Testing Native Grasses For Survival and Growth in Low pH Mine Overburden[1]

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Abstract

Overburden piles at the Molycorp molybdenum mine in North-Central New Mexico contain neutral rock types as well as mixed volcanic rocks, which are highly weathered materials with low pH and high salinity from pyrite oxidation. The mixing of rock types during overburden pile construction has resulted in heterogeneous substrates with a range of pH and soluble salt levels. An experiment to determine grass species more likely to survive and grow in these low pH overburden materials used substrate treatments consisting of an unadulterated acid rock, an acid:neutral overburden mixture ratio of 9:1, and an acid:neutral overburden mixture ratio of 3:1. Containerized grass seedlings of 54 species/ecotypes, primarily cool-season natives of the western U.S, were transplanted into these substrates. Species grown from seed collected at the Molycorp site having superior performance included *Muhlenbergia montana* (2 ecotypes), *Blepharoneuron tricholepis*, *Festuca* species (3 ecotypes), and a *Poa* species. A number of commercially available grass varieties had good survival and growth in these substrates: *Deschampsia caespitosa* 'Peru Creek', *Festuca arizonica* 'Redondo', *Festuca ovina* 'Covar', *Festuca ovina* 'MX-86', *Festuca* sp. 'Shorty', *Poa compressa* 'Reubens', *Pascopyrum smithii* 'Arriba, Barton, and Rosana', and *Elymus trachycaulus* 'San Luis'. Other native grass species that showed superior survival and growth in these acid rock substrates included *Elymus canadensis*, *Danthonia intermedia*, *Sporobolus wrightii*, *Poa nemoralis*, and *Hesperostipa comata*.

Additional Key Words: acidity, acid rock, EC, salinity, soluble salts.

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Introduction

The Molycorp open pit molybdenum mine near Questa, NM was in operation from 1965 to 1983 and required the removal of over 300 million tons of overburden. The overburden piles are situated at elevations from 2,400 to 3,000 m with surrounding vegetation of ponderosa pine, mixed conifer, and mountain shrub communities. Southerly aspects and steep slopes are the predominant natural site

features and overburden pile characteristics. The overburden piles consist of mixed volcanic rocks (rhyolitic and andesitic types referred to as acid rock) as well as black andesite and aplite intrusives (referred to as neutral rock). The mixed volcanic rocks are highly fractured and weathered with low pH and high salinity from pyrite oxidation (Steffen Robertson and Kirsten Inc. 1995). The mixing of rock types during overburden pile construction has resulted in heterogeneous substrates with a range of pH and soluble salt levels.

Objectives

The difficulties in establishing vegetation in low pH overburden compelled efforts to determine species with greater likelihood to survive and grow in these substrates. The objective of this study was to examine the suitability of various grasses for direct establishment in the range of overburden types at the Molycorp waste rock piles. The overburden materials with the highest salt levels may preclude plant growth until natural amelioration (i.e., leaching of salts) or substrate manipulation reduce the constraining constituents. It may be desirable to use amendments (e.g. neutral overburden) that ameliorate these severe chemical conditions to speed revegetation; a prerequisite will be to determine the appropriate incorporation rates for these amendments. This study provides some insight into the overburden pH and salt levels that allow adequate grass survival and growth.

Methods and Materials

The screening of grass species for growth and survival was conducted at the New Mexico State University's Mora Research Center, Mora, NM. The substrate treatments used in this experiment consisted of an unadulterated acid rock (LPH – low pH, low soluble salts), an acid:neutral overburden mixture ratio of 9:1 (HSS – high soluble salts, intermediate pH), and an acid:neutral overburden mixture ratio of 3:1 (LSS – low soluble salts, high pH). The acid rock was excavated from mixed volcanic rock on the second terrace of the Sulphur Gulch pile, while the neutral rock was dug from aplite and black andesite rock on the first terrace of the Sulphur Gulch pile. The 2 overburden types were crushed and screened to less than 13 mm and then mixed in the ratios described above and transported to the Mora Research Center in July 1995. Three replicate treatment blocks of each substrate were constructed in polyethylene nursery tubs with drain holes (capacity 750 liters, diameter 1.47 m, and depth 0.46 m). Each tub was filled with approximately 600 liters of substrate (an approximate depth of 0.4 m). The nine tubs were placed in a random arrangement in an outdoor facility used for testing plant tolerance to environmental stresses and were installed in the ground to a depth of about 0.4 m. The LPH substrate was placed into 3 tubs in August 1995 in anticipation of an experiment that was not conducted. The other substrates (HSS and LSS) were put into the other 6 tubs during August 1997, several weeks before planting. At the termination of the experiment (i.e., 2 months after harvesting and evaluation), 3 overburden samples were taken from each tub and analyzed for pH and electroconductivity (EC) as described in the Soil Quality Test Kit Guide manual (USDA 1998). The mean pH and mean EC both before planting and after harvesting are presented in **Table 1**. The leaching of the pure acid rock substrate (LPH) for an additional 2 years before planting resulted in the reduced EC in this substrate relative to the HSS substrate. Linear interpolation of the EC values for the LPH substrate yields an estimated EC of 2.6 dS/m at the time of planting.

Table 1 Mean pH and EC of substrate materials before (at the time of substrate placement) and after (2 months after biomass harvest) weathering and the period between these events.

