AVAILABLE NUTRIENTS AND EARLY GROWTH OF WOODY PLANTS VARY WITH OVERBURDEN MATERIAL IN LIGNITE MINESOILS OF LOUISIANA[1/]

by

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Abstract--In a strip mine reclamation test, different overburden mixtures were substituted for stockpiled topsoil. Before the pit was backfilled, soil tests were run on each type of overburden, and N, P, and K were applied at recommended rates. The pit area was divided into four equal, parallel strips. Strip A was covered with topsoil, B with mixed 12.5- to 18.3-m overburden, C with 0- to 6.1-m overburden, and D with 0- to 1.5-m overburden. All strips were irrigated frequently the first 2 years. Loblolly pine (*Pinus taeda* L.) and sawtooth oak (*Quercus acutissima* Carruthers) grew vigorously, and mean height after 4 years was about equal in all strips. Yaupon (*Ilex vomitoria* Ait.) failed in all strips; Amur honeysuckle (*Lonicera maackii* Maxim.) succeeded in strip A. Foliage of all species was chlorotic after the first year, despite repeated topdressing with N. Nitrogen in third-year foliage samples was distinctly higher for strip A than for the other strips. Soil samples collected after 5 years showed that N and organic matter were low in strips B, C, and D relative to A. Soil P, K, Ca and Mg did not differ substantially among strips. Exchangeable Al was not at toxic levels in any strip. With annual applications of N and regular weeding, sawtooth oak and water oak (*Quercus nigra* L.) could be established. No cultivation or fertilizer is needed for pine.

Additional Key Words: nitrogen deficiency, fertilizer, nutrient availability, drought, weeding

Introduction

In the reclamation of lands stripped for lignite, the prior removal, temporary storage, and later return of topsoil usually enhances the potential for rapid revegetation, but the earthwork is expensive. Furthermore, in some soils, the A horizon may be so shallow and/or the B horizon may be so acid or have such poor physical properties that the upper 15 cm of soil, redistributed upon the surface, is less favorable to plant life than some of the underlying regolith. Reclamation costs could be reduced and cover establishment accelerated if a mixture of overburden could be substituted for topsoil. To study these and other problems, an experimental opencast lignite mine was operated, closed, and reclaimed in northwestern Louisiana. This paper discusses the survival and growth of trees and shrubs in the study area during the first 4 years and some soil properties after 5 years.

This experiment was planned and conducted by the mine operator until January 1984. At the operator's request, the USDA Forest Service then assumed the maintenance, measurement, and evaluation of results.

Methods

The soils in the study area, before they were disturbed by mining, were in the Woodtell (fine, montmorillonitic, thermic Vertic Hapludalfs) and

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Metcalf (fine-silty, siliceous, thermic Aquic Glossudalfs) series. These are moderately well to somewhat poorly drained, very slowly permeable soils formed on uplands. These soils are used mainly for pine forest and pasture. Native vegetation is a mixture of shortleaf pine (*Pinus echinata* Mill.), loblolly pine, southern red oak (*Quercus falcata* Michx.), and post oak (*Q. stellata* Wangenh.). The study area was nearly level.

While the mine was being worked in 1980, seven different overburden materials were segregated and stockpiled:

SP1. "Topsoil"; the upper 0.15 m of the soil profile, consisting mainly of A horizon material but including some B horizon. Texture is sandy loam, available water holding capacity is 0.07 kg kg^{-1}, and total sulfur content is 0.3 g kg^{-1}.

SP2. "Subsoil"; mixed 0.15- to 0.45-m overburden consisting of B horizon material. Texture is clay, available water holding capacity is 0.11 kg kg^{-1}, and total sulfur content is 0.2 g kg^{-1}.

SP3. Mixed 0- to 1.5-m overburden, containing 10% A horizon by volume, and the remainder is B and C horizon material. Texture is clay, available water holding capacity is 0.11 kg kg^{-1}, and total sulfur content is 0.1 g kg^{-1}.

SP4. Mixed 1.5- to 6.1-m overburden. Texture is clay loam, available water holding capacity is 0.06 kg kg^{-1}, and total sulfur content is 0.5 g kg^{-1}.

SP5. Mixed 0- to 6.1-m overburden containing 2.5% A horizon material by volume. Texture is clay loam, available water holding capacity is 0.07 kg kg^{-1}, and total sulfur content is 0.2 g kg^{-1}.

SP6. Mixed 0.5- to 6.1-m overburden containing no A horizon material. Texture is sandy clay loam, available water holding capacity is 0.07 kg kg^{-1}, and total sulfur content is 0.2 g kg^{-1}.

