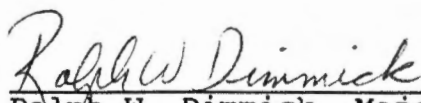


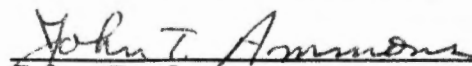
To the Graduate Council:

I am submitting herewith a thesis written by Cynthia L. Walker entitled "Municipal Sewage Sludge and Phosphorus as Soil Amendments for Enhancing Wildlife Habitat on Reclaimed Surface Mines." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

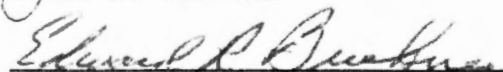


Ralph W. Dimmick, Major Professor

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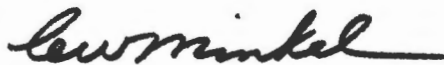


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Associate Vice Chancellor and
Dean of the Graduate School

MUNICIPAL SEWAGE SLUDGE AND PHOSPHORUS AS SOIL
AMENDMENTS FOR ENHANCING WILDLIFE HABITAT ON
RECLAIMED SURFACE MINES

A Thesis

Presented in Partial Fulfillment of

The Master of Science

Degree

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Cynthia L. Walker

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ABSTRACT

The purpose of this study was to evaluate the benefit of municipal sewage sludge and/or phosphorus as soil amendments for enhancing wildlife habitat on reclaimed surface mined land. Five forage seed mixtures beneficial to wildlife were tested: 1) Ladino clover and timothy 2) switchgrass, indiangrass, and little bluestem 3) kobe lespedeza and orchardgrass 4) korean lespedeza and orchardgrass 5) A. U. lotan lespedeza and orchardgrass. An unseeded control was included. The objectives of the experiment were 1) to compare species viability and plant productivity on surface mined land amended with and without sludge and/or phosphorus, 2) to evaluate minesoil acidity, fertility, and heavy metal content before and after soil amendment, and 3) to evaluate, over a two-year period, the dynamics of species composition of plots within the different amendments and seed mixtures.

Minesoil exhibited increased fertility levels with all soil amendments. Minesoil amended with sludge had the greatest increase in fertility. Amended minesoil had greater vegetation percent cover and stand height compared with the unamended control and there were significant differences in cover among soil amendments. Differences occurred in density of vegetative cover and stand height due to type of seed mix present. Stem counts of the individual species in the seed mixtures and the

volunteer grassy and broad-leaf species differed depending on the type of soil amendment and on the type of seed mix present.

Municipal sewage sludge effectively enhanced soil fertility and organic content of minesoil and aided establishment of vegetation. Phosphorus aided in the rapid establishment of vegetation, particularly legumes, on limed but otherwise unamended minesoil. A combination of sewage sludge and phosphorus fertilizer had a negative impact on some vegetative responses compared to sludge alone. Plants chosen to enhance wildlife habitat were successfully established and provided acceptable cover on surface minesoil.

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CHAPTER I

INTRODUCTION

Unregulated surface mining for coal left many acres of disturbed land in several states. Surface mining refers to the removal of the soil and strata over a mineral or fuel deposit in order to remove the deposit itself (Ramani and Grim, 1978). The Surface Mine Reclamation Act of 1977 (Wagner, 1979) finally addressed this type of land disturbance. It set certain requirements on the mining companies to restore the lands they mine as close to the original contour and natural state as possible. Mining companies are required to post a bond of \$10,000 or more for each mining site. This provides some assurance that the mining companies will complete the approved reclamation plan or lose their bond money. The topsoil removed during mining operations, or an approved substitute, must be replaced and a diverse vegetative cover must be reestablished within a specified period of time. The companies must meet these requirements within a 5 to 10 year period after mining is completed. Failure to comply results in an additional 5 to 10 years before they can reclaim their bond. Forfeiture can mean loss of license and other penalties (National Research Council, 1981).

The soil replaced after the surface mining process is complete is sometimes moderately to highly acid to neutral,

with pH ranging from 3.5 to 7.5. It commonly has high concentrations of aluminum and manganese, and low levels of nitrogen, phosphorus and organic matter. These conditions are detrimental to plant growth (Fribourg et al., 1981; Lyle, 1987; Sopper and Seaker, 1990). Corrective measures using liming and fertilization of the soil aid in establishing vegetative cover. However, it takes time to rebuild soil organic matter. Nitrogen may be the major element limiting the establishment of vegetation (Miles et al. 1973). Spoil from the "high-sulfur" coal of the eastern U. S. containing forms of FeS_2 must be limed sufficiently to counteract the continuing formation of sulfuric acid ($\text{FeS}_2 + \text{H}_2\text{O} + \text{O}_2 \rightarrow \text{H}_2\text{SO}_4 - - \text{H}^+$), or within two years the soil will become too acid to support a satisfactory vegetative cover (Sopper and Seaker, 1990). Soil fungi and actinomycetes, which help legumes fix nitrogen, cannot exist in these acidified soils (Darmer, 1973).

An alternative to standard fertilization is to use municipal sewage wastes. A typical plant nutrient analysis of N (nitrogen)=5 : P (phosphorus)=2.5: K (potassium)=0.4 (% dry matter basis) is representative for municipal sludges (Halderson and Zenz, 1978). Sludges are usually low in the nutrient K and may require supplementation (Sommers and Sutton, 1980). The advantages of reclamation with sewage sludge are the swift incorporation of organic matter and plant nutrients into the soil (Loehr et al., 1979). This encourages

the redevelopment of soil biota (Hill et al. 1979; Stadelmann and Furrer, 1983; Whitford and Elkins, 1986; Lyle, 1987), reduces reclamation cost and increases reclamation success (Lejcher et al., 1973; Parizek, 1986). It also provides a useful means for disposing of the vast amounts of sewage waste produced by municipal treatment plants (Greibel et al., 1979; Kardos et al., 1979; Kerr et al., 1979; Mays and Giordano, 1988). Soil monitoring regulations where sludge is used for amending soils in Tennessee require that the sludge be characterized, the soil pH be tested annually, and soil P, K, and heavy metals be monitored every three years (Southern Cooperative Series, 1986).

Minesoils are often moderately to extremely deficient in phosphorus, an important plant nutrient (Fribourg et al., 1981; Buck and Houston, 1986). Phosphorus is indispensable to all forms of life due to its genetic role in RNA and DNA and its functions in energy transfer. P is usually the main life-limiting agent in natural ecosystems due to its low availability (Ozanne, 1980). Low levels of soil phosphorus make the initial establishment of vegetation difficult. The low pH of some minesoils binds phosphorus 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 for plant uptake (Hani et al., 1981). Liming minesoil tends to neutralize acid conditions and makes many plant nutrients more readily

available by eliminating Fe, Al and Mn toxicity and reducing P fixation (Sanchez and Uehara, 1980). The addition of phosphorus to the soil is particularly helpful in the initial establishment of vegetation, especially when legumes are desired. If a legume-grass mixture is established, the legumes will add nitrogen to the soil via their nitrogen fixing capabilities making it available for non-legume plants (Bennett et al., 1978; Brown et al., 1986). Phosphorus increases nitrogen fixation by nodulated legumes. Grass growing with the legume responds with higher yields to the level of applied P giving maximum N fixation for the legume rather than to the level of P required by the grass itself (Ozanne, 1980).

One objective of returning a surface mine to an acceptable state is encouraging wildlife to inhabit the area. Unfortunately, many of the plants that have traditionally been used to establish vegetative cover due to their adaptability on poor, droughty soils or their ease of establishment (ex. *Serecea lespedeza* and weeping lovegrass) have not been the best choices for wildlife protective cover, nesting cover, or forage. These plants usually dominate the site. This limits the diversity in food and cover and may retard or prevent invasion of indigenous plant species (Sole and Mastrangelo, 1980; Vogel, 1981). The reclamation of these disturbed lands would be greatly enhanced if the use of a variety of plant species valuable to wildlife could be encouraged and shown to

be economically feasible (Russell, 1979). Also, the lack of typical soil arthropods is directly attributed to the lack of a developed litter layer on minesoil, which may limit the use of mine sites by insectivorous bird species (Pentecost and Stupka, 1979). The use of sewage sludge as a soil amendment may help alleviate this problem by creating the proper substrate for reinvasion of soil arthropods.

In the spring of 1989 an experiment was set up on a coal surface mine on the Gernt family property in Fentress County, Tennessee, on the Cumberland Plateau. The purpose of the study was to evaluate the relative benefits of using municipal sewage sludge with and without a supplement of phosphorus, and phosphorus alone as soil amendments in the reclamation of surface mined land. Five grass and grass-legume mixtures beneficial to wildlife were utilized to evaluate their response to these soil amendments. The objectives of the experiment were: 1) to compare species viability and plant productivity of seed mixtures beneficial for wildlife habitat on surface mined land amended with and without sludge and/or phosphorus, 2) to evaluate minesoil acidity, fertility and heavy metal content before and after soil amendment 3) to evaluate, over a five year period, the dynamics of species composition within the different amendments and seed mixtures. This study reports on the establishment of the experiment and the response of vegetation during the first two years after establishment.

CHAPTER II

STUDY AREA

The experiment was located on the Cumberland Plateau in Fentress County approximately 2 miles south of Jamestown, Tennessee west of state highway 127 at an approximate elevation of 1600 ft. ASL (Figure 1). The study site was on a 3.5-acre portion of the Gernt family property that had been surface mined for bituminous coal by the Meta-Elkhorn mining company. It was designated as area 10 OSM #2669 by the Office of Surface Mining. The coal bed that was mined is referred to as the Nemo Coal Seam. Approximately 25-30 ft. of overburden was removed to reach the coal seam, which was 24-39 inches thick. The topsoil was fine sandy loam containing weathered sandstone, coal, shale, and mica fragments (Branson et al., 1991). It was replaced after mining and the area was graded and limed.

Geology

The study area was located on a part of the Cumberland Plateau overthrust. Pennsylvanian geology is represented by the Crab Orchard Mountain group, and the study area is located on the Rockcastle conglomerate. The Pennsylvanian stratum exposed in the Crab Orchard Mountains begins with a basal sandstone which grades into siltstone or sandy shale. This is

TENNESSEE

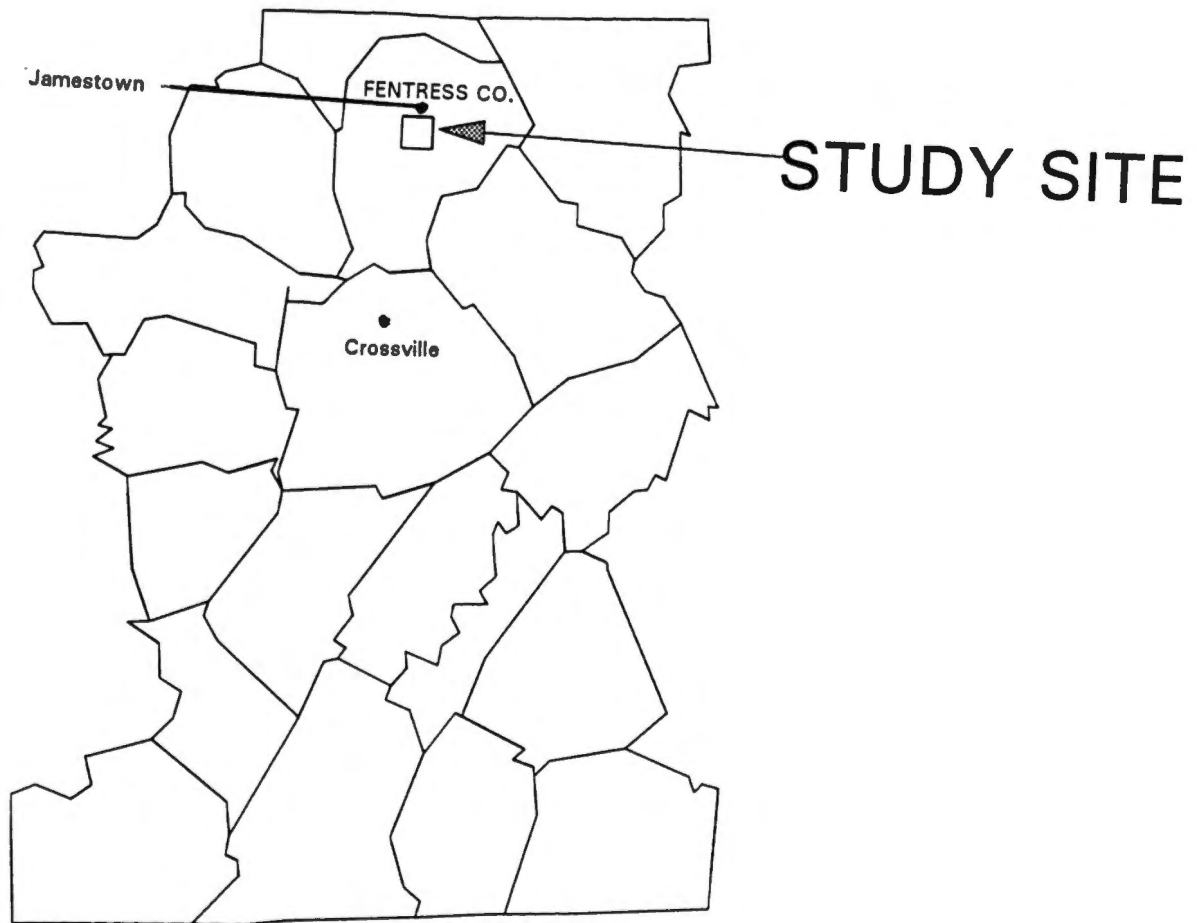


Figure 1: A map of the study site, including Fentress County and surrounding counties in Tennessee.

followed by underclay and then the coal zone. The coal zone often includes several benches of coal spread through an interval of as much as 20 feet. The coal zone is overlain by shale which may contain ironstone or occasionally impure limestone bands. This may grade into sandy shale or siltstone before the next sandstone. The sequence of strata is repeated several times. The Rockcastle sandstone is named from the exposures of the Crab Orchard Mountains in Rockcastle Cove near Jamestown, Tennessee, and is about 150 ft. thick. It is quartz sandstone with a shaly unit and coal horizon which occurs approximately in the middle of the formation. Exposures of this formation are seen along U. S. Highway 70 east and west of Crab Orchard, Tennessee (Stearns, 1954).

Soils

The Cumberland Plateau soils are Ultisols and Inceptisols and are formed directly from the Pennsylvanian sandstones and shales, or from materials weathered from them and moved downslope. The dominant soils are 2 to 4 feet deep over rock, well drained, loamy, strongly acid, and low in natural fertility (Springer and Elder, 1980) especially with respect to phosphorus (Jared, 1972).

A soil pit was dug after amendments were applied to characterize the soils at the study site. The surface layer was weathered sandstone with mica fines and had a pH of 7+. The second and third layers were weathered sandstone with high

carbon shale, and registered pH 4.5-5.0. Plant roots descended only through the 2nd layer. Those roots touching the third soil layer appeared slightly damaged. The upper layer was highly compacted from the weight of the grading vehicles (Branson et al., 1991). Compaction may negatively affect water infiltration (Fribourg et al., 1981; Vogel 1981). Excessive compaction is potentially the most serious obstacle to successful soil reconstruction, inhibiting root development and causing poor air and water movement and low plant productivity. Compaction may cause soils to take up to 20 years to return to their original productive capacity (Zell, 1982).

Topography

The Cumberland Plateau is a gently rolling to hilly highland marked on the east, south, and west side by a prominent escarpment. Numerous gorges have cut deeply into the plateau, resulting in waterfalls and rugged terrain (Springer and Elder, 1980). The topography of the study region is dissected with steep stream bluffs (Branson, et al., 1991). The study site was fairly level with gentle slopes in a few locations and easily accessible.

Climate

According to classification schemes of Koppen and Thornwaite, the climate of Tennessee is humid mesothermal with

abundant rainfall during all seasons (Trewartha and Horn, 1971). The Cumberland Plateau and Highland Rim mean annual temperatures range from 55 to 57 F. The average annual rainfall ranges from 52.00 to 59.07 inches. The dates of latest killing frost range from April 30 in lower elevations to May 10 in higher altitudes. The earliest killing frost dates range from Sept. 30 to Oct. 10. The average number of days in the growing season ranges from 172 to 190 (Brehm, 1926).

Monthly weather data were collected at the Allardt weather station in Fentress County for the study period (Appendix tables 18 and 19). The average annual temperature of the study site for 1989 was 54.2 F, slightly lower than normal. The yearly rainfall for 1989 was 67.78 inches, higher than the 52 to 59 inch normal rainfall. The average annual temperature for 1990 was 58.0 F and the yearly rainfall was 50.94 inches, slightly lower than normal.

Vegetation

The Cumberland Plateau vegetation is a component of the mixed mesophytic forest region. Climax forest communities are deciduous mixed mesophytic and hemlock-mixed mesophytic. Subclimax forests are pine and pine-oak and, prior to the chestnut blight, oak-chestnut (Jared, 1972). Stream banks and stream bogs may be occupied by swamp forest containing pin oak (*Quercus palustris*), sweetgum (*Liquidambar styraciflua*), red

maple (*Acer rubrum*), and swamp white oak (*Q. bicolor*) (Harlow et al., 1978). Beech (*Fagus grandifolia*), river birch (*Betula nigra*), alder (*Alnus rubra*) and swamp shrubs are also common. On the slopes, beech and tulip trees (*Liriodendron tulipifera*) are found, grading into oak and oak-pine communities on level ground. Other oaks and hickories may be present. Dogwoods (*Cornus florida*) are usually the dominant understory tree with scattered patches of shrubs such as rhododendron (*Rhododendron maximum*). Ravine slopes contain the more mesic hemlock-mixed (*Tsuga caroliniana*) mesophytic forests with occasional basswood (*Tilia americana*) and buckeye (*Aesculus octandra*). Communities of post oak (*Q. stellata*) and blackjack oak (*Q. marilandica*) occupy shallow, dry areas of the plateau where sandstone is close to the surface, a situation much like the location of the study area. Some of the plateau promontories contain open pine woods with a grassy layer of *Andropogon scoparius*, *A. glomeratus*, and *Sorghastrum nutans*. Frequent fires have modified these pine summits to prevent establishment of the climax communities on these dry ridges (Braun, 1974).

Wildlife

Big game species found on the Cumberland Plateau are white-tailed deer (*Odocoileus virginianus*), scattered herds of European wild boar (*Sus scrofa*), and wild turkey (*Meleagris gallopavo*). Small game species present are ruffed grouse

(*Bonasa umbellus*), mourning dove (*Zenaida macroura*), northern bobwhite (*Colinus virginianus*), eastern cottontail (*Sylvilagus floridanus*), fox squirrel (*Sciurus niger*), eastern gray squirrel (*Sciurus carolinensis*), waterfowl, and American woodcock (*Philohela minor*). Fur-bearing mammals are raccoon (*Procyon lotor*), beaver (*Castor canadensis*), river otter (*Lutra canadensis*), mink (*Mustela vison*), muskrat (*Ondatra zibethica*), red fox (*Vulpes fulva*), gray fox (*Urocyon cinereoargenteus*), and bobcat (*Lynx rufus*). A few of the many non-game species of the area are eastern chipmunk (*Tamias striatus*), southern flying squirrel (*Glaucomys volans*), longtail weasel (*Mustela frenata*), skunk (*Mephitis mephitis*), woodchuck (*Marmota monax*), blue heron (*Ardea herodias*), many species of songbirds, and the endangered red-cockaded woodpecker (*Dendrocopus borealis*) (Zimmerman, 1975; Burt and Grossenheider, 1976).

CHAPTER III

MATERIALS AND METHODS

Before the study began, the area was prepared according to surface mine reclamation regulations (Wagner, 1979). After the site was prepared, the area was surveyed by a licensed surveyor and the minesoil amended according to my study plan. Soil data was collected from the study site both pre- and post-amendment in 1989. Vegetation data was collected post-amendment in 1989 and 1990. Chemical analyses were performed on the sludge and soil samples and statistical analyses (SAS General Linear Models and Least Squares Means) were performed on the soil and vegetation data.

Site Preparation

The coal in the study area was excavated using earth-moving equipment and blasting. The mine company replaced the topsoil that was removed prior to mining, graded the area, and applied lime to the soil at a rate of no more than 2 tons per acre, the rate we requested. Samples of the minesoil were taken prior to the addition of lime or other amendments to establish a baseline level for soil pH and soil nutrients.

The study site was surveyed and divided into four blocks, each 210' long and 120' wide, for the experiment. Half of each block was amended with dewatered municipal sewage

sludge from Knoxville, Tennessee, or composted sludge from Rockwood, Tennessee. Acquisition difficulties necessitated the use of sludges from two sources. Half of each block was left unamended by sludge. The Rockwood sludge was composted in open-air drying beds at the Rockwood sewage treatment plant and the Knoxville sludge was limed and dewatered at the Knoxville sewage treatment plant. The sludges were transported in trucks which were weighed on the coal mine truck scales in order to calculate the quantity of sludge spread on each block. The sludge was dumped at rates varying from 8 to 16 tons per acre depending on the size of the truck load, spread with a box grader, and incorporated into the minesoil to a depth of 6 to 8" by discing.