Substrate	pH Before	pH After	EC Before (dS/m)	EC After (dS/m)	Weathering Period (months)
LPH (Low pH)	2.7	2.8	3.6	2.0	40
HSS (High Salinity)	3.3	3.4	3.2	2.2	15
LSS (Low Salinity)	3.7	3.9	2.1	2.0	15

The grass transplants were grown from commercially available seed, seed from evaluations at the Los Lunas Plant Materials Center, and seed collected from the vicinity of the Molycorp Mine. The tested species listed in (**Table 2 on Page 15)** consisted of primarily native cool season grass of the western U.S. with emphasis on the Rocky Mountains. The currently accepted taxonomy based on the Integrated Taxonomic Information Service (ITIS 2000) as well as traditional scientific name, vernacular name, seed source information, and grass tribe (as grouped by Allred 1993) are presented in **Table 2**. Several entries have origins outside North America (FEOV-C, POAL-G, POCO-R, and PHPR). FETR-S was bought commercially but was not labeled as to species and may not be a true variety or readily available.

Seeds of the 54 entries were sown in plug trays filled with a peat moss/perlite media. After plug root balls were well developed, the seedlings were transplanted during August 1996 into Ray Leach Super Cells (300 ml) containing the same media. The transplants were over-wintered outdoors; the following spring and summer, periodic clipping was required to allow uniform watering. The transplants were installed in the treatment blocks (i.e., tubs) during September 1997 using dibbles the same size and shape as the root balls. The entries were grouped by genera or grass tribe; each group was assigned an area with the same relative position in each tub. Within each group, the entries were placed in a different random arrangement in each tub. For 47 of 54 grass entries, 4 plants of each entry were placed in a row plot within the appropriate group area with about 4 cm spacing between each plant. The other 7 grass entries were represented by 1 to 3 plants per row plot. After planting and during dry periods, the grasses were watered by hand. Several times during the growing season of 1998, the plots were watered with a soluble fertilizer solutions containing 100 mg N/l from 20-10-20 Peters Peat Lite Special.

In September 1998, the grasses were harvested. The number of live plants and the number of plants with seedheads in each row plot were recorded. All live plants were harvested from each row plot as a group and placed in a paper bag for air drying and weighing. Thus, the total dry weights represent from 1 to 4 plants. The biomass per live plant was determined by dividing the total dry weight of the plot by the number of live plants in the plot. Analyses of variance was performed on biomass per live plant for each species/ecotype using SAS GLM to determine the effect of substrate (SAS Institute 1989). The data was analyzed as a complete randomized design with substrates representing treatments and replicate tubs within treatments representing error terms. The least significant difference (LSD) pair-wise comparison technique was used to determine significant differences between biomass means for entries with F-test probabilities less than 0.05. The survival data was analyzed using a categorical analysis of variance (CATMOD) procedure on the dichotomous response variable (live vs. dead) for each entry (SAS Institute 1990). The analysis of variance test statistic was an asymptotic chi-square test. Asymptotic pair-wise Z statistics (analogous to LSD) were used to determine significant differences between survival means for entries with chi-square test probabilities less than 0.05

Results and Discussions

Biomass Production in Overburden Treatments

The grand mean biomass for all species (see **Table 3**) was 0.54 g in the high salinity substrate (HSS) compared with 0.62 g in the low pH substrate (LPH) and 1.17 g in the low salinity substrate (LSS). Of the 18 entries with the greatest overall mean biomass (greater than 1.0 g/plant), 7 entries originated from Molycorp seed sources and included 4 genera (*Festuca, Poa, Blepharoneuron,* and *Muhlenbergia*). Eight commercially available species (DECA-PC, ELTR-SL, PASM-A, PASM-B, FEAR-R, FEOV-MX, PHPR, and POCO-R) along with SPWR, FETR-S, and PONE are the other 11 entries with the greatest biomass production per plant . Of the 18 best overall biomass producers, two grasses (FEMOLY-C and POMOLY) had biomass production greater than 1.7 g/plant in the high salinity substrate (HSS) while 14 of the other 16 entries (excluding ELTR-SL and FEAR-R) had biomass production between 0.7 and 1.4 g/plant in the HSS substrate. One grass (HECO), which did not have superior overall biomass production, was in this later biomass class (0.7 to 1.4 g/plant) in the HSS substrate. For the 12 entries with mean biomass greater than 1.0 g/plant in the low pH substrate (LPH), 9 were among the best overall biomass producers, but 3 entries were not (ACHY-N, CAREX, AGSC). In the LSS substrate, 5 of the best overall performers had biomass yields of less than 1.4 g/plant (DECA-PC, PHPR, SPWR, MUMO-AUB, and MUMO-GHS) while 4 of the intermediate overall performers had biomass yields greater than 1.4 g/plant (PASM-R, FEOV-C, FETH, and FETR-D).

Table 3 Analysis of variance and means tests of biomass (total dry weight in plot/number of live plants in plot) for native grasses grown in 3 low pH overburden treatments.

