RECLAMATION OF WASTE ROCK MATERIAL AT THE SUMMITVILLE MINE SUPERFUND SITE USING ORGANIC MATTER AND TOPSOIL TREATMENTS[1]

by

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Abstract: The Summitville Mine was a high elevation (3,500 m) open-pit gold mine located in southwestern Colorado. The mine was abandoned in 1992 leaving approximately 200 ha of disturbed area comprised partially of two large waste rock piles. Reclamation of waste rock material is challenging due to extreme climatic conditions in conjunction with a high acid-production potential and low organic matter concentration of the material. In addition, stockpiled topsoil at the site is acidic and may be biologically inactive due to long-term storage, and therefore sufficient plant growth medium may be limited. The purpose of this study was to determine the effect of organic amendments (mushroom compost vs biosolids) and topsoil (stockpiled vs non-stockpiled) on aboveground biomass, herbaceous cover, and trace element uptake. An on-site field study was established in 1995 to identify the most effective combination of treatments for successful reclamation of waste rock material. Incorporation of organic matter increased total aboveground production and cover, with mushroom compost being more effective than biosolids, but did not show significant trends relative to trace element uptake. The use of topsoil did not show a significant response relative to aboveground production, cover, and trace element uptake. This study shows that waste rock materials can be directly revegetated if properly neutralized, fertilized, and amended with organic matter. Additionally, stockpiled topsoil was equivalent in plant growth to non-stockpiled topsoil when neutralized with lime.

Additional Key Words: acid soils, sewage sludge, biosolids, trace elements

Introduction

Gold and silver mining began in the Summitville area during the early 1870's. In 1985, Summitville Consolidated Mining Co., a division of the Canadian firm Galactica Resources, began mining the site using open pit mining and a heap leach recovery method. On December 4, 1992 Galactica Resources declared bankruptcy. By December 16, the EPA Emergency Response Branch had assumed operation and maintenance responsibilities at the site. The area was declared a Superfund site May 1994, and to date, clean up has cost more than $120 million. Approximately 200 ha of disturbed land was left which included the gold heap leach pad, two large waste rock piles, an open pit, several underdrains, french drains, water impoundments, draining adits, and three wastewater treatment systems. Proposed site wide reclamation includes revegetation of waste rock material to establish an ecologically productive and self-sustaining plant community to provide erosion control as well as reduce contaminant flow to ground water. However, an unfavorable environment for plant growth exists due to extreme climatic conditions, low organic matter in disturbed areas, and high acid production potential from the pyritic materials present. Additionally, soil that was stockpiled for reclamation is acidic, and may have low biological activity due to the manner in which it was stored.

Providing a suitable growth medium for plant establishment is key to successful revegetation of drastically disturbed areas. In 1995, greenhouse and field studies were initiated to evaluate reclamation alternatives (Redente *et al.* 1996, Redente and Richard 1998). Many studies have illustrated numerous benefits of applying topsoil and/or organic matter (in addition to fertilizer and lime) to high elevation mine spoils prior to revegetation (Brown *et al.* 1976, Brown and Johnson 1976, Farmer *et al.* 1976). The purpose of this field study is to assess the use of various combinations of organic matter (mushroom compost vs biosolids) and topsoil (stockpiled vs non-stockpiled) for the production of sufficient aboveground and belowground

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biomass and plant cover to achieve site reclamation goals. This paper will focus on information gathered from field test plots during the first three growing seasons. Individual treatments will be referred to as TRT-1, TRT-2, etc. hereafter.

Methods and Materials

Site Description

The Summitville Mine Superfund Site is in Rio Grand County 29 km southwest of Del Norte, CO. It is surrounded by the Rio Grand National Forest within the San Juan Mountain Range. The entire permitted mine site covers 567 ha, and is comprised of six vegetative communities including alpine tundra, krummholz ecotone, spruce-fir forest, sub-alpine meadow, wet meadow, and willow shrubland. Bedrock within this region is highly mineralized, and contains high concentrations of fine-grained pyrite throughout all geologic zones. The average elevation on site is 3,500 m and mean annual precipitation is 140 cm, which occurs primarily as snow. The snow-free period is June through September. The Wrightman Fork, a tributary of the Alamosa River, drains much of the runoff and seepage from the site.

