2000 Billings Land Symposium

SUCCESSFUL TECHNIQUES FOR HIGH ALTITUDE STEEP SLOPE REVEGETATION

J. T. Harrington[1], A. M. Wagner[2], and D. R. Dreesen[3]

ABSTRACT

The Molycorp, Inc. Questa mine is located in northern New Mexico in an area of steep topography. Dump construction during the open pit operation utilized steep canyons to create the dumps. The resulting overburden slopes are relatively shallow, steep and high (over 500 feet). A state highway and river, located near the toe of the slopes preclude reshaping of the piles. The angle (steepness) of the slopes is similar to the natural topography, which supports primarily a mixed conifer ecosystem. Development of a self-sustaining ecosystem appropriate to the site is the underlying goal of the revegetation program. The relatively rapid physical weathering of the waste rock creates a suitable planting medium for the seedlings. An *in situ* method for reclamation was developed based on over 20 years of research and planting programs. Both the fast growing early successional overstory species (*Populus angustifolia, Quercus gambelii, Robinia neomexicana,* etc.) and the slower growing, later successional overstory species (*Pinus ponderosa, P. flexilis, Abies concolor,* etc.) are planted simultaneously along with appropriate understory species. The differential growth of the two types of overstory species is intended to shorten the time frame to achieve a more stable, later successional plant community. Standard forestry techniques were adapted for the reclamation program. In general, seedlings of the overstory and shrub species are hand planted on the slopes using hoedads and grasses and forbs are established using direct seeding techniques. First year survival for transplants has averaged 80%. This survival rate has been attributed to three main features of the program: 1) using site adapted (genetic) stock; 2) planting pre-conditioned container grown stock; and 3) proper planting techniques. The expanded revegetation program is in its fourth year with over 130,000 seedlings planted.

Additional Key Words: reforestation, reclamation.

[1]Associate Professor, Mora Research Center, New Mexico State University, Mora, NM 87732
[2]Molycorp, Inc., Questa, NM, 87556
[3]Los Lunas Plant Materials Center, Natural Resources Conservation Service, Los Lunas, NM 87031.

INTRODUCTION

The Molycorp Inc., Questa Molybdenum Mine has been in operation since 1921. The mine is located in an area of steep, mountainous topography in narrow canyons adjacent to the Red River five miles east of the town of Questa, New Mexico in Taos County. Underground mining occurred from 1921 to the early 1960s when open pit development of the ore body began. The open pit mine operated from 1965 through 1983. From 1983 to the present mining is an underground block caving operation.

The open pit period of extraction generated 328 million tons of overburden. Deposition of this overburden material utilized the natural steep, long slopes and narrow canyons for the development of the overburden piles. Today, the overburden pile surfaces are steep and long, in some cases exceeding 500 feet in length. Unlike other mining operations where overburden piles are situated on relatively flat ground and the height of the piles is indicative of pile depth, the depth of the overburden piles at Molycorp range from 60 to 125 feet in thickness (depth) (Robertson GeoConsultants, Inc. 1999). The resulting overburden depth was a function of several factors including underlying topographic features including slope, slope length and overburden structural composition and its influence on angle of repose. The resultant surface of the overburden piles has similar slope intensity to the adjacent natural topography.

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 dominated ecosystems range from ponderosa pine (*Pinus ponderosa*), mixed conifer (*P. flexilis*, *Pseudotsuga menziesii*, *Abies concolor*) to spruce-fir (*Picea engelmannii* and *Abies concolor*) stands. Topographic features, specifically elevation and aspect strongly influence species distribution (Wagner and Harrington, 1994). Areas in which the coniferous overstory have been disturbed, various shrub (*Quercus* spp., *Cercocarpus montanus*, *Ribes* spp.), aspen (*Populus tremuloides*) and narrowleaf cottonwood (*P. angustifolia*) dominated communities occur. Again, the distribution of these various communities is strongly influenced by topographic features and most likely edaphic features that impact rooting mantle thickness and water holding capacity.