Abbrev. Sci. Name	Substrate: Low pH Mean ± SE Biomass (g/plant)	High Salinity Mean ± SE Biomass (g/plant)	Low Salinity Mean ± SE Biomass (g/plant)	Overall Mean Biomass (g/plant)	ANOVA Prob. of F-test	ANOVA SS model/ SS total (r^2)
ACHY-N	1.21 ± 0.48	0.28 ± 0.40	0.87 ± 0.22	0.78	0.121	0.51
ACLE	0.30 ± 0.27	0.11 ± 0.16	0.22 ± 0.02	0.21	0.604	0.16
ACMOLY	0.08 ± 0.12 b*	0.13 ± 0.19 b	0.78 ± 0.29 a	0.33	0.031	0.69
ACRO	0.67 ± 0.27 a	0.00 ± 0.00 b	0.80 ± 0.04 a	0.49	0.005	0.83
AGSC	1.20 ± 0.75	0.11 ± 0.15	0.29 ± 0.21	0.53	0.110	0.52
BLTR	1.45 ± 0.69	1.26 ± 0.97	1.69 ± 0.53	1.46	0.847	0.05
BRCI	0.10 ± 0.07	0.47 ± 0.29	0.54 ± 0.22	0.37	0.157	0.46
BRMA	0.04 ± 0.05	0.00 ± 0.00	0.13 ± 0.18	0.05	0.519	0.20
BRMOLY	0.06 ± 0.08 b	0.40 ± 0.15 a	0.66 ± 0.08 a	0.38	0.004	0.84
CAREX	1.02 ± 0.30	0.53 ± 0.09	0.67 ± 0.22	0.75	0.152	0.47
DAIN	0.80 ± 0.10 a	0.48 ± 0.16 b	0.87 ± 0.11 a	0.72	0.043	0.65
DECA-PC	1.17 ± 0.20	1.09 ± 0.62	0.77 ± 0.15	1.01	0.569	0.17
ELCA	0.72 ± 0.24 ab	0.35 ± 0.26 b	1.23 ± 0.32 a	0.77	0.049	0.63
ELEL-AZ	0.44 ± 0.31	0.12 ± 0.17	0.79 ± 0.21	0.45	0.076	0.58

* **Different lowercase letters indicate significant difference among means within entry.**

Table 3 Analysis of variance and means tests of biomass (total dry weight in plot/number of live plants in plot) for native grasses grown in 3 low pH overburden treatments.

	Substrate					
Abbrev. Sci. Name	Low pH Mean ± SE Biomass (g/plant)	High Salinity Mean ± SE Biomass (g/plant)	Low Salinity Mean ± SE Biomass (g/plant)	Overall Mean Biomass (g/plant)	ANOVA Prob. of F-test	ANOVA SS model/ SS total (r^2)
ELEL-PMC	0.50 ± 0.30	0.32 ± 0.24	1.27 ± 0.42	0.69	0.058	0.61
ELGL	0.12 ± 0.09	0.00 ± 0.00	0.35 ± 0.35	0.16	0.315	0.32
ELLA-C	0.37 ± 0.07 ab	0.09 ± 0.08 b	0.50 ± 0.18 a	0.32	0.033	0.68
ELLA-S	0.37 ± 0.18	0.27 ± 0.06	0.39 ± 0.04	0.34	0.544	0.18
ELTR-P	0.54 ± 0.29	0.27 ± 0.38	1.26 ± 0.39	0.69	0.073	0.58
ELTR-R	0.33 ± 0.30	0.08 ± 0.11	0.72 ± 0.21	0.38	0.067	0.60
ELTR-SL	1.21 ± 0.72	0.31 ± 0.23	1.73 ± 0.69	1.08	0.130	0.49
ELVI	0.65 ± 0.58	0.32 ± 0.26	0.80 ± 0.30	0.59	0.531	0.19
FEAR-R	0.77 ± 0.40 b	0.41 ± 0.15 b	1.96 ± 0.68 a	1.05	0.036	0.67
FEID-J	0.22 ± 0.20	0.38 ± 0.49	0.82 ± 0.25	0.47	0.259	0.36
FEMOLY-C	0.67 ± 0.27 b	3.04 ± 1.15 a	1.78 ± 0.38 ab	1.83	0.043	0.65
FEMOLY-SGS	1.12 ± 0.44 b	1.13 ± 0.64 b	3.09 ± 0.47 a	1.78	0.015	0.76
FEMOLY-SGT	0.59 ± 0.09 b	1.35 ± 0.68 b	3.45 ± 1.28 a	1.80	0.033	0.68
FEOV-C	0.61 ± 0.38	0.43 ± 0.49	1.45 ± 0.54	0.83	0.151	0.47
FEOV-MX	0.58 ± 0.18	1.11 ± 0.92	2.48 ± 0.85	1.39	0.094	0.55
FESA	0.15 ± 0.07 b*	0.19 ± 0.05 b	0.97 ± 0.24 a	0.44	0.002	0.87
FETH	0.35 ± 0.33 b	0.25 ± 0.26 b	1.59 ± 0.54 a	0.73	0.026	0.70
FETR-D	0.67 ± 0.35 b	0.13 ± 0.13 b	1.41 ± 0.22 a	0.81	0.020	0.79
FETR-S	0.92 ± 0.30 b	0.75 ± 0.35 b	2.17 ± 0.57 a	1.28	0.028	0.70
HECO	0.61 ± 0.04	0.91 ± 0.43	0.85 ± 0.14	0.79	0.513	0.20
HENE	0.31 ± 0.22 ab	0.00 ± 0.00 b	0.62 ± 0.24 a	0.31	0.046	0.64
KOMA	0.45 ± 0.22	0.19 ± 0.07	0.44 ± 0.12	0.36	0.223	0.39
LECI-M	0.23 ± 0.15	0.11 ± 0.08	0.32 ± 0.14	0.22	0.316	0.32
LECI-T	0.26 ± 0.10	0.27 ± 0.08	0.42 ± 0.02	0.32	0.105	0.53
LETR-SH	0.12 ± 0.02 b	0.08 ± 0.06 b	0.46 ± 0.19 a	0.22	0.035	0.67
MUMO-AUB	1.35 ± 0.41	0.97 ± 0.28	1.23 ± 0.23	1.18	0.516	0.20
MUMO-GHS	1.38 ± 0.01	0.72 ± 0.24	1.30 ± 0.75	1.11	0.449	0.27
NAVI	0.69 ± 0.32 a	0.00 ± 0.00 b	0.53 ± 0.14 a	0.41	0.035	0.67
PASM-A	0.68 ± 0.36 b	1.30 ± 0.17 b	2.35 ± 0.35 a	1.45	0.004	0.83
PASM-B	1.09 ± 0.26	0.80 ± 0.85	2.21 ± 0.49	1.37	0.111	0.52
PASM-R	0.87 ± 0.29	0.49 ± 0.27	1.53 ± 0.41	0.96	0.052	0.63

