TESTS OF THE ABILITY OF HEAP LEACH MATERIAL TO SUPPORT PLANT GROWTH[1]

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Abstract: The ability of heap leach pads to support plant establishment is not documented in the scientific literature on mine reclamation. Two greenhouse studies were initiated to examine plant growth potential in this material. In the first study, *Zea mays* was used to compare growth in heap leach material before chemical treatment and in water rinsed post-treatment (after sodium cyanide, sodium hydroxide, cement, lime, and floculant addition) material. Soil mix amendment was essential for growth in post-treatment material and liquid fertilizers improved growth. The second study focused on the potential growth an survival of *Acacia greggii* (a species native to the mine site) in amended and unamended post-leach material with several liquid fertilizers. This species grew and survived in unamended material, but below-ground growth improved with the addition of non-ore bearing spoils (overburden) as an amendment.

Additional Key Words: Gold Mine Reclamation; Heap Leach; Overburden; *Zea mays*; *Acacia greggii*; Mojave Desert.

Introduction

Spoils from gold mining will remain as permanent features of the post-mining landscape. Mine spoils are often deficient in nutrients such as N, P, K, Ca, and Mg and have high concentrations of toxic materials (Pichtel et al. 1994). The process of extracting gold by leaching crushed ore bearing material with sodium cyanide, sodium hydroxide, cement, lime, and floculant (a high molecular weight polymer) alters chemical properties and texture of the crushed rock. The leach pad material, in this experiment, was field classified as a silty-sandy gravel (Udden-Wentworth size classification) with a gravel composition ranging from granule to pebble (Leeder 1991). This coarse texture may adversely affect nutrient and water retention. All of these conditions may inhibit plant establishment on mine soils. The ability of heap leach pads to support plant growth is not documented in the scientific literature on mine reclamation. However, amending other spoil types with soil and nutrients has improved vegetation establishment and decreased uptake of toxic materials in some mining operations (Apel 1983).

Two greenhouse pot studies were conducted at San Diego State University to determine the growth potential of plants in heap leach material. The first study compared plant growth in heap leach material before and after leaching. *Zea mays* L. cv Hopi blue (blue corn) was used as a test plant because it germinates readily and grows quickly. Plants were grown in thoroughly water rinsed pre-leach material (crushed ore less than 3/8 inch) and in post-leach material (leached ore: sodium cyanide, sodium hydroxide, cement, lime, and floculant), with and without a potting mix amendment and/or a liquid fertilizer. The second study examined growth potential of a native legume in post-treatment heap leach with amendments and rinses which may improve growth. *Acacia greggii* A. Gray (catclaw) was used because it is a potential species for revegetation of the heap leach pad. One recent experiment indicates that *A. greggii* has a high survival rate (87.9%) on non-toxic spoils (Fidelibus 1994). The current study examined seedling growth in treated and rinsed post-leach material with a 5 cm surface layer consisting of: 1) post-leach materials alone, 2) post-leach mixed with non-ore bearing spoils (overburden), and 3) post-leach mixed with growth media (pile of salvaged growth media). Fertilizer treatments of Triple Super phosphate, ammonium sulfate, and a Hoagland's solution were also examined. This was part of a larger study examining nitrogen and phosphorus uptake of plants grown in heap leach material.

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In both studies, plants were monitored for growth (final heights in all cells, including those that did not survive) and, following the greenhouse trial, were harvested and measured for root and shoot weights (and root length in *A. greggii*) as an indicator of potential long-term plant survival and growth. In addition, soil loss was measured to determine wash through in heap leach materials and whether it affects plant growth. The data from these analyses are the first step in determining whether amendments and/or fertilizers are necessary for plant growth on detoxified heap leach piles.

Materials and Methods

Zea mays

Pre- and post-leach material was collected from Viceroy Gold's Castle Mountain Mine located in the eastern Mojave Desert. The material was thoroughly rinsed with tap water. Salts in the spoils were of interest because of the sodium used in the heap leach treatment process. Magnesium (Mg), calcium (Ca) (Lanyon and Heald 1982), and sodium (Knudsen et al. 1982) concentrations were determined by atomic absorption methods. To examine the relative contribution of sodium as compared to total salts (Brady 1990), Sodium Adsorption Ratio (SAR) was calculated using the equation: $SAR=[Na]/([Ca+Mg]/2)^{1/2}$ (Virginia and Jarrell 1983), as plant growth may decrease with increased SAR (Darby 1993). Soil pH was measured with a glass electrode (McLean 1982).

