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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 1-1. 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 1-1 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 1-2 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 1-2. 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 solution 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. Analysis 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 1-3) 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 1-3: 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)	Substrate: High Salinity Mean ± SE Biomass (g/plant)	Substrate: 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
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

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

Table 1-3: 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)	Substrate: High Salinity Mean ± SE Biomass (g/plant)	Substrate: Low Salinity Mean ± SE Biomass (g/plant)	Overall Mean Biomass (g/plant)	ANOVA Prob. Of F-test	ANOVA SS model/ SS total (r^2)
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
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 1-3) 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 1-3**). 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 1-4). 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 1-4). 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 1-4: 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 (%)		Substrate: High Salinity Mean ± SE Survival (%)		Substrate: 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
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

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

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

Table 1-4: 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 (%)				Substrate: High Salinity Mean ± SE Survival (%)			Substrate: Low Salinity Mean ± SE Survival (%)				Overall Mean Survival (%)	ANOVA Prob. of Chi Square
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
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 1-5 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 1-5 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 1-5: Overall performance and ranking of grass species grown in the low pH substrate and high soluble salts substrate, grouped by grass tribe.

					Overall			Substrate	
		Overall	Overall	Overall	Average	Low pH		High Soluble Salts	
Grass Tribe	Abbrev. Sci. Name	Mean Biomass (g)	Mean Survival (%)	Mean Rating *	Combined Rank **	Biomass Rank	Survival Rank	Biomass Rank	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-	1.18	92	1.08	11	3	1	13	12

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

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

Table 1-5: Overall performance and ranking of grass species grown in the low pH substrate and high soluble salts substrate, grouped by grass tribe.

					Overall			Substrate	
		Overall	Overall	Overall	Average	Low pH		High Soluble Salts	
Grass Tribe	Abbrev. Sci. Name	Mean Biomass (g)	Mean Survival (%)	Mean Rating *	Combined Rank **	Biomass Rank	Survival Rank	Biomass Rank	Survival Rank
	AUB								
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
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

Table 1-5: Overall performance and ranking of grass species grown in the low pH substrate and high soluble salts substrate, grouped by grass tribe.

					Overall			Substrate	
		Overall	Overall	Overall	Average	Low pH		High Soluble Salts	
Grass Tribe	Abbrev. Sci. Name	Mean Biomass (g)	Mean Survival (%)	Mean Rating *	Combined Rank **	Biomass Rank	Survival Rank	Biomass Rank	Survival Rank
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 1-5) 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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Influence of Provenance on *Ribes Cereum* and *Symphoricarpos Oreophilus* Seed Germination in New Mexico Seed Sources[6]

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Abstract

Mountain snowberry (*Symphoricarpos oreophilus*) and wax currant (*Ribes cereum*) are co-occurring shrub species found in ponderosa pine and mixed conifer forests in New Mexico. These species are candidate species for mined land reclamation because both occur in full sunlight and in the understory and are found on a wide range of edaphic conditions. Mountain snowberry seeds have both a scarification and a stratification requirement for germination, whereas wax currant seeds require only stratification treatment. Separate studies were conducted examining the influence of provenance, from within New Mexico, on conventional seed propagation protocols for each species. The wax currant study utilized eight seed sources and the mountain snowberry study utilized seven seed sources. Seed sources were selected to represent the latitudinal range of the species in New Mexico, and an elevational range at the most northerly latitude sampled. There was considerable variability among seed sources of both species in overall germination rates and response to treatment severity. In wax currant, the southernmost source did not benefit from stratification, but for all of the more northerly sources, germination was improved by stratification treatments. There was also considerable variability among mountain snowberry seed sources in response to scarification treatments, but no distinct latitudinal trends were apparent. Implications of these studies on selection pressure and restoration are discussed.

Additional Key Words: seed dormancy, adaptation, provenance.

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Introduction

Native species are uniquely adapted to local climates and site conditions, and for this reason, they are being intensively studied as potential reclamation species. Mountain snowberry (*Symphoricarpos oreophilus* Gray) and *wax* currant (*Ribes cereum* Dougl.) are shrub species native to the Southwest, whose roles in reclamation are being evaluated in New Mexico. These species occur throughout montane regions of western North America at elevations of 1200 to 4000 meters (McMurray 1986, Marshall and Winkler 1995). Mountain snowberry and wax currant are frequently abundant, occur in numerous communities, and inhabit both understory and open microclimates (McMurray 1986, Marshall and Winkler 1995). Mountain snowberry and wax currant co-occur in ponderosa pine and mixed conifer forests in New Mexico. Both species are capable of growing on steep slopes, poor soils, and sites ranging from moist to dry. Mountain snowberry spreads (reproduces) rapidly once established through rhizomes and layering (McMurray 1986) and by seed. In contrast, wax currant reproduces primarily by seed. Both species have colonized disturbed sites at Molycorp Mine in Questa, New Mexico (Harrington- personal observation).

Natural plant invasion and succession occur slowly on most mine sites (Monsen 1984), and planting of nursery-grown native materials can speed up the time scale of revegetation. However, for many native shrub species, propagation techniques are not well researched, resulting in increased production costs (Dreesen and Harrington 1997). In addition, propagation literature is often based on studies involving few seed lots, and fails to take into account ecotypic variability. As a result, recommended protocols may be less than adequate for some seed sources.

Literature on seed propagation techniques for mountain snowberry is sparse. Early works on the seed propagation of common snowberry (*Symphoricarpos albus* Blake) and Indian currant snowberry (*Symphoricarpos orbiculatus* Moench) – two other North American species – have served as models for the genus. Seed dormancy in these species is imposed by both the seed coat and the embryo (Flemion 1934, Pfeiffer 1934, Flemion and Parker 1942).

Seed coat dormancy in *S. albus* is not thought to be due to barriers to water imbibition, but rather, dormancy is attributed to a combination of mechanical resistance of the seed coat and possible physiological control of embryonic tissues exerted by the seed coat (Pfeiffer 1934). Effective seed coat treatments must disintegrate or soften the outer seed coat fibers. Sulfuric acid scarification and moist after-ripening (which enables fungi to infect and soften seed coat fibers) are two techniques that have been used to overcome seed coat dormancy in snowberry species (Flemion 1934, Flemion and Parker 1942, Glazebrook 1941 cited in Krier 1948, Young and Young 1992).

The combination of both acid scarification and moist after-ripening treatments has been found to be most effective in promoting snowberry germination, but optimal acid scarification and moist after-ripening treatment durations vary widely from author to author. Recommended acid soak duration ranges from 20-75 minutes, and recommended treatment duration for subsequent after-ripening ranges from 14 to 120 days (Flemion 1934, Flemion and Parker 1942, Krier 1948, Young and Young 1992).

Snowberry seeds also exhibit embryo dormancy due to embryo immaturity, which is overcome by long periods of stratification (Flemion 1934, Flemion and Parker 1942). Recommendations for stratification treatment duration are less variable than those for scarification – in all cases from four to six months (Flemion 1934, Flemion and Parker 1942, Krier 1948, Evans 1974, Young and Young 1992).

As is the case with mountain snowberry, propagation literature for wax currant is based primarily on studies of closely related species. Several dormancy mechanisms are suspected to occur in some species of *Ribes*. These mechanisms include seed coat dormancy controlled by growth inhibitors and an impermeable seed coat and embryo dormancy resulting from a rudimentary embryo (Pfister 1974, Goodwin and Hummer 1993). However, for wax currant, embryo dormancy is the primary dormancy mechanism, and satisfactory germination has been achieved in the absence of scarification treatments (Pfister 1974). Embryo dormancy of wax currant has been overcome by stratification for a period of 120 to 150 days (Pfister 1974). This treatment resulted in 61% germination. However, when the same seeds underwent a second stratification treatment, an additional 11% of the original seeds germinated. For other *Ribes* species, there is a high degree of variability in optimal stratification treatment duration. Recommended stratification duration for *R. alpinum, R. americanum, R. aureum, R. cynosbati, R. hudsonianum, R. inerme, R. irriguum, R. lacustre, R. missouriense, R. montigenum, R. nevadense, R. odoratum, R. roezli, R. rotundifolium, R. sanguineum, and R. viscosissimum* range from 60 to 300 days depending on species (Fivaz 1931, Quick 1936, Heit 1971, Pfister 1974, Goodwin and Hummer 1993). Seed dormancy level has been found to vary widely among seed lots (Pfister 1974, Young and Young 1992).

Materials and Methods

Seeds used in both studies were collected during the months of August through October, 1997 at multiple locations (sources) throughout New Mexico (see Table 2-1).
Seeds were collected from a minimum of five plants and varying plant heights at each source. Sources were selected to encompass a range of latitudes within New Mexico and to reflect the range of elevations at the Molycorp Mine in Questa, New Mexico. Identification to species by floral characteristics was not accomplished for snowberry growing at the Sacramento and two Sandia sources. Foliar characteristics, however, were consistent with *S. oreophilus*. While *S. oreophilus* is known to occur at these elevations in these ranges, other species of *Symphoricarpos* may also occur at these locations (Martin and Hutchins 1981).

Following collection, seeds were cleaned and separated into 100-seed lots and placed in dry storage at 5^{o}C until use. The snowberry study consisted of one experiment examining various levels of acid scarification and moist after-ripening treatment. The wax currant study consisted of one experiment examining various levels of stratification duration.

The snowberry study was designed to examine the influence of provenance on germination response to a factorial combination of acid scarification and moist after-ripening treatments. Seven seed sources were used.

Table 2-1: Lot title, latitude, location, elevation, and collection date of mountain snowberry (*Symphoricarpos oreophilus*) and wax currant (*Ribes* cereum) seed sources.

Lot Title	Latitude	Location	Elevation	Collection Date
Mountain snowberry–*Symphoricarpos oreophilus*				
Capulin	3642' N	Molycorp Mine, Questa, NM	9,800 ft	9/04/97, 9/24/97
Vent	3642' N	Molycorp Mine, Questa, NM	8,200 ft	9/6/97
Cabin	3642' N	Molycorp Mine, Questa, NM	7,900 ft	9/2/97
Holman	3602' N	Holman, NM	7,800 ft	10/7/97
Sandia Crest	3510' N	Cibola National Forest	9,200 ft	10/11/97
Sandia Trail	3510' N	Cibola National Forest	7,700 ft	10/11/97
Sacramento	3258' N	Cloudcroft, NM	8,600 ft	9/21/97, 10/04/97
Wax currant- *Ribes cereum*				
Capulin	3642' N	Molycorp Mine, Questa, NM	9,800 ft	8/10/97
Raspberry Ridge	3642' N	Molycorp Mine, Questa, NM	9,800 ft	8/12/97
Pinon Knob	3642' N	Molycorp Mine, Questa, NM	9,500 ft	8/21/97
Headframe Hill	3642' N	Molycorp Mine, Questa, NM	8,400 ft	8/13/97
Mahogany Hill	3642' N	Molycorp Mine, Questa, NM	9,100 ft	8/13/97
Boxcar/Mill	3642' N	Molycorp Mine, Questa, NM	8,200 ft	8/13/97
Rociada	3550' N	Rociada, NM	7,800 ft	8/17/97
Gila	3406' N–3407' N	Gila National Forest–NM	8,200 ft.	8/21/97

Seeds underwent acid scarification treatment prior to after- ripening treatment. Each of the nine treatment combinations was tested on four 100-seed replications per source. All seeds were then stratified for 168 days. Germination data were analyzed as a three (acid scarification) by three (moist after-ripening) factorial separately by seed source. Concentrated sulfuric acid (Reagent ACS, 95.0-98.0%, VWR) was used for all acid scarification treatments. Snowberry seeds were exposed to acid for 0, 30, or 60 minutes. Seeds were placed in 10-ml of acid and stirred vigorously for 30 seconds to disperse the seeds. Following treatment the seeds were removed from the acid and rinsed with water for one minute under a running tap.

After-ripening treatment involved mixing snowberry seeds with moistened peat moss, placing the seed/peat mixture into polybags, and storing the polybags at room temperature (21^{o}C to 24^{o}C). The peat moss had been fully saturated and then firmly pressed to remove excess water. Seeds were after-ripened for 0, 21, or 42 days. Stratification was accomplished by mixing snowberry seeds with moistened peat moss and the seed/peat mixture was placed in polybags stored in a walk-in cooler. Snowberry seeds were stratified for 168 days. Cooler temperatures fluctuated from an average daily low of -1.2^{o}C to an average daily high of 5.4^{o}C.

Following stratification, germinated seeds were counted and removed. Seeds were considered germinated if the radical had emerged through the seed coat. Ungerminated seeds were then incubated to test for germination. Snowberry seeds were tested for germination between filter papers (Whatman 15.0 cm grade #1 qualitative) moistened with distilled water, which were set in 150 ml petri dishes sealed in 15x16 cm polybags. Petri dishes were set 30 cm beneath two 40-watt Sylvania Grow Lux fluorescent bulbs on FloraCart plant stands (Grower's Supply Company, Dexter, MI). The light cycle was 10 hours of light followed by a 14-hour dark period. Lab temperatures ranged from mean daily highs of 23.4°C +/- .1°C to mean daily lows of 21.7°C +/- .1°C.

The wax currant study evaluated the influence of provenance on germination response to stratification imposed as the only seed treatment. Experimental factors were seed source and stratification duration. Seeds from all eight sources were used. Stratification treatment durations were 0, 60, 90, and 120 days. All treatment combinations were tested with four replications of 100 seeds. Germination data were analyzed as a four (stratification) by eight (seed source) factorial, and then separately by source.
Wax currant seeds were stratified between filter papers (VWR 9.0 cm Qualitative Grade #3) moistened with distilled water, which were placed in 100 mm petri dishes sealed in 15x16 cm self-sealing polybags within a walk-in cooler. Wax currant seeds were stratified for 0, 60, 90, or 120 days. Cooler temperatures again fluctuated from an average daily low of -1.2°C to an average daily high of 5.4°C.

Following stratification, germinated seeds were counted and removed. Seeds were considered germinated if the radical had emerged through the seed coat. Ungerminated seeds were then incubated to test for germination. Wax currant seeds were tested for germination between filter papers (VWR 9.0 cm Qualitative Grade #3) moistened with distilled water, which were placed in 100 mm petri dishes sealed in 15x16 cm self-sealing polybags. Petri dishes in polybags were placed directly on greenhouse benches under natural light (filtered through shade cloth) with fluctuating temperatures. A one-foot border on all sides of each bench was left empty in order to minimize temperature differences between samples. Greenhouse temperatures ranged from a mean daily high of 34.1°C +/- 0.5°C to a mean daily low of 15.2°C +/- .26°C. After 7, 14, 21, and 28 days of incubation, germinated seeds were again counted and removed. Filter papers were remoistened as needed.

Categorical analysis of variance (SAS Proc Catmod, SAS Institute 1989) was used to determine treatment differences using the factorial treatment structures described for each experiment. The response variable was total germination, including both germination during treatment imposition and germination within 28 days after treatment imposition. This procedure is a generalization of the chi-square (X^2) test of homogeneity, which uses the "logit" – the natural log of the ratio of germinated to non-germinated seeds for each treatment – as the response. Maximum-likelihood analysis was used to calculate X^2 test statistics. Observed significance levels less than =0.05 were considered significant. Percentages and standard errors were calculated for main effects and interaction combinations. Approximate pairwise Z statistics were used to conduct pairwise comparisons of main treatment effects using a conservative alpha value of 0.05 divided by the number of comparisons. Pairwise comparisons of treatment combination were informally tested; means were considered different if the higher mean minus its standard error did not overlap the lower mean plus its standard error.

Results

Acid scarification, after-ripening, and for all but two mountain snowberry seed sources (Sandia Trail and Sacramento), the interaction between both factors impacted germination (p<05). Germination for individual seed sources was low and variable, when averaged over all treatments, and ranged from 8.5% to just over 35.1% (see Table 2-2).

Table 2-2: Mountain snowberry germination by seed source for data averaged over all other treatments

Seed Source	Mean Germination Percentage	Standard Error
Capulin	20.9	0.7
Vent	24.4	0.7
Cabin	20.9	0.7
Holman	35.1	0.8
Sandia Crest	31.4	0.8
Sandia Trail	22.1	0.7
Sacramento	8.5	0.5

Acid scarification treatment (when averaged over all levels of after-ripening) improved germination for all snowberry seed sources (see Figure 1 (A)). Thirty minutes was the optimal soak duration for all seed sources except Vent, for which a 60-minute soak was equally effective. Improvement in germination relative to non-acid-scarified seeds ranged from 19% to over 300%, depending on seed source. The response to longer acid scarification treatment was more variable and five of the seven seed sources (all except Holman and Vent) showed no improvement in germination relative to non-scarified seeds. Seeds from Sandia Crest, Sandia Trail, and Sacramento – the three southernmost sources – benefited the least from acid scarification.

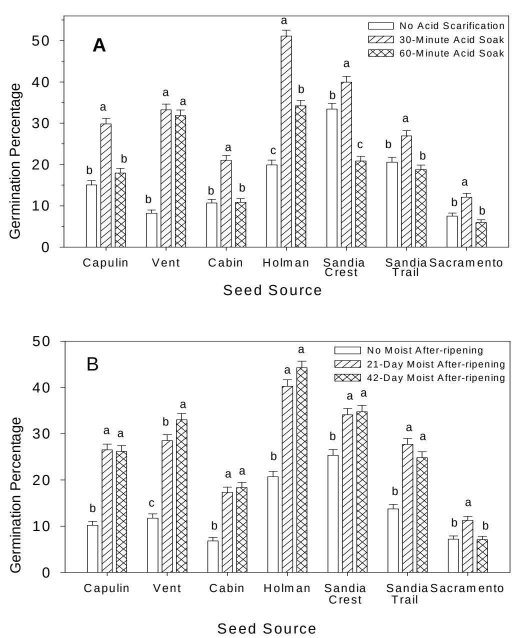

Figure 1. Main Effect of A. Acid scarification and B. Moist after-ripening on mountain snowberry germination.