Table 3 Analysis of variance and means tests of biomass (total dry weight in plot/number of live plants in plot) for native grasses grown in 3 low pH overburden treatments.

	Substrate							
	Low pH		High Salinity		Low Salinity		Overall	ANOVA	ANOVA
Abbrev. Sci. Name	Low pH Mean ± SE Biomass (g/plant)		High Salinity Mean ± SE Biomass (g/plant)		Low Salinity Mean ± SE Biomass (g/plant)		Overall Mean Biomass (g/plant)	ANOVA Prob. of F-test	ANOVA SS model/ SS total (r^2)
PHPR	1.08 ± 0.71		1.18 ± 1.03		1.02 ± 0.37		1.10	0.984	0.01
POAL	0.04 ± 0.06		0.19 ± 0.16		0.20 ± 0.10		0.14	0.363	0.29
POCO-R	0.25 ± 0.35	b	1.27 ± 0.57	ab	2.09 ± 0.41	a	1.21	0.019	0.73
POMOLY	0.82 ± 0.99		1.74 ± 0.52		2.70 ± 0.95		1.75	0.163	0.45
PONE	0.25 ± 0.21	b	1.12 ± 0.19	ab	2.05 ± 0.61	a	1.14	0.011	0.78
PSSP-S	0.69 ± 0.22		0.34 ± 0.38		1.01 ± 0.34		0.68	0.188	0.43
PSSP-W	0.11 ± 0.16		0.00 ± 0.00		1.19 ± 0.95		0.44	0.140	0.48
SCSC	0.26 ± 0.30		0.00 ± 0.00		0.75 ± 0.85		0.34	0.514	0.23
SPWR	2.14 ± 1.17		1.29 ± 0.35		1.24 ± 0.25		1.56	0.422	0.25
Grand Mean	0.62 ± 0.30		0.54 ± 0.30		1.17 ± 0.36		0.78	0.203	0.50

*** Different lowercase letters indicate significant difference among means within entry.**

Analyses of variance of biomass production (see **Table 3**) showed significant substrate effects (P<0.05) for 20 entries. Means testing showed the low salinity substrate (LSS) had significantly greater biomass (P<0.05) than the other substrates for 7 Festuca entries (FESA, FETR-D, FEMOLY-SGS, FETH, FETR-S, FEMOLY-SGT, and FEAR-R) and PASM-A, LETR-SH, and ACMOLY. Three species had greater mean biomass in the LPH and the LSS substrates than in the high salinity substrate (HSS): ACRO, NAVI, and DAIN. The low salinity substrate (LSS) had greater biomass than the low pH substrate (LPH) for 2 members of Poeae tribe: PONE and POCO-R. The only entries that had significantly greater biomass in the high salinity substrate (HSS) than in the LPH substrate were FEMOLY-C and BRMOLY. Two members of Triticeae tribe (ELLA-C and ELCA) and HENE had greater biomass in the LSS substrate than in the high salinity substrate (HSS). Among the better performing species, several Eragostideae tribe members (BLTR, MUMO-AUB, MUMO-GHS, and SPWR) and Aveneae tribe members (DECA-PC and PHPR) showed no significant difference (P>0.4) among substrate treatments:

Survival Percentages in Overburden Treatments

Five of the 14 entries with at least 85% overall survival were Molycorp seed sources from the *Festuca* (FEMOLY-SGT, FEMOLY-SGS, FEMOLY-C) and *Muhlenbergia* (MUMO-AUB, MUMO-GHS) genera (see **Table 3**). Four commonly available varieties are also included in this survival class: FEAR-R, ELLA-S, LECI-T, and FEOV-MX. This survival class also included DAIN, DECA-PC, PONE, SPWR, and FETR-S.

The differences in the grand mean survival percentages for the 3 substrates indicate that salinity level was better correlated with survival than substrate acidity level. The high salinity substrate (HSS) had the lowest survival when all species were averaged, 47% (see **Table 4**). For the 17 entries with at least 75% survival in the HSS treatment, 8 entries were Molycorp seed sources representing 5 genera (*Festuca, Muhlenbergia, Poa, Blepharoneuron, and Bromus*). Four commercially available species are also included in this survival class: FEAR-R, POCO-R, ELLA-S, and LECI-T. The other species in this survival class are DAIN, PONE, SPWR, FETR-S and DECA-PC. The results for the low salinity substrate (LSS) show 43 entries with greater than 90% survival.

The two species with multiple commercial varieties had small differences in overall survival percentages indicating little varietal influence on survival in these low pH overburden materials. These two species and their varieties were *Pascopyrum smithii* ('Barton' 81%, 'Rosana' 81%, and 'Arriba' 78%) and *Elymus trachycaulus* ('San Luis' 75%, 'Pryor' 67%, and 'Revenue' 61%).