Two substrate types, two amendments, and two irrigation treatments were applied in a complete factorial design (Table 1). There were eight replicates for each of the eight treatment combinations, arranged randomly within a block. Substrate consisted of pre-leach and post-leach material. Amendments consisted of none (control) and soil mix (comprised of sand, vermiculite, and potting mix at a ratio of 7:2:1). Irrigation treatments were reverse osmosis (RO) water (control) and Fertilizer (RO water and Roots Plus Seedling Starter (2:4:2) at a ratio of 384:1.

Table 1. Treatments for the *Zea mays* experiment*

Test plant:	*Zea mays*
Treatments	
Substrate:	Pre-leach, Post-leach
Amendment:	none, soil mix
Irrigation:	RO water, Fertilizer

*Complete factorial: 2x2x2, Replicates: 8. Pre-leach (crushed ore less than 3/8 inch), post-leach (crushed ore leached with sodium cyanide, sodium hydroxide, lime, cement, floculant), soil mix (sand, vermiculite, and potting mix at a ratio of 7:2:1), RO (reverse osmosis water), and fertilizer (RO and Roots Plus Seedling Starter at a ratio of 384:1).

In May 1993, 32 supercell containers (164 ml, Ray Leach™) were filled with pre-leach and 32 with post-leach material. Half of each substrate treatment received a 2.5 cm soil mix amendment placed on top of the material and half a small seed spot to assist early seedling survival. Pre-germinated *Zea mays* seeds (soaked overnight in reverse osmosis (RO) water and then placed in moistened Kimtex™ fabric for three days) were planted in the soil mix layer or in the seed spot (both at a depth of 2 cm). Within each substrate and amendment combination, half were watered with deionized reverse osmosis (RO) water and half with a liquid fertilizer (fert) solution. The containers received 50 ml of irrigation every 4 days.

In order to determine the amount of soil lost from irrigation, a pre-weighed cup was placed beneath each container to catch material washed through. The cups were dried and weighed at the end of the experiment. Following the 30 day greenhouse study, the blue corn was harvested, final shoot height and fresh and dry weights of the roots and shoots were measured and recorded.

Acacia greggii

Three soil amendments and four fertilizer treatments were applied in a complete factorial design (Table 2). There were three replicates for each of the 12 treatment combinations, arranged in three randomized blocks. Soil amendments consisted of post-leach material mixed with: 1) nothing (control), 2) growth media (pile of salvaged growth media) at a ratio of 2:1, or 3) overburden at a ratio of 2:1. Fertilizer treatments were: 1) RO Water (control), 2) Ammonium sulfate (AS) diluted 200:1 (Bunt 1988),

3) Hoagland's (Hoag), solution 2 (Hoagland and Arnon 1938), and 4) Triple Super phosphate (TSP) diluted 200:1 (Bunt 1988).

Table 2. Treatments for the Acacia greggii experiment*

Test plant:	*Acacia greggii*
Treatments	
Substrate:	Post-leach
Amendments:	none, overburden, growth media
Fertilizer:	none, AS, Hoagland's, TSP

*Complete factorial: 3x4, Replicates: 3. Ammonium sulfate (AS), Hoagland's solution 2 (Hoagland's), triple super phosphate (TSP).

Post-leach material was collected from Castle Mountain Mine, rinsed with tap water and then RO water to remove minerals. A portion was removed to create the soil amendment mixes. The remaining post-leach material was placed in 36, 12 oz cups with four 0.5 cm drain holes drilled in the bottom and a soil collector positioned beneath each container. Cups contained approximately 400 g of post-leach material. The cups were divided into three groups of 12, each group receiving a 5 cm surface layer of one of the three soil amendments. Native *Acacia greggii* seeds were pre-germinated in the same manner as *Z. mays* seeds and one seedling planted in each pot at a depth of 3 cm. The plants grown with no amendment received a seed spot of salvaged growth media (less than 1 g). Each soil amendment was divided into four groups of three seedlings and irrigated with 200 ml of one of the four fertilizer treatments.