The sludge was spread unevenly. Consequently the blocks were mapped with respect to density of sludge. These data were incorporated into the analysis using least squares means to compensate for the imbalance. After the sludge was applied, super triple phosphate 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/per acre of phosphorus.

A soil pit was dug in 1990 to 1 m in depth in order to characterize the layers in the minesoil (Branson et al. 1991). Field pH measurements were taken at each layer.

Experimental Design

The experiment is a split, split, split block with 4

replications. Each replication contains 4 different soil amendments and 6 seed treatments for a total of 96 plots (Figure 2).

Soil Amendments

Each replication contains a sludge amendment, a phosphorus amendment, a sludge/phosphorus combination amendment and an unamended control applied in randomly selected strips.

Seed mixtures

Once the soil amendments had been applied, plots were seeded with one of the following five seed mixtures, selected for their value to wildlife.

- 1) Ladino clover (LD), timothy (TI) - (LDT).
- 2) Switchgrass (SW), indiangrass (IND), little bluestem (LB) - (warm season grasses) (WSG).
- 3) Kobe lespedeza (KB), orchardgrass (OR) - (KBO).
- 4) Korean lespedeza (KR), orchardgrass (OR) - (KRO).
- 5) A. U. lotan lespedeza (AU), orchardgrass (OR) - (AUO).
- 6) No Seed Control (NS).

The purpose of the no seed control was to compare the seed mixtures used with the types of volunteer species that would appear on unseeded areas of the different soil amendments applied. Seeding was accomplished on 12 May 1989. Each block was divided into 6 strips across all soil

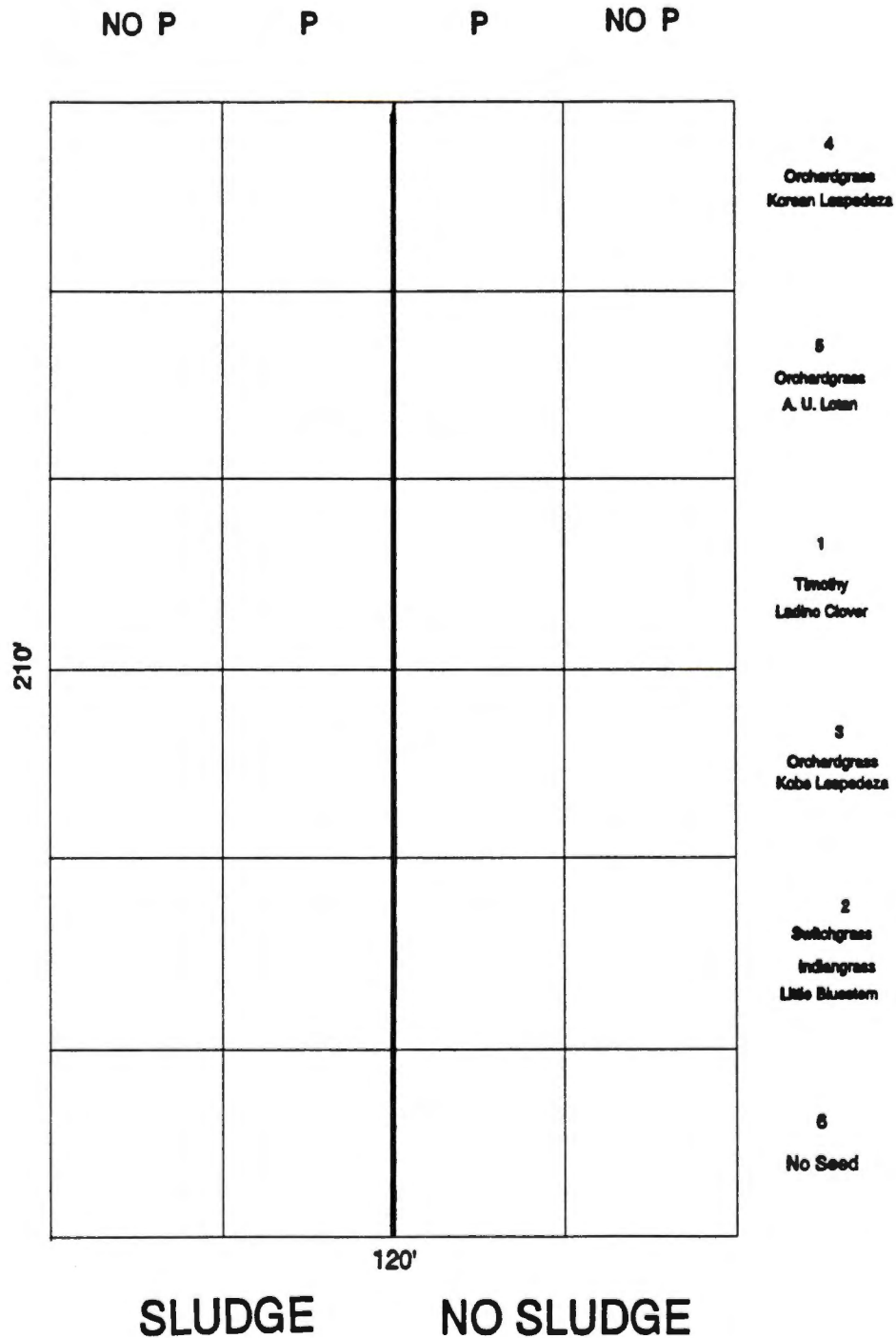


Figure 2: Schematic design of a representative experimental block containing the randomly located sludge and P amendments and seed mixtures.

amendments and the selected seed mixtures were randomly applied with a cyclone seeder (seeding rates - Appendix table 20). The areas surrounding and separating the blocks were seeded with tall fescue (*Festuca arundinacea*). The area was then mulched with straw (2.5 tons per acre).

Data Collection

Soil Sampling

Soil samples were taken with a soil auger from each block prior to the application of lime, soil amendments, and seeding in March 1989. Soil samples were collected after application of soil amendments from each amendment area during the second growing season in August 1990.

Vegetation Sampling

A computer program was generated for use in the data collection. The individual amendment/seed plots in the study measure 30' by 35'. The program generated random numbers that were converted into paces. Beginning in the southwest corner of each plot 5 different locations within each plot were selected with these random numbers and used as a location for sampling vegetation.

A square foot area at each sampling location was measured using a small metal quadrat (Oosting, 1956). Within this area the individual plants of each species seeded in the plot were

counted. All other species in the area were counted and identified as either a wild grass or a broad-leaf plant. Vegetation height for each location was measured in centimeters. Vegetative cover is the proportion, expressed in percent, of ground surface with plant material directly above it (Fischer, 1986). A visual estimate of percent cover for each area was obtained (Barnhisel et al., 1985). A point-quadrat device was also used to evaluate percent cover (Leisman, 1958; Buckner, 1985; Barbour et al, 1987). A point-quadrat is a frame composed of 10 movable pins. The number of hits on cover were recorded. Percent cover was calculated with the equation $\% \text{ cover} = (\text{hits on cover} / 10 \text{ total points}) 100$. (Barbour et al., 1987).

Data Analysis

Soil and Sludge pH

Soil pH was measured in the laboratory on representative samples of the sludges applied to the minesoil (Table 1) and on each of the soil samples taken at the site (Tables 2 and 3). Ten ml of distilled water was added to each 10g soil sample and stirred. The dewatered and composted sludge samples were very dry so it was necessary to add 20ml of water per 10g of sludge. The samples were allowed to stand for 1 hr with periodic stirring. The pH of each sample was then measured with a glass electrode pH meter (Southern Cooperative Series,

Table 1: Laboratory pH values of Rockwood and Knoxville municipal sewage sludge.

	<u>Sample 1</u>		<u>Sample 2</u>		<u>Sample 3</u>	
	pH A	pH B	pH A	pH B	pH A	pH B
Rockwood Sludge	6.2	6.4	6.3	6.4	5.9	5.8
Knoxville Sludge	10.4	11.0	11.2	11.3	----	----

1974).

Cation Analysis

Soil samples were analyzed for cations by several different methods. Samples were digested using the Dilute-Double-Acid-Extractable soil test (Baker and Amacher, 1982; Southern Cooperative Series 1974; Mehlich, 1984). Five g of each soil sample were weighed into a tared 125 ml Erlenmyer flask. Twenty ml of dilute double acid (0.05 N HCL and 0.025 N H₂SO₄) were added and the flasks stoppered and placed on an automatic shaker for 5 min. The samples were filtered through Whatman No. 1 filter paper. The samples were analyzed for P, Ca, K, Mg, Cu, Zn, Mn, and Fe on an Ion-Coupled Plasma Spectrophotometer (Shugar and Dean, 1990). Soil samples were also digested using Diethylenetriaminepentaacetic acid (DTPA) (Baker and Amacher, 1982; Mehlich, 1984). Ten g of soil and 20 ml of DTPA were placed on an automatic shaker for 2 hrs, then filtered through Whatman No. 42 filter paper and analyzed for Fe, Mn, Cd, Cu, Zn, and Pb on an Atomic Absorption Spectrophotometer (Shugar and Dean, 1990).

Vegetation Analyses

Statistical analyses of the vegetation data were performed by computer using SAS General Linear Models Procedure and Least Squares Means analysis (SAS Institute, 1989) to determine significance at the $p \leq 0.05$ level.

CHAPTER IV

RESULTS

Observation of the study site in June 1989, approximately one month after soil amendment and seeding, indicated dramatic differences in vegetative response among amendments. Seeds on unamended control areas had germinated, but plants were very sparse and severely stunted. Plants on phosphorus amended plots had germinated well and showed fair to good growth depending on the species. Sludge areas showed very dense, luxuriant growth, in part due to heavy weed and tomato contamination of the open-air composted Rockwood sludge. The dewatered Knoxville sludge had no weed contamination and showed very good germination of the experimental seeds. As the stands matured, it appeared that phosphorus application greatly enhanced performance of all the legume species. Grassy species such as timothy and orchardgrass appeared predominant or much more vigorous on sludge amended areas compared to the other amendments. Unseeded controls showed very sparse growth, but volunteer species were present even on unamended plots.

SOIL CHEMISTRY

Soil pH and Fertility

Soil samples were collected randomly across each

replication in 1989 before liming and amendment of the mine site. Samples were analyzed for pH, fertility, and heavy metals. During August 1990, soil samples were again collected randomly in each amendment strip after lime, soil amendments, and seed were applied. Samples were analyzed for the same constituents as in 1989.

Prior to soil amendment, pH of the experimental site was in the acid range, reading 5.1 to 5.2 across the area (Table 2). Calcium (Ca) levels were low, averaging 230 lbs/a. Phosphorus (P) was very low, almost below detection limits, ranging from 0.5 to 3.4 lbs/a. Potassium (K) averaged 67 lbs/a and magnesium (Mg) 50 lbs/a across the area.

Lime. The Meta-Elkhorn mining company applied lime to the entire site prior to sludge and phosphorus amendment at an approximate rate of 2 tons per acre. A dramatic increase in the Ca values between the preamendment analysis in 1989 (230 lbs/a) and the unamended, limed control for 1990 (2169 lbs/a) was attributed to the addition of lime (Table 2). Unfortunately, I could not do a direct statistical analysis of the effect of lime as an unlimed control was not included in the post amendment portion of the study. Lime increased 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. Mg levels were an average of 47 lbs/a with

Table 2: Minesoil fertility analysis in 1989 before liming and soil amendments and in 1990 after liming and soil amendments. N=4.

<u>Amendment</u>	Lbs/A				
	Ca	P	K	Mg	pH
Preamend	228 ± 49.97	2.1 ± 0.49	67.1 ± 1.96	49.8 ± 3.37	5.2 ± 0.02
Control	2169 ± 631.55	2.5 ± 46.17	77.2 ± 8.16	96.6 ± 17.74	6.3 ± 0.16
Phosphorus	3675 ± 706.09	30.7 ± 51.62	90.3 ± 9.12	143.5 ± 19.84	6.5 ± 0.18
Sludge	4280 ± 815.33	245.7 ± 59.60*	86.3 ± 10.53	173.0 ± 22.91	6.5 ± 0.21
S + P	4007 ± 706.09	98.5 ± 51.62	78.5 ± 9.12	138.0 ± 19.84	6.7 ± 0.18

Statistics based on analysis of least squares means

*Significant differences in soil fertility due to soil amendment based on Type III SS $pr > F \leq 0.05$

higher after the addition of lime.

Phosphorus. All soil fertility levels measured were higher on minesoil amended with phosphorus than on the limed, unamended control (Table 2). However, these changes were not significant at the 0.05 level.

Statistical analysis of the differences between the preamendment (prior to lime and soil amendment) fertility levels of 1989 and the limed, phosphorus-amended fertility levels of 1990 for all nutrients showed no significance (Table 3).

Sludge. Minesoils amended with sludge had higher P levels by 244 lbs/a compared to the unamended control and 215 lbs/a compared to the phosphorus amendment (Table 2). These differences were significant at the $p \leq 0.05$ level. Potassium levels on sludge plots were similar to levels on the control and on phosphorus. Ca and Mg levels were higher on sludge than on the other soil amendments, but not significantly.

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 3).

Combination Amendment. The combination sludge/phosphorus

Table 3: Differences in minesoil fertility of plots between 1989 and 1990 (Amended- minus unamended). n=4.

<u>Amendment</u>	Lbs/A				
	Ca	P	K	Mg	pH
Control	1918.6 $\pm$ 605.68	0.7 $\pm$ 46.02	10.8 $\pm$ 11.72	47.4 $\pm$ 17.77	1.14 $\pm$ 0.19
Phosphorus	3457.0 $\pm$ 677.17	28.4 $\pm$ 51.46	22.8 $\pm$ 13.11	97.5 $\pm$ 19.87	1.38 $\pm$ 0.21
Sludge	4088.3 $\pm$ 781.92	243.1 $\pm$ 59.42*	18.0 $\pm$ 15.13	122.3 $\pm$ 22.94	1.33 $\pm$ 0.24
Sludge + P	3768.8 $\pm$ 677.17	96.6 $\pm$ 51.46	11.8 $\pm$ 13.11	84.5 $\pm$ 19.87*	1.55 $\pm$ 0.21

Statistics based on analysis of least squares means.

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

amendment exhibited an across the board reduction in the nutrients when compared to the sludge amendment, possibly due to chemical binding (Table 2). Statistical analysis of soil fertility showed no significant effect of the combination amendment on any nutrients 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 3). Differences in the other nutrient levels were not significantly affected by the combination amendment.

Heavy Metals

Heavy metals were present in small quantities prior to soil amendment in 1989 (Table 4). Preamendment copper (Cu) levels averaged 0.75 lbs/a, iron (Fe) averaged 64 lbs/a, manganese (Mn) averaged 27 lbs/a, and zinc (Zn) averaged 4 lbs/a. Lead (Pb) and cadmium (Cd) levels were too low to detect in all samples analyzed.

Lime. The post amendment data for the 1990 limed, unamended control show heavy metal levels with a slight across the board reduction from the preamendment levels. (Table 4).

Phosphorus. None of the changes in heavy metal concentration

Table 4: Minesoil heavy metal analysis in 1989 before liming and soil amendment and in 1990 after liming and soil amendments. n=4.

<u>Amendment</u>	Lbs/A			
	Cu	Fe	Mn	Zn
Preamendment	0.76 $\pm$ 0.03	63.38 $\pm$ 4.32	26.88 $\pm$ 1.33	4.15 $\pm$ 0.28
Control	0.68 $\pm$ 1.41	51.80 $\pm$ 10.85	13.60 $\pm$ 3.46	3.26 $\pm$ 15.93
Phosphorus	0.82 $\pm$ 1.58	47.50 $\pm$ 12.13	19.00 $\pm$ 3.86	3.90 $\pm$ 17.82
Sludge	9.66 $\pm$ 1.82*	46.00 $\pm$ 14.01	29.68 $\pm$ 4.46*	100.33 $\pm$ 20.58*
Sludge + P	3.97 $\pm$ 1.58	49.50 $\pm$ 12.13	27.50 $\pm$ 3.86	31.12 $\pm$ 17.82

Statistics based on analysis of least squares means

*Significant differences in heavy metal concentration due to soil amendment based on type III ss $PR > F \leq 0.05$

between the limed control and the phosphorus amendment were statistically significant (Table 4).

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 phosphorus (Table 5).

Sludge. 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 4). 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 phosphorus amendment.

Cu and Zn levels were significantly higher on sludge plots after lime and sludge were applied ($P \leq 0.05$) (Table 5). 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.

Combination Amendment. Minesoils amended with the combination phosphorus/sludge amendment contained lower levels of Cu and Mn and much lower levels of Zn compared to the sludge amendment (Table 4). There was no significant effect of the combination amendment on any heavy metal concentrations compared to the unamended control.

Table 5: Changes in minesoil heavy metal concentration from 1989 and 1990 (Amended minus Unamended)

<u>Amendment</u>	Lbs/A			
	Cu	Fe	Mn	Zn
Control	-0.09 ± 1.42	-16.4 ± 14.61	-12.4 ± 5.36	-0.7 ± 15.88
Phosphorus	0.04 ± 1.58	-19.0 ± 16.34	-9.0 ± 5.99	-0.5 ± 17.76
Sludge	8.90 ± 1.83*	-9.3 ± 18.86	-1.3 ± 6.92*	95.8 ± 20.50*
Sludge + P	3.23 ± 1.58	-10.8 ± 16.34	-1.8 ± 5.99	27.2 ± 17.75

Statistics based on analysis of least squares means.

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

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 5).

VEGETATION RESPONSE

Vegetation response was measured for several parameters during two growing seasons, 1989 and 1990. These responses were related to the applications of soil amendments and seed mixtures. Statistical analyses were performed using SAS General Linear Models Procedure (SAS Institute 1989).

Percent Cover

Percent cover was estimated visually in August on five subsamples of each plot during the growing seasons of 1989 and 1990.

First Growing Season

Vegetation percent cover on all soil amendments in 1989 was greater than on the unamended controls at the $p \leq 0.05$ level (Table 6).

Table 6: Effect of seed mix and soil amendment on percent cover estimates in 1989. n=80.¹

Amend	LDT ₂	WSG	KBO	KRO	AUO	NS
%						
Control	1.0 ± 2.5	0.9 ± 2.5	5.6 ± 2.5	1.5 ± 2.5	1.2 ± 2.5	1.8 ± 2.5
Phos	6.5 ± 2.5	2.0 ± 2.5	12.1 ± 2.5	9.5 ± 2.8	5.7 ± 2.5	2.7 ± 2.7
Sludge	14.8 ± 3.2	14.9 ± 3.1	12.4 ± 3.6	17.4 ± 4.0	21.0 ± 3.7	18.2 ± 3.6
S + P	12.0 ± 2.5	6.3 ± 2.5	9.5 ± 2.5	11.4 ± 2.6	16.6 ± 2.6	11.2 ± 2.9

Statistics based on analysis of least squares means

¹There were significant differences in percent cover due to soil amendment in 1989 based on type III ss PR>F ≤0.05

₂ Abbreviations are defined on page 15.

Unamended Control. Cover on unamended control plots for 1989 ranged across seed mixtures from a mean of 0.9% to 5.6 % (Table 6). KBO had the greatest cover of the seed mixtures on the control plots and WSG the least cover (Figure 3). All seed mixtures had their lowest percent cover on unamended plots.

Phosphorus. Percent cover was greater for all seed mixtures on phosphorus plots in 1989 compared to the unamended control, ranging from a mean of 2.0 % to 12.1 % (Table 6). KBO had the greatest cover of the seed mixtures on phosphorus and WSG the least cover (Figure 3). KRO had greater cover on phosphorus than on the control ($p \leq 0.05$). KBO and KRO had greater cover on phosphorus than WSG ($p \leq 0.05$).

Sludge. Sludge amended plots had higher percent cover in 1989 for all seed mixtures than the unamended control and other soil amendments, ranging from a mean of 12.4 % to 21.0 % (Table 6). AUO had the greatest cover of the seed mixtures on sludge and KBO the lowest cover (Figure 3). Weeds in the composted sludge accounted for the high cover response on the no-seed plots amended with sludge. All seed mixtures except KBO had greater cover on sludge than on the control ($p \leq 0.05$). All seed mixtures except KBO had greater cover on sludge than on phosphorus at the $p \leq 0.05$ level.