Approximately one-half (26 out of the 54) entries had significant survival differences ($P<0.05$) among substrates (**Table 4**). The group of species having greater survival in both the low pH (LPH) and low salinity (LSS) substrates than in the high salinity substrate (HSS) included: 9 Triticeae members (ELTR-SL, ELTR-P, LETR-SH, LECI-M, PSSP-S, PASM-A, PASM-B, PASM-R, and ELCA); 3 members of the Stipeae (ACHY-N, ACRO, and HECO); as well as FETR-D, FEID-J, and PHPR. The *Bromus* ecotype from Molycorp, BRMOLY, and POCO-R were the only entries with significantly greater mean survival in both the high salinity (HSS) and low salinity (LSS) substrates than in the LPH treatment. Five Stipeae entries (HENE, ACLE, NAVI, ACMOLY and ACHY-N), 4 Triticeae entries (PSSP-W, ELEL-AZ, ELEL-PMC, and ELTR-R) and POAL had survival means in the order of LPH>LSS>or =HSS. Among the species with overall high survival (>80%), a number of entries showed no significant treatment effects ($P>0.2$) including 6 Poeae entries (FEAR-R, FEMOLY-SGT, FEMOLY-C, FEMOLY-SGS, FETR-S, and PONE), 4 Eragrostideae members (MUMO-GHS, MUMO-AUB, BLTR, and SPWR) as well as ELLA-S, DECA-PC, and DAIN.

Table 4 Analysis of variance and means tests of survival percentages of native grasses grown in 3 low pH overburden treatments.

Abbrev. Sci. Name	Substrate: Low pH Mean ± SE Survival (%)				High Salinity Mean ± SE Survival (%)				Low Salinity Mean ± SE Survival (%)				Overall Mean Survival (%)	ANOVA Prob. of Chi Square
ACHY-N	83	±	11[*]	a[**]	25	±	13	b	100	±	0	a	69	0.004
ACLE	45	±	15	b	9	±	9	c	100	±	0	a	51	0.009
ACMOLY	25	±	13	b	8	±	8	b	92	±	8	a	42	0.003
ACRO	100	±	0	a	0	±	0	b	100	±	0	a	67	0.006
AGSC	67	±	19		13	±	12		60	±	22		47	0.127
BLTR	92	±	8		83	±	11		73	±	13		83	0.511
BRCI	45	±	15		58	±	14		67	±	14		57	0.592
BRMA	10	±	9		0	±	0		22	±	14		11	0.526
BRMOLY	25	±	13	b	83	±	11	a	100	±	0	a	69	0.004
CAREX	83	±	11		67	±	14		92	±	8		81	0.326
DAIN	100	±	0		100	±	0		92	±	8		97	0.867
DECA-PC	92	±	8		75	±	13		100	±	0		89	0.315
ELCA	100	±	0	a	33	±	14	b	100	±	0	a	78	0.005
ELEL-AZ	50	±	14	b	25	±	13	b	83	±	11	a	53	0.030
ELEL-PMC	75	±	13	b	25	±	13	c	100	±	0	a	67	0.007

[*] **SE = square root (((% survival) x (% mortality)/sample count)**

[**] **Different lowercase letters indicate significant difference among means within entry.**

Table 4 Analysis of variance and means tests of survival percentages of native grasses grown in 3 low pH overburden treatments.

	Substrate													
	Low pH				High Salinity				Low Salinity				Overall	ANOVA
	Mean ± SE				Mean ± SE				Mean ± SE				Mean	Prob.
Abbrev.	Survival				Survival				Survival				Survival	of
Sci. Name	(%)				(%)				(%)				(%)	Chi Square
ELGL	42	±	14		0	±	0		25	±	13		22	0.173
ELLA-C	92	±	8		58	±	14		100	±	0		83	0.070
ELLA-S	100	±	0		92	±	8		100	±	0		97	0.867
ELTR-P	83	±	11	a	17	±	11	b	100	±	0	a	67	0.002
ELTR-R	67	±	14	b	17	±	11	c	100	±	0	a	61	0.006
ELTR-SL	100	±	0	a	25	±	13	b	100	±	0	a	75	0.002
ELVI	42	±	14		17	±	11		67	±	14		42	0.065
FEAR-R	100	±	0		100	±	0		100	±	0		100	na
FEID-J	92	±	8	a	50	±	14	b	100	±	0	a	81	0.031
FEMOLY-C	83	±	11		75	±	13		100	±	0		86	0.421
FEMOLY-SGS	100	±	0		92	±	8		100	±	0		97	0.867
FEMOLY-SGT	100	±	0		100	±	0		100	±	0		100	na
FEOV-C	92	±	8		58	±	14		100	±	0		83	0.070
FEOV-MX	100	±	0		58	±	14*		100	±	0		86	0.054
FESA	50	±	14		50	±	14		67	±	14		56	0.642
FETH	33	±	19		33	±	19		100	±	0		56	0.137
FETR-D	100	±	0	a**	13	±	12	b	100	±	0	a	71	0.003
FETR-S	100	±	0		75	±	13		100	±	0		92	0.233
HECO	100	±	0	a	50	±	14	b	100	±	0	a	83	0.025
HENE	38	±	17	b	0	±	0	c	100	±	0	a	46	0.023
KOMA	83	±	11		58	±	14		100	±	0		81	0.124
LECI-M	92	±	8	a	50	±	14	b	100	±	0	a	81	0.031
LECI-T	92	±	8		75	±	13		100	±	0		89	0.142
LETR-SH	92	±	8	a	42	±	14	b	100	±	0	a	78	0.013
MUMO-AUB	100	±	0		75	±	13		100	±	0		92	0.233
MUMO-GHS	100	±	0		92	±	8		100	±	0		97	0.907
NAVI	67	±	14	b	0	±	0	c	100	±	0	a	56	0.007
PASM-A	92	±	8	a	42	±	14	b	100	±	0	a	78	0.013
PASM-B	100	±	0	a	42	±	14	b	100	±	0	a	81	0.012
PASM-R	100	±	0	a	42	±	14	b	100	±	0	a	81	0.012
PHPR	92	±	8	a	33	±	14	b	75	±	15	a	67	0.023
POAL	17	±	11	b	17	±	11	b	92	±	8	a	42	0.003
POCO-R	33	±	14	b	100	±	0	a	100	±	0	a	78	0.005

