A Report Submitted to the Powell River Project

Effects of Biosolids-Amended Mined Land on Soil and Plant Quality

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Summary

Forage species provide environmental benefits as erosion-controlling, nutrient recycling vegetative ground covers, and they possess economic potential as animal feed sources hen used re-vegetate reclaimed surface mined land. Establishing forages on surface-mined soils in southwest Virginia is a challenge, because the steep, shallow soils are prone to erosion and provide poor nitrogen (N) and phosphorus (P) nutrition. Biosolids (domestic sewage sludges treated to permit land application) have demonstrated excellent economic and agronomic value as soil amendments for reclaiming disturbed soils, but concerns regarding the potential for heavy metal uptake by crops and transport through the food chain have prevented the widespread use of this potentially valuable amendment for restoring productivity to degraded lands. A study was successfully established in spring 1991 at the Powell River Project Demonstration Field Site in Wise County, Virginia to study the establishment success and longevity of sixteen cover crop species and species mixes planted in a surface-mined site that was amended with a standard mixture of composted wood chips and biosolids. The stand and biomass of the various species have been measured annually, but no monitoring of heavy metal uptake has been conducted. Vegetation has been mowed but not removed from the plots; thus, biosolids-borne heavy metals should remain within the soil-plant system. The purpose of this study was to determine whether forage crops grown on the biosolids-amended mine land can accumulate heavy metals to high enough concentrations as to be phytotoxic or pose toxicity concerns to livestock who feed on the forages. We sampled the soils and a variety of forages that were representative of the successfully-establishing species, including tall fescue, ladino clover, crown vetch, reed canarygrass, common sericea lespedeza, AULotan sericea lespedeza, switchgrass, a tall fescue-alfalfa mixture, and a switchgrass-AULotan mixture. The soil and plant tissue was analyzed for Cd, Cu, Ni, and Zn, the potentially toxic trace elements whose application rates in the biosolids most closely approached the limits set by the U.S. EPA. The concentrations of total recoverable Cu, Ni, and Zn were not affected by vegetative cover treatment. Soil Cd concentrations were below detection limits. Plant tissue concentrations of the trace elements varied with forage type but were lower than concentrations believed to be phytotoxic or possess food chain risks. The standard wood chips and biosolids treatment developed for reclaiming surface mined coal land in southwest Virginia provided no long term trace element concerns.

Introduction

Establishing vegetation on surface mined land in southwest Virginia is a challenge because the soils are prone to compaction and provide poor nitrogen (N) and phosphorus (P) nutrition. Forages provide benefits as a nutrient recycling vegetative ground cover and as an animal feed source. Establishment and maintenance of forages on surface-mined land is problematic because such soils are usually limiting in essential crop nutrients and organic matter that enhance soil chemical, biological, and physical properties necessary for vigorous plant growth.

The application of a standard soil amendment composed of composted wood chips and domestic wastewater sewage sludge (biosolids) in fall 1989 enabled the establishment of sixteen forage species and species mixes in spring 1991. The stand density and biomass produced by the surviving species have been measured annually since 1996, and annual reports have been provided to the Powell River Project (Abaye and Evanylo); however, no analysis of vegetation has been conducted to determine whether the forages successfully established on the biosolids-amended soils possess the potential for transporting heavy metals into the food chain or could become phytotoxic.

Previous work

Trace elements in crop tissues are elevated by biosolids application to land (Logan and Chaney, 1983). A risk assessment conducted by the U.S. Environmental Protection Agency (USEPA) established concentration limits and lifetime loading rates for As, Cd, Cu, Hg, Mo, Ni, Pb, Se and Zn applied to soil in biosolids to protect the public health and environment from deleterious effects of these nine trace elements (USEPA, 1992). The risk assessment included five pathways in which the transfer of trace elements from biosolids-amended soil to plant tissue was modeled using data from published research studies to establish plant uptake coefficients (UC). Most of the data utilized by the USEPA to calculate the UC were from studies in which trace element uptake by plants was measured during the years of biosolids application. The U.S. EPA risk assessment methodology assumed that trace element bioavailability does not change after biosolids applications cease.

