Phase II – Project Report
Final

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Image 1. University of Arizona greenhouses where the project took place.

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Resourceful.

Memorandum

To: Tom Furgason
Cc: Bev Everson
From: Kathy Arnold
Doc #: 8.6.6-007/09
Subject: **Transmittal of Electronic Copies of Reports**
Date: March 3, 2009

Rosemont is pleased to transmit electronic copies of the reports SWCA for your review:

1. Results of Phase 2 Hydrogeologic Investigations and Monitoring Program
2. University of Arizona Project Reports – Phase 1, Interim Phase 2, and Phase 2 Final
3. APP Application Document by Tetra Tech Volumes 1, 2, 3, 4, and 5

These reports were previously transmitted to the Forest Service on February 27, 2009.

Summary:

In a greenhouse study of reclamation options, four seed mixes, three soil types, three rainfall scenarios, and three amendment treatments were tested. Based on analysis of the 28 individual species of native plants tested, a mix of 10 species was selected in the Phase II experiment. The Gila and Glance soils supported growth comparable to current natural systems while the Arkose soil type supported some plant growth but at roughly one-third the productivity and half the species richness of the other two soil types. Plants established in all three rainfall scenarios (low, average, and high). Low rainfall did support a viable plant community but it was reduced compared to average and high rainfall which were similar to each other. The addition of tackified straw allowed production of more aboveground biomass but slightly reduced plant establishment while tackified straw with fertilizer greatly reduced the number of plants established but also produced more biomass. The ideal combination for reclamation is to seed the selected species mix on Gila or Glance soils with average or high rainfall, and amend with tackified straw. This report replaces the Phase II Preliminary Report (dated 12 March 2008) except for the review of US Forest Service seeding. Experimental work will continue with field trials (Phase III).

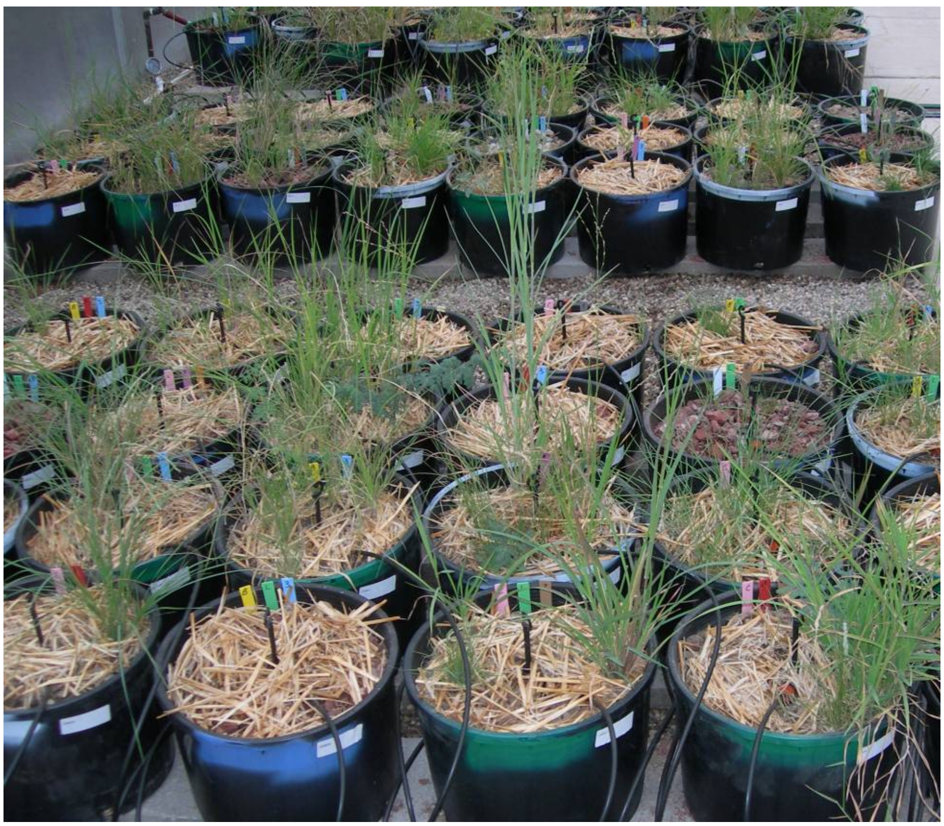

Image 2. Pots in the greenhouse 11 December 2007.

Contents

Greenhouse main project summary description (the full description and justification of the design can be found in the Final Report for Phase I, dated 6 July 2007):

There are four replications (duplicate pots) of each of the 108 treatment combinations: there are four seed mixes, three rainfall scenarios, three amendment levels, and three soil types.

Prospective seed mixes: Twenty-eight species (four overlapping mixes of ten or eleven species each) were chosen for greenhouse evaluation in this phase of the project. All selected species are natives and represent the native plant communities that would be on similar sites in good condition. The species chosen for testing represented a range of functional types of plants including: warm-season perennial grasses, cool-season perennial grasses, annual grasses, perennial forbs (broadleaved flowering plants), annual forbs, and shrubs. This array of plants maximizes the ability to select a successful mix at the end of the greenhouse testing but also will allow the final mix to have all the components of a resilient and productive plant community. All species chosen for inclusion were available from large-scale commercial seed vendors at the time of selection.

Rainfall scenarios: Three rainfall scenarios were chosen based on an evaluation of storm-by-storm rainfall data from two rain gauges near the site. The average scenario was an average rainfall year (equivalent to 384 mm or 15.1 inches of precipitation) rather than the average daily rainfall over the 31 year period. Having a sufficiently large storm size and appropriate interval between storms is critical for plant germination and establishment. Similarly the low rainfall scenario is a characteristic low rainfall year (equivalent to 245 mm or 9.6 inches of precipitation) from center of the range encompassing the bottom 20% of total rainfall years, and the high rainfall scenario is a high rainfall year (equivalent to 510 mm or 20.1 inches of precipitation) from center of the range encompassing the top 20% of rainfall years. Rainfall was simulated by installing individual spray heads in each pot which applied (rained down, Image 3) the prescribed amount of water on a schedule. For this project, the summer (monsoon) was considered to be from the end of August to the end of November or a little more than 90 days. The greenhouse temperature was maintained at mid-90° F during the day consistent with expected site conditions, but was not controlled at night. Once the monsoon season trial was complete, the plants were not given water again for the two months before the start of the winter season growth period. This mimics the normal dry period between seasons. For this project, the winter season was simulated as being from early February to early May or a little more than 90 days. (See Appendix 4 for actual watering dates and amounts. Other environmental data is available by request.)

Image 3. Individual spray head in one of the Greenhouse pots. Spray heads were used to simulate rainfall.

Soil/surface amendments: The amendments chosen for evaluation were: no amendment, tackified straw, and tackified straw combined with slow-release fertilizer. Tackified straw (equivalent to 2 tons of straw per acre) is straw that has been tackified (sprayed with a commercially available acrylic copolymer tackifier (like a glue) made for this purpose; Envirotac II, Environmental Products & Applications, Inc.) onto the soil. It is a popular amendment for regional reclamation efforts and ameliorates some of the harsh surface conditions common to the site. The second amendment, tackified straw combined with a slow-release fertilizer (Biosol, Biosol Inc.), provided a temporary source of nutrients in the surface soil during plant establishment.

Soil types: There were three soil types provided for testing: Arkose (a sedimentary rock mix of siltstone, sandstones and conglomerates from the Willow Canyon Formation, Image 4), Glance (Glance conglomerate limestone), and Gila (Gila Conglomerate, a late Tertiary alluvium). At the site, these are predicted to be the most common soil types used for reclamation. The soils for the experiment came from representative locations within the mine footprint. The individual soil types are a mixture of the top 3 meters of surface material from a site with that soil type. For simplicity we refer to these materials as soils for this report.


Image 4. Filling pots with the Arkose soil type. Note the red gravelly nature of the material.

Chronological summary of greenhouse activities:

Surface material (soil) from Rosemont site delivered – 4-15 June 2007.
Simulated summer monsoon irrigation began – 28 August 2007
Germination data by species collected – 31 August and 6, 25 September 2007
Simulated summer monsoon irrigation ended – 29 November 2007
Aboveground biomass collection by species – 5 December 2007 to 11 January 2008
Simulated winter rainy season irrigation began – 4 February 2008
Simulated winter rainy season irrigation ended – 3 May 2008
Aboveground biomass collection by species – 7-30 May 2008

Seed mix evaluation:

The experiment seeks the best seed mix across the combination of the three soil types and the three rainfall treatments. Priorities for selection are species that did well across all soil types and all rainfall scenarios. This should give the final mix the best chance of establishing on all the possible surfaces and aspects as well as the likely rainfall conditions. The final recommended seed mix (Table 1) was based on the species that had high establishment across all the combinations of soils and rainfalls. Individual species evaluations are included in Appendix 1. Information about other species properties are included in Appendix 2 and published elevation ranges are included in Appendix 3.

Green sprangletop	(*Leptochloa dubia*)	WSPG
Red threeawn	(*Aristida purpurea var. longiseta*)	WSPG
Blue grama	(*Bouteloua gracilis*)	WSPG
Arizona cottontop	(*Digitaria californica*)	WSPG
Curly mesquite	(*Hilaria belangeri*)	WSPG
Sideoats grama	(*Bouteloua curtipendula)*	WSPG
Bottlebrush squirreltail	(*Elymus elymoides*)	CSPG
Desert marigold	(*Baileya multiradiata*)	PF
Mexican gold poppy	(*Eschscholzia californica ssp. Mexicana*)	AF
False mesquite	(*Calliandra eriophylla*)	SH

Table 1. Final recommended seeding mix. Warm-season perennial grass (WSPG), Cool-season perennial grass (CSPG), Perennial forb (PF), Annual forb (AF), Shrub (SH). The allocation percentages for each functional type are 82%, 2%, 4%, 3%, 7%, and 2%, respectively.

Overall evaluation of the greenhouse experiment

A synthetic evaluation of the greenhouse experiment was done using four different but related measures: aboveground dry weight, species richness, functional group richness, and diversity index. This combination allowed a more complete assessment of the potential of the simulated site conditions to support a reclaimed plant community. The analysis focuses on the soil types, rainfall scenarios, and amendments because the plant species mixes were evaluated based on the performance of the individual species (see Appendix 1).