Table 4 Analysis of variance and means tests of survival percentages of native grasses grown in 3 low pH overburden treatments.

Abbrev. Sci. Name	Substrate: Low pH Mean ± SE Survival (%)		High Salinity Mean ± SE Survival (%)		Low Salinity Mean ± SE Survival (%)		Overall Mean Survival (%)	ANOVA Prob. of Chi Square
POMOLY	58 ± 14		75 ± 13		100 ± 0		78	0.173
PONE	83 ± 11		100 ± 0		100 ± 0		94	0.473
PSSP-S	100 ± 0	a	33 ± 14	b	100 ± 0	a	78	0.005
PSSP-W	10 ± 9	b	0 ± 0	b	55 ± 15	a	22	0.036
SCSC	50 ± 18		0 ± 0		33 ± 19		28	0.307
SPWR	83 ± 11		100 ± 0		100 ± 0		94	0.473
Grand Mean	75 ± 8		47 ± 10		91 ± 4		71	0.193

*** SE = square root(((% survival) x (% mortality))/sample count)**
**** Different lowercase letters indicate significant difference among means within entry.**

Best Performing Species

A comparison of the top 10 performers in overall survival and in overall biomass production yields 4 entries in common: FEMOLY-SGT, FEMOLY-SGS, SPWR, and FETR-S. In the low pH substrate (LPH) the following species had superior survival (100%) and biomass production (>1.0 g/plant): MUMO-GHS, MUMO-AUB, ELTR-SL, FEMOLY-SGS, and PASM-B. In the high salinity substrate (HSS) the following species had superior survival (>80%) and biomass production (>1.0 g/plant): FEMOLY-SGT, PONE, SPWR, POCO-R, FEMOLY-SGS, and BLTR. In the LSS substrate, the following entries had superior survival (100%) and biomass production (>2.0 g/plant): FEMOLY-SGT, FEMOLY-SGS, POMOLY, FEOV-MX, PASM-A, PASM-B, FETR-S, POCO-R, and PONE.

Percentage of Plants With Seedheads

The overall mean percentage of plants with seedheads was greater than 40% for a number of entries with superior survival and biomass production: POCO-R, POMOLY, BLTR, FEMOLY-C, MUMO-GHS, MUMO-AUB, and PASM-B. Four species had high percentages of seedheads (>80%) in the low pH substrate (LPH): FESA, HECO, ELTR-SL, and ACHY-N. Three Poeae entries had high seedhead percentages (>90%) in the high salinity substrate (HSS): BRMOLY, POCO-R, and POMOLY.

Summary Evaluation of Grass Tribes, Genera, Species, and Ecotypes

The overall biomass production and overall survival of grass species is presented in **Table 5** along with an overall rating (biomass multiplied by survival) and an overall combined rank (overall biomass rank plus overall survival rank divided by 2). In addition, **Table 5** shows the survival and biomass ranks in the 2 treatments with most extreme chemistry: the low pH substrate (LPH) and the high salinity substrate (HSS).

Table 5 Overall performance and ranking of grass species grown in the low pH substrate and high soluble salts substrate, grouped by grass tribe.

Grass Tribe	Abbrev. Sci. Name	Overall Mean Biomass (g)	Overall Mean Survival (%)	Overall Mean Rating [*]	Overall Average Combined Rank [**]	Substrate: Low pH Biomass Rank	Low pH Survival Rank	High Soluble Salts Biomass Rank	High Soluble Salts Survival Rank
Andropogoneae	SCSC	0.34	28	0.13	45	41	40	48	48
Aveneae	AGSC	0.49	47	0.27	39	6	35	44	45
Aveneae	DECA-PC	1.01	89	0.90	14	7	18	12	12
Aveneae	KOMA	0.36	81	0.29	31	32	28	38	19
Aveneae	PHPR	1.10	67	0.72	26	10	18	8	32
Danthonieae	DAIN	0.72	97	0.70	15	16	1	20	1
Eragrostideae	BLTR	1.46	83	1.22	11	2	18	7	10
Eragrostideae	MUMO-AUB	1.18	92	1.08	11	3	1	13	12
Eragrostideae	MUMO-GHS	1.11	97	0.95	12	12	1	17	7
Eragrostideae	SPWR	1.56	94	1.47	6	1	28	5	1
na	CAREX	0.75	81	0.60	22	11	28	18	18
Poeae	BRCI	0.37	57	0.21	41	50	44	21	19
Poeae	BRMA	0.05	11	0.01	54	54	53	48	48
Poeae	BRMOLY	0.38	69	0.26	37	52	50	24	10
Poeae	FEAR-R	1.05	100	1.04	9	17	1	23	1
Poeae	FEID-J	0.47	81	0.38	27	45	18	25	24
Poeae	FEMOLY-C	1.83	86	1.58	7	24	28	1	12
Poeae	FEMOLY-SGS	1.78	97	1.73	3	8	1	9	7
Poeae	FEMOLY-SGT	1.80	100	1.80	2	28	1	3	1
Poeae	FEOV-C	0.83	83	0.69	18	26	18	22	19
Poeae	FEOV-MX	1.39	86	1.20	11	29	1	11	19
Poeae	FESA	0.44	56	0.24	39	46	41	37	24
Poeae	FETH	0.73	56	0.41	34	36	48	35	32
Poeae	FETR-D	0.81	71	0.64	23	22	1	46	45
Poeae	FETR-S	1.28	92	1.17	10	13	1	16	12
Poeae	POAL	0.14	42	0.06	51	53	52	36	40
Poeae	POCO-R	1.21	78	0.94	19	42	48	6	1
Poeae	POMOLY	1.75	78	1.36	15	15	39	2	12