Design and Construction

The study consisted of eight treatments, replicated four times in a randomized complete block design. Construction of individual treatments prior to fertilizing, seeding, and mulching were as follows:

TRT-1: Incorporated limestone (16.5 Mg/1000Mg = 2.04 Mg/plot) and mushroom compost (89.6 dry Mg/ha = 2.36 wet Mg/plot) into upper 30 cm of waste rock. Applied 15 cm limed (8.3 Mg/1000Mg), stockpiled topsoil.

TRT-2: Incorporated limestone (16.5 Mg/1000Mg = 2.04 Mg/plot) and biosolids (89.6 dry Mg/ha = 2.13 wet Mg/plot) into upper 30 cm of waste rock. Applied 15 cm limed (8.3 Mg/1000Mg), stockpiled topsoil.

TRT-3: Incorporated limestone (16.5 Mg/1000Mg = 2.04 Mg/plot), mushroom compost (89.6 dry Mg/ha = 2.36 wet Mg/plot), and ProMac[3] (28.35 kg/plot) into upper 30 cm of waste rock. Applied 15 cm limed (8.3 Mg/1000Mg), stockpiled topsoil.

TRT-4: Incorporated limestone (16.5 Mg/1000Mg = 2.04 Mg/plot) and mushroom compost (89.6 dry Mg/ha = 2.36 wet Mg/plot) into upper 30 cm of waste rock. Applied 15 cm non-stockpiled topsoil.

TRT-5: Incorporated limestone (16.5 Mg/1000Mg = 2.04 Mg/plot) into upper 30 cm of waste rock. Applied 15 cm each of stockpiled and non-stockpiled topsoil.

TRT-6: Applied 15 cm additional waste rock. Incorporated limestone (16.5 Mg /1000Mg = 2.04 Mg/plot) and mushroom compost (134.4 dry Mg/ha = 3.54 wet Mg/plot) into upper 30 cm of waste rock.

TRT-7: Applied 15 cm additional waste rock. Incorporated limestone (16.5 Mg /1000Mg = 2.04 Mg/plot) and biosolids (134.4 dry Mg/ha = 3.18 wet Mg/plot) into upper 30 cm of waste rock.

TRT-8: Excavated plot to 30 cm and filled with 30.5 cm inert rock material (2.5-15.2 cm diameter washed of fines). Applied 15 cm stockpiled topsoil and 15 cm non-stockpiled topsoil.

After treatments were completed, plots were disked and fertilizer was applied. Treatments 6 and 7 did not receive topsoil applications, and were therefore treated with higher rates of fertilizer than TRT 1-5 and 8. Fertilizer rates were as follows:

TRT 1-5 and 8: ammonium nitrate (33-0-0) at 112 kg elemental N/ha = 5.6 kg/plot; triple super phosphate (0-44-0) at 168 kg elemental P/ha = 8.4 kg/plot; potassium chloride (0-0-60) at 112 kg elemental K/ha = 5.6 kg/plot

TRT 6 and 7: ammonium nitrate (33-0-0) at 168 kg elemental N/ha = 8.4 kg/plot; triple super phosphate (0-44-0) at 336 kg elemental P/ha = 16.8 kg/plot; potassium chloride (0-0-60) at 168 kg elemental K/ha = 8.4 kg/plot

Following fertilization, plots were disked again to 15 cm and then broadcast seeded by hand. Species and seeding rates are listed in Table 1. After seeding, plots were lightly disked to cover the seed. Plots were then covered with certified weed-free straw (6.7 Mg/ha) and the straw crimped into the soil using a D5 Caterpillar with wide tracks. Final plot dimensions were 10 by 20 m. Construction and seeding of test plots was completed on November 18, 1995.

Herbaceous Cover

Herbaceous canopy cover was visually estimated in August, 1996 and 1997, using a 50 x 100 cm quadrat placed every two meters along a 20 m randomly placed transect, for a total of 10 quadrats per plot. Cover was estimated in August, 1998, using the point intercept method. Two diagonal transects were placed in each plot, then cover was observed and

[3] ProMac® is a combination of liquids and controlled release pellets formulated to inhibit iron-oxidizing bacteria.