The other natural feature which appears to strongly influence vegetation distribution in this region are hydrothermal scars. These naturally occurring areas have highly erodible, and acidic "soils" (Meyer and Leonardson 1990). During the open pit-mining operations, hydrothermal scars were excavated along with intervening areas of more neutral geologic materials. Heterogeneous overburden piles resulted with a wide range of particle sizes, and chemistries (specifically pH).

Through the influence of overburden management and natural variability in the area, the piles represent a broad array of planting sites with a wide range of attributes which can influence revegetation success. Elevation ranges from 8,000 feet to 10,000 feet and almost every aspect occurs. In addition to the variability in the overburden thickness, overburden particle size ranges from clay sized fines to large cobble and overburden pH ranges from neutral (pH 7.0) to very acidic (pH < 3.0). In short, the overall site provides an ideal laboratory to evaluate the robustness of different revegetation treatments.

Traditional approaches to revegetation of overburden materials often involves drastic recontouring and capping with various materials to support plant growth, and in several cases manipulate water movement. However, many features of this site indicate that developing new revegetation techniques and technologies or modifying existing ones would be more advantageous to both Molycorp and the overall watershed. Some of the technologies and techniques developed from the *in situ* revegetation of the overburden would be applicable to other, natural areas in the watershed which are actively eroding.

REVEGETATION RESEARCH

Beginning in the mid-1970s Molycorp has been actively funding revegetation research at their Questa mine. Initially, this research effort began with the then Soil Conservation Service Plant Materials Center in Los Lunas, New Mexico (currently, the Natural Resource Conservation Service, Los Lunas Plant Materials Center (NRCS-LL-PMC). This research effort continues today. In 1992, Molycorp expanded this effort by expanding funding to include New Mexico State University researchers at the Mora Research Center (NMSU-MRC). This research effort also continues today. This report will summarize the accomplishments of several of these research projects. For sake of brevity, only those studies or portions of studies relating to the development of the revegetation project will be presented in this manuscript. Also, discussed will be the results of initial plantings associated with the operational revegetation plantings that began in fall 1996. Most data presented will be first year survival data or survival data after one growing season unless otherwise noted.

MATERIALS AND METHODS

The plants used in these studies and the operational program are container grown seedlings produced in greenhouses. The NMSU-MRC and NRCS-LL-PMC facilities have produced the plant materials used in these studies and operational plantings under appropriate production regimes. Seed or cutting sources are identified in each respective study. When possible and depending on the purpose of the study, local seed sources have been used. Planting of seedlings involved using traditional container planting techniques (dibble bars, hoedads, etc.) adjusted to accommodate unique site features such as rockiness and steep slopes.

Study A. Fertilization Effects on Early Survival and Vigor of Shrub Seedlings Planted on Neutral Overburden.

The purpose of this study was to evaluate the effects of fertilizer incorporation at planting on the survival and vigor of 24 shrub species.

Twenty-four species and ecotypes were evaluated in this study. Seedlings were grown in Supercells (10 in^3). Seedlings were planted at the end of July 1994 on a ripped bench plot (ripped to an average depth of 10 inches). Plots were watered before or after planting. Two planting locations on the overburden piles were used in this study. Replications varied from five to seven seedlings per source with fourteen rows per treatment replication. Half of the Super Cells were fertilized at planting with the other half receiving no fertilizer (control). Fertilizer treatment consisted of 6 grams/seedling of 17-6-23 3-4 month controlled release fertilizer. All plots were top dressed with 17-17-17 fertilizer in July 1996 and 1997. The plots were evaluated in September 1995 and 1997. Individual seedlings were classified with numeric vigor ratings of 4 = excellent, 3 = good, 2 = fair, 1 = poor, and 0 = dead.

RESULTS

Initial fertilizer application effects on survival was species and ecotype specific (Table 1). Ten of the 24 sources evaluated had pronounced (>10%) reductions in first year survival with the fertilizer treatment. By the 1997 survival evaluation only two sources, one *Artemesia frigida* and one *Rosa woodsii* source, appeared to have been negatively influenced by initial fertilization beyond the initial first year effects. Overall, three year survival was influenced by source rather than initial fertilization treatment. This trend is indicated by similar shifts in survival rates regardless of fertilization treatment from the 1995 to the 1997 evaluation (Table 1).