SP7. Mixed 12.5- to 18.3-m overburden containing no A horizon material. Texture is loamy sand, available water holding capacity is 0.05 kg kg^{-1}, and total sulfur content is 0.2 g kg^{-1}.

Care was exercised to minimize contamination of any stockpile from other stockpiles or spoil dumps. Samples were taken from each stockpile for soil tests. Ammonium nitrate and triple superphosphate were applied to all stockpiles at the minimum recommended rates (different for each overburden material, rates not recorded); muriate of potash was added to the SP7 overburden stockpile. Pensacola bahiagrass (*Paspalum notatum* Fluegge) and common bermudagrass (*Cynodon dactylon* L. Pers.) were seeded at a different rate for each type of overburden, and straw mulch was applied. Fair to good cover of bermudagrass and giant ragweed (*Ambrosia trifida* L.) developed on most stockpiles, but cover remained scant on the SP7 material.

After the mine was closed in the winter of 1980-81, the pit was backfilled to within 3 m of the final, leveled surface. The pit area was divided longitudinally into four parallel east-west strips, each 11.9 m in width (Fig.1). The northernmost strip (A) was backfilled with 2.6 m of SP6 overburden, overlain with 0.3 m of the SP2 material, and surfaced with 0.15 m of SP1 material. Strip B consisted of 2.45 m of mixed SP6 overburden covered by 0.6 m of the SP7 overburden. Strip C was entirely filled with SP5 material, and strip D consisted of 1.5 m of SP4 overburden covered by 1.5 m of SP3 material. Strip D was 13 m short on the east end because it contained the access ramp for backfilling. Lime and fertilizer were applied at different rates for each strip. Strip A received 3,360 kg ha^{-1} of lime, 37 kg ha^{-1} of N as ammonium nitrate, 215 kg ha^{-1} of P as triple superphosphate, and 290 kg ha^{-1} of K as muriate of potash. Strip B was given 1,120 kg ha^{-1} of lime, 37 kg ha^{-1} of N, 170 kg ha^{-1} of P, and 156 kg ha^{-1} of K. Strip C received 1,080 kg ha^{-1} of lime, 37 kg ha^{-1} of N, 256 kg ha^{-1} of P, and 525 kg ha^{-1} of K. Strip D was given 22,400 kg ha^{-1} of lime, 37 kg ha^{-1} of N, 256 kg ha^{-1} of P, and 324 kg ha^{-1} of K. Carpetgrass (*Axonopis affinis* Chase) was seeded, but bermudagrass quickly invaded and formed a vigorous stand.

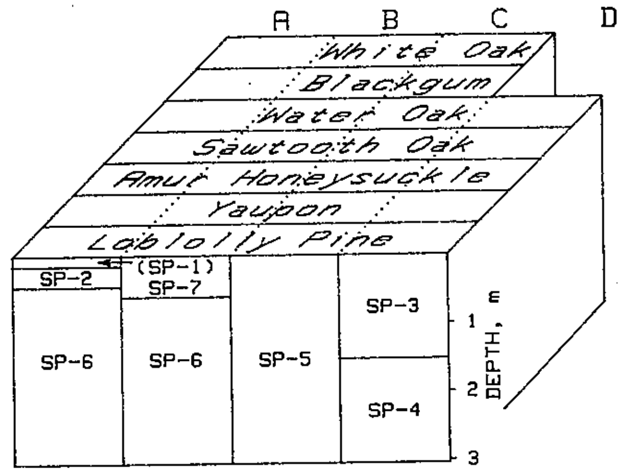

Figure 1. Diagram showing placement of overburden mixtures in strips and location of species plantings

Seven species were planted in strips running perpendicular to the overburden strips, with each species-overburden combination forming a plot. Only 26 plots were formed, because the ramp location precluded two plots on strip D. Loblolly pine, sawtooth oak, yaupon, and Shumard oak (*Quercus shumardii* Buckl.) were planted in pure stands at spacings of 0.9 x 0.9 m in each strip in February 1981. In January 1982, yaupon plots were replanted with yaupon, the Shumard oak plots were replanted with Amur honeysuckle, and new plots of water oak were planted on all four strips. Staghorn sumac (*Rhus typhina* L.) and blackgum (*Nyssa sylvatica* Marsh.) plots were planted at spacings of 0.9 x 0.8 m in strips A, B, and C. In January 1983, the staghorn sumac plots were replanted with white oak (*Quercus alba* L.). Plantings and replantings were made with 1-0 bare-rooted seedlings, except for the second yaupon planting, in which rooted cuttings in peat pots were used. All planting stock was obtained from commercial nurseries.