The plants were grown for 60 days (July - August 1994) in a greenhouse. The cells were watered twice a week with 200 ml of RO water, and once every two weeks, with the fertilizer treatment. Following the growing period, shoot height was measured and leaf number counted. The plants were then harvested and root and shoot weights and longest root extension length recorded. The soil collection cups were dried and weighed to measure soil washing through.

Statistical Analysis

An Analysis of Variance (ANOVA), with 95% confidence limits, was used to determine if substrate and water treatments had a statistically significant effect on the parameters measured in both studies (SuperANOVA statistical package, Abacus Concepts 1989). When F values were significant, a Fisher's Protected Least Significant Difference (PLSD) test (Day and Quinn 1989) was used to compare treatments. When individuals did not survive and were removed from the model (giving unequal sample sizes), the Tukey-Kramer HSD was used.

Results

Zea mays

Magnesium and calcium levels decreased and sodium content almost doubled in post-leach material (Table 3). This change in mineral concentrations more than doubled the SAR, indicating higher sodium toxicity. Initial and final pH changed little, remaining very alkaline.

Table 3. Pre- and Post-leach Material Comparison.*

Substrate	Mg	Ca	Na	SAR	pH
	-----meq/L-----				
Pre-leach	8.3	14.7	14.8	4.36	9.4
Post-Leach	3.3	12.1	27.6	9.95	9.2

* Pre-leach (crushed ore less than 3/8 inch), post-leach (crushed ore leached with sodium cyanide, sodium hydroxide, lime, cement, floculant), Magnesium (Mg), calcium (Ca), sodium (Na), sodium adsorption ratio (SAR).

Substrate had a significant effect on growth ($p<0.003$) with the highest proportion of surviving plants growing in pre-leach material (Table 4). Height, root weights, and shoot weights were significantly lower in plants grown in post-leach than in pre-leach material. Root to shoot ratio (R:S) and soil lost from wash through increased in post-leach pots.

Table 4. F, p, and mean values from ANOVA on *Zea mays**

		Growth	Final Ht	Root Wt.	Shoot Wt.	R:S	Soil lost
Substrate	F	9.42	45.70	18.07	15.902	11.58	8.082
	p	0.003	0.001	0.001	0.002	0.005	0.006
		--------cm--------		----------g----------			---g--
Pre-leach		7.89 a	19.44 a	0.97 a	0.16 a	7.40 a	0.60 a
Post-leach		2.15 b	13.76 b	0.50 b	0.06 b	9.82 b	0.85 b
Amendment	F	23.97	0.08	0.90	0.14	1.56	44.13
	p	0.001	0.998	0.360	0.718	0.234	0.001
		--------cm--------		----------g----------			---g---
None		0.96 a	15.40 a	0.99 a	0.09 a	11.37 a	1.03 a
Soil mix		9.08 b	18.17 a	0.82 a	0.14 a	7.65 a	0.42 b
Irrigation	F	1.08	41.12	3.98	8.69	11.88	0.149
	p	0.303	0.001	0.068	0.011	0.004	0.701
		--------cm--------		----------g----------			---g---
RO		3.65 a	14.59 a	0.81 a	0.09 a	10.07 a	0.76 a
Fertilizer		6.40 a	20.48 b	0.87 a	0.17 b	6.46 b	0.69 a

*Raw means presented on data log transformed for analysis. All individuals were analyzed for growth (final heights in all cells, including non-survivors) and soil lost, while survivors were used to analyze final height (Final Ht.), root weight (Root Wt.), shoot weight (Shoot Wt.), and root to shoot ratio (R:S). Values followed by the same letter in a column are not significantly different ($p<0.05$) using Fishers PLSD (growth and soil lost) and Tukey-Kramer (all others). Pre-leach (crushed ore less than 3/8 inch), post-leach (crushed ore leached with sodium cyanide, sodium hydroxide, cement, lime, floculant), soil mix (sand, vermiculite, and potting mix at a ratio of 7:2:1), RO (reverse osmosis water), and fertilizer (RO and Roots Plus Seedling Starter at a ratio of 384:1).