Table 1. Seed mixture and seeding rate used on revegetation test plots. Seeding density was 0.67 seeds/cm^2. Environmental factors influencing plant growth, including a rating of acid tolerance (AT) and average required precipitation (ppt), are shown. N = native; I = introduced; P = perennial.

		Common Name	Scientific Name	Environmental Factors	Seed Rate (lb PLS/ac)
		Grasses			
N	P	Slender wheatgrass	*Agropyron trachycaulum*	16" ppt; AT = 3 **	3.0
I	P	Redtop*	*Agrostis stolonifera*	20" ppt; AT = 3	1.0
N	P	Bentgrass	*Agrostis scabra*	no information	1.0
I	P	Meadow foxtail*	*Alopecurus pratensis*	25" ppt; AT = 2	1.0
N	P	Mountain brome var. *Bromar*	*Bromus marginatus*	16" ppt; AT = 0	3.0
I	P	Orchardgrass* var. Latar	*Dactylis glomerata*	18" ppt; AT = 2	2.0
N	P	Tufted hairgrass	*Deschampsia caespitosa*	20" ppt; AT = 2	1.0
I	P	Sheep fescue* var. Durar	*Festuca ovina*	10-12" ppt; AT = 1	1.0
N	P	Alpine Timothy	*Phleum alpinum*	no information	1.0
N	P	Alpine bluegrass	*Poa alpina*	20" ppt; AT = 1	1.0
N	P	Canada bluegrass var. Reubens	*Poa compressa*	18" ppt; AT = 2	1.0
		Forbs			
N	P	Western yarrow	*Achillea millifolium*	AT = 1	1.0
N	P	Engleman aster	*Aster englemannii*	AT = 1	0.5
I	P	Cicer milk vetch* var Lutana	*Astragulus cicer*	12-18" ppt; AT = 1	1.0
I	P	Sainfoil* var. Eski	*Onobrychis viciaefolia*	15-18" ppt; AT = 1	3.0
N	P	Rocky Mt. Penstemon	*Penstemon strictus*	AT = 0	3.0
I	P	Inoculated alsike clover*	*Trifolium hybridum*	35" ppt; AT = 2	2.0
I	P	Inoculated red clover*	*Trifolium pratense*	35" ppt; AT = 1	2.0

* Indicates introduced species

** Indicates plant adaptation to acidic conditions: 0 = not adapted; 1 = marginal; 3 = best.

recorded for 80 points at 0.5 m intervals along the transects (40 points per transect).

Aboveground Biomass

Aboveground biomass was sampled in August, 1997 and 1998, with four 50 x 100 cm randomly placed quadrats in each plot. Vegetation in each quadrat was clipped to ground level, separated by species, and composited among quadrats to produce one sample per plot. Biomass was then dried to a constant weight at 60°C and weighed.

Plant Tissue Trace Element Analysis

Tissue samples from two of the dominant grass species were collected from each plot for trace element analysis, August of each year. Orchardgrass (*Dactylis glomerata* L.) was collected during each growing season. In addition, mountain brome (*Bromus marginatus* Nees) was collected in 1996, slender wheatgrass (*Agropyron trachycaulum* (Link) Malte) was collected in 1997, and meadow foxtail (*Alopecurus pratensis* L.) was collected in 1998. Tufted hairgrass (*Deschampsia cespitosa* (L.) Beauv.), the dominant grass in reference meadow areas, was also collected in 1997. Plant materials were stored at 4°C and transported to CSU where samples were washed with deionized water, dried at 60°C, finely ground, and digested with nitric and perchloric acids. Samples were then sent to the CSU Soil, Water, and Plant Testing Laboratory where they were analyzed for trace element concentrations of Mn, Cu, Zn, Cd, and Pb.

Results and Discussion

Herbaceous Cover and Biomass

The best plant growth during the first growing season (1996), when considering herbaceous cover[4], occurred on treatments with stockpiled topsoil and mushroom compost incorporated into limed waste rock (TRT-1 and TRT-3). This was due to the presence of

[4] Total cover refers to total vegetative cover, and does not include litter or rock.

