PERFORMANCE OF TREES AND SHRUBS ON SLUDGE-AMENDED ACIDIC MINESOILS[1]

by

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Abstract. Surface mining activities during the late 1950's produced extremely acidic minesoils when shales high in pyrites were mixed with sandstone and other parent materials. A study was initiated in 1975 on the 126-ha Palzo mine site in southern Illinois to determine survival and growth of selected trees, shrubs, grasses, and forbs following heavy applications (400 to 1000 mg/ha) of municipal sewage sludge on one such site. Municipal sewage sludge was incorporated to a depth of 30 cm or more on six compartments ranging from 1.1 to 3.0 ha in area. Thirteen different trees and shrub species were established in two or more compartments in 1976. Woody plant survival after 15 years ranged from 28 to 33% for green ash, Virginia pine, and silver maple to between 6 and 12% for sycamore, baldcypress, loblolly pine, river birch, and bur oak. Few, if any, of the eastern white pine, autumn olive, European black alder, American tulipwood, or white oak still survive. Height growth ranged from 6.0 to 8.0 m for sycamore, loblolly pine, silver maple, and river birch compared to 3.8 to 4.7 m for green ash, baldcypress, bur oak, and Virginia pine. Of more than 20 different volunteer trees and shrub species found on the sludge-treated compartments, only Virginia pine, river birch, and ash have more than 6 trees/ha. Results suggest long-term survival and acceptable tree growth are related to improved chemical soil conditions created by sludge application, reduced erosion, rock weathering, nutrient recycling, and continued addition of organic matter from plant litter to this once acidic minesoil.

Additional Key Words: Palzo mine site, sewage sludge, Shawnee National Forest.

Introduction

In the early 1970's the 126-ha Palzo mine site in southern Illinois was considered to be one of the most acidic minespoils in the United States (Jones and Cunningham 1979). Strip mining between 1958 and 1962 with a power shovel left pyrite exposed in shale associated with the parting layer between the lower Davis and upper Dekoven coal seams, sandstone and other parent materials from the overburden. The exposed pyrite quickly oxidized to Fe^{+2} and H_2SO_4 resulting in extremely acid minesoils (pH values between 2.5 and 3.0) devoid of vegetation. The USDA Forest Service initiated a study in 1975 to determine the feasibility of using anaerobically digested municipal sewage sludge to neutralize the acidic minesoil and, thereby, enable establishment of herbaceous and woody plant covers.

Preliminary studies suggested a heavy application of sludge solids (300 to 600 Mg/ha) would increase pH of the soil medium, provide a source of nutrients, and improve the physical condition of the soil medium (McBride et al. 1977, Stucky and Newman 1977). In 1976, Southern Illinois University initiated a study to determine what tree, shrub, grass, and forb species were most suited for establishing a plant cover on these amended minesoils. It was unclear at that time if plant cover could be maintained without continual application of sludge solids and if soil

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erosion could be reduced to prevent exposing additional acid-forming pyrite.

Our purpose was to reevaluate after the fifteenth growing season the original study objectives (Roth et al. 1979) to (1) determine if municipal sludge, when used as a soil amendment on acid strip spoils, has beneficial effects on tree survival and growth rates and (2) identify tree species for recommendation on similarly mined sites, based on species overall survival and growth performance. An additional objective was to determine how much natural regeneration was occurring on the amended minesoils and other soils at the Palzo mine site in the Shawnee National Forest.

Materials and Methods

The 126-ha Palzo mine site was strip mined by power shovel from 1958 to 1962. This was prior to a comprehensive state reclamation law for Illinois. The USDA Forest Service acquired the site in 1966 and reshaped 81 ha of a western watershed to a maximum slope of 15% using the tract as a training site for heavy-equipment operators. Results from several research and small-scale field trials suggested that applications of 672 dry tons/ha of municipal sludge solids would allow plant covers to be established on these highly acidic minesoils (McBride et al. 1977, Stucky and Newman 1977).

Anaerobically digested solids from a secondary municipal treatment plant with some industrial inputs were transported by rail to a primary lagoon located 5 km from the Palzo site. Sludge containing between 10 to 15% solids was pumped from secondary on-site lagoons through 10-cm-diameter flexible tubes to a manifold mounted on a Rome disk which incorporated sludge approximately 30 cm deep into the mine soil surface. Application rates were estimated at 33 Mg/ha per application with total applications ranging from 426 to 997 Mg/ha across most of the site (Stucky et al. 1980). Chemical analysis showed the sludge could provide the needed alkalinity needed to raise the minespoil pH and provide the nutrients needed for plant growth (Table 1).