[*] **Overall Mean Rating = Overall Biomass (g) x Overall survival (%/100)**

[**] **Overall Average Combined Rank = (Rank of Overall Biomass + Rank of Overall Survival)/**

Table 5 Overall performance and ranking of grass species grown in the low pH substrate and high soluble salts substrate, grouped by grass tribe.

Grass Tribe	Abbrev. Sci. Name	Overall Mean Biomass (g)	Overall Mean Survival (%)	Overall Mean Rating *	Overall Average Combined Rank **	Substrate: Low pH Biomass Rank	Low pH Survival Rank	High Soluble Salts Biomass Rank	High Soluble Salts Survival Rank
Poeae	PONE	1.14	94	1.08	10	43	28	10	1
Stipeae	ACHY-N	0.78	69	0.54	28	5	28	31	36
Stipeae	ACLE	0.21	51	0.11	48	39	44	42	44
Stipeae	ACMOLY	0.33	42	0.14	47	51	50	39	45
Stipeae	ACRO	0.49	67	0.33	34	23	1	48	48
Stipeae	HECO	0.79	83	0.66	19	27	1	14	24
Stipeae	HENE	0.31	46	0.15	48	38	41	48	48
Stipeae	NAVI	0.41	56	0.23	40	19	37	48	48
Triticeae	ELCA	0.77	78	0.60	25	18	1	26	32
Triticeae	ELEL-AZ	0.45	53	0.24	40	33	41	40	36
Triticeae	ELEL-PMC	0.69	67	0.46	32	31	36	29	36
Triticeae	ELGL	0.16	22	0.03	53	47	46	48	48
Triticeae	ELLA-C	0.32	83	0.27	31	34	18	41	19
Triticeae	ELLA-S	0.34	97	0.33	24	35	1	32	7
Triticeae	ELTR-P	0.69	67	0.46	32	30	28	33	40
Triticeae	ELTR-R	0.38	61	0.23	40	37	37	47	40
Triticeae	ELTR-SL	1.08	75	0.81	24	4	1	30	36
Triticeae	ELVI	0.59	42	0.24	40	25	46	28	40
Triticeae	LECI-M	0.22	81	0.17	35	44	18	43	24
Triticeae	LECI-T	0.32	89	0.28	29	40	18	34	12
Triticeae	LETR-SH	0.22	78	0.17	38	48	18	45	28
Triticeae	PASM-A	1.45	78	1.12	17	21	18	4	28
Triticeae	PASM-B	1.37	81	1.10	14	9	1	15	31
Triticeae	PASM-R	0.96	81	0.78	19	14	1	19	28
Triticeae	PSSP-S	0.68	78	0.53	28	20	1	27	32
Triticeae	PSSP-W	0.44	22	0.10	44	49	53	48	48

*** Overall Mean Rating = Overall Biomass (g) x Overall Survival (%/100)**
**** Overall Average Combined Rank = (Rank of Overall Biomass + Rank of Overall Survival)/2**

The one representative of the Andropogoneae tribe in the experiment, SCSC, was a Molycorp seed source and exhibited overall poor performance. Although this species was collected from a native stand on weathered acid rock (pH = 4.3), the root zone soils had low salinity (EC = 0.1 dS/m). The much higher salinity of the 3 substrates in the experiment is probably one of the main factors in the poor performance of this species.

The experiment tested 4 species in the Aveneae tribe and each species showed at least one good performance ranking in one of the two extreme substrates. Tufted hairgrass, DECA-PC, had a good overall ranking along with an excellent biomass ranking in the low pH (LPH) substrate and good rankings in the other 3 categories. Timothy, PHPR, had good to excellent rankings for biomass production in both substrates and good survival in the low pH (LPH) substrate. Rough bentgrass, AGSC, showed a superior ranking only for biomass in the low pH (LPH) substrate.

The single member of the Danthonieae tribe, DAIN, had good overall ranking with excellent survival in the two extreme treatments. The CAREX species (in the Cyperaceae family) had a fair overall ranking and fair to good rankings in the extreme substrates.

The 4 entries representing the Eragostideae tribe had very good overall rankings with good to excellent survival and biomass rankings in both extreme substrates. Three of these entries were Molycorp seed sources: BLTR, MUMO-GHS, and MUMO-AUB. Giant sacaton, SPWR, was one of the best performers in the high salinity (HSS) substrate, while MUMO-AUB was one of best performers in the low pH substrate (LPH).