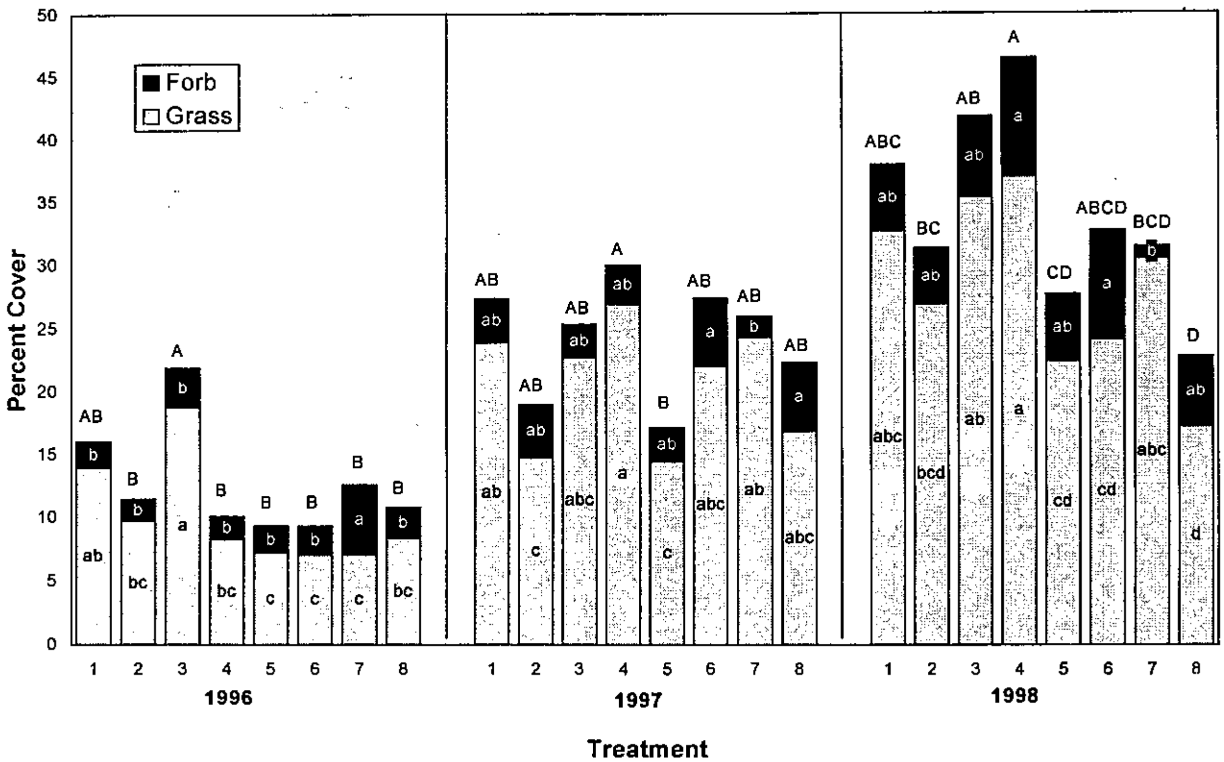

Figure 1. Total percent herbaceous cover for the first three growing seasons, with treatments separated by grasses and forbs. The Least Significant Difference (LSD) among treatments for total vegetation cover is represented by the upper case letter(s) above the bar, at alpha = 0.05. LSD separation for grasses and forbs among treatments is represented by the lower case letter(s) within each bar segment, at alpha = 0.05. LSD values represent mean separation within each year. Different letters among treatments represent significant differences.

two grass species, mountain brome and orchardgrass. Of these treatments, TRT-3 had greater cover than TRT-2 and TRT 4-8 (Figure 1). No additional trends for total cover were evident at this time.