Description of the evaluation metrics:

Aboveground dry weight: The oven-dry aboveground biomass of each species was determined at the end of each phase of the greenhouse experiment by clipping the aboveground plant material, sorting it by species, oven drying it (70°C for 48 hours), and weighing it. This metric is also referred to as biomass production or production. Numbers reported in this section represent the total aboveground biomass per pot (cumulative of the species for both simulated seasons). Biomass gives a relative measure of how much of the total resources have been used for each treatment combination. Biomass was expected to be similar across all the pots because the numbers of plants and proportions of functional groups was very similar across all the pots. (It was the same at seeding, but some species failed to establish – see Appendix 1.) Biomass provides a rough indication of the productivity of the reclaimed plant communities compared to those expected to naturally occur on the site.

Species richness: Species richness refers simply to the number of species within a given area, in this case the number of species per pot. Species richness is an important indicator of a healthy plant community. The species richness was determined at the time the pots were clipped (above) by counting the number of plant species in each pot. The number of individuals was also recorded which allowed calculation of functional group richness and Shannon's index (described below).

Functional group richness: Functional group richness is simply the number of functional groups per pot. Functional groups are those described for the species selected: Warm-season perennial grass (WSPG), Cool-season perennial grass (CSPG), Perennial forb (PF), Annual forb (AF), and Shrub (SH). Functional group richness is important because plant communities are more stable with more functional groups. This metric allows separation of situations where one treatment combination was represented by multiple species of WSPG while another might have the more desirable presence of multiple functional groups.

Shannon's index: Shannon's index is a measure of species' evenness in relation to biodiversity. A high index indicates that the numbers of individuals (abundance) of each species are relatively close to each other (proportions are nearly the same). A low index would indicate that one or more species dominate the system. The formula for Shannon's index is:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

H' is the notation for the shannon's index. *S* is the number of species (species richness) and *p* is the relative abundance of each species (the proportion of the total).

Shannon's index helps correct for situations where multiple individuals of one species establish and only a single individual of another species establishes. Plant communities with high diversity index values are thought to be more resistant to invasion and resilient to disturbances. Many books and websites are available to explain more about this index.

Results and discussion:

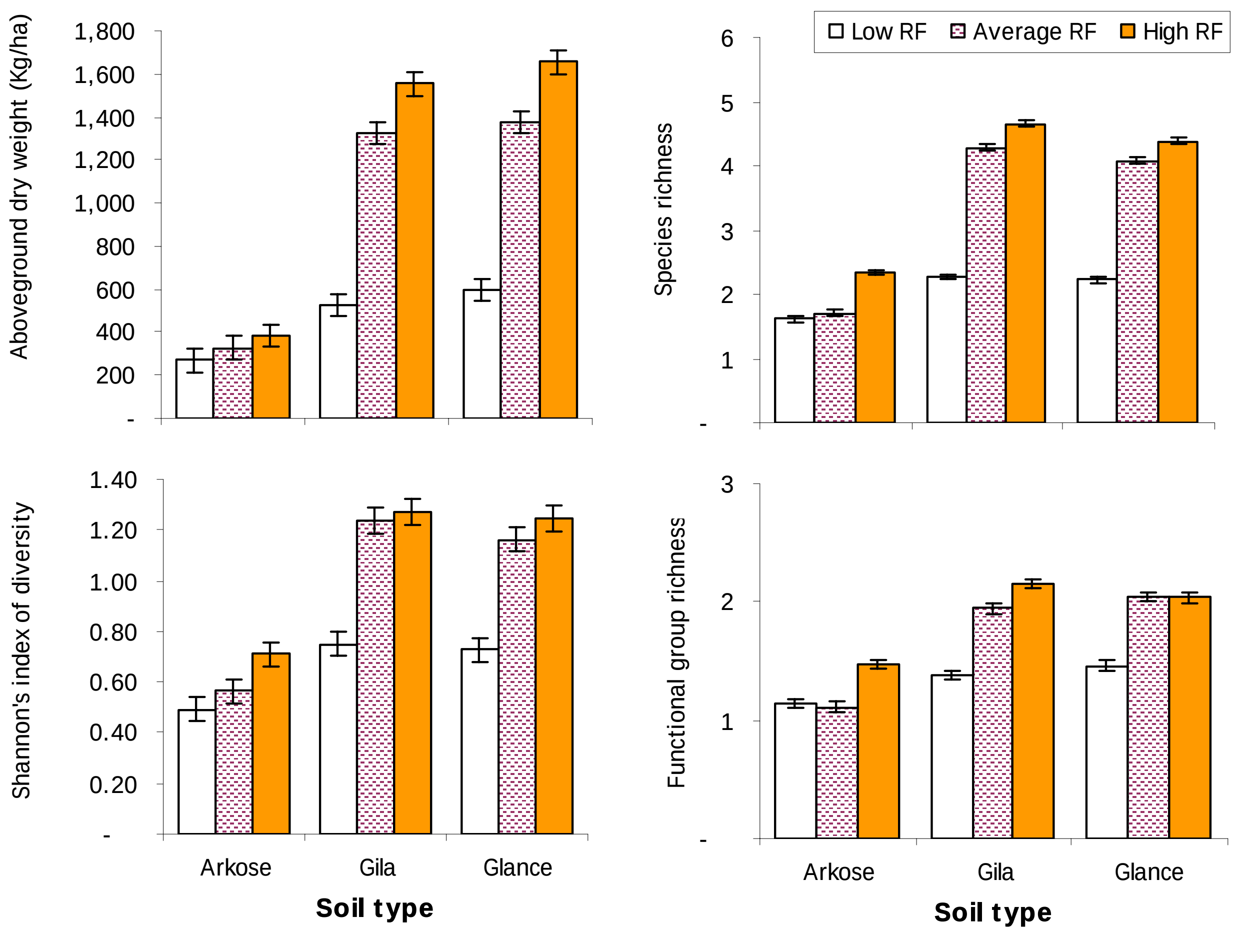

Figure 1. Results of the synthetic evaluation of the greenhouse experiment. Error bars are the standard error of the mean.

For aboveground dry weight (Figure 1), the Gila and Glance soils were both better growth media than Arkose and supported about 3-4 times as much biomass production as Arkose (1134 and 1208 vs. 328 kg/ha; 1005 and 1077 vs. 290 lbs/ac). Based on the Ecological Site Descriptions used to select the species mixes (Table 2) the averages for Gila and Glance are in line with the production that one would expect for the site. The values for the Arkose soil type are lower than one would expect for these sites. For Gila and Glance soils, increased rainfall resulted in increased biomass production. The Arkose soil was not sensitive to the differences in rainfall – the production was substantially the same for all three levels.

Ecological Site Description	Annual Production (lbs/ac) low	average	high
loamy slopes 12-16	426	905	1505
clay loam upland 16-20	453	1075	1530
loamy slopes 16-20	763	1520	2350
loamy upland 12-16	619	1000	1800
sandy loam upland 16-20	1804	1645	2374
average	813	1229	1911.8

Table 2. Expected annual production of these NRCS Ecological Site Descriptions in Major Land Resource Area 041 – Southeastern Arizona Basin and Range. Equivalent averages in kg/ha are 911, 1376, and 2141, respectively.

The results among Species richness, Functional group richness, and Shannon's index measures were similar (Figure 1). This is not unexpected because the measures are moderately interrelated. The Gila and Glance soils had nearly the same results for all of these measures. For the Gila and Glance soils, there was no substantial difference between the average and high simulated rainfall. This is to be expected for these plants are adapted to semi arid conditions. When the minimum requirements for establishment are met, the plants will then be able to stay in the system. The low rainfall treatment dropped all three measures by about one third for Gila and Glance because species did not establish due to insufficient moisture levels. For the Arkose soil type, the low and average rainfalls had similar and low numbers, while the high rainfall treatment was approximately equal to the low rainfall for Gila and Glance. This likely indicates that the available water in the Arkose soil type was much lower than for the Gila or Glance.

The coarser texture of Arkose (the fraction smaller than 2 mm was sandy with almost no particles in the silt and clay fractions; see page 13) stood out compared to Glance (loamy sand) and Gila (sandy loam). Soil texture determines water holding capacity, and affects soil structure which is the arrangement of soil particles in stable secondary units called aggregates. The shape, size and cohesion strength of aggregates characterize soil structure. The surface size and nature of soil particles (sand, silt, and clay) influence its ability to retain nutrients and chemicals because the sites for chemical reactions in soil are on particle surfaces. Good soil structure has low bulk density and high porosity with a mixture of small and large pore spaces that permit continuous water and air movement in soil and provide habitats for microorganisms and space for root growth. Among the three soil types, Arkose has the least amount of fine particles, and we noticed that irrigation water often drained from the bottoms of pots. This may explain the lack of sensitivity to the rainfall treatments – the additional water was not retained by the soil; it just passed through. Arkose soil type appears quite variable from superficial observation of the site. In an arid environment, the water holding capacity of a soil is very important as soil moisture content is often the limiting factor for seedling establishment and plant growth. Thirteen out of the 28 species showed germination rates being affected by soil type (Appendix 1). Arkose was the growing media with the lowest quality with respect to the reclamation measures tested. However, despite it being essentially red gravel, it will support a plant community, albeit limited. It is likely that plant production would improve in the years following reclamation in all soil types as the soils develop and the plants mature.

The results of the different rainfall scenarios came out predictably in the sense that high rainfall (20.1 inches) produced the best results for all of the measures. More notable is that the low rainfall treatment (9.6 inches) was able to support a plant community. This confirms that plants are able to grow on these materials and that some establishment can occur even in low rainfall years and in poor soils.

Adding straw mulch did not improve establishment rates in the low rainfall scenario and adding fertilizer had a detrimental effect on establishment rates (Figure 2). We further tested the effect of straw mulch amendment and its interaction with simulated rainfall scenarios in a separate experiment, which also showed no interactive effect between the two treatment variables. This experiment also showed no significant difference in germination rate and seedling vigor associated with the amendment treatment. (See amendment experiment section.)

