MUNICIPAL SEWAGE SLUDGE AND PHOSPHORUS AS AMENDMENTS FOR MINESOILS ON THE CUMBERLAND PLATEAU[1].

by

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Abstract. A study was conducted to evaluate the benefit of applying municipal sewage sludge and/or phosphorus on surface mined land on the Cumberland Plateau in Fentress County, Tennessee. The objective of the study was to evaluate minesoil fertility and plant response after treatment. The site was prepared according to surface mine regulations and sampled before and after treatment. The experiment was conducted as a split, split, split block arranged in a randomized complete block design with four replications. Each replication contained a sludge treatment, a phosphorus treatment, a sludge/phosphorus combination treatment and a control. Minesoils amended with sludge alone had the greatest increase in fertility and plant response. Phosphorus alone had a comparable, though slightly lower response of plant growth on the sludge. Legume species responded particularly well on phosphorus. A combination of sludge and phosphorus had a slightly suppressive effect on some plant growth responses compared to sludge alone.

Additional Key Words: Minesoil Fertility, Sludge Application, Revegetation.

Introduction

The impact of surface mining for coal on the land is a major environmental concern. Surface mined land has been reclaimed to the standards of the Surface Mine Reclamation Act of 1977 (Wagner, 1979) since its inception. New soils created after the surface mining processes range from highly acid to neutral pH values. Soils that are highly acid have high concentrations of Al and Mn. Additionally, these soils contain low levels of N, P and organic matter (OM). Researchers have reported that these conditions are detrimental to plant growth and corrective measures should be employed for successful establishment of vegetation (Fribourg *et al.*, 1981; Lyle, 1987; Sopper and Seaker, 1990). Spoil from the "high-sulfur" coal of the eastern U. S. containing various forms of pyrite (FeS_2) must be limed sufficiently to counteract the continuing formation of sulfuric acid. Within two years spoil will become too acid to support a satisfactory vegetative cover if not limed sufficiently (Sopper and Seaker, 1990).

An alternative to standard fertilization is to use municipal sewage wastes. Halderson and Zenz (1978) reported that typical plant nutrient analyses of municipal sewage wastes is as follows; N = 5% ; P = 2.5%; and K = 0.4% (on % dry matter basis). Advantages of reclamation with sewage sludge are the rapid incorporation of OM and plant nutrients into the minesoil (Loehr *et*

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al., 1979).

Studies in Pennsylvania showed that applying sludge to minesoils enhanced seed germination and vegetative growth (Loehr *et al.*, 1979). A study of sludge application on revegetated minesoil in West Virginia indicated that grass density and biomass increased with increased application of sludge, while numbers and biomass of legume species decreased (Skousen, 1988). Data and observations on the Fentress County mine site (Walker, 1993) confirmed this observation.

Sludge provides an immediate addition of OM and microorganisms to the soil. Natural accumulation of organics usually takes many years to complete. Municipal sludges also contain varying quantities of the needed P from detergents and other sources and could supply up to 27% of the P needed in agriculture (Sommers and Sutton, 1980; Suss, 1981). The P available to plants in sludge varies from 20-100% compared with 100% in monocalcium phosphate (Haan, 1981). However, the larger quantities of P, N and OM in municipal sludge could counteract the chemical binding of P that takes place due to poor minesoil conditions.

Moisture stress causes P to be unavailable to plants (Ozanne, 1980). The OM in sludge helps the soil retain moisture, which could aid P availability. Sludge stabilized by heavy lime treatment can have value as a liming agent as well as by adding organics and N (Jacobs, 1981). Application of limed sludge must be carefully controlled as excessive quantities of limed sludge can create pH levels that are too high and conditions detrimental to plant growth (Morel, 1981; Walker, 1993).

Minesoils are often moderately to extremely deficient in P which is an important plant nutrient for establishing most plant species (Fribourg *et al.*, 1981; Buck and Houston, 1986). The low pH of some minesoils binds P to Al and Fe in chemically insoluble forms unavailable for plant use. Phosphate dissolved in H_2SO_4 (a by-product of pyrite oxidation in acid minesoil) is too strongly bound to Fe and Al oxides for plant uptake (Hani *et al.*, 1981). The addition of P to the soil is particularly helpful in the initial establishment of vegetation, especially when legumes are desired.