Combination Amendment. The combination sludge + phosphorus

Seed Mixtures

LDT
 WSG
 KBO
 KRO
 AUO
 NS

33

Cover Estimates in Percentages

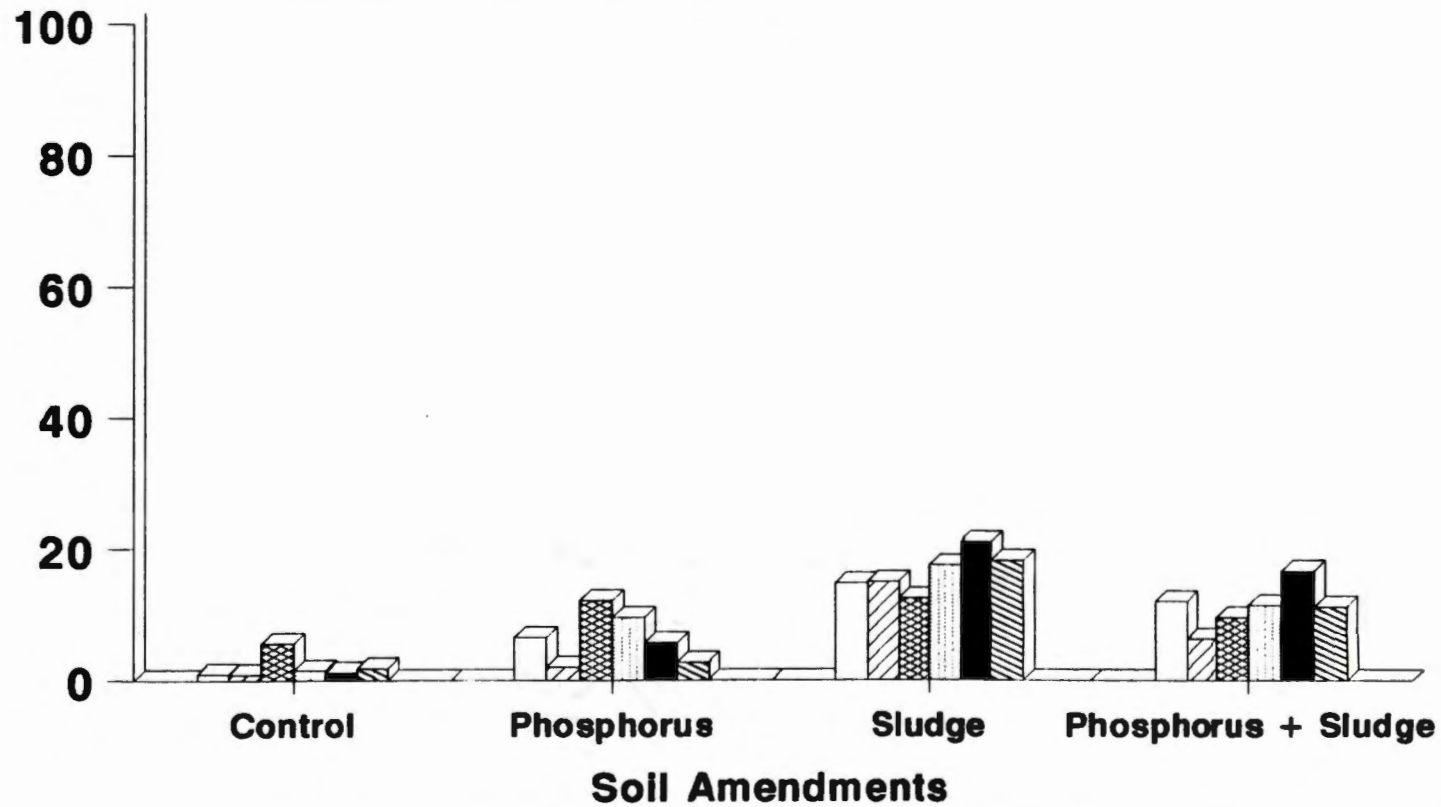


Figure 3: Visual percent cover estimates for 1989, seed mixtures, relative to soil amendments

, Abbreviations are defined on page 15.

amendment had lower percent cover in every seed mixture compared to sludge (Table 6). The combination amendment had higher percent cover with all seed mixtures compared to the unamended control in the first growing season ($p \leq 0.05$). Mean percent cover on this amendment ranged from 6.3 % to 16.6 %. AUO had the greatest cover of all the seed mixtures on the combination and WSG the lowest (Figure 3). WSG had lower cover on the combination amendment than on the sludge ($p \leq 0.05$). AUO had greater cover on the combination than KBO and WSG ($p \leq 0.05$).

The soil amendments and seed mixtures are ranked in order of descending percent cover in Appendix table 21. KBO, KRO, and AUO had significantly greater percent cover than WSG across all soil amendments ($p \leq 0.05$).

Second Growing Season

Vegetation percent cover on all soil amendments in 1990 was greater than on the unamended controls ($p \leq 0.05$) (Table 7).

Unamended Control. Cover percentages in 1990 indicated that by the second growing season, the differences in percent cover due to soil amendment had begun to converge as more growth developed (Table 7). The unamended controls continued to exhibit sparse growth. Percent cover ranged from means of

Table 7. Effect of seed mix and soil amendments on percent cover estimates in 1990. n=80.

1

<u>Amend</u>	LDT ₂	WSG	KBO	KRO	AUO	NS
				%		
Control	15.1 ± 4.8	21.3 ± 6.6	38.3 ± 6.0	19.7 ± 6.2	20.7 ± 4.9	28.2 ± 7.4
Phos	65.3 ± 4.8	60.0 ± 6.6	87.3 ± 6.0	73.9 ± 6.0	62.8 ± 4.9	48.8 ± 7.3
Sludge	79.6 ± 6.4	76.7 ± 9.9	82.3 ± 8.1	77.5 ± 8.5	96.1 ± 7.2	49.8 ± 8.5
S + P	77.9 ± 4.9	78.3 ± 7.2	81.9 ± 6.2	88.5 ± 6.0*	74.7 ± 5.3	71.5 ± 8.0

 Statistics based on analysis of least squares means

¹There was a significant difference in percent cover due to soil amendment in 1990 based on type III ss PR>F ≤0.05

² Abbreviations are defined on page 15.

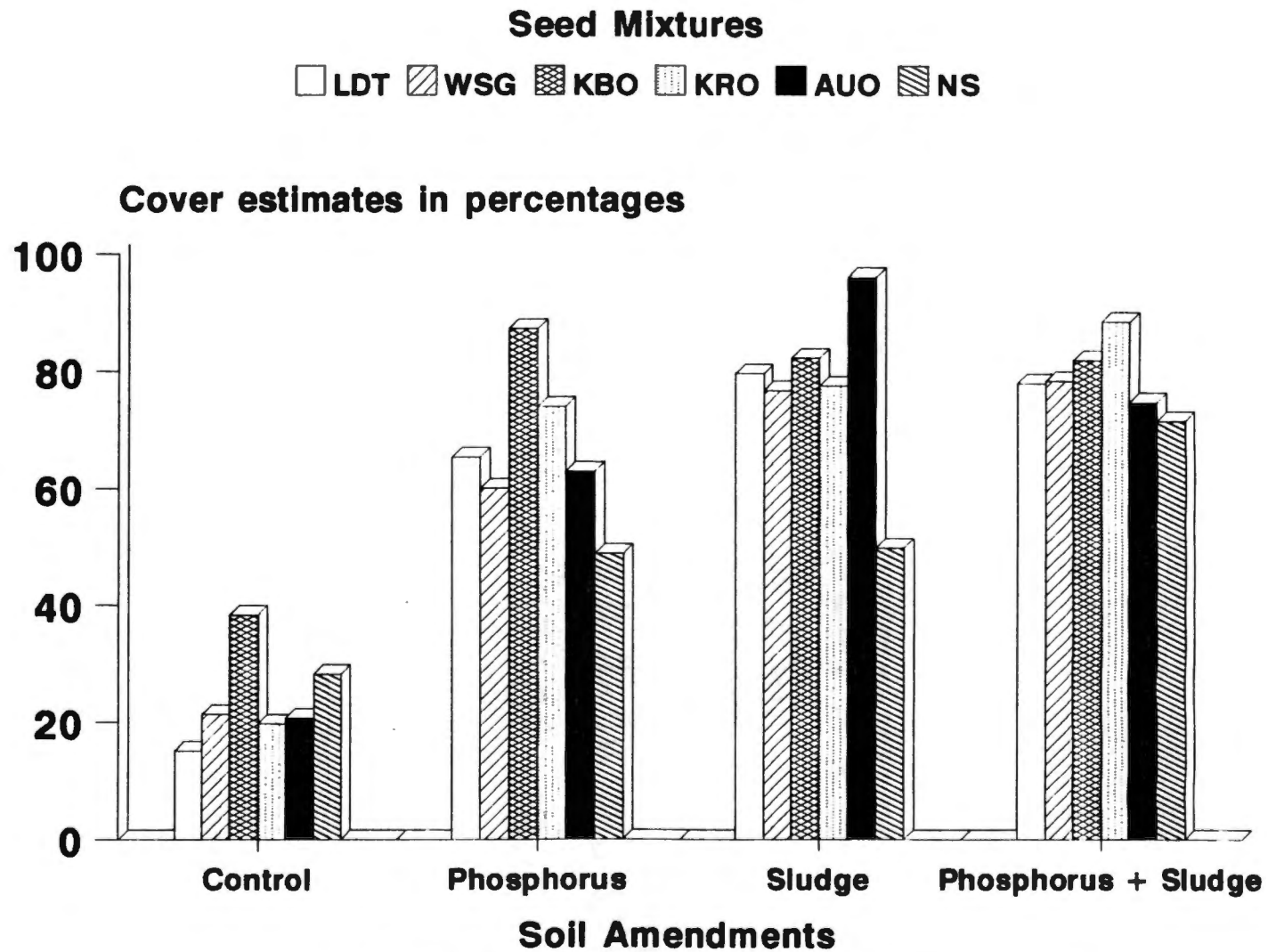


Figure 4: Percent cover estimates,
seed mixtures, relative to soil amendments in 1990
 , Abbreviations are defined on page 15.

15.1% to 38.3%. KBO had the greatest cover of the seed mixtures on the unamended control and LDT the lowest cover (Figure 4). All seed mixtures had the lowest percent cover on the unamended control.

Phosphorus. The plots amended with phosphorus had higher percent cover in all seed mixtures in 1990 than unamended plots ($p \leq 0.05$) (Table 7). Percent cover estimates ranged from a mean of 48.8% to 87.3%. KBO had the greatest percent cover of the seed mixtures on phosphorus and NS the lowest cover (Figure 4). Seed mixtures containing lespedeza species had greater cover on phosphorus than the other mixtures. LDT and WSG had lower percent cover than KBO on phosphorus ($p \leq 0.05$).

Sludge. The sludge maintained significantly higher cover on all seed mixtures than the unamended controls in 1990 ($p \leq 0.05$) (Table 7). Percent cover on the sludge amendment ranged from a mean of 49.8% to 96.1%. AUO had the greatest percent cover of the seed mixtures on sludge and NS the lowest cover (Figure 4). The high percent cover on NS plots on sludge in 1989 was reduced in 1990, likely due to the death of annual weeds in the composted sludge. NS had lower cover than the other seed mixtures on sludge ($p \leq 0.05$). Seed mixtures containing grasses had the highest cover on sludge. AUO cover was greater on sludge than on phosphorus ($p \leq 0.05$).

Combination Amendment. Percent cover on the combination amendment in 1990 was greater in all seed mixtures than on unamended plots ($p \leq 0.05$) (Table 7). Cover ranged from a mean of 71.5 % to 88.5 %. KRO had the greatest cover of the seed mixtures on the combination amendment and NS the lowest cover (Figure 4).

Soil amendments and seed mixtures in 1990 are ranked in order of descending percent cover in Appendix Table 22. NS had lower percent cover on all amendments than the other seed mixtures ($p \leq 0.05$).

Point-Quadrat

A point-quadrat sampling device was used to calculate percent cover objectively. Of 10 points, the number of points touching plants were recorded in 5 subsamples of each plot. Hits on plants were converted to percentages.

First Growing Season

Vegetation percent cover on all soil amendments in 1989 was greater than on the unamended controls ($p \leq 0.05$) (Table 8).

Unamended Control. The unamended control plots in 1989 exhibited low cover, ranging from a mean of 9.5% to 21.0%

(Table 8). KBO had the greatest cover of the seed mixtures on the control and KRO the lowest (Figure 5). All seed mixtures had the lowest cover on unamended plots.

Phosphorus. Percent cover in plots amended with phosphorus ranged from 16.0% to 42.5% (Table 8). Cover on phosphorus plots was greater than the unamended control ($p \leq 0.05$). LDT had the greatest cover of the seed mixtures on phosphorus and WSG the lowest cover (Figure 5). Seed mixtures containing legumes (clover and lespedeza) had greater cover on phosphorus plots than seed mixtures without legumes.

Sludge. Sludge amended plots had significantly greater cover than the unamended controls in 1989 ($p \leq 0.05$). Cover ranged from 39.0% to 67.1% (Table 8). AUO had the greatest percent cover of the seed mixtures on sludge and KBO the lowest cover (Figure 5). Seed mixtures containing grass species had the highest cover on sludge. WSG, AUO and KRO had higher cover on sludge than on phosphorus ($p \leq 0.05$).

Combination Amendment. The cover on the combination amendment in 1989 was greater than the unamended control ($p \leq 0.05$) (Table 8). Cover ranged from a mean of 25.5% to 43.9%. AUO had the most cover of the seed mixtures on the combination and KBO the lowest cover (Figure 5). AUO, KRO and LDT had

Table 8: Point quadrat: Effect of seed mix and soil amendment on percent cover calculated from number of hits on vegetation of 10 points in 1989. n=80.¹

<u>Amend</u>	LDT ₂	WSG	KBO	KRO	AUO	NS
			%			
Control	11.5 ± 4.4	16.0 ± 4.4	21.0 ± 4.4	9.5 ± 4.4	17.0 ± 4.4	19.5 ± 3.4
Phos	42.5 ± 4.5	16.0 ± 4.4	29.0 ± 4.4	30.5 ± 5.0	29.4 ± 4.2	18.9 ± 4.8
Sludge	58.0 ± 5.8	47.0 ± 5.5	39.0 ± 6.3	61.0 ± 7.1	67.1 ± 6.7	43.0 ± 6.8
S + P	43.0 ± 4.4	33.5 ± 4.5	25.5 ± 4.4	35.6 ± 4.7	43.9 ± 4.6	39.3 ± 5.1

Statistics based on analysis of least squares means

¹There were significant differences in point quadrat percent cover due to soil amendment in 1989 based on type III ss PR> F ≤ 0.05.

₂ Abbreviations are defined on page 15.

Seed Mixtures

LDT
 WSG
 KBO
 KRO
 AUO
 NS

41

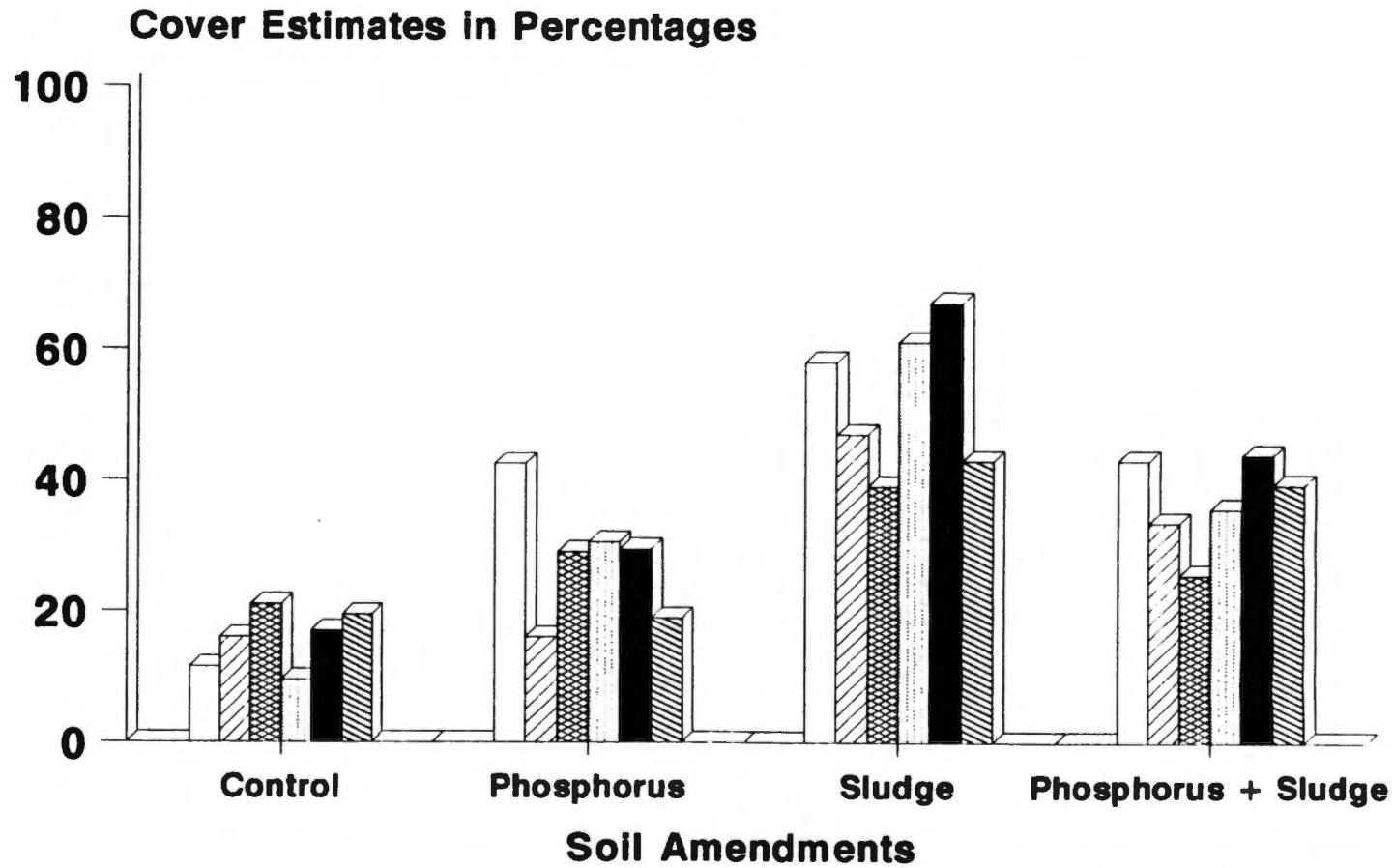


Figure 5. Quadrat percent cover calculated for 1989, seed mixtures, relative to soil amendments

Abbreviations are defined on page 15.

lower cover on the combination plots than on sludge ($p \leq 0.05$). Seed mixtures and soil amendments in 1989 are ranked by descending vegetative cover in Appendix Table 23.

Second Growing Season

Vegetation percent cover on all soil amendments in 1990 was greater than on the unamended controls ($p \leq 0.05$) (Table 9).

Unamended Control. The 1990 measurements showed cover on all soil amendments converging as stands developed (Table 9). The cover on unamended plots ranged from a mean of 30.0% to 45.0%. KBO had the greatest cover of the seed mixtures on control plots and LDT the lowest cover (Figure 6). All seed mixtures had their lowest cover on control plots.

Phosphorus. Cover on the phosphorus plots was significantly higher than on the unamended control plots ($p \leq 0.05$) (Table 9). Cover on phosphorus ranged from 60.0% to 77.0%. KRO had the greatest cover of the seed mixtures on phosphorus and NS the lowest (Figure 6). KBO had greater cover on phosphorus plots than AUO ($p \leq 0.05$).

Table 9: Point quadrat: Effect of seed mix and soil amendment on percent cover calculated from number of hits vegetation out of 10 points in 1990. n=80.¹

<u>Amend</u>	LDT ₂	WSG	KBO	KRO	AUO	NS
Control	30.0 ± 4.3	37.0 ± 5.8	45.0 ± 6.1	36.8 ± 6.0	32.5 ± 4.7	43.0 ± 6.5
Phos	67.5 ± 4.3	65.0 ± 5.6	77.0 ± 6.1	74.0 ± 5.8	60.0 ± 4.7	61.0 ± 6.5
Sludge	78.2 ± 5.8	72.2 ± 8.6	80.0 ± 8.2	71.0 ± 8.3	96.7 ± 7.0	56.0 ± 7.4
S + P	80.5 ± 4.4	81.2 ± 6.3	83.7 ± 6.3	87.5 ± 5.8	75.3 ± 5.1	71.8 ± 7.0

Statistics based on analysis of least squares means

¹There was a significant difference in point quadrat percent cover due to soil amendment in 1990 based on type III ss PR>F ≤0.05

₂ Abbreviations are defined on page 15.