The Poeae tribe was represented by 18 entries with overall performance ranging from excellent to very poor. Of the 20 entries with the best overall performance, 10 belonged to the Poeae tribe. Of these 10 Poeae entries, 4 were Molycorp seed sources (FEMOLY-C, FEMOLY-SGS, FEMOLY-SGT, and POMOLY) and 6 were commercial sources (FEAR-R, FEOV-C, FEOV-MX, FETR-S, POCO-R, and PONE). Among the *Bromus* species, BRCI and BRMOLY exhibited fair to good biomass and survival rankings in the high salinity substrate (HSS), but very poor performance in the low pH substrate (LPH). Mountain brome, BRMA, had the worst ranking of all species tested. The *Festuca* entries with good to excellent survival and biomass rankings in the low pH substrate (LPH) included FEAR-R, FEMOLY-SGS, and FETR-S. In the high salinity substrate (HSS), 5 entries exhibited good to excellent survival and biomass rankings: FEOV-MX, FEMOLY-C, FEMOLY-SGS, FEMOLY-SGT, and FETR-S. Three Poa entries (POCO-R, POMOLY, and PONE) had very good to excellent rankings in the high salinity substrate (HSS), but mainly poor rankings in the low pH substrate (LPH). Alpine bluegrass, POAL, was the third poorest in overall average combined rank.

The Stipeae tribe entries had generally poor rankings except for ACHY-N and HECO. ACHY-N had an excellent biomass ranking in the low pH substrate (LPH), while HECO had an excellent survival ranking in the low pH (LPH) substrate and a good biomass ranking in the high salinity substrate (HSS). The Molycorp seed source Stipeae, ACMOLY, had very poor performance overall and in the 2 extreme substrates. This species was a superior performer on neutral low salinity overburden in other studies at the mine site indicating an intolerance to acid and saline conditions. ACRO had an excellent survival ranking in the low pH (LPH) substrate but a very poor survival ranking in the high salinity substrate (HSS).

The only overall good performers among the Triticeae tribe were the 3 *Pascopyrum smithii* varieties. ‘Arriba’ had a substantially better biomass ranking in the high salinity substrate (HSS); whereas ‘Rosana’ and ‘Barton’ had higher biomass and survival rankings in the low pH substrate (LPH). Several other species had high survival rankings in the LPH substrate (ELLA-S, ELTR-SL, and ELCA), but only ELTR-SL had an excellent biomass ranking in this substrate. In general, none of Triticeae except the *Pascopyrum smithii* varieties had good biomass rankings in the HSS substrate, although ELLA-C, ELLA-S, and LECI-T had good or better survival rankings in this substrate.

Conclusions

The differences in grass species performance among the substrates would lead to different species recommendations depending on the type of substrate to be revegetated. The chemical constraints (pH, EC, or both) and their variability in the overburden area to be revegetated are crucial factors that would affect species recommendations.

Species recommendations can be based on the overall performance in all 3 substrates for a highly variable overburden site with chemical characteristics spanning the range found in this experiment. The entries among the top one-third in the overall average combined rank or in the overall rating (see **Table 5**) can be classified into 3 groups:

1. Molycorp seed sources – BLTR, MUMO-GHS, MUMO-AUB, FEMOLY-C, FEMOLY-SGS, FEMOLY-SGT, and POMOLY.
2. Commonly available varieties – DECA-PC, FEAR-R, FEOV-C, FEOV-MX, POCO-R, ELTR-SL, PASM-A, PASM-B and PASM-R.
3. Other species – DAIN, SPWR, FETR-S, HECO, and PONE.

For sites with low pH but not extreme salinity, species recommendations can be based on superior performance in the low pH (LPH) substrate (top one-third in survival and growth rank).

1. Molycorp seed sources – BLTR, MUMO-GHS, MUMO-AUB, and FEMOLY-SGS.
2. Commonly available varieties – DECA-PC, FEAR-R, PASM-B, PASM-R, and ELTR-SL.
3. Other species – DAIN, PHPR, ELCA, and FETR-S.

A different set of species had superior performance in the high salinity substrate (HSS) and would be recommended for sites where salinity would be the primary limiting factor.

1. Molycorp seed sources – BLTR, MUMO-GHS, MUMO-AUB, FEMOLY-C, FEMOLY-SGS, FEMOLY-SGT, and POMOLY.
2. Commonly available varieties – DECA-PC and POCO-R.
3. Other species – CAREX, SPWR, FETR-S, and PONE.

If cost was not a consideration, the production of Molycorp ecotype seed for *Muhlenbergia* and *Blepharoneuron* would provide 2 warm season grasses of generally superior performance which are not typically commercially available. The Molycorp ecotypes of *Festuca* are among the best performers especially in the high salinity substrate (HSS). Although several commercial sources of *Festuca* had good performance (FEAR-R, FEOV-MX, and FETR-S), the Molycorp ecotypes were superior. In overall rank POMOLY is similar to POCO-R and may be the same species; however, POMOLY was superior in biomass production in the low pH substrate (LPH). A similar comparison can be developed for BRMOLY and BRCI with BRMOLY having superior survival in the high salinity substrate (HSS). The production of ACMOLY or SCSC seed could not be justified based on their performance in these acid rock substrates; their merits depend solely on superior growth and survival in neutral rock or very low salinity acid rock.

A number of commercially available grass varieties had good survival and growth in a range of overburden chemistries: DECA-PC, FEAR-R, FEOV-C, FEOV-MX, POCO-R, PASM-A, PASM-B, PASM-R, and ELTR-SL. Other grass species, which may or may not be commercially available, showed superior survival and growth in these acid rock substrates: ELCA, DAIN, SPWR, FETR-S, PONE, PHPR and HECO.

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