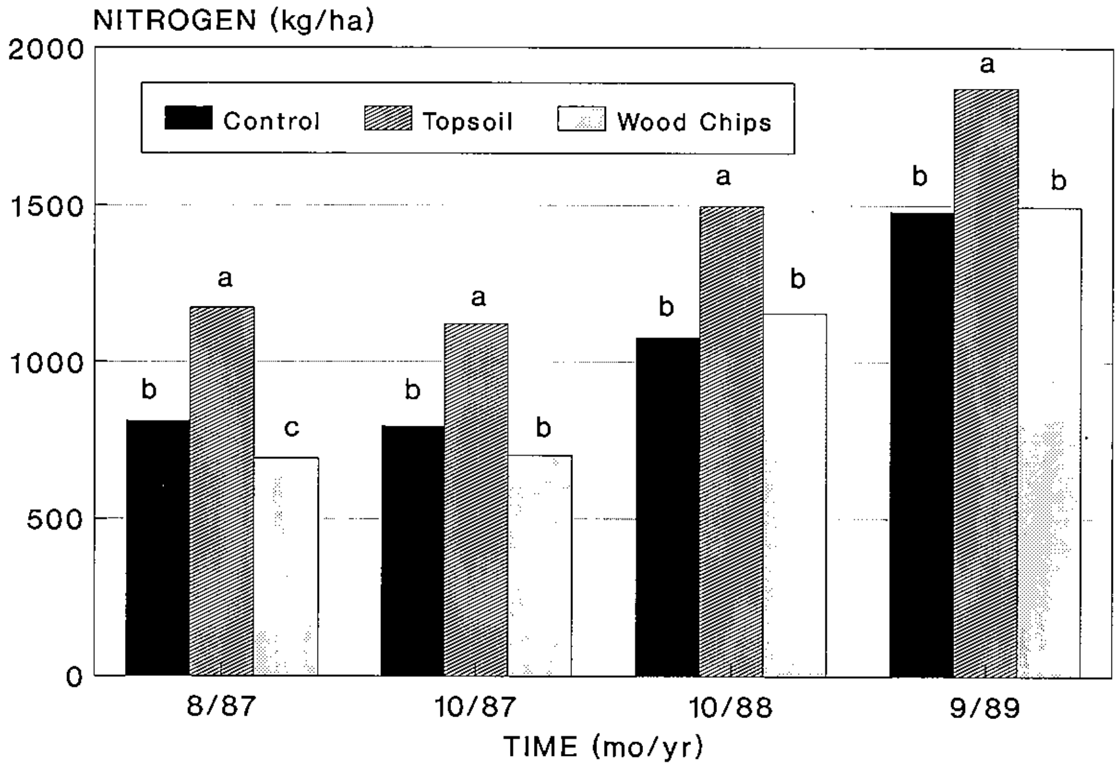

Figure 1. Effect of organic amendments on total minesoil N. For each date, bars with different letters are significantly different at the 0.05 level.