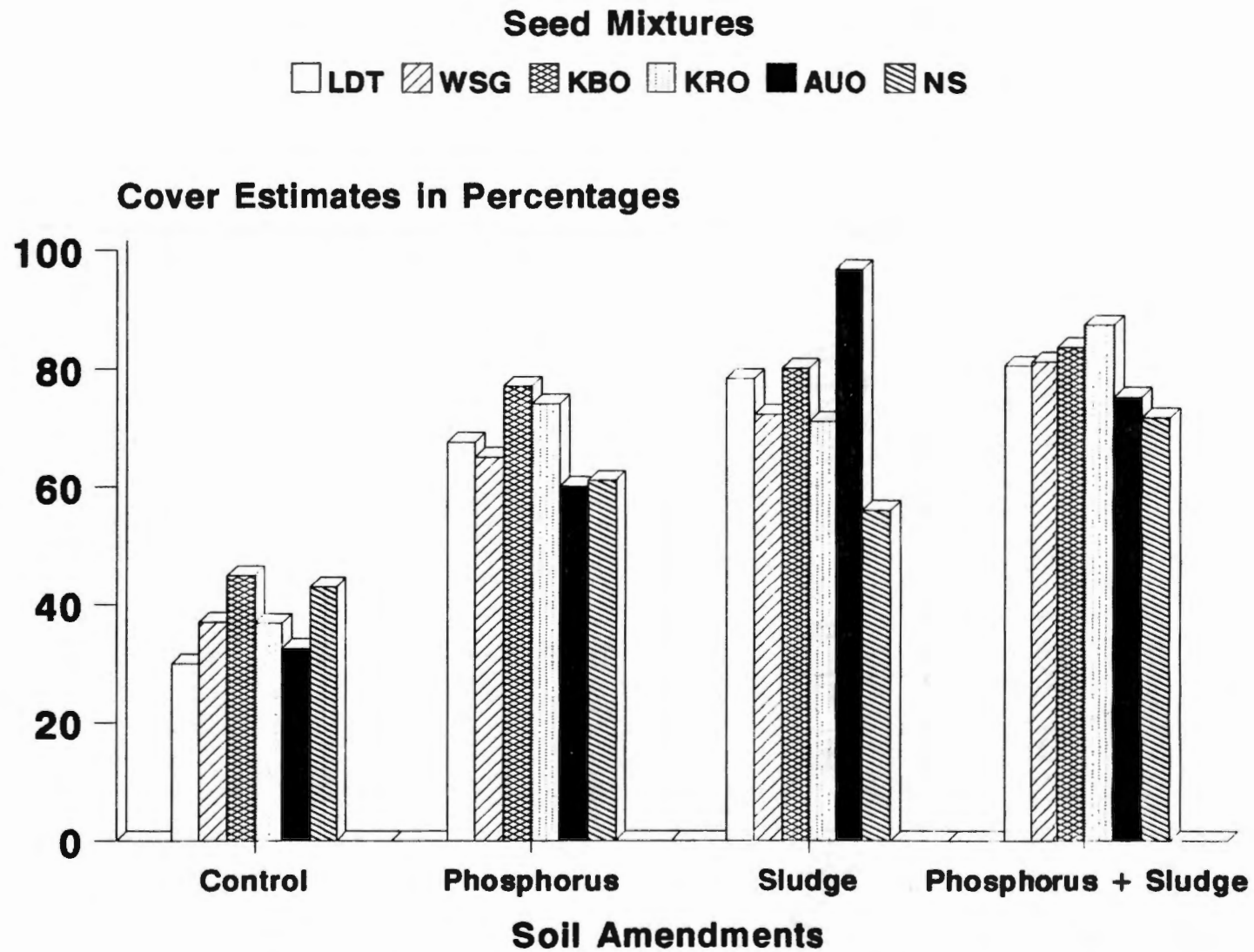


Figure 6. Quadrat percent cover calculated for 1990, seed mixtures, relative to soil amendments

Abbreviations are defined on page 15.

Sludge. In 1990, plots amended with sludge had higher cover than the plots amended with phosphorus and the unamended controls. Cover on sludge ranged from 56.0% to 96.7%, greater on all seed mixtures than on the unamended control ($p \leq 0.05$). AUO had the greatest cover of the seed mixtures on sludge and NS the lowest (Figure 6). AUO had greater cover on sludge than on phosphorus ($p \leq 0.05$).

Combination Amendment. Cover on the combination amendment ranged from 71.8% to 87.5%, significantly greater than the unamended control ($p \leq 0.05$) (Table 9). KRO had the greatest cover of the seed mixtures on the combination and NS the lowest cover (Figure 6). AUO had lower cover on the combination amendment than on sludge ($p \leq 0.05$). Soil amendments and seed mixtures in 1990 are ranked by descending cover in appendix table 24.

Stand Height

Average stand height of vegetation in centimeters was measured in five subsamples of each plot in both 1989 and 1990. Least Squares Means were used to analyze the effects of soil amendments on vegetation height.

First Growing Season

Vegetation stand height on all soil amendments in 1989 was taller than on the unamended controls ($p \leq 0.05$) (Table 10).

Unamended Control. In 1989 plants seeded in the unamended control plots showed severe stunting with mean heights ranging from 4.7 to 12.2 cm (Table 10). All seed mixtures were shortest on unamended control plots (Figure 7). KBO was the tallest of the mixtures on the control and NS the shortest.

Phosphorus. Stand heights on the phosphorus amendment ranged from 7.0 to 17.6 cm, significantly taller over all seed mixtures than those in the unamended control plots ($p \leq 0.05$) (Table 10). KBO was the tallest of the seed mixtures on phosphorus and LDT the shortest (Figure 7). AUO attained its greatest height on phosphorus. WSG, KBO, KRO and AUO were taller on phosphorus than the unamended control at the ($p \leq 0.05$).

Sludge. Plant heights on the sludge amendment in 1989 ranged from 7.6 to 18.1 cm, taller than on the unamended controls at the $p \leq 0.05$ level (Table 10). KRO was the tallest of the mixtures on sludge and LDT the shortest (Figure 7). LDT, WSG, KBO, KRO, and NS attained their greatest height on

Table 10: Effect of seed mix and soil amendment on vegetation stand height in 1989.
n=80.¹

<u>Amend</u>	LDT ₂	WSG	KBO	KRO	AUO	NS
cm						
Control	4.7 ± 1.7	7.3 ± 1.7	12.2 ± 1.7	8.7 ± 1.7	6.2 ± 1.7	3.7 ± 1.7
Phos	7.0 ± 1.8	12.1 ± 1.7	17.6 ± 1.7	14.4 ± 2.0	17.0 ± 1.8	8.0 ± 1.9
Sludge	7.6 ± 2.3	11.8 ± 2.2	17.3 ± 2.5	18.1 ± 2.8	14.4 ± 2.6	13.9 ± 2.5
S + P	10.4 ± 1.7	11.0 ± 1.8	14.8 ± 1.7	18.3 ± 1.8	14.4 ± 1.8	9.0 ± 2.0

Statistics based on analysis of least squares means

¹There was a significant difference in stand height due to soil amendment 1989 based on type III ss $PR > F \leq 0.05$

₂ Abbreviations are defined on page 15.

Seed Mixtures

LDT
 WSG
 KBO
 KRO
 AUO
 NS

48

Stand Height In Centimeters

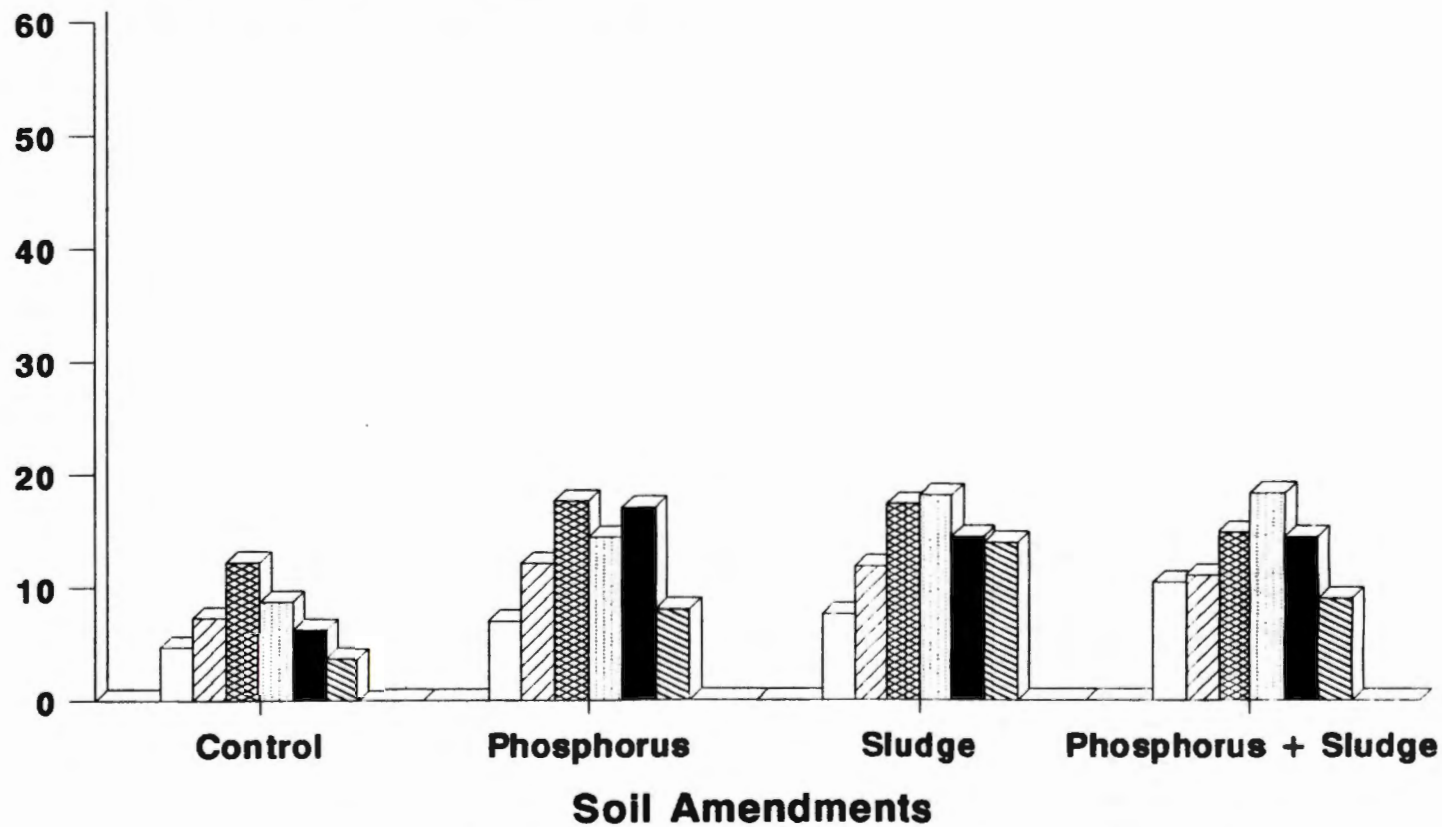


Figure 7: Stand height in centimeters for 1989, seed mixtures, relative to soil amendments

Abbreviations are defined on page 15.

sludge. LDT was shorter on sludge than KBO, KRO, and AUO ($p \leq 0.05$).

Combination Amendment. In 1989, plants on the combination sludge + P amendment were 9.0 to 18.3 cm, taller than those on unamended controls ($p \leq 0.05$) (Table 10). KRO was the tallest of the seed mixtures on the combination amendment and LDT the shortest (Figure 7). KRO was taller on the combination plots than LDT and WSG ($p \leq 0.05$). KBO, KRO, and AUO were taller on the combination plots than NS ($p \leq 0.05$). Soil amendments and seed mixtures are ranked by descending height in Appendix Table 25.

Second Growing Season

Vegetation stand heights on all soil amendments in 1990 were taller than on the unamended controls ($p \leq 0.05$) (Table 11).

Unamended Control. In 1990 plant heights over all soil amendments converged (with a few exceptions due to species differences) except for plants on the unamended control (Table 11). Stand heights on the unamended control ranged from 10.5 cm to 22.2 cm. All of the seed mixtures, with the exception of KRO, had the shortest plants on the unamended controls (Figure 8). WSG was the tallest of the seed mixtures

Table 11: Effect of seed mix and soil amendment on vegetation stand height in 1990. n=80.¹

<u>Amend</u>	LDT ₂	WSG	KBO	KRO	AUO	NS
cm						
Control	10.5 ± 2.0	22.2 ± 5.0	19.4 ± 1.8	21.5 ± 2.9	22.9 ± 2.8	21.9 ± 5.0
Phos	18.0 ± 2.0	31.2 ± 5.0	23.9 ± 1.8	20.1 ± 2.8	50.3 ± 2.8	24.0 ± 5.8
Sludge	23.4 ± 2.7	55.0 ± 7.5	24.9 ± 2.4	26.6 ± 3.9	49.4 ± 4.1	25.7 ± 5.0
S + P	22.6 ± 2.0	46.6 ± 5.4	25.5 ± 1.8	26.2 ± 2.8	53.2 ± 3.0	28.4 ± 5.4

Statistics based on analysis of least squares means

¹There was a significant difference in stand height due to soil amendment 1990 based on type III ss $PR > F \leq 0.05$.

₂ Abbreviations are defined on page 15.

Seed Mixtures

LDT
 WSG
 KBO
 KRO
 AUO
 NS

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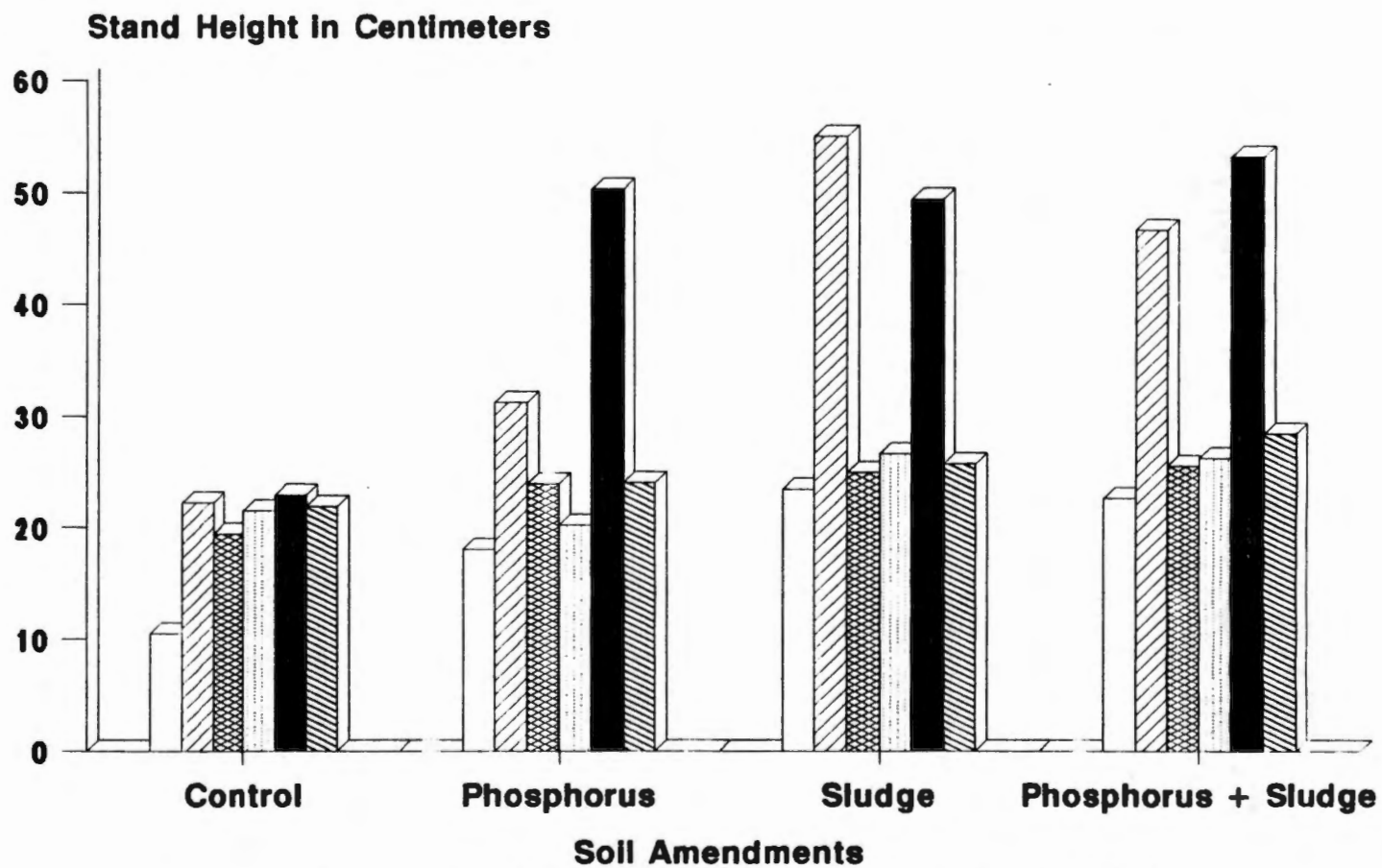


Figure 8: Stand Height in centimeters in 1990 seed mixtures, relative to soil amendments

Abbreviations are defined on page 15.

on the control and LDT the shortest.

Phosphorus. Stand heights on the phosphorus amendment in 1990 ranged from 18.0 to 50.3 cm (Table 11). Plants were taller on phosphorus than on the unamended controls ($p \leq 0.05$). AUO was the tallest of the seed mixtures on phosphorus and LDT the shortest (Figure 8).

Sludge. Stand height on the sludge amendment in 1990 ranged from 23.4 to 55.0 cm (Table 11). Plants were taller on sludge than on the unamended controls ($p \leq 0.05$). WSG was the tallest of the seed mixtures on sludge and LDT the shortest (Figure 8). LDT, WSG, and KRO attained their greatest heights on sludge. WSG was taller on sludge than on phosphorus ($p \leq 0.05$).

Combination Amendment. Stand heights on the combination amendment in 1990 ranged from 22.6 to 53.2 cm (Table 11). Plants were taller on the combination amendment than on the unamended control ($p \leq 0.05$). AUO was the tallest of the seed mixtures on the combination amendment and LDT the shortest (figure 8). KBO, AUO, and NS attained their greatest heights on the combination amendment. WSG was taller on the combination amendment than on phosphorus ($p \leq 0.05$) level. Soil amendments and seed mixtures are ranked by descending height in Appendix Table 26. Plant heights were significantly

different due to type seed mixture on all soil amendments ($p \leq 0.05$).

Species Composition

Individual plants were identified and stems counted in five subsamples of each plot for both growing seasons of the experiment. Least Squares Means and SAS GLM analyses were performed on the data (SAS Institute, 1989).

First Growing Season

Unamended Control. Legumes had greater stem density on the unamended control plots than orchardgrass in 1989 (Table 12) (Figure 9). Warm season grasses had the lowest stem density of all mixtures on unamended plots, with little bluestem the least numerous species. Though densities were low on the unamended plots, the warm season grasses that did germinate showed less stunting than plants in other seed mixtures. AUO had the highest stem density on unamended plots. Lespedezas were more numerous on unamended plots than were grasses.

Phosphorus. Legume species were denser and larger on phosphorus plots in 1989 compared to the unamended control (Table 12) (Figure 10). A. U. Lotan decreased in density on phosphorus compared to unamended plots while orchardgrass

Table 12: Effect of seed mix and soil amendment on species stems per sq ft in 1989. n=160.

<u>Amend</u>	<u>LDT₂</u>			<u>WSG</u>				<u>KBO</u>			<u>KRO</u>			<u>AUO</u>		
	n=240															
	<u>LD</u>	<u>TI</u> ²		<u>SW</u>	<u>IN</u>	<u>LB</u>		<u>KB</u>	<u>OR</u>		<u>KR</u>	<u>OR</u>		<u>AU</u>	<u>OR</u>	
Control	17	5	<u>+4.3</u>	2	2	.1	<u>+0.8</u>	37	8	<u>+3.8</u>	33	7	<u>+4.8</u>	47	6	<u>+4.3</u>
Phos	42	14 ^{1*}	<u>+4.4</u>	3	4	.1 ¹	<u>+0.8</u>	29	8 ¹	<u>+3.8</u>	29	16	<u>+5.4</u>	33	13 ¹	<u>+4.5</u>
Sludge	25	13	<u>+5.6</u>	3	6	.5 ^{1*}	<u>+0.9</u>	20	16	<u>+5.4</u>	50	25 [*]	<u>+7.7</u>	13	20	<u>+6.5</u>
S + P	43	24 ^{1*}	<u>+4.3</u>	2	2	1	<u>+0.8</u>	23	13	<u>+3.8</u>	18	18	<u>+5.1</u>	10	16 [*]	<u>+4.6</u>

Statistics based on analysis of least squares means

*Significant difference in total stem density of this seed mixture due to soil amendment based on type III ss PR>F ≤ 0.05 .

¹Significant difference in species counts within this seed mixture due to soil amendment in based on type III ss PR>F ≤ 0.05 .

Abbreviations are defined on page 15.

