New Mexico Locust (*Robinia neomexicana*) Establishment on Mining Overburden

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Abstract

Mining presents challenges in revegetation efforts, particularly on exposed overburden. New Mexico locust (*Robinia neomexicana* Gray) has long been considered a good candidate for mine reclamation in the Southwestern United States, although little published data exists. Scarified New Mexico locust seeds were hydroseeded onto mining overburden screened to < 15 cm (6 in). Emergence was evaluated during the latter part of one field season using a blocked, split-plot design with the whole-plot factor of three mulch treatments (0, 1,121, or 2,242 kg/ha [0, 1,001, or 2,002 lb/ac]) and the split-plot factor of three composted, biosolid treatments (0.0, 112.5, or 225.0 Mg/ha [0.0, 50.2, or 100.4 ton/ac]). No differences were evident in emergence among mulch and biosolid treatment combinations. A higher number of emergents were observed in locations shaded by rocks than in open areas, and a higher percentage of seedlings that emerged from the protected areas were observed to survive than those that emerged in open areas. Future studies are required to confirm whether rock cover is beneficial to seed emergence and survival whereas organic amendments, incorporated or surface applied, had no effect at the rates applied.

Introduction

Mine reclamation, for cases in which little topsoil exists, may require amending rocky overburden with organic matter. The high rock fragment content has low water-holding capacity and fertility and can inhibit plant root volume (Munn et al. 1987). Rocky surface conditions can reduce erosion but may also reduce seed-to-soil contact (Redente et al. 1982), a problem when direct seeding.

New Mexico locust (*Robinia neomexicana* Gray) is a legume (Fabaceae) with several qualities that make it a good candidate for revegetation in disturbed areas: it fixes nitrogen, stabilizes soil, grows quickly, and, once established, is drought tolerant (Kuhns 1998, Thornburg 1982, USDA NRCS 2012, Vogel 1987). Transplanted New Mexico locust showed a fair survival rate after 6 years in a variety of New Mexico overburden materials (Dreesen 2000). Information regarding New Mexico locust germination in the field, however, is limited almost exclusively to laboratory (Khadduri et al. 2003) and greenhouse (Lin et al. 1996) experiments.

New Mexico locust is a rhizomatous, perennial, woody shrub or small tree (Wooton 1913). It is native to the American Southwest and Mexico, at an elevation range of 1,370 to 2,740 m (4,500 to 9,000 ft) in New Mexico (Carter 1997) but has been documented as high as 2,950 m (9,700 ft) elsewhere (Niering and Lowe 1984). It is found in understory and open areas (Martin and Hutchins 1984) and along montane riparian zones (Cudworth and Koprowski 2011, Danzer et al. 2001, Freeman and Dick-Peddie 1970, Martin 2007, Medina and Martin 1988, Skartvedt 2000, Toolin et al. 1979). Ease in establishment from seed has been categorized as “medium” and spread from seed as “good” (Plummer 1977). After it is established, New Mexico locust grows quickly (USDA NRCS 2012).

New Mexico locust is adapted to a variety of soil textures from sandy to clayey (Thornburg 1982, Vincent 1996, USDA NRCS 2012) and is often found on rocky sites (Buegge 2001, Darrow 1950, Frey and Schwenke 2012, Wooton 1913). Soil fertility requirement is “low” and calcium carbonate tolerance is “high” (USDA NRCS 2012). New Mexico locust forms a symbiotic association with *Rhizobium* (Kuhns 1998), and the nitrogen-fixing capacity in monoculture is up to 95 kg/ha/yr (85 lb/ac/yr) (USDA NRCS 2012). As a consequence, it is adaptable to a wide range of chemical and physical soil conditions and is tolerant of nutrient-poor soils, making it a strong competitor when establishing and growing in a variety of edaphic conditions.

Often plants growing on harsh (droughty, full sun) sites are found under inanimate objects such as tree stumps (Coop and Schoettle 2009) or rocks (Parker 1987). Before the term "nurse rock" was first used (Parker 1987), Kay (1978) noted that surface rocks offered several benefits to plant establishment and Conn and Snyder-Conn (1981) reported that cracks in rocks provided favorable germination conditions. Nurse rocks benefit plants across environments ranging from warm desert (Masrahi et al. 2012) to cool, high-elevation areas (Resler et al. 2005).