All snowberry seed sources benefited from some level of after-ripening treatment (when averaged across acid scarification treatments), but degree of germination improvement and optimal treatment level were variable (see Figure 1 (B)). A 21-day after-ripening treatment enhanced germination by 35% to over 160% depending on seed source. Latitude of seed source impacted response to after-ripening. Improvement in germination following either after-ripening treatment was greatest for the most northerly sources – Capulin, Vent, and Cabin. Improvement was intermediate for Holman, the mid-latitude seed source. For the three most southerly seed sources – Sandia Crest, Sandia Trail, and Sacramento – after-ripening was less effective. For five seed sources (all except Vent and Sacramento) germination rates were similar following both after-ripening treatments. Only the Vent seed source had a higher germination rate when exposed to the longer after-ripening treatment. Only the most southerly source – Sacramento – did not benefit from the longest after-ripening treatment.

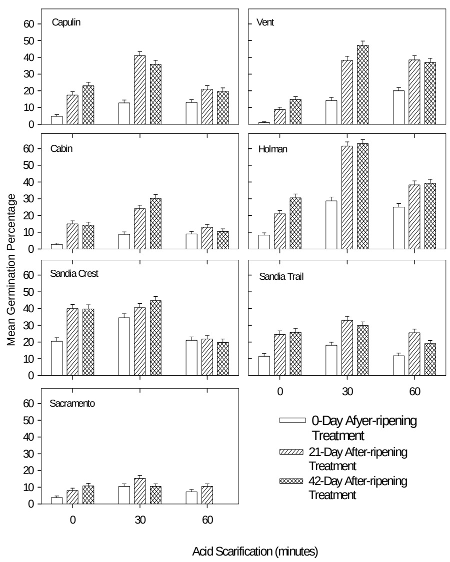

Figure 2: Effect of interaction between acid scarification, moist after-ripening, and seed source on mountain snowberry germination.

For all seed sources, the highest germination rates were seen with a combination of a 30-minute acid scarification treatment followed by either a 21-day or a 42-day after-ripening treatment (see Figure 2). For four of seven sources (Capulin, Cabin, Holman, and Sandia Crest) there was a marked decrease in germination when acid scarification duration was increased from 30 to 60 minutes in combination with either of the after-ripening treatments.

Stratification and its interaction with seed source impacted wax currant germination ($p<.05$). Increasing stratification length improved germination for seven of eight seed sources (see Figure 3). For those sources, this trend indicates variable stratification requirement within each seed lot. Stratification did not affect germination of the southernmost source (Gila). Averaged over all stratification treatments, germination by source was highly variable ranging from 4% to 60% (see Table 2-3). Looking at only the best stratification treatment for each source, germination ranged from 8.5% to 88.8%. There were no consistent differences in overall germination due to elevation or latitude of seed source.

Table 2-3: Wax currant percentages and standard errors for germination averaged across stratification treatments and by stratification treatment.

	Seed Source							
	Caplin	**Rasberry Ridge**	**Pinon Knob**	**Mahogany Hill**	**Headframe Hill**	**Boxcar**	**Rociada**	**Gila**
Overall Germination	4.3 +/- 0.5	54.3 +/- 1.2	37.4 +/- 1.2	30.9 +/- 1.2	32.5 +/- 1.2	60.0 +/- 1.2	52.3 +/- 1.2	46.0 +/- 1.2
Stratification Control Germination	0.5 +/- 0.4	4.2 +/- 1.0	2.0 +/- 0.7	0.8 +/- 0.4	2.0 +/- 0.7	6.3 +/- 1.2	3.0 +/- 0.9	45.8 +/- 2.5
60-Day Stratification Germination	1.0 +/- 0.5	60.0 +/- 2.4	25.8 +/- 2.2	27.8 +/- 2.2	27.3 +/- 2.2	66.0 +/- 2.4	50.8 +/- 2.5	42.8 +/- 2.5

Table 2-3: Wax currant percentages and standard errors for germination averaged across stratification treatments and by stratification treatment.

	Seed Source							
	Caplin	**Rasberry Ridge**	**Pinon Knob**	**Mahogany Hill**	**Headframe Hill**	**Boxcar**	**Rociada**	**Gila**
90-Day Stratification Germination	7.0 +/- 1.3	70.8 +/- 2.3	53.8 +/- 2.5	53.0 +/- 2.5	47.0 +/- 2.5	79.0 +/- 2.0	72.8 +/- 2.2	44.3 +/- 2.5
120-Day Stratification Germination	8.5 +/- 1.4	82.0 +/- 1.9	68.0 +/- 2.3	42.3 +/- 2.5	53.8 +/- 2.5	88.8 +/- 1.6	82.5 +/- 1.9	51.3 +/- 2.5

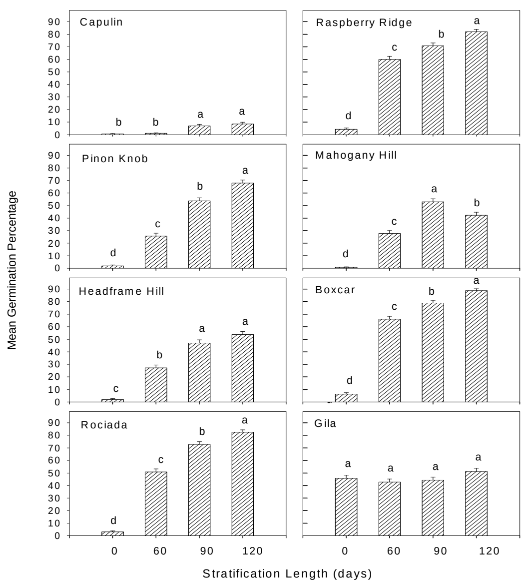

Figure 3. Effect of stratification length on wax currant germination by seed source. Means labelled with the same letter are not significantly different.

Discussion

Acid scarification and moist after-ripening treatments promote germination in the genus *Symphoricarpos* by degrading restrictive seed coats (Flemion and Parker 1942, Flemion 1934, Pfeiffer 1934). Evidence from studies on excised embryos indicates that seed coat-degrading treatments also affect the developing embryo, allowing subsequent maturation (Flemion 1934, Pfeiffer 1934). Moist after-ripening and acid scarification may alter chemical inhibitors in the seed coat allowing some developmental processes to occur during stratification that would otherwise be inhibited.

Previous work on common snowberry found that the combination of acid scarification and moist after-ripening was more effective than optimal level of either treatment alone (Flemion 1934, Pfeiffer 1934). This study found the combination of acid scarification and moist after-ripening to be best for all seed sources across a range of New Mexico latitudes and elevations.

Dormancy is an adaptive trait that prevents germination at times of year when a seedling would be unlikely to survive (Vleeshouwers et al. 1995). Common among temperate-zone shrub species, dormancy times germination to occur at the onset of the warm season (Baskin and Baskin 1998). For snowberry, however, a stratification requirement caused by embryo dormancy (Flemion 1934, Pfeiffer 1934, Flemion and Parker 1942) adequately prevents winter germination of the species. The scarification requirement for this species may serve other purposes.

Snowberry seeds are characterized by embryos that are initially immature and seed coats that are restrictive (Pfeiffer 1934). Both of these factors combine to ensure that embryos lack sufficient growth potential for germination until they have attained a high degree of maturation (Baskin and Baskin 1998). Maturation, which occurs during stratification, does not take place unless stratification is preceded by some seed coat-degrading treatment (Pfeiffer 1934). This requirement delays germination to the second spring following dispersal or later. Variability in seed coat thickness likely results in some seeds requiring more than one warm season for adequate degradation to take place, thus spreading germination across time and ensuring the establishment of a seed bank. Variability in depth of seed coat dormancy due to provenance may reflect adaptations to differing environmental conditions. Seed source variability in response to acid scarification has been found to occur in Kentucky coffeetree (*Gymnocladus dioicus*) (Ball and Kisor 1985). For that species, seeds collected in Minnesota did not benefit from acid scarification, while seeds collected in Ohio and Illinois did show a benefit. In this study, variability in scarification requirement was apparent in degree only. The three southernmost sources benefited less from acid scarification and after-ripening than did the four northernmost.

For wax currant, variability in the stratification requirement among seed sources is best explained by latitude of provenance. Germination increased with increasing duration of stratification for all northern New Mexico seed sources, while the southernmost source (Gila) germinated equally well with or without stratification. This result is consistent with the thought that for temperate woody species requiring stratification, seeds collected from sites with more severe winters would be expected to have a greater depth of dormancy than seeds collected from sites with milder winters (Meyer and Monsen 1991). Wax currant seeds collected from northern New Mexico sites had highly variable stratification requirements within seed lots, consistent with a strategy of spreading germination over time and establishing a seedbank (Meyer and Kitchen 1994). Seeds from the southernmost source (Gila) lacked a stratification requirement. Lack of a stratification requirement indicates a lack of weather-predicting and seedbank-establishing mechanisms (Meyer and Kitchen 1994). However, stratified seeds from the Gila source germinated more rapidly than unstratified seeds. Slow germination has been shown to be an effective mechanism in preventing autumn germination of *Artemisia tridentata* (mountain big sagebrush) seeds (Meyer and Monsen 1991).

The emphasis on the use of local provenances for restoration is based on the premise that local ecotypes have adapted to local environments as an evolutionary response to particular selection pressures. Variability in seed propagation requirements among ecotypes suggests that seed dormancy characteristics are also adaptations to local environments in the face of the same selection pressures. The speed and completeness in which revegetation of a particular area can occur depends upon the ability of outplanted material to propagate itself on site. This characteristic of local plant material is as important as any other.

Acknowledgements

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The Influence of Seed Source and Stock Size on First-Year Performance of Direct-Transplanted Conifer Seedlings[11]

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Study Number: NMPMC-P-9803-CR

Abstract

The ability of an organism to survive and grow in an environment is partly controlled by the organism's genotype. The influence of genotype on seedling survival and the large amount of genetic variability within forest tree species has, in part, led the U.S.D.A.-Forest Service, in cooperation with many state forest agencies, to develop seed zones. Seed zone delineation is an attempt to prevent using seedlings from unfit or non-adapted seed sources on a planting project. A current approach in reforestation involves matching planting stock type to site conditions and developing a planting stock with attributes best suited to the site. This system is often referred to as a target seedling system. One target parameter often used is the overall seedling size. The influence of seedling size on reforestation and afforestation success has been well documented. The objectives of this study were to examine the influence of seed source or genotype, and stock size on transplant success of seedlings transplanted directly into overburden piles at the Molycorp Mine in northern New Mexico. Four sources of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), two northern New Mexico and two southern New Mexico seed sources were evaluated. Seedlings from each seed source were produced in three different container sizes, 16.4 cm^3, 115 cm^3 and 164 cm^3 containers to generate three stock sizes. Two planting sites were used at the mine. The overall study design was a randomized complete block design within an overall split plot design with planting sites being main plots. First year survival and covering of seedlings by overburden movement on the rock pile slopes were recorded. Data were analyzed using categorical model analysis with treatment comparisons utilizing a Bonferroni adjustment to reduce the likelihood of making a Type I error. Overall, survival was low (<35%) with the smallest stock sizes having the lowest survival. Smaller seedlings had greater losses (39%) due to covering than did the mid- and large-size seedlings, 29 and 32%, respectively. Seed source did not influence survival or covering responses.

Additional Key Words: overburden, genetics, seedling size.

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Introduction

The ability for an organism to survive and grow in an environment is partly controlled by the organism's genotype. In terrestrial plant species, including forest tree species, there exists well-documented variation in the genetic make up of members in the population (Zobel and Talbert 1984). Two widely accepted rules governing tree seed movement which apply to this study are: "*Do not move high-elevation or high-latitude sources to low elevations or low latitudes, or the reverse*" and "*Do not plant trees originating on basic soils on acid soils or vice versa*" (both from Zobel and Talbert 1984). These two rules are based on the assumption that adaptation to these two environmental conditions, growing season length and timing, and edaphic conditions are under strong genetic control. The influence of genotype on seedling survival and the large amount of genetic variability within forest tree species has, in part, led the U.S.D.A.-Forest Service, in cooperation with many state forest agencies, to develop seed zones (Harrington et al. 1996a, 1996b). Seed zone delineations are an attempt to prevent the use of seedlings from unfit or non-adapted seed sources in a planting project. Therefore, use of plant material from a given zone on projects within the same zone, should lead to improved success of reforestation efforts. However, in many tree species, including ponderosa pine, the large interval between seed crops may necessitate seedlings from seed outside the area of the planting be used.

A current approach in reforestation involves matching planting stock type to site conditions. This system is often referred to as a target seedling system (Rose et al. 1990). Target attributes are developed based on physiological and/or morphological parameters intrinsic to the seedling, such as root to shoot ratio, seedling size, root growth potential or dormancy intensity. One target parameter often used is the overall seedling size. The influence of seedling size on reforestation and afforestation success has been well documented in the reforestation field (readers are referred to Mexal and Landis 1990 and articles cited therein). One simple way to manipulate seedling size when using container grown stock is by changing container size.

The Questa Molybdenum mine is currently operated as an underground block cave mine and the site is located in the Taos Range of the Sangre de Cristo Mountains, part of the Southern Rocky Mountain physiographic province. The mine is located within an area of high topographic relief, entirely on the south facing slopes along the north side of the Red River Valley. Elevations at the site range from approximately 2518 m to 3300 m. Deeply incised, steep-sided valleys dissect the mine site and surrounding area. The climate is semi-arid with mild summers and cold winters. Precipitation is common throughout the year, with the driest month typically being January and the wettest being August. Long-term average temperature at Red River is 4.2^{o} C according to the National Climate Data Center 1961-1990 records. Distribution of precipitation is variable and varies with elevation but is estimated to average 406 mm at the lower elevations and increases by about 12.7 mm for every 330 m in elevation.

The open-pit mining period occurred between 1964 and 1983. During open pit operations, the mine rock associated with development of the pit was placed in a series of mine rock piles in the vicinity of the open pit. Approximately 328 million tons of mine rock was placed in a series of piles that are tiered against the mountain slopes in the upper reaches of several canyons. Construction of the piles followed standard mining practices at the time. The piles were constructed in lifts created by end dumping over the pile crests. This method of construction results in pile slopes being at their angle of repose between berms or benches. The sequence of pile lift construction was generally from the top down. Bench surfaces were compacted by heavy equipment and trucks.

Objectives

The objectives of this study were: 1) to evaluate the effect of seed source on the survival of ponderosa pine seedlings; and, 2) to evaluate the effect of container size on the survival of ponderosa pine seedlings planted on waste rock piles at the Molycorp, Inc. Questa mine site in north-central New Mexico.

Materials and Methods

This study utilized seedlings generated from four ponderosa pine seed sources from New Mexico. One seed source was from the U.S.D.A. Forest Service seed zone in which the mine is located (U.S.D.A. seed zone 710; (Carson National Forest, northeastern Rio Arriba and north western Taos Counties, New Mexico;); and one from an adjacent seed zone to the west of this seed zone, U.S.D.A. seed zone 620 (Carson National Forest, north-central Rio Arriba County, New Mexico). The other two sources were from more southern seed zones (U.S.D.A. seed zones 170; Gila National Forest, west-central Catron County, New Mexico) and 840 (Lincoln National Forest, Lincoln County, New Mexico). Seedlings from each of the four seed sources tested were produced in growing containers of three sizes: 16.4 cm^3, 115 cm^3, and 164 cm^3. The 16.4 cm^3 container has a cavity depth of 10.4 cm and cavity top width of 1.6 cm. The 115 cm^3 container has a cavity depth of 12.0 cm and cavity top width of 2.5 cm. The 164 cm^3 container has a cavity depth of 21.0 cm and cavity top width of 2.5 cm. Seedlings were propagated from seed in a greenhouse under a modified greenhouse production regime in the respective treatment containers filled with a 2:1:1 (v:v:v) peat:perlite:vermiculite growing media. General greenhouse conditions included a 16-hour photoperiod (ambient light plus supplemental light from high pressure sodium vapor lamps suspended above the seedlings); day temperatures ranging from 20 to 27^{o}C, night temperatures ranging from 19 to 23 ^{o}C. Seedlings were irrigated as needed. Nutrients were provided by two fertilizer treatments. A resin-coated, slow release fertilizer (Osmocote, 14-14-14, 3-4 month) was incorporated into the media at a rate of 4 kg/ m^3. Secondly, seedlings were fertilized twice weekly with a liquid fertilizer (Peter’s 20-20-20 Peat Lite Special) mixed to deliver 100 ppm total N (Harrington 1996c). Four weeks prior to planting, seedlings were moved from the greenhouse to a shade house and received no further liquid fertilizers. This was done to allow the seedlings to acclimate to ambient conditions. Seedlings had set a terminal bud before they were shipped to the planting site.