Seedling vigor after one year was impacted the fertilizer treatment, with those plants fertilized initially, in general showing higher vigor ratings. By the 1997 evaluation, this difference had become less pronounced (Table 1).

Study B. Grass Species Trial.

The purpose of this study was to evaluate grass species and varieties on overburden when planted as transplants. The influence of fertilization at time of planting and fertilization after two growing seasons was also evaluated.

Grass seedlings were grown in horticultural six-pack containers, placed outside for hardening and fertilized with soluble fertilizer prior to transplanting. Sixty species and varieties (sources) were used in this study. Transplants were planted in two locations in ripped (to 10 inches) bench plots. Six plots were used with two plots receiving fertilizer (6 grams/seedling of 17-6-12, 3-4 month controlled release fertilizer) and four plots without fertilizer at planting. Seedlings were transplanted August 8 and 9, 1994 and plots were watered before and immediately after planting. All plots received fertilizer (17-17-17) in July 1995 and 1997. The plantings were evaluated September 1995 and 1997 for vigor and survival. Vigor was rated as described above.

RESULTS

Only data from 18 of the 60 cultivars/species are shown, including the best performing grasses and those with Molycorp accesssions. The best performing grasses are listed below. In general, vigor was improved by fertilizer treatment (Figure 1). The average vigor rating for best performing species were greater than 3.25 in the fertilizer treatment and greater than 1.5 in the control. In general, survival was not affected by initial fertilizer treatment (Figure 2).

Native cool season grasses:	Canada Wildrye, Streambank Wheatgrass, Western Wheatgrass, Reed Canarygrass
Native warm season grasses:	Spike Muhly
Introduced cool season grasses:	Orchardgrass, Tall Fescue, Timothy

Table 1. Survival and mean vigor ratings for shrubs planted in 1994 and evaluated in 1995 and 1997. Fertilizer treatment was applied at initial planting.

Species	1995 Survival		1997 Survival		1995 Vigor		1997 Vigor	
	Cont	Fertil.	Cont	Fertil.	Cont	Fert	Cont	Fertil.
Achillea spp.	98	98	97	100	1.89	3.58	3.80	3.40
Artemesia frigida	98	94	62	66	1.81	3.19	3.39	3.41
Artemesia frigida	97	83	76	28	1.62	2.93	3.83	3.77
Artemesia frigida	100	82	48	40	1.85	3.11	3.56	2.80
Artemesia spp.	96	91	87	88	1.60	3.08	3.45	3.43
Artemesia tridentata	80	58	56	47	1.53	2.49	2.25	1.0
Atriplex canescens	93	88	33	32	1.14	1.75	2.38	2.38
Berberis fendleri	--	84	--	92	--	2.75	--	2.22
Cercocarpus montanus	95	81	82	69	1.73	2.58	3.21	3.41
Chrysothamnus nauseosus	95	89	87	89	2.11	2.55	3.73	3.55
Chrysothamnus nauseosus	95	91	82	93	2.00	2.45	3.44	3.58
Eriogonum spp.	97	77	95	76	2.08	3.11	3.72	3.47
Eriogonum spp.	94	81	95	77	2.20	3.64	3.66	3.59
Jamesia americana	88	70	80	62	1.07	2.42	2.49	3.31
Prunus virginiana	93	82	96	82	2.47	2.83	3.43	3.13
Prunus virginiana	86	69	86	69	2.34	2.44	3.04	3.28
Ribes cereum	81	82	81	79	1.08	1.55	3.23	2.94
Ribes spp. (spiny)	93	84	78	78	1.09	1.52	3.33	2.59
Ribes spp. (spiny)	95	93	78	89	1.14	1.78	3.15	2.49
Robinia neomexicana	74	81	27	17	3.00	2.78	3.17	2.33
Robinia fertilis	82	86	70	67	3.29	2.83	3.19	2.43
Rosa woodsii	99	100	95	98	2.07	2.34	3.18	3.38
Rosa woodsii	96	87	95	71	2.00	2.26	2.99	2.76
Rubus spp.	100	51	93	68	1.64	2.90	3.88	3.36

Study C. Effects of Seed Source and Container Size on the Survival of Ponderosa Pine Seedlings.