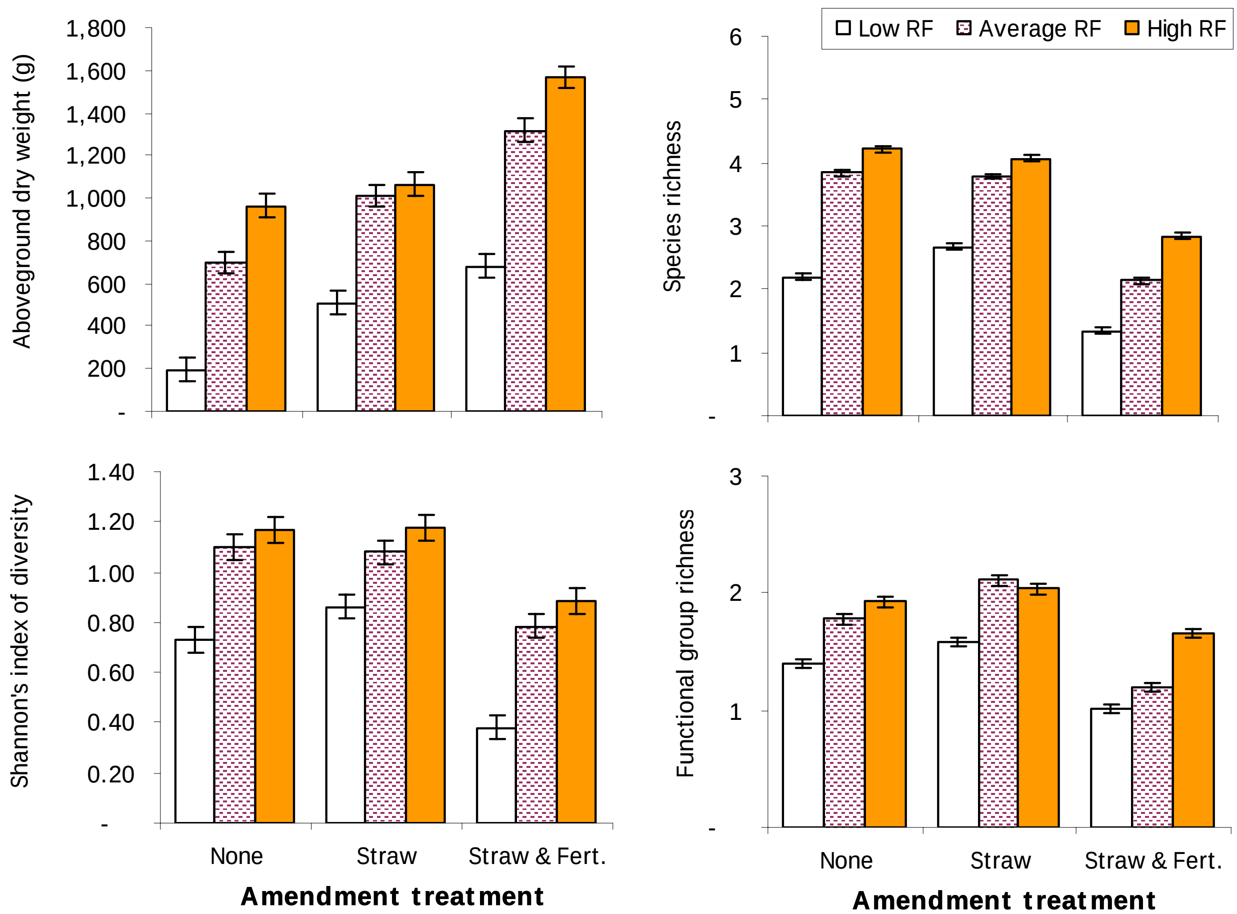

Figure 2: Total aboveground dry biomass, species and functional group richness, and Shannon's index for the simulated rainfall levels and amendment treatment. Wilks' Lambda = 2.88, p = 0.0001. Error bars are standard error of the mean.

The amendment results were surprising in that the addition of straw helped to produce significantly more biomass but did not significantly change the other measures. Straw was expected to increase establishment, especially in the low rainfall treatment, because it was thought to ameliorate dry conditions. The addition of straw had been predicted to be positive for germination as well, but the increase in biomass may merit its use for reclamation. The lack of more substantial effect may have been due to this project taking place in the greenhouse instead of under field conditions.

The addition of fertilizer further increased the production of biomass but decreased diversity and richness which gives it a negative connotation. Perennial species adapted to arid environments tend to have lower requirement for nitrogen. It is possible that some of the tested species are intolerant to high nitrogen concentration in soil during germination as each plant has very specific requirements for germination. The reduced richness and diversity weighs against a recommendation for adding fertilizer.

Recommendations:

The reported species mix is expected to do well for reclaiming the site with some reclamation being possible even in a low rainfall scenario. The Arkose soil has the least reclamation potential of the materials tested and may be better mixed with one of the other soil types to allow for a better soil texture. The Gila and Glance soils have good potential for reclamation when they are similar to the material provided for this study. The addition of straw, while having mixed effects, is recommended, but fertilizer is not recommended.

Tailings addition experiment:

Purpose:

The tailings experiment was a required part of the contract. Given the low amounts of fine particles in some of the material being tested (specifically the Arkose soil), it is possible that the addition of tailings may improve plant establishment or growth in some situations. No testing or measurements of the fate of the tailings were conducted. The experiment specifically only evaluated the performance of vegetation.

Description:

The tailings experiment was conducted on the Arkose material using the three rainfall treatments previously established (low, average, high) except that the duration of the experiment was abbreviated. The three levels of rainfall simulation (55 mm, 101 mm, and 137 mm) were administered to simulate the first 25 days of the low, average, and high summer monsoon precipitation, based on the analysis from the setup of the main greenhouse experiment. The tailings additions were: no addition, addition of 20% tailings, and addition of 40% tailings. Seed mix 1 was used (see the Phase I report for details). No amendment of straw or fertilizer was used. There were nine unique treatment combinations (three rainfall scenarios each with three tailings levels). Other aspects of this experiment were the same as for the main experiment.

The tailings added to the Arkose material experiment were expected to increase water holding capacity and increase both germination and establishment. The percentage tailings added make the three treatments fall in the categories sand, loamy sand, and sandy loam on the soil classification triangle (the breakpoints for changing types by increasing the silt fraction are 15 and 30%; see

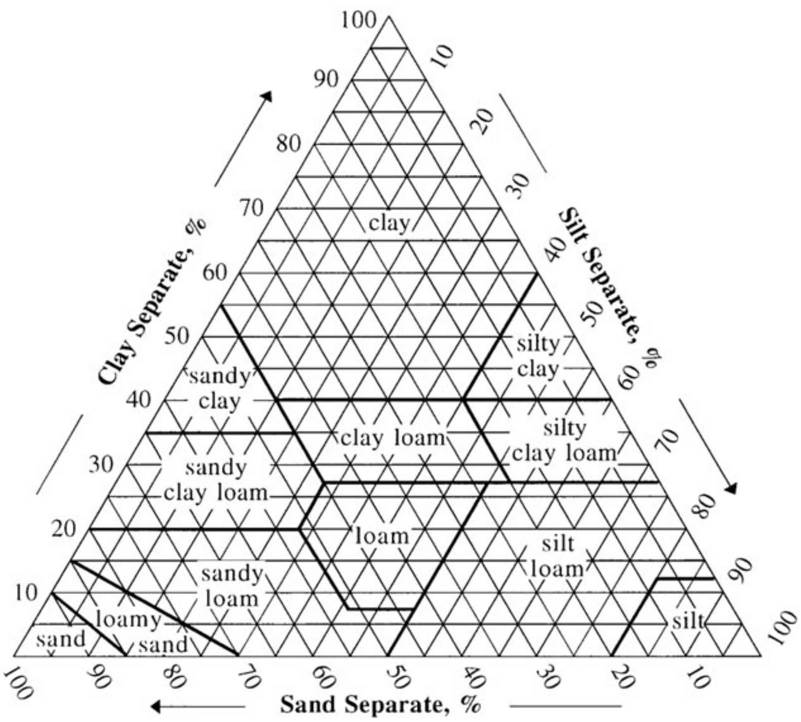

Figure 3. Soil Texture Classification Triangle, from: http://soils.usda.gov/technical/handbook/images/Part618Exhibit8_hi.jpg. The particles in the Arkose material below 2 mm in diameter are comprised of 88% sand, 8% silt, and 4% clay. This falls at the lower left corner of the triangle. The tailings generally fall in the silt fraction and addition of 20% makes the material more like loamy sand and the addition of 40% makes the material more like sandy loam.

Figure 3). The amount of available tailings was limited so the pot size was restricted to 1 gallon pots and only four replications of each of the nine unique treatment combinations were possible.

No amendments were tested because germination initially appears lower with amendments than without while plant vigor appears higher with amendments. The most straightforward results come from un-amended pots.

Chronological summary of greenhouse activities:

Mixed tailings with Arkose soil – 24 October 2007
Sowed seeds – 5 November 2007
Commenced irrigation schedule – 5 November 2007
Terminated irrigation – 29 November 2007
Clipped and dried seedlings – mid December 2007

Results

Even though there was no interactive effect between tailing mixture treatment and rainfall scenarios (Wilks' Lambda = 1.16, $p = 0.28$), the results were different from the main experiment. The three levels of rainfall simulations resulted in no significantly different seedling aboveground dry weight, germination percentage per pot, species richness, or Shannon's diversity index. Adding either 20% or 40% of tailings to Arkose soil yielded greater biomass and a greater germination rate for the entire pot (Figure 4).

The addition of tailings into Arkose also increased diversity as indicated by the higher Shannon's index, and improved species richness. However, the increase in germination rate, aboveground dry weight, species richness, and diversity were not significantly different between 20% and 40% of tailing mixed with Arkose so the threshold for tailings addition is below 20%. None of the 11 species in the seed mix showed any adverse effect from the addition of tailing mixture in terms of germination rate or growth.