The objective of this study was to evaluate the benefit to plant growth and soil fertility of applying municipal sewage sludge and/or P on surface mined land in Tennessee.

Materials and Methods

Site Location

The experiment was located on the Cumberland Plateau in Fentress County approximately 2 miles south of Jamestown, TN and west of state highway 127 at an approximate elevation of 1600 ft. above mean sea level (Fig. 1). The study site was a 3.5 acre portion of an area that had been surface mined for bituminous coal by the Meta-Elkhorn mining company. Approximately 25-30 ft. of overburden was removed to reach the Nemo coal seam. The minesoils were dominately a fine sandy loam texture containing weathered sandstone, coal, and shale fragments (Branson *et al.*, 1991).

Geology and Soils

The study area was located on the Cumberland Plateau overthrust containing Pennsylvanian age sandstone and shale (Stearns, 1954). The Crab Orchard Mountain group (Rockcastle conglomerate) was identified as the sandstone removed during the mining. The Rockcastle formation is characterized as a sandstone with a shaly unit and coal horizon which occurs approximately in the middle of the formation.The native soils on the Cumberland Plateau are Ultisols and Inceptisols that have formed in residuum in the Pennsylvanian sandstones and shales, or in colluvium from sandstone and shale. The dominant soils are 2 to 4 feet deep over rock (Springer and Elder, 1980) well drained, loamy, strongly acid, and low in natural fertility especially with respect to phosphorus (Jared, 1972).

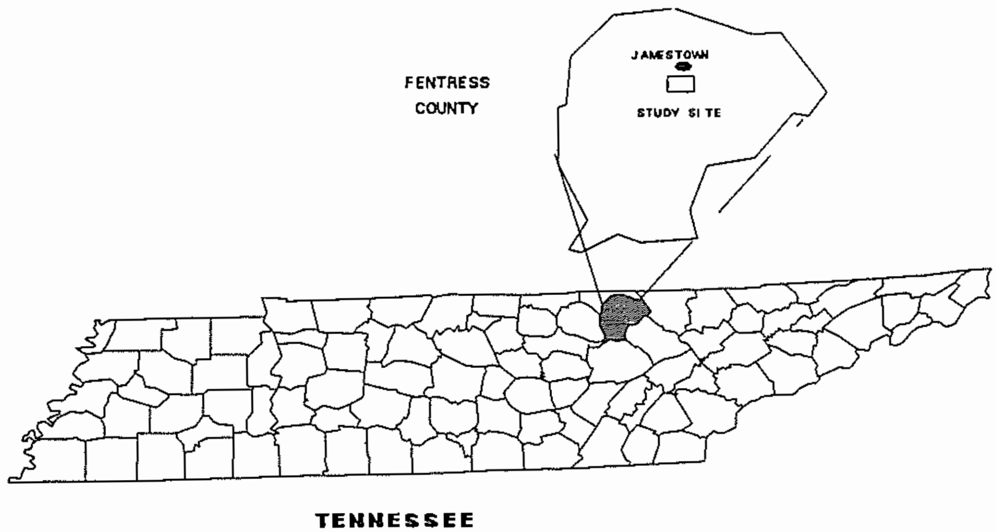

Figure 1. A map showing the study site, located in Fentress County, Tennessee.