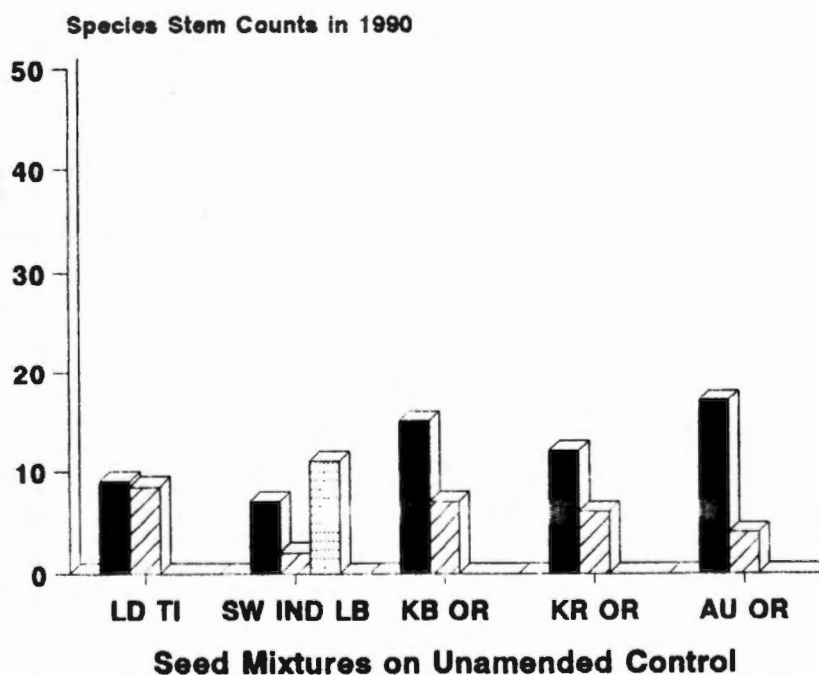
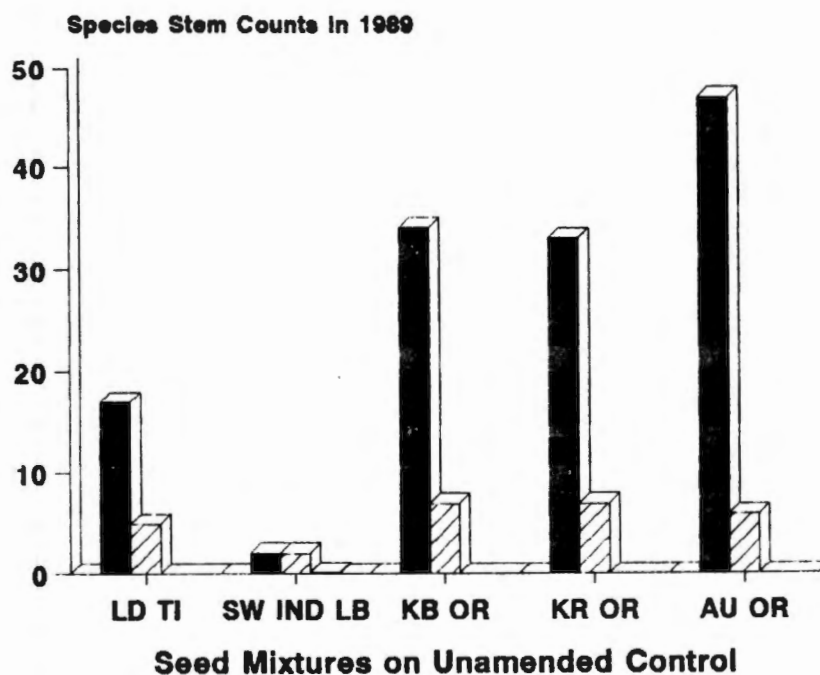


Figure 9: Species stem counts on unamended control plots, seed mixtures, in 1989 and 1990
 , Abbreviations are defined on page 15.

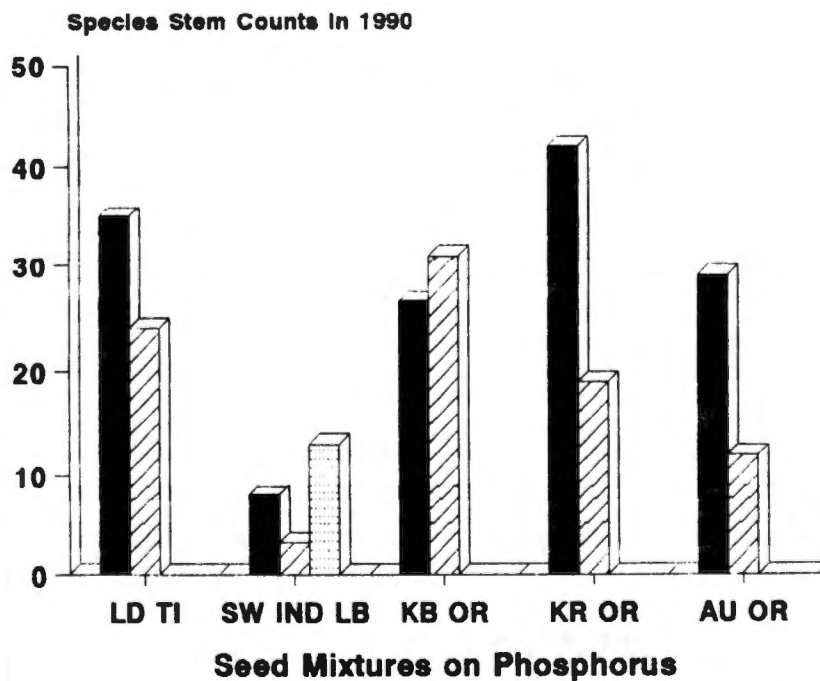
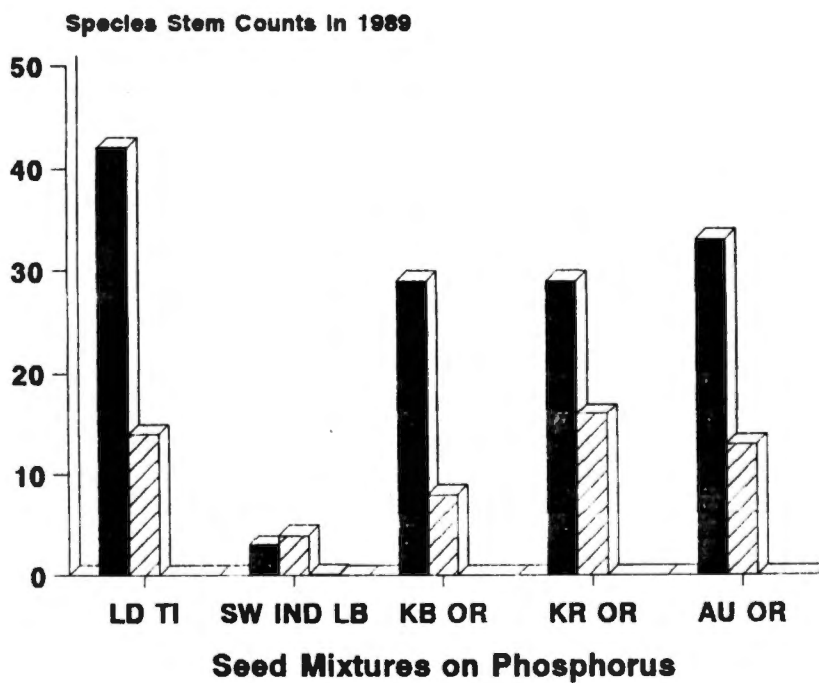


Figure 10: Species stem counts on phosphorus plots, seed mixtures, in 1989 and 1990
 , Abbreviations are defined on page 15.

densities increased. Orchardgrass was denser on phosphorus plots than on the unamended plots in all seed mixtures. The legumes had greater stem densities on phosphorus than did orchardgrass. LDT had greater total density on phosphorus than on the unamended control ($p \leq 0.05$). Ladino clover was denser than timothy on phosphorus. Indiangrass and switchgrass were denser than little bluestem on phosphorus. Kobe lespedeza and A. U. Lotan were denser on phosphorus than orchardgrass. These species differences were significant at the $p \leq 0.05$ level.

Sludge. Ladino clover was significantly less dense on sludge plots than on phosphorus (Table 12) (Figure 11). WSG had greater total density on sludge than on the unamended control. Switchgrass and indiangrass were denser than little bluestem on sludge. KRO had greater total density on sludge than on the unamended control and phosphorus plots. Korean lespedeza was denser than orchardgrass on sludge. Orchardgrass was denser than A. U. Lotan on sludge. The legumes had greater stem density than orchardgrass on all sludge plots with the exception of AUO. Though the legumes had higher stem density on sludge plots, the orchardgrass was more vigorous and larger in size. These differences were statistically significant at the $p \leq 0.05$ level.

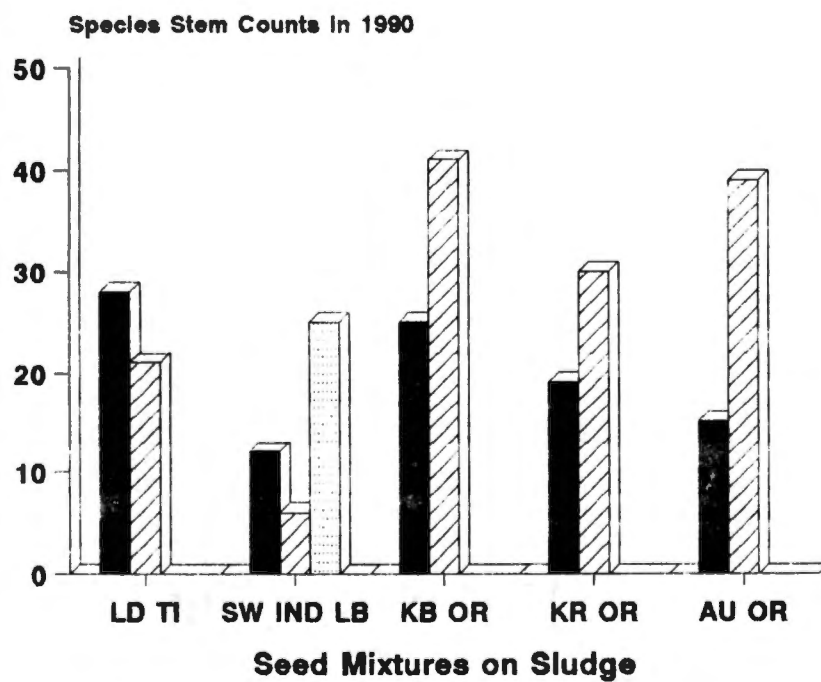
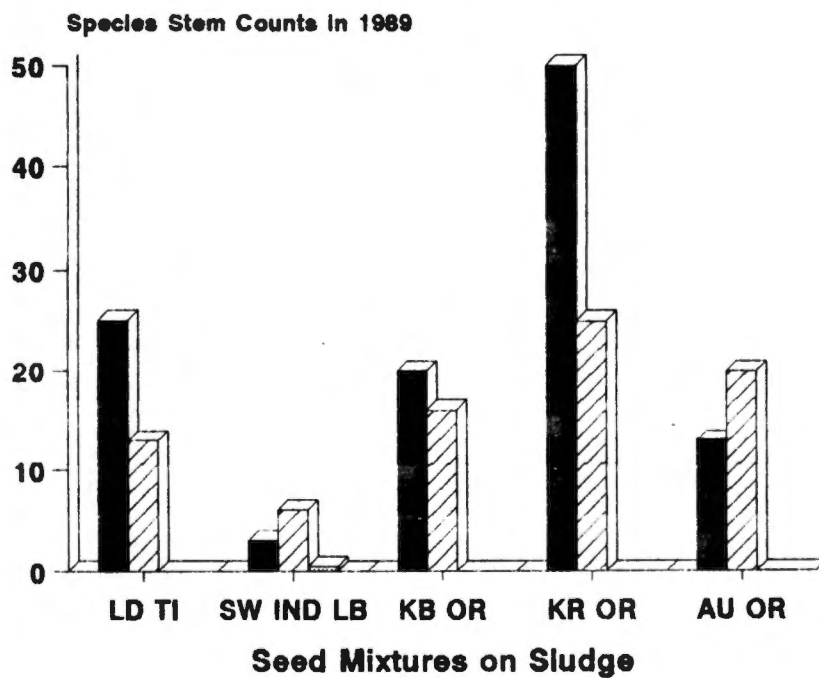


Figure 11: Species stem counts on sludge plots, seed mixtures, in 1989 and 1990
 , Abbreviations are defined on page 15.

Combination Amendment. LDT had higher stem density in 1989 on the combination sludge/phosphorus amendment than on both the unamended control and sludge ($p \leq 0.05$) (Table 12) (Figure 12). Ladino clover was denser than timothy on the combination amendment. KRO was less dense on the combination amendment than on sludge. AUO had greater density on the unamended control than on the combination amendment. These differences were significant ($p \leq 0.05$).

Visual observation of the 1989 growth indicated that high stem density is not necessarily an indication of vigorous plant growth and good vegetative establishment. Poor soil conditions may produce stunting so severe that the percent cover might be 1 percent or less even with a high stem density.

Second Growing Season

Unamended Control. Densities of all seed mixtures in 1990 were lowest on unamended control plots (Table 13). Lespedeza species were approximately twice as dense as orchardgrass on unamended plots.

Phosphorus. LDT, KBO, KRO and AUO densities were higher in 1990 on phosphorus compared to unamended plots ($p \leq 0.05$) (Table 13) (Figure 10). Little bluestem was denser

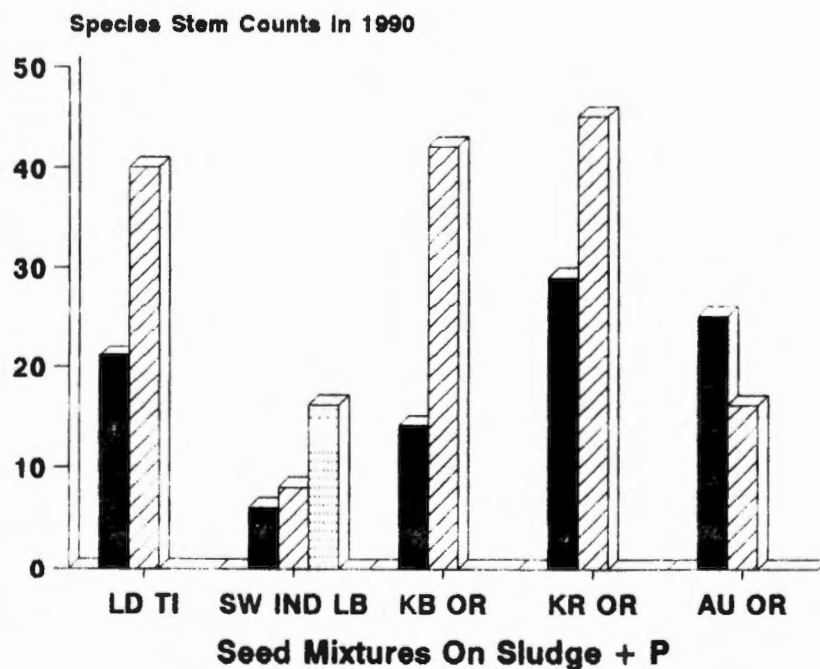
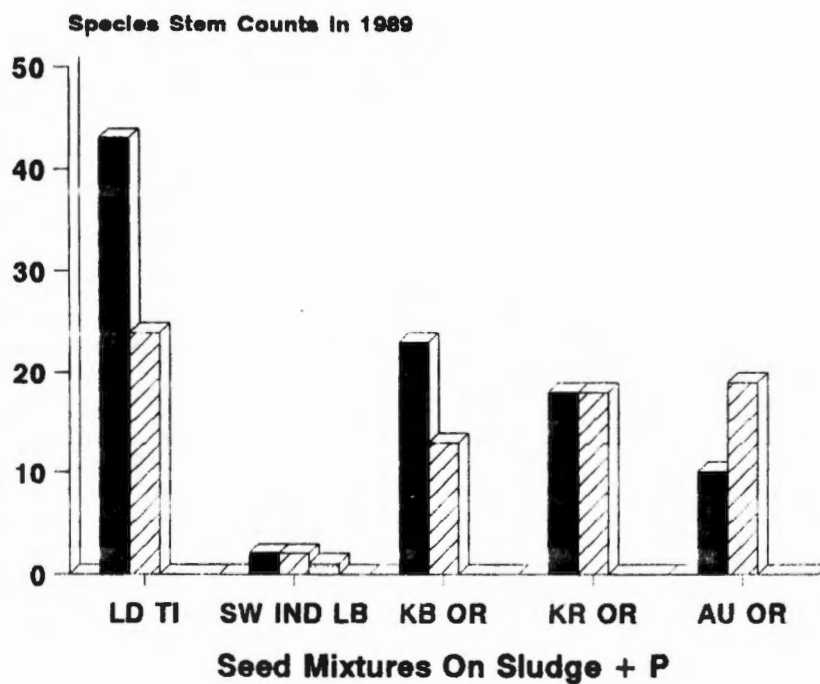


Figure 12: Species stem counts on combination plots
Seed mixtures in 1989 and 1990
 , Abbreviations are defined on page 15.

Table 13: Effect of seed mix and soil amendment on species stems per sq ft in 1990. n=160

	'LDT			WSG ¹				KBO			KRO			AUO ¹		
<u>Amend</u>	<u>'LD</u>	<u>TI</u>		<u>SW</u>	<u>IN</u>	<u>LB</u>		<u>KB</u>	<u>OR</u>		<u>KR</u>	<u>OR</u>		<u>AU</u>	<u>OR</u>	
Control	9	9	± 4.2	7	2	11	± 2.8	15	7	± 5.7	12	6	± 5.6	17	4	± 2.9
Phos	35	24*	± 4.2	8	3	13 ¹	± 2.8	27	31*	± 5.7	42	19 ^{1*}	± 5.4	29	12 ^{1*}	± 2.9
Sludge	28	21*	± 5.6	12	6	25 ^{1*}	± 4.1	25	41*	± 7.6	19	30*	± 7.7	15	39 ^{1*}	± 4.4
Sl+P	21	40 ^{1*}	± 4.3	6	8	16 ¹	± 3.0	14	42 ^{1*}	± 5.5	29	45*	± 5.4	25	16 ^{2*}	± 3.2

Statistics based on analysis of least squares means

¹Abbreviations for species and seed mixtures defined on p. 15.

*Significant difference in total density of this seed mixture due soil amendment based on type III ss $PR > F \leq 0.05$

¹Significant difference in species density within this seed mixture due to soil amendment within this seed mix based on type III ss $PR > F \leq 0.05$.

than indiangrass on phosphorus (Figure 14). Korean lespedeza was denser than orchardgrass on phosphorus (Figure 16). A. U. Lotan was denser than orchardgrass on phosphorus (Figure 17). These differences were significant ($p \leq 0.05$).

Sludge. Densities of all seed mixtures were greater on sludge than on the unamended control plots (Table 13) (Figure 11). Little bluestem was denser on sludge than on phosphorus. Orchardgrass was denser than A. U. Lotan on sludge. Orchardgrass was denser on sludge than on phosphorus. A. U. Lotan was less dense on sludge than on phosphorus. These differences were significant ($p \leq 0.05$).