Although New Mexico locust is tolerant of poor soils, amendments are suggested to benefit revegetation, including organic matter, mulch, and supplemental irrigation. Organic matter in the form of composted municipal biosolids is often applied at rates of 56 to 224 Mg/ha (25 to 100 ton/ac) or more to hard rock mine sites (EPA 2007). Soils with incorporated composted biosolids have been reported to hold moisture longer than unamended soils (Risse et al. 2009) and organic compounds within compost may facilitate long-term soil aggregate stability (Piccolo and Mbagwu 1990). Composts typically have low C:N ratios for nitrogen mineralization (Harmsen and Kolenbrander 1965) providing slow, long-term beneficial release of nitrogen and other nutrients (Granberry et al. 2001, Maynard 2000).

Composted biosolids are available from wastewater treatment plants and often contain high-nutrient content, but may also be high in salts or heavy metals. When composts are applied on slopes, inorganic forms of nitrogen such as nitrate and ammonium are more likely than organic forms to runoff (Risse et al. 2009). Nitrogen additions not lost as runoff can persist for decades after application in revegetated areas (Wick et al. 2009). Composted biosolids have demonstrated no effect on seed germination of some species (Ligneau and Watt 1995), but reduced germination (Ayuso et al. 1996, Ozores-Hampton et al. 1999) or delayed germination (Wollan et al. 1978) in other species.

Another amendment that is commonly recommended for revegetation using direct seeding is mulch. On the ground, mulch protects seeds (Barnett et al. 1967), decreases soil moisture evaporation, and reduces soil erosion. Mulch should be applied after seeding to increase seed-to-soil contact (Ferns et al. 1996, Parrish and Anderson 1994, Wood and Buchanan 2000), although excess mulch atop seed can slow or prevent seed germination due to cooling or acting as a physical barrier (Lyle 1987).

Data are limited regarding germination and emergence of New Mexico locust *in situ*. The objective of this study was to determine the effects of surface rock cover, incorporated composted biosolid, and mulch treatments on the emergence and survival of seeded New Mexico locust in overburden material.

Materials and Methods

The study was conducted at New Mexico State University's John T. Harrington Forestry Research Center at Mora, NM (formerly the Mora Research Center). Climate in this region is semiarid, with precipitation occurring bimodally as monsoonal rain from July to September and moderate to heavy snow from November to April. Temperature fluctuates both seasonally and diurnally. Mean daily temperature fluctuation is 18 °C (32 °F), and mean frost-free (greater than 0 °C or 32 °F) days are approximately 130 (Western Regional Climate Center data—http://www.wrcc.dri.edu).

Seed

New Mexico locust seedpods were collected from the John Harrington Forestry Research Center in August 2009. The pods were air dried for approximately 3 weeks, and seeds were separated from pods by hand maceration. Debris was removed via threshing, followed by use of a seed blower. Seeds were stored in plastic freezer bags at approximately 3 °C (37 °F) until used.

Seeds were separated with a 3.00-mm (0.12-in) seed sieve (Humboldt Mfg. Co., Norridge, IL) into large (38,818 seeds/kg [17,605 seeds/lb]) and small (57,750 seeds/kg [26,190 seeds/lb]) sizes. Only large seeds were used for this trial. Seeds (16,200) were scarified by dropping them into boiling tapwater. The heat was immediately shut off, the hot water poured off and replaced with room temperature (~22 °C [72 °F]) tapwater, and the seeds then allowed to soak for 24 hr. The seeds were then removed from the water and air dried for 2 hr to approximately 50 percent moisture loss (based on germination studies described in Mexal et al., 2015). Moisture content was determined by weighing batches of seeds in 15-min intervals, from full hydration to 50 percent water loss. Seed, *Rhizobium* inoculant (17.90 g [0.63 oz]) (Plant Probiotics, Indianapolis, IN) and 10.00 g (0.35 oz) guar gum (Source Naturals, Santa Cruz, CA) were placed in a container, sprayed with sufficient tapwater to fully moisten the constituents, and hand shaken for 1 minute. The scarified seeds were counted into individual lots of 300, placed in plastic bags, and stored at 3 °C (37 °F) over night.