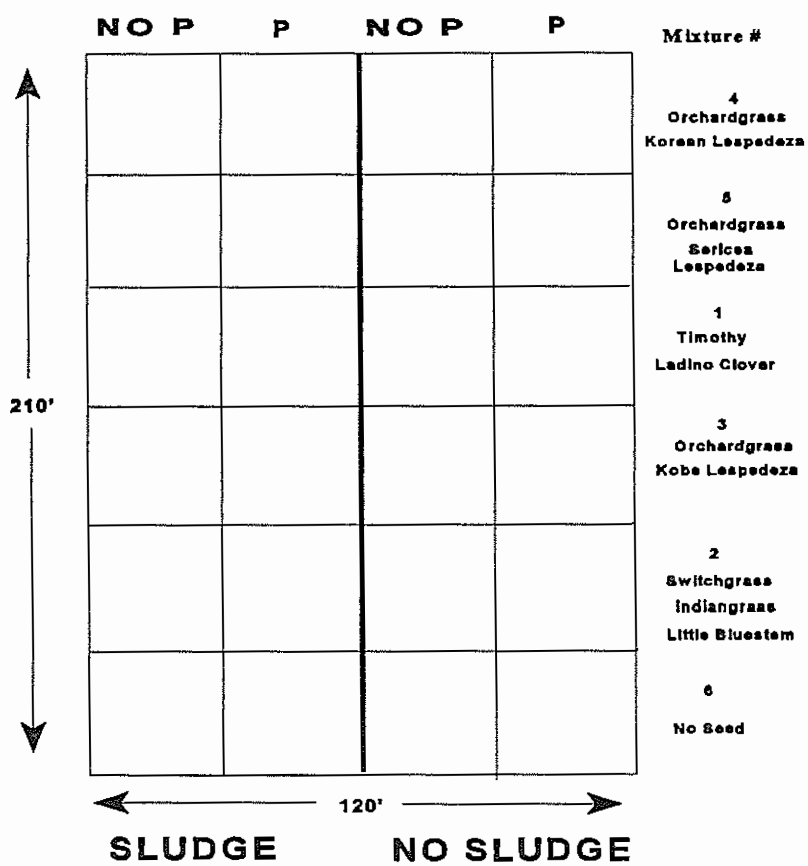

Figure 2. Schematic design of a representative experimental block containing the randomly located sludge and P amendments and seed mixtures.

Field Methods

The study site was prepared and limed by the mine company according to surface mine reclamation regulations prior to installation of the research plots and soil amendments (Wagner, 1979). The research area was divided into four blocks, each measuring 210' long and 120' wide, for the experiment. Figure 2 shows a representative experimental block. Eight soil samples were collected at 6 inch depths from within each split block and combined into bulk samples prior to soil amendment. One-half of three blocks was amended with open-air, composted sludge from Rockwood, Tennessee. One-half of one block was amended with limed, dewatered, municipal sewage sludge from Knoxville, Tennessee. Acquisition difficulties necessitated the use of sludges from two sources. One-half of each block was left unamended by sludge. Bulk samples were collected from each load of sludge before it was applied to the site. The sludge was dumped at rates varying from 8 to 16 tons per acre depending on the amount in the truck (1 truck load was applied to each block), spread with a box grader, and incorporated into the minesoil to a depth of 6 to 8" by discing. It was not possible to incorporate uniform quantities of sludge throughout the sludge blocks. After the sludge was applied, triple superphosphate $Ca(H_2PO_4)_2$ was applied by a cyclone hand spreader to half of each sludge strip and half of each unamended strip at a rate of 50 lbs P/acre .

The statistical design was a split, split, split block with 4 replications. Each replication contained 4 different soil amendments and 6 seed treatments in 30' by 35' plots (Fig. 2). Each replication contained a sludge amendment, a P amendment, a sludge + P combination amendment and an unamended-limed control applied in randomly selected strips. Plots were then seeded in randomly selected strips across all amendments with one of the following five seed mixtures.

1) Ladino clover, *Trifolium repens*, timothy, *Phleum pratense* (LDT)
2) Switchgrass, *Panicum virgatum*, indiangrass, *Sorghastrum nutans*, little bluestem, *Schizachyrium scoparium* (WSG)
3) Kobe lespedeza, *Lespedeza striata*, orchardgrass, *Dactylis glomerata* (KBO)
4) Korean lespedeza, *Lespedeza stipulacea*, orchardgrass (KRO)
5) Sericea lespedeza (A. U. Lotan), *Lespedeza cuneata*, orchardgrass (AUO)
6) No Seed Control (NS)

Vegetation was identified and percent cover was estimated visually in five one square foot quadrats within each plot post-amendment in 1989 and 1990. Soil samples were collected to 6 inch depths and combined as a bulk sample from each half block preamendment in 1989. A soil sample was collected from each seed plot and combined as a bulk sample from within each amended and unamended strip in each block in 1990.

Sample Analysis

The blocks were mapped for areas of light to heavy sludge content and this information was considered in the plant statistical analysis. Chemical analyses were performed on the soil samples and statistical analyses (SAS General Linear Models and Least Squares Means) were performed on the soil and vegetation data (SAS, 1989).

Soil and Sludge pH. The pH was measured in the laboratory on representative samples of the sludges applied to the minesoil. The sludge from Rockwood, TN had an average pH of 6.2. The sludge from Knoxville, TN had an average pH of 11.0. The pH was measured on each of the soil samples taken at the site (Southern Cooperative Series, 1974).