Combination Amendment. Except for WSG total densities of the seed mixtures except WSG in 1990 were significantly lower on the combination amendment than on the unamended control ($p \leq 0.05$) (Table 13) (Figure 12). Timothy was denser than ladino clover on the combination amendment (Figure 13). Timothy was denser on the combination amendment than on either phosphorus or sludge. Ladino clover was less dense on the combination amendment than on phosphorus. Little bluestem was denser than switchgrass on the combination amendment (Figure 14). Orchardgrass was denser than kobe lespedeza on the combination amendment (Figure 15). Orchardgrass in KBO was denser on the combination amendment than on phosphorus. Orchardgrass in AUO was less dense on the combination amendment than on sludge

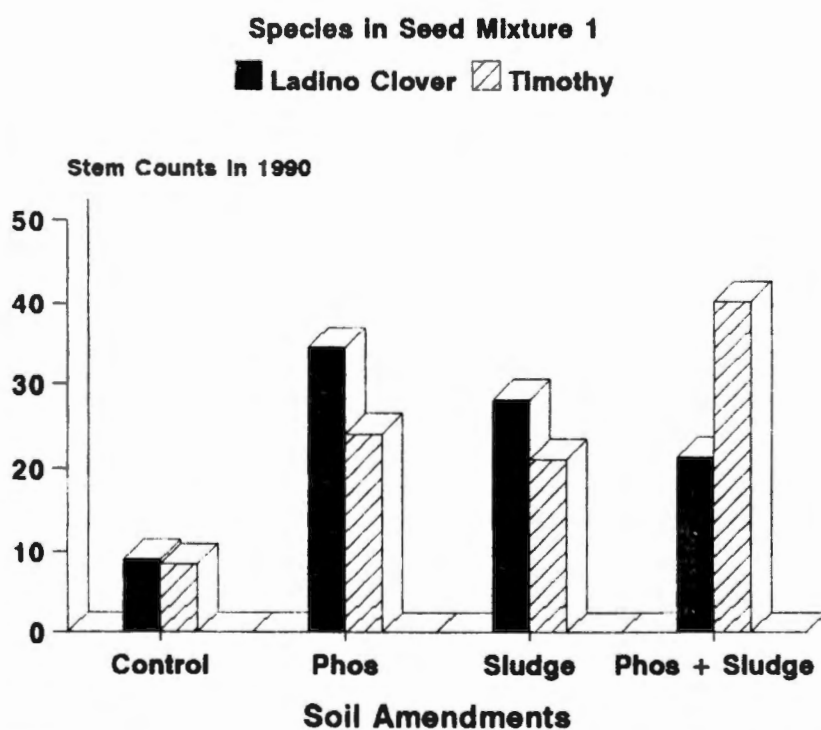
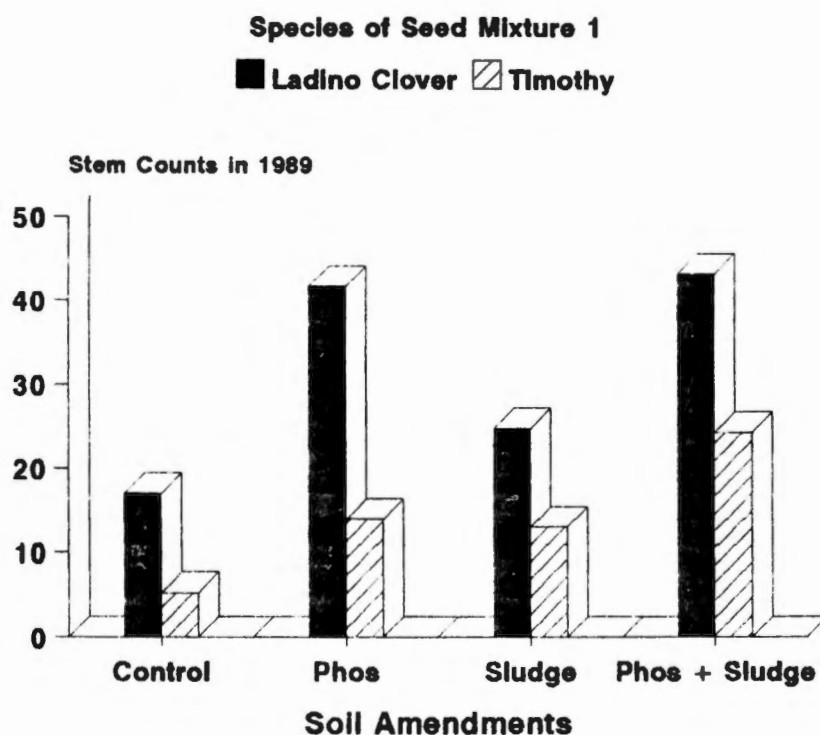


**Figure 13: Stem counts of ladino clover and timothy
Relative to soil amendments in 1989 and 1990**

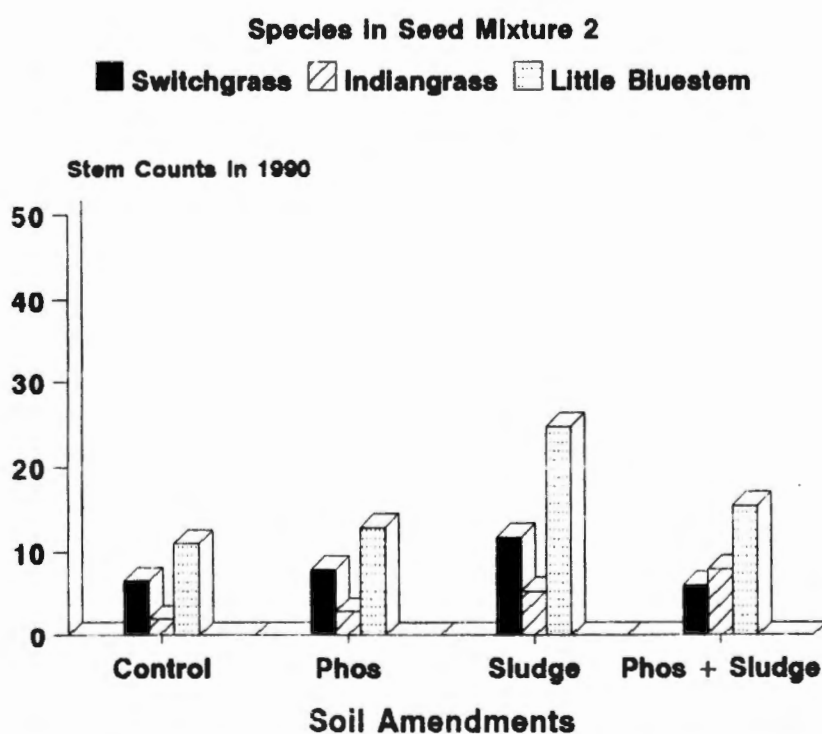
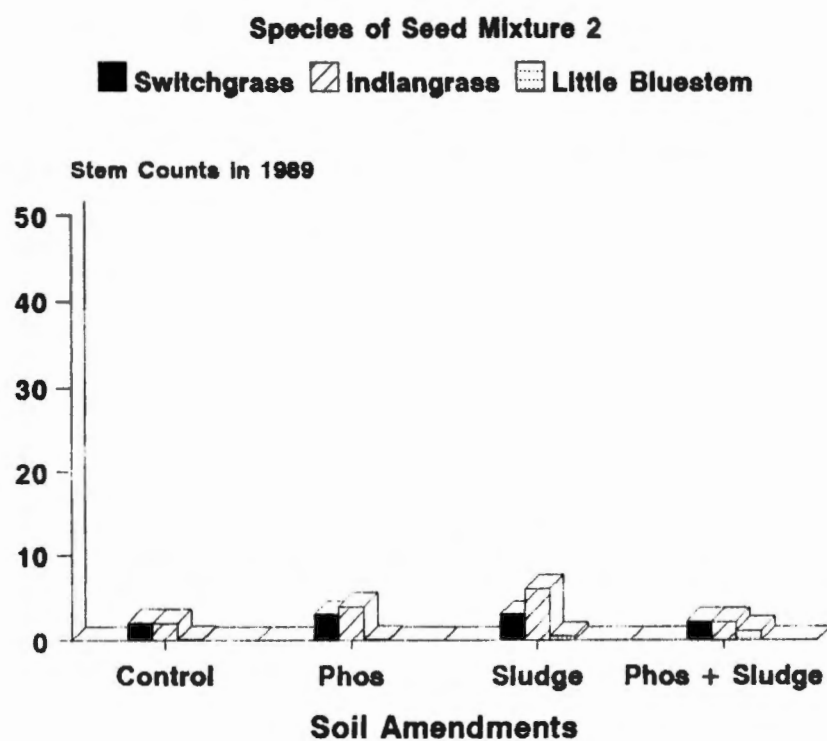


Figure 14: Stem counts of switchgrass, indiangrass and little bluestem relative to soil amendments in 1989 and 1990

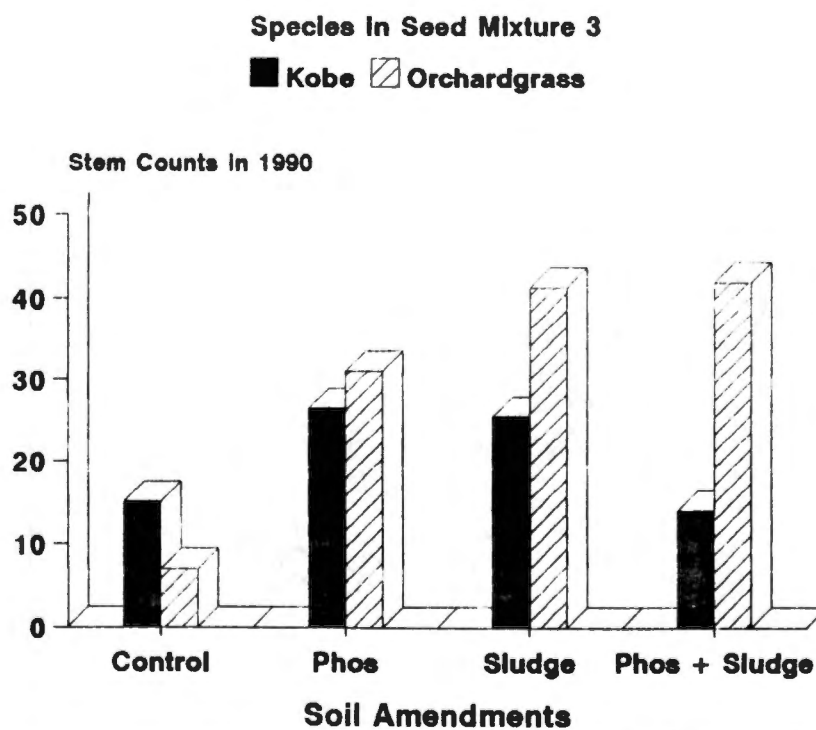
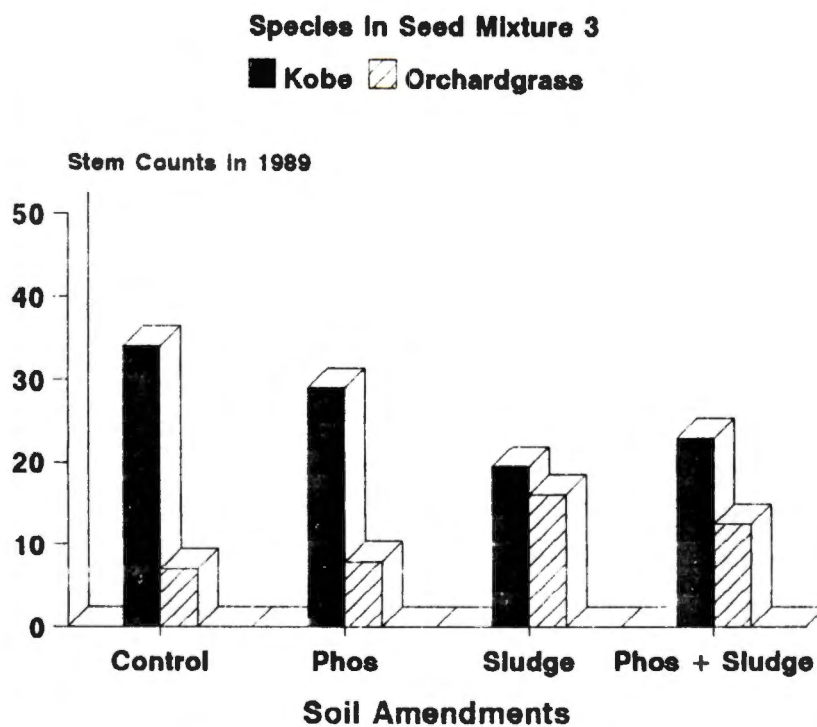


Figure 15: Stem counts of kobe lespedeza and orchardgrass relative to soil amendments in 1989 and 1990

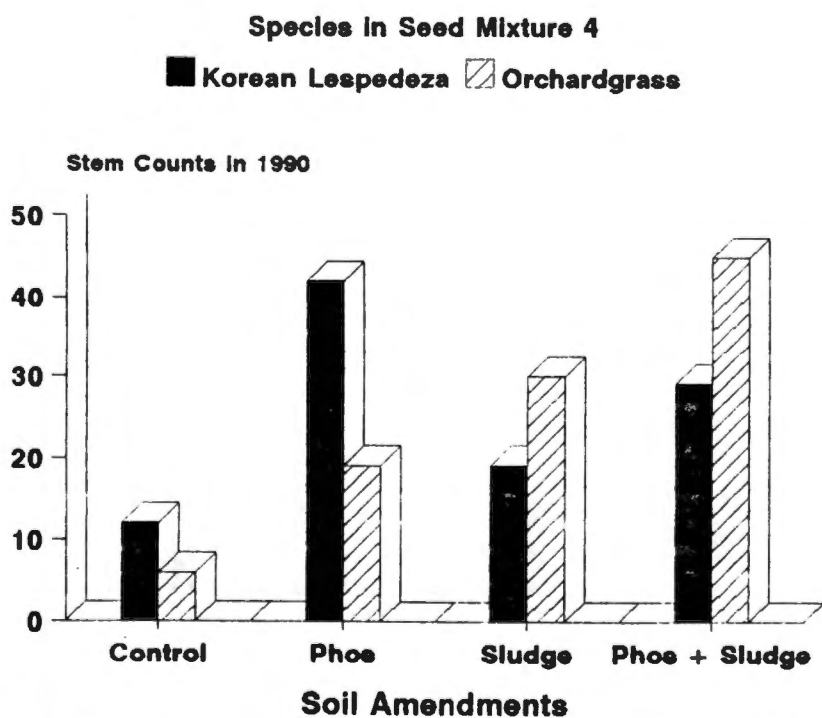
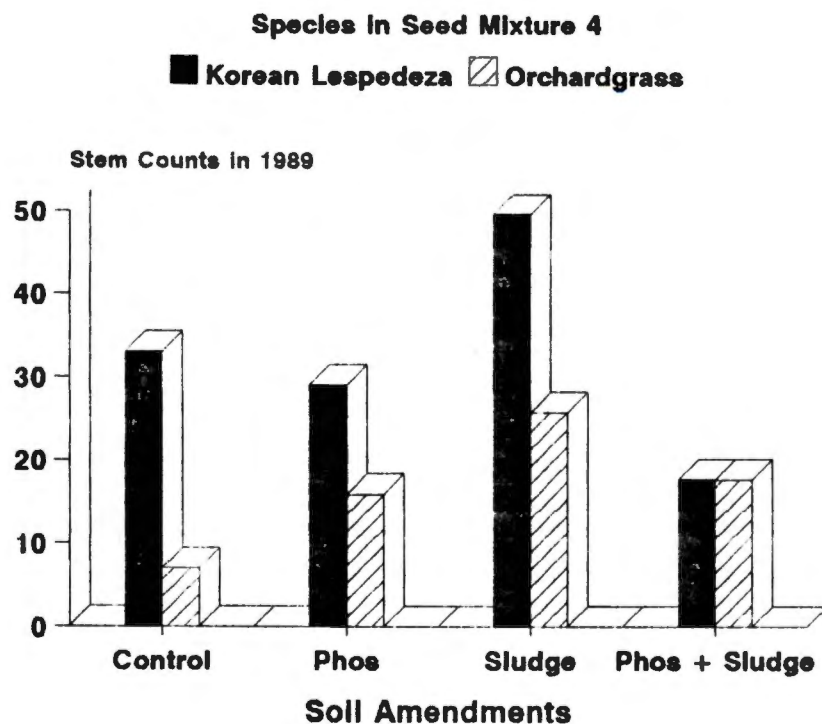


Figure 16: Stem counts of korean lespedeza and orchardgrass relative to soil amendments in 1989 and 1990

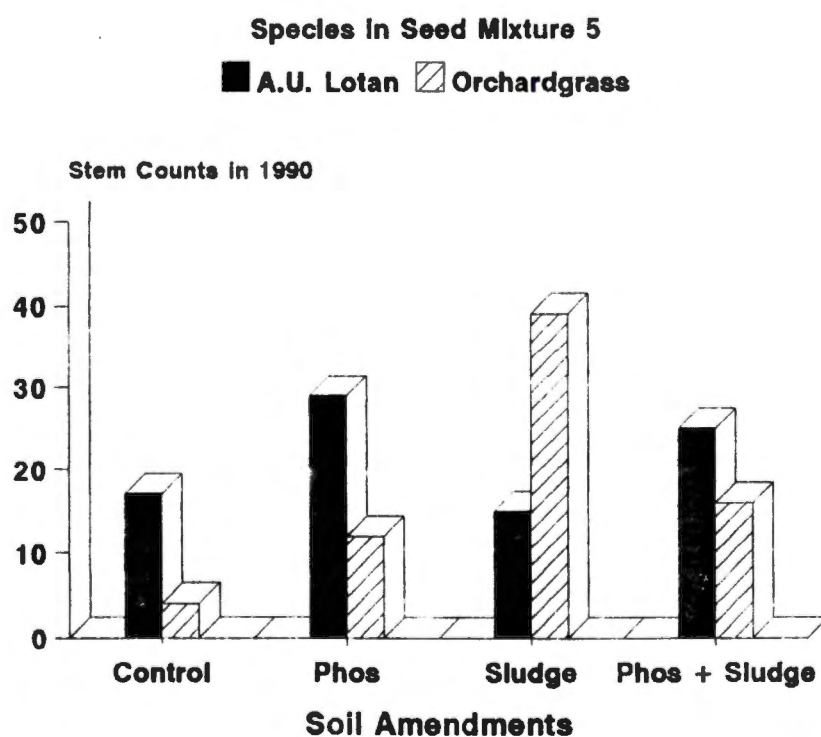
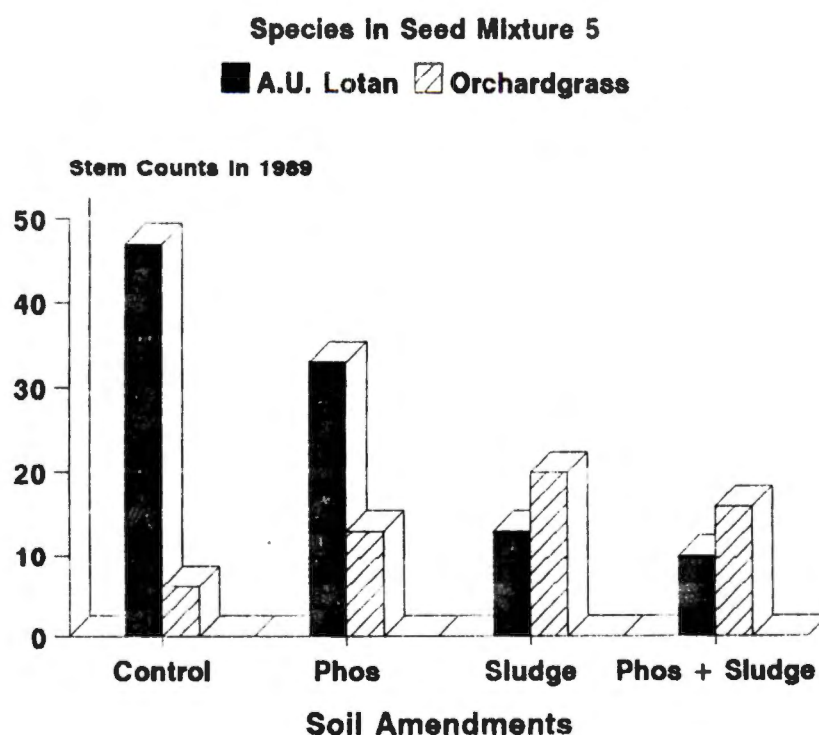


Figure 17: Stem counts of A. U. lotan lespedeza and orchardgrass relative to soil amendments in 1989 and 1990

(Figure 17). These differences were significant ($p \leq 0.05$).

Volunteer Species

Unseeded plant species appearing in study plots were identified as either wild grasses (this included any grasslike plants such as sedges, rushes, etc.) or broad-leaf plants (broad-leaf weeds and tree seedlings). Stems of each group were counted in five subsamples of each plot in 1989 and 1990. Least Squares Means analyses were performed on the data. This information was used to record the incursion of volunteer species in the plots. It was also used as an indicator of the vigor and competitiveness of the seeded experimental plants and their ability to compete with invading species.

Wild Grasses

First Growing Season

Unamended Control. Wild grasses appeared on all unamended plots in the first growing season (Table 14). They were densest on WSG plots and least dense on KRO plots.

Phosphorus. Wild grass density on phosphorus did not differ significantly from the unamended control (Table 14). Wild grass density was greatest on phosphorus plots seeded with

Table 14: Effect of seed mix and soil amendment on wild grass stem density in 1989. N=80.

Amend	!LDT ¹	WSG	KBO	KRO	AUO	NS
stems/sq ft						
Cont	4.9 ± 1.4	4.5 ± 1.3	1.1 ± 1.3	0.8 ± 1.4	2.2 ± 1.4	2.7 ± 1.4
Phos	4.7 ± 1.4	2.2 ± 1.3	1.8 ± 1.4	0.3 ± 1.5	2.3 ± 1.4	4.9 ± 1.5
Sludge	12.5 ± 1.8*	5.2 ± 1.7*	0.4 ± 1.9*	0.5 ± 2.1*	8.1 ± 2.0*	3.0 ± 1.9*
S + P	6.1 ± 1.3*	5.2 ± 1.4*	1.6 ± 1.3*	4.3 ± 1.4*	7.0 ± 1.4*	3.0 ± 1.6*

Statistics based on analysis of least squares means.

¹There was a significant difference in wild grass stem density due to type seed mix in 1989 based on type III ss $PR > F \leq 0.05$

*Soil amendment significantly different from unamended control based on type III ss $PR > F \leq 0.05$

¹Abbreviations for species and seed mixtures defined on p. 15.

NS and LDT and lowest on plots seeded with KRO (Figure 18).

Sludge. Wild grass densities were higher on sludge than on any other amendment, but this difference was significant only compared to the unamended control ($p \leq 0.05$) (Table 14). Wild grasses were denser on LDT plots than on all other seed mixtures ($p \leq 0.05$). Wild grass densities were greater on sludge than on phosphorus in plots seeded with LDT and AUO ($p \leq 0.05$). Wild grass densities were lowest on sludge plots seeded with KBO and KRO (Figure 18).

Combination Amendment. Wild grass density was greater on the combination amendment than on the unamended control ($p \leq 0.05$) (Table 14). Wild grass density was greatest on combination plots seeded with AUO and lowest on KBO. Wild grass density on plots seeded to LDT was lower on the combination amendment than on sludge ($p \leq 0.05$) (Figure 18).

Second Growing Season

Unamended Control. Wild grasses densities in 1990 were greatest on unseeded unamended plots and lowest on plots seeded to KBO (Table 15) (Figure 18).

