# Root Growth of Apache Plume and Serviceberry on Molybdenum Mine Overburden in Northern New Mexico

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**Abstract**: This study evaluated root growth of Apache plume (*Fallugia paradoxa*) and Saskatoon serviceberry (*Amelanchier alnifolia*) on overburden at the Molycorp mine near Questa, NM. Container grown, 1-year-old seedlings were transplanted, and either fertilized or not fertilized at the time of planting in August 1995. Survival and shoot growth were monitored in 1996 and 2000. Root density was determined at three distances (planes) from the base of the plant at six depths in 2000. Fertilization effects on serviceberry root densities were depth dependent. Total root density of unfertilized plants was greater than fertilized plants. Serviceberry total root density differed among planes (distances from base of plant) between fertilization treatments. Fertilized plants had fewer roots in the 10-cm plane relative to the 20- and 30-cm planes. Fertilized plants of Apache plume had higher total root densities at depths >20 cm within the 20-cm plane than plants not fertilized at time of planting. Although overall performance in terms of shoot growth was positive for both species, survival was generally low and root density varied when fertilized at time of planting. Factors including fertilizer characteristics, planting date, and site conditions may have influenced species performance.

## Introduction

New Mexico State and Federal laws require that mined lands be reclaimed to support a designated postmining land use (State of New Mexico 1999). Forestry as a postmining land use has been encouraged by regulatory agencies since the mid to late 1990s (Boyce 1999). Metal mines within the mountainous Western United States including the Molycorp molybdenum mine near Questa, NM, are selecting forestry as a postmine land use to re-establish a plant community comparable to adjacent native vegetation.

Open-pit mining at the molybdenum mine generated over 300 million metric tons of overburden from 1965 until 1983. The overburden exists in piles that range in altitude from 2,400 to 3,000 m and are composed of mixed igneous rocks (rhyolite and andesite) and black andesite and aplite materials (referred to as neutral rock). Mine overburden can be low in organic matter, soil microorganisms, and plant nutrients such as nitrogen and phosphorus and can lack soil structure and texture that are important to soil fertility and water holding capacity (Allen 1989; Feagley 1985). These properties make it challenging for plants to establish, thus overburden or plant amendments are often recommended (Brown and others 1996; Gardiner 1993).

Research studies on the survival of directly transplanted trees and shrubs on the overburden began in the early 1990s (Harrington and others 2001a,b,c). These studies indicated that the overburden was suitable to support plant life, in terms of transplant survival. In most instances, however, shoot growth was limited. Other research has shown that shoot growth of newly transplanted tree and shrub seedlings can benefit from supplemental fertilization in both minimally disturbed (Fan and others 2002; Houle and Babeux 1994; Walker 1999a) and drastically disturbed ecosystems (Fisher and others 1983; Voeller and others 1998; Walker 1999b). Growth response to fertilizer application, however, can be both species specific (Voeller and others 1998; Houle and Babeux 1994) and site specific (Gleason and others 1990).

The ability of transplanted seedlings to establish new roots into a planting medium is essential to their survival and subsequent growth. Plants with a well-established root system add to the success of postmine revegetation, control erosion, and improve overall postmine conditions. Most fertilization studies, however, focus primarily on shoot growth characteristics and disregard belowground growth. Early plantings of ponderosa pine (*Pinus ponderosa*) at the Molycorp mine were evaluated for root growth after 6 years of growth. Rooting depth of some plants extended beyond 2 m in the

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overburden (Harrington, unpublished data). This observation led to questions regarding growth allocation of directly transplanted trees and shrubs at the Molycorp mine with fertilization treatments.

This study evaluated the influence of fertilization at time of planting on root distribution and growth of two native woody shrubs, Saskatoon serviceberry (*Amelanchier alnifolia*) (hereafter referred to as serviceberry) and Apache plume (*Fallugia paradoxa*), transplanted into overburden at the Molycorp Questa Mine. Root densities and distributions were described at six depths and three distances from the base of each plant to examine the effects of fertilizer applications at the time of planting.