The seedlings were planted from September 13 to 16, 1993. Planting holes were prepared using a planting bar for the 115 cm^3 and 164 cm^3 sizes and sharpshooter shovel for the 16.4 cm^3 size. Seed source and container size treatments were randomly allocated to each member of the planting crew. This randomization process was repeated for each planting block and was done to remove planter variance from the study. Seedlings received no supplemental irrigation after planting.

The first planting site was approximately 30 meters up the face of the lower front mine rock pile, called the Sulphur Gulch rock pile. This site was quite variable with several rills and a significant amount of large cobble on the surface. The overburden material at this site had a paste pH of greater than 6.0 and a paste TDS of 260 mg/L (SRK 1995). Most of the waste rock was gray in color and in some locations a finer textured substrata was evident. The second planting site was located at the base of the third (from the bottom) bench on the same rock pile. This site was only mildly sloped and had very little large rock. The overburden material at this site had a paste pH of 2.7 and a paste TDS of 1380 mg/L (SRK 1995). The lower, furthest east blocks, were in a highly compacted area. The waste rock at this site was brown to yellow in color.

The treatment design was a factorial design of seed source (four levels), and container size (three levels) and resulted in a total of twelve treatment combinations. The outplanting design was a split plot design with the two main plots being the two planting sites. Each planting site contained six randomized complete blocks. Due to the large planting area involved, blocking was done to account for site variability impacts on survival. Each treatment was represented in each block by a 10-tree row plot.

The response unit was the average survival or presence of overburden covering of the 10-tree row plot of each treatment within each block. Questions of primary interest were examining intrinsic stock attributes of genotype or seed source and seedling size based on container size. Portions of the planting blocks were covered by rock materials moving on the slopes. This was particularly evident at the first planting site. A seedling was considered covered when sufficient materials had been deposited to cover the cotyledon scar on the stem.

Categorical statistical analysis was conducted on the two dichotomous response variables, survival and covering. For each of the response variables a categorical analysis of variance was conducted using the CATMOD procedure in SAS (SAS Institute, 1990) with generalized least squares as the technique for obtaining estimates and concomitant statistics. Test statistics are asymptotic chi-square tests and test hypothesis of equal proportions of surviving (or covered) for the factors: Site; Block within Site; Seed Source; Container Size; Source by Size interactions; Site by Source Interaction; Site by Size interaction; and Site by Source by Size interaction. Null hypotheses were rejected at the significance level of alpha = 0.05. When a chi-square test for a main effect was rejected, asymptotic pairwise Z statistics and their observed significance levels were calculated to test that pairs of levels of the main effect factor were the same. To control the comparison-wise Type I error rate a Bonferroni adjustment was used. This adjustment is more conservative and only will declare differences if the observed significance level is less than 0.05 divided by the number of pairwise comparisons (i.e. 0.05/3 = 0.0166).

Results and Discussion

The planting date coincided with the first frost date. Overall, precipitation during the study period was above average (see Table 3-1). Study-wide survival was low, averaging slightly over 30%. Seed source or provenance did not influence first-year survival even though average survival ranged from 18 to 31% by seed source (see Table 3-2 and 3-3). However, assessing an exotic seed source's fitness for a site may take more than one year to determine (Zobel and Talbert 1984). This is due, in part, to annual variation in climatic attributes such as early or late frosts. Both the onset of terminal elongation and growth cessation and hardening are linked to environmental signals, primarily chilling units and photoperiod respectively (Kozlowski and Pallardy 1997). For example, seedlings that have satisfied their chilling hour accumulation and initiated growth early in the growing season may be susceptible to late frosts.

The two larger stock sizes, 115 cm^3 and 164 cm^3, had better survival relative to the smaller stock size evaluated (see Tables 3-2 and 3-4). The relationship of transplant (seedling) size and early survival has been examined extensively in the reforestation field. Published reports on the influence of stock size on survival vary in response to this effect ranging from no effect (Patterson 1991, Maiers 1997) to improved survival of larger stock (Amidon et al. 1981, Endean and Hocking 1972, Helgerson et al. 1989, Rose et al. 1991, Maiers 1997). The influence of site limitations can play an important role in this relationship. In a traditional reforestation situation, larger stock may have an advantage if site preparation activities were insufficient to control the competing vegetation (Helgerson et al. 1992, Maiers 1997, Maiers and Harrington 1999). If competing vegetation is adequately controlled, the advantage of the larger stock may be negated (Maiers and Harrington 1999). In this study, the larger seedlings may have been more suited to the site, in that they were less susceptible to losses due to covering (**see** Tables 3-5 and 3-6), and possibly better able to access deeper soil moisture. Seedling shoot heights for seedlings produced in the 16.4 cm^3 containers were between 8 and 10 cm whereas seedling shoot heights ranged from 13 to 18 cm in the larger two containers. Seedlings produced in the larger containers also had larger root collar diameters (caliper; 2.2 mm) than the seedlings produced in the smaller containers (1.6 mm). Both of these features, shoot height and caliper may impart greater resistance or tolerance to covering. In subsequent studies on this site, both on benches and pile faces, losses due to covering have been appreciably less (Harrington et al. 2000, Harrington and Dreesen unpublished data). These subsequent studies have relied on the 164 cm^3 and larger planting stock that may explain the reduction in covering losses.

Table 3-1: Average monthly precipitation for Red River, New Mexico and the monthly precipitation for the 12 months spanning this study

Month	Average Monthly Precipitation (mm)	1993/1994 Monthly Precipitation (mm)
August (93)	80.8	160.8
September	42.2	30.7
October	37.6	32.5
November	32.3	44.5
December	29.5	20.6

Table 3-1: Average monthly precipitation for Red River, New Mexico and the monthly precipitation for the 12 months spanning this study

Month	Average Monthly Precipitation (mm)	1993/1994 Monthly Precipitation (mm)
January (94)	26.9	22.9
February	28.4	41.4
March	42.9	72.9
April	40.1	99.8
May	46.0	75.7
June	35.6	34.5
July	66.5	42.7
August	80.8	109.0

Table 3-2: Categorical analysis of variance table for survival response for ponderosa pine seedlings grown in different size containers planted on overburden at the Molycorp, Inc. Mine in north-central New Mexico

Source	df	Chi- Square	Observed Probability
Intercept	1	52.27	0.0000
Site	1	3.00	0.0834
Block (Site)	9*	43.24	0.0000
Source	3	3.98	0.2632
Size	2	32.60	0.0000
Source*Size	6	3.38	0.7597
Site*Source	3	0.82	0.8437
Site*Size	2	0.32	0.8505
Site*Source*Size	6	3.04	0.8041
Residual	99	70.40	0.9868

* Block (Site) contains one or more redundant or restricted parameters.

Table 3-3: The influence of seed source on ponderosa pine seedling survival planted on overburden piles at the Molycorp Inc. Questa Mine. (Means are not significantly different at $\alpha = 0.05$).

Seed Source (Seed Zone)	Mean Survival Percentage (± S.E.)
710	22.1 ± 2.8
620	30.8 ± 3.1
170	17.7 ± 2.6
840	25.0 ± 2.9

Table 3-4: The influence of stock size on ponderosa pine seedling survival planted on overburden piles at the Molycorp Inc. Questa Mine. (Means followed by the same letter are not significantly different at $\alpha = 0.05$).

Stock Size (cm^3)	Mean Survival Percentage (± S.E.)
16.4	5.6 ± 1.4 a
115.0	31.5 ± 2.6 b
164.0	32.6 ± 2.7 b

Table 3-5: Categorical analysis of variance table for covering response for ponderosa pine seedlings grown in different size containers planted on overburden at the Molycorp, Inc. Mine in north-central New Mexico.

Source	df	Chi- Square	Observed Probability
Intercept	1	58.17	0.0000
Site	1	29.29	0.0000
Block (Site)	9*	105.45	0.0000
Source	3	1.40	0.7054
Size	2	11.13	0.0038
Source*Size	6	5.29	0.5072
Site*Source	3	1.50	0.6816
Site*Size	2	4.03	0.1334
Site*Source*Size	6	3.94	0.6852
Residual	99	63.54	0.9979

* - Block (Site) contains one or more redundant or restricted parameters.

Table 3-6: The influence of stock size on ponderosa pine covering planted on overburden piles at the Molycorp Inc. Questa Mine site. (Means followed by the same letter are not significantly different at $\alpha = 0.05$).

Stock Size (cm^3)	Mean Survival Percentage ($\pm$ S.E.)
16.4	39.3 $\pm$ 2.3 a
115.0	29.3 $\pm$ 2.2 b
165.0	31.6 $\pm$ 2.2 b

Planting site also influenced the covering response observed in this study (see Table 3-5). Planting site 1, located in the middle of the face of the rock pile had greater losses attributed to covering (42 $\pm$ 1.8%) than did the other, flatter planting site (22 $\pm$ 1.7%). While not monitored as part of this study, it appears some of the material deposited on the seedlings came from two primary processes, surface movement and equipment activities on the pile faces above the planting sites. Surface movement refers to the downward movement of gravel sized and smaller materials due to climatic forces, most likely during heavy rain events. It was observed that other work being performed above the planting site resulted in larger materials being dislodged and rolling down the pile faces. While not measured, it was evident that some of the covering losses observed were due to materials larger than the gravel sized particles that are not associated with erosional surface movement. The larger two seedlings sizes had shoot attributes, taller and more robust stems, which may have allowed them to withstand some particle deposition more so than the seedlings produced in the smaller container.

Conclusions

Movement of surface rock materials on this site, regardless of the origin, necessitates the use of planting stock of sufficient size to tolerate this movement or it requires measures be taken to reduce the movement of material. The results of this study indicate that larger stock sizes, greater than 115 cm^3, will be required for direct planting of seedlings on this site under current conditions. A balance that must be achieved will be between a seedling that has adequate shoot height and sturdiness to withstand the surface particle movements that can occur on this site, while still remaining small enough to plant economically. Additionally, early results indicate that stock produced with seed from sources near the mine site and further south in the state can survive when planted directly into the overburden. However, the recommendation of using the two southerly seed sources evaluated in this study at this site must be preliminary, in that the climate from only one growing season was evaluated. First-year survival is an early measure in terms of provenance evaluation in trees but subsequent evaluations of the materials surviving after one-year will either support or negate this claim.

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The Influence Of *Pisolithus Tinctorius* Inoculation On Greenhouse Growth And First-Year Transplant Survival Of Conifer Seedlings[16]

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Study Number: NMPMC-P-9803-CR

Abstract

Mycorrhizal fungi form a symbiotic association with the root systems of most higher plants. Mycorrhizae colonization of root systems is believed to improve tolerance to adverse soil conditions such as low pH or high salinity. Mined land reclamation may require transplanting seedlings onto harsh sites that may have low pHs, high salinity, low nutrient status, etc. The purpose of this study was to examine whether inoculation of conifer seedlings in the greenhouse with *Pisolithus tinctorius* would improve first year survival of seedlings transplanted onto overburden material at the Molycorp Questa Mine in northern New Mexico. Seedlings of *Pinus ponderosa, P. edulis, P. strobiformis, P. flexilis, P. aristata, P. sylvestris, and P. nigra* were used in this study. Subsets of each species were inoculated with *Pisolithus tinctorius* at either six or ten weeks after germination or not artificially inoculated. Seedlings were evaluated for growth response in the greenhouse after inoculation and before transplanting. Inoculation and growth media composition significantly impacted shoot height and caliper growth but responses were species-dependent and the magnitude of the differences between inoculated and non-inoculated seedlings were small. Seedlings were transplanted in August 1996 on a site at an elevation of 9,500 ft. and with substrate pH ranging from 3.5 to 4.0. The impact of inoculation with *Pisolithus tinctorius* on survival was variable by species. Only *P. strobiformis* had improved survival with inoculation (>20%).

Additional Key Words: acid soils, disturbed land reclamation, reforestation.

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Introduction

The significance of mycorrhizae on higher plant – environment interactions is well known. Ectomycorrhizae, those mycorrhizae which do not penetrate root cells, are commonly found in association with coniferous species including members of the genus *Pinus*. It has been estimated that there are over 5000 species of ectomycorrhizae fungi world wide (Marx 1991). Benefits of mycorrhizal associations to plants used in reforestation and revegetation may include improved survival (Marx 1991, Marx et al. 1992, Marx and Cordell 1989), enhanced growth (Browning and Whitney 1992), improved tolerance to water deficits (Boyle and Hellenbrand 1991; Svenson et al. 1991), and superior performance on low nutrient sites (Marx 1991). However, these responses are often species, both host and fungal, specific as well as site specific.

There is a cost to the host plant along with the benefits of the association. Mycorrhizal fungi, like all fungi, are heterotrophic organisms which depend on an external source of organic carbon for their energy needs. In ectomycorrhizal plants it is estimated that as much as 24% of the total carbon assimilated is allocated or used by the fungal symbiont (Vogt et al. 1982). More frequently, estimates of this cost to the host plant range from 15 to 20% of the total carbon assimilated (Soderstrom 1991). A considerable amount of work has been done examining the impact of this "cost" in producing container reforestation and revegetation planting stock (St. John and Evans 1990; Marx 1991). In general, alterations, primarily in fertility regimes, are required when producing stock with good mycorrhizae colonization. Marx (1991), summarizing the state of research at the time, concluded that any condition which impacts carbon allocation to roots will impact ectomycorrhizal development. The challenge is to develop a seedling production regime in which the end product has the desirable or target morphological and physiological attributes, including sufficient mycorrhizal development, to meet planting needs.
The mine site used (Questa molybdenum mine) in this study is located in the Taos Range of the Sangre de Cristo Mountains in northern New Mexico. Elevation at the site ranges from 2400 to 3000 meters. The terrain surrounding the mine supports primarily coniferous ecosystems with riparian ecosystems in the bottoms of many canyons having perennial streams or rivers. The conifer ecosystems include ponderosa pine (*Pinus ponderosa*), mixed conifer (*P. flexilis, Pseudotsuga menziesii, Abies concolor*) to spruce-fir (*Picea engelmannii* and *A. concolor*) stands. Distribution of these species is influenced by topographic features as well as aspect.

Open pit mining operations were conducted between 1965 and 1983. During this time approximately 300 million metric tons of waste rock were produced and placed in rock piles surrounding the open pit. In general, mixed volcanic waste rock was excavated from a hydrothermal scar area of the pit (SRK 1995). These mixed volcanic rocks were derived from upper rhyolitic and lower andesitic series rocks of Tertiary age. The mixed volcanics are highly fractured and weathered, and typically exhibit a paste pH in the range of 2.3 to greater than 6.0, the majority less than 3.5. Paste extractions of these rocks typically indicate a high TDS content. The remainder of the waste rock was derived from propylitic black andesite, aplite and granite. Black andesite, aplite and granitic intrusives (mine aplite) typically exhibit neutral paste pH and low paste TDS content.

Objectives

The potential for colonizing disturbed sites with soil microorganisms, such as mycorrhizae, via the use of inoculated container grown planting stock is becoming increasingly accepted. Three experiments were conducted to examine the effects of *Pisolithus tinctorius* inoculation on the nursery culture and first-year survival of container grown pines planted directly into overburden at the Molycorp, Inc. Questa mine. The first experiment examined the effect of timing of inoculation on shoot growth and stem caliper during greenhouse culture. The second experiment examined the influence of growth media composition on the same responses evaluated in the first experiment. The third experiment examined the first-year survival of inoculated or non-inoculated seedlings planted on the overburden piles at the Molycorp Inc., Questa mine.

Materials and Methods

Experiment 1

Six species of pine were used in this study: *Pinus aristata, P. edulis, P. nigra, P. ponderosa, P. strobiformis*, and *P. sylvestris*. Seedlings were grown from seed in a greenhouse under a modified greenhouse production regime in 164 cm^3 containers filled with a 2:1:1 (v:v:v) peat:perlite:vermiculite growing media. General greenhouse conditions included a 16-hour photoperiod (ambient light plus supplemental light from high pressure sodium vapor lamps suspended above the seedlings); day temperatures ranging from 20 to 27^{o}C, night temperatures ranging from 19 to 23 ^{o}C. Seedlings were irrigated as needed. The only fertilizer seedlings received was from a resin-coated, slow release fertilizer (Osmocote, 14-14-14, 3-4 month) incorporated into the media at a rate of 4 kg/ m^3. This reduced fertility regime, relative to the standard seedling production regime, was based on previous studies that found high fertility levels can reduce mycorrhizal colonization of root systems and use of slow release fertilizers has been shown to be less detrimental than water soluble fertilizers (Maronek et al. 1982; Crowley et al. 1986; St. John and Evans 1990).

Three inoculation treatments were used. The first treatment involved inoculating 196 seedlings of each species with a commercial source of *Pisolithus tinctorius* six weeks after germination. Inoculation was accomplished by drenching the root plug with a spore suspension of *P. tinctorius* in water (MycorTree PT Spore Spray, Plant Health Care, Inc., Pittsburgh, PA, USA 1995). The second inoculation treatment was similar to the first, except that inoculation occurred at ten weeks after germination and involved 196 seedlings of each species. The third treatment, the control group, was not artificially inoculated and included 196 seedlings of each species. At 20 weeks after germination, shoot height from the cotyledon scar to the tip of the growing apex was measured to the nearest 0.5 cm using a ruler. Stem caliper was measured to the nearest 0.1 mm using a digital caliper. Mycorrhizal colonization was determined by removing five to ten seedlings of each inoculation by species treatment combination from their containers and visually inspecting the root plug for presence of mycorrhizal inoculation using a procedure modified from Cordell et al. (1990). Lateral roots growing on the periphery of the root plug were examined for the presence of root bifurcations and fungal hyphae as indicators of the presence of mycorrhizal colonization.