Cation Analysis. Soil samples were extracted using the Mehlich I soil test (Baker and Amacher, 1982; Southern Cooperative Series 1974). The extracts were analyzed for P, Ca, K, Mg, Cu, Zn, Mn, and Fe on an Inductively-Coupled Plasma Spectrophotometer (Shugar and Dean, 1990).

Results and Discussion

Observation of the study site in

June 1989, (one month after treatment and seeding) revealed dramatic differences in vegetative response among amendments. Seeds on unamended control areas had germinated, but plants were very sparse and severely stunted. Plants on P amended plots had germinated well and showed fair to good growth depending on the species. Sludge treated areas showed dense, luxuriant growth, in part due to heavy weed and tomato seed contamination of the open-air composted Rockwood sludge. The lime-stabilized, dewatered Knoxville sludge had no weed seed contamination, possibly due to high pH, and the applied experimental seeds germinated well. Excessive applications of lime-stabilized sludge were apparently toxic to the plants as no seeded species germinated in isolated spots of excessively concentrated Knoxville sludge. It appeared that P application greatly enhanced performance of all the legume species (Fig. 3). Grass species such as timothy and orchardgrass grew much more vigorously on sludge amended areas than on the other amendments. Unseeded controls had very sparse growth on all amendments, but volunteer species were present even on unamended plots. The plots amended with the combination sludge + P had slightly less cover than those amended with sludge. All treatments except the unamended plots resulted in 60 to 90% cover in 1990 (Fig.4). Grasses were more vigorous on sludge treated soils while legumes were predominant on P treatments. The percent cover of all seed mixtures on the combination (sludge + P) amendment remained slightly lower than the same mixtures on sludge alone, perhaps due to chemical toxicity or binding of needed phosphorus or other nutrients.

Table 1 shows minesoil fertility analyses on experimental plots before and after treatment. Values for pH on preamendment plots ranged narrowly between 5.1 to 5.2 for the plots. Ca averaged 228 lbs/a. Phosphorus concentrations ranged from 0.5 to 3.4 lbs/a, near the lower end of detection limits. K averaged 67 lbs/a and Mg 50 lbs/a.

Table 1 shows a dramatic increase in the Ca values between the preamendment analysis in 1989 (228 lbs/a) and the unamended control for 1990 (2169 lbs/a) which was attributed to the addition of lime during site preparation. Lime increased the pH of the unamended control plots to an average of 6.3. P and K levels showed little change from the preamendment levels after lime application. K levels were low for legumes and plants that germinated on limed, unamended plots were severely stunted. Mg levels were an average of 47 lbs/a higher after the addition of lime.

Effect of amendment on soil fertility

All soil fertility levels measured were higher on minesoil amended with P than on the limed, unamended control (Table 1). However, these changes were not significant at the $p \leq 0.05$ level. Statistical analysis of the differences between the preamendment (prior to lime and soil amendment) fertility levels of 1989 and the limed, P-amended fertility levels of 1990 for all nutrients showed no significance (Table 2). Minesoils amended with sludge had higher P levels by 244 lbs/a compared to the unamended control and 215 lbs/a compared to the P amendment (Table 1). These differences were significant at the $p \leq 0.05$ level. K levels on sludge plots were similar to levels on the unamended control and on P amendments. Ca and Mg levels were not significantly higher on sludge than on the other soil amendments. Statistical analysis of the differences in the preamendment (prior to lime and soil amendment) fertility levels from 1989 and the limed, sludge-amended levels from 1990 show P levels to be significantly higher on the sludge amendment at the $p \leq 0.05$ level (Table 2).

The combination sludge + P amendment exhibited a reduction of P and Mg, when compared to the sludge amendment, possibly due to inconsistent sludge application (Table 1). However, the percent cover of vegetation was lower on the combination amendment than the sludge with the application error considered. Statistical analysis of soil fertility showed no significant effect of the combination amendment on any nutrients