The objectives for this study were to evaluate the effect of seed source and container size on the survival of ponderosa pine (*Pinus ponderosa*) seedlings planted on steep overburden slopes.

The study used seedlings from four ponderosa pine seed sources. The sources were from throughout New Mexico representing 4 USDA Forest Service seed zones including the mine's seed zone (USDA Forest Service seed zone 710), one adjacent to the mine's seed zone to the west (620), and two southern seed zones (170 and 840).

Seedlings from each of the four seed sources tested were produced in one of three growing containers. Sizes evaluated included 1 in^3, 7 in^3, and 10 in^3 containers. Seedlings were produced at the NMSU-MRC facility using a standard production regime.

Table 2. Species shown in Figures 1 and 2 listed below:

NUMBER	SCIENTIFIC NAME	COMMON NAME	SOURCE/VARIETY
1	*Dactylis glomerata*	Orchardgrass	Paiute
2	*Festuca arundinacea*	Tall Fescue	Fawn
3	*Festuca ovina*	Sheep Fescue	Covar
4	*Festuca ovina*	Sheep Fescue	Molycorp H
5	*Festuca ovina*	Sheep Fescue	Molycorp LS
6	*Festuca ovina*	Sheep Fescue	Molycorp LT
7	*Schizachyrium scoparium*	Little Bluestem	Molycorp GHS
8	*Schizachyrium scoparium*	Little Bluestem	Pastura
9	*Bouteloua gracilis*	Blue Grama	Alma
10	*Bouteloua gracilis*	Blue Grama	Willis
11	*Elymus canadensis*	Canada Wildrye	
12	*Elymus lanceolatus*	Thickspike Wheatgrass	Critana
13	*Elymus lanceolatus*	Streambank Wheatgrass	Sodar
14	*Muhlenbergia wrightii*	Spike Muhly	El Vado
15	*Pascopyrum smithii*	Western Wheatgrass	Arriba
16	*Pascopyrum smithii*	Western Wheatgrass	Rosanna
17	*Phalaris arundinacea*	Reed Canarygrass	
18	*Phleum pratense*	Timothy	Climax

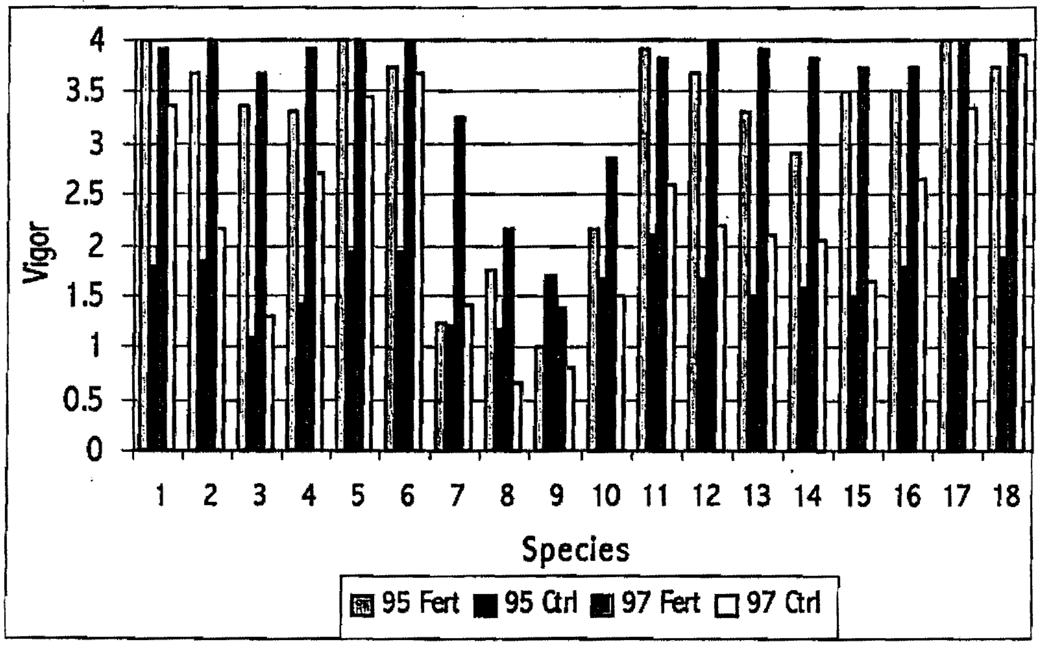

Figure 1. Effect of fertilizer at planting on vigor of grass transplants, with planting occurring in 1994. See Table 2 for species codes.