Overburden Material

Overburden material was sourced from a hardrock mine located in New Mexico's Taos Range within the Sangre de Cristo Mountains, part of the Southern Rocky Mountain physiographic province. Elevation of the mine site ranges from 2,300 to 3,300 m (7,500 to 10,800 ft). The overburden material is composed of highly weathered, intrusive, igneous rock. Soil texture within the overburden is sandy loam to loamy sand ranging from 66 to 77 percent sand, 18 to 27 percent silt, and 4 to 12 percent clay (Tahboub 2001). Rock fragment is 48 to 77 percent (Tahboub 2001), typical of mine soils and overburden (Ashby et al. 1984). Saturated paste pH of the overburden is generally neutral to slightly alkaline (6.8 to 7.7), total dissolved solids are 410 mg/L (410 ppm), electrical conductivity and sodium adsorption ratio are also low (Shaw et al. 2002, Tahboub 2001), indicating that the overburden is neither saline nor sodic. In addition, organic matter content ranges from 0.3 to 0.7 percent (Tahboub 2001). The overburden contains high amounts of calcium carbonate, indicated by strong effervescence of the material when reacted with 1 percent hydrochloric acid (USDA NRCS 2011).

Treatments

Eighteen 2.4 by 2.4 m (8.0 by 8.0 ft) square frames were constructed of lumber. Sheets of flattened expanded metal carbon steel (#13, Reliance Steel Company Albuquerque, NM) were cut and placed on the frames to support the overburden. Two 3.8 by 14.0 cm (2.0 by 6.0 in) dividers were attached to the frames (over the expanded flattened mesh metal screen) to further subdivide them into three 236.2 by 78.7 cm (93.0 by 31.0 in; 1.85 m^2 [19.10 ft^2]) "subframe" units (figure 1). Water-permeable weed barrier (Dewitt Pro 5, Greenhouse Supply, Albuquerque, NM) was cut and placed on the bottom of each individual subframe and stapled to all sides.

The 18 frames were divided into 3 clusters (blocks) of 6. Within each block, 2 frames were randomly assigned to receive zero, medium (1,121 kg/ha [1,001 lb/ac]), or high (2,242 kg/ha [2,002 lb/ac]) mulch applications for a total of 6 replicates per whole-plot treatment (mulch) level. Within each frame,

Figure 1. Single 2.4 by 2.4 m (8.0 by 8.0 ft) square frame divided into three subframes. Overburden has been added above metal mesh screen and weed barrier (not visible) in far right subframe. (Photo by Jon Hawthorne, 2012)

subframes (subplots) were randomly assigned to incorporation of zero, medium (112.5 Mg/ha [50.2 ton/ac]), or high (225.0 Mg/ha [100.4 ton/ac]) biosolid treatment. The medium biosolid rate was suggested for testing by Chevron Mining, Inc., and we included zero and high rates for comparison.

Each subframe was filled with overburden, screened to remove rocks larger than 15 cm (6 in), to a depth of 7 cm (3 in). Screened (< 1.3 cm [0.5 in]) composted biosolids were purchased from the City of Santa Fe, NM's wastewater treatment plant. Biosolids were analyzed by the city and reported to be slightly acidic, low in salts, and contain 52 percent organic matter based on loss-on-ignition during combustion and 25 percent moisture. Offered as "compost," the product is a mixture of wastewater-derived biosolids and green waste composed of pulverized wood, brush trimmings, and horse bedding (http://www.santafenm.gov/index.aspx?NID=1313). The composting process significantly reduces pathogens in the biosolids, which are consequently considered "Class A" and publicly available. Biosolids were weighed separately for each subframe, placed on top of the overburden, and manually incorporated into the overburden with a heavy rake.