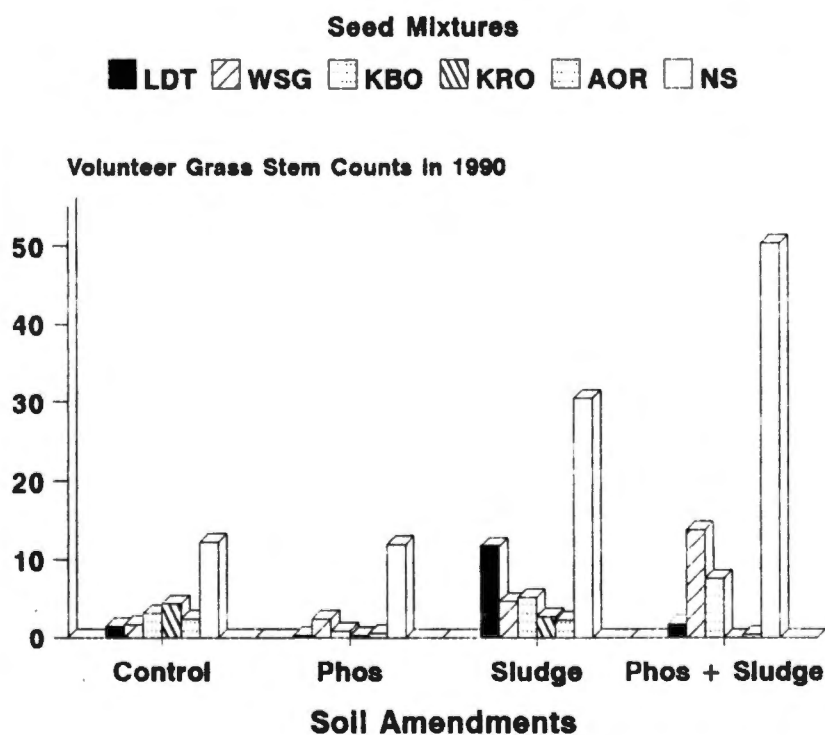
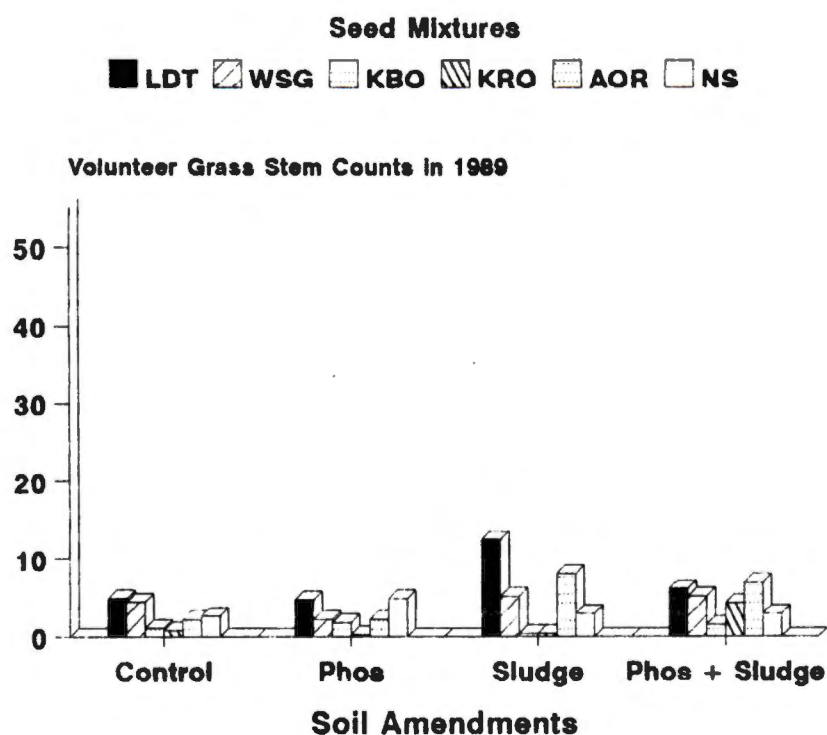


Figure 18: Stem counts of wild grasses within each seed mixture relative to soil amendments in 1989 and 1990

Table 15: Effect of seed mix and soil amendment on wild grass stem density in 1990. n=80.

<u>Amend</u>	¹ LDT	WSG	KBO	KRO	AUO	NS ¹
stems/sq ft						
Control	1.4 ± 3.9	1.7 ± 3.9	3.0 ± 3.9	4.3 ± 4.0	2.4 ± 3.9	12.2 ± 3.9
Phos	0.3 ± 3.9	2.4 ± 3.9	0.8 ± 3.9	0.2 ± 3.9	0.5 ± 3.9	12.0 ± 3.9
Sludge	11.6 ± 5.3	4.6 ± 5.9	5.1 ± 5.3	2.6 ± 5.5	2.2 ± 5.9	20.5 ± 4.6
S + P	1.6 ± 4.0*	13.8 ± 4.3*	7.5 ± 4.0*	0.0 ± 3.9*	0.4 ± 4.0*	50.3 ± 4.0*

Statistics based on analysis of least squares means.

¹A significant difference in wild grass density due to type seed mix in 1990 based on type III ss $PR > F \leq 0.05$

*Soil amendment significantly different from the unamended control based on type III ss $PR > F \leq 0.05$

¹Abbreviations for species and seed mixtures defined on p. 15.

Phosphorus. Phosphorus amendment had no significant effect on wild grass density in 1990 (Table 15) (Figure 18). Wild grass density was greatest on unseeded phosphorus.

Sludge. Wild grasses were denser on unseeded sludge plots than with all other seed mixtures ($p \leq 0.05$) (Table 15) (Figure 18).

Combination Amendment. Wild grasses achieved their greatest density on the unseeded combination plots (Table 15) (Figure 18). Wild grass densities were significantly greater on the combination amendment than on unamended controls at the $p \leq 0.05$ level. Wild grasses were densest on unseeded combination plots at the $p \leq 0.05$ level.

Broad-Leaf Plants

First Growing Season

Unamended Control. Broad-leaf plants in 1989 were densest on unseeded unamended plots and least dense on plots seeded with the lespedeza-orchardgrass mixtures (Table 16) (Figure 19).

Phosphorus. Stem densities of broad-leaf plants were not significantly different on phosphorus than on the unamended controls (Table 16) (Figure 19).

Table 16: Effect of seed mix and soil amendment on broad-leaf stem density in 1989. n=80.

	'LDT	WSG	KBO	KRO	AUO	NS
<u>Amend</u>	stems/sq ft					
Control	1.4 $\pm$ 1.4	2.1 $\pm$ 1.4	0.9 $\pm$ 1.4	0.2 $\pm$ 1.4	0.6 $\pm$ 1.4	2.4 $\pm$ 1.4
Phos	1.5 $\pm$ 1.4	3.2 $\pm$ 1.3	6.1 $\pm$ 1.4	0.6 $\pm$ 1.6	1.4 $\pm$ 1.4	2.7 $\pm$ 1.5
Sludge	2.7 $\pm$ 1.8*	4.1 $\pm$ 1.7*	0.5 $\pm$ 2.0*	2.1 $\pm$ 2.2*	11.2 $\pm$ 2.1*	4.6 $\pm$ 2.0*
S + P	1.3 $\pm$ 1.4	1.8 $\pm$ 1.4	0.9 $\pm$ 1.4	0.5 $\pm$ 1.5	3.8 $\pm$ 1.5	6.5 $\pm$ 1.6

Statistics based on analysis of least squares means.

*Soil amendment significantly different from the unamended control based on type III ss $PR > F \leq 0.05$

'Abbreviations for species and seed mixtures defined on p. 15.

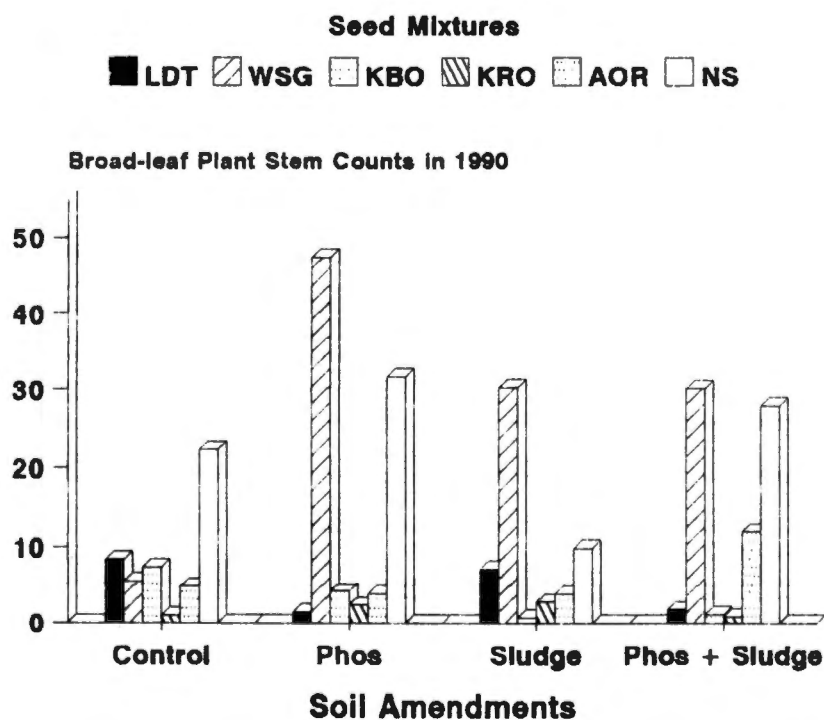
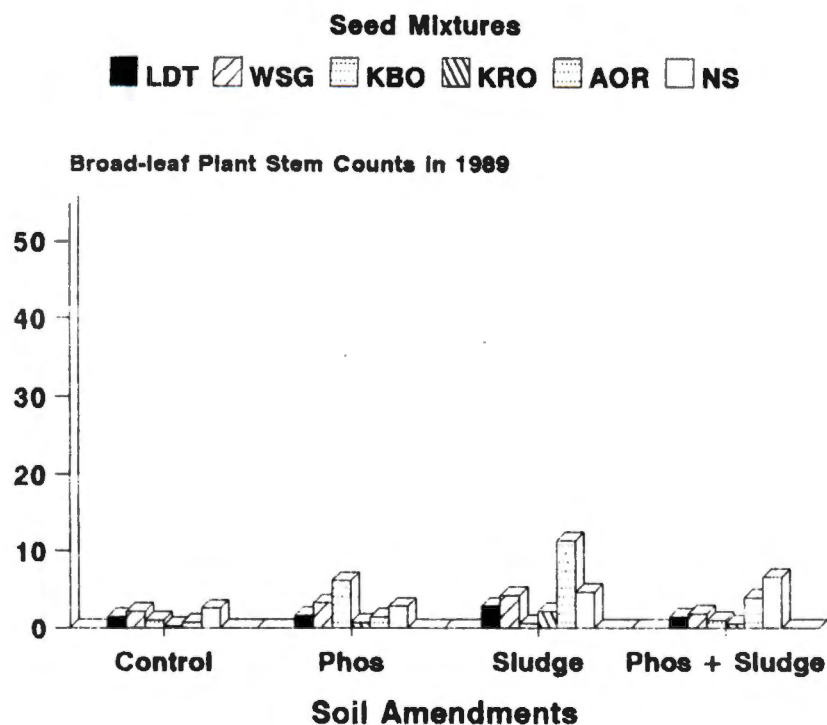


Figure 19: Stem counts of broad-leaf plants within each seed mixture relative to soil amendments in 1989 and 1990

Sludge. Broad-leaf density in 1989 was greater on sludge plots than on unamended controls ($p \leq 0.05$) (Table 16) (Figure 19). Broad-leaf density was greatest on sludge plots seeded to AUO and lowest on plots seeded to KBO ($p \leq 0.05$).

Combination Amendment. Broad-leaf density was lower on the combination amendment than on sludge (Table 16). Broad-leaf densities were greatest on unseeded combination plots and lowest on plots seeded to KBO and KRO (Figure 19)

Second Growing Season

Broad-leaf density in 1990 was greatest on the unseeded plots on all soil amendments and the unamended control ($p \leq 0.05$).

Unamended Control. Broad-leaf stem density in 1990 was greater on unamended plots than in 1989 (Table 16, Table 17). Broad-leaf density was greatest on unseeded, unamended plots and lowest on plots seeded to KRO (Figure 19).

Phosphorus. Broad-leaf densities on the phosphorus amendment in 1990 were greater than on unamended controls ($p \leq 0.05$) (Table 17). Stem density on phosphorus was greater than on unamended controls in all plots except those

Table 17: Effect of seed mix and soil amendment on broad-leaf stem density in 1990.
n=80.

	¹ LDT	WSG	KBO	KRO	AUO	¹ NS
Stems/sq ft						
Control	8.3 ± 5.9	5.5 ± 5.9	7.4 ± 5.9	1.0 ± 6.0	4.8 ± 5.9	22.3 ± 5.9
Phos	1.3 ± 5.9*	47.5 ± 5.9*	4.2 ± 5.9*	2.3 ± 5.9*	3.8 ± 5.9*	31.7 ± 5.9*
Sludge	7.0 ± 7.9	30.3 ± 8.8	0.6 ± 8.0	2.7 ± 8.3	3.8 ± 8.8	9.9 ± 6.8
S + P	1.7 ± 6.0	30.2 ± 6.4	1.1 ± 6.0	0.8 ± 5.9	12.0 ± 6.4	28.0 ± 6.4

Statistics based on analysis of least squares means.

¹A significant difference in broad-leaf density due to type seed mix in 1990 based on type III ss PR>F ≤0.05

*Soil amendment significantly different from the unamended control based on type III ss PR>F ≤0.05

¹Abbreviations for species and seed mixtures defined on p. 15.

containing LDT and KBO. Broad-leaf density was greatest on unseeded phosphorus plots and lowest on plots seeded to LDT ($p \leq 0.05$).

Sludge. Sludge amendment had no significant effect on broad-leaf plant density in the second growing season compared to the unamended control (Table 17). Broad-leaf densities were greatest on sludge plots seeded to WSG and lowest on plots seeded to KBO ($p \leq 0.05$) (Figure 19).

Combination Amendment. The combination amendment had no significant effect on broad-leaf stem density in 1990 compared to the unamended control (Table 17). Broad-leaf density was greatest on unseeded combination plots and lowest on plots seeded to KRO ($p \leq 0.05$) (Figure 19).

CHAPTER V

DISCUSSION

Lime as a Soil Amendment

Acid soil conditions on some surface mines have a detrimental effect on seed germination and plant growth. Surface minesoil acidity is also a health concern as research has shown that plant uptake of heavy metals increases as soil pH decreases (Chaney et al. 1987). Liming the soils to increase pH appears to reduce plant uptake of these materials (Sommers and Nelson, 1981). Toxic elements are precipitated at a pH of 5.5 or above to a form unavailable to the plant (Vogel, 1981). Metal levels in soils on the Fentress County mine site were lower on the limed, control plots than the preamendment levels (Tables 4 and 5). Lime application and sludge application have both been shown to increase minesoil pH (Mathias et al. 1979). Application of lime to the Fentress County site increased soil pH from 5.2 to 6.3. The sludge and combination soil amendments increased soil pH an additional 0.2 to 0.4 units (Table 2). Sludge stabilized by heavy lime treatment, such as the Knoxville sludge in this study, can have value as a liming agent as well as by adding of organics and nitrogen (Jacobs, 1981). Application of limed sludge must be carefully controlled. Excessive quantities of the Knoxville sludge in isolated locations created pH levels that were too

high and detrimental to plant growth.

Phosphorus as a Soil Amendment

Phosphorus application in this study enhanced the establishment of vegetation. Plots amended with phosphorus in Fentress County were visibly higher in vegetative cover than plants on unamended control plots. Plants on phosphorus were more vigorous in both growing seasons than plants on unamended control plots (Tables 6 and 7). The phosphorus amendment was sufficient to establish vigorous stands of all the species of legumes in the legume/grass seed mixtures planted. Phosphorus 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 phosphorus amended plots will add nitrogen and, eventually, organic material 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 super triple phosphate. Super phosphate contains 20% Ca, which explains the increase in Ca levels seen on phosphorus amended plots (Lyle, 1987). K levels were higher on the phosphorus amendment than on sludge and combination amendments.

Municipal Sludge as a Soil Amendment

Previous studies of fertilization with sewage sludge have indicated that equal or better long term benefits may be derived from the incorporation of sludge than from traditional fertilizers (Hani, 1981; Larsen, 1981; Vogel, 1981; Wolt, 1985). My analyses of percent cover support this contention (Tables 6 and 7). Vegetative cover was consistently greater on sludge and combination sludge + P plots than on phosphorus or unamended plots. A large crop of tomatoes appeared on the plots amended with sludge from Rockwood in the first growing season, but these disappeared the second growing season. Unseeded controls on sludge and combination plots had greater vegetative cover than unseeded controls on unamended plots and phosphorus 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.

Studies in Pennsylvania showed that applying sludge to mine spoils enhanced seed germination and vegetative growth (Loehr, 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 confirmed this observation. Orchardgrass was more competitive

than lespedeza species on the sludge and combination amendments than on phosphorus. Timothy improved relative to ladino clover on sludge amended plots. Vegetation growth and cover were improved on sludge plots relative to the other amendments with all seed mixtures, including the unseeded control. The relatively high cover values on the unseeded sludge plots were due to the heavy weed contamination present in the Rockwood sludge.

Sludge has the advantage of the immediate addition of organic matter and soil microorganisms to the soil, a process which usually takes many years to complete. Municipal sludges also contain varying quantities of the needed phosphorus from detergents and other sources and could supply 27% of the P needed in agriculture (Sommers and Sutton, 1980; Suss, 1980). However, the P available to plants in sludge varies from 20-100% compared with 100% in monocarbon phosphate (Haan 1981). In my study, the P soil level was 215 lbs/a higher in sludge amended plots than in the phosphorus amended plots. The larger quantities of P in municipal sludge could counteract the chemical binding of phosphorus due to poor minesoil conditions. Moisture stress causes P to be unavailable to plants (Ozanne, 1980). The organic matter in sludge helps the soil retain moisture, which could aid P availability.

Phosphorus and phosphates generally present in sewage sludge (Sommers and Sutton, 1980; Suss, 1980) would be additional to the super triple phosphate added to the

combination amendment in this study. The slightly reduced performance of plants on the combination sludge + phosphorus amendment may be due to excessive phosphorus levels, allowing increased chemical binding of phosphorus into an unusable form. Ca and Mg levels were higher on sludge amendments than on phosphorus indicating sludge to be a possible source of these nutrients. K was found in similar low quantities on all three soil amendments.

A possible disadvantage of sludge application includes accumulation of heavy metals in the soil and vegetation. Copper and zinc levels were significantly increased on the sludge amended plots compared to the preamendment levels. However, levels of all metals analyzed in the soil samples were below USEPA recommended maximum amounts of trace metal loadings for agricultural croplands (Parizek, 1986). Lead and cadmium levels were below detection limits. Plant uptake of heavy metals increases as soil pH decreases (Chaney et al. 1987). Ammoniacal fertilizers can have the adverse effect of increasing soil acidity. Combined with the low pH on minesoils, traditional fertilization could increase the uptake of metals than might occur from use of sewage sludge (Sommers et al. 1987). Heavy metal accumulation is not generally a problem unless crops for human consumption are being grown on soils treated with repeated applications of sludge (Sommers and Sutton, 1980). Element concentrations are higher in vegetal parts of plants than in grain, seed and roots (Koskela

et al. 1985). Results using municipal sludge in reclamation of mine sites for recreational or wildlife management purposes should not create a metals problem as a single sludge application is commonly used. Metal accumulation and health issues are more of a concern with multiple applications of sludge (Wolt, 1985).

Health hazards such as survival of disease organisms in sewage sludge are of concern (Sagik et al. 1979). Health concerns are more a public perception than a real problem due to the sterilization and dewatering processes with which the sludges are treated (White, 1979; Loehr, 1981). Liming, composting, drying, and anaerobic digestion considerably reduce pathogenic material (Kofoed, 1983). Municipal sludges used in Fentress County were either open-air composted or limed and dewatered and should pose no health risks.

Vegetation for Wildlife Habitat

One of the interests of this study was the enhancement of wildlife habitat on reclaimed surface mine sites. To accomplish this it was necessary to increase wildlife cover and year round food supply. Seed mixtures were chosen to meet these criteria.

Ladino clover is a useful forage for white-tail deer (*Odocoileus virginianus*). It also provides forage for wild turkey (*Meleagris gallopavo*), ruffed grouse (*Bonasa umbellus*) and northern bobwhite (*Colinus virginianus*). It performed very

well on the phosphorus amendments with little invasion of wild grasses and broad-leaf plants. It performed well on the sludge and combination amendments although more volunteer species invaded on sludge (Tables 12 and 13). Ladino clover grows well on soils high in phosphorus, but it is not tolerant of drought conditions (Fribourg et al. 1990) such as often occur on surface minesoil. It did not do well on unamended minesoil, where it was heavily invaded by wild grasses and broad-leaf plants. Timothy provides good cover and forage, but it was difficult to establish and maintain on all but the combination sludge/phosphorus amendment in this study. This could be due to the fact that P levels decline rapidly in timothy plants and timothy requires more phosphorus for early maintenance. This critical P requirement decreases as timothy matures (Mays et al. 1980). It could also be due to timothy response to the microclimate of the study area, as it is near the limit of its natural range.