During the second growing season (1997), both cover and biomass production began to show a distinct trend with the best overall plant growth occurring on treatments with mushroom compost incorporated into limed waste rock (TRT-1, TRT-3, TRT-4, and TRT-6), regardless of topsoil treatment (Figures 1 and 2). Treatments which incorporated biosolids (TRT-2 and TRT-7) had relatively moderate levels of production, while treatments lacking organic matter amendment (TRT-5 and TRT-8) had the lowest overall production. Again, these patterns were primarily influenced by grass production, though a shift in species dominance was observed with a considerable increase in slender wheatgrass as well as tufted hairgrass, meadow foxtail and sheep fescue, and a notable decline in mountain brome.

Trends noted during 1997 became more apparent during the third growing season (1998). The best overall plant growth during the 1998 growing season, when considering both aboveground biomass and cover occurred on treatments with mushroom compost incorporated into the limed waste rock (TRT-1, TRT-3, TRT4, and TRT-6), regardless of topsoil treatment (Figures 1 and 2). These treatments had greater total biomass production than treatments that did not incorporate mushroom compost. These differences can be attributed to variation in grass production as there was no significant difference in forb production among the eight treatments.

In 1998, treatments that received a mix of stockpiled and non-stockpiled topsoil and no organic amendments (TRT-5 and TRT-8) supported the lowest overall biomass production, with TRT-5 supporting the lowest total plant production of the eight treatments. Treatments which incorporated biosolids into limed waste rock (TRT-2 and TRT-7) showed moderate production regardless of topsoil treatment. Production

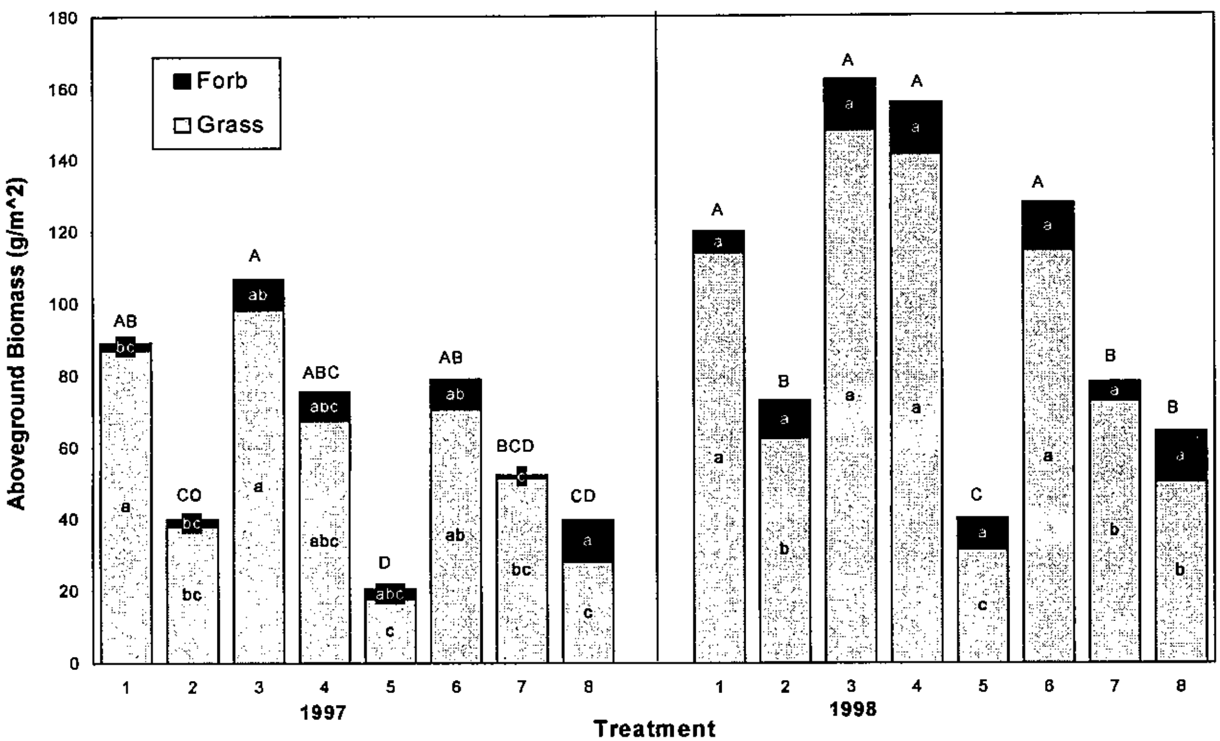

Figure 2. Aboveground biomass (g/m^2) for field treatments, sampled in 1997 and 1998. The Least Significant Difference (LSD) among treatments for total biomass is represented by the letter(s) above the bar, at alpha = 0.05. LSD separation for grasses and forbs among treatment is represented by the letter(s) within each bar segment, at alpha = 0.05. LSD values represent mean separation within each year. Different letters among treatments represent significant differences.