All plots were irrigated frequently in 1981 and 1982. All the planted trees and shrubs were quickly overtopped by herbaceous competition, and frequent mowing was necessary. The loblolly pine and sawtooth oak plots were thinned in March 1984, leaving 1,502 pine stems ha^{-1} and 5,975 oak stems ha^{-1}. Nitrogen was applied as ammonium nitrate to all plots at 56 kg ha^{-1} in May 1984 and 28 kg ha^{-1} in April 1985.

The plots were inventoried following the 1984 growing season. Survival was determined, percentage of plot area occupied by crowns of the planted species (ground cover) was estimated. and total tree height and stem diameter at root collar (4 cm above ground surface) were measured.

Foliage samples were collected from the loblolly pine, sawtooth oak, and water oak plots in August 1983, and N, P, and K were determined on a Kjeldahl digest by ammonium probe, by colorimetry, and by atomic absorption, respectively.

Surface soil samples (0 to 15 cm) were collected from all the plots in September 1985. Each sample was dried and passed though a 2-mm sieve. Soil pH was determined by pH electrode in a 1:1 soil:water paste. Organic matter content was determined by wet oxidation without external heat (Jackson 1958) and total soil nitrogen by the Kjeldahl method (Bremner and Mulvaney 1982). Available phosphorus was extracted by shaking the soil for 15 minutes with 0.03N NH_4F + 0.1N HCl (Jackson 1958) and then was assayed colorimetrically. Bases were extracted with 1N NH_4OAc (Chapman 1965) and the solutions analyzed by atomic absorption spectrophotometry. A 1N KCl extract was used to determine total acidity by titration (Thomas 1982) and exchangeable aluminum by atomic absorption (Barnhisel and Bertsch 1982).

Because there was no replication, statistical analysis is impossible, and all comparisons and interpretations are subjective. To obtain an estimate of overburden variability, standard deviations of soil properties were calculated by using species plots within overburden type as observations.

Results

Tree Survival and Growth

Of the eight species tried in this test, loblolly pine was the most successful in occupying the site, regardless of the type of overburden. First-year survival of loblolly pine was 63% in the plots in strips A and D, 75% in the plot in strip C, and 90% in the strip B plot. No mortality occurred after the first year. Ground cover was 100% in all four plots in the third year. After the thinning at age 3, stand density of loblolly pine averaged 1,502 stems ha^{-1} in the four plots. Fourth-year mean height of loblolly pine was 3.58 m in the strip D plot and 3.08 m in the other three plots. Current-year average height growth was 1.00 m in the strip D plot and 0.85 m in the other three plots. Mean stem diameter of loblolly pine 4 years after outplanting was 9.4 cm in the plot in strip D and 8.3 cm in the plots in A, B, and C (Table 1). The stem diameter of loblolly pine at age 4 responded strongly and positively to the thinning at age 3.

The most successful hardwood species was sawtooth oak, which, after 4 years, averaged 11,110 stems ha^{-1}. Ground cover 1 year after thinning was 90% in the plots in strips A and D and 35% in the plots in B and C. Fourth-year mean height of resi-

Table 1.--Quadratic mean stem diameters at root collar by species, date, and overburden mixture

Species	Date	Overburden strip† A	B	C	D
		---cm---			
Loblolly pine	Dec. 82	2.6	3.1	2.5	3.1
	Oct. 83	4.2	4.1	4.1	5.4
	Mar. 85††	8.3	8.3	8.2	9.4
Sawtooth oak	Dec. 82	1.3	1.7	2.0	2.1
	Oct. 83	2.3	1.9	2.4	2.3
	Mar. 85††	3.8	2.4	3.2	3.5
Water oak	Nov. 82	0.6	0.8	0.7	0.7
	Oct. 83	0.2	0.2	0.2	0.2
	Mar. 85	1.5	2.0	1.3	1.7
White oak	Oct. 83	0.2	0.2	0.2	NP †††
	Mar. 85	0.9	1.0	1.1	NP
Yaupon	Nov. 82	0.7	0.6	0.6	0.7
	Oct. 83	1.0	0.7	0.5	0.5
	Mar. 85	1.2	0.6	0.6	0.6
Blackgum	Nov. 82	0.7	0.9	0.8	NP †††
	Oct. 83	0.2	0.2	0.2	NP
	Mar. 85	0.8	1.1	1.1	NP