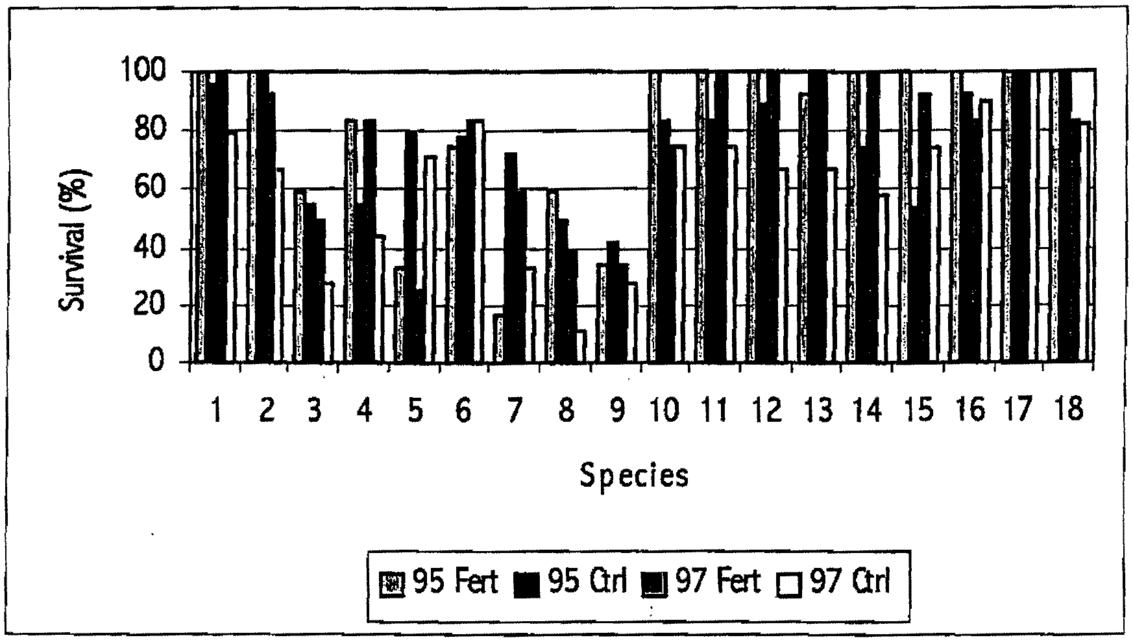

Figure 2. Effect of fertilizer at planting on survival of grass transplants, planting occurred in 1994. See Table 2 for species codes.

The seedlings were planted September 13-16, 1993. Dibble bars were used for the larger containers and a sharpshooter shovel for the 1 inch^3 container. Treatments, seed source and container size, were randomly allocated in each planting block. Two planting sites were used in the study. Both sites were near the base of the slopes.

The treatment design was a factorial design of seed source (four), and container size (three) for 12 treatments. The outplanting design was a split plot design with the two main plots being the planting sites. Each main plot consisted of six randomized complete blocks. Each treatment was represented in each block by a 10 tree row plot.

The response unit was the average of the 10 tree row plot of each treatment within each block. Because the plots were installed at the base of slopes some areas were lost by covering by overburden material. Survival values were adjusted to be a percentage of the number of living seedlings based on total number of non-covered seedlings.

RESULTS

Smaller seedlings were more prone to covering than were larger stock types (39% compared to 30%). Survival was greater for the largest two stock types, 10 in^3 and 7 in^3 (Figure 3). Some treatments had 90% survival. The smaller stock type, 1 in^3, had a survival rate of 5%. The poorest performing seed source was the southern seed source (seed zone 170). The three other seed sources performed comparably, with an average survival of 24% (Figure 4).