on TRT-2 and TRT-7 did not differ from the capillary barrier treatment (TRT-8), which did not receive an organic matter amendment.

Observations made in September 1998 revealed that fine particles have filled in the capillary barrier constructed in TRT-8. Therefore, separation of the rooting zone from underlying untreated waste rock has been compromised. Assuming that the capillary barrier was functional during the first two years of the study, variation between TRT-8 and TRT-5 may therefore be attributed to the initial lack of contact between topsoil and waste rock on TRT-8. Note that TRT-8 had more grass production than TRT-5 in 1998.

Total cover followed trends similar to those reported for biomass production, but with less significant separation among treatments (Figure 2). Treatments with mushroom compost incorporated into the waste rock had the greatest overall herbaceous cover. There was no significant difference in the total plant cover produced on these four treatments (TRT-1, TRT-3, TRT-4, and TRT-6), although TRT-6 had significantly less grass cover than TRT-3 and TRT-4. Treatments which incorporated biosolids (TRT-2 and TRT-7) supported moderate cover. Treatments receiving no organic amendments (TRT-5 and TRT-8) had the lowest total cover.

In 1998, grass production and cover were dominated by five species including both native and introduced perennial grasses: slender wheatgrass (native), meadow foxtail (introduced), orchardgrass (introduced), tufted hairgrass (native), and Timothy (*Phleum pratense* L.) (introduced). Of these five species, only Timothy was not seeded. Conversely, forb production and cover were dominated by just one native, perennial species which was seeded: western yarrow (*Achillea millefolium* L.).

The application of ProMac (TRT-3) did not significantly increase nor decrease aboveground biomass, cover, nor root growth in comparison to TRT-1, which was the same treatment without ProMac. Therefore, variation between TRT-3 and other

Table 2. 1998 concentrations of elements (mg/kg) in aboveground plant tissue for orchardgrass (*Dactylis glomerata*) and meadow foxtail (*Alopecurus pratensis*). Least Significant Difference (LSD) are represented by the letter (s) below means within columns, within each group of species, at alpha = 0.05. DAGL = *Dactylis glomerata*; ALPR = *Alopecurus pratensis*. Statistical differences were not determined between species. Different letters among treatments represent significant differences.

	Mn (mg/kg)		Cu (mg/kg)		Zn (mg/kg)		Cd (mg/kg)		Pd (mg/kg)	
	DAGL	ALPR	DAGL	ALPR	DAGL	ALPR	DAGL	ALPR	DAGL	ALPR
TRT-1	414 bc	478 a	23.8 abc	13.0 b	65.8 abc	62.6 ab	0.031 a	0.047 b	1.5 c	1.7 d
TRT-2	393 cd	377 abc	20.7 bc	15.8 b	65.0 abc	64.4 ab	0.077 a	0.046 b	1.8 c	2.2 d
TRT-3	485 bc	476 a	19.2 c	12.8 b	49.9 cb	55.2 b	0.091 a	0.239 a	2.1 c	2.1 d
TRT-4	496 bc	366 abc	21.4 abc	15.9 b	64.9 abc	73.9 a	0.028 a	0.038 b	4.2 b	3.8 bc
TRT-5	701 a	402 ab	26.7 a	14.2 b	88.8 a	67.1 ab	0.075 a	0.061 b	8.0 a	5.5 a
TRT-6	207 e	152 d	20.1 bc	17.5 b	41.9 c	64.3 ab	0.020 a	0.026 b	1.6 c	2.3 d
TRT-7	243 de	252 cd	24.9 ab	23.1 a	57.9 bc	72.6 a	0.052 a	0.047 b	1.8 c	2.7 cd
TRT-8	571 ab	341 bc	23.4 abc	14.0 b	72.5 ab	64.9 ab	0.028 a	0.109 ab	5.5 b	5.0 ab
* Approximate leaf tissue concentrations considered excessive or toxic to plants:										
	300-500		20-100		100-400		5-30		30-300	
* Approximate leaf tissue concentrations considered normal or sufficient for plants:										
	20-300		5-30		27-150		0.05-0.2		5-10	

