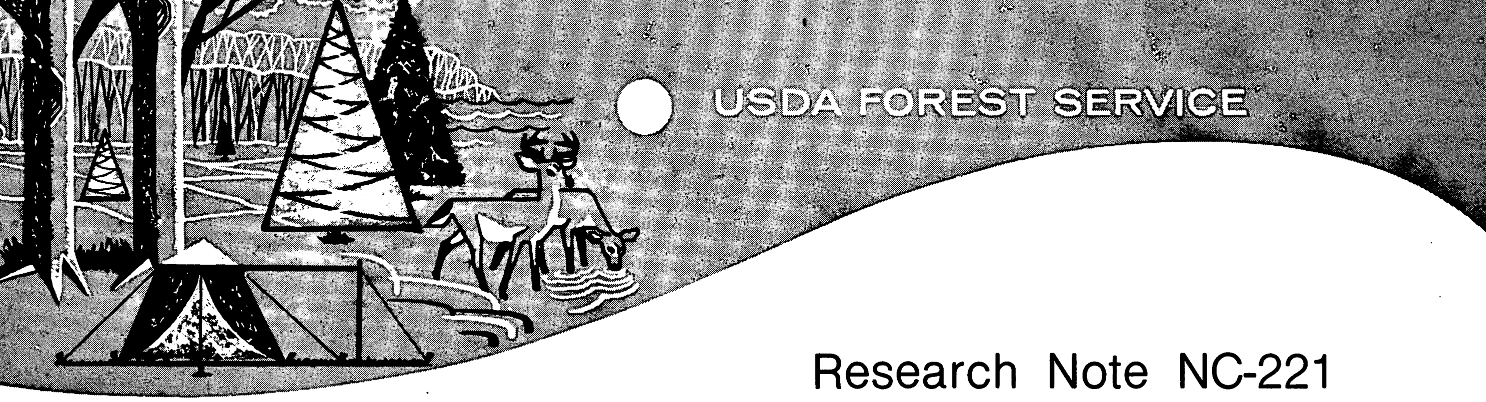

Research Note NC-221

NORTH CENTRAL FOREST EXPERIMENT STATION, FOREST SERVICE—U.S. DEPARTMENT OF AGRICULTURE

Folwell Avenue, St. Paul, Minnesota 55101 1977

SLUDGE-TREATED COAL MINE SPOILS INCREASE HEAVY METALS IN COVER CROPS

F. D. McBride, *Forestry Technician, Carbondale, Illinois*
C. Chavengsaksongkram, *Soil Chemist, Department of Agronomy, University of Illinois, Urbana, Illinois, and*
D. H. Urie, *Principal Hydrologist, East Lansing, Michigan*

ABSTRACT.--Four species of forage were grown in a greenhouse on acid strip mine spoil treated with municipal sewage sludge. Foliar levels of heavy metals exceeded those recommended for animal consumption. No plant toxicity symptoms were evident.

OXFORD: 114.449.8U628.36:114.26. KEY WORDS: cadmium, strip-mine, reclamation, forage, sewage.

Acid spoil banks resulting from strip-mining of coal pose a severe rehabilitation problem because of toxic concentrations of cations and droughty surface soils. Digested sewage sludge has been used as one means of creating a medium for establishing plant growth in Ohio, Pennsylvania, and Illinois. In Illinois, research has been conducted by the USDA Forest Service on the Palzo tract of the Shawnee National Forest near Crab Orchard, representative of about 4,900 ha of the highly acid spoil conditions in Illinois (Haynes and Klimstra 1975). Rehabilitation plans have been developed cooperatively with the Metropolitan Sanitary District of Greater Chicago to use liquid sludge on about 73 ha of nonvegetated land (Cunningham, R. *et al.* 1975).

Preliminary field studies of the ameliorating effects of sludge on acid mine spoil showed that lasting effects required at least 178 metric tons/ha for continued growth of test vegetation (Lejcher and Kunkle 1973). Greenhouse tests of higher dosage rates were begun in 1972 for evaluation of the chemical changes in percolating subsoil water (Cunningham, R. *et al.* 1975).

Tests of plant growth on agricultural soils that have received high dosages of sewage sludge indicate the need to maintain high pH values to reduce toxicity of metals on test plants. Suggested limits for total metal additions to soils, with a cation exchange capacity (CEC) greater than 15 m.e./100 g, are: Zinc 870 kg/ha, Copper 435 kg/ha, Cadmium 17 kg/ha (Sommers and Nelson 1976).