Six irregularly shaped study compartments ranging from 1.1 to 3.0 ha were laid out across the western watershed following sludge application along with one additional 0.5 ha compartment along a ridgetop that did not receive any sludge applications (Figure 1). The sludge-treated compartments were subdivided into three nearly equal-sized planting units to test establishment of woody species only, herbaceous species only, and combinations of both woody and herbaceous species (Jayko 1978). No herbaceous or combination planting units were established on the control compartment and the combination planting unit was not established in compartment #6. The southern two-thirds of compartment #3 was destroyed by heavy equipment after the 1980

Table 1.--Analysis from a representative sludge sample from Metropolitan Sanitary District of Greater Chicago Callumet lagoon number 11[a].

Parameter	Analysis (mg/kg)	Parameter	Analysis (mg/kg)
Alk. as $CaCO_3$	13,588	Fe	52,519
Cl	1,618	Pb	893
SO_4	2,137	Mg	11,908
Kjeldahl N	35,534	Mn	656
NH_3-N	3,740	Hg	7
Al	10,992	Ni	122
Cd	244	K	2,137
Ca	16,794	Na	1,832
Cr	1,214	Zn	7,053
Cu	1,420		

[a] Information obtained from Jones and Cunningham (1979) for samples taken at the time of sludge treatment by rail to Palzo mine site.

measurements and it was not included in the 1991 analysis of survival and growth of planted trees and shrubs.

Woody species planting units were seeded with annual rye (*Secale cereale* L.) late in 1975 to provide an initial vegetative cover. In the combination planting units, various grasses and legumes were drilled in 10-m-wide strips perpendicular to the tree rows. The species planted included tall fesuce (*Festuca arundinacea* Schreb.), orchard grass (*Dactylis glomerata* L.), ryegrass (*Lolium perenne* L.), switchgrass (*Panicum virgatum* L.), crownvetch (*Coronilla*

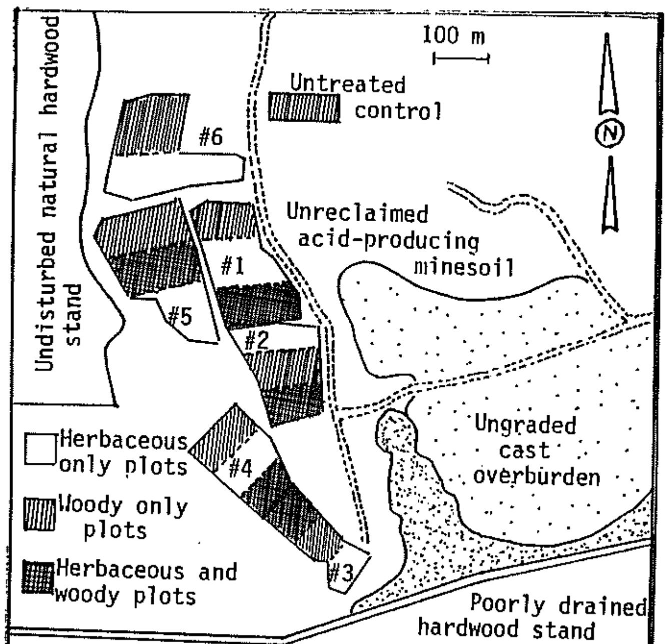

Figure 1. Location of compartments, planting units, ungraded cast overburden, and natural woods on the Palzo strip mine.

varia L.), lespedeza (Lespedeza cuneata (Dumont) G. Don. and L. striata (Thumb.) H.&A.), birdsfoot trefoil (Lotus corniculatus L.), and red clover (Trifolium pratense L.).

The woody species planting units and combination (woody and herbaceous species) planting units were divided into three-row tree plots consisting of 87 to 120 trees on a nominal 2.4 m by 2.4 m spacing. Tree rows ran from south to north in all compartments except the combination planting unit in Compartment #4. Eight to thirteen woody species were randomly assigned to each three-row tree plot within each compartment and hand planted in the spring of 1976. Eastern white pine (Pinus strobus L.), loblolly pine (P. taeda L.), Virginia pine (P. virginiana Mill.), baldcypress (Taxodium distichum (L.) Rich.), silver maple (Acer saccharinum L.), European black alder (Alnus glutinosa L. Gaertn.), river birch (Betula nigra L.), green ash (Fraxinus pennsylvanica Marsh.), American tulipwood (Liriodendron tulipifera L.), sycamore (Platanus occidentalis L.), white oak (Quercus alba L.), bur oak (Q. macrocarpa Michx.), and autumn olive (Elaeagnus umbellata Thumb.) occurred in two or more sludge-treated compartments depending on availability of seedlings from several Illinois and Indiana tree nurseries.