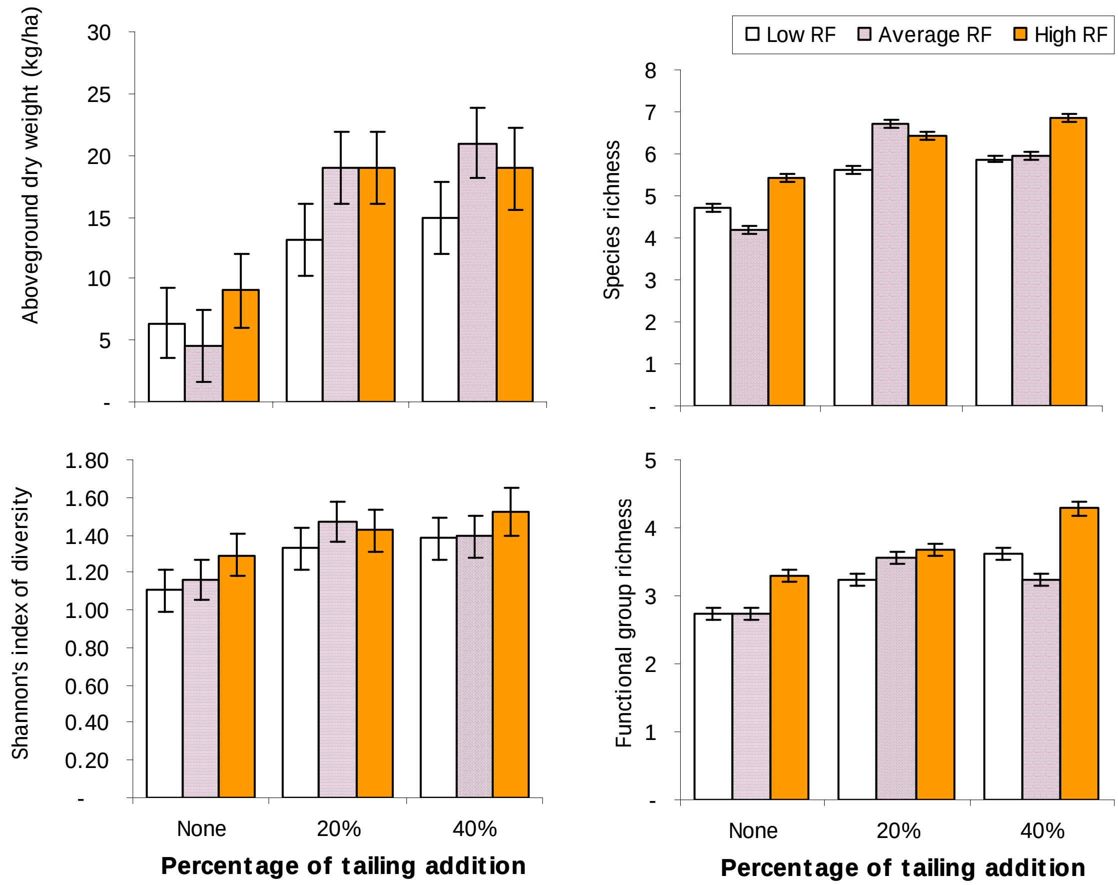

Figure 4: Aboveground dry weight, species and functional group richness, and Shannon's index for the simulated rainfall levels and tailing treatment. Wilks' Lambda = 1.16, p = 0.28. Error bars are standard error of the mean.

Recommendation

The improvement in the germination rate, aboveground biomass, richness, and diversity by adding tailings (20% or 40%) to Arkose soil may be due to the enhancement of water holding capacity in the soil with increased fine particles to the soil texture. The results from this experiment show no clear difference between 20% and 40% tailing mixture, so an amount of 20% or less by weight should be considered if the objective is improved plant growth. More research could better pinpoint the threshold amount of tailings needed to improve plant growth in the short term. Given the generally undesirable image of tailings, more research into the longer term effects on vegetation as well as the fate of tailings is needed before adopting a strategy of amending with tailings. While no research was conducted on addition of tailings to Gila and Glance soils in this study, it seems unlikely that they would benefit from tailings addition.

Amendment experiment:

Purpose:

The amendment experiment was undertaken to help define the amount or range of straw application that was most beneficial to plant germination. This experiment was generated as a result of the preliminary analysis of the main greenhouse experiment which showed that the addition of straw decreased germination. This finding was unexpected and we hypothesized that the amendment with straw might have a narrow effective range and that more research might help define the most beneficial quantities.

Description:

The experiment had four levels of amendment treatment: no amendment, Envirotac II (the tackifier) without straw, 0.5 t ac^{-1} (tons per acre) equivalent straw plus Envirotac II (low straw + tackifier), and 1.0 t ac^{-1} straw with Envirotac II (high straw + tackifier). The Envirotac II acrylic copolymer was hand sprayed over the straw mulch or directly over the soil with a 32 oz spray bottle at the manufacturer's recommended rate. The experiment was replicated five times (each unique treatment combination had five duplicate pots). Pots were filled with a soil composite of 40% peat moss, 33.5% perlite, 5.5% vermiculite, 14% sand, and 7% of Glendale silt loam soil. We hand broadcast seeds in the same mixture and proportion as in seed mix 1 of the main experiment. Pots were watered to mimic the three levels of annual rainfall used in the main experiment and as described in the tailings experiment above. We simulated the first 25 days of a full summer growing season to determine germination. We harvested and tallied established seedlings one week after the irrigation terminated.

Chronological summary of greenhouse activities:

Prepared potting composite – 31 October 2007
Sowed seeds – 2 November 2007
Commenced irrigation schedule – 5 November 2007
Terminated irrigation – 29 November 2007
Clipped and dried seedlings – early December 2007
Collected biomass data – January 2008

Results and Discussion:

Most of the species showed no significant difference in germination rate or biomass as a result of the straw mulch or acrylic copolymer application. Addition of straw mulch at 0.5 t ac^{-1} or 1.0 t ac^{-1} with Envirotac II did not significantly affect the composite germination rate, seedling biomass, species richness, or diversity (Wilks' Lambda = 1.26, $p = 0.25$). Direct application of Envirotac II also did not cause significant difference in these response variables.

The simulated rainfall treatment resulted in significantly different total germination rates and seedling vigor but had little effect on species richness and diversity (Wilks' Lambda = 12.41, $p < 0.0001$). Low rainfall had the worst performance: germination rate = 9 %; biomass = 35.8 kg/ha;

species richness = 3; Shannon's index = 1.03. Multivariate analysis of variance (MANOVA) results also showed no interactive effect between amendment and rainfall treatments (Wilks' Lambda = 0.84, p = 0.68). High and average rainfall amounts yielded the highest total germination rates and seedling diversity (Figure 5). While the difference in total germination rate and seedling diversity between high and average rainfall across the four amendment treatment levels was not distinguishable, the low rainfall resulted in lower aboveground biomass, diversity, and total germination rate across all amendment treatment levels (Figure 5). The interaction between amendment and rainfall treatments of most interest was between low rainfall and straw addition. Adding straw had no effect or slightly reduced germination (not significant), while biomass was increased by 0.5 t ac^{-1} addition of straw but decreased by 1.0 t ac^{-1} addition of straw (again trends not significant; Figure 5). The biomass levels are low across all levels because the experiment only ran for 25 days.

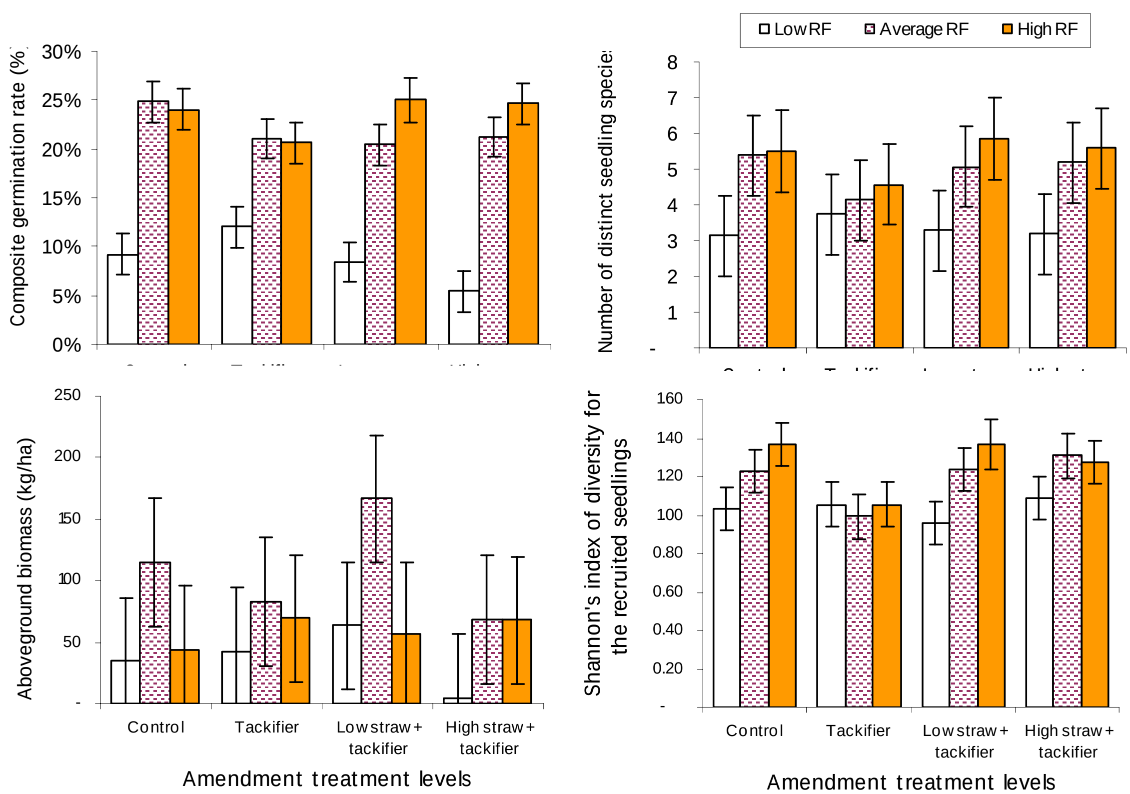

Figure 5: Means of composite germination rate, seedling dry weight, species richness and diversity as varied by the four amendment treatment levels crossed with the three rainfall amounts. The error bars are standard error of mean. Wilks' Lambda = 0.84, p = 0.68.

Recommendations:

Numerous studies have demonstrated straw mulch can help retain soil moisture content, regulate soil energy budget, add micro-topographical heterogeneity, create microsites, and enhance plant biomass production and crop yield. Despite that, the results of this experiment showed no distinct improvement in total germination rate, seedling biomass, species richness, or diversity from amendment treatment. Some of this may be an artifact of conducting this experiment in pots in the greenhouse. The remaining effect may be attributed to the fact that some species are incompatible in regard to mulching because of their intolerance to shade for germination. We saw that desert marigold, bottlebrush squirreltail, and sand dropseed had better performance under no straw and under the equivalent of 0.5 t ac^{-1} straw plus Envirotac II. This could be expected because both bottlebrush squirreltail, and sand dropseed are intolerant to shade. To find the appropriate straw mulch application rate for a native species mix, it would demand more experiments of different application rates that are more effective in raising the threshold between low rainfall amount and more favorable precipitation amount. Measuring the water potential and temperature in soil would provide a more direct measurement as well. In addition, since this experiment was conducted in a greenhouse, the effects of run-off, wind erosion and soil surface drying from wind were not simulated or examined.