The use of sewage sludge for amelioration of phytotoxic conditions on acid spoils requires high dosages to alleviate acidity and reduce drought stresses, but is justified on highly acid spoil where the availability of micro-elements to plants might be expected to exceed plant tolerance limits.

COVER CROP TESTS

Greenhouse tests were conducted in 30.5 x 60.5 x 122 cm deep leaching chambers by the North Central Forest Experiment Station at Carbondale, Illinois. Dosages of 336 and 672 t/ha dry weight equivalent of sewage sludge were incorporated into the surface 12.5 cm of spoil to simulate field procedure. Lime was added at 0, 22.4, and 44.8 mt/ha rates with two replicate chambers for each treatment combination. Dosage rates of nutrients and metals in the sludge are listed below:

Sludge application rate t/ha	*336*	*672*
Element	Loading rate kg/ha	
N	7280	14560
P	6160	12320
K	1300	2600
Ca	11760	23520
Mg	4640	9280
S	4370	8740
Fe	18140	36270
Cu	250	500
Cr	1680	3360
Cd	70	140
Pb	770	1540
Ni	17	34
Zn	1144	2287

The sludge-treated chambers were leached with distilled water semi-monthly for 20 months. Percolating water was collected for analysis on a monthly basis. Results of analysis of this leachate are reported elsewhere (Cunningham, R. *et al.* 1975).

Four species of forage were planted at two planting dates in the leaching chambers according to the following schedule:

Species	*Date planted*	*Date harvested 1*	*2*	*3*
Rye (grain)	5/08/74	6/06/74		
Ky-31 Tall Fescue	6/10/74	1/02/75	3/31/75	6/3/75
Reed Canary Grass	5/08/74	7/22/74		
Sudan Grass	10/18/74	1/22/75	3/31/75	6/3/75

The 12 replicates of each sludge treatment were equally divided between the two species planted on each date. Three lime treatments were superimposed. The six chambers planted to rye were replanted to tall fescue after the rye was harvested. The chambers planted to reed canary grass were replanted to sudan grass. Three clippings from the second set of species were harvested on the dates shown.

Foliage was clipped about 2 cm above the soil surface. Root systems were pulled out, washed thoroughly with distilled water, and dried and weighed. Vegetation samples were dried to constant weight, weighed, and ground for analysis. Vegetative materials were analyzed at the Agronomy Lab, University of Illinois.

METHODS OF ANALYSIS OF PLANT TISSUE

Plant tissues were wet-ashed in Folin-Wu tubes using a 10 ml mixture of 5:1 HNO_3:$HClO_4$. The ashed samples were then analyzed for Ca, Mn, Zn, Cd, Cr, and Cu by atomic absorption with background correction for matrix effects. Total nitrogen analysis was done according to the procedure of Bremner (1965).

RESULTS

Application of sludge increased the cation exchange capacity of the soil (table 1). Peterson and Gschwind (1972) reported a CEC of Chicago sludge of 73 meq/100 g solids. pH values were increased by sludge applications. Reductions in acidity were measurable only to about 30 cm depths.

Table 1.--*Cation exchange capacity and pH of the spoil profile of the sludge-lime treatments*[1]

Spoil depth	Sludge application rates mt/ha 0	332	664
0-7.5 cm			
CEC	15-20 meq/100g	20-29	27-40
pH	2.5-3.0	5.0-5.6	5.5-5.7
7.5-15 cm			
CEC	16-17	20-23	23-27
pH	2.6-3.0	4.6-4.8	5.1-5.4
15-22.5 cm			
CEC	16-20	17	16-21
pH	2.7-2.8	2.6-3.1	3.3-4.3
22.5-30 cm			
CEC	14-17	15-17	15-18
pH	2.7-2.9	2.8-2.9	3.0-3.1

[1]Spindler, Dean R. 1976. Fate and effects of sewage sludge and lime on chemical characteristics of acid strip mine spoils. Unpublished M.S. thesis. Southern Illinois Univ., Carbondale, Illinois.

Concentrations of various nutrient elements are shown in table 2 for foliage and roots. Root systems extended to the depth of sludge incorporation, 12.5 cm. Root systems were generally higher in all trace metals except Mn than foliage. In general, higher dry matter production occurred on the 664 mt/ha treatment.