The treatment design was a factorial combination of species (6) by inoculation treatment (3). The experimental design was a completely randomized design with each species x inoculation treatment combination being replicated by 196 seedlings. Growth data was analyzed using analysis of variance (PROC GLM; SAS Inc. 1990). Two analyses were run, the first model tested included species in the model being tested. The second set of analysis was run by species looking at the main effect of inoculation treatment on the two growth attributes.

Experiment 2

Only *P. ponderosa* seedlings were used to examine the influence of growth media composition on the efficacy of *P. tinctorius* colonization. The three growth media were a 2:1:1 (v:v:v), 1:1:1 or a 1:2:1 mixture of peat:perlite:vermiculite. The three growth media were labeled heavy, medium and light, and had calculated dry bulk densities of approximately 0.126, 0.103 and 0.101 g/cm^3 , respectively. The calculated wet bulk densities for the heavy, medium and light growth media were 0.584, 0.576 and 0.531 g/cm^3 , respectively. Growth media bulk densities were calculated from published component values (Landis et al., 1990). Seedlings were produced and inoculated as described for Experiment 1. The same three inoculation treatments used in Experiment 1 were used in this experiment. Shoot height, stem caliper, and successful mycorrhizal colonization were measured or determined as described in Experiment 1.

The treatment design was a factorial combination of growth media composition (3) by inoculation treatment (3). The experimental design was a completely randomized design with each growth media x inoculation treatment combination being replicated by 196 seedlings. Growth data was analyzed using analysis of variance (PROC GLM; SAS Inc. 1990).

Experiment 3

Seedlings produced in Experiments 1 and 2 were used in this experiment. In addition, *P. flexilis* seedlings receiving the same treatment combinations as described in Experiment 1 were also used in this experiment. Seven-month old seedlings were planted in late August of 1996 using planting bars on a bench site at the Molycorp, Inc. mine (Capulin overburden pile). The site had previously been ripped to mitigate compaction problems at the site resulting from the bench being previously used as haulage/dumping area during the open pit operation of the mine. A 45 cm inch ripping depth was targeted, however, actual ripping depth varied from 45 cm to less than 15 cm. The site was also variable in terms of overburden chemical properties (see Table 4-1). Three overburden samples from each block were taken and analyzed for chemical and physical properties. Samples were taken from a depth of 5 cm to 15 cm at each sampling location. Samples were sent to commercial laboratory for analysis (Energy Laboratories, Inc. Billings, MT, USA). Following planting, seedlings were irrigated by hand with approximately 4 liters of water per seedling. No further irrigation occurred. The treatment design was a factorial combination of species (9 (7 tree species + 2 additional *P. ponderosa* media composition treatments resulting from experiment 2)) by inoculation treatment (3). The experimental design was a randomized complete block design with 8 blocks. Each species by inoculation treatment combination was replicated by a 10-tree row plot per block. The response variable, survival, was the percent survival for the 10-tree row plot.

Survival data were first analyzed as a nine (species) by three (mycorrhizal treatment) by eight (block) factorial, and then separately by source. Categorical analysis of variance (SAS PROC CATMOD, SAS Institute 1990) was used to determine treatment differences using the factorial treatment structures described for each experiment. This procedure is a generalization of the chi-square test of homogeneity, which uses the "logit"–the natural log of the ratio of surviving to non-surviving trees for each treatment combination--as the response variable. Low cell counts made it necessary to use generalized least squares. Observed significance levels less than or equal to 0.05 were considered significant. Percentages and standard errors were calculated for main effects and interaction combinations. Finally, approximate pairwise Z statistics were used to conduct pairwise comparisons of main treatment effects using a conservative alpha value of 0.05 divided by the number of comparisons.

Table 4-1: Overburden Chemical and Physical Properties for the Experiment 3 Planting site. Numbers Reflect the Mean of Three Samples Measured for Each Block

	Block							
Overburden Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
pH [1]	4.60	4.30	4.40	4.23	3.87	3.47	3.20	3.00
Conductivity (mmhos/cm) [1]	0.46	1.55	0.95	1.66	2.42	2.09	5.43	8.15
Base Sat. (%)[1]	19.63	20.93	21.33	24.17	24.37	30.50	26.43	26.40
Calcium (meq/1) [1]	0.97	6.29	3.86	15.07	2.99	2.58	8.98	3.26
Magnesium (meq/1) [1]	0.36	1.02	1.11	1.68	2.92	3.76	6.82	12.25
Sodium (meq/1) [1]	0.49	0.55	0.67	0.46	0.40	0.28	0.45	0.55
S.A.R. [1]	0.67	0.41	0.46	0.27	0.23	0.20	0.30	0.51
Organic Matter (%)	0.29	0.29	0.30	0.25	0.25	0.27	0.22	0.25
Phosphorus (ug/g) [2]	3.87	5.13	7.70	10.70	9.07	23.97	3.50	4.90
Potassium (ug/g) [3]	72.00	65.00	73.33	62.33	51.33	52.67	48.67	67.67
Aluminum (ug/g) [4]	9.93	9.13	8.17	5.70	1.17	3.00	152.77	201.53
Copper (ug/g) [4]	0.70	0.50	0.47	0.60	0.47	0.30	0.57	0.63
Iron (ug/g) [4]	264.33	346.00	308.67	318.00	448.67	403.67	436.00	544.00
Manganese (ug/g) [4]	34.23	12.93	24.17	6.83	5.93	4.57	3.90	4.50
Zinc (ug/g) [4]	1.40	1.23	1.47	0.63	1.43	0.73	2.00	2.13
Molybdenum (ug/g) [5]	0.77	0.80	0.73	0.63	0.77	0.60	0.53	0.57
Physical Parameter								
Sand (%)	82.33	76.67	78.33	73.33	70.33	59.67	69.67	67.00
Silt (%)	9.33	13.33	12.67	13.33	17.67	21.00	19.00	17.67
Clay (%)	8.33	10.00	9.00	13.33	12.00	19.33	11.33	15.33

[1] Saturation Paste Extract
[2] Sodium Bicarbonate Extract
[3] Ammonium Acetate Extract
[4] DTPA
[5] ABDTPA

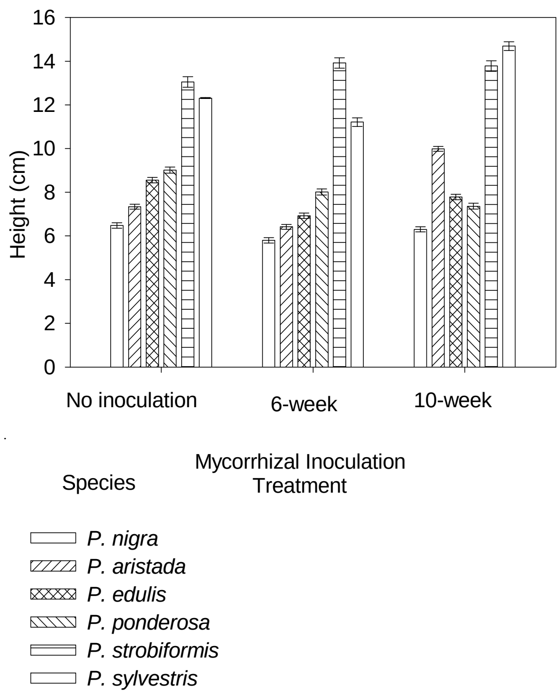

Figure 1. Influence of mycorrhizal inoculation on 20-week height of container-grown pine species.

Results and Discussion

The influence of *Pisolithus tinctorius* inoculation on shoot development in the first experiment varied between species with three species (*P. edulis, P. nigra* and *P. ponderosa*) being adversely affected by inoculation (see Tables 4-2, 4-3, Figures 1 and 2). While inoculation had a statistically significant impact on both shoot attributes (height and caliper) of all species, except caliper size in *P. edulis*, actual differences in shoot sizes were quite small (see Figures 1 and 2). This resulted in very little variability in overall shoot sizes of treated seedlings used in the third experiment. Similarly, both inoculation and growth media composition impacted both shoot parameters of *P. ponderosa* in the second experiment, though the differences were quite small (see Table 4-4 and 4-5). In this experiment, the range of average stem caliper among treatments was less than 1.1 mm. Average seedling size for all the species produced in this study, regardless of inoculation treatment, was smaller than expected. This may have been due, in part, to the lower fertility regime used. Traditionally, these species are produced using a combination of slow- release and water-soluble fertilizers. The fertility regime used in this study relied solely on the slow-release fertilizer. The target minimum shoot height for conifer seedlings produced at the Mora Nursery is 15 cm. Average shoot height of seedlings produced in this study ranged from 14 cm for *P. strobiformis* and *P. sylvestris* to 6.5 cm for the slower growing *P. edulis*.

Table 4-2: Analysis of Variance Table for Pisolithus tinctorius Inoculation Effects on Caliper and Height Growth for Six Pine Species

		Height Growth		Caliper Growth	
Source	**df**	**MS**	**Pr>F**	**MX**	**Pr>F**
Model	17	40.68	0.0001	1746.37	0.0001
Species (S)	5	116.72	0.0001	1040.01	0.0001
Inoculation (I)	2	5.61	0.0001	93.58 0.0001	
S * I	10	9.68	0.0001	44.71	0.0001
Error	3480	0.28		5.09	

Both inoculation treatments were successful in colonizing the root systems of all treated seedlings in all six species evaluated. Over 70% of the feeder roots of inoculated seedlings had evidence of mycorrhizal colonization compared to less than 5% of all the feeder roots inspected in the control group. All seedlings in both the six-week and ten-week inoculation treatments had mycorrhizal colonization based on visual inspection. The outer part of the root balls of these seedlings had very pronounced hyphal layers and a considerable amount of root bifurcation. The amounts of both these attributes were considerably greater than is normally observed in the nursery, indicating that the elevated levels were due to the inoculation treatments. This colonization is in contrast to the control seedlings where the hyphal wefts, if present, were smaller and the frequency of root bifurcation less. Other studies have also found that unless intentionally inoculated, container grown seedling mycorrhizal colonization can be sporadic (Marx 1991). Since, mycorrhizal species was not identified as part of this process we cannot confirm the hyphal wefts and root bifurcation were from the *P. tinctorius* used in the inoculum. However, the scant amount of mycorrhizal roots in the control group or elsewhere in the nursery lead the investigators to conclude the mycorrhizae present in the root systems of inoculated seedlings was the applied *P. tinctorius.*

First year survival was influenced by tree species, blocking, their interaction and the interaction of tree species and inoculation treatment (see Table 4-6). Overall, species survival ranged from 59% for *P. flexilis* to 26% for the *P. ponderosa* grown in the lowest density, 1:2:1 media (see Figures 3, 4). Only in two species, *P. nigra*, and *P. strobiformis*, was survival influenced by an inoculation treatment relative to control (**see** Table 4-7). In *P. strobiformis*, both inoculation treatments improved survival. *P. nigra* seedlings, inoculated at ten weeks after germination, had reduced survival compared to control seedlings and seedlings inoculated six weeks after germination (see Figure 3). The results are in contrast to other reported studies where mycorrhizal seedlings had improved survival (Marrs et al. 1999, Cordell et al. 1999). In these studies and reviews, overall improvement in survival ranged from 3% (Davies and Call 1990 as cited by Marrs et al. 1999) to over 35 % (Cordell et al. 1999).

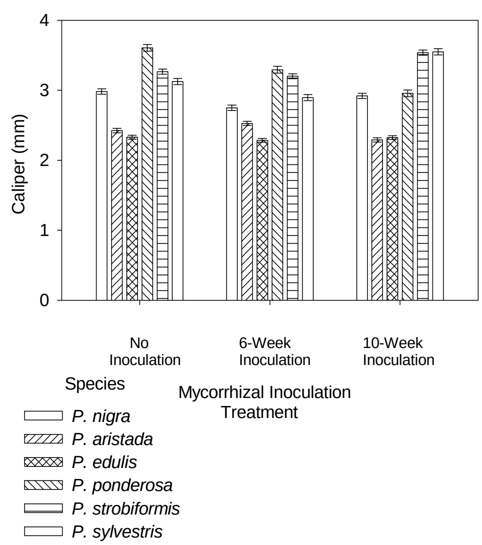

Figure 2. Influence of mycorrhizal inoculation on 20-week stem caliper of container-grown pine species. Bar reflects +/- one standard error.

Table 4-3: Summary Analysis of Vairance on the Effect of *Pisolithus tinctorius* Inoculation on Caliper and Height Growth of six pine species, analyzed by Species.

			Caliper Growth		Height Growth	
	Source	**Df**	**MS**	**Pr>F**	**MS**	**Pr>F**
P. aristata	Inoculation	2	2.73	0.0001	667.34	0.0001
	Error	569	0.18		2.35	
P. edulis	Inoculation	2	0.11	0.4712	130.33	0.0001
	Error	582	0.14		2.89	
P. nigra	Inoculation	2	2.89	0.0001	24.39	0.0002
	Error	583	0.28		286	
P. ponderosa	Inoculation	2	20.56	0.0001	135.86	0.0001
	Error	585	0.46		3.72	
P. strobiformis	Inoculation	2	6.25	0.0001	42.29	0.0228
	Error	583	0.25		11.12	
P. sylverstris	Inoculation	2	21.43	0.0001	613.52	0.0001
	Error	578	0.37		7.5	

Table 4-4: Analysis of Variance Table for the Effect of *Pisolithus tinctorius* Inoculation and Growth Media Composition on *Pinus ponderosa* Shoot Caliper and Height Growth After 20 Weeks.

		Caliper Growth		Height Growth	
Source	**Df**	**MS**	**Pr>F**	**MS**	**Pr>F**
Model	8	20.35	0.0001	116.22	0.0001
Media (M)	2	14.83	0.0001	39.81	0.0001
Inoculation (I)	2	3.52	0.0004	150.08	0.0001
M * I	4	31.52	0.0001	137.55	0.0001
Error	1744	0.44		3.36	

Table 4-5: Influence of *Pisolithus tinctorius* Inoculation Treatment and Growth Media Composition on Caliper and Shoot Height Growth of Container Grown *P. ponderosa* Seedlings.

Media Composition	Inoculation	Caliper (mm) (mean ± S.E.)	Shoot Height (cm) (mean ± S.E.)
Light (121)	None	2.5 ± 0.05	7.6 ± 0.13
Light (121)	@ 6 weeks	3.0 ± 0.05	7.6 ± 0.13
Light (121)	@ 12 weeks	3.5 ± 0.05	8.6 ± 0.13
Medium (111)	None	3.0 ± 0.05	8.4 ± 0.13
Medium (111)	@ 6 weeks	2.9 ± 0.05	6.4 ± 0.13
Medium (111)	@ 12 weeks	3.2 ± 0.05	8.1 ± 0.13
Heavy (211)	None	3.6 ± 0.05	9.0 ± 0.13
Heavy (211)	@ 6 weeks	3.3 ± 0.05	8.0 ± 0.13
Heavy (211)	@ 12 weeks	3.0 ± 0.05	7.4 ± 0.13

The magnitude of the blocking effect, when analyzed in the complete model or by species, was an overriding factor in the survival response (see Figure 5). Survival between blocks ranged from slightly over 8% in block 5 to near 70% in blocks 1 and 2.

This may be due to differences in substrate geology (see Table 4-1) and probably more importantly, the depth achieved during the ripping process prior to planting. Other studies have found or implied the deleterious effect of compaction on seedling survival (Cleveland and Kjelgren 1994; Graves 1999; Vimmerstedt et al., 1999). In field notes at the time of planting it was noted that blocks 5, 6, and 7 all had a high occurrence of shallow ripping (approximately 15 cm). These three blocks also had the lowest first-year survival rates. Others have reported improved survival when treatments such as tillage, ripping or backhoe excavation are used to mitigate the effects of compaction (Cleveland and Kjelgren 1994; Graves 1999; Vimmerstedt et al., 1999). While compaction (blocking) appeared to influence survival, it did not influence the survival response to inoculation (see Table 4-6).

Table 4-6. Categorical Analysis of Variance Table for First Year Survival of Seedlings of Seven Pine Species Receiving Differing *Pisolithus tinctorius* Inoculations

Source	df	Chi-Square	Observed Significance Level
Intercept	1	51.78	0.0001
Species	6	47.46	0.0001
Inoculation	2	5.12	0.0774
Block	7	198.83	0.0001
Species * Inoculation	12	32.77	0.0011
Species * Block	42	124.16	0.0001
Inoculation* Block	14	11.02	0.6843
Species*Inocul.*block	84	186.30	0.0001

Table 4-7: Summary Categorical Analysis of Variance Table for the Effect of *Pisolithus tinctorius* Inoculation on First-Year Survival of Seven Pine Species by Species.

	Source	df	Chi-Square	Observed Significance Level
P. aristata	Inoculation	2	7.0	0.0300
	Block	7	48.9	0.0001
	Inoculation * Block	14	26.0	0.0300
P. edulis	Inoculation	2	0.8	0.6800
	Block	7	48.7	0.0001
	Inoculation * Block	14	29.6	0.0100
P. flexilis	Inoculation	2	1.6	0.4500
	Block	7	64.8	0.0001
	Inoculation * Block	14	22.5	0.0700
P. nigra	Inoculation	2	17.2	0.0001
	Block	7	35.7	0.0001
	Inoculation * Block	14	30.8	0.0100
P. ponderosa	Inoculation	2	4.3	0.1200
	Block	7	34.4	0.0001
	Inoculation * Block	14	20.2	0.1200

Table 4-7: Summary Categorical Analysis of Variance Table for the Effect of *Pisolithus tinctorius* Inoculation on First-Year Survival of Seven Pine Species by Species.