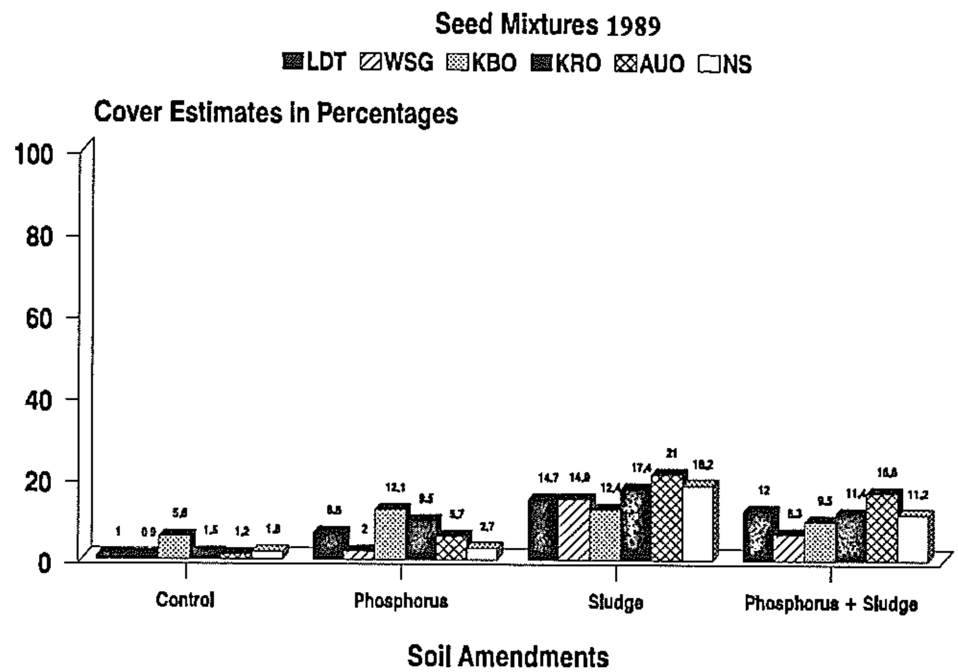

Figure 3. Mean percent cover estimated visually for each wildlife seed mixture relative to soil amendments during the first growing season in 1989. Abbreviations defined in Field Methods.

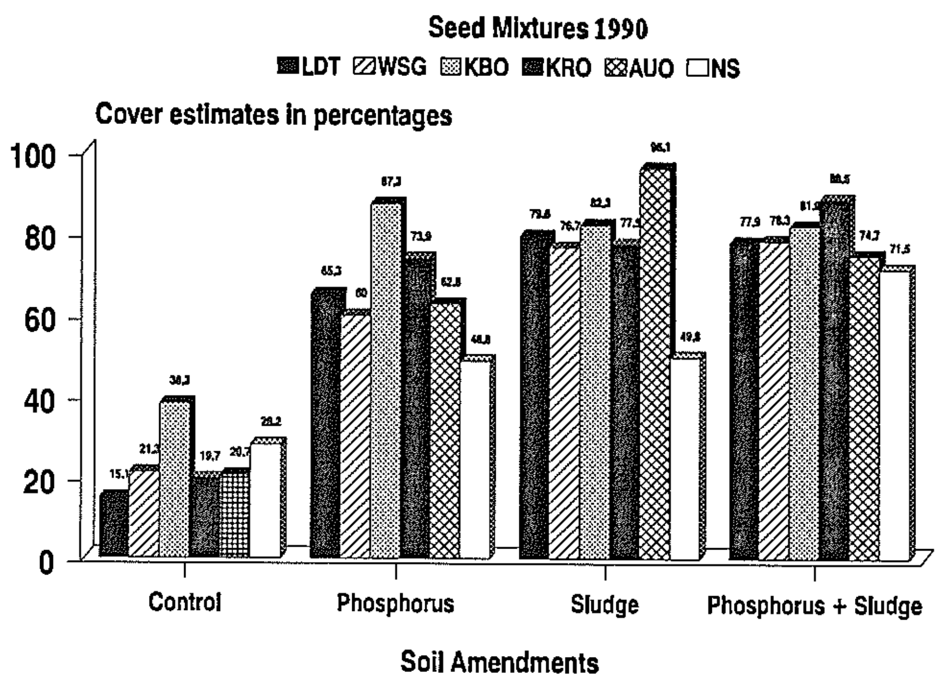

Figure 4.Mean percent cover estimated visually for each wildlife seed mixture relative to soil amendment during the second growing season in 1990. Abbreviations defined in Field Methods.

Table 1: Minesoil fertility analysis in 1989 before liming and soil amendments and in 1990 after liming and soil amendments. N=4. Least squares means ± standard error are shown.