† Amur honeysuckle diameters not determined.
†† Residual stems after the plots were thinned in March 1984.
††† NP - no plot because of ramp location.

dual stems of sawtooth oak was 1.24 m in the strip B plot and 1.65 m in the remaining plots. Average height growth of residual trees was 0.33 m in the plot in strip A and 0.16 m in the plots in B, C, and D. Average stem diameter (residual stems) of sawtooth oak was 2.4 cm in the plot in strip B and 3.5 cm in the plots in A, C, and D. Like the loblolly pine, the sawtooth oak plots were thinned, but every cut oak stem sprouted. So, the thinning had little, if any, effect on mean stem diameter of residual trees.

Water oak was the second most successful broadleaf species planted. Water oak, after 3 years, had 7,788 stems ha^{-1} in the plot in strip A and averaged 10,446 in the plots in B, C, and D. Ground cover was about 20% in the plot in strip A, 30% in the plots in B and D, and 15% in the plot in C. Third-year mean height of water oak averaged 0.93 m in all four plots. Current-year height growth averaged 0.50 m in all four plots. In all the water oak plots, stem diameter at the end of 1983 was much less than half its value at the end of 1982. What accounts for this negative growth? Irrigation was discontinued at the end of 1982, and rainfall was very scant in April 1983; consequently, most of the stems died. A vigorous sprout rose from nearly every rootstock (numbers of stems remained practically unchanged), and the sprout, after one growing season, was not as large in diameter as the previous stem.

Growth of white oak was rather slow, but the species is normally slow growing when established in plantations (Clausen 1983; Tworkoski _et al._ 1983; Farmer 1981). Two-year survival was acceptable, averaging 10,120 stems ha^{-1} in the three plots (strips A, B, and C). Ground cover at age 2 was too low to be estimated. Mean height of white oak averaged 0.58 m in the three plots. Height growth averaged 0.02 m in the second year. Drought caused above-ground stem mortality as in water oak, so the stem diameter of the white oak at the end of 2 years was less than half the average diameter in the first year.

Of all the species tested, Amur honeysuckle was the one most affected by the different types of overburden. Amur honeysuckle after 3 years had 1,603 stems ha^{-1} in the plot in strip B and 2,104 in the other plots. However, ground cover was 90% in the plot in strip A, 50% in the plot in D, and less than 10% in the plots in B and C. Third-year mean height of Amur honeysuckle was 1.06 m in the plots in A and D and 0.38 m in the plots in B and C. Current-year height growth averaged 0.37 m in the plots in A, C, and D and was zero in the plot in B.

Nutrient Contents of Foliage

Foliage of every broadleaf species was very chlorotic in the middle and late summers of 1983 and 1984. Foliage sampled in August 1983 from the three fastest growing species showed that trees on strips containing low amounts of A horizon were probably deficient in nitrogen (Table 2). Sawtooth oak appeared to be the most nitrogen-sensitive and loblolly pine the least sensitive of these three species. The concentrations of P and K were not affected by the type of overburden. The concentration of P in the water oak foliage was perceptibly lower than in the other two species.

Soil Properties

As indicated by the foliar analysis, nitrogen was evidently the soil nutrient that affected growth the most. This was caused by the different amounts of A horizon included in the overburden placed on the surface. After 5 years, the level of organic matter in the strip A plots was 21 g kg^{-1} (Table 3), or about twice as high as the levels in strips B and C. Organic matter content of strip D was intermediate at 16 g kg^{-1}. Total nitrogen levels of soil paralleled the soil organic matter contents except in strip B, where the nitrogen content was lower than the organic matter content would indicate. In strips A, C, and D the C:N ratio was about 23 while in strip B it was 34. The organic matter in the strip B samples consisted of the lignite fragments characteristic of newly excavated SP7 material plus the soil organic matter formed by natural soil-forming processes in 5 years of exposure on the surface.