The seven study compartments remeasured in 1990 received varying amounts of sludge solids in 1975 (Table 2). Subsequent analyses of soil pH, nitrogen, cadmium, and cation exchange capacities indicated that more variation existed in sludge application rates within planting compartments than between planting compartments (Jayko 1978, Stucky et al. 1980). Some of this variation was due to poor agitation of the sludge in the primary and secondary lagoons and equipment failures when applying sludge. Because of the within-planting compartment variation, no attempt was made to correlate survival and growth of trees to calculated sludge application rates.

All trees within each three-row plot were measured in the late summer of 1990 to determine total tree height, number of stems greater than 1.6 m in height, and diameter at breast height (dbh) for each stem. Planting records were used to determine total number of trees planted in each species plot. The number of trees destructively sampled by Morin (1980) and Svoboda (1981) were subtracted before computing percent survival for each planted tree and shrub species.

All volunteer trees and shrubs greater than 1.6 m in height were mapped and measured for tree height and dbh. Average number of plants per hectare was determined for each species by planting unit and averaged across all sludge-treated compartments.

A 16 ha-area consisting of a natural hardwood stand that had never been stripped and a 24-ha area that was stripped to remove only the Dekoven coal seam were also sampled (Figure 1). Five 2-m by 100-m parallel transects were laid out approximately 20 m apart in both the natural stand and the ungraded cast overburden across a series of narrow ridges and valleys with steep shoulders to determine density and growth of trees and shrubs. In 1975, the ungraded cast overburden was well stocked with young trees, and the trees in the natural stand appeared to be 40 to 50 years old.

Table 2.--Characteristics of planting units as to size, estimated sludge application, number of woody species evaluated per compartment, and average number of planted trees per species per 3-row tree plots at Palzo mine site.

Compartment	Sludge application	Woody only	Herbs and Woody	Species plot	Trees/ plot
	Mg/ha	ha	ha	#	#
Control	0	0.50	--	14	93
1	560	0.71	1.20	13	111
2	668	0.69	0.52	13	111
3[a]	997	0.45	0.42	8	105
4	619	0.54	0.55	12	105
5	462	1.10	1.17	13	87
6	448	0.70	--	11	120

[a] Compartment #3 was destroyed after 1980 during subsequent reclamation activities at the Palzo mine site.

Results

Survival of Planted Trees and Shrubs

Survival of the planted trees and shrubs in 1990 varied from 0 to 33% across the woody species planting zones for the six compartments that were remeasured (Table 3). Overall, green ash, Virginia pine, and silver maple showed the greatest survival (28 to 33%). Other species like sycamore, baldcypress, loblolly pine, river birch, and bur oak had relatively poor overall survival with average survival rates ranging from 6 to 12%. Less than 5% of the eastern white pine, autumn olive, European black alder, American tulipwood, or white oak still survive 15 years after the trees were planted.

Overall survival values may not give a true indication of the ability of each species to tolerate and grow on the acidic, sludge-amended minespoils because of the high initial mortality that occurred during the first growing season (Table 3). Much of the first-year mortality was attributed to poor-quality planting stock, late planting, competition from the dense stand of rye, and below-normal precipitation (500 mm vs 595 mm, April through October) during the first growing season after the trees were planted (Jayko 1978). A few species like loblolly pine had poor initial survival with above average post establishment survival over the last 14 years. Other species like white oak and autumn olive had

Table 3.--Survival 1 and 15 year after establishing trees and shrubs in woody species planting units on the six compartments.