The results of the main experiment, which used field soils and tracked the vegetation through the equivalent of a year (included both a summer and winter season), also showed a lack of effect of straw addition on germination and richness, but showed a longer term increase in aboveground biomass. The use of straw is recommended for further testing in the field phase of this experiment.

Presentation of data :

The Amendment experiment was presented at the Ecological Society of America annual meeting August 2009, Milwaukee, WI.

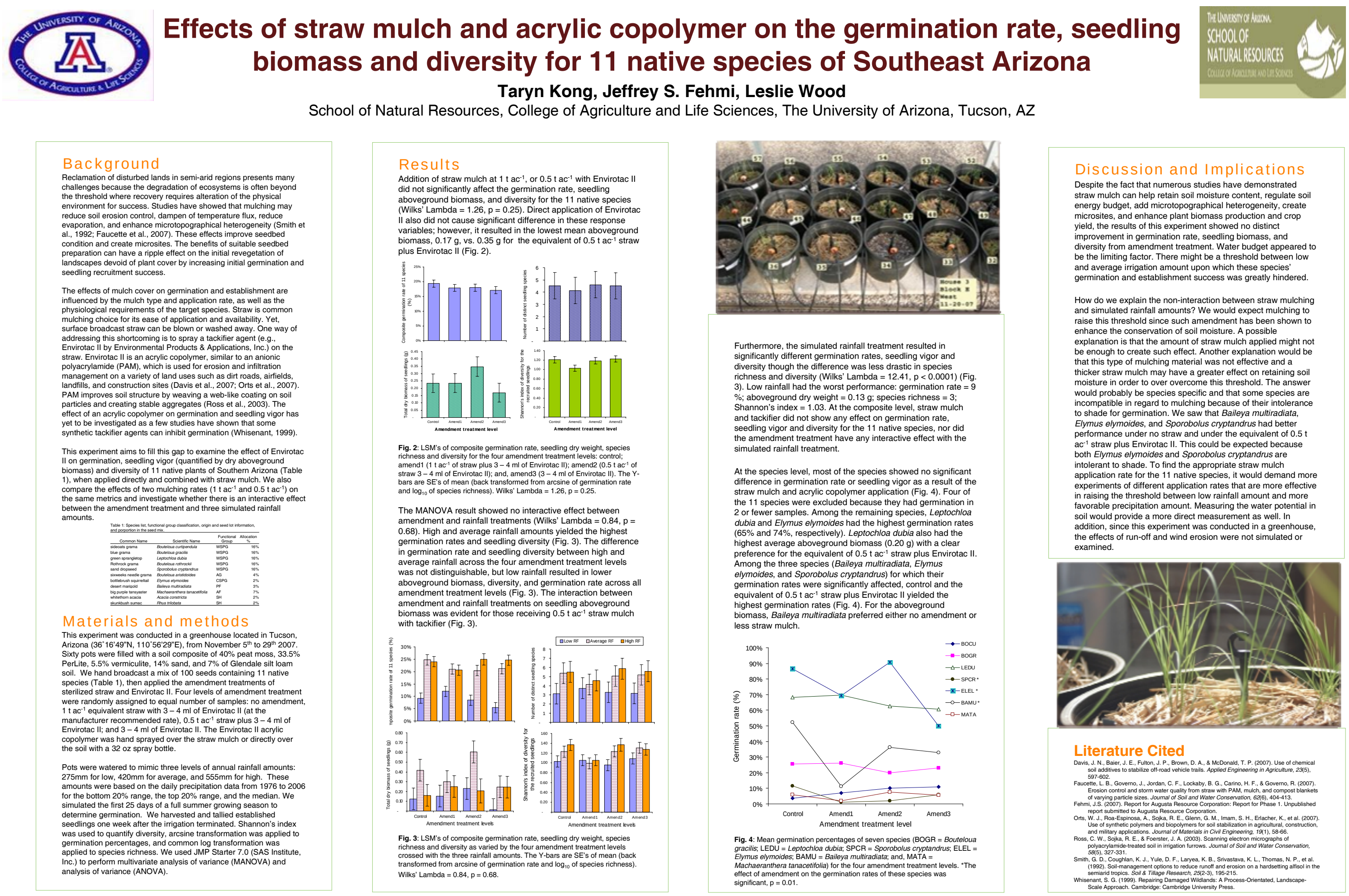

Image 5. A copy of the poster presented at the Ecological Society of America annual meeting August 2009, Milwaukee, WI, by Ms. Taryn Kong.

Additional presentation(s) expected at Ecological Society of America annual meeting August 2010 as well as publication in peer-reviewed journals.

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Appendix 1. Individual species evaluations:

Recommended species: These species did well across the range of soil types and rainfall scenarios and better than others in the experiment. The germination rates noted are the average of laboratory assessments (detailed in Appendix 5).

Warm season perennial grasses

Green sprangletop (*Leptochloa dubia*) – a component of mix 1. Established in 100/108 pots (93%). This species established very well across all soil types and rainfalls. The seed averaged 87.5% germination when tested separately and in the experiment 16 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in all of the pots.

Green sprangletop is a drought tolerant, cold tolerant, shallow-rooted bunch grass which is also tolerant to a wide range of soil textures, soil fertilities, soil depths and parent materials. In addition, it acts as a nurse plant for other desert species by providing shade and improved soil moisture for seeds of less tolerant warm season perennial grasses (TPWD 2008).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	100	100	92	97
	Ave	92	100	92	94
	Low	100	83	75	86
	Grand Total	97	94	86	93

Table A1-1. *Leptochloa dubia* percent occurrence by pot.

Red threeawn (*Aristida purpurea var. longiseta*) – a component of mixes 3 and 4. Established in 179/216 pots (83%). This species established well across all rainfalls and soil types. The seed averaged 52% germination when tested separately and in the experiment 20 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in all of the pots.

Red threeawn is highly competitive during periods of drought as it requires fairly dry soil for germination and growth. Germination is not dependent upon stratification or light but requires high temperatures. The success of this species results in part from its seeds' use of divergent awns and sharp-pointed calluses to penetrate soil, and the species' ability to grow deep roots in a short amount of time (USDA FS 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	**High**	92	96	92	93
	Ave	67	96	100	88
	Low	71	67	67	68
	Grand Total	76	86	86	83

Table A1-2. *Aristida purpurea var. longiseta* percent occurrence by pot.

Blue grama (*Bouteloua gracilis*) – a component of mixes 1 and 2. Established in 156/216 pots (72%). This species established well across all soil types and rainfalls. The seed averaged 46.5 % germination when tested separately and in the experiment 16 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in all of the pots.

Blue grama may germinate best under constant temperatures between 60° and 100° F (Knipe 1967), but is also at an advantage because it is highly water efficient, especially under warm climatic conditions. Once germinated, establishing seedlings send out most of their roots in the upper layers of soil to take advantage of even small amounts of rainfall (USDA FS 2008). A disadvantage of this species is that it has been found to exhibit decreased germination and establishment in the presence of adult plants of the same or other species (USDA FS 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	**High**	67	100	96	88
	Ave	63	96	83	81
	Low	42	58	46	49
	Grand Total	57	85	75	72

Table A1-3. *Bouteloua gracilis* percent occurrence by pot.

Arizona cottontop (*Digitaria californica*) – a component of mixes 2 and 3. Established in 144/216 pots (67%). This species established well across all soil types and rainfalls. The seed averaged 64.5% germination when tested separately. In mix 2, 16 seeds were planted in each pot and in mix 3, 20 seeds were planted in each pot. Therefore under ideal conditions we would have expected presence in all of the pots.

Arizona cottontop grows finely branched roots that are concentrated in the top 8 inches of soil unless the soil is very coarse and gravelly, in which case its roots will extend down as far as 40 inches (USDA FS 2008). This adaptation may help it to establish in the various soil types of the Rosemont site. This species is more likely to become established in a high rainfall year. In low soil fertility areas, Arizona cottontop will tend to flourish under mesquite trees and other nitrogen fixing plants (USDA FS 2008).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	25	100	100	75
	Ave	46	96	96	79
	Low	29	58	50	46
	Grand Total	33	85	82	67

Table A1-4. *Digitaria californica* percent occurrence by pot.

Curly mesquite (*Hilaria belangeri*) – a component of mix 3. Established in 66/108 pots (61%). This species established across all rainfalls and soil types. The seed averaged 25% germination when tested separately and in the experiment 20 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in all of the pots.

Curly mesquite seeds are often sterile because plants are not self-fertile. This particular species is not known to be very drought tolerant. Germination rates and storage length can be increased by the removal of the seed fascicles, but plants produce few seeds and seeds have been reported to have a short life span that begins in July with the coming of the summer rains and ends by mid-October (USDA FS 2008). Advantages to the use of this species in restoration is that it establishes and grows quickly and reproduces more by stolons than by seed, thus creating a "mat" that would aid in soil stabilization (USDA FS 2008).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	42	92	100	78
	Ave	42	92	75	69
	Low	25	25	58	36
	Grand Total	36	69	78	61

Table A1-5. *Hilaria belangeri* percent occurrence by pot.

Sideoats grama (*Bouteloua curtipendula*) – a component of mixes 1, 2, and 4. Established in 156/324 pots (48%). Established well across all soil types and rainfalls except for lower establishment in Arkose in low and average rainfall (6% and 8% respectively). The seed averaged 28% germination when tested separately. In pots seeded with mixes 1 and 2, 16 seeds were planted in each pot and in pots seeded with mix 4, 20 seeds were planted in each pot. We would have expected presence in 99% pots seeded with mixes 1 and 2 and in all pots seeded with mix 4.

Sideoats grama has widely varying germination rates which are highly dependent upon place of seed origin. Other factors that affect germination are temperature, light, moisture, and planting depth. "Temperatures between 50 and 86 degrees Fahrenheit (10 and 30 °C) are generally best for germination" (USDA FS 2008). Light and planting depth tend to go hand in hand since the closer seed is to the surface, the more light the seed will receive. Sideoats grama has higher germination rates at 1" planting depth than at depths shallower or deeper than 1" and germination does not seem to be affected by water stress. However, seedlings that have not become well established can die during a short period of drought. In addition to spreading by seed, sideoats grama reproduces very successfully by tillering (USDA FS 2008).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	36	69	81	62
	Ave	8	58	69	45
	Low	6	61	44	37
	Grand Total	17	63	65	48

Table A1-12. *Bouteloua curtipendula* percent occurrence by pot.

Cool season perennial grasses

Bottlebrush squirreltail (*Elymus elymoides*) – a component of mix 1. Established in 55/108 pots (51%). Established across all rainfalls and soil types but had modestly lower establishment in Arkose (8%). The seed averaged 61.5% germination when tested separately and in the experiment 2 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in 86% of the pots.