* Values from Kabata-Pendias and Pendias (1984).

treatments is most likely due to topsoil and organic amendment differences than to the addition of ProMac.

Plant Tissue Trace Element Analysis

Trace element analysis for contaminants of interest (including Mn, Cu, Zn, Cd, and Pd) from the first three growing seasons indicate that plant tissue concentrations of Mn may be of potential concern. Tissue concentrations of Cu and Zn were slightly elevated in plants sampled from some treatments in 1996, but were within normal limits in 1997 and 1998.

During the 1998 growing season orchardgrass and meadow foxtail were sampled from each plot and analyzed for trace elements of concern (Table 2). Of the five trace elements analyzed, only Mn showed elevated tissue concentrations in orchardgrass and meadow foxtail (Kabata-Pendias and Pendias 1984). Tissue concentrations of Cu and Zn were within limits considered normal for most plants, while Cd and Pd were typically below normal levels. Low levels of Cd and Pb in plant tissue samples should not be of concern as these elements are not considered essential for plant growth.

In 1998, orchardgrass had the highest Mn concentrations on treatments which did not receive organic amendments and had a mixture of unlimed stockpiled and non-stockpiled topsoil (TRT-5 and TRT-8). These concentrations fell at the upper limit of levels considered excessive. Concentrations of Mn on these treatments were greater than those on all other treatments except TRT-4 which also received unlimed topsoil. Note that orchardgrass in TRT-5 and TRT-8 consistently accumulated higher amounts of trace elements than other treatments. Treatments that did not receive topsoil, but did receive organic amendment (TRT-6 and TRT-7) were the only ones with Mn concentrations below levels of potential concern. Mn concentrations on these treatments were less than those on all other treatments except TRT-2. In general, treatments with stockpiled topsoil and organic amendment showed intermediate Mn concentrations.

Similar to patterns seen for orchardgrass, treatments that did not receive topsoil, but did receive organic amendment (TRT-6 and TRT-7) were the only ones with meadow foxtail Mn tissue concentrations below levels of potential concern. Mn concentrations of meadow foxtail on these treatments were significantly less than those on all other treatments except TRT-8. All other treatments produced tissue concentrations of Mn that fell within the range of values considered to be excessive, but there was no discernible pattern.

Overall, plant tissue concentrations of Cu, Cd, Zn, and Pb do not appear to be influencing the establishment of vegetation on the test plots as concentrations of these elements do not have distinct patterns corresponding to those seen for biomass, cover, or root growth. Conversely, Mn may be influencing the growth of some species. For instance, orchardgrass had the lowest biomass and cover on TRT-5 and TRT-8, while having the highest tissue concentrations of Mn.

Conclusions

Field treatments were designed to test a variety of waste rock amendments and types of topsoil to determine the most effective combination for site-wide reclamation at the Summitville Mine Superfund Site. It is expected that species composition and production will continue to change over time as plants interact, modify their environment, and as soil development proceeds.

The following preliminary conclusions can be drawn from the results of the first three years of this study:

1) Stockpiled topsoil that was limed, supported plant growth comparable to that supported by non-stockpiled topsoil overlying treated waste rock.
2) Mushroom compost was more effective as an organic amendment than sewage sludge in terms of nutrient availability, and therefore facilitated plant growth to a greater extent.
3) Waste rock material supported plant growth when treated with limestone and organic amendments that was comparable to growth produced when stockpiled or non-stockpiled topsoil was used to cover waste rock.
4) Placement of a capillary barrier between topsoil and underlying waste rock did not improve plant growth compared to treatments involving placement of topsoil directly over amended waste rock.
5) The use of ProMac did not significantly improve plant growth.

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