Sudan grass was a high accumulator of cadmium, especially at the high lime rates (table 3). Reed canary grass also accumulated cadmium at higher concentrations than

Table 2.--*Nutrient content of foliage and roots of forage crops grown on sludge amended spoils*

Species	Sludge level:	Nutrient element concentration %				
	mt/ha	*Ca*	*Mg*	*K*	*P*	*N*
Rye foliage	332	0.79	0.71	2.65	0.67	3.70
	664	.82	.61	3.25	.58	4.23
Reed canary	332	.54	.62	1.83	.37	2.87
grass foliage	664	.65	.49	2.58	.41	2.77
Tall fescue foliage	332	.76	1.14	1.10	.60	2.77
	664	.90	.95	1.34	.57	3.39
Sudan grass foliage	332	.81	1.00	.77	.36	1.55
	664	.85	.71	1.05	.28	2.03
Rye roots	332	.39	.41	1.55	.63	2.92
	664	.39	.41	2.08	.65	3.12
Reed canary	332	.39	.28	.86	.54	2.13
grass roots	664	.40	.28	1.28	.61	2.15
Tall fescue roots	332	.67	.42	.43	.53	1.62
	664	.67	.45	.52	.63	1.91
Sudan grass roots	332	.45	.56	.34	.31	.87
	664	.49	.52	.40	.23	1.28
Average all spp.	332	.72	.86	1.58	.50	2.72
(foliage)	664	.80	.69	2.05	.46	3.27
Average all spp.	332	.47	.41	.79	.50	1.88
(roots)	664	.48	.41	1.07	.53	2.11

rye or fescue. Selection of these two forage crops for erosion control would also serve to retain metals on the site in the organic matter portion of the soil. Green manure management of sudan grass and reed canary grass would serve as an excellent method of holding cadmium in the surface soil to protect against leaching to ground water.

Zinc concentrations in foliage were consistantly reduced by higher lime rates. Cadmium concentrations showed no consistent relation to liming, except in sudan grass. The highest cadmium levels occurred at 332 mt/ha sludge treatment and 0 mt/ha lime rate. It is also interesting to note that uptake of cadmium by sudan grass, and to some extent by rye grass, always occurred at low sludge and lime treatment. This seems to indicate that the source of cadmium uptake is that which is indigenously present in the spoil materials. Laboratory analysis of spoils and roof shales from the area indicated the presence of sphalerite, a zinc sulfide ore, with cadmium sulfide as co-deposits. This explains why uptake of zinc is always high at low lime and low sludge treatments.

Nitrogen levels in both foliage and roots were highest in the high (664 t/ha) sludge rate for each species.

Zinc and cadmium levels were comparable to those reported by Jones *et al.* (1975) on agricultural soils treated with sludge at similar rates. King and Morris (1972) found that liming reduced the concentrations of Mn, Cu, and Zn in rye foliage where natural soils were fertilized with high rates of sludge. On the acid spoils liming reduced Zn and Mn consistently but Cu was erratically affected. Yields tended to be reduced by high lime rates in soils treated with 664 mt/ha of sludge (significant from 0, 332). This is probably due to the catalytic effect of high pH on oxidation of pyrite which is resulted from higher rate of ferric (Fe III) formation (Singer 1970).

Repeated cropping by the same crop would be required to determine the trend in metal concentrations.

Table 3.--*Chemical composition and yield of foliage grown on sludge and lime amended spoil*

Species	Sludge rate	Lime rate	Yield	Mn	Zn	Cd	Cr	Cu	Cd/Zn
	t/ha	*t/ha*	*kg/ha*	- - - -	- - - -	*ppm*	- - - -	- - - -	%
Rye (annual)[1]	332	0	2383	223	554	6.4	9.0	12.0	1.2
		22.4	2489	171	424	6.6	15.5	17.5	1.5
		44.8	2391	169	244	3.5	4.5	21.5	1.5
	664	0	2950	186	358	4.9	4.5	12.0	1.4
		22.4	2692	168	292	3.9	4.0	10.5	1.3
		44.8	3290	173	210	3.1	4.0	10.0	1.5
Reed canary grass[1]	332	0	2428	308	710	3.1	6.5	15.5	0.4
		22.4	2325	303	602	5.5	8.0	17.5	0.9
		44.8	2729	248	449	5.3	5.0	14.5	1.2
	664	0	2342	273	686	7.1	7.5	17.5	1.0
		22.4	2532	310	591	6.8	6.0	15.0	1.1
		44.8	1993	218	572	6.5	7.0	14.0	1.1
Ky 31, tall fescue[2]	332	0	566	409	557	6.2	.83	15.6	1.1
		22.4	934	331	397	3.9	1.23	15.5	1.0
		44.8	1193	365	270	3.2	2.0	14.3	1.2
	664	0	1012	332	402	4.6	1.0	16.1	1.2
		22.4	1224	270	437	6.0	.93	11.1	1.4
		44.8	984	253	293	5.3	1.3	13.9	1.8
Sudan grass[2]	332	0	1124	370	787	18.4	.73	16.1	2.3
		22.4	1620	371	682	15.6	1.0	13.7	2.3
		44.8	2310	287	383	7.3	1.77	10.4	1.9
	664	0	2304	262	510	8.2	.83	14.8	1.6
		22.4	2330	250	423	9.6	1.2	11.9	2.3
		44.8	2290	185	362	8.5	1.13	11.0	2.3