	Source	df	Chi-Square	Observed Significance Level
P. strobiformis	Inoculation	2	6.7	0.0300
	Block	7	18.8	0.0100
	Inoculation * Block	14	39.9	0.0001
P. sylverstris	Inoculation	2	0.9	0.6500
	Block	7	38.4	0.0001
	Inoculation * Block	14	32.5	0.0001

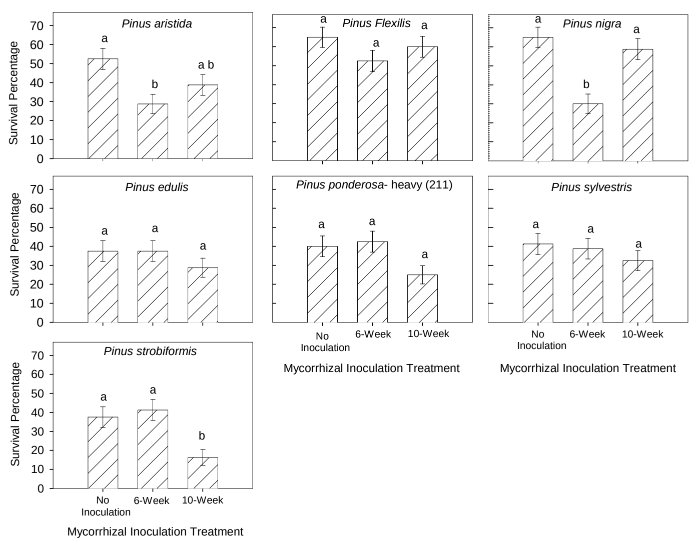

Figure 3. Influence of mycorrhizal inoculation and species on first-year survival of container-grown pine seedlings planted on over-burden. Bar reflects +/- one standard error. Means within a species with the same letter are not significantly different at alpha = 0.05.

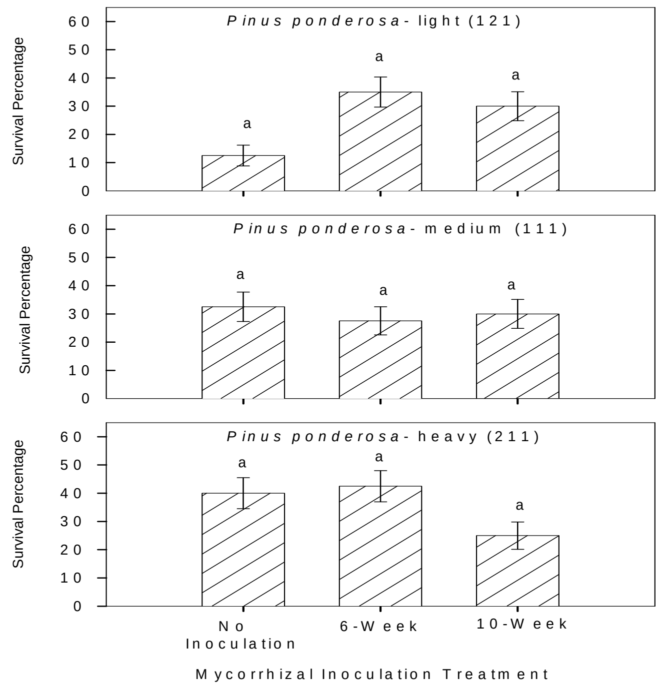

Figure 4. Influence of mycorrhizal inoculation and media density on first-year survival of *P. ponderosa* seedlings planted on overburden. Bar reflects +/- one standard error. Means within media density with the same letter are not significantly different at alpha = 0.05.

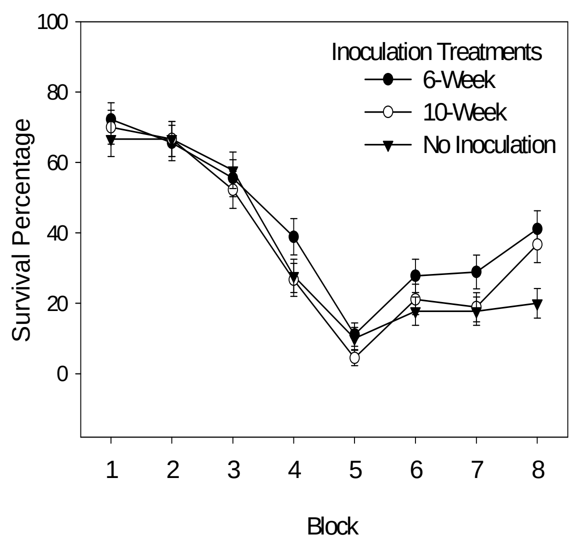

Figure 5. Effect of Interaction between mycorrhizal inoculationtreatment and blocking on survival of pine seedlings planted on overburden. Bar reflects +/- one standard error.

Conclusions

From this work, artificial inoculation of conifer seedlings with mycorrhizae merits further investigation. It is clear that changes to production techniques in the greenhouse are needed in order to produce seedlings meeting target height in the expected time. The benefit of *P. tinctorius* inoculation may be species-specific with only one of the seven species having first-year survival improved by inoculation in this study.

Acknowledgements

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Evaluation Of Giant Sacaton For Use In Field Windstrips Rancho la Frontera, Columbus, NM

By: Danny G. Goodson[20]

Study Number: NMPMC-P-9801-CP

May 24, 2001 Planting and Evaluation:
On May 24, 2001, a windstrip was installed on Mr. Aker's Rancho la Frontera near Columbus, NM. The windstrip was installed to help reduce wind erosion of the farmland next to the road. The windstrip is a 1000-foot, single-row of Giant Sacaton transplants that were spaced 6 feet apart. The transplants were started from seed in a greenhouse at the New Mexico Plant Materials Center (NMPMC) in Los Lunas, NM. The seed to start the transplants was harvested from Giant Sacaton plants grown at the NMPMC.
The 167 transplants were hand-transplanted along an underground drip irrigation line. This drip line receives water from the farm's irrigation system. Chemigation provides the necessary nutrients to the plants through the irrigation system.

On May 26, 2001, Mr. Akers installed another 1000 feet of windstrip. Because a drip line had not been connected to the irrigation system, this planting was not done at the same time as the May 24 planting. This subsequent planting was installed using the same procedure as the May 24 planting.

We will evaluate the 6-foot spacing to determine if a greater width and height can be reached by increasing the amount of in-row spacing.

Existing Windstrips:

- I visually inspected the condition of the 1999 and 2000 windstrip plantings. As of this date, the windstrip had not been mowed. Both plantings looked very good and had quite a bit of new growth among the previous growth from 2000.
- Elmer Veeder of the NRCS Deming Field Office, Mr. Akers and I discussed maintaining the windstrip. To promote new, vigorous growth and to remove the old growth, we advised Mr. Akers to mow the windstrip as soon as possible. Mr. Akers hopes that he will be able to harvest seed (possibly as soon as 2001) to plant additional windstrips.

Water Erosion Plantings:

- I checked the seeding of vine mesquite in a flush-ditch system. Several vine mesquite plants have established, and they are exhibiting good, vigorous growth. We are evaluating the use of vine mesquite in Mr. Akers flush-ditch system to determine its potential for reducing soil erosion in these ditches. To adequately make this determination, more plantings will have to be established.

[20] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

August 2, 2001 Evaluation

- The 1999 and 2000 windstrip plantings looked very good and had put on excellent growth since being mowed in May 2001. The plants responded very well to the mowing, and they should provide excellent wind erosion protection next Spring. The plants averaged a seed stalk height of 68 inches and a foliage height of 52 inches. Seed production from the plants looks very promising and should provide seed for Mr. Akers to produce more plants of Giant Sacaton in future years.
- The May 24 and 26, 2001 windstrip planting was in very poor condition. We noted a very low survival rate, and the surviving plants had not grown since they were transplanted. The plants were pale green in color and appeared to be dying. This site may contain a residual chemical in the soil, and all of the plants may be lost this year. I will perform another evaluation in the fall to check for survival rate and growth, but we will have to replant the windstrip.

October 25, 2001 Evaluation

On October 25, 2001, we checked all of the plantings for survival and growth:

- The 1999 and 2000 windstrips continue to look very good, and they had an average seed stalk height of 78 inches and foliage height of 60 inches. The plants had produced an abundant seed crop, and Mr. Akers was able to collect seed. We determined that we needed to raise the mowing height to approximately 12 inches. This new height will be evaluated in 2002 to determine if it will promote more growth in the plants.
- The May 2001 windstrip planting looked much healthier than it had in August 2001. The survival rate was at 32 percent. The plants' color was greener, and their growth was fairly good. Foliage height averaged 18 inches. Some plants had seed stalks, and those stalks averaged 30 inches in height.

The plants had survived whatever chemical was present at the time of planting, and they appeared to be established. The windstrip still needs to be replanted in 2002. We recommend using larger transplant material in the replanting effort. By the next planting in 2002, the chemical or chemicals in the soil may have degraded to a point that will allow the plants a better chance to survive and become established.

Alma blue grama–Foundation Quality Seed Production

By: Danny G. Goodson[21]

Study Number: NMPMC-S-8801-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
7 and 8	2.7	1983 and 1988	90 lbs. Nitrogen 130 lbs. Phosphorous	(3" application) 6/7/01 6/29/01 7/15/01 9/12/01	11/2/01	59 lbs.

[21] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

El Vado spike muhly
Foundation Quality Seed Production

By: Danny G. Goodson [22]

Study Number: NMPMC-S-0002-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
7	0.25	09/19/2000	150 lbs. Nitrogen 100 lbs. Phosphorous	(3" application) 4/10/01 5/2/01 5/16/01 6/12/01 7/12/01 7/29/01 9/12/01	10/31/01	3.18 lbs.

[22] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Elida sand bluestem–Breeder Quality Seed Production

By: Danny G. Goodson [23]

Study Number: NMPMC-S-8803-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
31S	0.14	1988	50 lbs. Nitrogen 50 lbs. Phosphorous	(3" application) 5/16/01 6/13/01 7/13/01 8/10/01	8/6/01	

[23] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Grant cane bluestem
Foundation Quality Seed Production

By: Danny G. Goodson [24]

Study Number: NMPMC-S-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
9	1.75	1999 and 2000	100 lbs. Nitrogen 100 lbs. Phosphorous	(3" application) 5/23/01 6/25/01 9/14/01	8/6/01	27.24 lbs.

[24] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Hachita blue grama
Foundation Quality Seed Production

By: Danny G. Goodson [25]

Study Number: NMPMC-S-7801-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
16 and 19	2.0	1963 and 1973	125 lbs. Nitrogen 130# Phosphorous	(3" application) 6/22/01 8/10/01	10/24/01	116 lbs.

[25] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Evaluate Forage triticale Planting at Jeff Glenn Farm

By: Danny G. Goodson[26]

Study Number: NMPMC-T-00001-PA

Background

On September 5, 2000, a trial demonstration of triticale was planted on Mr. Glenn's farm. Three, 3-acre plots were seeded with three different varieties of Triticale:

- Trical 102
- Curtis and Curtis Seed triticale
- Kelly Green Seeds Plus B (a blended variety of wheat and oats)

To plant the seed, they used a John Deere 8300 grain drill. Mr. Glenn completed the irrigation and fertilization during the growing season. Cattle grazed the plots as soon as the plants had sufficient growth. All plots have received the same management during the trial.

November 6, 2000 Evaluation

I visually checked the plots for germination and growth. No significant difference could be seen in the plots at that time. Twenty pounds per acre of a liquid Nitrogen fertilizer had been applied to the plots, and irrigation was applied to promote optimum growth. Gary Garrison of the Silver City Field Office established a clipping frame inside an enclosure on each of the three plots.

May 25, 2001 Evaluation

I visually checked the plots a second time on this date. Cattle have been grazing the plots since December 2, 2000 in a rotational grazing scheme. Mr. Glenn stated that grazing would continue for one more rotation, and then he would disk-out the plots. Gary Garrison established and maintained a clipping schedule of the frames during the grazing season. Mr. Glenn noted the trical 102 plot did not appear to be as productive as the other varieties during the entire grazing period.

Gary Garrison recorded the following clipping data for the Forage triticale trial Demonstration. A 9.6 square foot clipping frame was used to collect the forage. Clipping height approximated the average grazed height of the pasture:

- Seeded on 9/5/2000
- Grazing trial began on 12/2/2000

[26] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Date	Trical 102 Lbs/Ac	Plus B Lbs/Ac	Curtis and Curtis Lbs/Ac
12/7/2000	1128 gw* 429 adw**	1606 gw 610 adw	1162 gw 476 adw
1/2001	1316 gw 526 adw	1090 gw 384 adw	1498 gw 584 adw
3/16/2001	621 gw 267 adw	535 gw 237 adw	441 gw 174 adw
4/24/2001	525 gw 250 adw	434 gw 240 adw	425 gw 174 adw
5/14/2001	290 gw 111 adw	332 gw 123 adw	437 gw 141 adw
Total gw	3870	3963	3997
Total adw	1583	1549	1594

* gw=green weight
** adw=air dry weight

Conclusions

The data from the clipping plots suggests little difference in the amount of forage produced by each of the varieties. The trical 102 had a smaller amount of forage available, and this possibly reduced the grazing potential of Mr. Glenn's pasture. Overall the Curtis and Curtis triticale seems to have performed better, especially early and late in the grazing season but not at a significant rate.

This was a forage trial only, and animal production was not determined in any respect. The forage plots were treated equally during the grazing period, and the results were based upon clippings and visual observations only.

Forage triticale varieties are being developed continually. Trial plantings should be done to evaluate their potential at this locale or wherever triticale is being grown for forage. Mr. Glenn has expressed a desire to continue with Forage triticale trial studies on his farm. We will make contacts with triticale specialists to select other varieties that may be tried in this area.

Jose tall wheatgrass
Foundation Quality Seed Production

By: Danny G. Goodson [27]

Study Number: NMPMC-S-6501-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
16	1.0	1965	150 lbs. Nitrogen 75 lbs. Phosphorous	(3" application) 4/3/01 4/30/01 5/18/01 6/5/01 7/16/01 10/11/01 10/29	8/23/01	234 lbs.

[27] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Largo tall wheatgrass
Foundation Quality Seed Production

By: Danny G. Goodson [28]

Study Number: NMPMC-S-9902-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
12	0.45	5/3/1999	150 lbs. Nitrogen 50 lbs. Phosphorous	(3" application) 4/3/01 4/27/01 5/15/01 6/7/01 6/29/01 7/23/01 9/24/01 10/23/01	8/27/01	57.04 lbs.

[28] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Demonstration Range Seeding Mulch Trial at David Olgilvie Ranch

By: Danny G. Goodson [29]

Study Number: NMPMC-T-02101-CP

Background

The NRCS Silver City Field Office requested assistance from the New Mexico Plant Materials Center (NMPMC) concerning a revegetation project on the David Olgilive Ranch. The Olgilive Ranch is located between Silver City and Cliff, New Mexico, and the Mangus Creek runs through it. The part of the Mangus that runs through the affected area is a severely eroded channel, approximately 20 feet deep and ranging from 50 to 100 feet wide. For many years, this area along the creek has been overgrown with annual weeds mainly consisting of Russia Thistle, Kochai, and Annual Sunflowers. No perennial forage, especially native grasses, has returned to the large sections of the valley. Why the native vegetation disappeared is not clearly understood. Native rangeland in the surrounding foothills contains good stands of native forage, and therefore a seed bank along the creek is available for revegetating, but for some unknown reason this has not taken place.

May 25, 2001 Evaluation

On May 25, 2001, Gary Garrison from the NRCS Silver City Field Office and I visited the ranch. Except for annual weeds, we did not observe any green vegetation, although there was some widely scattered, native grass species such as Sand dropseed, Giant Sacaton, and Galleta in the vicinity. Mr. Olgilive's livestock are grazing in this pasture. Mr. Olgilvie has expressed the desire to revegetate the valley to improve the native forage and to improve the grazing potential of his ranch. Reducing the amount of annual weedy species would also help to alleviate the hazard of blowing debris against fencelines and across the state highway that runs through the valley.

August 1, 2001 Planting

On August 1, 2001, the seed and mulch to be used in the trial planting was delivered to the Silver City Field Office. Over the next few days, a plot was established on the valley floor. Mr. Olgilvie and the Silver City Field Office staff completed seeding and mulching. The following species of seed was planted in the trial plots:

- Sideoats grama
- Blue grama
- Galleta
- Alkali Sacaton.

To break up the soil surface, they prepared the seedbed by dragging a harrow behind a truck. They then hand-broadcast the seed over the trial plot. The trial plot consisted of

[29] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

two areas measuring approximately 50 square feet. On one of the areas, they applied native grass mulch, and on the other area they did not apply any mulch. The PMC produced and provided the mulch used in the trial. The mulch consisted of bales of native grass hay from the seed production fields at the PMC.

October 24, 2001 Evaluation

On October 24, 2001, Gary Garrison and I visually evaluated the demonstration plots. We judged the rainfall on the site to be normal or slightly above normal for the period just prior to and after the seeding occurred.