Table 2.--Nutrient concentrations of foliage samples collected from selected species in August 1983

Species	Overburden strip	N	P	K
		$g\ kg^{-1}$		
Loblolly pine	A	13.1	1.5	8.4
	B	9.5	1.3	8.4
	C	10.5	1.4	9.0
	D	11.4	1.3	7.6
Sawtooth oak	A	14.1	1.4	5.3
	B	9.7	1.7	6.2
	C	10.0	1.1	3.7
	D	10.8	1.2	4.5
Water oak	A	12.4	1.0	6.1
	B	10.8	0.9	6.7
	C	11.1	0.9	4.6
	D	11.7	0.9	5.4

Soil pH and associated aluminum and manganese levels did not appear to be a problem in these overburdens. The pH of surface soil averaged 5.0 in strips A and B and 5.7 and 5.6 in C and D, respectively; the overall range in pH was 4.6 to 5.7. Exchangeable aluminum averaged 0.11 cmol (p^+) kg^{-1} overall and was not higher in strips B, C, and D than in strip A. Exchangeable manganese did not reach toxic levels in any of the strips and was highest in strip A, which most closely approximated the original soil condition.

Because of the fertilizer applied to the spoil piles before they were replaced in the pit, the other nutrients were sufficient for tree growth. Available P ranged from 13 to 166 mg kg^{-1} in plots and averaged 62 in strips A, B, and C; in strip D it was 38 mg kg^{-1}. Exchangeable K levels ranged from 0.20 to 0.44 cmol (p^+) kg^{-1}, which should be sufficient for the species tested. Exchangeable Ca did vary with type of overburden, ranging from 1.4 cmol (p^+) kg^{-1} in strip B to 10.1 cmol (p^+) kg^{-1} in strip D. However, because of the higher exchange capacity of strip D, the percentage of exchange capacity

Table 3.--Chemical analyses of the four overburden strips, averaged across all the test species

Measurement, unit	Overburden strip† A		B		C		D	
pH, unit	5.0	(0.3)	5.0	(0.2)	5.7	(0.5)	5.6	(0.4)
Organic matter, g kg^{-1}	21	(5.0)	11	(2.0)	12	(5.0)	16	(4.0)
Total N, g kg^{-1}	0.85	(0.44)	0.32	(0.05)	0.54	(0.09)	0.68	(0.18)
Available P, mg kg^{-1}	44	(25)	62	(20)	80	(55)	38	(16)
Exchangeable K, cmol (p^+) + kg^{-1}	0.34	(0.07)	0.20	(0.05)	0.44	(0.12)	0.39	(0.03)
Exchangeable Ca, cmol (p^+) kg^{-1}	2.2	(0.3)	1.4	(0.2)	6.3	(1.1)	10.1	(2.3)
Exchangeable Mg, cmol (p^+) kg^{-1}	0.8	(0.3)	1.1	(0.3)	6.7	(0.6)	4.0	(0.1)
Exchangeable Na, cmol (p^+) kg^{-1}	0.08	(0.05)	0.05	(0.02)	0.56	(0.09)	0.21	(0.03)
Exchangeable Al, cmol (p^+) kg^{-1}	0.13	(0.13)	0.11	(0.03)	0.08	(0.08)	0.13	(0.13)
Exchangeable H, cmol (p^+) kg^{-1}	1.17	(0.36)	1.07	(0.32)	1.34	(0.68)	1.61	(0.32)
Sum of cations, cmol (p^+) kg^{-1}	4.7	(0.7)	3.9	(0.8)	15.4	(2.1)	16.4	(2.0)
Exchangeable Mn, mg kg^{-1}	13.1	(1.7)	3.2	(0.9)	7.0	(2.1)	5.2	(1.9)

† Standard deviations are given in parentheses.

occupied by calcium did not differ among strips, averaging 47%. The calcium to magnesium ratio was 2.8 in strip A, 1.5 in B, 0.9 in C, and 2.5 in D. Exchangeable Na was seven times higher in strip C compared to strip A, but this level is only 4% of exchange capacity, well below the 15% point at which plant growth begins to be affected.

Discussion and conclusions

Loblolly pine was the fastest growing species tested--in height, in stem diameter, and in percentage of ground covered. It was one of the two best survivors. Loblolly pine grew as vigorously on the overburden mixtures (strips B, C and D) as it did on strip A, which approximated the original soil condition. Loblolly pine probably would have covered the site and formed a stand, even without mowing and supplementary nitrogen fertilizer.

Sawtooth oak was the best survivor and was the fastest-growing, best ground-covering hardwood. It did not respond to thinning, but it did dominate the site. Like loblolly, it probably would have survived even without mowing, although its growth may have been retarded.

As previously stated, all these plots were irrigated frequently in 1981 and 1982. Loblolly pine and sawtooth oak were irrigated both years; yaupon, Amur honeysuckle, water oak, and blackgum were irrigated for 1 year; but white oak (replacing staghorn sumac) was not irrigated. Because of this confounding, we cannot be sure that some of these other species, especially water oak, would not have grown as vigorously as sawtooth oak if they had received similar irrigation regimes. Thus far, the 2-year-old white oak has outgrown the 3-year-old blackgum, which received 1 year of irrigation, so it may be too early to evaluate the performance of white oak. The height growth and diameter growth of all broadleaf species were greatly inhibited in 1983, probably by drought.