Concerns have been raised that the bioavailability of added trace elements may increase after biosolids applications cease and the binding capacity of the biosolids is reduced as organic matter is mineralized (McBride, 1995). Barbarick et al. (1995), Dixon et al. (1995), and Logan et al. (1997) have provided evidence that biosolids metals' uptake by wheat, corn, and several vegetables does not increase after biosolids applications cease; however, none of these researchers investigated the effects of metal bioavailability on forages. It is critical to investigate the bioavailability of heavy metals to forage species because: 1) biosolids are one of the best economic and agronomic sources of nutrients and

organic matter for reclaiming disturbed land, and 2) forages have proven to be highly successful economic crops for the re-vegetating disturbed land.

Objectives

To determine whether uptake of Cd, Cu, Ni, and Zn by forage species grown on biosolids-amended surface mined soils pose trace element food chain or phytotoxicity concerns.

Methods

A reclamation study was established in spring, 1991 on reclaimed surface mine soil characterized by overburden material of 2 parts sandstone: 1 part siltstone. A mixture of wood chips plus sewage sludge at 112 Mg/ha (50 tons/acre), now considered to be the standard reclamation practice for surface-mined coal land in Virginia (Haering and Daniels, 1991), was incorporated in fall 1989 with a chisel plow to provide a source of N, P, and organic matter and planted with ryegrass.

The sixteen forage treatments shown below were established in April 1991 after the initial attempt at establishment in summer 1990 failed due to drought. Plots have been mowed each year to return plant-produced C and recycled nutrients into the soil organic pool.

Original treatments:

1. Tall fescue - var KY31
2. Orchardgrass
3. Ladino clover - var Regal
4. Crown vetch
5. Birdsfoot trefoil - var Empire
6. Alfalfa - var HiPhy
7. Reed canarygrass - var Palatin
8. Common Sericea lespedeza
9. AULotan Sericea lespedeza
10. Switchgrass
11. Caucasian bluestem
12. Tall fescue/ladino clover
13. Tall fescue/alfalfa
14. Orchardgrass/birdsfoot trefoil
15. Switchgrass/AULotan
16. Reforestation mix (foxtail millet, perennial ryegrass, red top, Kobe lespedeza, Appalow lespedeza, and birdsfoot trefoil)

The experimental design is a randomized complete block with each treatment replicated four times. Individual plots are 15.2 m^2 (13 ft. by 13 ft.), and are separated by alleys into which tall fescue has been established.

The site has been maintained for eleven years (1991-2002) by mowing and leaving the vegetation in place to prevent removal of metals from the soil-plant system. Competition by species native to the region has resulted in the decline and loss of many of the originally-planted species, and dominance of other original species during the eleven years since vegetation was established. We sampled a variety of plant types that were representative of the successfully-

establishing species and included treatments 1 (tall fescue), 3 (ladino clover), 4 (crown vetch), 7 (reed canarygrass), 8 (common sericea lespedeza), 9 (AULotan sericea lespedeza), 10 (switchgrass), 13 (tall fescue-alfalfa mixture), and 15 (switchgrass-AULotan mixture).

Vegetation was sampled by cutting two random 0.09 m^2 quadrats of plant material to within 5 cm of the soil surface on August 6, 2002. Biomass was calculated by weighing plant material dried at 65EC. Plant material was ground, digested and analyzed for Cd, Cu, Ni, and Zn by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Soil was sampled from the same treatment plots from which plant tissue was sampled and analyzed for routine soil test analysis (Donohue and Friedericks, 1984) and total Cd, Cu, Ni, and Zn by ICP-AES employing USEPA Method 3051 (USEPA, 1995b).

Results and Discussion

Nearly every routine soil test variable (pH, P, K, Ca, Mg, Mn, and Cu) was statistically identical (P>0.1) between vegetation treatments (Table 1). Soil Zn was higher under the switchgrass-AULotan mix treatment and lower under the switchgrass only treatment than under all other vegetative treatments ((P < 0.03, data not shown). The differences were likely due to spatial variability rather than a biological effect. Vegetative treatments did not alter soil pH or the concentrations of plant nutrients under the management practices implemented (i.e., returning plant material to the soil).