Amendment	Lbs/A Ca	P	K	Mg	pH
Preamend[@]	228 ± 50	2 ± 0.5	67 ± 2	50 ± 3	5.2 ± 0.02
Control[1]	2169 ± 632	3 ± 46	77 ± 8	97 ± 18	6.3 ± 0.16
P	3675 ± 706	31 ± 52	90 ± 9	144 ± 20	6.5 ± 0.18
Sludge	4280 ± 815	246 ± 60*	86 ± 11	173 ± 23	6.5 ± 0.21
S + P	4007 ± 706	99 ± 52	79 ± 9	138 ± 20	6.7 ± 0.18

*Significant differences in soil fertility due to soil amendment based on Type III SS PR>F ≤0.05

[@]Nutrients before application of lime and soil amendments.

[1] Unamended, limed control. Statistics do not include preamendment values.

Table 2: Differences in minesoil fertility of plots between 1989 and 1990 (Amended minus unamended). N=4. Least squares means + standard error are shown.

Amendment	Lbs/A Ca	P	K	Mg	pH
Control	1919 ± 606	1 ± 46	11 ± 12	47 ± 18	1.1 ± 0.19
P	3457 ± 677	28 ± 52	23 ± 13	98 ± 20	1.4 ± 0.21
Sludge	4088 ± 782	243 ± 59*	18 ± 15	122 ± 23	1.3 ± 0.24
S + P	3769 + 677	97 + 52	12 + 13	85 + 20*	1.6 + 0.21

*Significant differences in soil fertility due to soil amendment based on Type III SS PR>F ≤ 0.05.

compared to the limed control. Statistical analysis of the differences in the preamendment (prior to lime and soil amendment) fertility levels from 1989 and the limed, combination amended levels from 1990 showed Mg levels significantly higher on the combination amendment at the $p \leq 0.05$ level (Table 2). Differences in the other nutrient levels were not significantly affected by the combination amendment.

Effect of soil amendment on heavy metals

Heavy metals were present in small quantities prior to soil amendment in 1989 (Table 3). Preamendment Cu levels averaged 0.75 lbs/a, Fe averaged 64 lbs/a, Mn averaged 27 lbs/a, and Zn averaged 4 lbs/a. Pb and Cd levels were too low to detect in all samples analyzed. The post amendment data for the 1990 limed, unamended control show heavy metal levels on all control plots decreasing slightly from the preamendment levels (Table 3). None of the changes in heavy metal concentration between the limed control and the P amendment were statistically significant (Table 3). Differences in heavy metal concentrations from preamendment (prior to lime and soil amendment) levels in 1989 to post-amendment levels in 1990 did not change significantly with the application of P (Table 4). Minesoils amended with sludge had Cu levels 9.0 lbs/a higher than the unamended control ($p \leq 0.05$) and 8.8 lbs/a higher than the phosphorus amendment ($p \leq 0.05$) (Table 3).

Sludge amendment had no significant impact on the levels of Fe. Sludge had significantly higher levels of Mn and Zn compared with the unamended control and the P amendment. Copper and Zn levels were significantly higher on sludge plots after lime and sludge were applied ($p \leq 0.05$) (Table 3). Mn levels were significantly lower on sludge ($p \leq 0.05$) than the preamendment levels. Application of sludge and lime did not significantly change Fe levels.

Minesoils amended with the combination sludge + P amendment contained lower levels of Cu and Mn and much lower levels of Zn compared to the sludge amendment, possibly due to inconsistent sludge application (Table 3). There was no significant effect of the combination amendment on any heavy metal concentrations compared to the unamended control. Statistical analysis of the differences between preamendment (prior to lime and soil amendment) metal levels in 1989 and post-amendment levels in 1990 indicated no significant differences on the limed, combination amendment from preamendment levels (Table 4).

Phosphorus as a Soil Amendment

P application in this study enhanced the establishment of vegetation. Plots amended with P in Fentress County were visibly higher in vegetative cover and the plants were more vigorous than plants on unamended control plots in both growing seasons (Figures 3 and 4). The P amendment was sufficient to establish vigorous stands of all the species of legumes in the legume/grass seed mixtures planted. P application in this study resulted in higher initial vegetative response. Other studies have shown that continued applications of P are required to maintain long term stands (Barnhisel *et al.* 1979).