## Materials and Methods

### Site Description

Molycorp, Inc., molybdenum mine is located near Questa, NM, in the Red River Canyon and produces the largest amount of molybdenum in the State (Schilling 1965; State of New Mexico 1999). Overburden from open-pit mining was deposited on the steep mountainsides of Red River Canyon. The overburden piles are highly heterogeneous, consisting of parent materials with a range of acidic and soluble salt levels (Steffan and Kirsten 1995).

Vegetative communities surrounding the mine consist of coniferous forests dominated by ponderosa pine, mixed conifer (Douglas fir [*Pseudotsuga menziesii*] and limber pine [*P. flexilis*]), and spruce-fir (Engelmann spruce [*Picea engelmannii*] and white fir [*Abies concolor*]) stands (Harrington and Wagner 1994). Naturally formed alteration scars occurring in acidic (pH = 1.8 to 3.5) materials, occur at the mine and throughout the Red River Canyon (Meyer and Leonardson 1990; Steffan and Kirsten 1995). Plants from adjacent communities have established in the periphery of these scars (Wagner and Harrington 1994).

Two planting sites (Blind Gulch and Spring Gulch) were located on terraced portions of overburden piles at the molybdenum mine. Spring Gulch (2,780 m) is composed primarily of neutral rock with an average pH of 7.7, electrical conductivity (EC) of 0.5 dS/m, and coarse fragment fraction (content) of 69 percent. Blind Gulch (2,860 m) consists of both acidic and neutral overburden materials. Chemical composition of the overburden across the planting area at Blind Gulch was varied. Average values for pH, EC, and coarse fragment fraction (content) in planting blocks one and two were 4.4 and 7.3, 1.2 and 1.3 dS/m, and 60 and 59 percent, respectively.

### Planting Stock

Seedlings of Apache plume (Questa, NM, seed source) and serviceberry (Utah seed source) were propagated at the Natural Resources Conservation Service Plant Materials Center in Los Lunas, NM. Seedlings were grown in 164-$cm^3$ containers (Ray Leach Super Cells) in a peat:perlite growing media (two parts peat moss and one part perlite by volume). Plants were fertilized with a water soluble 20-10-20 fertilizer (Peter's Peat Lite Special).

### Fertilization Treatments

Prior to transplanting, sites were ripped to a depth of 45 cm and irrigated. Ripping was accomplished using three 65-cm ripping bars attached to the back of a crawler tractor. In August 1995, seedlings (approximately 10 to 20 cm tall) were transplanted into the two sites in a randomized complete block design and irrigated the day after planting. Three blocks per site were established and each block had two parallel rows, 50 cm apart. Within each row, plant spacing was 30 cm. One row of each replicate block received fertilization treatment at the time of planting and the other row did not receive fertilizer (control plots). Six grams of Sierra, Inc., 17-6-12 plus micronutrients slow-release fertilizer (Scotts Company, Marysville, OH) were placed into each planting hole prior to transplanting the seedlings. Release duration of this fertilizer is 3 to 4 months at 21 °C. From 1996 through 2000 all plants received supplemental fertilization once each year.

### Survival and Shoot Growth

In September 1996 and August 2000 survival of both species was documented. In Spring 2001, shoot growth (height and crown width) was measured to the nearest centimeter for each plant. An average crown width was calculated for each plant using two perpendicular measurements of crown width oriented at 45 degrees to the direction of the planting row.

### Root Measurements

In blocks one and two from each site, two plants per species per fertilization treatment were measured for root growth and distribution. Roots were evaluated using techniques described by Parsons and others (1998). Initial excavation in November 2000 was performed using a backhoe to create a trench 1.5 m deep and 2 m long, 45 cm from the base of each shrub row. A 30 by 30 cm vertical plane was hand excavated 30 cm from the base of each plant where a 30 by 30 cm sampling frame was placed for root evaluation. The frame was constructed out of clear Plexiglas and divided by lines into 36, 5 by 5 cm grid cells. In each grid cell, roots were counted and divided into three diameter classes: <0.5, 0.5 to 2.0, and >2.0 mm. Root measurements were repeated at 20 and 10 cm from the base of each plant within the same vertical sampling frame.