Dry seeds of bottlebrush squirreltail require a period of after-ripening which is facilitated by dry storage. In other words, germination increases and dormancy levels decrease as periods of dry storage increase (USDA FS 2008). After-ripening ensures that environmental conditions are conducive to germination and survival. Bottlebrush squirreltail is not adapted to coarse textured soils (USDA FS 2008, USDA NRCS 2008) which may explain low germination rates in the Arkose soil type. In the Arizona desert, bottlebrush squirreltail germinates in the fall and in the summer at higher elevations (USDA FS 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	**High**	17	100	58	58
	Ave	25	58	75	53
	Low	33	42	50	42
	Grand Total	25	67	61	51

Table A1-6. *Elymus elymoides* percent occurrence by pot.

Perennial forb

Desert marigold (*Baileya multiradiata*) – a component of mixes 1 and 4. Established in 71/216 pots (33%). Established well across all soil types and rainfalls except for low establishment (14%) in Arkose in low rainfall. The seed averaged 64.5% germination when tested separately. In mix 1, 3 seeds were planted in each pot and in mix 4, 2 seeds were planted in each pot. We would have expected presence in 96% of pots seeded with mix 1 and 88% of pots seeded with mix 4.

Although desert marigold is drought tolerant, it tends to thrive with a consistent provision of water (Pima County Cooperative Extension 2008). However, too much water can result in crown rot (University of Texas 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	**High**	13	75	42	43
	Ave	25	42	46	38
	Low	4	17	33	18
	Grand Total	14	44	40	33

Table A1-8. *Baileya multiradiata* percent occurrence by pot.

Annual forb

Mexican gold poppy (*Eschscholzia californica ssp. Mexicana*) – a component of mixes 2 and 4. Established in 23/216 pots (11%). Established well in the Arkose soil type and across all rainfalls. The seed had 36% germination when tested separately. In mix 2, 7 seeds were planted in each pot and in mix 4, 8 seeds were planted in each pot. We would have expected presence in 96% pots seeded with mix 2 and 97% pots seeded with mix 4.

Mexican gold poppy is tolerant to a wide range of soil types and is drought tolerant, but populations have been found to be genetically specialized to soil type (Cook 1965) which may affect germination rates when seed sown has not been harvested from the site on which it is being planted.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	25	4	0	10
	Ave	17	0	8	8
	Low	29	13	0	14
	Grand Total	24	6	3	11

Table A1-9. *Eschscholzia californica* percent occurrence by pot.

Shrub

False mesquite (*Calliandra eriophylla*) – a component of mix 2. Established in 69/108 pots (64%). This species established across all rainfalls and soil types. The seed had 90% germination when tested separately and in the experiment 2 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in 99% of the pots.

False mesquite thrives best in dry, gravelly soils in full sun and is drought tolerant. Although it is a slow growing shrub, seedlings grow and establish quickly without pretreatment (University of Texas 2008).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	50	100	92	81
	Ave	58	83	75	72
	Low	25	50	42	39
	Grand Total	44	78	69	64

Table A1-10. *Calliandra eriophylla* percent occurrence by pot.

Alternate species selections: These species met the requirement for establishment across all soil types and rainfalls, but had lower establishment rates or rates less balanced across all the combinations of soil and rain.

<u>Warm season perennial grasses</u>

Tanglehead (*Heteropogon contortus*) – a component of mix 2. Established in 56/108 pots (52%). This species established across all rainfalls and soil types but had modestly lower establishment in Arkose (33%) and low rainfall (22%). The seed averaged 12% germination when tested separately and, in the experiment, 16 seeds of this species were planted in each pot. Therefore, under ideal conditions we would have expected presence in 87% of the pots.

Tanglehead seeds have long twisted awns that aid in germination by untwisting during precipitation events thereby "screwing" seed into the soil. Germination rates were higher in the greenhouse but the effect of awn removal on viability of seed does not seem to explain the difference between field and laboratory results.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	42	92	75	69
	Ave	33	83	75	64
	Low	25	17	25	22
	Grand Total	33	64	58	52

Table A1-11. *Heteropogon contortus* percent occurrence by pot.

Sand dropseed (*Sporobolus cryptandrus*) – a component of mixes 1 and 4. Established in 101/216 pots (47%). Established moderately well across all soil types and rainfalls. The seed averaged 67.5% germination when tested separately. In pots seeded with mix 1, 16 seeds were planted in each pot and in pots seeded with mix 4, 20 seeds were planted in each pot. We would have expected presence in all pots seeded with mix 1 or 4.

Sand dropseed is a prolific (10,000 seeds per panicle) producer of very small seed (5,298,000 seeds/lb) but viability and seedling vigor can be quite variable. Though drought resistant once established, seedlings are usually slow to develop. Germination can be enhanced by scarification or trampling by livestock as well as alternating between warm and cold temperatures (USDA FS 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	High	29	75	50	51
	Ave	42	75	50	56
	Low	29	33	38	33
	Grand Total	33	61	46	47

Table A1-13. *Sporobolus cryptandrus* percent occurrence by pot.

Cane beardgrass (*Bothriochloa barbinodis*) – a component of mixes 2 and 3. Established in 99/216 pots (46%). This species established moderately well across all soil types and rainfalls. The seed averaged 13.5% germination when tested separately. In pots seeded with mix 2, 16 seeds were planted in each pot and in pots seeded with mix 3, 20 seeds were planted in each pot. We would have expected presence in 91% of the pots seeded with mix 2 and 95% of the pots seeded with mix 3.

The most suitable conditions for cane beardgrass are 12 to 20 inches mean annual precipitation and silty to clayey soil (USDA FS 2008). Where annual precipitation is only 5 to 7 inches, it can sometimes be found in areas of high water concentration or where flooding occasionally occurs. Cane beardgrass rarely grows in dense stands, but rather can normally be found as scattered individual plants (USDA FS 2008).

		Soil Type			
		Arkose	Gila	Glance	Grand Total
Rainfall simulation	High	42	75	83	67
	Ave	8	83	58	50
	Low	29	13	21	21
	Grand Total	26	57	54	46

Table A1-14. *Bothriochloa barbinodis* percent occurrence by pot.

Plains lovegrass (*Eragrostis intermedia*) – a component of mix 2. Established in 28/108 pots (26%). This species established across all rainfalls and soil types but had lower establishment in Arkose (14%) and low rainfall (17%). The seed averaged 82.5% germination when tested separately and, in the experiment, 2 seeds of this species were planted in each pot. Therefore under ideal conditions we would have expected presence in 97% of the pots.

Plains lovegrass is most productive on sands and sandy loams and least productive on shallow, stony, and cobbly soil. In south-central Arizona, its occurrence has been found to have a strong positive correlation with slope (USDA FS 2008). Plains lovegrass usually emerges during the summer rainy season when temperatures alternate between 68 and 104 degrees F and these are the conditions at which maximum germination has been found to occur (Roundy et al. 1992).

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	17	42	50	36
	Ave	8	33	33	25
	Low	17	17	17	17
	Grand Total	14	31	33	26

Table A1-7. *Eragrostis intermedia* percent occurrence by pot.

Perennial forb

Desert senna (*Senna covesii*) – a component of mixes 2 and 4. Established in 27/216 pots (13%). This species established across all rainfalls and soil types but had very low establishment in Arkose (3%) and low rainfall (6%). The seed averaged 27% germination when tested separately. In pots seeded with mix 2, 3 seeds were planted in each pot and in pots seeded with mix 4, 2 seeds were planted in each pot. We would have expected presence in 61% of the pots seeded with mix 2 and 47% of the pots seeded with mix 4. There is little known about the germination requirements for this species.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**Ave**	4	29	13	15
	High	0	29	21	17
	Low	4	8	4	6
	Grand Total	3	22	13	13

Table A1-15. *Senna covesii* percent occurrence by pot.

Species not recommended: These species performed poorly in the greenhouse trials. They had low or no establishment in one or more soils or rainfall scenarios. While different seed sources or alternative practices may enhance their establishment (six of these species had 5% or less germination in the laboratory, indicating low seed quality), further follow-up is not recommended at this time. Some of these species could be candidates for mixes targeting a specific soil type but do not meet the requirement for the general use of reclaiming lands on this site.

Species with unbalanced establishment

Whitethorn acacia (*Acacia constricta*) – a component of mixes 1 and 4. This species established in 15/216 pots (7%) without a consistent pattern other than the suggestion that it did better with high rainfall (accounting for 8 of 15) and soils other than Arkose (only 2 established on Arkose). It does establish on these soils. The seed averaged 16% germination when tested separately. Two seeds were planted in each pot seeded with either mix 1 or 4. We would have expected presence in 29% of the pots.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	0	13	21	11
	Ave	8	4	8	7
	Low	0	8	0	3
	Grand Total	3	8	10	7

Table A1-16. *Acacia constricta* percent occurrence by pot.

Catclaw acacia (*Acacia greggii*) – a component of mix 3. This species established in 18/108 pots (17%). This species established well across all rainfalls but did not establish in the Arkose soil type. The seed averaged 67.5% germination when tested separately. With 1 seed planted per pot, we would have expected presence in 68% of the pots.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	0	17	33	17
	Ave	0	33	25	19
	Low	0	17	25	14
	Grand Total	0	22	28	17

Table A1-17. *Acacia greggii* percent occurrence by pot.

Skunkbush sumac (*Rhus trilobata*) – a component of mix 1. This species established in 24/108 pots (22%). This species established across all rainfalls but had no establishment in Arkose (0%). The seed averaged 13.5% germination when tested separately. With 2 seeds planted per pot, we would have expected presence in 25% of the pots.

		Soil Type			
		Arkose	**Gila**	**Glance**	**Grand Total**
Rainfall simulation	**High**	0	58	17	25
	Ave	0	42	42	28
	Low	0	17	25	14
	Grand Total	0	39	28	22

Table A1-18. *Rhus trilobata* percent occurrence by pot.

Species with establishment below 10%

Fourwing saltbush (*Atriplex canescens*) – a component of mix 3. This species established in none of the pots (0/108; 0%). The seed averaged 13.5% germination when tested separately. With one seed planted per pot, we would have expected presence in 13.5% of the pots.

Prairie Junegrass (*Koeleria macrantha*) – a component of mix 3. This species established in 2/108 pots (2%), both in the Glance soil type and high rainfall. The seed averaged 59% germination when tested separately. With 2 seeds planted per pot, we would have expected presence in 89% of the pots.