[1]First crop on chamber.
[2]Second crop on chamber, mean of 3 clippings.

Leaching chambers not treated with sludge failed to produce any vegetative material for analysis. Lime treatments did not produce conditions amenable to growth of grasses without addition of sludge.

In selecting the best erosion control cover for the Palzo rehabilitation project, drought resistance must be considered as well as the factors discussed here. Rye offers the opportunity for dormant season cover as well as the lowest cadmium concentration in the foliage. A more drought-resistant species will be needed to maintain adequate ground cover during the summer months.

If a forage crop were to be selected for animal fodder on the basis of foliar cadmium concentration, rye would be the best choice although the levels are higher than those recommended for animal consumption (Melsted 1973). Although the two sludge rates were excessive in agricultural terms, crops did not show toxicity symptoms. If the use of the vegetation is to be limited to erosion control, reed canary grass offers the best trace element accumulation in the plant materials. Cadmium, zinc, and copper incorporated into plant tissues would be, at least temporarily, withheld from leaching to ground water or moving to streams by surface runoff.

REFERENCES

Bremner, J. M. 1965. Total nitrogen. In Methods of soil analysis, Part 2. p. 1171-1176, C. A. Black, ed. Am. Soc. Agronomy, Madison, Wisconsin.

Cunningham, R. S., C. K. Losche, and R. K. Holtje. 1975. Water quality implications of strip-mine reclamation by wastewater sludge. p. 643-646. In Second national conference on water reuse Proc., Chicago, Illinois.

Haynes, R. J., and W. D. Klimstra. 1975. Illinois lands surface mined for coal. 201 p. Coop Wildl. Res. Lab, Southern Illinois Univ., Carbondale, Illinois.

Jones, R. L., T. D. Hinesly, E. L. Ziegler, and J. J. Tyler. 1975. Cadmium and zinc contents of corn leaf and grain produced by sludge amended soil. J. Environ. Qual. 4(4):509-514.

King, L. D., and H. D. Morris. 1972. Land disposal of liquid sewage sludge. II. The effect of soil pH, managese, zinc and growth and composition of rye (*Secale cereale* L.), J. Environ. Qual. 1(4):425-429.

Lejcher, T. R., and S. H. Kunkel. 1973. Restoration of acid spoil banks with treated sewage sludge. In Recycling treated municipal wastewater and sludge through forest and cropland. p. 184-199. Pennsylvania State Univ. Press.

Melsted, S. W. 1973. Soil-plant relationships. In Recycling municipal sludges and effluents on land. p. 121-128. National Assoc. of State Universities and Land Grant Colleges, Washington, D.C.

Peterson, J. R., and J. Gschwind. 1972. Leachate quality from acid mine spoil fertilized with liquid digested sewage sludge. J. Environ. Qual. 1(4):410-412.

Singer, Philip C. 1970. Oxygenation of Ferrous iron. Water Pollution Control Research Series 14010 June, 1969. U. S. Dept. of the Interior. Federal Water Quality Admin. Washington, D.C.

Sommers, L.E., and D.W. Nelson. 1976. Analyses and their interpretation for sludge application to agricultural land. In Application of sludge and wastewaters on agricultural land: a planning and educational guide. B. D. Knezek and R. H. Miller, eds. North Central Reg. Res. Publ. 235. p. 3.1-3.7. Ohio Agric. Res. and Dev. Cent., Wooster, Ohio.

☆U. S. GOVERNMENT PRINTING OFFICE: 1977--767423/32 REGION NO. 6