The legumes on P amended plots will add N and, eventually, OM to the minesoil. However, this will occur more slowly than with organics supplied through the addition of municipal sludge. Ca, Mg and K fertility levels were increased with the application of triple superphosphate $Ca(H_2PO_4)_2$. Triple super phosphate contains 20% Ca, which explains the increase in Ca levels seen on P amended plots (Lyle, 1987). K levels were similar on all three soil amendments ,though slightly lower on the sludge + P amendment.

Municipal Sludge as a Soil Amendment

Previous studies of fertilization with sewage sludge have indicated that equal or better long

Table 3: Minesoil heavy metal analysis in 1989 before liming and soil amendment and in 1990 after liming and soil amendments. n=4.Least squares means ± standard error are shown.

Amendment	Lbs/A Cu	Fe	Mn	Zn
Preamendment[8]	0.76 ± 0.03	63 ± 4	27 ± 1	4.2 ± 0.3
Control[1]	0.68 ± 1.41	52 ± 11	14 ± 4	3.3 ± 16
Phosphorus	0.82 ± 1.58	48 ± 12	19 ± 4	3.9 ± 18
Sludge	9.66 ± 1.82*	46 ± 14	30 ± 5*	100.3 ± 21*
Sludge + P	3.97 ± 1.58	50 ± 12	26 ± 4	31.1 ± 18

*Significant differences in heavy metal concentration due to soil amendment based on type III SS PR>F ≤0.05.
[8]Nutrients before application of lime and soil amentments.
[1]Unamended, limed control. Statistics do not include preamendment values.

Table 4 Changes in minesoil heavy metal concentration between 1989 and 1990 (Amended minus Unamended). N=4. Least squares means ± standard error are shown.

Amendment	Lbs/A Cu	Fe	Mn	Zn
Control	-0.09 ± 1.42	-16.4 ± 14.6	-12.4 ± 5.4	-0.7 ± 16
Phosphorus	0.04 ± 1.58	-19.0 ± 16.3	-9.0 ± 6.0	-0.5 ± 18
Sludge	8.90 ± 1.83*	-9.3 ± 18.9	-1.3 ± 6.9*	95.8 ± 21*
Sludge + P	3.23 ± 1.58	-10.8 ± 16.3	-1.8 ± 6.0	27.2 ± 18

*Significant differences in heavy metal concentration due to soil amendment based on Type III SS PR>F ≤ 0.05.

term benefits may be derived from the incorporation of sludge than from traditional fertilizers (Hani *et al.*, 1981; Larsen, 1981; Vogel, 1981; Wolt, 1985). Analyses of percent cover in this study support this contention (Figures 3 and 4). Vegetative cover was consistently greater on sludge and combination sludge + P plots than on P or unamended plots. Orchardgrass was more competitive than lespedeza species on the sludge and sludge + P combination amendments than on P. Timothy densities were greater than those of ladino clover on sludge amended plots. Vegetative growth and cover were improved on sludge plots relative to the other amendments with all seed mixtures, including the unseeded control (amendments and seed mixtures defined in Field Methods). The relatively high cover values on the unseeded sludge plots were due to high concentrations of weed seeds present in the Rockwood sludge. Unseeded controls on sludge and combination plots had greater vegetative cover than unseeded controls on unamended plots and P plots. Improved soil conditions of higher fertility, organics, and better moisture retention on sludge and combination plots encouraged the appearance and growth of volunteer plant species, including tree seedlings such as tulip poplar, maple, and cedar.

Conclusions

1. Minesoil acidity was reduced from preamendment levels by the application of lime. The P, sludge, and combination amendments further reduced acidity.
2. All nutrient levels were higher on the P amendment than on the limed control.
3. A greater quantity of nutrients was detected on minesoil amended with sludge than on the other amendments.
4. The combination sludge + P amendment exhibited a lower level of all nutrients and slightly less vegetative cover compared to the sludge amendment.
5. Lime application reduced heavy metal levels from preamendment levels.
6. A single application of 16 tons/a of municipal sludge did not add unacceptable levels of heavy metals.
7. The combination sludge + P amendment had lower heavy metal levels than the sludge amendment with the exception of iron.
8. The sludge amendment had greater vegetative cover than all other amendments in the first growing season.
9. Percent cover on the P, sludge and combination amendments increased, with less difference between amendments, in the second growing season. All amendments had greater cover than the control.

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