Seed of prairie junegrass ripens in late summer to fall and has low viability but germination is possible, even during periods of water stress. The highest germination rates have been found to occur at 64 degrees F (USDA FS 2008).

Muttongrass (*Poa fendleriana*) – a component of mix 3. This species established in 6/108 pots (6%), with 4 of the 6 in the Arkose soil type. The seed averaged 15% germination when tested separately. With 2 seeds planted per pot, we would have expected presence in 28% of the pots.

Most muttongrass populations are dominated by female plants that produce viable seed apomicticly (without pollination). However, plants also reproduce sexually and by tillering. It is usually found on dry sites and tolerates a wide range of soil types and pH. In Arizona it is found between 5,000 and 11,000 ft elevations (USDA FS 2008).

Gooseberryleaf globemallow (*Sphaeralcea grossulariifolia*) – a component of mix 3. This species established in 8/108 pots (8%) across all soil types but only 1 of 8 was in low rainfall. The seed averaged 18% germination when tested separately. With 3 seeds planted per pot, we would have expected presence in 45% of the pots.

Species with low seed quality from the vendor as well as establishment below 5%

Sixweeks needle grama (*Bouteloua aristidoides*) – a component of all the mixes. This species established in 5/432 pots (1%). This species did best in the Glance soil type with average rainfall (4 of 5). The seed averaged 2.5% germination when tested separately. 4 seeds were planted in every pot. We would have expected presence in 10% of the pots. The low seed quality of this species reduces the value of the greenhouse testing and with better quality seed a different result may have occurred.

Rothrock grama (*Bouteloua rothrockii*) – a component of mixes 1 and 4. This species established in 1/216 pots (0.005%). The seed averaged 1% germination when tested separately. In pots seeded with mix 1, 16 seeds were planted in each pot and, in pots seeded with mix 4, 20 seeds were planted in each pot. We would have expected presence in 15% of the pots seeded with mix 1 and 18% of the pots seeded with mix 4. The low seed quality of this species reduces the value of the greenhouse testing and with better quality seed a different result may have occurred.

Big purple tansyaster (*Machaeranthera tanacetifolia*) – a component of mix 1. This species established in 4/108 pots (4%) but did not establish on the Gila soil type. The seed averaged 1.5% germination when tested separately. With 7 seeds planted per pot, we would have expected presence in 10% of the pots. The low seed quality of this species reduces the value of the greenhouse testing and with better quality seed a different result may have occurred.

Whitestem paperflower (*Psilostrophe cooperi*) – a component of mix 2. This species established in none of the pots (0/108; 0%). However it is known that this species has strong seed dormancy so the duration of the experiment may not have matched the species biology. The seed averaged 4% germination when tested separately. With 2 seeds planted per pot, we would have expected presence in 8% of the pots.

Desert globemallow (*Sphaeralcea ambigua*) – a component of mix 4. This species established in 1/108 pots (1%). The seed averaged 5% germination when tested separately. With 2 seeds planted per pot, we would have expected presence in 10% of the pots. The low seed quality of this species reduces the value of the greenhouse testing and with better quality seed a different result may have occurred.

Orange caltrop (*Kallstroemia grandiflora*) – a component of mix 3. This species established in none of the pots (0/108; 0%). The seed averaged 1.5% germination when tested separately. With 7 seeds planted per pot, we would have expected presence in 64% of the pots. The low seed quality of this species reduces the value of the greenhouse testing and with better quality seed a different result may have occurred.

Appendix 2 Characteristics of species considered

Common Name	Scientific Name	Sci. Code	Functional Group	Drought tol. Level	Moist. use	Min. precip. to estab. (in)	Max. precip. to estab. (in)	Adapted to coarse text. soil	Adapted to medium text. soil	Min. PH	Max. PH
whitethorn acacia	*Acacia constricta*	ACCO	SH	high	low	4	11	Yes	Yes	7	8.5
catclaw acacia	*Acacia greggii*	ACGR	SH	high	low	4	11	Yes	Yes	7	8.5
red threeawn	*longiseta*	ARPU	WSPG	high	low	2	15	Yes	Yes	5.5	7.5
fourwing saltbush	*Atriplex canescens*	ATCA	SH	high	medium	5	18	Yes	Yes	6.5	9.5
desert marigold	*Baileya multiradiata*	BAMU	PF	Not available							
sixweeks needle grama	*Bouteloua aristidoides*	BOAR	AG	Not available							
cane beardgrass	*Bothriochloa barbinodis*	BOBA	WSPG	high	medium	12	20	Yes	Yes	7	8.2
sideoats grama	*Bouteloua curtipendula*	BOCU	WSPG	medium	medium	6	25	Yes	Yes	5.5	8.5
blue grama	*Bouteloua gracilis*	BOGR	WSPG	high	medium	8	22	Yes	Yes	6.6	8.4
Rothrock grama	*Bouteloua rothrockii*	BORO	WSPG	Not available							
false mesquite	*Calliandra eriophylla*	CAER	SH	high	low	2	10	Yes	Yes	7	8.5
Arizona cottontop	*Digitaria californica*	DICA	WSPG	high	low	5	14	Yes	Yes	7.5	8.3
bottlebrush squirreltail	*Elymus elymoides*	ELEL	CSPG	high	low	5	16	No	Yes	6	8.4
plains lovegrass	*Eragrostis intermedia*	ERIN	WSPG	high	low	5	18	Yes	Yes	5.7	7.8
Mexican gold poppy	*mexicana*	ESCA	AF	medium	low	8	18	No	Yes	5.8	7.5
tanglehead	*Heteropogon contortus*	HECO	WSPG	high	low	5	14	Yes	Yes	6	8
curly mesquite	*Hilaria belangeri*	HIBE	WSPG	high	low	5	12	Yes	Yes	6	8
orange caltrop	*Kallstroemia grandiflora*	KAGR	AF	Not available							
prairie Junegrass	*Koeleria macrantha*	KOMA	CSPG	high	high	14	20	Yes	Yes	6	8
green sprangletop	*Leptochloa dubia*	LEDU	WSPG	high	medium	12	24	Yes	Yes	6	8
big purple tansyaster	*Machaeranthera tanacetifolia*	MATA	AF	medium	medium	16	24	No	Yes	6.5	8.5
muttongrass	*Poa fendleriana*	POFE	CSPG	high	low	10	18				
whitestem paperflower	*Psilostrophe cooperi*	PSCO	SH	Not available							
skunkbush sumac	*Rhus trilobata*	RHTR	SH	medium	low	8	20	Yes	Yes	6.5	8.2
desert senna	*Senna covesii*	SECO	PF	Not available							
desert globemallow	*Sphaeralcea ambigua*	SPAM	PF	high	low	5	15	Yes	Yes	7.5	8.5
sand dropseed	*Sporobolus cryptandrus*	SPCR	WSPG	high	low	8	16	Yes	Yes	6.6	8
globemallow	*Sphaeralcea grossulariifolia*	SPGR	PF	medium	low	8	14	Yes	Yes	5	7

Table A2- 1. Hydrological characteristics of experiment species and their establishment requirements

Appendix 3 Evaluation of recommended species by elevation range

Common name	Latin name	Functional group	Elevation range (ft)
Green sprangletop	(*Leptochloa dubia*)	WSPG	2500-6000
Red threeawn	(*Aristida purpurea var. longiseta*)	WSPG	3000-6000
Blue grama	(*Bouteloua gracilis*)	WSPG	4000-8000
Arizona cottontop	(*Digitaria californica*)	WSPG	1000-6000
Curly mesquite	(*Hilaria belangeri*)	WSPG	3000-6000
Sideoats grama	(*Bouteloua curtipendula*)	WSPG	2500-7500
Bottlebrush squirreltail	(*Elymus elymoides*)	CSPG	2500-10000
Desert marigold	(*Baileya multiradiata*)	PF	2000-5000
Mexican gold poppy	(*Eschscholzia californica ssp. Mexicana*)	AF	2000-4500
False mesquite	(*Calliandra eriophylla*)	SH	2000-5000
Alternate species			
Tanglehead	(*Heteropogon contortus*)	WSPG	1000-5500
Plains lovegrass	(*Eragrostis intermedia)*	WSPG	3000-6000
Sand dropseed	(*Sporobolus cryptandrus*)	WSPG	200-7000
Cane beardgrass	(*Bothriochloa barbinodis*)	WSPG	1000-5800
Desert senna	(*Senna covesii*)	PF	1000-3000

Table A3 - 1. Ranges of plant species by elevation.

Appendix 4 Actual watering schedule

University of Arizona - School of Natural Resources
Rosemont mine land reclamation project
Phase 2 watering schedule - Summer

Day count	Date	Day	Low (mm)	Avg. (mm)	High (mm)	Low (ml)	Avg. (ml)	High (ml)
1	08/28/07	Tuesday			15			1,103
2	08/29/07	Wednesday		15	15		1,103	1,103
3	08/30/07	Thursday	10	15	15	735	1,103	1,103
4	08/31/07	Friday	10	15	15	735	1,103	1,103
5	09/01/07	Saturday						
6	09/02/07	Sunday						
7	09/03/07	Monday	5	8	11	368	588	809
8	09/04/07	Tuesday						
9	09/05/07	Wednesday						
10	09/06/07	Thursday	5	8	11	368	588	809
11	09/07/07	Friday						
12	09/08/07	Saturday						
13	09/09/07	Sunday	5	8	11	368	588	809
14	09/10/07	Monday						
15	09/11/07	Tuesday						
16	09/12/07	Wednesday	5	8	11	368	588	809
17	09/13/07	Thursday						
18	09/14/07	Friday						
19	09/15/07	Saturday	5	8	11	368	588	809
20	09/16/07	Sunday						
21	09/17/07	Monday						
22	09/18/07	Tuesday	5	8	11	368	588	809
23	09/19/07	Wednesday						
24	09/20/07	Thursday						
25	09/21/07	Friday	5	8	11	368	588	809
26	09/22/07	Saturday						
27	09/23/07	Sunday						
28	09/24/07	Monday	5	8	11	368	588	809
29	09/25/07	Tuesday						
30	09/26/07	Wednesday						
31	09/27/07	Thursday	5	8	11	368	588	809
32	09/28/07	Friday						
33	09/29/07	Saturday						
34	09/30/07	Sunday	5	8	11	368	588	809
35	10/01/07	Monday						
36	10/02/07	Tuesday						
37	10/03/07	Wednesday	5	8	11	368	588	809
38	10/04/07	Thursday						
39	10/05/07	Friday						
40	10/06/07	Saturday	5	8	11	368	588	809
41	10/07/07	Sunday						
42	10/08/07	Monday						
43	10/09/07	Tuesday	5	8	11	368	588	809
44	10/10/07	Wednesday						
45	10/11/07	Thursday						