### Data Analysis

The experimental design was a completely randomized design set in a split-split plot. Whole plot treatment was site and block within site was the whole plot error term. The split factor was fertilization treatment and the split-split factors were plane and depth. "Plane" refers to the horizontal distance away from the plant perpendicular to the row (10, 20, or 30 cm).

Survival of each species in 1996 and 2000 was analyzed through Chi-square tests in SAS using PROC FREQ (SAS Institute 1997). Shoot growth (height and crown width) was analyzed for each species using analysis of variance in SAS

(PROC GLM) to indicate simple and interaction effects of site and treatment.

Root counts were analyzed separately for each species using analysis of variance in a 2 (site) x 2 (fertilization treatment) x 3 (plane) x 6 (depth) factorial (PROC MIXED, SAS Institute 1997). Roots from three categories were combined for a weighted total to obtain a total root density (number of roots per 150 $cm^2$). Roots 0 to 0.05 mm were assigned a midpoint value of 0.025, roots 0.05 to 2.00 mm were assigned a midpoint value of 1.25, and roots greater than 2.00 mm were assigned a midpoint value of 2.25.

For root response, PROC MIXED calculated F statistics, means, and standard errors of both main effects and interaction combinations. Main effects of plane and depth and their interactions with fertilization treatments were evaluated, and least significant differences (LSD) were carried out for pairwise comparisons of main effects of plane and depth on root growth. All treatment effects for survival, and shoot and root growth were evaluated for significance at the 0.05 alpha level.

## Results

### Saskatoon Serviceberry

Fertilization at time of planting increased serviceberry crown width relative to unfertilized control plants ($p = 0.0015$). Crown widths of fertilized and control plants were 31.2 and 19.0 cm, respectively. However, fertilization at time of planting reduced survival of serviceberry, compared to controls, at both planting sites in 1996 ($P = 0.0006$) and 2000 ($p = 0.0002$). Survival of nonfertilized control plants was highest at the Spring Gulch site (table 1).

Fertilization at time of planting influenced total root density of serviceberry depending on sampling depth ($P < 0.0001$; fig. 1). Fertilized plants had lower total root densities at 5- to 10- and 10- to 15-cm depths than control plants. Across horizontal planes, fertilization treatments influenced total root density of serviceberry ($P < 0.010$, fig. 2). Serviceberry plants not fertilized at time of planting had greater total root density in the 10-cm plane than fertilized plants.

### Apache Plume

Shoot growth of Apache plume plants fertilized at time of planting was greater than unfertilized plants (height, $P < 0.0001$; crown width, $P = 0.0022$). Average height and crown width of fertilized plants were 42.4 and 43.2 cm, while average height and crown width of control plants were 21.3 and 29.0 cm, respectively. Survival of Apache plume was influenced by site and fertilization treatments in 1996 ($p = 0.0035$) and 2000 ($p = 0.0018$). Nonfertilized plants at Spring Gulch had the highest survival in both years out of all site by treatment combinations, while fertilized plants at Blind Gulch had the lowest survival in 1996 and 2000 (table 2).

Fertilization at time of planting influenced Apache plume total root density depending on depth and plane ($P = 0.0012$;