Addition of soil mix to the substrate increased growth nine-fold. No growth occurred in post-leach material without the amendment and only three plants grew in pre-leach without amendment. However, those plants which did survive in unamended pre-leach had similar heights, root weights, shoot weights, and R:S. Soil lost more than doubled from amended to unamended substrate.

The addition of fertilizer did not change growth, root weights, or soil lost. Heights increased significantly and shoot weights nearly doubled with the addition of fertilizer. Root to shoot ratio decreased with the addition of nutrients.

There were no significant interactions between substrate and irrigation on *Z. mays* growth. However, there was an interaction between material and amendment on lost soil (Figure 1). Soil wash through was high in unamended pre- and post-leach material, but pre-leach material had 75% greater loss. The addition of the soil mix resulted in low, and nearly equal amounts of soil wash through.

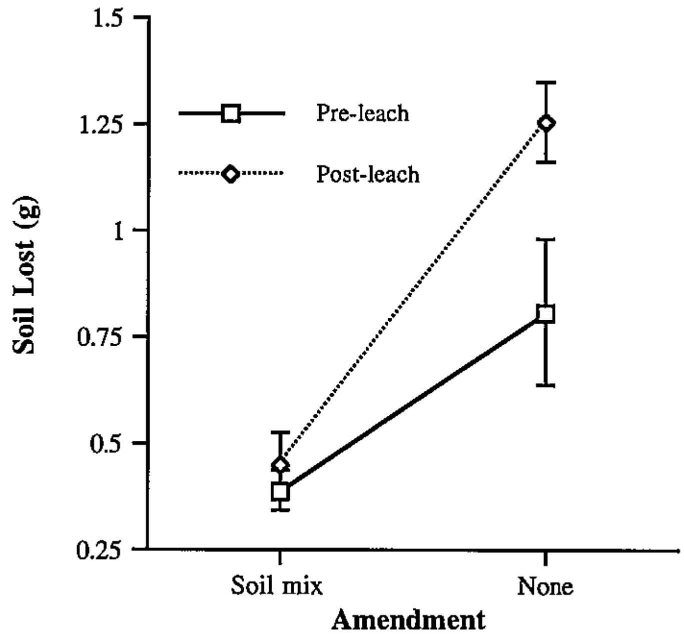

Figure 1. Interaction of substrate and amendment on the amount of soil lost by wash through. Significant interaction at p<0.036. Substrates are pre-leach (crushed ore less than 3/8 inch without additives) and post-leach (crushed ore leached with sodium cyanide, sodium hydroxide, cement, lime, and floculant).

Acacia greggii

Catclaw seedlings established best in materials with overburden or no amendment (Table 5) and fared poorly in the growth media amended substrates. Final height and shoot weights followed similar patterns. Seedlings grown in overburden amended substrates had the greatest root extension and root weights. Fertilizer was not significant for any response variable.

Table 5. F, p, and mean values from ANOVA on *Acacia gregii**

		Growth	Final Ht.	Leaves	Root Ext.	Root Wt.	Shoot Wt.	R:S	Soil Lost
	F	3.89	4.35	2.85	7.75	7.17	9.53	2.47	0.78
Amendment	p	0.034	0.048	0.110	0.011	0.014	0.006	0.142	0.469
		------cm------		--no--	--cm--	----------g----------			---g---
None		4.46 a	7.43 ab	9.44 a	6.89 a	0.12 a	0.26 a	0.54 a	2.40 a
Overburden		4.70 a	7.70 b	8.50 a	12.87 b	0.20 b	0.25 a	0.86 a	4.01 a
Growth media		1.30 b	5.20 a	7.20 a	6.00 a	0.10 a	0.13 b	0.84 a	3.53 a

*Raw means presented on data log transformed for analysis. All individuals were analyzed for growth (final height, including non-survivors) and soil lost, while survivors were used to analyze all other measurements. Values followed by the same letter in a column are not significantly different (p<0.05) using Fishers PLSD (growth and soil lost) and Tukey-Kramer (all others). Column abbreviations: final height (Final Ht.), root extension (Root Ext.), root weight (Root Wt.), shoot weight (Shoot Wt.), and root to shoot ratio (R:S).