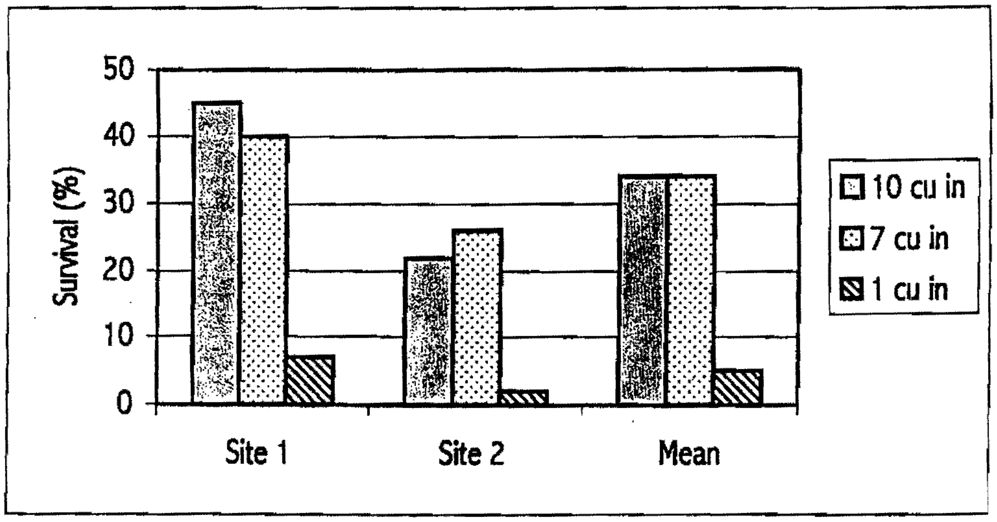

Figure 3. Effect of container size on transplanted ponderosa pine seedling survival.

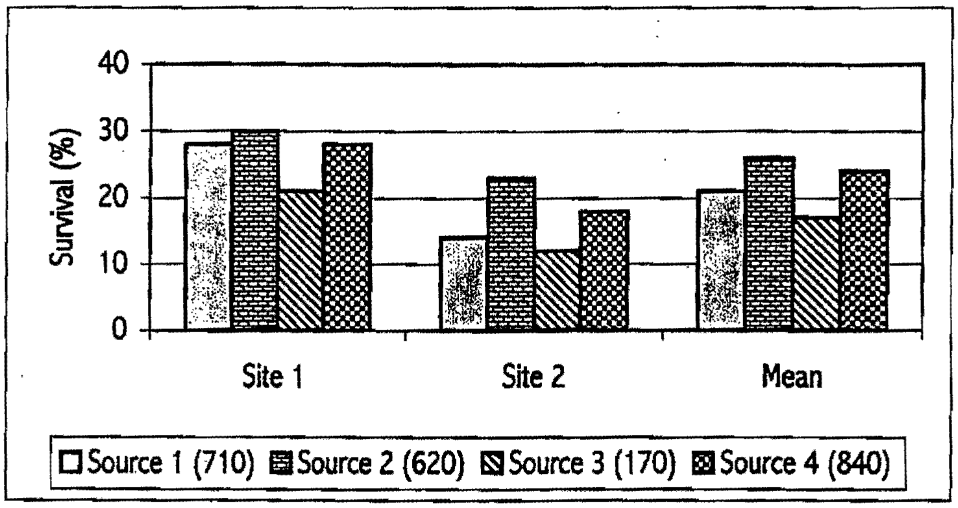

Figure 4. Effect of seed source on transplanted ponderosa pine seedling survival.

Study F. Effects of Planting Site Aspect, Elevation and Substrate Chemistry on Survival of Spring and Fall Planting Conifer Seedlings.

The objectives of this study were to survey effects of aspect and elevation on conifer transplant survival for spring and late summer planted seedlings and to examine the impact of substrate chemistry on conifer transplant survival for spring and late summer planted material.

This study utilized seedlings generated from two ponderosa pine (Pinus ponderosa) seed sources, one seed source of Douglas fir (*Pseudotsuga menziesii*) and one seed source of Englemann spruce (*Picea engelmannii*). All seedlings were greenhouse grown in 9 in^3 containers. Seedlings were removed from their containers, bagged, boxed and refrigerated (34^oF) until planted. All seedlings were dormant when planted.

