ANACONDA REVEGETATION TREATABILITY STUDY[1]

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Abstract: The Anaconda Revegetation Treatability Study (ARTS) is being conducted to demonstrate in-place treatments of mill tailings, smelter wastes and soils impacted by smelter emissions at the Anaconda Smelter National Priorities List Site in Anaconda, Montana. A study area of approximately 11,000 acres has been divided into the following five subareas: the Opportunity Tailings Ponds, the Anaconda Tailings Ponds, Smelter Hill, Old Works and Adjacent Areas. Acidic mill tailings that contain elevated metal levels are contained in the Opportunity and Anaconda Tailings Ponds systems. The other three areas have been affected by smelting processes and stack emissions. The soils contain elevated metal concentrations and have pH values ranging from acidic to neutral.

ARTS is being conducted in four phases. The first completed in 1993, included reviews of reclamation literature and data searches to determine factors controlling the revegetation of acid metalliferous materials at the Anaconda site and other locations with conditions similar to Anaconda. Other Phase I activities included physical and chemical data collection and the selection of demonstration sites within the designated subareas. The second phase included laboratory and greenhouse tests that were used to develop effective amendment/vegetation treatments. Large demonstrations have been implemented in all of the subareas as part of Phase III. On Smelter Hill a five acre site was treated with selected amendments using specialized equipment and seeded with selected vegetation in the Fall of 1993. A one acre demonstration site in the Old Works area was treated with various combinations of amendments and two pieces of heavy equipment were used to incorporate the amendments into these soils. This site was seeded with selected plant species in the Spring of 1994. Another demonstration on a one acre site located on soils which have been primarily surfically impacted is determining the effectiveness of different sources of organic matter (wood wastes, commercial compost, and composted manure) in combination with different lime materials in providing a suitable rootzone. Field demonstrations on tailings ponds were constructed in the Fall of 1994. In Phase IV the effectiveness of the treatments at each site will be monitored. Changes in soil chemistry, rootzone hydrology and vegetation response will be measured.

Key Words: Revegetation; Smelter; Tailings; Soils.

Introduction

Ore processing facilities were constructed at Anaconda in 1884. The ores mined in Butte, Montana were shipped to Anaconda and processed using a variety of techniques for nearly 100 years of operation. Inorganic materials such as mill tailings, and slag are found at various locations on the site. These materials contain arsenic and metals such as copper, cadmium, zinc and lead. In addition, soils throughout the site contain arsenic and metals due to aerial emissions from the milling and smelting process.

In 1983, the Anaconda Smelter Site was listed on the National Priorities List under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The site includes Smelter Hill, Old Works/East Anaconda Development, Anaconda Soils, Regional Water and Waste, and Flue Dust operable units. In 1988, the Environmental Protection Agency (EPA) in consultation with the Montana Department of Health and Environmental Sciences (MDHES) and the Atlantic Richfield Company (ARCO), reached agreement for performance of the Anaconda Smelter Remedial Investigation/Feasibility

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Study (RI/FS). The Anaconda Revegetation Treatability Study (ARTS) is being conducted pursuant to this agreement by Montana State University under the direction of a Technical Committee comprised of representatives of ARCO, EPA and MDHES.

Study Area

A study area of approximately 11,000 acres has been divided into the following five subareas: the Opportunity Tailings Ponds, the Anaconda Tailings Ponds, Smelter Hill, Old Works and Adjacent Areas. The locations of these subareas are shown on Figure 1. Each subarea is unique, differing in physical setting, geochemistry and physical characteristics. A brief description of each subarea is presented below.

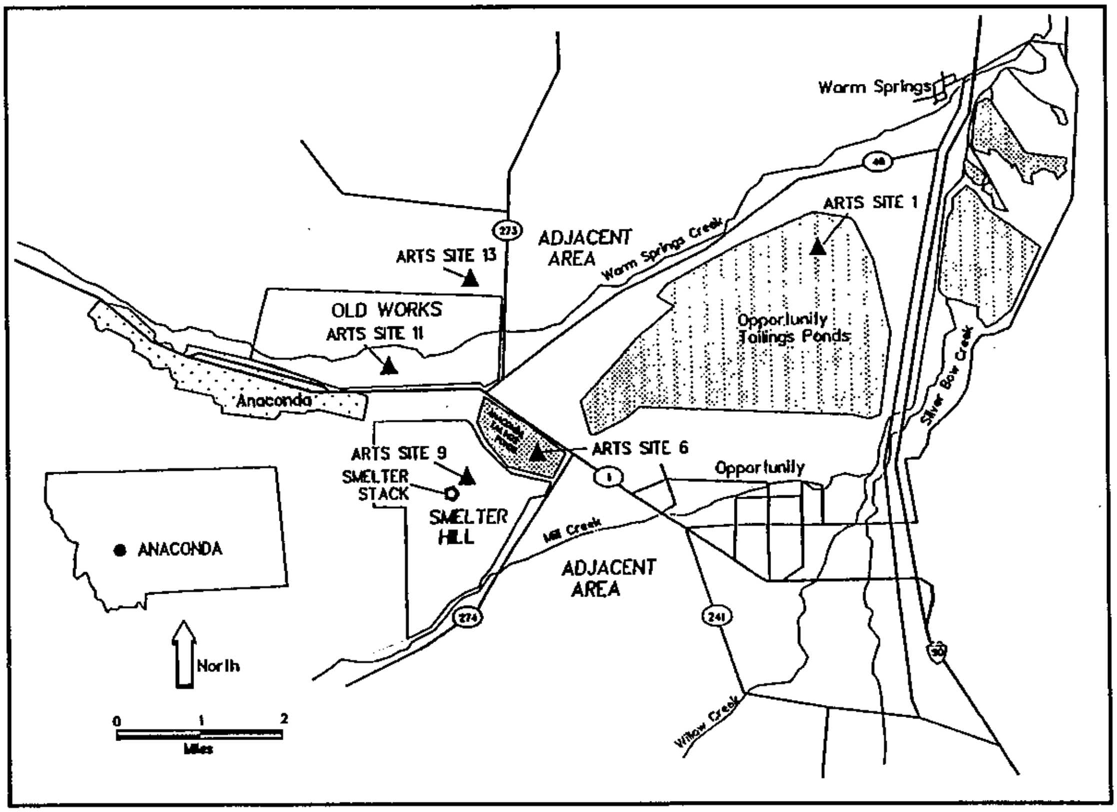

Figure 1 Location of five selected ARTS demonstration sites

Opportunity Ponds

The Opportunity Ponds cover an area of approximately 3,400 acres and contain approximately 234,000,000 tons of mill tailings from ore processing operations (Tetratech, 1985). The ponds were in operation from 1914 through 1980. The ores processed at the Anaconda Smelter Site were typically sulfide, and the mill tailings are acid producing when oxidized. The physical characteristics of the tailings vary considerably due to differences in the ores processed and the processing methods used. Grain sizes vary from coarse sand to fine clay. Arsenic and metals such as copper, lead, zinc, and cadmium are found in varying concentrations throughout the ponds.

Anaconda Ponds

The Anaconda Ponds include an area of approximately 560 acres and contain approximately 103,000,000 tons of mill tailings (Tetratech, 1987). The oxidized zone of the tailings range from 3 to 6 feet and are acidic (pH 2 to 4). The grain sizes vary considerably from coarse sands to clays and contain metals similar to those found in the Opportunity Ponds.

Smelter Hill

The ARTS study area on Smelter Hill is a 1,020 acre tract. This area includes the locations of concentrating, smelting and refining operations. The Anaconda Reduction Works began operations in 1902 and continued until 1980. Between 1982 and 1985 most structures were demolished and approximately 345 acres on the lower portions of the hill were revegetated by placing 12 to 18 inches of cover soil over a 100 to 400 ton per acre crushed lime stone layer. Many of these areas have been successfully vegetated, while others are only sparsely vegetated (ARCO, 1994). Natural revegetation is occurring in areas north, south and east of the stack. The area west of the stack is very steep (>50%) and supports little naturally established vegetation. The slopes north and east of the stack range from 25% to 33%.

Old Works

The Old Works is a 1,340 acre tract of milling and smelting wastes from the Upper and Lower Works which operated from 1884 to about 1902. Operations ceased when the Anaconda Reduction Works began operation. Present surface features at this site include demolition debris, mixed slag and jig tailings (Red Sands), heap roast slag and fluvially deposited tailings (ARCO, 1993).

Natural revegetation has occurred in many areas of the Old Works. Trees, shrubs and grasses are established in the riparian areas adjacent to Warm Springs Creek and some species are beginning to establish themselves on the hillsides above the flood plain. Vegetation has also recovered on portions of the hillsides above the Old Works.

Adjacent Areas

Adjacent areas include lands near the Old Works, Smelter Hill and Anaconda/Opportunity Ponds where plant growth has been impacted primarily by wind and water deposited wastes. The adjacent areas include approximately 4,800 acres.

The area between the Old Works and Opportunity Ponds consists of impacted soils that range from little or no visible tailings present, to tailings 1 to 18 inches in depth. Plant growth is often absent or consists of trees and shrubs with little or no grass or forb production.

South of the Opportunity Ponds, tailings are present on the surface at depths ranging from one inch to several feet. Plant growth is mainly deep rooted plants or shrubs. Southeast of the Anaconda Ponds plant growth may have been impacted by smelter stack emissions. In this area stands of young vigorous plants are found mainly in more protected areas. These plants appear to be expanding into the barren areas (Reclamation Research Unit, 1993).

Treatability Study Objectives

CERCLA requires that remedial alternatives must be evaluated in relationship to a reduction of risks to human health and the environment. The evaluation is influenced by contaminants present, their concentration, volume of contaminated media and potential exposure pathways.

As part of this process, the primary objective of ARTS is to develop and evaluate land reclamation techniques for establishing vegetation on five selected subareas within the Anaconda Smelter NPL Site. This evaluation will consider the ability of the technologies to meet the following criteria for selection of a final remedy under CERCLA:

- Provide overall protection of human health and the environment;
- Comply with Applicable or Relevant and Appropriate Requirements (ARARS);

- Reduce through treatment, the mobility and toxicity or volume of waste materials;
- Be cost effective;
- Be implementable on a large scale;
- Provide both short and long-term effectiveness;
- Minimize long-term maintenance; and
- Be acceptable to the community.

In addition to these criteria this study will also evaluate these technologies ability to:

- Preserve or enhance area aesthetics.

The ARTS treatability study is being conducted in four phases. Phase I includes reclamation literature reviews and data assessments. Phase II includes laboratory and greenhouse investigations. Phase III is the implementation of the field scale demonstrations. Phase IV will monitor the effectiveness of the treatments in reducing contaminated movement in the surface water runoff, air and bioaccumulation pathways.

Phase I

Phase I has been completed and had the following objectives:

- Review and summarize site-specific reclamation procedures used by ARCO and the Anaconda Minerals Company and postulate why the procedures were successful or unsuccessful;
- Evaluate revegetation attempts at other locations with characteristics similar to the Anaconda site;
- Document areas of natural revegetation and postulate responsible mechanisms; and
- Collect data to identify and characterize demonstration sites within the five subareas.

The research into previous reclamation procedures used by ARCO and the Anaconda Minerals Company indicated that the reclamation procedures most successful to date utilized a cap consisting of a crushed lime rock barrier and varying depths of cover soil. Attempts at in-situ reclamation were generally poor due to reacidification of the soil over time. The cause of the soil reacidification was most likely due do inadequate soil amendment rates.

A literature search of reclamation procedures used at sites similar to Anaconda was conducted. Pertinent documents were reviewed and 190 were cataloged. A listing of these documents is provided in the ARTS Phase I Report (Reclamation Research Unit, 1993).

Vegetation surveys of the five subareas were conducted during 1992 and 1993. Plant species found in unreclaimed areas were identified and listed. Many of the species identified were also successful in the Phase II greenhouse studies.

Field demonstration sites have been selected at locations that represent physical, geochemical, and agronomic limitations to revegetation within the five subareas. Initially 17 candidate sites were identified. Upon completion of Phase I field reconnaissance, site screening and sampling, five sites were selected to conduct field demonstrations. These locations are Site 9 - Smelter Hill, Site 11 - Old Works, Site - 13, Adjacent Areas, Site 1 - Opportunity Ponds and Site 6 - Anaconda Ponds. Both tailings pond sites were selected since there were found to be differences in the particle size of the tailings. The Opportunity Ponds having finer tailings while the Anaconda Ponds have coarser tailings. The location of these sites are shown on Figure 1.

Phase II

Phase II laboratory and greenhouse testing of soil amendments and selected plant species has been completed. This phase had the following objectives:

- Develop and test amendments for each subarea that will enable contaminated soils and tailings to support vegetation;

- Evaluate native and commercial plant species to determine those best adapted to amended or non-amended soils and tailings materials; and

- Recommend amendment/vegetation treatments to be evaluated in the field demonstrations for each subarea.

In the laboratory portion of Phase II neutralizing and organic soil amendments have been analyzed for purity, physical characteristics, and reactivity. The purpose of testing amendment materials was to measure their effectiveness in controlling pH and in reducing metal/arsenic mobility in the soils from the five subareas. Selection of amendments (both combinations and rates) used in the greenhouse studies were also based on these results.

Four of the selected demonstration sites have acid-producing materials. Neutralization rates (lime rates) were calculated utilizing modified acid base accounting developed as part of Streambank Tailings and Revegetation Studies (STARS) (Reclamation Research Unit, 1987) and verified by analyzing leachate from the amended soils. The method used to collect leachate was to place saturated amended soils in a modified Tempe Pressure Cell (available from Soil Moisture Equipment Company). The unit was pressurized to 0.5 bars and the leachate collected and analyzed for pH, EC, copper and arsenic. Laboratory testing of amendments has been completed. Table 1 lists amendments that were evaluated.

The calculated lime rates were found to be successful in raising the soil pH to neutral, and reducing the solubility of copper. In some cases arsenic solubility was slightly increased.

The specific goals for the greenhouse trials are: 1. evaluate plant performance to amended root zone materials; 2. evaluate species for their ability to germinate and grow in the amended materials; 3. determine fertilizer rates; 4. recommend plant species to be seeded at each demonstration site.

The soils from the five demonstration sites selected have different physical and chemical characteristics therefore, the specific greenhouse aims were different for each site.

- Smelter Hill - evaluate plant species and fertilizer and organic amendment effect on plant response.

- Old Works - evaluate plant species and lime, fertilizer and organic amendments effect on soil neutralization and plant response.

- Adjacent Areas - evaluate plant species and lime, fertilizer and organic amendments effect on soil neutralization and plant response.

- Tailings Ponds - evaluate plant species and lime, fertilizer, organic amendments and other soil amendments effect on soil neutralization and plant response.

Table 1

Laboratory Tests of Amendments for ARTS

ARTS Demonstration Site	Amendments	Tempe Cell Tests	Response Variables*
Smelter Hill Site 9 - acid materials	$CaCO_3$	Yes	pH, EC
	$CaCO_3$ + $Ca(OH)_2$	Yes	pH, EC
	Kiln Dust	Yes	pH, EC
	Control	Yes	pH, EC
Smelter Hill Site 9 - alkaline materials	Composted manure	No	--
	phosphorus	No	--
	$CaCl_2$	No	--
	Soluble Fe and/or Cu	Yes	pH, EC, As, Cu
Old Works Site 11	$CaCO_3$	Yes	pH, EC, As, Cu
	$CaCO_3$ + $Ca(OH)_2$	Yes	pH, EC, As, Cu
	Kiln Dust	Yes	pH, EC, As, Cu
	Control	Yes	pH, EC, As, Cu
	Woodchips	No	--
	Slag	No	--
Adjacent Area Site 13	$CaCO_3$	Yes	pH, EC, As, Cu
	$CaCO_3$ + $Ca(OH)_2$	Yes	pH, EC, As, Cu
	Kiln Dust	Yes	pH, EC, As, Cu
	Control	Yes	pH, EC, As, Cu
	Composted manure	No	--
	Others	--	--
Anaconda Ponds Site 6	$CaCO_3$	Yes	pH, EC, As, Cu
	$CaCO_3$ + $Ca(OH)_2$	Yes	pH, EC, As, Cu
	Kiln Dust	Yes	pH, EC, As, Cu
	Control	Yes	pH, EC, As, Cu
	Composted manure	No	--
	Others	--	--
Opportunity Ponds Site 1	$CaCO_3$	Yes	pH, EC, As, Cu
	$CaCO_3$ + $Ca(OH)_2$	Yes	pH, EC, As, Cu
	Kiln Dust	Yes	pH, EC, As, Cu
	Control	Yes	pH, EC, As, Cu
	Composted manure	No	--
	Others	--	--

*Response variables are measured in leachate solutions from Tempe Pressure Cells.

Factors which limit plant growth vary for each demonstration site however, they include acidity, elevated metals levels, poor soil physical characteristics and low fertility.

Soil samples were collected from each of the five demonstration sites and were prepared at the Controlled Environment Facility (CEF) at Montana State University. Soil amendments were added to the soils and thoroughly mixed. The pH of the amended soils were monitored weekly until the pH was 7.8 or lower. The amended soils were then placed in the plant growth tubes and watered to field capacity. Fifteen seeds of the selected grass species for each site were planted at the appropriate depth. After germination and growth to approximately 8 cm, any seedlings in excess of ten were removed from the pots. The duration of the growth periods ranged from two to three months. Each plant specie were grown in separate pots and each specie growth trial replicated three times. During the growth period the environmental parameters in the greenhouse area maintained near optimum growth levels expected during the growing season in Anaconda, Montana. Humidity was not manipulated but ranged from 30%-40%. Temperatures were maintained at 20-24 degrees C during the daylight period and between 14-17 degrees C during the dark period. Plants were grown under a constant 14 hour light and 10 hour dark cycle.

The following response variables were measured at harvest: number of surviving plants, color, height, vigor and weight. Tables 2a and 2b list species response, amendments used and fertilizer rate by site.

Phase III

Phase III was begun in 1993 and completed in 1994. Phase III had the following objectives:

- Test technologies identified in Phase I and Phase II under field conditions at specific sites in each subarea;
- Determine effective techniques for applying and incorporation of amendments on a large scale; and
- Develop planting techniques for large scale revegetation.

Demonstration sites were constructed at Sites 9, 11 and 13 in 1993 and at Sites 1 and 6 in 1994. The experimental design for each site is different due to differences in soil characteristics at each location. Soil amendments (lime, organic matter and fertilizer) and seed mixes for each demonstration site were determined by the results of the Phase III laboratory and greenhouse testing.

The design for Site 9 was developed on the following site characteristics: 1) steep slopes (approximately 3:1); 2) elevated soil metals' concentrations; 3) generally neutral soils except for those located near an old rail grade that are acidic; and 4) soils with high rock content and no organic matter. Manure was spread over the entire site at a rate of 371 cubic yards per acre. Lime was applied at the rate of 300 tons per acre. Due to the steepness of this site erosion control features such as soil pitting, dozer basins and berms were constructed at various intervals down the slope.

The design for Site 11 was developed based on the following characteristics: 1) this site is flat and no native soils are present; 2) the soils are tailings from former ore milling operations at the Old Works Smelter site; 3) the tailings are acidic (2.5-3.0 pH) and contain elevated metals; 4) the tailings have been deposited over cobbly alluvium; and 5) there is no organic material in the soils. At this site four different treatments are being evaluated. Lime and manure were spread on two of the plots at the rates of 156 tons calcium carbonate per acre and 270 cubic yards per acre respectively. These amendments were then incorporated to 24 inches using a rotary mixer on one plot and a disc plow on the other. The remaining two plots received lime as the only soil amendment at the same rate as the first two plots. The lime was incorporated to 24 inches using the rotary mixer on one plot and a disc plow on the other. At

Table 2a

Response of Red Top (*Agrostis Alba*), Tufted Hairgrass (*Deschampsia Caespitosa*), Sheep Fescue (*Festuca Ovina* Covar and Durar), Alfalfa (*Medicago Sativa* Alphagraze), and Canada Bluegrass (*Poa Compressa*) Seeded Into Amended Wastes (Acid Portion) From Smelter Hill - ARTS Site 9

	Plant Response Variables and (Units)						
						Plant Roots (Number)	
Plant Species & Amendments Added*	**Survivability (%)**	**Plant Weight (g)**	**Plant Height (cm)**	**Plant Color+**	**Plant Vigor+**	**5 cm Depth**	**10 cm Depth**
Red Top							
Lime/Fertilizer	65	0.055	20.8	3.0	3.0	60	60
Lime/Fertilizer/Manure	39/72**	.100/.213	13.7/27.5	3.0/3.0	3.0/4.0	30/60	25/60
Tufted Hairgrass							
Lime/Fertilizer	100	0.008	6.8	3.0	1.0	12	12
Lime/Fertilizer/Manure	50/45	.045/.016	11.3/9.3	3.0/3.0	3.0/2.0	10/16	0/6
Sheep Fescue (Covar)							
Lime/Fertilizer	40	.004	5.0	3.0	1.0	12	10
Lime/Fertilizer/Manure	25/15	.017/.006	4.1/4.5	3.0/3.0	2.0/1.0	20/5	25/5
Alfalfa (Alphagraze)							
Lime/Fertilizer/Manure	33/39	.272/.176	16.6/12.5	3.0/3.0	3.0/2.0	25/10	20/20
Sheep Fescue (Durar)							
Lime/Fertilizer/Manure	45/40	.022/.038	7.6/8.9	3.0/3.0	2.0/3.0	30/40	20/24
Canada Bluegrass							
Lime/Fertilizer/Manure	25/20	.090/.116	20.2/30.4	3.0/3.0	3.0/3.0	20/15	12/7

* Lime was added at 470 T/a/24"
Fertilizer was N = 50 lbs/a/24" plus 18 lbs/a/6"
P_2O_5 = 248 lbs/a/24" plus 400 lbs/a/6"
B = 3 mg/kg
Manure = 272 g/3180 g waste or 2" manure mixed with waste in growth tube.
+Plant Color Scale: 0=Brown; 1=Yellow; 2=Pale Green; 3=Green; 4=Dark Green.
+Plant Vigor Scale: 0=Dead; 1=Poor; 2=Acceptable; 3=Good; 4=Robust.

** Value for each growth tube

Table 2b

Mean Response of Thickspike Wheatgrass (*Leymus lanceolatus*), Alfalfa (*Medicago sativa*), Montana Golden Pea (*Thermopsis Montana*), Intermediate Wheatgrass (*Elytrigia intermedia*), Streambank Wheatgrass (*Agropyron riparium*), Slender Wheatgrass (*Elymus trachycaulus*), and Mammoth Wildrye (*Leymus racemosus*) Seeded Into Amended Wastes (Alkaline Portion) From Smelter Hill, ARTS Site 9.

Response Variables and (Units)	Treatment (Amendment* for Each Species Was Low O.M. and Low Phosphorus)							
	Control	Thickspike Wheatgrass	Alfalfa	Montana Golden Pea	Intermediate Wheatgrass	Streambank Wheatgrass	Slender Wheatgrass	Mammoth Wildrye
Survivability (%)	0	0	0	0	93.0	0	0	30.0
Plant Weight (g)	0	0	0	0	0.055	0	NR	0.061
Plant Height (cm)	0	0	0	0	14.3	0	4.8	16.7
Plant color (scale+)	0	0	0	0	2.7	0	0.7	2.3
Plant vigor (scale+)	0	0	0	0	1.7	0	1	1.3
Plant roots @ 5 cm depth (number)	0	0	0	0	17.0	0	0	13.3
Plant roots @ 10 cm depth (number)	0	0	0	0	19.3	0	0	3.3

*Amendments:

Low O.M. (organic matter) was 300 t composted manure/a. Mixed in top 24" of growth tube.

Low phosphorus was 100 lbs. of P_2O_5/a. All growth tubes were fertilized with 20 lbs N/a and 2 lbs B/a.

+Plant Color Scale: 0=Brown; 1=Yellow; 2=Pale Green; 3=Green; 4=Dark Green.

+Plant Vigor Scale: 0=Dead; 1=Poor; 2=Acceptable; 3=Good; 4=Robust.

Table 3

Mean Response of Slender Wheatgrass (*Elymus trachycaulus*), Intermediate Wheatgrass (*Elytrigia intermedia*), and Yellow Sweetclover (*Melilotus officinalis*) Seeded Into Amended Wastes From the Old Works, ARTS Site 11

	Treatments (Amendments* Added to Waste Material)			
Response Variables and (Units)	**Control**	**Slender Wheatgrass**	**Intermediate Wheatgrass**	**Yellow Sweetclover**
Survivability (%)	0	100	63.3	50.0
Plant Weight (g)	0	0.036	0.259	0.298
Plant Height (cm)	0	19.7	32.5	25.4
Plant color (scale+)	0	2.0	3.0	3.0
Plant vigor (scale+)	0	1.0	2.7	3.0
Plant roots @ 5 cm depth (number)	0	63.0	80.0	80.0
Plant roots @ 10 cm depth (number)	0	43.0	70.0	70.0

*Amendments:

Slender wheatgrass was seeded into wastes amended with lime and fertilizer, but no organic matter.

Intermediate wheatgrass was seeded into wastes amended with lime, fertilizer, and high organic matter.

Yellow Sweetclover was seeded into wastes amended with lime, fertilizer, and high organic matter.

Lime was 100 t/a $CaCO_3$ = 35 t/a CaO mixed into top 24" of growth tube.

Fertilizer was 45 lbs/a N, 112 lbs P_2O_5/a and 158 lbs/a K_2O and 2 lbs B/a mixed in top 24" of growth tube.

High organic matter was 160 t/a composted manure mixed in top 6" of growth tube.

+Plant Color Scale: 0=Brown; 1=Yellow; 2=Pale Green; 3=Green; 4=Dark Green.

+Plant Vigor Scale: 0=Dead; 1=Poor; 2=Acceptable; 3=Good; 4=Robust.

Table 4

Results of Greenhouse Species Trials for Amended* Soils at ARTS Site 13 (Adjacent Areas)

Plant Species	Mean Response						
	Survivability (%)**	Plant Weight (g)	Plant Height (cm)	Plant Color (+)	Plant Vigor (+)	Plant Roots @ 5 cm (#)	Plant Roots @ 10 cm (#)
Red Top	100.0 a	.105 ab	18.3 bcd	2.75 a	2.50 bc	40.0 ab	10.0 a
Crested wheatgrass	93.3 a	.107 ab	25.3 d	3.00 a	2.00 b	58.3 b	43.3 a
Intermediate Wheatgrass	10.0 a	.227 c	33.9 e	3.00 a	3.33 c	86.7 c	91.7 b
Siberian wheatgrass	83.3 a	.041 a	14.8 abc	3.00 a	1.67 ab	21.7 a	3.3 a
Smooth brome	73.3 a	.074 ab	17.7 bcd	2.67 a	2.00 b	28.3 ab	6.0 a
Thickspike wheatgrass	100.0 a	.061 a	20.7 cd	2.75 a	2.00 b	33.8 ab	9.3 a
Western wheatgrass	76.7 a	.081 ab	24.9 d	3.00 a	2.33 bc	41.7 ab	24.3 a
Slender wheatgrass	93.3 a	.147 abc	25.1 d	3.00 a	2.33 bc	40.0 ab	35.0 a
Sheep fescue	76.7 a	.026 a	8.5 a	3.00 a	2.00 b	25.0 ab	13.3 a
Basin wildrye	93.3 a	.096 ab	25.1 d	3.00 a	2.67 bc	31.7 ab	28.3 a
Yellow sweetclover	50.0 a	.202 bc	18.5 bcd	3.00 a	2.67 bc	17.3 a	18.3 a
Alfalfa	83.3 a	.102 ab	11.5 ab	3.00 a	2.67 bc	23.3 a	31.7 a
Canada bluegrass	93.3 a	.019 a	8.9 a	2.33 a	1.00 a	14.3 a	9.3 a

*Amendments:

Lime at 3.4 t/a $CaCO_3$ and 1.7 t/a $Ca(OH)_2$

Manure at 270 t/a

Fertilizer at 30 lbs N/25 lbs P/0.25 lbs B/a

**Means within each *column* with different letters are statistically distinct (ANOVA at $P \leq 0.05$) and were separated using Student-Newman-Keuls test.

+Plant Color Scale: 0=Brown; 1=Yellow; 2=Pale Green; 3=Green; 4=Dark Green.
+Plant Vigor Scale: 0=Dead; 1=Poor; 2=Acceptable; 3=Good; 4=Robust.

Sites 9 and 11 amendments were incorporated using the following procedures:

- Spread 80% of amendments and fertilizer;
- Incorporate amendments to 24";
- Apply the remaining 20% of amendments; and
- Incorporation of amendments to approximately 6" with a chisel plow.

The design for Site 13 was developed based on the following characteristics: 1) soils with surficially elevated metals' levels and acidic pH (4.0-5.5); 2) cobbly alluvium containing calcium carbonate at a depth of approximately one foot; and 3) low soil organic material content.

At this location six plots were established using the following treatments:

Plot 1 Amendment rates: 12.6 tons per acre incorporated to 12 inches and 135 cubic yards of manure per acre incorporated to 6 inches.

Plot 2 Amendment rates: 7.6 tons per acre of calcium carbonate and 3.9 tons per acre of calcium hydroxide incorporated to 12 inches. 135 cubic yards per acre of one inch minus log yard waste incorporated to six inches.

Plot 3 Amendment rates: 7.6 tons per acre of calcium carbonate and 3.9 tons per acre of calcium hydroxide incorporated to 12 inches. 135 cubic yards per acre of Phase IV Eko Kompost incorporated to six inches.

Plot 4 Amendment rates: 7.6 tons per acre of calcium carbonate and 3.9 tons per acre of calcium hydroxide incorporated to 12 inches. 135 cubic yards per acre of manure incorporated to six inches.

Plot 5 Amendment rates: 7.6 tons per acre of calcium carbonate and 3.9 tons per acre of calcium hydroxide incorporated to 12 inches.

Plot 6 Mix 0-24 inch soil profile with disc plow.

At Site 13 a similar two step method was used to uniformly incorporate the amendments to 12". Approximately 80% of the lime and organic material were incorporated to 12" using a Baker Plow. The remaining amendments were applied and incorporated to 6" with a chisel plow.

The design for Site 1 was developed based on the following characteristics: 1) soils are tailings from the past milling operations at the Washoe Smelter. 2) the tailings are acidic (2.5-3.0 pH) and contain elevated levels of metals. 3) the tailings are fine texture and contain no organic matter.

At this site the following three treatments are being evaluated:

Plot 1 Amendment rates: 29.1 tons per acre of calcium oxide and 78.1 tons of calcium carbonate incorporated to 15 inches with the rotary mixer. 824 tons of slag and 422 cubic yards of Eko Kompost incorporated to 19 inches with the rotary mixer. Topdress 0-3 inch depth with 4 tons calcium oxide per acre, 10.5 tons calcium carbonate per acre and 67 cubic yards of Eko Kompost per acre.

Plot 2 Amendment rates: 35.1 tons per acre of calcium oxide and 94.3 tons of calcium carbonate incorporated to 18 inches with the rotary mixer. 262 tons of slag and 133.3 cubic yards of Eko Kompost incorporated to 6 inches with agricultural rototiller. Topdress 0-3 inch depth with 4 tons calcium oxide per acre, 10.5 tons calcium carbonate per acre and 67 cubic yards of Eko Kompost per acre.

Plot 3 Amendment rates: 39.0 tons per acre of calcium oxide and 104.7 tons of calcium carbonate incorporated to 19 inches with the disc plow. 133.3 cubic yards of Eko Kompost incorporated to 6 inches with agricultural rototiller. Topdress 0-3 inch depth with 4 tons calcium oxide per acre, 10.5 tons calcium carbonate per acre and 67 cubic yards of Eko Kompost per acre.

The design for Site 6 was developed based on the following characteristics: 1) soils are tailings from the past milling operations at the Washoe Smelter. 2) the tailings are acidic (2.5-3.0 pH) and contain elevated levels of metals. 3) the tailings are very fine in texture.

At this site the following three treatments are being evaluated:

Plot 1 Amendment rates: 158.6.0 tons per acre of calcium oxide and 417 cubic yards of Eko Kompost incorporated to 20 inches with the rotary mixer in a three step process. Topdress 0-3 inch depth with 7 tons calcium oxide per acre, 19 tons calcium carbonate per acre and 62.5 cubic yards of Eko Kompost per acre and incorporate with an agricultural rototiller.

Plot 2 Amendment rates: 127.0 tons per acre of calcium oxide, 417 cubic yards of Eko Kompost and 843 tons per acre of slag incorporated to 20 inches with the rotary mixer in a three step process. Topdress 0-3 inch depth with 7 tons calcium oxide per acre, 19 tons calcium carbonate per acre, 62.5 cubic yards of Eko Kompost per acre and 130 cubic yards of hog fuel and incorporate with an agricultural rototiller.

Plot 3 Amendment rates: 95 tons per acre of calcium oxide and 1686 tons per acre of slag incorporated to 20 inches using multiple passes with a disc plow. 125 cubic yards of Eko Kompost incorporated to 6 inches making two passes with an agricultural disc. Topdress 0-3 inch depth with 7 tons calcium oxide per acre, 19 tons calcium carbonate per acre and 62.5 cubic yards of Eko Kompost per acre and incorporate with an agricultural rototiller.

Site 9 was drill seeded in the fall of 1993. Sites 11 and 13 were seeded the spring of 1994. Sites 1 and 6 will be seeded the spring of 1995.

Phase IV has the following objectives:

- Evaluate the long-term effectiveness of treatments established in the field demonstrations;
- Evaluate contaminant loading on and in vegetation;
- Evaluate effectiveness of amendment incorporation; and
- Evaluate potential for wind and water erosion.

Initial work began on Phase IV in 1993 with the evaluation of the depth and uniformity of amendment incorporation at Sites 9, 11 and 13. Preliminary results from the evaluation of amendment incorporation indicate that the disc plow is capable of incorporating amendments to a 24 inch depth although the uniformity is less than that achieved by the rotary mixer. The effect of this on vegetation response will be monitored for the next two growing seasons. Phase IV work is projected to be complete in 1996.

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