Discussion

Zea mays

Zea mays had more difficulty growing on post-leach materials from Castle Mountain Mine than on pre-leach. Growth was best in pre-leach material with the addition of soil mix. No growth occurred in the post-leach material alone and survival was low in pre-leach material alone. These plants had high soil loss, which may also indicate high nutrient and water losses in these pots. This suggests that texture may be a significant problem. In addition, the high alkalinity of pre-leach and post-leach substrates, may have inhibited growth in unamended material.

Although the post-leach material was rinsed before the *Z. mays* was planted, sodium levels were nearly double those in the pre-leach material, suggesting that cyanide may also have been present in the post-leach material (not measured). Sodium in soils may interfere with the uptake of potassium and calcium (Ting 1982) and saline soils have been found to inhibit root growth in *Z. mays* (Zidan et al. 1990). The high levels of sodium found in the post-leach materials may have inhibited root growth, which in turn could limit shoot growth. The individuals grown in post-leach materials, without amendment, and/or without fertilizer had very high R:S. *Zea mays* may have responded to low nutrient availability by decreasing shoot biomass and, therefore, increasing the roots mass to support shoots (Kuchenbuch and Jung 1988). Cyanide may also have been present in the leach substrates. Plant growth did not occur in unamended leach and plants were smallest in amended post-leach treatments, possibly indicating growth interference. In some plant species, cyanide can stimulate seed germination, but further exposure can inhibit growth (Zagorski and Lewak, 1983).

The decrease in magnesium content after leaching may also contribute to poor survival. Magnesium is an essential element required for activation of many of the enzymatic reactions that transfer phosphates (Barbour et al. 1987). The result of magnesium deficiency may be a decrease in energy production and an interference in nutrient uptake (Ting 1982). A modest decrease in calcium levels was also found in leach material. This change may not be directly detrimental to plant health, however, some evidence suggests that increased calcium levels may counter the adverse effects of sodium on *Z. mays* root growth (Zidan et al. 1990). In addition, SAR, which is an indicator of relative sodium toxicity (considering magnesium and calcium) (Brady 1990), more than doubled after leaching.

Acacia greggii

Native *A. greggii* plants seem well suited to establishment in post-leach pad material. Plant growth and shoot heights were not significantly diminished in unamended post-leach material, but may experience nutrient deficiencies over time. The addition of non-ore bearing spoils as an amendment may improve the below-ground aspect of the plants, improving the chances of long term survival.

Acacia greggii survived well (75%) in unamended leach pad material compared to blue corn (0%). *Acacias* have been found to establish roots in substrates that contain little water and through substrate airspaces (Breazeale and Crider 1934). The growth media seed spot, along with the cotyledon, may enable the plant to send out a shoot and extensive roots. However, root biomass and root extension were greater when overburden substrate was available in the surface layer. This may have supplied nutrients and water to the surface roots and allowed other roots to descend through the soil column. Many of the individuals grown with the overburden amendment had tap roots in the soil collection cup where some water had pooled.

Little can be concluded from the fertilizer data. The RO treatments did as well or better than the other fertilizers. This was only a 60 day study and the fertilizer effect may not yet be evident for several reasons. Seedlings in unamended post-leach may not have exhausted the nutrients in the growth media seed spot or cotyledon. Also, *A. greggii*, like many native plants, may not respond to increased soil fertility.

The use of overburden material as an amendment increased root growth and, potentially, long term plant survival. All treatments received the same amount of irrigation, however, there may have been a water relations problem in the greenhouse pots that will not exist in the field. Growth media soils were probably too moist for *A. greggii* seedlings, which prefer coarse, well aerated soils. A higher dilution growth media amendment or decreased watering regime may have positive effects on this plant. Above-ground growth was good in unamended cells, but below-ground growth was retarded, which may lead to failure over the long term.