Seven planting sites were evaluated providing a range of aspects, elevations and substrate chemistry (see Table 3). Planting dates were early June and late August 1994. Only ponderosa pine was planted in June, and all four sources were planted in August.

Treatments evaluated were species and seed sources and planting date. Other factors examined were elevation, aspect and substrate chemistry. The treatment design was an incomplete factorial design with main factors being species – seed source and planting date. The outplanting study design was a randomized complete block. The seven planting sites served as complete blocks.

Each seed source by planting date combination was represented in each block by 10, 10-tree row plots. The response unit was the average of the 10-tree row plot of each treatment within each block. The survival response is as described above in Study E.

Table 3: Elevation, aspect, field pH and field conductivity for planting sites.

Site Number	Elevation (feet)	Aspect	Field pH	Field Conductivity
A	9200	South	2.9	2900 μS
B	9000	Southwest	5.0	110 μS
C	9000	South	5.5	70 μS
D	9000	Southeast	--	--
E	9400	South	3.7	720 μS
F	9400	East	2.8	1450 μS
G	8550	East	6.5	40 μS

The overall adjusted survival of this study was 44% with spring planted seedlings having an average survival of 68% (Table 4). On four sites, spring planted ponderosa pine seedlings had survival rates of 80%, with two sites in excess of 90%. Fall planted material from the same seed sources did not perform as well, with one site having a decline in survival from over 80% to 11%. Englemann spruce, planted only in the fall, had a survival rate of 65%. It was the only species to do well with the late summer planting.

Average survival by planting site ranged from 20% to 65% with all plantings having some replications with 0% and 100% survival. Planting sites A and F were acidic sites and had similar survival of approximately 47%. Species seed source and planting date trends of reduced survival and overall ranking were similar for both sites with the exception of late summer planting of one source of ponderosa. This seed source had almost no survival at planting site F while planting site A had survival of over 33% (Table 4). The somewhat less acidic site, planting site E, also had good spring ponderosa pine survival (91%), however fall planting performance was significantly reduced. The only trend in survival for neutral planting sites was the better performance for spring planted ponderosa pine.

First Year Survival of a Fall Operational Planting

In September of 1996, a trial operational planting was conducted on the top portion of one of the lower (elevation) overburden piles. The planting was done by hand using a contract planting crew. The plant material, consisted of a wide range of plant species. In general the relative proportion of plant forms was 35% deciduous trees; 40% coniferous trees; and, 25% shrubs. All plant materials were grown in reforestation containers

Table 4. Effect of planting location, species and planting date on seedling survival.

	Mean Survival (%)						
Treatment	Plot A	Plot B	Plot C	Plot D	Plot E	Plot F	Plot G
Spring ponderosa (1)	76	37	39	75	84	90	86
Spring ponderosa (2)	56	23	22	86	97	84	96
Fall ponderosa (1)	45	38	2	17	12	39	70
Fall ponderosa (2)	33	5	5	42	9	3	34
Fall Englemann spruce	42	74	48	67	52	76	99
Fall Douglas fir	21	13	8	5	0	19	9

(Supercells or Styro77 Styroblocks) at the NMSU-MRC Research Nursery. Planting crews were told to select plant materials to maximize diversity at the planting site. (Note: some members of the planting crew were better at this than others.) The planting crews were given instructions to plant seedlings four feet apart within rows and the rows were to be 4 feet apart.

In August of 1997, nine $100m^2$ (50m x 2m) transects in the planting area were randomly selected and measured. Species composition and frequency were recorded. Status categories included: living, dead, living and partially buried, dead and partially buried. No interpretations of the vigor of the seedlings were made. For ease of installation and consistency, all transects were placed perpendicular to the slope direction.