The area without mulch showed no signs of seedling germination for any of the species. The soil surface in this plot had crusted over, and the soil was dry under the crust. The mulch-covered area had numerous seedlings of at least three of the planted species sprouting through the mulch. The species we noted were Sideoats grama, Blue grama and Galleta. The seedlings appeared to be established and vigorous.

The native grass bales used for the mulch contained seed, and we hope this seed will germinate and produce additional plants in the plot. Two species of native grass (Bottlebrush squirreltail and Indian ricegrass) were used as mulch and should produce seedlings in 2002.

Conclusions

We need to test different types of mulch. The area needing revegetation is quite large, and we need to identify the best and most economical methods of mulching.
We will evaluate the trial plots again in 2002, and more seeding trials will be discussed with the landowner and the Silver City Field Office.

Paloma indian ricegrass
Foundation Quality Seed Production

By: Danny G. Goodson [30]

Study Number: NMPMC-S-9401-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
8 and 25N	1.0	11/17/1992 12/1/1999	75 lbs. Nitrogen 75 lbs. Phosphorous	(3" application) 3/29/01 4/10/01 4/23/01 5/4/01 5/17/01 6/19/01 8/10/01 10/9/01 10/23/01	5/25/01	50.34 lbs.

[30] Agronomist, Natural Resources Conservation Services, New Mexico Plant Materials Center, Los Lunas, NM

Evaluation Riparian Species for Erosion Control at the Wendell Reagan Ranch

By: Danny G. Goodson [31]

Study Number: NMPMC-T-9801-RI

Background

In 1998 a riparian planting was installed close to Mr. Wendell Reagan's ranch located near House, New Mexico. The planting is located on the along the face of a cutbank in the Truchas draw which is a dry arroyo that runs through Mr. Reagan's ranch. The planting was established using unrooted, cut poles of five different riparian species; Cottonwood, Willow, Seepwillow, Stretchberry and False Indigobush. The poles were cut from stock grown at the New Mexico Plant Materials Center (PMC)

October 30, 2001 Evaluation

On October 30, 2001, I performed an evaluation of the erosion control riparian planting at the Regan Ranch. The arroyo has developed a series of cutbanks that contribute heavy loads of silt to the drainage, and they have reduced the amount of Mr. Reagan's available grazing land. The water erosion has resulted in having to relocate a fenceline on the property's boundary each time the bank sloughs off into the channel.

I examined the survival and growth rates of the planting. The plants have not been protected from livestock since the installation. Damage produced by the livestock continues to be a problem. Growth of the surviving trees was minimal in 2001. The survival rate has not changed from 2000, and those trees that were not damaged by animals appear to be good shape. Several trees that were previously damaged are surviving and have sprouted new growth below the damaged areas.

Conclusions

This site needs protection from livestock, and it should receive additional plantings of riparian species. Coyote willow has done well on the site, and additional plantings of this species would contribute to stabilizing the soil in the channel. This would allow native species of grasses and shrubs to become established.

Because this was a dryer than normal year for precipitation, no major flow events were noticed along the planting site. As the established plants continue to grow, erosion during flow events should be reduced at this site. The established plants may also be a seed source for the area when they reach seed bearing age.

A final evaluation will be done in 2002. Further discussions on any additional plantings will be done with the landowner and NRCS staff from the Tucumcari Field Office.

[31] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Salado alkali sacaton
Foundation Quality Seed Production

By: Danny G. Goodson [32]

Study Number: NMPMC-S-6701-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
25N	1.0	5/26/1992	150 lbs. Nitrogen 100 lbs. Phosphorous	(3" application) 6/12/01 7/16/01	No harvest	N/A

[32] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Evaluation Accession Trial at Sam Ray Ranch

By: Danny G. Goodson [33]

Study Number: NMPMC-P-9901-RA

Background

To help improve the grazing potential on his ranch, Mr. Sam Ray requested assistance from the NRCS Field Office in Datil, New Mexico in February 1999. The Datil Field Office contacted the New Mexico Plant Materials Center (NMPMC) to set up a demonstration range seeding on Mr. Ray's ranch. The seeding would be an attempt to vegetate the area with native range grasses and shrubs. Also, this trial planting would be used to evaluate the species potential for use in reseeding attempts in this area of the state.

In 1999, the trial planting was completed on the Sam Ray ranch (located near Quemado, New Mexico). The planting consisted of 12 different native species and was installed using the PMC plot drill. The site was disked to prepare the seedbed for drilling, and it was fenced to protect it from livestock.

The following accessions and cultivars were seeded into 200-foot rows, 12 rows per plot. The rows were spaced 1 foot apart, and each plot contains one accession or cultivar:

Accession/Cultivar	Scientific Name	Common Name
Arriba	*Pascopyrum smithii*	Western Wheatgrass
NM 812	*Atriplex canescens*	Fourwing Saltbush
Pastura	*Schizachyrium scoparium*	Little Bluestem
Niner	*Bouteloua curtipendula*	Sideoats Grama
Hachita	*Bouteloua gracifis*	Blue Grama
9066433	*Dalea candida*	White Prairieclover
Nogal	*Bouteloua eriopoda*	Black Grama
Lovington	*Bouteloua gracilis*	Blue Grama
Salado	*Sporobolus airoides*	Alkali Sacaton
9066390	*Bothriochloa barbinodis*	Cane Bluestem
NM-333	*Krascheninnikovia lanata*	Winterfat
Viva	*Pleuraphis jamesii*	Galleta
Rodan	*Pascopyrum smithii*	Western Wheatgrass
Elida	*Andropogon hallii*	Sand Bluestem

[33] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

November 2, 2001 Evaluation

This evaluation revealed that little germination had occurred. Mr. Ray stated that very little precipitation had occurred since the planting. The planting produced a few plants of Fourwing saltbush, Galleta, and Western wheatgrass, but not enough to count as being established on the site. The planting was installed late in the growing season, which may have affected the outcome. Any plants that did germinate may have died due to winter. Weeds may have also contributed to the failure of the plantings. Texas blueweed is on the site and could have provided enough competition to hinder the germination and growth of the seeded species.

Conclusions

Mr. Ray would like to try to establish this demonstration planting again. The new planting should be accomplished no later than July 30th 2002 so that the seedlings have a better chance to survive the winter period. Also, an expanded list of native species should be used in the seeding. Seedbed preparation and weed control will be mandatory for this and any future plantings at this location.

Develop Plan for Evaluating Initial Evaluation Planting, tobosa grass

By: Danny G. Goodson [34]

Study Number: NMPMC-P-8301-RA

Background

On August 7, 2001, I evaluated the tobosa (*Hilaria mutica*) initial planting. Using the 2001 data, and data from previous years, the staff at the New Mexico Plant Materials Center (NMPMC) selected seven accessions to use for advanced studies. I will continue to evaluate these selections along with producing new seed for use in evaluation studies. These evaluations will be both on and off the NMPMC, using field trials and demonstration projects. Release of a tobosa accession will be determined by the outcome of these trials and plantings.

August 7, 2001 Evaluation

The following accessions have been selected from the planting in Field 6 on the NMPMC to be used for advanced testing purposes:

Accession	Collection Location
476275	Jornada Range Exp Station, Dona Ana County
9009424	Horse Canyon, Dona Ana County
9009413	Lordsburg, New Mexico
9009414	Lordsburg, New Mexico
9009419	Muir Ranch, Hidalgo County
9009418	Lordsburg, New Mexico
9009420	Las Cruces, New Mexico

Conclusion

We will lift these accessions from Field 6 during the winter of 2001–2002. To start new tobosa grass plants, we will divide the lifted accessions, place them into containers, put them in the greenhouse, and allow them to reach the replanting stage. We then will transplant the new plants into a new field at the NMPMC. These new plants will start the evaluation process again, and they will produce a release of tobosa grass.

[34] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Tusas bottlebrush squirreltail Foundation Quality Seed Production

By: Danny G. Goodson [35]

Study Number: NMPMC-S-9903-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
13	.95	5/3/1999	75 lbs. Nitrogen 75 lbs. Phosphorous	(3" application) 4/16/01 5/10/01 6/29/01 10/11/01	6/8/01	136 lbs.

[35] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Vaughn sideoats grama
Foundation Quality Seed Production

By: Danny G. Goodson [36]

Study Number: NMPMC-S-9401-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
25N	.33	5/26/1992	50 lbs Nitrogen 50 lbs. Phosphorous	(3" application) 5/17/01 6/19/01 7/12/01 8/10/01 10/11/01	No harvest	N/A

[36] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Viva galleta grass
Foundation Quality Seed Production

By Danny G. Goodson [37]

Study Number: NMPMC-S-7501-RA

Field #	Acres	Planting Date	Year 2001 Fertilizer Applications	Irrigation Dates	Harvest Date	Harvest (Cleaned Wt.)
13	3.20	1975	100 lbs. Nitrogen 100 lbs. Phosphorous	(3" application) 6/20/01 7/31/01 9/24/01 10/11/01	No harvest	N/A

[37] Agronomist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Demonstration Planting at El Pueblo Acequia Pecos River, San Miguel County, New Mexico

By: Gregory A. Fenchel [38]

Study Number: NMPMC-T-0102-RI

Introduction

1,650 coyote willows and 60 black willows were to be planted on the West Bank of the Rio Pecos April 9–12, 2001 at the newly built Army Corps of Engineer's diversion dam near El Pueblo, New Mexico. This planting is mitigating for loss of wildlife habitat associated with this construction project. This planting will also provide an opportunity for a demonstration planting on using only vegetation to control erosion of newly contoured riverbank and to test the Plant Material Center's (PMC's) new technique to use an electric rotary hammer drill to install willows in very cobbled and gravely soil.
The planting was delayed by two weeks so the dam could be completed. During the time of the delay, the willow pole cuttings began to grow roots (see Figure 24-1) where the cutting was in contact with water. As spring progressed, the air temperature increased which raised the temperature of the water in the tanks and accelerated the rooting process. This process is usually considered undesirable because some of the limited stored energy in the willow stem is utilized for root growth, and the new roots are often rubbed off during the planting process.

Figure 24-1: Cuttings growing in water tanks.

The site where the 60 black willows were to be planted was not ready by April 12. The contractors had not leveled or seeded the site with herbaceous cover, so it was not planted with the willows. The site was leveled and fenced, but there was no evidence of a seeding (see Figure 24-2). The PMC will plant black willow pole cuttings in February or March of 2002.

Methodology

The source of the coyote and black willow is the Middle Rio Grande Valley, NM at approximately 5000-ft. in elevation. Once cut, the willows poles were kept hydrated in tanks of water until they could be transported to the planting site. The willows were planted with electric rotary hammer drills (DeWALT® Model DW530) fitted with 1-inch diameter, 3-foot bits (see Figure 24-3).

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[38] Manager, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

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Figure 24-2: Planting location for black willow pole planting.

With one drill, two people can plant 500 willow poles per day to a 3-foot depth. The new riverbank was built with a small bulldozer on somewhat steep slopes nearly at the angle of repose (see Figure 24-4).
Because of the steep incline of the bank, willows were planted at a relatively dense rate on approximately 1-foot centers from the edge of the river to the crest of the bank.. To help stabilize the bank, the willows were planted for approximately 200 linear feet (see Figures 24-5 and 24-6).

Results

On June 12, 2001, the willows were evaluated for survival rates. The willows have a 91% survival rate with a total of 137 willows considered dead because they did not have any green leaves.

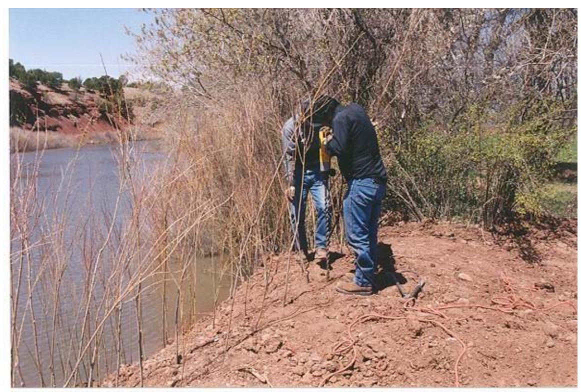

Figure 24-3: Planting Coyote willow using a hammer drill.

Some willows that were considered dead could possibly resprout at the base during this current growing season. Those that were dead were generally found on the upper slope of the bank where they may have been above the capillary soil moisture from the stream (**see Figures 24-7 and 24-8**). Overall, the willows planted looked very vigorous. Currently, there does not appear to be any surface soil erosion where the willows have been planted.
The Hammer drills worked moderately well in the rocky soil. They were able to generate 3-foot holes most of the time. However, the drill bits did get jammed between the rocks in some holes preventing them from rotating. Consequently, the drill would spin instead of the bit, forcing the operator to release the drill.

Figure 24-4: Newly contoured riverbank before planting

Figure 24-5: Willows planted to edge of river

Figure 24-6: Same location showing willows were planted to the crest of the bank.

Figure 24-7: Willow on the upper bank may have become droughty and died.

Figure 24-8: A second location where willow died on the upper bank.

Tall Pot Transplants Established With Hydrogel

By: Gregory A. Fenchel [39]*, David R. Dreesen* [40]*, Joseph G. Fraser* [41]

Study Number: NMPMC-T-0001-RA

Introduction

Developing a successful transplanting system that has minimal follow-up maintenance, particularly irrigation was needed for landscaping highway medians and right-of-ways in the arid southwest. Container planting of shrubs, with some irrigation, is essential for successful revegetation of most dry sites. The selection of tall-pot containers coupled with the application of a superabsorbent hydrogel (sodium carboxymethyl cellulose) for irrigation is being tested at three locations in northern New Mexico that receive an average annual precipitation of 10 to 14 inches (see Appendix A). Two superabsorbents having substantially different cost per application are also being evaluated. The New Mexico State Highway and Transportation Department (NMSHTD) was the primary funding agency for this study and demonstration project. Other funding sources include the Wildland Native Seed Foundation and the New Mexico Plant Materials Center (PMC) Interagency Riparian Group.

The superior performance of containerized transplants grown in tall-pots (containers longer than 24 inches) has been well-documented (see Figure 25-1). After eight years of field experience testing different container size transplants, Bainbridge (1994) concludes that seedlings grown in deep containers (i.e. PVC pipe) have improved survival and growth compared to smaller transplants grown in Super Cells or plant bands. He also found that excellent seedling survival and growth can be expected even in areas with less than 3 inches of rain per year if plants are properly planted and provided with minimal water (2-3 supplemental waterings totaling about 2 quarts). The Center for Arid Lands Restoration at Joshua Tree National Monument in California has developed a tall-pot made with 32 inch tall, 6 inch diameter PVC pipe with a wire mesh base held by cross wires. Survival rates for 32-inch transplants on a south-facing slope in the low desert were more than 40 percent greater than for 16-inch transplants (Holden 1992).

Figure 25-1: 28-inch rootball of a shrub grown in a PVC tall-pot

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Plant trials on mill tailings disposal sites have shown that it is essential to supply irrigation water during the first two growing seasons where annual precipitation is 11 to 12 inches (Ludeke, 1977).

As an alternative to traditional irrigation, a superabsorbent hydrogel can be applied. A superabsorbent hydrogel is a crosslinked polymer or acrylonitrile with cellulose that absorbs and retains water hundreds of times its own weight. There are several types of superabsorbents that have been developed (see Table 25-1).

Table 25-1: Types of Superabsorbents

Chemical Name or Ingredient	Market Application	Period
Polyethylene Oxide/sawdust	Soil amendment	1965–1978
Polyvinyl Alcohol	Diapers	1975–present
Acrylonitrile/starch	Tampons, napkins, soil amendment, planting seedlings	1979–present
Potassium Propenoate/Propenamide copolymer	Soil amendment, gel seeding, plug-mix planting, root-dip,	1982–present
Acrylic Acid	Diapers, sanitary napkins, water treatment, soil amendment	1981–present
Acrylamide	Diapers, sanitary napkins, soil amendment	1983–present
Acrylic Acid/Acrylamide	Diapers, soil amendment	1985 – present

Copied from Erazo (1987)

Some superabsorbents have been traditionally used in horticulture and agriculture successfully as soil additives as reported by Erazo (1987) to: 1) improve water holding capacity, 2) improve aeration and drainage of soil mix, 3) reduce irrigation frequency, and 4) increase shelf life of plants in cold storage. Also, some superabsorbents have been used as root dips for shipping and planting bare root seedlings.

DRiWATER, Inc. has developed a unique usage for a superabsorbent as an irrigation source for transplants in arid environments. When the powdered product is hydrated, each granule acts as a tiny water reservoir that becomes available to plants as microbial degradation of the cellulose releases free water that is available for movement into soil or plants through root absorption. DRiWATER, Inc. sells their product either as a powder or already hydrated in quart containers. The product in containers is opened, turned upside down, and partially buried in the root zone of a plant. Additionally, the superabsorbant sold by DRiWATER, Inc. (like some other hydrogels) is appropriate for use with plants because they are nonphytotoxic and have a neutral pH (see Attachment 1).

Methodology

Native shrub species of ecotypes with origins within a 300-mile radius of the planting (see Table 25-2) sites were grown in 30-inch tall, 4-inch diameter sewer pipe at the New Mexico Plant Materials Center located in Los Lunas, New Mexico.