Each subframe was seeded in early August by adding 300 scarified seeds and 5.00 L (1.32 gal) of tapwater to an 18.9 L (5.0 gal) bucket, then placing a submersible pump (Little Giant Pump Company Model No. 5-MSP) in the bottom center of the bucket to simulate hydroseeding. The screen on the bottom of the pump was removed to allow for passage of seeds into the pump, and screws were placed in holes at the pump's four corners to raise it approximately 5.0 mm (~0.2 in) above the bottom of the bucket. The bucket was gently agitated until most of the seeds had been discharged (approximately 10 sec). Any seeds remaining in the bucket (usually < 5 percent) were applied to the subframe by adding enough water to the bottom of the bucket (without pump) and hand applying the seed/water combination onto the center of the subframe. A cardboard barrier was positioned to keep seeds within the confines of the subframe during seeding.

Mulch treatments were applied the day following seeding. Mulch, composed of tree waste processed twice through a wood chipper, was acquired from Las Vegas, NM. Air dry mulch was weighed out separately for each subframe, applied by hand, and raked across the overburden to distribute evenly after seeding. After mulching, each frame was covered with wildlife netting (1.90 cm [0.75 in] mesh; Greenscapes Home and Garden Products Inc., Calhoun, GA) to prevent predation.

Irrigation was applied via garden hose and sprayer to the frames at an initial rate of 1.20 L (0.32 gal) or 0.65 mm (0.03 in) per subframe 6 and 8 days after seeding to wet the surface. From days 10 through 18, each subframe was irrigated daily to the point at which irrigation water pooled on the overburden surface and drainage through the weed barrier was evident. The increased irrigation met reference evapotranspiration (ET) demands (NMSU Climate Center 2012). Using the same approach, frames were watered twice daily from days 19 through 27, and once daily between days 28 and 47.

Data Collection and Statistical Analysis

Emergence was counted and recorded every 3 days through day 33 and weekly thereafter through day 47. Poultry leg bands (Kuhl Corp., Flemington, NJ) were placed on new emergents to track emergence by day (Mexal and Fisher 1987). A different color was used for each day (figure 2). Emergence was tallied by day for each frame (mulch treatment) and subframe (biosolid treatment) for 47 days after seeding. Days to 50 percent final emergence (referred to here as "E_{50}" similar to the use of 50 percent germination or "G_{50}" in lab studies) were computed by comparing seedling emergence with total emergence over time. Proximity to rocks was recorded for each emergent. Emergents were considered "protected" if they were directly below a rock (shaded by overhead sun) or "open" if not below a rock. Survival was defined as emergents still living at 47 days after seeding.

Data in the randomized blocked split-plot experimental design were analyzed to assess the effects of mulch (the whole-plot factor) and biosolid (the subplot factor) treatments on emergence of New Mexico locust. In addition to fixed effects for mulch, biosolids, and their interaction, the model included random effects for block and whole-plot experimental units. Total emergence and survival at 47 days were analyzed using SAS version 9.3 PROC GLIMMIX software (SAS Institute Inc. 2011) to fit a generalized linear mixed model that explicitly recognized a binomial response distribution, used the logit link, and was fitted using Laplace integral approximation. Data-scale inverse linked estimates were reported. The E_{50} was analyzed using a model assuming normality with SAS version 9.3 PROC MIXED software. Emergence and survival in protected versus open areas were summarized descriptively. Significance was defined at $p \leq 0.05$.

Figure 2. New Mexico locust seedlings emerging from under rocks in overburden. Different colored bands indicate different days of emergence as observed in the field. Wildlife netting visible is ~10 cm (4 in) above the seedlings. (Photo by Jon Hawthorne, 2012)

Results

Emergence ranged from 6.1 to 8.6 percent, with no significant differences among treatment combinations (table 1). Emergence began on day 15, 5 days after irrigation was increased to meet reference ET demands (figure 3). A rainfall event of 22.30 mm (0.88 in) on day 25 was followed by marked increase in new emergence on days 27 and 30. Emergence peaked on day 30, and no additional emergence occurred by day 47. E_{50} was significantly higher in plots with zero biosolids than in plots with the high biosolid treatment (30.33 ± 0.42 days versus 29.00 ± 0.42; p = 0.0114), but did not differ from plots with the medium biosolid rate (29.50 ± 0.42 days). Survival was 83.1 percent (range = 75.0 to 87.5 percent) and did not differ among treatments (data not shown).