Phase 2 watering schedule – Summer (continued)

Day count	Date	Day	Low (mm)	Avg. (mm)	High (mm)	Low (ml)	Avg. (ml)	High (ml)
46	10/12/07	Friday	5	8	11	368	588	809
47	10/13/07	Saturday						
48	10/14/07	Sunday						
49	10/15/07	Monday	5	8	11	368	588	809
50	10/16/07	Tuesday						
51	10/17/07	Wednesday						
52	10/18/07	Thursday	5	8	11	368	588	809
53	10/19/07	Friday						
54	10/20/07	Saturday						
55	10/21/07	Sunday	5	8	11	368	588	809
56	10/22/07	Monday						
57	10/23/07	Tuesday						
58	10/24/07	Wednesday	5	8	11	368	588	809
59	10/25/07	Thursday						
60	10/26/07	Friday						
61	10/27/07	Saturday	5	8	11	368	588	809
62	10/28/07	Sunday						
63	10/29/07	Monday						
64	10/30/07	Tuesday	5	8	11	368	588	809
65	10/31/07	Wednesday						
66	11/01/07	Thursday						
67	11/02/07	Friday	5	8	11	368	588	809
68	11/03/07	Saturday						
69	11/04/07	Sunday						
70	11/05/07	Monday	5	8	11	368	588	809
71	11/06/07	Tuesday						
72	11/07/07	Wednesday						
73	11/08/07	Thursday	5	8	11	368	588	809
74	11/09/07	Friday						
75	11/10/07	Saturday						
76	11/11/07	Sunday	5	8	11	368	588	809
77	11/12/07	Monday						
78	11/13/07	Tuesday						
79	11/14/07	Wednesday	5	8	11	368	588	809
80	11/15/07	Thursday						
81	11/16/07	Friday						
82	11/17/07	Saturday	5	8	11	368	588	809
83	11/18/07	Sunday						
84	11/19/07	Monday						
85	11/20/07	Tuesday	5	8	11	368	588	809
86	11/21/07	Wednesday						
87	11/22/07	Thursday						
88	11/23/07	Friday	5	8	11	368	588	809
89	11/24/07	Saturday						
90	11/25/07	Sunday						
91	11/26/07	Monday	5	8	11	368	588	809
92	11/27/07	Tuesday						
93	11/28/07	Wednesday						
94	11/29/07	Thursday	5	8	11	368	588	809
Total watered			170	285	390	12,495	20,948	28,665

Gap between summer and winter monsoon: >2 months, no water

University of Arizona - School of Natural Resources
Rosemont mine land reclamation project
Phase 2 watering schedule - Winter

Day count	Date	Day	Low (mm)	Avg. (mm)	High (mm)	Low (ml)	Avg. (ml)	High (ml)
1	02/04/08	Monday	5	5	5	368	368	368
2	02/05/08	Tuesday						
3	02/06/08	Wednesday						
4	02/07/08	Thursday		3	3		221	221
5	02/08/08	Friday						
6	02/09/08	Saturday						
7	02/10/08	Sunday	5	5	5	368	368	368
8	02/11/08	Monday						
9	02/12/08	Tuesday						
10	02/13/08	Wednesday			3			221
11	02/14/08	Thursday						
12	02/15/08	Friday						
13	02/16/08	Saturday	5	5	5	368	368	368
14	02/17/08	Sunday						
15	02/18/08	Monday						
16	02/19/08	Tuesday		3	3		221	221
17	02/20/08	Wednesday						
18	02/21/08	Thursday						
19	02/22/08	Friday	5	5	5	368	368	368
20	02/23/08	Saturday						
21	02/24/08	Sunday						
22	02/25/08	Monday			3			221
23	02/26/08	Tuesday						
24	02/27/08	Wednesday						
25	02/28/08	Thursday	5	5	5	368	368	368
26	02/29/08	Friday						
27	03/01/08	Saturday						
28	03/02/08	Sunday		3	3		221	221
29	03/03/08	Monday						
30	03/04/08	Tuesday						
31	03/05/08	Wednesday	5	5	5	368	368	368
32	03/06/08	Thursday						
33	03/07/08	Friday						
34	03/08/08	Saturday			3			221
35	03/09/08	Sunday						
36	03/10/08	Monday						
37	03/11/08	Tuesday	5	5	5	368	368	368
38	03/12/08	Wednesday						
39	03/13/08	Thursday						
40	03/14/08	Friday		3	3		221	221
41	03/15/08	Saturday						
42	03/16/08	Sunday						
43	03/17/08	Monday	5	5	5	368	368	368
44	03/18/08	Tuesday						
45	03/19/08	Wednesday						

Phase 2 watering schedule – Winter (continued)

Day count	Date	Day	Low (mm)	Avg. (mm)	High (mm)	Low (ml)	Avg. (ml)	High (ml)
46	03/20/08	Thursday			3			221
47	03/21/08	Friday						
48	03/22/08	Saturday						
49	03/23/08	Sunday	5	5	5	368	368	368
50	03/24/08	Monday						
51	03/25/08	Tuesday						
52	03/26/08	Wednesday		3	3		221	221
53	03/27/08	Thursday						
54	03/28/08	Friday						
55	03/29/08	Saturday	5	5	5	368	368	368
56	03/30/08	Sunday						
57	03/31/08	Monday						
58	04/01/08	Tuesday			3			221
59	04/02/08	Wednesday						
60	04/03/08	Thursday						
61	04/04/08	Friday	5	5	5	368	368	368
62	04/05/08	Saturday						
63	04/06/08	Sunday						
64	04/07/08	Monday		3	3		221	221
65	04/08/08	Tuesday						
66	04/09/08	Wednesday						
67	04/10/08	Thursday	5	5	5	368	368	368
68	04/11/08	Friday						
69	04/12/08	Saturday						
70	04/13/08	Sunday			3			221
71	04/14/08	Monday						
72	04/15/08	Tuesday						
73	04/16/08	Wednesday	5	5	5	368	368	368
74	04/17/08	Thursday						
75	04/18/08	Friday						
76	04/19/08	Saturday		3	3		221	221
77	04/20/08	Sunday						
78	04/21/08	Monday						
79	04/22/08	Tuesday	5	5	5	368	368	368
80	04/23/08	Wednesday						
81	04/24/08	Thursday						
82	04/25/08	Friday			3			221
83	04/26/08	Saturday						
84	04/27/08	Sunday						
85	04/28/08	Monday	5	5	5	368	368	368
86	04/29/08	Tuesday						
87	04/30/08	Wednesday						
88	05/01/08	Thursday		3	3		221	221
89	05/02/08	Friday						
90	05/03/08	Saturday						
Total watered			75	99	120	5,513	7,277	8,820

Gap between summer and winter monsoon: >2 months, no water

Appendix 5 Germination testing

Germination testing

Germination of all species was assessed in two ways. The primary assessment method was conducted in the greenhouse by recording the actual germination under the conditions and treatments specified for this experiment. The second and third methods were conducted in a germination chamber where temperature, light (fluorescent and incandescent lights), and relative humidity were controlled according to July monsoon averages (Weather Underground 2008, Time and Date.com 2008; see Table A5-1). One method incorporated the use of petri dishes. Depending on the size of seeds, 25 to 100 seeds of each species were placed in a petri dish between sheets of filter paper. Grass and forb seeds were placed between 2 sheets (1 sheet top and bottom) of filter paper and tree and shrub seeds were placed between 4 sheets (2 sheets top and bottom) of filter paper. All seeds were then sprayed with water to saturate filter paper and lids were then placed on petri dishes. Seeds were sprayed again whenever filter paper started to dry out. Germination was checked approximately every three days for one month. In the third method, seeds were laid out in 5 numbered rows of 5 - 20 seeds each on 2 layers of paper towels (Brawny solid white). Paper towels were sprayed to damp with a bleach-water solution (1/2 cap-full bleach to 32 oz. water) and folded up (sprayed on each fold over) so that rows lay on top of each other (i.e. towels folded between rows). Folding started at row 5 with the towel folded over row 5, sprayed, row 5 folded over row 4, sprayed, & so on, until row 1 was at the bottom & covered by the rest of the rows. The roll was then used to carefully wipe up any overspray on the table so that the roll was just saturated when it was put into a gallon ziplock freezer bag. 5 rolls were laid flat inside each bag and laid on shelves so that all row 1's faced the bottom of the chamber. Seeds were checked for germination every third day for one month.

Time	Temp (°F)	%RH	% Floures.	Incan
0:00	64	80	0	off
0:30	64	82	0	off
1:00	64	83	0	off
1:30	63	84	0	off
2:00	63	88	0	off
2:30	63	87	0	off
3:00	61	91	0	off
3:30	61	91	0	off
4:00	61	91	0	off
4:30	59	94	0	off
5:00	59	94	0	off
5:30	59	96	10	off
6:00	61	94	17	off
6:30	68	83	25	off
7:00	72	71	33	off
7:30	77	61	42	off
8:00	81	53	50	off
8:30	84	42	58	off
9:00	86	36	67	off

9:30	90	28	75	off
10:00	91	25	83	off
10:30	93	21	92	off
11:00	95	17	100	on
11:30	97	14	100	on
12:00	99	7	100	on
12:30	99	8	100	on
13:00	97	9	100	on
13:30	95	16	100	on
14:00	95	13	100	on
14:30	95	12	92	off
15:00	93	17	83	off
15:30	93	16	75	off
16:00	95	14	67	off
16:30	93	18	58	off
17:00	90	22	50	off
17:30	88	29	42	off
18:00	84	40	33	off
18:30	79	50	25	off
19:00	77	57	17	off
19:30	73	63	10	off
20:00	72	69	0	off
20:30	70	71	0	off
21:00	68	77	0	off
21:30	18	77	0	off
22:00	17	79	0	off
22:30	17	77	0	off
23:00	17	78	0	off
23:30	16	80	0	off
23:59	17	79	0	off

Table A5-1: data obtained from an average of the data from every day in July, 2007 at 31.6156°N, 110.6044°W (http://www.wunderground.com). Average monsoon start date: July 3rd; sunrise:~5:30 AM, sunset:~7:30 PM, solar noon:~12:30 (http://www.timeanddate.com/worldclock/astronomy.html)