GRASSLAND REVEGETATION FOR MINE RECLAMATION IN SOUTHEAST ARIZONA

By

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ABSTRACT

Mine land reclamation techniques were tested in arid Southeast Arizona for their potential to enhance reclamation success on two sites at different elevations (1400- and 1650-meters above sea level) on two sandy loam soils (Arkose and Gila Conglomerate). Seedbed preparation (smooth or rough surface) and straw mulch treatments (surface mulch, mulch incorporated into the soil, or no mulch) were tested for their potential to establish vegetation and prevent erosion. Gila soil retained 12.9% more soil moisture than the Arkose soil and was preferred by the seed mix (Gila: 64.4 plants m^{-2}; Arkose: 23.2 plants m^{-2}). A rough surface with surface mulch was recommended. Gila soil was more susceptible to erosion likely because it contained smaller soil particles. Rock cover was associated with significantly ($P=0.0138$) reduced rate of soil movement (0.1588 cm soil loss or accumulation per 1 percent rock cover). Proper soil management can be critical for reclamation success.

Key words: Revegetation, Rosemont Copper Company, Mine reclamation, Native Species, Arid

INTRODUCTION

Arid climates present challenges for reclamation due to limited and unpredictable precipitation along with highly variable temperatures (Stoddart, 1946; Ries and Day, 1978). Reclamation seeding efforts depend on precipitation and when suitable conditions do not occur, seeds do not germinate or may germinate and die leaving the soil bare and vulnerable to erosion (Abbott & Roundy, 2003; Pritchard *et* al, 2004; Wilson *et al*, 2004). Choosing vegetation that is adapted to limited precipitation, variable temperatures and low nutrients will improve revegetation success (Grant *et al*, 2011). Along with site adapted seed, supplementary treatments, including seedbed preparation and adding mulch to the soil, can be used to conserve limited resources and accelerate repairs of damaged processes in an arid climate (Biederman & Whisenant, 2005).

Mechanical treatments for seedbed preparation are commonly used to mitigate compaction created during the construction phase of reclamation or to make surface conditions more suitable for seed germination (Wood & Buchanan, 2000; Schor & Gray, 2007). Reconstructing and recontouring slopes of mine lands using heavy equipment can leave sites with compacted surface layers which can prevent penetration by plant roots reducing vegetative growth (Abdel-Magid, 1987; NRCS, 2003) as well as preventing water infiltration which can result in erosion (Li *et al*, 2011). Using heavy equipment to rip the soil can reduce compaction and improve conditions (Vallentine, 1980; Pikul & Aase, 1998) but leaves the surface with a rough complex texture. Common practice is to make the surface smooth again before beginning reclamation seeding. Given that microtopographic variation and soil texture determine safe sites for seeding germination (Oswald & Neunschwander, 1993) the freshly ripped, rough surface seems like it may be better for seed germination than the more common smooth surface. This idea is supported in a study by Winkel *et al* (1991), which placed three perennial grasses into four environments to evaluate the effects of microsites on seedling emergence. Emergence of all three species was highest from gravel, followed by mulch, cracks, and bare soil. In the Southwest during mesic conditions, usually from July to October, seedbed microsites were more favorable for germination than bare soil alone (Winkel *et al*, 1991). However, given that different species have different stimuli requirements for germination and establishment which are directly impacted by microtopography (Winkel *et al*, 1991; Oswald & Neuenschwander, 1993) the choice of a rough or smooth surface may be complicated by the species chosen for seeding.

Roughness down to the soil texture scale may also have a significant influence on soil moisture and germination by manipulating climatic impact on seeds. Although a coarse-textured soil may hold less water, it also allows water to infiltrate deeper into the soil to avoid evaporation (Dreesen, 2008). Fine-textured soils retain water closer to the surface, which is easily lost to evaporation and drying winds (Mellouli *et al*, 2000). Microsites are small spaces that modify soil moisture, temperature and other environmental conditions (Winkel *et al*, 1991). They occur naturally, but may also be created by using seedbed preparation, which may be dependent on soil texture. Coarser soils often have more voids and microsites may be defined as the space next to a rock, as it may conserve more soil moisture (Elmarsdottir *et al*, 2003). Bare soils (no mulch treatments) offer a different environment to seeds than sites with mulch amendments.

Mulch can ameliorate harsh environmental conditions to encourage vegetation establishment and provide erosion control until vegetation is established (Norland, 2000). There are several different types of mulch including straw, hay, wood chips, bark, gravel, manure and sewage sludge (Norland, 2000; Wood & Buchanan, 2000; Whisenant, 2005). Even Russian Thistle, *Salsola* sp., has proven to be an effective mulch in Arizona (Day *et al,* 1979 and Day & Ludeke, 1987). Organic mulch such as straw simulates plant litter under natural conditions and its benefits appear to be greatest in arid climates (Whisenant, 2005). Mulch has been shown to reduce evaporation, increase soil moisture, lower soil temperatures, decrease radiant energy, aid infiltration, reduce run-off, erosion, and nutrient loss, provide seed and seedling protection, and promote seedling growth (Winkel *et* al, 1991; Oswald & Neuenschwander, 1993; Ji & Unger, 2001; Mulumba & Lal, 2008; Biederman & Whisenant, 2009). In a study by Unger & Parker (1976), evaporation reduction in soil using wheat, sorghum and cotton mulch concluded that wheat mulch was the most effective at reducing evaporation while using the least amount of mulch. Winkel *et al* (1991) found that soil moisture decreased in bare soil more quickly than sites with mulch.

Mulch applied on top of the soil surface creates a layer of protection for seeds and seedlings from seed predators and environmental conditions (Winkel *et al*, 1991; Oswald & Neunschwander, 1993; