RESULTS OF SPECIES TRIALS ON LOW pH OVERBURDEN MATERIALS FOR MINE LAND RECLAMATION[1]

by

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Abstract. The Molycorp molybdenum mine in north-central New Mexico operated as an open pit mine from the mid 1960s to the early 1980s. The overburden piles generated during this operation are heterogeneous in respect to rock types containing neutral rock types as well as mixed volcanic rock types. The mixed volcanic rocks are highly weathered materials with low pH and high salinity resulting from pyrite oxidation. Undisturbed areas surrounding the mine site having similar mixed volcanic rock types as found in the overburden piles, support vegetation indicating there may be native plants in this climatic region which are adapted to low pH conditions and associated soluble constituents found in these materials. This study was set up to evaluate the survival of different native and exotic plant materials across a range of overburden materials found at the Molycorp site. Determining what species can survive on the different overburden materials is instrumental in implementing an effective reclamation program at the site. Two overburden rock types representing both the mixed volcanic rock types and the neutral rock types, were crushed and mixed to generate 4 different overburden materials. These materials ranged in pH from 2.7 to 4.4 and had electrical conductivities ranging from 1.9 to 3.6 ds/m. The overburden materials were placed into 15-gallon horticultural pots located at the Mora Research Center, Mora, NM. The study used 164 cm^3 container transplants of the following 52 plant types: ten conifer species, 16 legume species, five species of forbs and sub-shrubs, and 21 shrub species. The study was initiated in June 1995 and survival evaluated in June 1996. Survival results for species are presented. When 70% survival and a vigor rating of good are used as the criteria for determining potential for a species to be used in the reclamation program 42 and 38 species would be suitable for the two overburden materials with the highest pH and lowest EC, respectively. In the substrate with the second lowest pH (3.3) and second highest EC (3.2 ds/m), 21 species or sources had greater than 70% survival. In the most acidic overburden having the highest EC (3.6 ds/m), six coniferous tree species and three shrub species had greater than 70% survival. As an initial screening tool this study has provided information on species with potential for direct establishment on low pH (<3.3), high EC (>3.2 ds/m) overburden.

Additional Key Words: acid soils, disturbed land reclamation.

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Introduction

The Molycorp Inc. molybdenum mine is located in north central New Mexico between the towns of Questa and Red River, New Mexico. The mine operated as an open-pit mine from the mid-1960s through the early 1980s at which time underground

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mining techniques were employed. During the open-pit portion of the mine's history, approximately 328 million tons of overburden were produced and deposited on the steep mountainsides characteristic of the area. The resultant overburden piles range in elevation from 2,400 to 3,000m with primarily southerly facing aspects. The open-pit mining process resulted in a range of overburden types being generated depending on the geological material being excavated. The overburden piles consist of mixed volcanic rocks (andesitic and rhyolitic types; referred to as acid rock) and aplite and black andesite intrusives (referred to as neutral rock). The mixed volcanics are highly fractured and weathered with low pH and high salinity resulting from pyrite oxidation (SRK Inc. 1995). The mixing of rock types during the development of the overburden piles resulted in heterogeneous substrates with a range of acidity and soluble salt levels (SRK Inc. 1995).

The vegetation surrounding the mine is primarily coniferous forest ranging from ponderosa pine (*Pinus ponderosa*) stands to mixed conifer stands dominated by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), limber pine (*P. flexilis*) to spruce-fir stands dominated by Englemann spruce (*Picea englemannii*) and white fir. Within the same physiographic region of the mine are naturally occurring erosional scars. These scars are also referred to as acid scars, alteration scars or hydrothermal scars, and characteristically consist of low paste pH materials (1.8 – 3.5; SRK Inc. 1995; Meyer and Leonardson 1990). Many of these undisturbed scar areas have plants from the indigenous communities colonizing the scar areas (Wagner and Harrington 1994). Overstory coniferous trees, limber pine, ponderosa pine, Douglas fir and Englemann spruce are the most visible species colonizing these scars, however, some grasses, and shrubs are also present in these areas. The encroachment into these scar areas has been occurring for a long period of time as evidenced by the oldest living conifer, an estimated 1700-year-old limber pine found growing in one such area (Swetnam and Brown 1992).

Objectives

The challenges of establishing plant material in low pH overburden and the occurrence of species growing on adjacent sites having low pH substrate compelled efforts to determine species with greater likelihood to survive, and subsequently grow in these substrates. The objective of this study was to evaluate the suitability of various native and non-native trees, shrubs, forbs and legumes for direct establishment on the overburden types at the Molycorp waste rock piles. Potentially, the most restrictive of these overburden materials would be those with the highest salt levels, which also had the greatest acidity levels found in the piles. Therefore, it may be beneficial to also examine the influence of incorporating materials with lower salt levels and less acid to determine if that process would mitigate any limitations of the more acidic material in terms of early survival.

Materials and Methods

The survival screening of tree and shrubs on overburden from the Molycorp mine was conducted at the New Mexico State University – Mora Research Center in Mora, NM. The substrate treatments used in this study consisted of unmixed acid rock (LPH – low pH, high soluble salts); an acid:neutral overburden mixture ratio of 3:1 (v:v; LSS – low soluble salts, high pH); an acid:neutral overburden mixture ratio of 9:1 (v:v; HSS – high soluble salts, intermediate pH); and an acid:neutral overburden mixture ratio of 1.25:1 (v:v; HPH – high pH, low soluble salts). The acid rock was excavated from mixed volcanic rock on the second terrace of the Sulphur Gulch pile and the neutral rock was excavated from aplite and black andesite rock on the first terrace of the Sulphur Gulch pile. The two-overburden types were crushed and screened to less than 13 mm and then mixed at the ratios described above and transported to the Mora Research Center in July of 1995. The overburden was stored in 30-gallon, airtight polyethylene barrels until the initiation of the study. Three samples of each overburden combination were analyzed for pH and electroconductivity (EC) as described in the Soil Quality Test Kit Guide manual (USDA 1998). The mean pH and mean EC for each substrate are presented in Table 1. No overburden measurements were taken at the end of this study. However, in a corollary study on grass using the same overburden combinations at the same test facility, post-weathering values have been reported (Dreesen et al. 2001).

Table 1. Mean pH and EC of overburden substrate materials prior to planting.

Substrate	Mixing Ratio (acid/neutral)	pH	EC (ds/m)
LPH	1:0	2.7	3.6
HSS	9:1	3.3	3.2
LSS	3:1	3.7	2.1
HPH	1.25:1	4.4	1.9

Five days prior to planting substrates were placed into 15-gallon horticultural pots with a drain hole in the base. Pots containing the overburden were placed into 15-gallon horticultural pots installed at ground level.

The pot installed at the ground level had a single drain hole connected to a closed drain system. This system is often referred to as a pot-in-pot system. The voids between pots installed at ground level were backfilled. The tops of the pots containing the overburden material were approximately 2 cm above ground level while the overburden level within the pot was at ground level. This pot configuration was employed to reduce temperature increases and diurnal fluctuation in root zone temperatures of the overburden material. Also, the pot-in-pot system, while allowing for free drainage of the pot containing the overburden material eliminated the occurrence of moisture from the surrounding soil being drawn into the pot containing the overburden material. Pots were irrigated thoroughly to remove any air voids following substrate placement into the pots. Pots were allowed to drain for two days prior to planting. The study was conducted in the landscape simulator at the New Mexico State University – Mora Research Center, Mora, NM. This facility consists of a 12-meter by 30-meter greenhouse frame with motorized wall and roof panels. The walls and roof panels were only deployed during rain events during the growing season. A total of 320 pots (80 per substrate) were used in this study. Ten pots of each material, LPH, LSS, HSS and HPH, were assigned to each of eight blocks. All plant materials used in this study were grown in 164 cm^3 containers (Ray-Leach Super Cells; Stuewe & Sons Inc., Corvallis, OR, USA) at either the Research Nursery at the NMSU – Mora Research Center (coniferous species) or at the USDA Research Nursery in Los Lunas, NM (all other species) (Table 2). All plants were grown in a peat:perlite:vermiculite media or a peat:perlite media. Ten species of conifers, 16 species of legumes, five species of forbs/sub-shrubs and 21 species of shrubs (27 seed sources) were evaluated in this study. Seedlings were planted into the 15-gallon pots containing the overburden materials in June 1995, using a homemade planting bar. Irrigation was done using a micro-irrigation system (Robert's Spotspitters, four per pot) with pressure regulators to ensure all pots received the same amount of irrigation. Output rate for each emitter was nine liters per hour. Pots were irrigated for 15 minutes, once every seven days from the time of planting until the first frost, (mid-September 1995) and resumed on May 15, 1996 and continued until the end of the measurement period. This irrigation regime resulted in each pot receiving nine liters of irrigation per week. A maximum of 15 seedlings were planted in each pot (Total maximum volume of root plugs would be less than 5% of the volume of overburden material in any given pot). At the end of June 1996 plant survival was evaluated. Due to plant material constraints, not all species were evaluated in each substrate nor were the same number of replications installed (Table 2). In some ecotypes of species growing in the adjacent forest community, insufficient seed was produced to generate desired plant numbers (96 plants). When plant numbers were limiting, emphasis was placed on evaluating HSS, LSS and HPH overburden mixtures with the minimum of three plants per substrate per replication.

The intent of this study was to evaluate species, in some instances ecotype, response to substrate. The overall study design was a randomized complete block design with a maximum of eight blocks and a minimum of two blocks. Each species x substrate x block was replicated by three seedlings per block (Table 2). The response variable was the observed survival for the entire block. Categorical analysis of variance was used to analyze the dichotomous response variable survival (PROC CATMOD, SAS Institute, 1990). PROC CATMOD was used with generalized least squares as the technique for obtaining estimates and concomitant test statistics. Test statistics are asymptotic chi-square tests. This approach was chosen because it allows for the analysis of binomial data, survival, without requiring transformation. The analysis was performed for each species independently. Post-hoc tests included pairwise comparisons and contrasts. Asymptotic pairwise Z statistics (analogous to Least Squares Difference) and their observed significance levels were calculated to test pairs of overburden treatments.

To evaluate the influence of blocking, a preliminary analysis of the conifer species was performed. This approach was chosen to simplify the number of analysis performed and because the conifers were replicated in all the blocks. The effects included in this model were overburden treatment, block and the overburden x block interaction. Only the overburden effect was significant at $\alpha = 0.05$. In subsequent analysis, reported in this paper, the model effects included only overburden pH.

Results

Species performance is reported by plant category: coniferous species, legumes, forbs, and shrub/sub-shrubs. Across all coniferous species, overall survival ranged from 76% in the LPH overburden material to 92% for both the LSS and HSS overburden materials to 99% in the HPH overburden. All coniferous species exhibited some mortality when planted in the LPH overburden material, while two of the native pines, *P. ponderosa* (PIPO) and *P. flexilis* (PIFL) had no mortality in the other three-overburden mixtures (Table 3). Survival of five species of conifers, *P. aristata* (PIAR), *P. flexilis* (PIFL), *P. strobiformis* (PIST), *P. ponderosa* (PIPO) and *Picea englemannii* (PIEN) was

Table 2. Species code, scientific and common names, source and number of replications of species evaluated in this study.

Species Code	Scientific Name	Common Name	Source	Plant Category	Number Of Blocks
ABCO	*Abies concolor*	White Fir	N.M.S.U.	Conifer	8
ACMI	*Achillea millefolim*	White Yarrow	Molycorp	Forb	6
ALTE	*Alnus tenuifolia*	Thinleaf Alder	Carson NF	Shrub	5
AMCA	*Amorpha canescens*	Indigo Bush	Corrales	Shrub	8
AMFR	*Amorpha fruticosa*	Leadplant	Corrales	Shrub	6
ARFI1	*Artemesia frigida*	Fringed Sage	Molycorp TY	Forb	3
ARFI2	*Artemesia frigida*	Fringed Sage	Molycorp EP	Forb	3
ASCLE	*Asclepias spp.*	Milkweed	Molycorp	Forb	6
ASCI	*Astragalus cicer*	Cicer Milkvetch	Commercial	Legume	7
ASMI	*Astragalus missouriensis*	Missouri Milkvetch	Commercial	Legume	4
ATCA	*Atriplex canescens*	Four wing Saltbush	Commercial	Shrub	4
CAAR	*Caragana arborescens*	Siberian Pea Shrub	Commercial	Shrub	8
CEMO	*Cercocarpus montanus*	Mountain Mahogany	Molycorp	Shrub	6
CHNA1	*Chrysothamnus nauseosus*	Rubber Rabbitbrush	Molycorp B	Shrub	8
CHNA2	*Chrysothamnus nauseosus*	Rubber Rabbitbrush	Molycorp M	Shrub	4
COVA	*Coronilla varia*	Crownvetch	Commercial	Legume	8
DAAU	*Dalea aurea*	Golden Dalea	Commercial	Legume	5
FAPA	*Fallugia paradoxa*	Apache Plume	Molycorp	Shrub	8
FONE	*Forestiera neomexicana*	New Mexico Olive	Jemez	Shrub	4
HEBO	*Hedysarum boreale*	Northern Sweetvetch	Commercial	Legume	6
HODU1	*Holodiscus dumosus*	Rock Spirea	Molycorp GH	Shrub	5
HODU2	*Holodiscus dumosus*	Rock Spirea	Molycorp HD	Shrub	4
JAAM1	*Jamesia americana*	Cliffbush	Molycorp UB	Shrub	4
JAAM2	*Jamesia americana*	Cliffbush	Molycorp GH	Shrub	4
LASY	*Lathyrus sylvestris*	Flatpea	Commercial	Legume	8
LOCO	*Lotus corniculatus*	Birdsfoot Trefoil	Commercial	Legume	4
LOOR	*Lotus oroboides*	Deervetch	Univ. Arizona	Legume	4
LUAL	*Lupinus alpestris*	Mountain Lupine	Commercial	Legume	3
LUPE	*Lupinus perennis*	Wild Lupine	Commercial	Legume	2
MESA	*Medicago sativa*	Alfalfa	Commercial	Legume	3
OXLA	*Oxytropis lambertii*	Lambert's Locoweed	Commercial	Legume	6
OXSE	*Oxytropis sericea*	Woolly Locoweed	Commercial	Legume	2
PEBA	*Penstemon barbatus*	Scarlet Bugler	Molycorp GH	Forb	7
PEPU	*Petalostemum purpureum*	Purple Prairie Clover	Commercial	Legume	8
PECA	*Petalostemum candidum*	White Prairie Clover	Commercial	Legume	4
PHMI1	*Philadelphus microphyllus*	Mock Orange	Molycorp	Shrub	8
PHMI2	*Philadelphus microphyllus*	Mock Orange	Cibola NF	Shrub	4
PHMO	*Physocarpus monogynus*	Ninebark	Cibola NF	Shrub	5
PIEN	*Picea englemannii*	Englemann Spruce	Commercial	Conifer	8
PIPU	*Picea pungens*	Blue Spruce	Commercial	Conifer	8
PIAR	*Pinus aristata*	Bristlecone Pine	Carson NF	Conifer	8
PIED	*Pinus edulis*	Pinon Pine	Santa Fe NF	Conifer	8
PIFL	*Pinus flexilis*	Limber Pine	Molycorp	Conifer	8
PIPO	*Pinus ponderosa*	Ponderosa Pine	Carson NF	Conifer	8
PIST	*Pinus strobiformis*	Southwestern White Pine	Lincoln NF	Conifer	8
PISY	*Pinus sylvestris*	Scot's Pine	Commercial	Conifer	8

Table 2, continued.

Species Code	Scientific Name	Common Name	Source	Plant Category	Number Of Blocks
PRVI	*Prunus virginiana*	Chokecherry	Molycorp	Shrub	6
PSME	*Pseudotsuga menziesii*	Douglas Fir	Carson NF	Conifer	8
RHTR1	*Rhus trilobata*	Skunkbush Sumac	Bighorn	Shrub	4
RHTR2	*Rhus trilobata*	Skunkbush Sumac	Molycorp M	Shrub	4
ROFE	*Robinia fertilis*	Bristly Locust	Cibola NF	Shrub	6
RONE	*Robinia neomexicana*	New Mexico Locust	Cibola NF	Shrub	5
ROWO	*Rosa woodsii*	Woods Rose	Molycorp	Shrub	4
RUBUS	*Rubus spp.*	Raspberry	Molycorp	Shrub	3
SANE	*Sambucus neomexicana*	NM Elderberry	Gila NF	Shrub	3
SHAR	*Shepherdia argentea*	Silver Buffaloberry	Commercial	Shrub	5
SOLID	*Solidago spp.*	Goldenrod	Molycorp UB	Forb	6
THMO	*Thermopsis montana*	Golden Banner	Commercial	Legume	7

unaffected by overburden mixture (Table 3). For the four species whose survival was impacted by overburden material, survival in the LPH or the overburden material with the lowest pH and highest EC, was significantly lower than in the other three overburden materials. These four species were *Pinus sylvestris* (PISY), *P. edulis* (PIED), *Pseudotsuga menziesii* (PSME) and *Picea pungens* (PIPU). *Abies concolor* (ABCO) had low survival in the low pH and high EC overburden material, LPH (71%) and in the LSS (88%) overburden material. This species had 100% survival in the other two overburden materials evaluated. Others have reported good performance of *P. sylvestris* in acidic (pH 4.0) spoils (Powell 1988). Five of the ten species of coniferous trees evaluated in this study have been recommended for consideration in mined land reclamation (Plass and Powell 1988). Only the non-native *P. sylvestris* (PISY), and native *P. edulis* (PIED), *Pseudotsuga menziesii* (PSME) and *Picea pungens* (PIPU) growing the LPH overburden material had less than 70% survival.

Survival of the eight shrub/shrub species evaluated in the LPH overburden material ranged from 100% for *Amorpha fruticosa* (AMFR) and *Prunus virginiana* (PRVI) to 0% for *Alnus tenuifolia* (ALTE) averaging 64% (Table 4). Survival for the other three overburden materials evaluated ranged from 82% in the HSS to 88% and 89% in the LSS and HPH overburden materials. Two species, *Alnus tenuifolia* (ALTE) and *Robinia fertilis* (ROFE) performed poorly on all three of these overburden materials. Others have reported good performance of *R. fertilis* in low pH (4.0) mine spoils (Powell 1988). The two sources of *Holodiscus dumosus* (HODU1 and HODU2), both propagated from seed collected at the Molycorp mine, had very different survival over the HSS, LSS, and HPH overburden materials. While both showed no differences in survival across the three overburden materials, the source from the Goat Hill Scar area (HODU1) had an average survival of 87% compared to the source collected in the High Dump area (HODU2), which had an average survival of 28%. This indicates there may be some within-species variability in *Holodiscus dumosus* sensitivity to edaphic (overburden) conditions. The species of locust evaluated, *Robinia fertilis* (ROFE) and *R. neomexicana* (RONE) also had very different survival responses across the three overburden materials on which they were evaluated. While survival in either species was not affected by overburden material, the *R. fertilis* (ROFE) had consistently lower survival than did the *R. neomexicana* (RONE), 35% versus 100% (Table 4). While others have reported favorable performance of *R. fertilis* in low pH (4.0) mine spoils, this was not evident in this study (Powell 1988). The other 4 shrub species with 2 sources, *Chrysothamnus nauseosus* (CHNA1 and CHNA2), *Jamesia americana* (JAAM1 and JAAM2), *Philadelphus microphyllus* (PHMI1 and PHMI2), and *Rhus trilobata* (RHTR1 and RHTR2) had less than 20% difference in survival between the sources in any given overburden material.

Seven, shrub/sub-shrub species had no mortality in the HSS, LSS and HPH substrates (Table 4). Those species were *Amorpha fruticosa* (AMFR), both sources of *Chrysothamnus nauseosus* (CHNA1, CHNA2), *Forestiera neomexicana* (FONE), *Philadelphus microphyllus* (PHMI1), *Rhus trilobata* (RHTR1), *Robinia neomexicana* (RONE), and *Rosa woodsii* (ROWO) (Table 4). Fifteen of the 20 shrub/sub-shrub species evaluated had greater than 70% survival in the

Table 3. Average survival response of ten conifer species directly planted on overburden substrates from the Molycorp Inc., Questa Mine.

Species Code	Survival (%) Overburden Substrate LPH	HSS	LSS	HPH	Observed Probability
PIAR	83 a	100 a	88 a	100 a	0.2698
PIFL	92 a	100 a	100 a	100 a	0.6214
PIPO	87 a	100 a	100 a	100 a	0.3218
PIST	96 a	100 a	92 a	100 a	0.7004
PIEN	83 a	71 a	75 a	100 a	0.2078
PISY	63 a	100 b	96 b	100 b	0.0042
PIED	62 a	96 b	100 b	100 b	0.0042
PSME	63 a	79 ab	92 b	92 b	0.0476
PIPU	58 a	71 ab	87 b	100 bc	0.0293
ABCO	71 a	100 b	88 a	100 b	0.0488

Letters denote significant ($\alpha = 0.05$) difference in survival of a species across the overburden materials evaluated in this study.

HSS, LSS, and HPH overburden materials. Only the two species mentioned previously, *Alnus tenuifolia* (ALTE) and *Robinia fertilis* (ROFE) and one source of *Holodiscus dumosus* (HODU2) had less than 70% survival in the HSS, LSS, and HPH overburden materials. The only species with a significant response to overburden material was the PHMI1 source of *Philadelphus microphyllus* (PHMI) where survival was 58% in the LPH overburden material compared to 100% in the other three overburden materials. While many of the shrub/sub-shrub species evaluated have been previously recommended for reclamation by others (Plass and Powell 1988), several species native to the southern Rocky Mountains warrant further investigation. These species include *Amorpha canescens, Cercocarpus montanus, Forestiera neomexicana, Jamesia americana, Robinia neomexicana,* and *Rosa woodsii* based on their performance in this study.

Forb/sub-shrub survival ranged from 56% to 100% when grown in the HSS, LSS and HPH overburden materials (Table 5). Due to plant material limitation no species in this category were evaluated on the LPH overburden material. Survival exceeded 70% except for one source of *Artemesia frigida* (ARFR2) with 56% survival on the LSS overburden material and the other *A. frigida* source (ARFR1) having 67% survival on the HPH overburden material (Table 5). None of the species in this category had a significant survival response to overburden material (Table 5). Three species *Achillea millefolim* (ACMI), *Asclepias spp* (ASCLE) . and *Solidago spp* (SOLID). had greater than 90% survival in the three overburden materials evaluated.

As a plant category, the legumes had the lowest overall survival across the four overburden materials evaluated, ranging from 40% in the LPH to 63% in the LSS overburden material. Only three legume species were evaluated in the LPH overburden material, *Astragalus cicer* (ASCI), *Lathyrus sylvestris* (LASY), and *Medicago sativa* (MESA). These were also the only three species that had a significant survival difference across overburden materials (Table 6). For two of the species *Astragalus cicer* (ASCI). and *Medicago sativa* (MESA) the poor survival in the LPH overburden material was different than the survival in the three other overburden materials, HSS, LSS, and HPH.

Six of the 16 legumes had greater than 70% survival in the HSS overburden material. These species were *Astragalus cicer* (ASCI), *Lotus corniculatus* (LOCO), *Medicago sativa* (MESA), *Petalostemum candidum* (PECA), *Petalostemum purpureum* (PEPU), and *Thermopsis montana* (THMO). These six species and *Coronilla varia* (COVA), *Dalea aurea* (DAAU) and *Lathyrus sylvestris* (LASY) had greater than 70% survival in the LSS and HPH overburden materials. Seven species, *Astragalus missouriensis* (ASMI), *Hedysarum boreale* (HEBO), *Lotus oroboides* (LOOR), *Lupinus alpestris* (LUAL), *Lupinus perennis* (LUPE), *Oxytropis lambertii* (OXLA), and *Oxytropis sericea* (OXSE) had survivals below 50% in all three overburden materials evaluated. Legumes and

Table 4. Average survival response of twenty one shrub/sub-shrub species directly planted on overburden substrates from the Molycorp Inc., Questa Mine.

Species Code	Survival (%) Overburden Substrate LPH	HSS	LSS	HPH	Observed Probability
ALTE	0* a	33 a	20 a	33 a	0.7553
AMCA		94 a	94 a	89 a	0.7709
AMFR	100 a	100 a	100 a	100 a	NS
ATCA		100 a	100 a	94 a	0.8738
CAAR	83 a	92 a	100 a	92 a	0.4488
CEMO		94 a	94 a	100 a	0.8968
CHNA1		100 a	100 a	100 a	NS
CHNA2		100 a	100 a	92 a	0.8670
FONE		100 a	100 a	100 a	NS
HODU1	67*a	67 a	100 a	93 a	0.1525
HODU2		33 a	17 a	33 a	0.3018
JAAM1		92 a	92 a	100 a	0.8907
JAAM2		75 a	100 a	100 a	0.2334
PHMI1	58 a	100 b	100 b	100 b	0.0021
PHMI2		83 a	100 a	100 a	0.4726
PHMO	33* a	60 a	67 a	80 a	0.4363
PRVI	100* a	83 a	100 a	100 a	0.4726
RHTR1		100 a	100 a	100 a	NS
RHTR2		92 a	92 a	83 a	0.5763
ROFE		22 a	44 a	39 a	0.3599
RONE		100 a	100 a	100 a	NS
ROWO		100 a	100 a	100 a	NS
RUBUS		100 a	78 a	100 a	0.4541
SANE		67 a	100 a	100 a	0.2925
SHAR	67* a	73 a	93 a	100 a	0.2515

Letters denote significant ($\alpha = 0.05$) difference in survival of a species across the overburden materials evaluated in this study.

* - Data for substrate LPH reflects data from one block.

NS – All plants of this species survived in all overburden substrates evaluated.

Table 5. Average survival response of five forb species directly planted on overburden substrates from the Molycorp Inc., Questa Mine.

Species Code	Survival (%) Overburden Substrate LPH	HSS	LSS	HPH	Observed Probability
ACMI		100 a	94 a	100 a	0.8738
ARFR1		78 a	78 a	67 a	0.8264
ARFR2		78 a	56 a	78 a	0.5030
ASCLE		100 a	92 a	100 a	0.8968
PEBA		71 a	90 a	95 a	0.1002
SOLID		100 a	100 a	100 a	NS

Letters denote significant ($\alpha = 0.05$) difference in survival of a species across the overburden materials evaluated in this study.

NS – All plants of this species survived in all overburden substrates evaluated.

Table 6. Average survival response of sixteen legume species directly planted on overburden substrates from the Molycorp Inc., Questa Mine.

Species Code	Survival (%) Overburden Substrate LPH	HSS	LSS	HPH	Observed Probability
ASCI	54 a	100 b	100 b	100 b	0.0009
ASMI		22 a	44 a	28 a	0.3375
COVA		58 a	83 a	100 a	0.1293
DAAU		67 a	92 a	92 a	0.2063
HEBO		6 a	17 a	0 a	0.3377
LASY	29 a	42 a	79 b	71 b	0.0018
LOCO		78 a	89 a	100 a	0.5781
LOOR		8 a	50 a	25 a	0.1081
LUAL		0 a	33 a	0 a	0.4166
LUPE		0 a	0 a	22 a	0.4541
MESA	38 a	96 b	96 b	100 b	0.0001
OXLA		17 a	17 a	17 a	1.0000
OXSE		0 a	0 a	0 a	NS1
PECA		95 a	100 a	100 a	0.8757
PEPU		100 a	100 a	100 a	NS2
THMO		93 a	100 a	100 a	0.8711

Letters denote significant ($\alpha = 0.05$) difference in survival of a species across the overburden materials evaluated in this study.
* - Data for substrate LPH reflects data from one block.
NS1 – All plants of this species died in all overburden substrates evaluated.
NS2 – All plants of this species survived in all overburden substrates evaluated.

actinorhizal species can play a critical role in overburden material amelioration. Often these species are referred to as nurse trees or nurse plants due, in part, to their ability to form symbiotic associations with *Rhizobium spp.* in the case of legumes, and *Frankia spp.* in the case of actinhorizal plants. These associations can make appreciable contributions to nitrogen deficient, waste rock sites.

Transplanting container-grown plants is often more expensive than establishing plants from seed as if often done with grasses and forbs. Many tree and shrub species have recalcitrant seed, which germinate sporadically in nature (Kleinman 1996). However, if successful, establishing tree and other arborescent plants by use of container grown stock can be advantageous. Advantages include greater control over species distribution, shortened establishment periods (McGilvray and Barnett 1981), and the ability to inoculate sites with favorable soil biota (Cordell et al. 1999). To be successful, particularly in high-elevation waste rock sites, emphasis needs to be placed on plant material selection (Munshower 1994).

Conclusions

While cover soils confer many advantages in establishing vegetation on waste rock piles, they are not indispensable (Munshower 1994). To assess the potential of plants (in this present study, trees and shrubs, and forbs), it is necessary to conduct preliminary investigations to determine which species have potential for inclusion into a revegetation program involving establishing vegetation directly into overburden materials. In this study, a broad range of species survived on the range of overburdens evaluated. Both exotic and naturally occurring species had high survival rates. There does appear to be some within-species variability in the survival response for some species (i.e. *Holodiscus dumosus* and *Rhus trilobata*, to a lesser extent). Further work will be necessary to examine within-species variability. The high survival rate of some of the species tested at the lowest overburden pH was encouraging. Included in this group are those species, which are naturally establishing on adjacent, low pH scar areas.

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