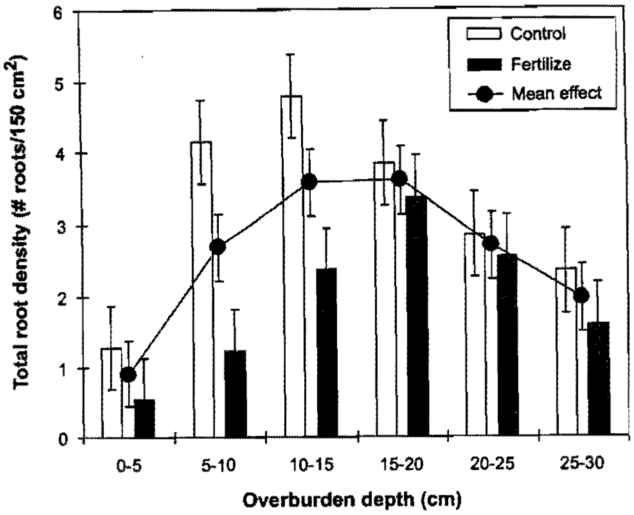


**Figure 1**—Total root density of serviceberry for control and fertilization treatments across overburden depths. Mean represents the effect of overburden depth averaged across fertilization treatments. Bars represent ± one standard error, n = 4.

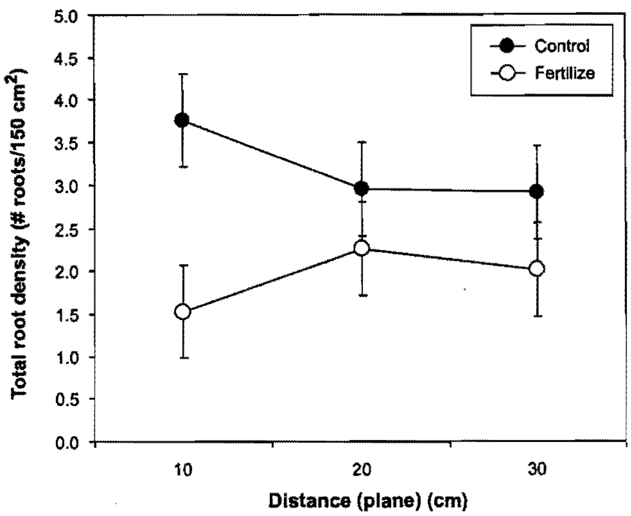


**Figure 2**—Total root density of serviceberry for control and fertilization treatments at three distances (planes). Bars represent ± one standard error, n = 4.

**Table 1**—One- and 5-year survival of serviceberry by site and fertilization at time of planting.

| Site | Treatment | Survival[a] 1996 | Survival[a] 2000 | Percent[b] |
|---|---|---|---|---|
| Spring Gulch | Control | 15 | 14 | 93 |
| Blind Gulch | Control | 10 | 10 | 67 |
| Spring Gulch | Fertilize | 6 | 4 | 27 |
| Blind Gulch | Fertilize | 5 | 4 | 27 |

[a]Survival as in number of individual plants, n = 15.
[b]Percent survival in 2000.

**Table 2** —One- and five-year survival of Apache plume by site and fertilization at time of planting.

| Site | Treatment | Survival[a] 1996 | Survival[a] 2000 | Percent[b] |
|---|---|---|---|---|
| Spring Gulch | Control | 21 | 20 | 95 |
| Blind Gulch | Control | 13 | 12 | 57 |
| Spring Gulch | Fertilize | 16 | 16 | 76 |
| Blind Gulch | Fertilize | 11 | 9 | 43 |

[a]Survival as in number of individual plants, n = 21.
[b]Percent survival in 2000.

fig. 3). In the 20-cm plane, total root density of fertilized plants was greater at depths below 20 cm than all other treatments.

## Discussion

### Survival and Shoot Growth

Survival of fertilized serviceberry and Apache plume plants was low the first year after planting, although fertilized plants that survived were larger than control plants. Increased shoot growth with fertilizer applications is concurrent with other literature. Burgess and others (1995) found NPK fertilization treatments improved shoot growth of white pine (*Pinus strobiformis*). Fertilizer applications on a reclamation site in Idaho increased growth of both native and introduced plant species (Williams and others 1990). Nitrogen and phosphorus applications greatly increased pine seedling height on mine overburden in Alabama (Zarger and others 1973).