In every subplot, the number of seeds emerging in rock-shaded areas was higher than the number emerged in open areas. Among treatment groups, 0.3 to 1.6 percent of seeds emerged in open areas while 5.4 to 7.7 percent of seeds emerged in shaded areas; the proportion of emergents occurring in shaded areas ranged from 77.8 to 94.6 percent. Considerable differences existed between survival of emergents that were noted in open areas and those that emerged protected underneath rocks (0 to 12.5 percent versus 92.4 to 95.1 percent, respectively) (figure 4).

Table 1. Emergence percent estimates using generalized linear mixed model fitted with Laplace integral approximation (SE).

Mulch (kg/ha)	Biosolid (Mg/ha)			Mean (%)
	0	112.5	225	
0	7.95 (0.79)	8.45 (0.82)	8.61 (0.83)	**8.34**
1,121	6.96 (0.73)	7.24 (0.75)	7.35 (0.75)	**7.18**
2,242	6.99 (0.73)	6.11 (0.67)	7.60 (0.77)	**6.90**
Mean (%)	**7.30**	**7.27**	**7.85**	**7.47**

p-values: Biosolid main effect (p = 0.4082), mulch main effect (p = 0.1014), and interaction (p = 0.6895).

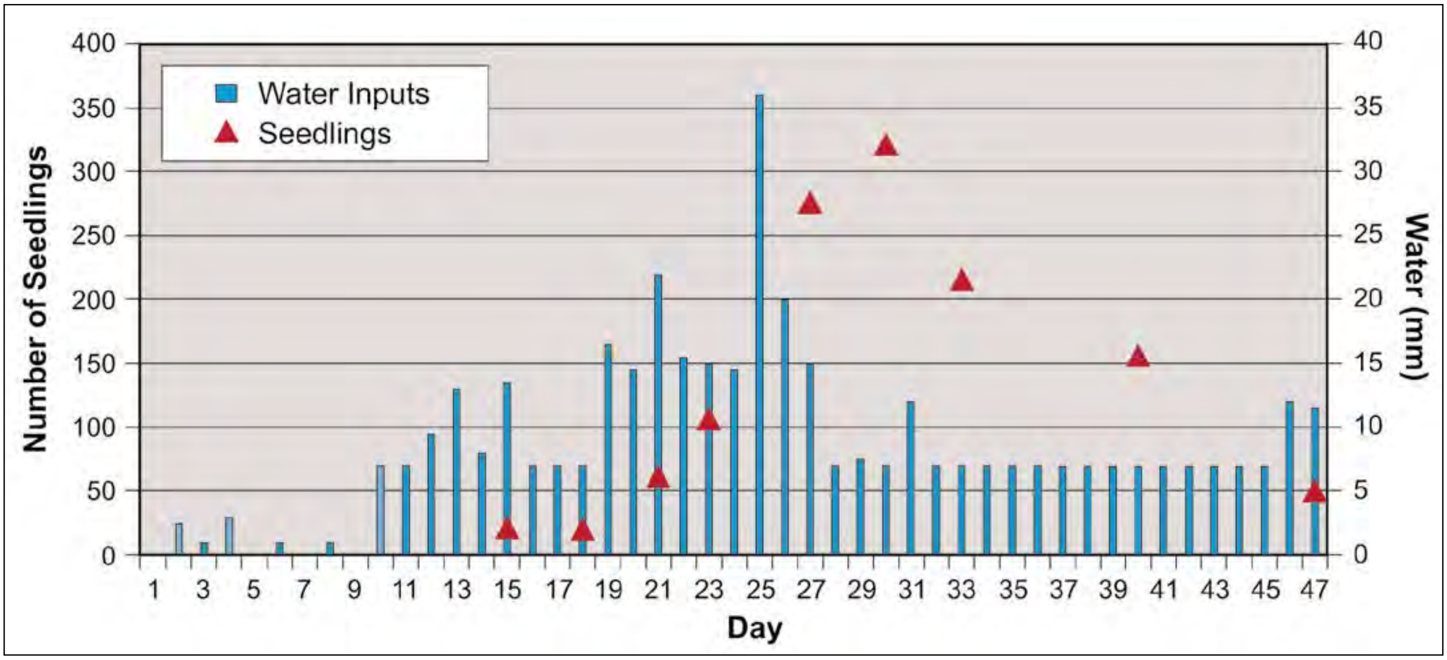

Figure 3. Number of newly emerged New Mexico locust seedlings on days after seeding and daily water inputs (rainfall plus irrigation).

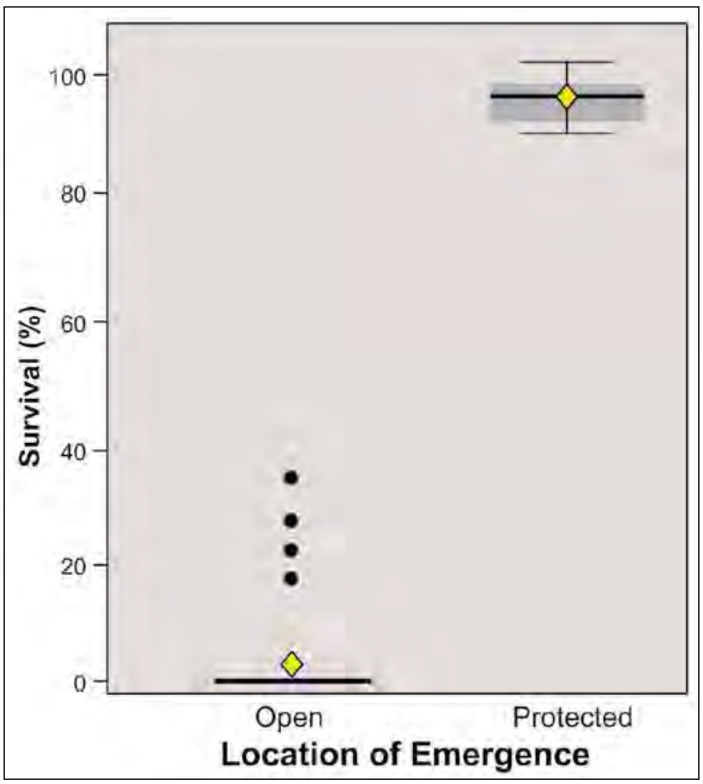