Staghorn sumac, Shumard oak, yaupon, and blackgum apparently were failures on this site regardless of the type of overburden on which they were planted. Poor first-year survival of Shumard oak was caused by *Cylindrocladium* and *Phytophthora* root rots (Affeltranger and Burns 1983). The seedlings were infected in the nursery before being lifted. After one growing season, the few surviving Shumard oaks were replaced with yaupon. However, after 3 years yaupon was a failure on every type of overburden. The number of stems averaged 7,082 per ha in the four plots, but ground cover was only 10% in strip A and less than 5% in strips B, C, and D. The stem diameter of yaupon after 3 years was 1.2 cm in the plot in strip A and averaged 0.6 cm in the other three plots. Blackgum after 3 years was another failure. Ground cover was less than 5% in all three plots. There were 3,055 stems ha^{-1} in strip A and 7,642 in strips B and C. Third-year mean height of blackgum averaged 0.58 m in the three plots, and height growth averaged 0.08 m. In the third year, blackgum suffered the same mortality problems as the water oak and white oak, causing the average stem diameter to be less than in the second year.

Of the soil properties measured, total nitrogen levels seemed to be the most deficient and affected the species differently. The height of water oak was not related to the amount of soil nitrogen, but the height of Amur honeysuckle increased with increasing levels of nitrogen (Fig. 2). The heights of loblolly pine and sawtooth oak were not affected by the soil nitrogen levels; however, yaupon was very successful on strip A, which contained the highest amounts of soil nitrogen. Possibly the levels of nitrogen fertilizer applied were enough to overcome deficiences for the loblolly pine, sawtooth oak, and white oak but were insufficient for the other species tested. The nitrogen-supplying capacity of new mine spoil frequently is less than that of older, long-vegetated spoil or of undisturbed soil of similar nitrogen content (Reeder and Berg 1977). Hons and Hossner (1980) found that very little of the total soil N in Texas lignite minesoils was plant-available and that the nitrification rate of applied NH_4-N was extremely low.

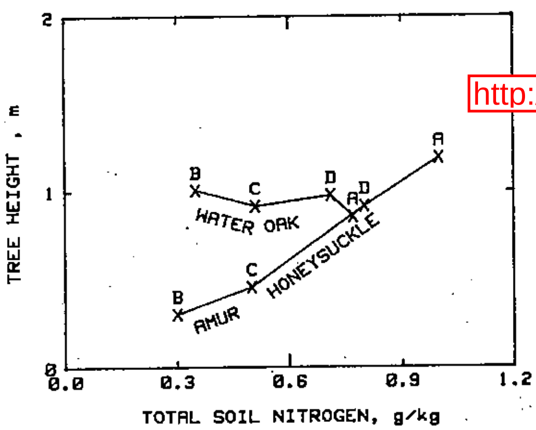

Figure 2. Effect of total soil nitrogen of different types of overburden on third-year height of Amur honeysuckle and water oak

No evidence of toxic chemical levels was found. Soil pH was well within the range favorable to tree growth, and concentrations of aluminum and manganese were not excessive. Low soil pH is often a problem in strip mine soils because of high sulfur contents. Because total sulfur concentrations were low in all the overburdens tested, pH and associated aluminum toxicity were not limiting reclamation of the site.

In a preliminary study such as this, it is impossible to determine which variables should be controlled when the study is established. Therefore, the results are confounded and interpretations must be limited and drawn with care. Apparently, loblolly pine or similar pine species should be the species of first choice. Because of the inherently low nutrient concentrations and low water availability on sites such as this, hardwoods are difficult to establish (Hunt and Cleveland 1978; Fitzgerald et al. 1975). If hardwoods are desired for wildlife or esthetic purposes, weed control, irrigation, and nitrogen fertilizer will be required for several years. Another alternative may be to plant a mixture of hardwoods and pines. If overburden mixtures containing no topsoil are used, then nitrogen-fixing trees, shrubs, or forbs, such as *Robinia*, *Amorpha* (Brown et al. 1983), *Gleditsia*, *Caragana* (Wade et al. 1985), or *Lespedeza* (Mays and Bengtson 1985) can be planted to reduce the amount of fertilizer nitrogen required.

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