Low survival has been associated with the use of slow-release fertilizers in other studies. Fisher and others (1983) observed slow-release fertilizer caused high mortality in juniper seedlings (*Juniperus monosperma*). At an eastern Sierra Nevada surface mine, slow-release fertilizers applied at doses of 30 g increased mortality of containerized, transplanted Jeffrey pine (*Pinus jeffreyi*), whereas doses of 10 and 20 g did not affect mortality (Walker 1999b). Transplanting date and release time of the fertilizer used in the study may have caused the observed mortality during the first year for serviceberry. Fisher and others (1983) suggest transplanting and fertilizing containerized tree seedlings during the summer rainfall period (July) in the Southwest rather than in late summer and fall. Slow-release fertilizer applications in August were more detrimental to juniper seedling growth and survival than May and July applications. It was speculated that low night temperatures following recent nutrient additions resulted in frost damage in August (Fisher and others 1983). Mortality of ponderosa pine seedlings in northern Idaho was influenced by dose and rate of slow-release fertilizer, with high doses and 9- and 12-month release times increasing mortality (Fan and others 2002).

Survival and shoot growth of transplanted and fertilized woody seedlings appear to be influenced by many abiotic factors including planting date and the amount, formulation, and rate of release of slow-release fertilizer. Based on published reports and our findings, transplanting Apache plume and serviceberry earlier in the growing season, early to midsummer, with a concurrent application of a slow-release fertilizer that releases nutrients when plants are actively growing, may reduce mortality and promote shoot growth for both species.

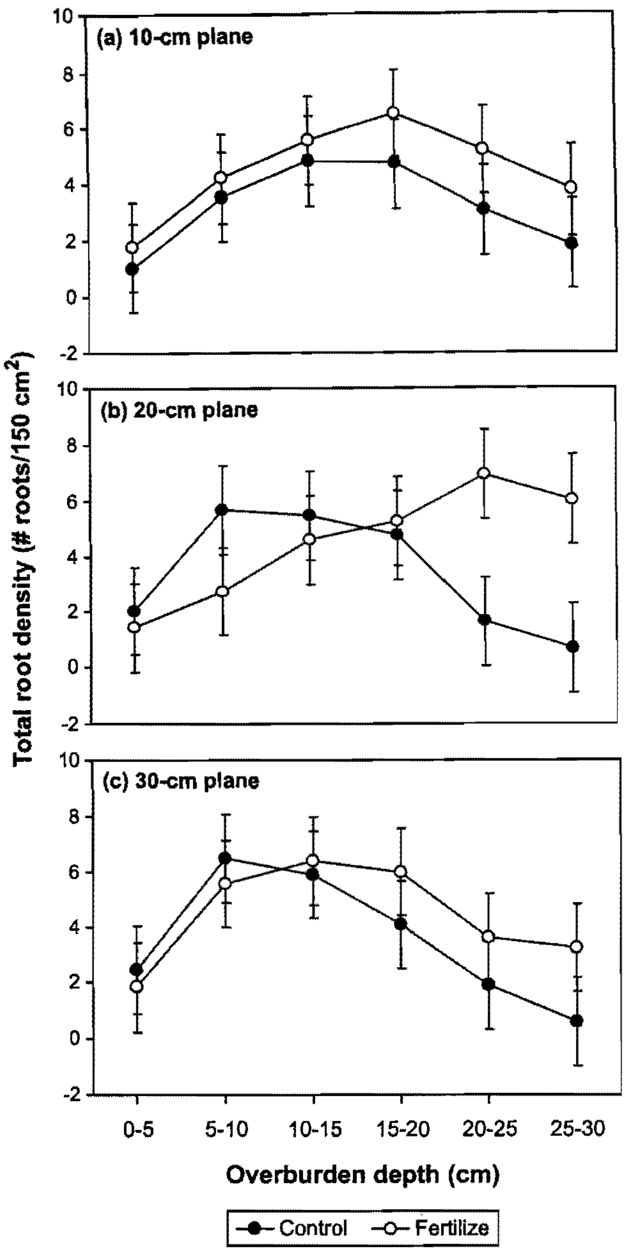


**Figure 3**—Total root density of Apache plume for control and fertilization treatments across overburden depths at three distances (planes). Bars represent ± one standard error, n = 4.