Table 25-2: Native Plant Species and Origin of Shrubs Planted at Milan, Eldorado, and Santa Fe

Scientific Name	Common Name	Accession Number or Cultivar Name	Origin
Amelanchier uathensis	Utah Serviceberry	Commercial	Southwest CO
Cercocarpus montanus	Mountain mahogany	Commercial	North Central NM
Cercocarpus ledifolius	Curl leaf mahogany	Commercial	Southeastern Utah
Forestiera neomexicana	New Mexico privet	Jemez	North Central NM
Philadelphyus microphyllus	Littleleaf mockorange	Commercial	Southwest CO
Prunus virginiana	Chokecherry	9004629	North Central NM
Quercus gambelli	Gambel oak	Commercial	North Central NM
Quercus undulata	Wavyleaf oak	9066437	North Central NM
Rhus trilobata	Three leaf sumac (skunkbush)	Bighorn	Bighorn, WY
Ribes cereum	Wax currant	9066057	North Central AZ
Robinia neomexicana	New Mexico locust	9066428	Northeastern NM
Rosa woodsii	Wood's rose	9066421	North Central NM
Shepherdia argentea	Silver buffaloberry	9066475	Southwest CO
Chamaebatiaria millefolium	Fernbush	9062866	North Central CO
Berberis fremontii	Fremont barberry	9066439	Southwest CO
Krascheninnikovia lanata	Winterfat	9066471	Southwest CO

Depending upon species, it generally takes about three years to produce a mature root ball from seed in this container (some take four years or longer, for example, mountain mahogany, winterfat and Mormon tea). These containers have two split seams that run most of the pipe length to encourage spiraling roots to grow downward and ease root ball removal. The bottoms of the containers are sealed with a porous fabric to allow drainage. The fabric was manufactured with a Spin-Out coating (copper hydroxide) to control root penetration.

During the fall of 2000 and 2001, more than 2,200 transplants of 16 different species were planted in northern New Mexico at three locations: Milan, Santa Fe, and Eldorado Village.

Planting holes were dug with 9-inch diameter, 40-inch long Beltec auger powered by a 50-horsepower farm tractor. Holes, 3-foot in depth, were hand cleaned using standard post-hole diggers. Plants were then removed from containers, placed in holes, and back-filled. Prior to backfilling, an irrigation tube was placed in each hole (see Figure 25-2).

This tube allows the plant to be irrigated with either hydrated sodium carboxymethyl cellulose (HSCC), starched based superhydrogel or water near the bottom of the root-ball to encourage growth of a deeper root system. The irrigation tubes are constructed from a PVC sewer pipe 3-inches in diameter and 40-inches in length**, (**see Figure 25-3). The orifice is capped to prevent animal entry and exposure of the root systems to sunlight. The 10-inch top section of the tube can be removed from the 30-inch perforated main tube body. After the end of the irrigation period (two years), the top 10-inch section of pipe will be removed and the remainder will be back-filled with soil. Because the lower portion of the tube should contain substantial root development, it will remain in place.

Figure 25-2: Watering plants through irrig.ation tubes to hydrate the soil in the root zone (November 2000)

Disturbed soil caused by the shrub planting and irrigation water create an ideal site for weeds to germinate. Weeds should be controlled for optimal shrub growth and visual esthetics. Pre-emergent weed control herbicides are ideal for this use.

The three plantings will be evaluated for survival in fall of 2001 through 2003.

Milan Planting

A total of 99 shrubs and trees were planted on September 12, 2000 on Highway NM 124 median in Milan, NM in front of the NMSHTD District Office. This area receives an annual average precipitation of 10- to 12-inches. The subsurface soil was damp from recent precipitation. The planting covers about 1/4 mile of highway median with the plants spaced on 10-foot centers and separated into four groups (see Figure 25-4 and Attachment 2). Additionally, 16 ponderosa pine and 25 piñon pine were planted December of 2001 when the root-balls of these plants were fully developed.

The HSCC was applied to the plants in early June 2001 (once spring moisture was near depletion). Five apache plume plants that were planted without irrigation tubes received about 5 gallons of surface water. The entire planting received an application of Pendulum herbicide for weed control. An 8-foot swath was sprayed over the top of the shrubs, at the rate of 1 gallon per acre, in March 2000. Plant survival was evaluated on October 10, 2001.

Figure 25-3: Irrigation tubes used in the 3 plantings

Figure 25-4: The planting on the median of NM Highway 124 in Milan (November 2000)

Results:
Plants receiving hydrostarch through the irrigation tubes displayed 98 percent survival rate (see Tables 25-3 and 25-4, and Figures 25-5 and 25-6). The five Apache plume plants that received only surface irrigation died. The 41 shrubs installed in front of the New Mexico State Highway District Office also received regular surface irrigation by the Highway Department. Subsequently, these plants were twice as large as the other plants.

Table 25-3: Survival Rate of Shrubs as of November 29, 2001–Median of Highway NM 124, Milan, NM

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Fallugia paradoxa	Apache plume	Northern Arizona	17	16	94	Good
Forestiera neomexicana	New Mexico olive	Northern New Mexico	12	12	100	Good
Rhus trilobata	Skunkbush sumac	Northern New Mexico	29	29	100	Good
Total			58	57	98	

Table 25-4: Survival Rate of Shrubs as of November 29, 2001–Road Shoulder Irrigated Regularly On Highway 124, Milan, NM

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Forestiera neomexicana	New Mexico olive	Northern New Mexico	36	36	100	Excellent
Robinia neomexicana	New Mexico locust	Northern New Mexico	15	15	100	Excellent
Total			41	41	100	

Eldorado Planting

From November 6 to December 8, 2000, 808 tall-pot, native shrubs were planted on the median of NM Highway 285 (beginning at the Interstate 25 junction and continuing 3 miles south). The area is known as Eldorado Village. This area receives approximately 10–12 inches of annual precipitation. The actual planting took 11 days to complete, but because of snowstorms, the planting was frequently delayed. Community volunteers assisted the PMC with the installation. Volunteers and PMC Staff installed the plants in 5- to15-unit random clusters on the median project (see Figure 25-7) in areas selected by the NMSHTD and by Ms. JoEllen Schilmoeller, liaison for the Eldorado Community

Figure 25-5: New Mexico locust transplants at the conclusion of the first growing season (Fall 2001) on the road shoulder of NM 124, located in front of District Office building.

Highway 285 project. Ms. Schilmoeller also arranged for the more than 25 community volunteers to help with planting and irrigation water that was supplied by the Eldorado Utilities Department. All plants were watered during the last week of the planting period.

In March 2001, the highway median was sprayed with a mix of Pendulum (at the rate of one gallon per acre) and Brominal (at the rate of 1 quart per acre). Many annual weeds had already emerged by this time.

In early May 2001, after plants broke winter dormancy and the soil began drying out from spring moisture, 600 plants received a 2-gallon application of HSCC (see Figure 25-8). 148 plants received 2 gallons of a less expensive, starch-based hydrated superabsorbent (for approximately ¼ of the cost). 30 plants received approximately 3 gallons of water. Plants will receive a second treatment in the spring of 2002. The first year application of HSCC was purchased by the Wildland Native Seed Foundation and donated to this project.

Figure 25-6: New Mexico olive transplants at the conclusion of the first growing season (Fall 2001) on the median of NM Hwy124.

To control weeds, PMC personnel hand-hoed the highway median in July 2001. These median areas were not sprayed with Pendulum and had high densities of annual kochia, Russian thistle, and yellow sweetclover. Weeds compete for water and light potentially reducing survival of transplants. There was excellent weed control in areas that were sprayed with Pendulum (see Figures 25-9 and 25-10).

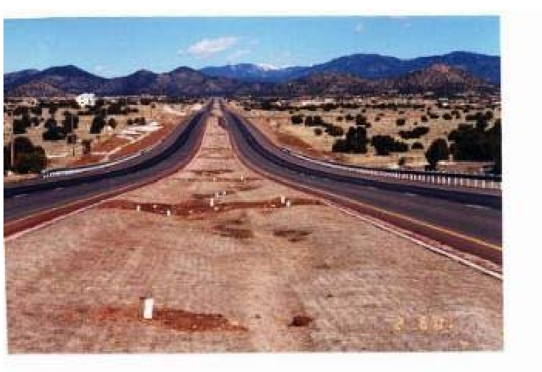

Figure 25-7: Plants were installed in open areas of a blanket seeding on the median of NM Highway 285 (January 2001)

We evaluated the survival rate of the shrubs on June 7, 2001. In September and October of 2001, an additional 921 native shrubs in tall-pots were planted. These plants received a 3-gallon application of water promptly after planting.

Because it was an extremely dry and warm fall season, the plants received a second 3-gallon application of water in late October. The plants continued growing until mid-November.

Results:
Survival of all tall-pot shrubs averaged 97 percent (see Table 25-5). The lowest survival rate was displayed by Apache plume (76 percent) and Mormon tea (72 percent). Apache plume generally does not do well in poorly drained soils. The soils of this highway median were generally high in clay and contained a compacted layer about 6 inches from the surface impeding drainage and aeration. Of all species planted, the Mormon tea generally had the poorest developed root ball. When the plants were removed from their containers, often the outside soil layer, surrounding the root-ball, would crumble.
There was no difference in transplant survival of those receiving the two superabsorbent starches or water. The survival rate averaged 97 percent for both types of starches, and 100 percent for water alone.

Figure 25-8: Applying starch-based superabsorbant to plants on the median of Highway 285 (June 2001)

Figure 25-9: New Mexico locust tall-pot transplants on the median of Highway 285 by conclusion of first growing season (November 2001)

Table 25-5: Survival Rate of Shrubs as of June 7, 2001–Median of Highway 285, Eldorado, NM

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Amelanchier utahensis	Utah serviceberry	Northern Arizona	14	12	86	Good
Krascheninnikovi lanata	Winterfat	Northern Arizona	6	6	100	Fair
Cercocarpus montanus	Mountain mahogany	Northern New Mexico	71	69	97	Good
Cercocarpus ledifolius	Curlleaf mountain mahogany	Northern Arizona	3	3	100	Fair
Chamaebatiaria millefolium	Fernbush	Northern Arizona	37	37	100	Good
Berberis fremontii	Fremont barberry	Northern	10	8	80	Poor

Table 25-5: Survival Rate of Shrubs as of June 7, 2001–Median of Highway 285, Eldorado, NM

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
		Arizona				
Ephedra viridis	Mormon tea	Northern Arizona	18	13	72	Poor
Fallugia paradoxa	Apache plume	Northern Arizona	25	19	76	Good
Lycium pallidum	Wolfberry	Central New Mexico	36	35	97	Good
Nolina microcarpa	Beargrass	Northern Arizona	14	13	93	Poor
Celtis reticulata	Netleaf hackberry	Central New Mexico	5	5	100	Good
Prunus virginiana	Chokecherry	Northern New Mexico	8	8	100	Good
Quercus undulata	Wavyleaf oak	Northern New Mexico	78	77	99	Good
Rhus glabra	Smooth sumac	Northern New Mexico	5	5	100	Good
Rhus trilobata	Skunkbush sumac	Northern New Mexico	56	55	98	Good
Ribes cereum	Wax currant	Northern New Mexico	12	12	100	Good
Robinia neomexicana	New Mexico locust	Northern New Mexico	20	20	100	Good
Rosa woodsii	Wood's rose	Northern New Mexico	163	162	99	Good
Shepherdia argentea	Silver buffaloberry	Northern New Mexico	26	26	100	Good
Symphoricarpos oreophilus	Snowberry	Northern Arizona	6	6	100	Good
Total			790	768	97	

Figure 25-10: Wolfberry tall-pot transplants on the median of Highway 285 by conclusion of first growing season (November 2001)

Santa Fe Planting

479 tall-pot native shrubs were planted on the interchange of Ridgecrest Road on Highway 599 in Santa Fe, NM (see Figure 25-11 and Attachment 3**)** from October 3–10, 2000.
The planting consisted of 199 New Mexico olive, 161 skunkbush sumac, and 119 wavyleaf oak. This area averages about 12 to 14 inches of annual precipitation. The shrubs were

planted on hillside terraces, in separate 100- to 200-foot single rows on 8-foot centers (see Figure 25-11 and Attachment 3). Plants received 3 gallons of water in irrigation tubes immediately after planting. Because the area had been receiving heavy precipitation during and after the planting, the starch-based superabsorbent was not applied until early June 2001. Three of the four plantings (northwest, northeast, and southeast quadrants) received HSCC. The planting in the southwest quadrant received the less expensive starch-based superabsorbent. For a treatment control, 18 plants have been irrigated only with water, receiving a 3-gallon application each time an application of hydrated supersbsorbent was applied.

In February 2001, Pendulum was applied at 1-gallon per acre to control annual weeds.

Results:
On November 17, 2001, the planting was evaluated for survival. It displayed nearly a 100 percent survival rate (see Tables 25-6, 25-7, 25-8, and 25-9, and Figure 25-12). Subsequently there was no measurable difference between the two different starched-based superabsorbents. Only one plant was dead, and it was a skunkbush sumac receiving the HSCC by irrigation tube.

Figure 25-11: Northwest quadrant planting just after installation on New Mexico Highway 599 at the Ridgecrest Road interchange (October 2000)

Figure 25-12: Northwest quadrant near the conclusion of the first growing season on New Mexico Highway 599 at the Ridgecrest Road Interchange (November 2001)

Table 25-6: Survival Rate of Shrubs in the Northwest Quadrant–Highway 599 Interchange at Ridgecrest Road

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Forestiera neomexicana	New Mexico Olive	Northern New Mexico	27	27	100	Good
Rhus trilobata	Skunkbush sumac	Northern New Mexico	52	52	100	Good
Total			79	79	100	

Table 25-7: Survival Rate of Shrubs in the Northeast Quadrant–Highway 599 Interchange At Ridgecrest Road

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Forestiera neomexicana	New Mexico olive	Northern New Mexico	88	88	100	Good
Quercus undulata	Wavyleaf oak	Northern New Mexico	32	32	100	Good
Rhus trilobata	Skunkbush sumac	Montana	27	27	100	Good
Total			147	147	100	

Table 25-8: Survival Rate of Shrubs in the Southwest Quadrant–Highway 599 Interchange At Ridgecrest Road

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Forestiera neomexicana	New Mexico olive	Northern New Mexico	31	31	100	Good
Quercus undulata	Wavyleaf oak	Northern New Mexico	50	50	100	Good
Rhus trilobata	Skunkbush sumac	Montana	25	25	100	Good
Total			106	106	100	

Table 25-9: Survival Rate of Shrubs in the Southeast Quadrant–Highway 599 Interchange At Ridgecrest Road

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
Forestiera neomexicana	New Mexico olive	Northern New Mexico	53	53	100	Good
Quercus undulata	Wavyleaf oak	Northern	27	27	100	Good

Table 25-9: Survival Rate of Shrubs in the Southeast Quadrant–Highway 599 Interchange At Ridgecrest Road

Plant Species	Common Name	Origin	Total Planted	Alive	Percent Survival	Vigor
		New Mexico				
Rhus trilobata	Skunkbush sumac	Montana	58	59	100	Good
Total			138	139	99	

Conclusions

Of the 1,386 tall-pot transplants receiving one of the two hydrogels or water by an irrigation tube, only 29 plants had died by the end of the first growing season. This equates to a 98 percent survival rate. At Milan, the five transplants without irrigation tubes and that received the two 5-gallon surface applications of water had died. There was no measurable difference in survival of plants between the two hydrogels tested.

Based on the data for 1 year, the study results suggest that nearly a 100 percent survival rate can be achieved using tall-pots with irrigation tubes, and for transplants without hydrogel, just two applications of water are sufficient. One 3-gallon water application should be applied when the plants are first installed in the fall. A second water application should be applied in June to carry the plant through the droughty period before the monsoon period begins in July. A single application of water may be adequate to maintain survival, but this was not tested.

Acknowledgements

We would like to extend our gratitude to the New Mexico Highway and Transportation Department, Eldorado Community, Wildland Native Seeds Foundation and the Plant Materials Center Interagency Riparian Group for their valuable contributions.

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Attachment 1
Material and Safety Data Sheet

DRiWATER 1/1/93

MATERIAL SAFETY DATA SHEET

DRiWATER, Inc.
600 East Todd Road
Santa Rosa, CA 95407
Phone: 707 588-1444

DRiWATER SOIL AMENDMENT

MSDS #2
Date: January 1, 1993

I. Product Identification

WARNING! SURFACE SUBJECT TO SPILLS CAN BECOME SLIPPERY.

Product: DRiWATER	HMIS RATING (1)	
CAS# (Unassigned)	Health Hazard	1 Slight
	Flammability Hazard	0 Minimal
	Reactivity Hazard	0 Minimal

INGREDIENTS:	Sodium carboxmethyl celluose (2%) CAS# 9004-32-4; aluminum sulfate (.1%) CAS# 10043-01-3; water.
APPEARANCE AND ODER:	Colorless, odorless, tasteless gel.

DRiWATER, Inc. has compiled the information and recommendations contained in this Material Safety Data Sheet from sources believed to be reliable and to represent the most reasonable current opinion on the subject when the MSDS was prepared. Nor warranty, guaranty or representation is made as to the correctness of sufficiency of the information. The user of this product must decide what safety measures are necessary to safely use this product, either alone or in combination with other products, and determine its environmental regulator compliance obligations under any applicable federal or state laws.

II. Hazardous Ingredients and Exposure Limits

This material is not expected to cause physiologic impairment at low concentration.