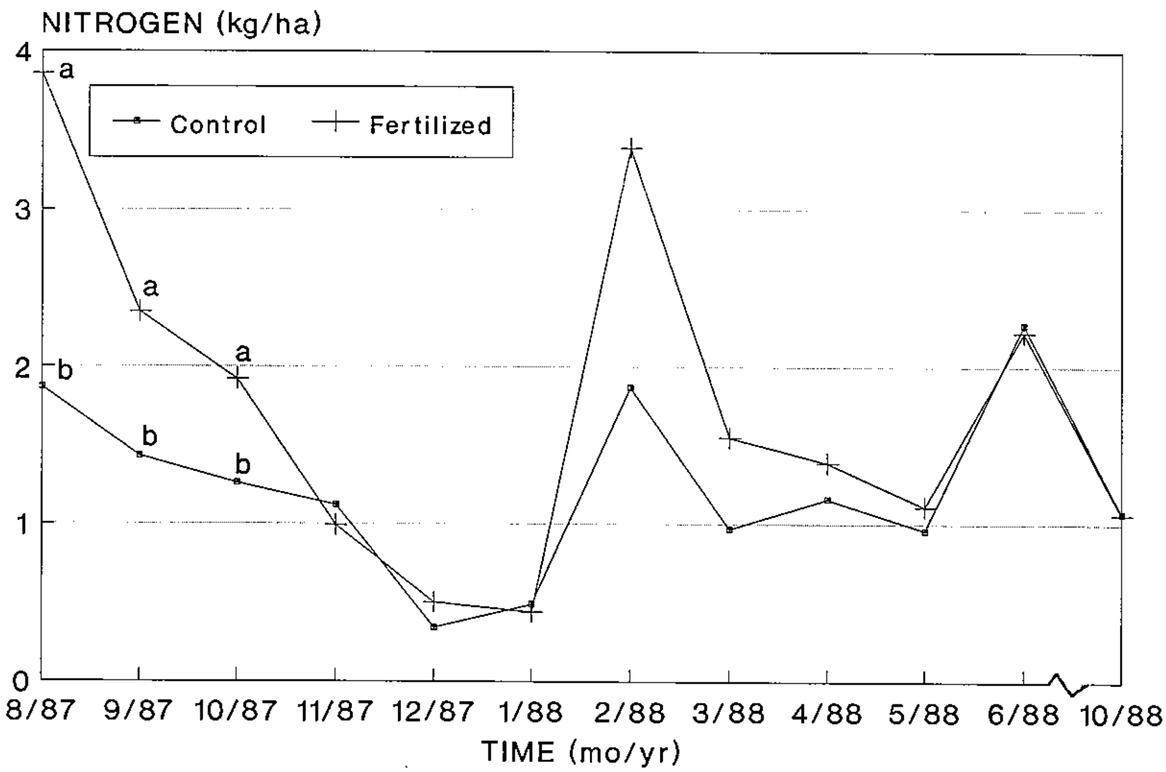

Figure 2. Effect of fertilization on KCl-extractable N. For each date, points with different letters are significantly different at the 0.05 level.

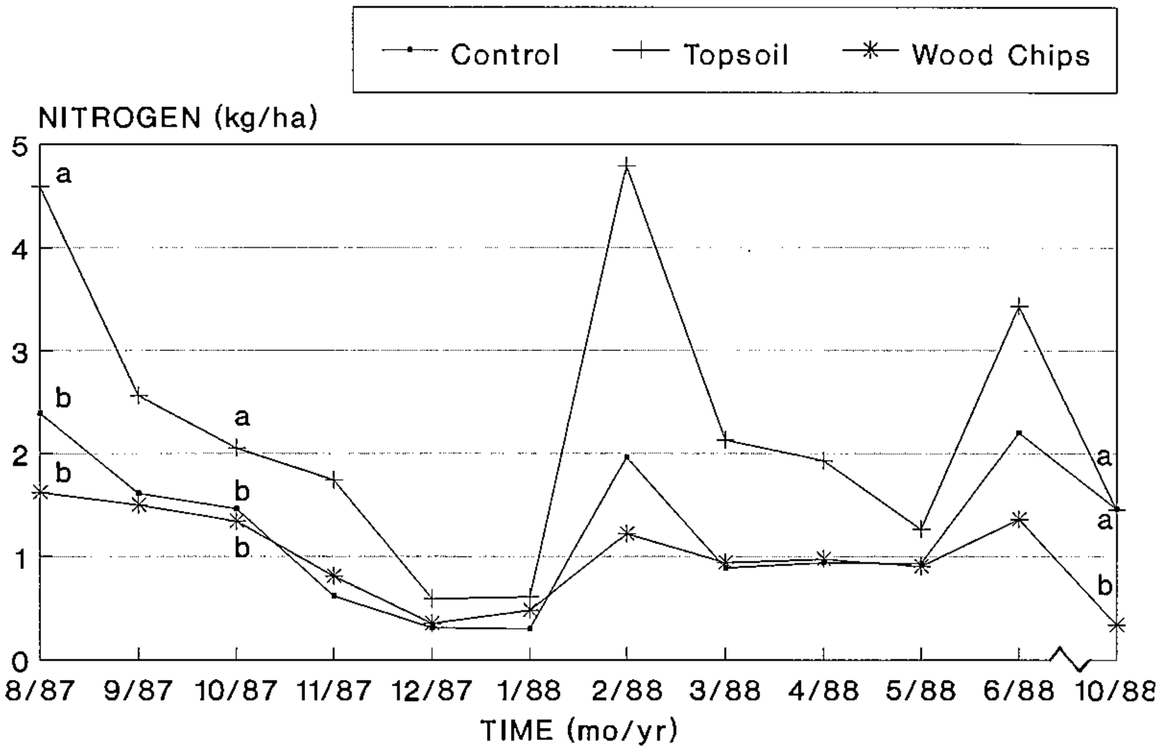

Figure 3. Effect of organic amendments on KCl-extractable KCl-extractable N. For each date, points with different letters are significantly different at the 0.05 level.