Table 1. Mean values of soil pH and Mehlich I extractable P, K, Ca, Mg, Mn, and Cu for the vegetative treatments monitored.

pH	P	K	Ca	Mg	Mn	Cu
	----------mg kg^{-1}----------					
5.77	148	71	1823	324	27	5.6

The soil test values of P, Ca, and Mg (“Very High”) and K (“Medium”) would likely have provided adequate concentrations of the macro essential plant nutrients. Soil Mn, Cu, and Zn (mean = 55 mg/kg) were well above limiting concentrations

The concentrations of total recoverable (USEPA 3051) Cu, Ni, and Zn in the soil beneath different species were not affected by treatments (Table 2). Threshold values for total soil concentrations of metals considered excessive have been proposed by various researchers. Kabata-Pendias and Pendias (1984) summarized such data for Cd (3-8 mg/kg), Cu (60-125 mg/kg), Ni (100 mg/kg), and Zn (70-400 mg/kg). The USEPA (1995a) set higher standards for Cu (750 mg/kg), Ni (210 mg/kg), and Zn (3750 mg/kg) in biosolids-amended soil because of the reduced bioavailability of these metals when applied in the biosolids matrix. According to Kabata-Pendias and Pendias (1984), Cu and Zn concentrations in the biosolids-amended soil should be in the phytotoxic range, but the USEPA would not consider these soils to be problematic. Soil Ni

concentrations are lower than the phytotoxic threshold concentrations suggested by all researchers. Cadmium concentrations were below detection limits (<0.1 mg/kg) in all treatments.

Table 2. Mean soil concentrations of USEPA 3050 “total” Cu, Ni, and Zn.

Cu (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
346	23	338

The forage species exhibited differential uptake of the heavy metals that could affect the recommended use of forages planted on biosolids-remediated land (Table 3). Crown vetch accumulated the highest concentrations of Cd and Zn, AULotan sericea lespedeza accumulated the highest concentration of Ni, and switchgrass accumulated the highest concentration of Cu. While other differences existed, there were no obvious uptake patterns for the four metals among the various species.

Table 3. Effects of vegetative treatment on plant tissue metal concentration.

Treatment	Cu	Cd	Ni	Zn
Name (No.)	----------mg kg^{-1}----------			
Tall fescue (1)	7.0 cd	0.49 b	2.8 c	41 b
Ladino clover (3)	6.9 cd	0.47 b	2.9 bc	45 b
Crown vetch (4)	6.9 cd	1.0 a	4.8 ab	184 a
Reed canarygrass (7)	6.9 cd	0.25 cd	3.0 bc	71 b
Common sericea lespedeza (8)	10.0 ab	0.45 bc	3.1 bc	44 b
AULotan sericea lespedeza (9)	8.4 bc	0.59 b	5.6 a	83 b
Switchgrass (10)	10.1 a	0.21 d	4.0 abc	66 b
Tall fescue-alfalfa mix (13)	5.7 d	0.52 b	4.1 abc	37 b
Switchgrass-AULotan mix (15)	8.9 ab	0.22 d	2.9 c	60 b
Pr>F	0.01	0.01	0.04	0.01

The effects of species on metal concentrations in mixed species treatments appeared to be additive, rather than synergistic. That is, metal concentrations in the tall fescue-alfalfa treatment (which was dominated by tall fescue) were no different than in the tall fescue only treatment, and metal concentrations in the switchgrass-AULotan treatment (which were dominated by switchgrass) were no different than in the switchgrass only treatment.

The metals Cu, Ni, and Zn are readily taken up by plants but are phytotoxic at concentrations that pose little risk to human or animal health. The excessive uptake of these elements will result in plant mortality before their concentrations in plant material pose any risk to the food chain. This has been termed the “soil-plant barrier” by Chaney (1980). Although the plants accumulated trace element differentially, the concentrations in the forages did not exceed thresholds for concern (i.e., >40 mg Cu/kg, >50 mg Ni/kg, >400 mg Zn/kg) documented by Chaney (1994).

Cadmium poses human or animal health risks at plant concentrations that are not generally phytotoxic; thus, Cd could be a concern due to bioaccumulation through the soil-plant-animal food chain. Even the highest concentration of Cd in this study (1.0 mg Cd/kg in crown vetch) was lower than established conservative levels of concern (Kabata-Pendias and Pendias, 1984).

Conclusions

The use of biosolids as an amendment for reclaiming disturbed land is economically and agronomically beneficial. Local government officials are hesitant to permit such use of treated sewage sludge because of potential environmental and health concerns. This research demonstrates that there should be little concern of plant accumulation of Cd, Cu, Ni, and Zn by a wide variety of forages grown on coal mine land reclaimed with biosolids according to the standard reclamation practice recommended for Virginia coal mined land.

Deliverables

In addition to the report of the funded project contained herein, we are in the process of completing a manuscript that will be submitted to the Journal of Environmental Quality on plant stand success and quality of forages grown on biosolids-amended surface mined land 11 years after establishment.

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