The need for nutrient rinses was not well quantified in this study. Fertilizer may be necessary for plants, such as *Z. mays* that are more nutrient dependent than the native legume. However, the long term effects of fertilizers must be further studied.

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References

Abacus Concepts. 1989. SuperANOVA. Abacus Concepts, Inc. Berkeley, CA.

Apel, M. L. 1983. Leachability and revegetation of solid waste from mining. EPA Project Summary -600/s2-82-093. Cincinnati, OH.

Barbour, M. G., J. H. Burk, and W. D. Pitts. 1987. Terrestrial Plant Ecology. 2nd edition. Benjamin/Cummings. Menlo Park, CA.

Brady, N. C. 1990. The Nature and Properties of Soils, 10th edition. Macmillan Publishing Co. NY.

Breazeale, J. F. and F. J. Crider. 1934. Plant association and survival, and the build-up of moisture in semi-arid soils. University of Arizona College of Agriculture, Agricultural Experiment Station. Technical Bulletin No. 53. Tucson, AZ.

Bunt, A. C. 1988. Media and Mixes for Container Grown Plants. Allen & Unwin. Winchester, MA.

Darby, M. M. 1993. Distribution of Rhizobia and VA Mycorrhizal Fungi in Two Desert Soils and their Effects on the Growth of *Prosopis glandulosa* var. *torreyana* (Mesquite) at Varying Nutrient Levels. Masters Thesis. San Diego State University, CA.

Day, R. W. and G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecological Monographs 59(4):433-463.
http://dx.doi.org/10.2307/1943075

Fidelibus, M. W. 1994. Jellyrolls reduce outplanting costs in arid land restoration (California). Restoration and Management Notes 12(1):87.

Hoagland, D. R. and D. I. Arnon. 1938. The Water-Culture Method for Growing Plants Without Soil. University of California College of Agriculture. Circular 347. Berkeley, CA.

Knudsen, D., G. A. Peterson, and P. F. Pratt. 1982. Lithium, sodium and potassium. In A. L. Page, R. H. Miller, and D. R. Keeney (eds.). Methods of Soil Analysis, Part 2, 2nd ed. Agronomy 9(2):225-246.

Kuchenbuch, R. and J. Jung. 1988. Changes in root-shoot ratio and ion uptake of maize (*Zea mays* L.) from soil as influenced by a plant growth regulator. Plant and Soil 109:151-157.
http://dx.doi.org/10.1007/BF02202079

Lanyon, L. E., and W. R. Heald. 1982. Magnesium, calcium, strontium, and barium. In A. L. Page, R. H. Miller, and D. R. Keeney (eds.). Methods of Soil Analysis, Part 2, 2nd ed. Agronomy 9(2):247-262.

Leeder, M. R. 1991. Sedimentology: Process and Product. HarperCollins Academic. London, UK.

McLean, E. O. 1982. Soil pH and lime requirement. In A. L. Page, R. H. Miller, and D. R. Keeney (eds.). Methods of Soil Analysis, Part 2, 2nd ed. Agronomy 9(2):199-224.

Pichtel, J. R., W. A. Dick, and P. Sutton. 1994. Comparison of amendments and management practices for long-term reclamation of abandoned mine lands. Journal of Environmental Quality 23:766-772. http://dx.doi.org/10.2134/jeq1994.00472425002300040022x

Ting, I. P. 1982. Plant Physiology. Addison-Wesley. Menlo Park, CA.

Virginia, R. A. and W. M. Jarrell. 1983. Soil properties in a mesquite-dominated Sonoran Desert ecosystem. Soil Science Society of America Journal 47(1):137-144.
http://dx.doi.org/10.2136/sssaj1983.03615995004700010028x

Zagorski, S. and S. Lewak. 1983. Independent mode of action of cyanide and light on lettuce seed germination. Physiologia Plantarum 58:193-196.
http://dx.doi.org/10.1111/j.1399-3054.1983.tb04168.x

Zidan, I., A. Hassan, and P. M. Neumann. 1990. Does salinity reduce growth in maize root epidermal cells by inhibiting their capacity for cell wall acidification? Plant Physiology 93:7-11.
http://dx.doi.org/10.1104/pp.93.1.7