Table 4. Effect of fertilization on cumulative leachate N loss.[1]

Fertilizer treatment	Time Period 7/87-10/87	11/87-10/88	Total
	------------------kg N ha^{-1}------------		
Control	1.9b[2]	0.9a	2.8b
Fertilized	17.5a	1.3a	18.8a

[1]Pooled across organic amendment treatments.

[2]Values within a column followed by different letters are significantly different according to Duncan's multiple range test at the 0.05 level.

Table 5. Effect of reclamation treatments on aboveground herbaceous biomass and N.

Treatment	10/87 dry weight	10/87 N	10/88 dry weight	10/88 N	10/89 dry weight	10/89 N
	--------------------	----	kg ha^{-1}	----	----	--------------------
Organic amendment						
Control	4108a[1]	52.7b	4564a	102.8a	5998a	135.7a
Topsoil	5684a	70.2a	4106a	94.1a	6670a	153.4a
Wood chips	1109b	32.4c	4583a	93.6a	5043b	101.3b
Fertilizer						
Control	2518a	38.2b	4936a	110.4a	5801a	131.3a
Fertilized	4749b	65.3a	3900a	83.2a	6006a	129.0a

[1]Values within a column for organic amendments or for fertilizer treatments followed by different letters are significantly different according to Duncans's multiple range test at the 0.05 level.

Table 6. Effect of reclamation treatments on pitch x loblolly hybrid pine survival.

Treatment	1st-year survival	2nd-year survival
	---------- %	----------
Organic amendment		
Control	87ab[1]	83ab
Topsoil	73b	60b
Wood chips	98a	98a
Fertilizer		
Control	76b	71b
Fertilized	97a	90a

[1]Values within a column for organic amendments or for fertilizer treatments followed by different letters are significantly different according to Duncans's multiple range test at the 0.05 level.

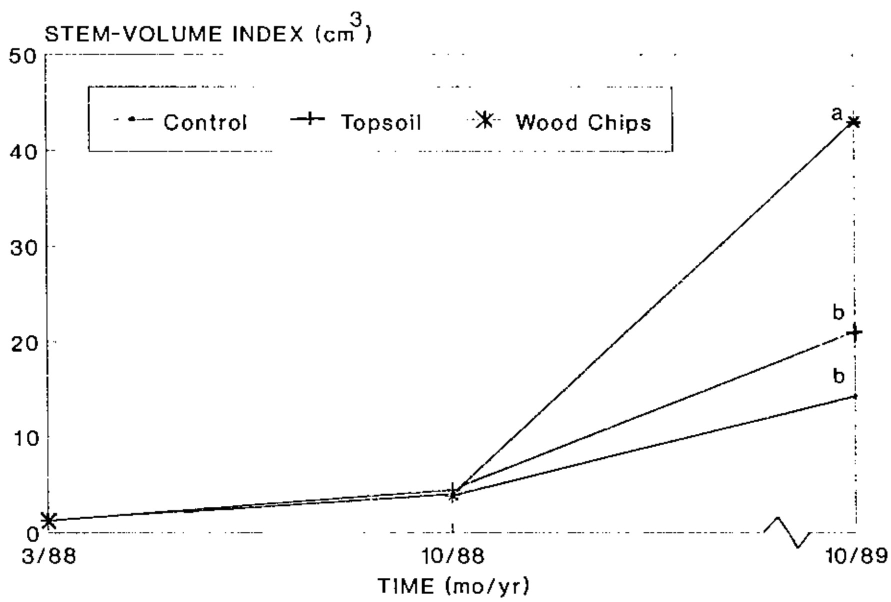

Figure 4. Effect of organic amendments on stem-volume index of pitch x loblolly hybrid pines. Points with different letters are significantly different at the 0.05 level.

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