Figure 4. Box and whisker plot for survival at the end of the 47-day study (as a percent of total seed broadcast in each subframe) of New Mexico locust seedlings in "open" space (between rocks) or "protected" by rocks. Biosolids and mulch treatments were combined. The mean is represented by a diamond. Filled circles are outliers.

Discussion

Emergence of New Mexico locust in this study was similar to that of hand broadcast black locust after one growing season (7 to 10 percent) (Vogel and Berg 1973). Direct seeding, either for reforestation or restoration, generally results in low germination and seedling establishment. Direct seeding success is inherently variable, depending on site quality, seed quality, and environmental factors, including predation. Hence, seeding rates are often high. Little et al. (1958) found that direct seeding of pitch pine (*Pinus rigida* Mill.) in New Jersey resulted in 2.5 to 13 percent emergence, depending on site quality and seed size. Doust et al. (2006) found small-seeded species (similar to locust seed size) averaged 1 to 4 percent emergence after 2 months when broadcast onto cultivated soil. Seeding New Mexico locust at the recommended rate of 1.50 million seeds/ha (0.61 million seeds/ac) could result in more than 15,000 seedlings/ha (6,073 seedlings/ac) or 1.00 seedling/m^2 (0.84 seedlings/yd^2) with just 1 percent germination and survival. Thus, 7 to 10 percent emergence in the first growing season should lead to successful establishment on restoration sites.