RESULTS

Overall, survival ranged from 89% to 69%. The plot containing the 31% mortality was unique in that large portions of this transect (in excess of 35%) were covered by cobble sized material and those areas were not planted. The majority of the mortality was observed immediately adjacent to these cobble areas. Therefore, this plot was eliminated from the summary analysis (Table 5). The next highest mortality level was 24%. When separated by life form (conifer tree, deciduous tree, shrub) the deciduous tree, primarily narrowleaf cottonwood (*Populus angustifolia*) had the lowest survival rate of 62% (live and buried live). Coniferous trees had a survival rate of 88% of which 9% were partially buried. Shrubs had the highest survival rate of 92% (Table 5).

Partially buried seedling frequency ranged from none to 19% with an average of 9% (Table 5). Shrubs had the highest frequency of partial burying at 14% while the coniferous and deciduous trees had partial burying rates of 9% and 5% respectively.

Species diversity across the plots ranged from 10 to 16 species per plot averaging 11 species per plot. All life forms were represented in each plot. Plant density ranged from 6.700 plants per hectare (2,735 plants per acre) to 10,500 plants per hectare (4,286 plants per acre) and averaging 8,838 plants per hectare (3,648 plants per acre).

Table 5. Summary survival and partially buried responses of the 1996 Fall Operational Planting. Evaluation occurred late August 1997.

Life form	Total percent survival (%)	Percent Non-Buried Alive (Mean ± SE)	Percent Non-Buried Dead (Mean ± SE)	Percent Buried Alive (Mean ± SE)	Percent Buried Dead (Mean ± SE)
Conifers	88	78 ± 4	9 ± 3	9 ± 3	<1
Deciduous Trees	62	58 ± 4	36 ± 4	4 ± 1	1 ± 0.5
Shrubs	92	78 ± 8	8 ± 4	14 ± 5	0
Total	81 ± 2				

Total Buried = 9% ± 3%; Number of Species per Plot = 11 ± 1

SUMMARY

The results from these studies and others have indicated that traditional forest artificial regeneration techniques could provide a feasible means for revegetation of the overburden piles at the Molycorp Questa Mine. These studies have illustrated that there appear to be a wide array of plant species which can survive the various planting sites these piles provide. From these studies several general conclusions can be deduced. First, regarding seedling stock size, bigger is better. This is evident in the problem of seedlings being covered on some of the planting sites. In Study E, the smaller seedlings had shoot sizes generally less than three inches. These smaller seedlings were easily laid over and buried by the slightest surface movement. Other studies not reported here also had some partial losses due to seedlings being buried following planting. This is even more important when planting occurs near the base of the slope.

The second general conclusion is that species and seed sources must be carefully evaluated when selecting material for sites. This is probably most pronounced when considering substrate pH. Several studies have shown that several species can withstand the lower pH of some portions of the overburden piles indicating that there are seed sources of several species suitable to the various planting sites in the overburden piles.

The third general conclusion is that planting earlier in the growing season can improve survival. It should be noted here, that as subsequent studies and operational planting have been installed, overall survival, independent of planting date, has improved. The difficulty at this particular mine is that the initiation of the frost free period precedes the summer moisture by about 6 weeks. We have found that planting dormant stock immediately after snow melt when the overburden is generally at field capacity we obtain our highest rates of first year survival. This planting window precedes the last spring frost by two to four weeks.

The final general conclusion which can be drawn from these studies, is that further work needs to be performed on fertilizer applications. It appears that adding fertilizer at the time of planting may improve first year vigor but it also increases first year mortality rates. However, in all the studies conducted thus far, the plant material was transplanted towards the end of the growing season. This may have caused unnecessary shoot growth late in the growing season. Further work will need to be done on the timing of fertilization treatments.

REFERENCES

Meyer, J. and R. Leonardson. 1990. Tectonic, Hydrothermal and Geomorphic Controls on Alteration Scar Formation near Questa, New Mexico. New Mexico Geological Society Guidebook, 41st Field Conference, Southern Sangre de Cristo Mountains, New Mexico, 1990.

Robertson GeoConsultants, Inc. 1999. Interim Report: Questa Waste Rock Pile Drilling, Instrumentation and Characterization Study. Interim Report 052007/1. Prepared for Molycorp, Inc. September 6, 1999.

Wagner, A. M. and J. T. Harrington. 1994. Revegetation Report for Molycorp, Inc. Report prepared for Molycorp, Inc. – New Mexico Mine Permit TA001RE.