Species	Fall 1976 Survival[a]	Fall 1990 Survival		Post estab. surv.
	ave.	ave.	range	
	--%--	--%--	--%--	--%--
E. white pine	18.5	3.2	0.0- 7.6	17.3
Loblolly pine	12.1	9.0	0.0- 15.0	74.4
Virginia pine	47.0	28.4	6.2- 80.0	60.4
Baldcypress	58.9	8.5	1.9- 24.7	14.4
Silver maple	75.4	33.0	7.4- 86.5	43.8
European alder	25.3	1.8	0.0- 4.8	7.1
River birch	27.7	10.3	1.2- 19.6	40.7
Green ash	64.3	28.0	0.0- 86.7	43.5
Amer. tulipwood	15.6	0.0	--- ---	0.0
Sycamore	15.3	6.6	0.0- 27.9	43.1
White oak	56.2	0.0	--- ---	0.0
Bur oak	77.0	11.9	5.4 29.1	15.5
Autumn olive	44.5	0.0	--- ---	0.0

[a]Information obtained from Jayko (1978) and reanalyzed to exclude control unit, the combination planting units, and all of compartment #3.

above average survival after the first growing season but total post-establishment mortality over the last 14 years. Only Virginia pine, silver maple, and green ash showed above average survival after the first growing season as well as over the subsequent fourteen growing seasons.

Overall tree survival was not improved when established with mixed grasses and forbs on test plots (12.8%) compared to survival of planted trees and shrubs in the woody species planting units (11.9%). There was also no evidence of a continued interaction among woody plant species in the presence or absence of the herbaceous test plots that had been observed after the first growing season where hardwood survival was increased in the herbaceous test plots and conifer survival was decreased (Jayko 1978).

Growth Response of Planted Trees and Shrubs

River birch, silver maple, loblolly pine, and sycamore had the greatest height growth after fifteen growing seasons (Table 4). Height growth for these species ranged from 6.0 to 8.0 m when averaged across the woody species and combination planting units of the sludge-treated compartments. The tallest trees were found with silver maple in the combination planting unit of Compartment #2; however, silver maple showed wide variation ranging from 5.1 m to 11.4 m across the sludge-treated compartments. Of the four fastest growing species, river birch showed the most consistent growth with a range of 5.9 to 9.8 m across all compartments. The slowest height growth occurred with green ash, baldcypress, bur oak and Virginia pine. Of these species, Virginia pine showed the most consistent growth

Table 4.--Height, diameter at breast height, and number of stems after fifteen growing seasons for planted trees with greater than 5% survival in sludge-treated compartments.

Species	Height	DBH	Stems/ tree
	--m--	--cm--	--#--
River birch	8.00 a	13.6 ab	2.1 b
Silver maple	6.80 ab	8.9 bcd	3.3 a
Loblolly pine	6.06 abc	17.3 a	1.2 b
Sycamore	6.00 abc	10.9 bcd	1.4 b
Virginia pine	4.74 bc	12.1 abc	1.5 b
Bur oak	4.19 c	7.0 cd	1.4 b
Baldcypress	3.89 c	8.2 bcd	1.2 b
Green ash	3.79 c	5.4 d	2.1 b

[a] Means with the same letter within columns are not significantly different at the 5% level according to Scheffe's multiple comparison test.

with a range of 3.5 to 5.1 m across all compartments. Average growth for all eight species with greater than 5% survival was not significantly different between the woody species and combination planting units, and no species-by-planting-unit interactions were found.

The greatest diameter growth occurred with loblolly pine, river birch, and Virginia pine (Table 4). Loblolly pine produced the largest trees with diameter growth ranging from 14.0 to 20.8 cm across the sludge-treated compartments. The pine species (loblolly and Virginia pine) outperformed most of the hardwood species for diameter growth after fifteen growing seasons. Stem form for most species tended to be relatively poor with most trees producing multiple curved stems from low forks. Silver maple produced an average of 3.3 stems per tree which was significantly more than for any other species. Neither diameter growth nor tree form was found to be altered after fifteen growing seasons when established with or without mixed species herbaceous test plots.

The root systems on one or two trees of eight species in Compartments 1 and 2 were examined to a depth of 50 cm during the fifteenth growing season. Silver maple and river birch had extensive fibrous root systems to a depth of approximately 30 cm that were restricted primarily to the sludge-treated surface layers. A few trees like bur oak and baldcypress had developed roots that penetrated the compaction interface created during the grading of the site and subsequent sludge application. Root penetration tended to occur in the decomposing sandstone rocks mixed in the graded overburden.

Natural Regeneration

More than 20 species were regenerating in one or more compartments across the sludge-treated western watershed at the Palzo mine site (Table

5). The most frequent volunteer species in these compartments were white and green ash, Virginia pine, and river birch. These species when planted also had above average post-establishment survivals in these same compartments. The large population of volunteer cottonwood found after the first growing season (Jayko 1978) did not persist in any of the compartments.