Annual lespedezas such as Korean and kobe supply seeds and leaves for northern bobwhite, eastern cottontails (*Sylvilagus floridanus*), and woodchucks (*Marmota monax*). Annual lespedezas are important winter foods northern bobwhites and mourning doves (*Zenaida macroura*) in the South (Collins, 1970). However, annual lespedezas will not provide dependable year round cover when seeded alone.

Bobwhite will eat serecea lespedeza seed, but its primary value is protective cover. It is not as desirable for wildlife

habitat as many other species. *Serecea lespedeza* is well adapted to Tennessee and grows well on eroded, droughty sites and all types of soil except when they are poorly drained. (Fribourg et al. 1990). Deer will eat low tannin varieties of *serecea*, such as the A. U. lotan *lespedeza*, but find high tannin varieties low in palatability (Ball et al. 1991).

Korean, kobe, and A. U. lotan *lespedezas* all established well on the phosphorus, sludge, and combination amendments in this study, and were rarely heavily invaded by volunteer species. by the end of the second year, all *lespedezas* were beginning to spread into the areas surrounding the plots in which they were seeded.

Orchardgrass provides dense cover and forage; it established very well on sludge and combination amendments and fairly well on the phosphorus amendment. Orchardgrass is sensitive to P deficiency (Mays et al. 1980), but was outcompeted by *lespedezas* on the phosphorus amendment.

Warm season grasses were slow to establish the first growing season, possibly due to the fact that they have difficulty competing against weeds in their early stages of growth (United States Department of Agriculture, 1991). They were frequently invaded by wild grasses and broad-leaf plants. A late planting date may be advantageous to the warm season grasses (Nilson et al. 1985). The second year the stands improved in size and vigor. Competition against weeds improved as stands matured. Switchgrass and little bluestem established

the most vigorous stands. Indiangrass did not establish as well as the others, though the indiangrass plants that survived seemed vigorous, as reported by Dickerson et al. (1988). Indiangrass may have been at a disadvantage in this mixture. The U. S. D. A, (1991) recommends that indiangrass not be used in a seed mixture with switchgrass due to their different maturity dates.

Mays et al. (1980) stated that plants with low growth rates adapt to nutrient deficiency more readily than those with fast growth rates, so slow establishment may have certain advantages. The warm season grasses appeared relatively successful on unamended areas compared to the other species. They have lower nutrient requirements and are more efficient users of P and N than cool season grasses (Jung et al. 1988; Jung et al. 1990). Analysis of Fentress County minesoil fertility indicated much lower levels of P, K, and Mg on unamended control plots than on the other soil amendments (Table 2). The warm season grasses, though low in number the first season, were the most vigorous plants seeded on unamended control plots. Switchgrass is easy to establish on surface mined land (even when unamended), good for stabilizing cover, and is useful for wildlife as winter stand-up cover (Ruffner and Steiner, 1973). It also provides seeds for song and game birds (Brown et al. 1986). Switchgrass has superior tolerance to soils with low pH (Stuckey and Bauer, 1979) and is often a preferred forage by rabbits and deer when offered

as free choice (Brenner, 1978). Warm season grasses are useful as nesting cover for game birds and rabbits (Vogel, 1981). Where long term, low-maintenance cover is desired switchgrass and little bluestem are among the best species identified to date (Gaffney and Dickerson, 1987). The warm season grasses in this study did best on the sludge amendment and reasonably well on the other amendments, including the unamended control.

Diversity of vegetative structure is often more important than food production for wildlife habitat (Kimmel and Samuels, 1978). More species would benefit from interspersing grass-legume plantings with pockets of trees and shrubs as secondary reclamation. An increase in vegetation diversity such as occurs when shrubs invade an herbaceous community, may be accompanied by an increase in avian diversity. For some species of wildlife, use of an area increases in direct proportion to the amount of habitat "edge". Large, uniform stands of one or two plant species should be avoided (Whitmore, 1978). Volunteer species of all types invaded the study plots, particularly on the unamended, unseeded sites where there was no competition from seeded species. The sludge amendment supplied a good substrate for greater diversity of invading species, as it provided conditions more suitable for plant growth. However, establishment of invaders was often prevented by competition from vigorous stands of seeded species.

With proper planning and management, the use of plant

species better suited for wildlife can be successfully and economically incorporated into surface mine reclamation. The presence of wildlife at the Fentress County mine site was noted within the first year of establishment, 1989. Whitetail deer tracks and droppings were observed among the test plots and northern bobwhites and mourning doves were observed on several occasions.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Objective 1

To compare species viability and plant productivity of seed mixtures beneficial for wildlife habitat on surface mined land amended with and without sludge and/or phosphorus.

1. The seed mixtures planted across the amendments were 1) ladino clover and timothy 2) switchgrass, indiangrass, and little bluestem 3) kobe lespedeza and orchardgrass 4) korean lespedeza and orchardgrass 5) A. U. lotan and orchardgrass 6) unseeded control.

Conclusions

2. All seed mixtures had the lowest percent cover on the limed, unamended plots.

3. The sludge amendment produced the highest cover response in the first growing season.

4. The sludge and combination amendments consistently produced the highest vegetative cover in both growing seasons.

5. Seed mixtures containing legumes had their greatest percent cover on phosphorus amended plots.

6. Seed mixtures containing grasses had their greatest percent cover on plots amended with sludge and combination amendments.
7. LDT, KBO, and KRO attained their greatest heights on the sludge and combination amendments.
8. Warm season grasses attained their greatest height on the sludge amendment.
9. A. U. lotan and orchardgrass attained their greatest height on the phosphorus and combination amendments.
10. The unseeded control attained its greatest height on the combination amendment.
11. Plants on the sludge and combination amendments consistently grew taller than on the phosphorus and unamended plots.

Objective 2

To evaluate minesoil acidity, fertility and heavy metal content before and after soil amendment.

1. The amendments applied to the surface minesoil were lime, phosphorus, municipal sewage sludge, and a combination sludge + phosphorus.

Conclusions

2. Minesoil acidity was greatly reduced post amendment by the application of lime. The phosphorus, sludge, and combination

amendments further reduced acidity.

3. All nutrient levels were increased on the phosphorus amendment from the limed control.

4. A greater quantity of nutrients was detected on minesoil amended with sludge than on the other amendments.

5. The combination amendment exhibited a reduction in level of all nutrients compared to the sludge amendment.

6. Lime application reduced heavy metal levels from preamendment levels.

7. A single application of 16 tons/a of municipal sludge did not add unacceptable levels of heavy metals.

8. The combination amendment had lower heavy metal levels than the sludge amendment with the exception of iron.

9. Increased soil pH due to lime or sludge application can reduce availability of some heavy metals for plant uptake or laboratory analysis.

Objective 3

To evaluate the dynamics of species composition of plots within the different amendments and seed mixtures.

Conclusions

1. Ladino clover had greater stem density than timothy on all plots and amendments both growing seasons except for the

combination amendment in the second season.

2. Ladino clover attained its greatest density on the phosphorus amendment.

3. Timothy attained its greatest stem density on the combination amendment.

4. Switchgrass attained its greatest stem density on sludge.

5. Indiangrass attained its greatest density on the combination amendment.

6. Little bluestem attained its greatest density on the sludge amendment. Its density was greater than all other species in the mixture on all plots.

7. Warm season grass mixture was the least dense of all seed mixtures in both growing seasons.

8. Kobe lespedeza had greater stem density than orchardgrass on all plots in the first season; its greatest density was on the unamended control. In the second year, it was most dense on the phosphorus and sludge amendments.

9. Orchardgrass was denser than kobe on all amendments except the unamended control in the second season. Its greatest density was on the sludge and combination amendments both years.

10. Korean lespedeza had greater stem density than orchardgrass on all amendments except the combination amendment in the first season. It was most dense on sludge. The density of korean lespedeza was exceeded by orchardgrass on the unamended and phosphorus plots. It was densest on

phosphorus the second season.

11. During the second year, orchardgrass was denser than Korean lespedeza on the sludge and combination amendments; its density was greatest on the combination amendment.

12. A. U. lotan was denser than orchardgrass on the unamended and phosphorus plots during year 1; it was densest on the unamended plots. In year 2 it was denser than orchardgrass on all but the sludge plots. Phosphorus and combination amendments yielded the highest densities.

13. Orchardgrass was denser than A. U. lotan on the sludge and combination plots the first season and on the sludge plots the second season. It was the most dense on sludge in both seasons.

14. Stem density was not necessarily an indication of stand or species vigor. High stem density was often accompanied by severe stunting.

15. Wild grasses invaded unseeded control plots amended with sludge in larger numbers than did broad-leaf plants.

16. Broad-leaf plants were more numerous than wild grasses on unseeded control plots containing phosphorus.

17. Fewest wild plants invaded legume, orchardgrass mixtures.

18. Warm season grasses experienced the greatest volunteer species invasion of the seed mixtures.

19. Korean and kobe lespedezas had invaded adjacent plots and border strips by the second season.

General Conclusions

1. Phosphorus fertilization can establish vigorous stands of legume species on surface minesoil.
2. Municipal sludge provided the most consistently vigorous stands of vegetation and encouraged invasion of the greatest number of volunteer species.
3. Adding phosphorus to sludge slightly decreased vegetative cover compared to sludge alone on all seed mixtures except korean, orchardgrass and the unseeded control.
4. Legumes reached their greatest densities on amendments containing phosphorus.
5. Grasses achieved their greatest densities on amendments containing municipal sludge, though timothy and orchardgrass attained their greatest densities on the combination amendment
6. Warm season grasses were slow to establish, but gained vigor and density by the second season. They established the best of all the mixtures on limed, unamended plots.
7. Seed mixtures beneficial to wildlife habitat can be used successfully in the revegetation of surface mined land.

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APPENDICES

Table 18. Average monthly temperature and average maximum and minimum temperature in degrees F and average rainfall in inches. Data from the Allardt Weather Station for 1989.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T Mx	52	44	62	66	71	78	82	82	73	67	56	35
T Mn	32	27	39	43	50	60	65	62	56	42	35	17
T Av	42	36	50	58	63	69	75	72	64	54	44	23
Rain	5.5	8.7	6.6	3.4	5.8	9.0	3.4	4.9	10	3.3	4.1	3.0

Table 19. Average monthly temperature and average maximum and minimum temperature in degrees F and average rainfall in inches. Data from the Allardt Weather Station for 1990.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T Mx	50	54	59	67	72	81	83	84	80	67	61	52
T Mn	32	35	40	42	50	60	63	62	57	45	39	33
T Av	41	44	50	58	63	76	76	75	69	55	49	41
Rain	3.5	5.2	3.2	2.4	5.2	3.9	2.5	2.2	2.5	4.9	3.1	12

Table 20: Species seeding rates in lbs/A.

Species		Lbs/A
Timothy	<i>Phleum pratense</i>	5
Ladino clover	<i>Trifolium ripens</i> L.	3
Switchgrass	<i>Panicum virgatum</i> L.	4
Indiangrass	<i>Sorghastrum nutans</i>	5
Little Bluestem	<i>Schizachyrium scoparium</i>	4
Orchardgrass	<i>Dactylis glomerata</i>	8
Kobe Lespedeza	<i>Lespedeza striata</i>	10
Korean Lespedeza	<i>Lespedeza stipulacea</i>	10
A. U. Lotan	<i>Lespedeza sericea</i>	15
Tall Fescue	<i>Festuca arundinacea</i>	15

Table 21: Percent cover in 1989 - soil amendments and seed mixtures ranked by descending cover.

<u>Percent Cover</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
21.0 $\pm$ 3.7	Sludge	AUO ₁
18.2 $\pm$ 3.6	Sludge	NS
17.4 $\pm$ 4.0	Sludge	KRO
16.6 $\pm$ 2.6	S + P	AUO
14.9 $\pm$ 3.1	Sludge	WSG
14.7 $\pm$ 3.2	Sludge	LDT
12.4 $\pm$ 3.6	Sludge	KBO
12.1 $\pm$ 2.5	Phosphorus	KBO
12.0 $\pm$ 2.5	S + P	LDT
11.4 $\pm$ 2.6	S + P	KRO
11.2 $\pm$ 2.0	S + P	NS
9.5 $\pm$ 2.5	S + P	KBO
9.5 $\pm$ 2.8	Phosphorus	KRO
6.5 $\pm$ 2.5	Phosphorus	LDT
6.3 $\pm$ 2.5	S + P	WSG
5.6 $\pm$ 2.5	Control	KBO
5.7 $\pm$ 2.5	Phosphorus	AUO
2.7 $\pm$ 2.7	Phosphorus	NS
2.0 $\pm$ 2.5	Phosphorus	WSG
1.8 $\pm$ 2.5	Control	NS
1.5 $\pm$ 2.5	Control	KRO
1.2 $\pm$ 2.5	Control	AUO
1.0 $\pm$ 2.5	Control	LDT
0.9 $\pm$ 2.5	Control	WSG

₁ Abbreviations are defined on page 15.

Table 22: Percent cover in 1990 - soil amendments and seed mixtures ranked by descending cover.

<u>Percent Cover</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
96.1 $\pm$ 7.2	Sludge	AUO ₁
88.5 $\pm$ 6.0	S + P	KRO
87.3 $\pm$ 6.0	Phosphorus	KBO
82.3 $\pm$ 8.1	Sludge	KBO
81.9 $\pm$ 6.2	S + P	KBO
79.6 $\pm$ 6.4	Sludge	LDT
78.3 $\pm$ 7.2	S + P	WSG
77.9 $\pm$ 4.9	S + P	LDT
77.5 $\pm$ 8.5	Sludge	KRO
76.7 $\pm$ 9.9	Sludge	WSG
74.7 $\pm$ 5.3	S + P	AUO
73.9 $\pm$ 6.0	Phosphorus	KRO
71.5 $\pm$ 8.0	S + P	NS
65.3 $\pm$ 4.8	Phosphorus	LDT
62.8 $\pm$ 4.9	Phosphorus	AUO
60.0 $\pm$ 6.6	Phosphorus	WSG
49.8 $\pm$ 8.5	Sludge	NS
48.8 $\pm$ 7.3	Phosphorus	NS
38.3 $\pm$ 6.0	Control	KBO
21.3 $\pm$ 6.6	Control	WSG
28.2 $\pm$ 7.4	Control	NS
20.7 $\pm$ 4.9	Control	AUO
19.7 $\pm$ 6.2	Control	KRO
15.1 $\pm$ 4.8	Control	LDT

, Abbreviations are defined on page 15.

Table 23: Point quadrat: Percent cover in 1989 - soil amendments and seed mixtures ranked by descending cover.

<u>Percent Cover</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
67.1 $\pm$ 6.7	Sludge	AUO ₁
61.0 $\pm$ 7.1	Sludge	KRO
58.0 $\pm$ 5.8	Sludge	LDT
47.0 $\pm$ 5.5	Sludge	WSG
43.9 $\pm$ 4.6	S + P	AUO
43.0 $\pm$ 4.4	S + P	LDT
42.5 $\pm$ 4.5	Phosphorus	LDT
43.0 $\pm$ 6.8	Sludge	NS
39.0 $\pm$ 6.3	Sludge	KBO
39.3 $\pm$ 5.1	S + P	NS
35.6 $\pm$ 4.7	S + P	KRO
33.5 $\pm$ 4.5	S + P	WSG
29.0 $\pm$ 4.4	Phosphorus	KBO
30.5 $\pm$ 5.0	Phosphorus	KRO
29.4 $\pm$ 4.2	Phosphorus	AUO
25.5 $\pm$ 4.4	S + P	KBO
21.0 $\pm$ 4.4	Control	KBO
19.5 $\pm$ 4.4	Control	NS
18.9 $\pm$ 4.8	Phosphorus	NS
17.0 $\pm$ 4.4	Control	AUO
16.0 $\pm$ 4.4	Phosphorus	WSG
16.0 $\pm$ 4.4	Control	WSG
11.5 $\pm$ 4.4	Control	LDT
9.5 $\pm$ 4.4	Control	KRO

₁ Abbreviations are defined on page 15.

Table 24: Point quadrat: Percent cover in 1990 - soil amendments and seed mixtures ranked by descending cover.

<u>Percent Cover</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
96.7 $\pm$ 7.0	Sludge	AUO ₁
87.5 $\pm$ 5.8	S + P	KRO
83.7 $\pm$ 6.3	S + P	KBO
81.2 $\pm$ 6.3	S + P	WSG
80.5 $\pm$ 4.4	S + P	LDT
80.0 $\pm$ 8.2	Sludge	KBO
78.2 $\pm$ 5.8	Sludge	LDT
75.3 $\pm$ 5.1	S + P	AUO
74.0 $\pm$ 5.8	Phosphorus	KRO
77.0 $\pm$ 6.1	Phosphorus	KBO
72.2 $\pm$ 8.6	Sludge	WSG
71.8 $\pm$ 7.0	S + P	NS
71.0 $\pm$ 8.3	Sludge	KRO
67.5 $\pm$ 4.3	Phosphorus	LDT
65.0 $\pm$ 5.6	Phosphorus	WSG
61.0 $\pm$ 6.5	Phosphorus	NS
60.0 $\pm$ 4.7	Phosphorus	AUO
56.0 $\pm$ 7.4	Sludge	NS
45.0 $\pm$ 6.1	Control	KBO
43.0 $\pm$ 6.5	Control	NS
37.0 $\pm$ 5.8	Control	WSG
36.8 $\pm$ 6.0	Control	KRO
32.5 $\pm$ 4.7	Control	AUO
30.0 $\pm$ 4.3	Control	LDT

₁ Abbreviations are defined on page 15.

Table 25: Vegetation stand height in centimeters: 1989 - soil amendments and seed mixtures ranked by descending height.

<u>Height</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
18.1 $\pm$ 2.8	Sludge	KRO ₁
18.3 $\pm$ 1.8	S + P	KRO
17.6 $\pm$ 1.7	Phosphorus	KBO
17.3 $\pm$ 2.5	Sludge	KBO
17.0 $\pm$ 1.8	Phosphorus	AUO
14.8 $\pm$ 1.7	S + P	KBO
14.4 $\pm$ 2.6	Sludge	AUO
14.4 $\pm$ 1.8	S + P	AUO
14.4 $\pm$ 2.0	Phosphorus	KRO
13.9 $\pm$ 2.5	Sludge	NS
12.2 $\pm$ 1.7	Control	KBO
12.1 $\pm$ 1.7	Phosphorus	WSG
11.8 $\pm$ 2.2	Sludge	WSG
11.0 $\pm$ 1.8	S + P	WSG
10.4 $\pm$ 1.7	S + P	LDT
8.7 $\pm$ 1.7	Control	KRO
8.0 $\pm$ 1.9	Phosphorus	NS
7.6 $\pm$ 2.3	Sludge	LDT
7.3 $\pm$ 1.7	Control	WSG
7.0 $\pm$ 1.8	Phosphorus	LDT
6.3 $\pm$ 1.7	Control	AUO
4.7 $\pm$ 1.7	Control	LDT
3.7 $\pm$ 1.7	Control	NS

₁ Abbreviations are defined on page 15.

Table 26: Vegetation stand height in centimeters: 1990 - soil amendments and seed mixtures ranked by descending height.

<u>Height</u>	<u>Soil Amendment</u>	<u>Seed Mixture</u>
55.0 $\pm$ 7.5	Sludge	WSG ₁
53.2 $\pm$ 3.0	S + P	AUO
50.3 $\pm$ 2.8	Phosphorus	AUO
49.4 $\pm$ 4.1	Sludge	AUO
46.6 $\pm$ 5.4	S + P	WSG
31.2 $\pm$ 5.0	Phosphorus	WSG
28.4 $\pm$ 5.4	S + P	NS
26.6 $\pm$ 3.9	Sludge	KRO
26.2 $\pm$ 2.8	S + P	KRO
25.7 $\pm$ 5.4	Sludge	NS
25.5 $\pm$ 1.8	S + P	KBO
24.9 $\pm$ 2.4	Sludge	KBO
24.0 $\pm$ 5.8	Phosphorus	NS
23.9 $\pm$ 1.8	Phosphorus	KBO
23.4 $\pm$ 2.7	Sludge	LDT
22.9 $\pm$ 2.8	Control	AUO
22.6 $\pm$ 2.0	S + P	LDT
22.2 $\pm$ 5.0	Control	WSG
21.9 $\pm$ 5.0	Control	NS
21.5 $\pm$ 2.9	Control	KRO
20.2 $\pm$ 2.8	Phosphorus	KRO
19.4 $\pm$ 1.8	Control	KBO
18.0 $\pm$ 2.0	Phosphorus	LDT
10.5 $\pm$ 2.0	Control	LDT

₁ Abbreviations are defined on page 15.

VITA

VITA

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