Seeds in our study were scarified then dried to 50 percent moisture content to facilitate seeding, as hydroseeding can reportedly crush hydrated, scarified New Mexico locust seed (Hine et al. 1997). Drying the seed to 50 percent moisture content obviated this issue but may have reimposed dormancy or seeds may have failed to emerge for other reasons. Nevertheless, little emergence occurred in the study until at least 7.5 mm (0.3 in) of water was applied as irrigation, enough to provide seeds on the surface with sufficient moisture to germinate and emerge. Rainfall events in subsequent days were generally followed by increased emergence. The effect of moisture on emergence indicates that New Mexico locust should be seeded before seasonal monsoons occur. Olson and Karrfalt (2008) recommend seeding "locust" between March and May. This recommendation is logical if no irrigation is planned, and emergence is reliant on snowmelt or incipient soil moisture.

Biosolids and Mulch Effects on Emergence

The nonsignificant differences among biosolid and mulch treatments on total emergence of New Mexico locust were unexpected. Mulch is recommended to help retain surface moisture, but the rates applied in this study, which were based on rates that could be applied via hydromulching and evaluated previously in a similar mine revegetation study (Golder Associates 2004), appeared to have no effect. Biosolids incorporated in the overburden consisted of only 52 percent organic matter; while biosolids can be up to 70 percent organic material, most treated biosolids have surprisingly high amounts of inorganic material (Epstein 2002). Thus any anticipated benefit may be reduced by the inorganic components of biosolids.

While biosolids did not improve seed germination, it did reduce E_{50} time, which was in contrast to other studies (Lin et al. 1996, Wollan et al. 1978) and may have been due to increased soil-to-seed contact or improved water-holding capacity.

This study suggested little benefit from application of either mulch or biosolids. Although mulch is often available free of charge, it can be expensive to transport and apply. Composted biosolids can be costly to purchase and to incorporate on site. The biosolids used in this study, purchased from one of the nearest sources to the mine, cost \$15.76/m^3 (\$11.50/yd^3).

Effects of Rocks on Seedling Emergence and Survival

Although rock fragments are often viewed as having a negative effect on seeding and moisture retention in soil (Carlucci et al. 2011, Haussmann et al. 2010, Kleier and Lambrinos 2005), we noted more seedling emergence in the proximity of rocks than in open space. Rocks may have facilitated germination and emergence by providing protected microsites or they may have served as catchment zones, resulting in higher seed concentrations. Nevertheless, seedling survival at 47 days was higher in the proximity of rocks compared with open areas; similar to other studies (Maestre et al. 2003, Peters et al. 2008, Resler et al. 2005). However, seedling emergence in protected versus open sites was not a factor in this study design. Future studies specifically designed to assess the effect of protected versus open sites are needed to understand the benefits of surface rocks.

These beneficial "nurse rocks" have also been referred to as safe sites (Fowler 1988) and microsites (Kleier and Rundel 2004). Rocks may have benefitted New Mexico locust emergence by serving as a seed trap (Haussmann et al. 2010) and by preventing desiccation of seeds and seedlings by protecting them from sun and wind, decreasing soil temperature, and increasing moisture content (Nobel et al. 1992). The overburden hardened noticeably after wetting and drying cycles and may have prevented seed radicle entry and establishment (Campbell and Swain 1973). Another benefit from rocks is that they provide leverage against which the seeds can push, allowing the radicle to enter the surface instead of pushing the seed over and raising the radicle (Dowling et al. 1971).

Conclusions

Because no differences in emergence or survival existed between any of the treatment groups, neither composted biosolids nor wood fiber mulch are warranted at the rates tested. Rainfall coupled with supplemental irrigation was required for seedling establishment.

In this study, rocks larger than 15 cm (6 in) were removed from the overburden. Nevertheless, surface rocks may provide protected sites for New Mexico locust to germinate, emerge, and become established. We observed more seedlings under rocks compared with open areas suggesting that surface rocks provide beneficial habitat for seedling establishment. Leaving rocks in place may be key to mine reclamation and revegetation, particularly in a semiarid region.

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