A surprising amount of regeneration occurred on the untreated compartment (Table 5). There were indications that disturbance adjacent to our control compartment had resulted in the addition of lime and fertilizers to the compartment. Regeneration within the control compartment suggests that loblolly pine, river birch, and sweetgum are more tolerant of acidic minesoils than most other species found growing at the Palzo mine site.

The ungraded cast overburden from above the Dekoven coal seam produced a diverse population of hardwoods with few conifers. Most of this regeneration was established before grading and treating of the adjacent compartments. Much of the current regeneration is short-lived, shade-intolerant species such as American elm, black locust, river birch, and sycamore. Few red oak species and no white oak or hickory species were found suggesting these ungraded spoils will not, for many years if ever, regenerate into oak-hickory stands typical of the adjacent natural stand.

Discussion

This study on amended acidic minesoil has provided new insight on tolerance of trees to adverse conditions and environmental factors as they relate to tree establishment and growth. The successful establishment and acceptable growth after fifteen growing season for woody species on the highly acidic Palzo minesoils can be related to improved chemical soil conditions following application of high rates of municipal sewage sludge. The sludge solids had a high pH and eliminated much of the acidity. Stucky et al. (1980) reported an average soil pH of 5.3 after the first growing season and 4.9 after the third growing season. The principal volunteer woody species found in 1977 consisted of eastern cottonwood, sassafras, white ash, red maple, box elder, red mulberry, and river birch (Jayko 1978). The long-term survival of acid-tolerant species like river birch, Virginia pine, and loblolly pine and loss of less acid tolerant species like cottonwood in the sludge-treated compartments (Vogel 1981) and untreated compartments suggest soil pH has fallen below 4.5 during the last twelve growing seasons under many of the trees.

The heavy addition of both organic matter and nutrients in the sludge made tree establishment possible on these extremely acid minesoils essentially devoid of vegetation the previous 14 to 18 years. During the last 15 years the trees have continued to add organic matter through litter and appear to be recycling nutrients to maintain acceptable growth of the more acid-tolerant tree species. Tree species differed markedly in the types of root systems found in soil pits dug adjacent to established trees. Some showed only development of extensive fibrous root systems in the upper soil layers where sludge solids had been incorporated. For others, deep root penetration was occurring following decomposition of sandstone rocks in the compacted interface created during grading and sludge application.

We conclude that addition of heavy applications of sewage solids provided needed organic matter and plant nutrients, but it did not maintain the pH's found after incorporating the sludge. Acid-tolerant species must still be planted to maintain long-term growth on minespoils high in exposed shales containing pyrites. In addition, it should be noted that the best tree growth occurred on ungraded spoils where acid-forming materials were kept out of the tree rooting zone.

Table 5. Woody regeneration found fifteen growing seasons after treating with municipal sewage sludge compared to regeneration on an untreated control compartment, an adjacent ungraded cast overburden, and an adjacent natural stand.

Species	Natural stand	Ungraded spoil	Control unit	Sludge treated
	#trees/ha			
Baldcypress	----	----	2.2	0.8
Loblolly pine	----	8.3	19.6	0.8
Virginia pine	----	----	----	7.8
E. white pine	----	25.0	8.7	0.2
Red cedar	50.0	----	4.4	1.2
Mixed elms	10.0	233.0	----	2.7
Black alder	----	25.0	----	----
Black cherry	20.0	16.7	----	1.1
Black locust	----	150.0	----	1.5
Honey locust	----	----	----	0.8
Hickory	190.0	----	----	----
Black gum	100.0	100.0	----	----
Bur oak	----	----	----	0.2
White oak	140.0	----	----	----
Other wh. oaks	10.0	----	----	0.2
Mixed red oaks	100.0	58.3	2.2	0.3
Cottonwood	----	8.3	----	0.6
Hornbeam	410.0	----	----	----
Dogwood	50.0	41.7	----	----
Mixed ashes	20.0	33.3	----	11.6
Persimmon	----	16.7	----	0.4
Sumac	----	----	2.2	2.7
Mulberry	----	----	----	1.8
River birch	----	166.7	47.9	8.8
Sassafras	340.0	66.7	----	0.1
Hard maples	----	50.0	2.2	0.4
Sugar maple	200.2	----	----	----
Sugarberry	----	66.7	----	----
Sweetgum	----	50.0	28.3	4.8
Sycamore	----	91.7	----	0.5
A. tulipwood	----	16.7	----	0.1

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