### Root Growth

Fertilization treatment effects on plant root density and distribution vary in the literature. In this study, there was no main effect of fertilization on overall root density for either species, but fertilization at time of planting did affect root distribution. Studies have shown alteration in plant root distribution in relation to fertilizer applications. For example, grasses increased their root growth in response to increased soil nutrients (Eissenstat and Caldwell 1988). Friend and others (1990) found that Douglas-fir plants produced more roots in nitrogen-rich than in nitrogen-poor microenvironments. In nitrogen stressed environments, Douglas-fir plants had a greater frequency of roots within nitrogen rich microenvironments than in nonstressed environments (Friend and others 1990). Similarly, Ringwall and others (2000) observed that fertilized leafy spurge plants allocated a greater portion of root biomass within the first 10 cm of soil and distributed a larger portion of roots in fertilized areas of the planting medium. It appears that root system distribution can be manipulated by fertilization at time of planting, but responses may be species dependent, as seen in our study.

Fertilization at time of planting had a negative effect on total root density of serviceberry at the base of the plant relative to the nonfertilized control. The rapid release of nutrients coupled with transplanting in late summer when plants were still actively growing may have promoted shoot development at the expense of root development into the overburden. As a consequence, plants receiving fertilizer at time of planting may have had insufficient root systems to support their growth and survival during the first year following plantings. Fertilization had an overall positive effect on total root density of Apache plume deeper in the profile at 20 cm from the base of the plant. Although fertilization decreased survival of Apache plume, its effect on shoot growth and root density suggests that the treatments were not as detrimental to the plant's performance as it was in serviceberry. Species were analyzed separately in this study; however, comparisons as to their response to fertilization at time of planting are important for future decisions about species selection and revegetation designs.

Fertilizer applications at time of planting may increase the establishment of herbaceous species (annuals, grasses, and forbs), which can negatively impact (for example, nutrient and water competition) survival and shoot and root growth of transplanted shrubs and trees (Cook and others 1974). Although not measured, plots fertilized at time of planting did have an observable increase of volunteer herbaceous plants (grasses and annual forbs) compared to control plots in 2000. It is not known when these plants became established, but favorable conditions did exist for them to establish within these plots. Favorable conditions may include fertilizer applications and lack of root competition near the soil surface (<20 cm), since both species fertilized at time of planting allocated a greater portion of roots deeper in the soil than at the surface. However, further evaluations are needed to determine whether the observed root response in both species was due directly to fertilizer applications or indirectly from competition from volunteer plants, or both.

## Conclusions

Although overall performance in terms of shoot growth was positive for both species when fertilized at time of planting, other fertilizer-related factors will need to be investigated to enhance establishment, growth, and long-term survival of plants planted directly into mine overburden at high elevations. Slow-release fertilizer formulation, release rate and total amount applied should be investigated more closely. While these factors have been investigated in other systems (Fan and others 2002; Walker 1999a,b), the impact of these treatments on plants at high elevations (>2,500 m) remains largely unknown.

Additional factors, which need further investigation, are related to fertilizer treatments for high elevation planting and include time of planting relative to the end of the growing season. Previous studies at this mine indicate two periods suitable, in terms of available moisture, for transplanting. These are during the midsummer rain period and in early fall. Incorporation of fertilizer, in particular nitrogen fertilizer, on fall plantings is not recommended; however, further work is warranted to look at planting and fertilizing earlier in the growing season than was performed in this study. The effects of incorporating slow-release fertilizer at this time will impact plant response. Too slow a release rate or too short a timeframe to the end of the growing season may increase mortality rates. Transplanting in midsummer, as recommended by Fisher and others (1983), may have prevented mortality in both species when fertilized. Timed properly this treatment can result in larger, more vigorous plants.

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