III. Typical Physical & Chemical Characteristics

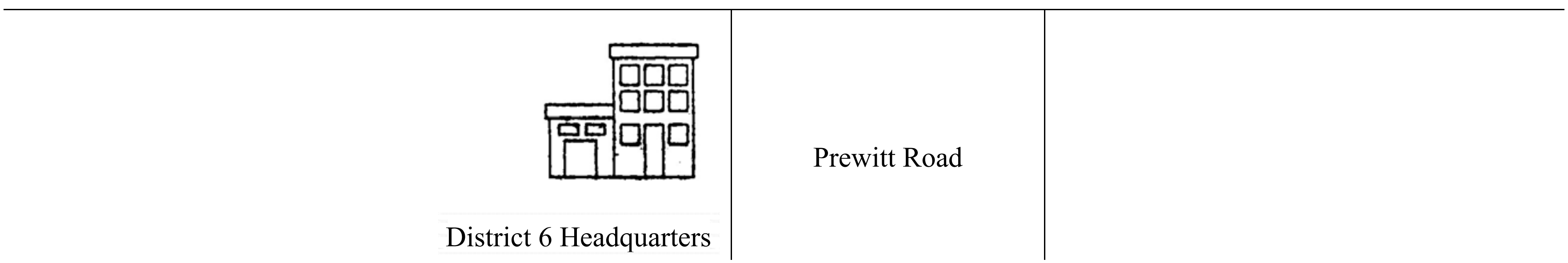
SURFACES SUBJECT TO SPILLS WITH THIS PRODUCT CAN BECOME SLIPPERY!

Boiling Point:	100 C
Freezing Point:	0 C
Solubility in Water:	Not Soluable
Specific Gravity:	1.01
PH of 2% Solution:	7 +/ .5

Attachment 2

FAPA 5 PIPO 3 RHTR 5 PIED 5	RHTR 5 PIPO 3 RHTR 5	FAPA 5 RHTR 5 PIED 5	PIED 5 FAPA 5 FONE 5	RHTR 5 PIPO 5 RHTR 5	FONE 5 FAPA 5 PIED 5

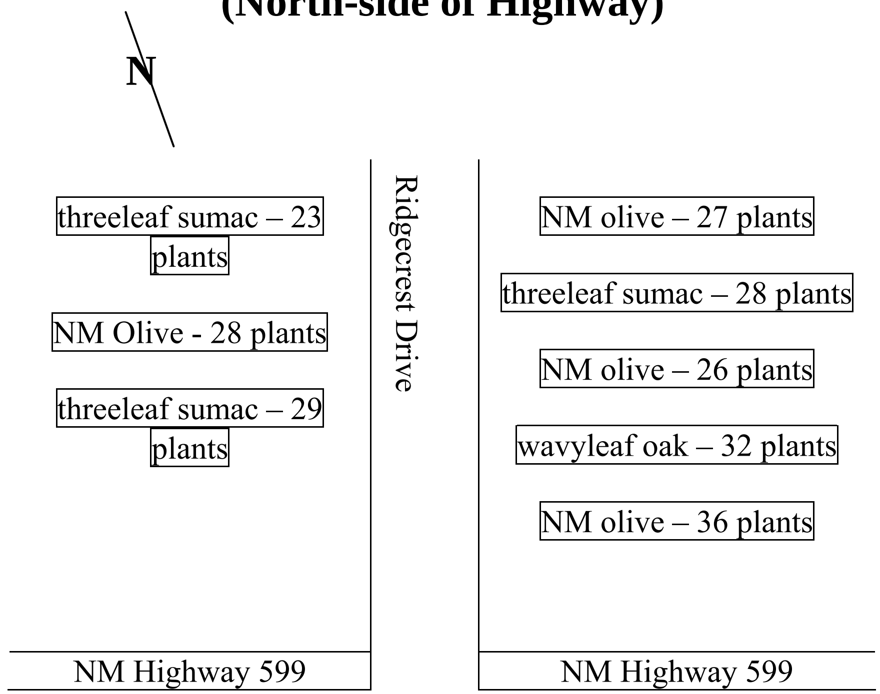
NM Highway 124



FAPA = Fallugia paradoxa	apache plume
PIPO = Pinus ponderosa	ponderosa pine
RHUS = Rhus trilobata	threeleaf sumac
PIED = Pinus edulis	pinyon pine
FONE = Forestiera neomexicana	NM olive

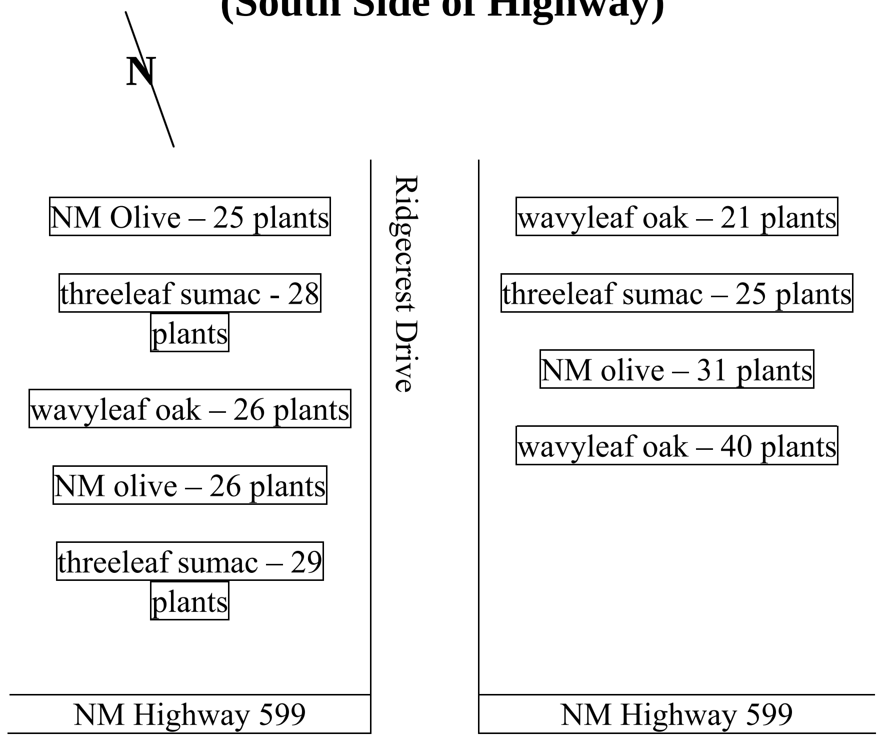
Attachment 3

Plot Plan for Thirty-Inch Transplants with Hydrogel at Santa Fe NM (2000) (North-side of Highway)



Attachment 3 (Continued)

Plot Plan for Thirty-Inch Transplants with Hydrogel at Santa Fe NM (2000) (South Side of Highway)



Attachment 4 - Planting Locations

Blunt Panic (*Panicum obtusum*)

By: E. Ramona Garner [42]

Study Number: NMPMC-P-9901-RA

Blunt Panic is a native, stoloniferous, perennial, warm-season grass. It is found typically in sandy or gravelly soil, chiefly in moist sites along stream and ditch banks. It is fair to good forage for livestock and wildlife and can withstand heavy grazing. Because of its stoloniferous habit blunt panic often grows in dense stands and is may be used to stabilize washes and prevent soil erosion.

Seed of blunt panic typically has low germination. This low germination is due to a low percent of seed fill. Populations of blunt panic typically have three ploidy levels; diploid (2n=36), triploid (2n=27) and tetraploid (2n=36 and 2n=40). Of the three ploidy levels present, only the diploid plants were sexual in their mode of reproduction. The triploid and tetraploid plants are facultative apomictics with both sexual and apomictic florets.

Bulk seed collections of blunt panic were made from 80 collections throughout New Mexico. In 1983, seedlings were transplanted to the field into non-replicated accession rows. Plots were 2 rows of 14 plants per row. In 1995 seed was hand harvested for each of the 80 accessions in the preliminary evaluation field. In 1997, germination tests were conducted on the eighty accessions. Single plants from the 30 accessions with the highest germination were grown and transplanted into the field in August 1997. Upon maturity these accessions will be evaluated for seed fill and forage yield.

[42] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Desert needlegrass (*Achnatherum speciosum*)

By: E. Ramona Garner [43]

Study Number: NMPMC-P-9504-CR

Desert needlegrass is a native, cool-season, perennial bunchgrass. It is occurs from Colorado west to Nevada and south into Arizona, southern California and northern Mexico. It produces significant foliage and provides good forage when young. Summer forage contains as much as 6.7% protein which drops to 2.3% when dormant. It is palatable to livestock and wildlife. Desert needlegrass may reproduce asexually and sexually. It is wind pollinated and each plant has the potential to produce large amounts of seed. Vegetative reproduction occurs with the annual growth of new tillers. Compared to other needlegrasses, desert needlegrass occurs in the most arid and harsh environments.

Desert needlegrass was collected from various rocky sites in or near the hogbacks region of northwestern New Mexico in 1995 through 1996. In 1997 all seed was mixed and placed into an evaluation planting. These plants will be evaluated for time of flowering when they become mature. Seed of like flowering plants will be mixed and put into an advanced evaluation.

[43] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Giant Sacaton (*Sporobolus wrightii*)

By: E. Ramona Garner [44]

Study Number: NMPMC-P-8401-CP

Giant Sacaton is a native, robust perennial warm-season bunchgrass. It is distributed throughout the southwestern United States, usually occurring on low alluvial flats and flood plains. It is useful forage for livestock and wildlife. Under irrigation, giant sacaton may reach heights exceeding 2 m. Based upon its density and height; it has the potential as a windbreak plant for irrigated cropland.

Seed collections of giant sacaton were made from 37 locations throughout New Mexico. These collections were used to establish non-replicated accession rows in the field. Based on a visual evaluation of vigor and height 10 superior plants were selected. From these 10 plants 1 super selection was made.

In 1992 clonal shoots of each selected plant were planted into a testcross block with the super plant as the male tester. In 1995 seed was hand harvested from each female parent. This seed was used to establish an evaluation containing parents and progeny. The progeny were derived from seed and the parents were vegetatively propagated. Both sets of plants were grown in 6-inch square pots for 8 months in an attempt to equalize carbohydrate reserves in the seed derived plants and the clones.

At maturity these plants will be evaluated for height, width and vigor.

[44] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Longtongue muttongrass (*Poa fendleriana longiligula*)

By: E. Ramona Garner [45]

Study Number: NMPMC-P-9504-CR

Longtongue muttongrass is a native cool-season bunchgrass with occasional short rhizomes. Although muttongrass species are dioecious, populations may have 85% female plants that produce seed without pollination. *Poa fendleriana longiligula* differ in that populations are mostly or totally female. Longtongue muttongrass provides good forage for wildlife and livestock. It may be grazed throughout the year, but it is most beneficial in early spring when other green forage is scarce. It has a deep fibrous root system that provides good soil erosion control, however it use in restoration projects is limited by the lack of seed availability.

Longtongue muttongrass was collected from various sites throughout the San Juan basin in northwestern New Mexico in 1995 and 1996. In 1997 the seed was mixed and planted as individual plants into a preliminary evaluation. The plants were visually evaluated in 1998, 1999 and 2000 for time of flowering. It was determined that there was no difference in time of flowering. The seed from these plants will be used to plant an advance evaluation planting.

[45] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Mexican white sagebrush (*Artemisia ludoviciana mexicana*)

By: E. Ramona Garner [46]

Study Number: NMPMC-P-9801-WL

Mexican white sagebrush is a native, fast growing, aromatic, long-lived perennial forb. Plants usually occur in clusters 1 to 3 ft tall. It is extremely drought and cold tolerant. Mexican White Sagebrush may reproduce both sexually and asexually. It produces numerous wind-dispersed seed in the fall. Vegetative reproduction is by rhizomes. Colonies have been reported to reach diameters of 50 feet. It has a wide ecological scope and is able to occupy a diversity of sites throughout the western United States. Mexican white sagebrush may be more palatable than the other species of Louisiana sagebrush. However, all species of Louisiana sagebrush have value as food and environmental protection for livestock and wildlife. It is a very important species in restoring disturbed sites. It is easily established and plants spread rapidly by rhizomes, providing excellent soil cover and stabilization.

Mexican white sagebrush was collected from various sites throughout the San Juan basin in northwestern New Mexico in 1995 and 1996. In 1997 the seed was mixed and planted as individual plants into a small preliminary evaluation. The plants were visually evaluated in 1998, 1999 for time of flowering, seed yield, seed viability and various agronomic characters related to harvest. From the test planting it was determined that this accession produced large amounts of viable seed and reached a mature height that facilitated easy harvest. It was determined that there was relatively no difference in time of flowering. The seed from these plants was used to produce containerized plants to use in an advance evaluation planting in the fall of 1999. In early spring 2000 there was no visible sign of these plants; jackrabbit predation had destroyed all above ground plant parts. However, by late spring shoots appeared and there was no lasting damage. These plants will be evaluated for plant size and clump size.

[46] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

New Mexico feathergrass (*Stipa neomexicana*) and needleandthread (*Hesperostipa comata*)

By: E. Ramona Garner [47]

Study Number: NMPMC-P-9504-CR

New Mexico feathergrass and needleandthread are native perennial cool-season grass. They provides fair to good forage for livestock and wildlife. However, their long awns may prove injurious to livesock. It is widely believed that both can tolerate high levels of soil salinity; however this can not be verified through scientific literature. The breeding system of needleandthread is self-pollination. New Mexico feathergrass also appears to be primarily self-pollinated.

Seed of 61 needleandthread and 6 New Mexico feathergrass accessions were obtained from bulk seed collections throughous New Mexico, Arizona and Montana. In 1985 these bulk collections were established in a field into non-replicated accession rows. Plots consisted of 2 rows of 14 plants. Fifteen needleand thread accessions and 3 New Mexico Feathergrass accessions were selected based on survival, foliage height and basal width. Seed was bulk harvested from all plants of the selected accessions.
A replicated entry evaluation of the selected accessions was established at 2 sites in 1994. The experimental units consisted of a plot containing 2 plants. The experiment at both sites was conducted in a randomized complete block with 9 replications. Site 1 has salinity levels ranging from 3.3 to 4.5 ms,cm^{-1} and site 2 ranges from 0.42 to 0.44 ms,cm^{-1}. In 1996 site 1 was abandoned because the site was overun with weeds and a majority of the plants had died.

In 2000 the site 1 planting was evaluated for possible evaluation. It was determined that the condition of the planting would distort any comparisons that might be made. In an attempt to salvage the project it was decided that we would visually select the superior plants. The species were divided by placing flags at each New Mexico feathergrass accession. The species were then visually evaluated for vigor and 12 superior plants from each species were selected. Of the 15 original needleandthread accessions 8 were represented selection of superior plants. All three of the original New Mexico feathergrass accessions were represented (see Table 28-1).

Table 28-1: **Selection Of Superior Plants Of Needleandthread And New Mexico Feathergrass**

New Mexico feathergrass Accessions		needleandthread Accessions	
Accession	**Percent of Superior Selections**	**Accession**	**Percent of Superior Selections**
9032448	50%	9012934	17%
9032447	33%	9032478	8%

[47] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

Table 28-1: **Selection Of Superior Plants Of Needleandthread And New Mexico Feathergrass**

New Mexico feathergrass Accessions		needleandthread Accessions	
Accession	**Percent of Superior Selections**	**Accession**	**Percent of Superior Selections**
Wapaki	17%	9029816	17%
		9029823	17%
		9027066	8%
		9025658	8%
		9032478	8%
		9029812	17%

Prairie junegrass (*Koelaria marcantha*)

By: E. Ramona Garner [48]

Study Number: NMPMC-P-9801-RA

Prairie junegrass is a cool season perennial grass, native to North America and temperate areas of Europe. Its range extends across the western, central and northeastern United States. In New Mexico it occurs at elevations between 5,500 and 10,000 feet. It provides excellent forage for all classes of livestock and wildlife. Populations of prairie junegrass may be either diploid (2n=14) or tetraploid (2n=28). Researchers have reported that ploidy level increases with drought stress and that tetraploid populations may reach anthesis as much as 21 days before their diploid counterpart.

Collections of prairie junegrass were made from 98 locations throughout New Mexico. The populations from New Mexico and two exotic populations were planted into non-replicated preliminary evaluation in 1984. These plots consisted of 2 rows of 14 plants. In 1989, three early flowering and three late flowering accessions were visually selected from this evaluation. The ploidy level of the selected accessions is unknown. The three early maturing accessions were collected from similar areas suggesting that they may have the same ploidy (Table 1). Two of the late maturing accessions are from Torrance County, NM suggesting that they may have the same ploidy level.

Table 1: Collection site information for prairie junegrass (*Koelaria macrantha*) accessions selected in 1989 for vigor and forage value.

Accession or PI Number	Maturity	Origin	MLRA	Elevation
9035465	early	Catron	39	6519
9035466	early	Catron	39	7483
9035467	early	Catron	39	6598
9035559	late	Torrance	70	6798
9035594	late	Torrance	70	6699
PI-207489	late	Afghanistan	-	-

Polycross blocks were established for the early and late accessions in 1989. Plants for both blocks were derived from the original collections.

The polycross block for the late maturing accessions did not perform as expected and was abandoned in 1997. In 1998 superior plants were selected from the late maturing polycross block established in 1989. Seed was collected from these plants and clones were established from the parents. A preliminary evaluation was established in 1999 to compare the parents to the progeny. This planting is replicated 6 times and is a latin

[48] Agronomist/Plant Scientist, Natural Resources Conservation Service, New Mexico Plant Materials Center, Los Lunas, NM

square design. Upon maturity these accessions will be evaluated for forage and seed yield.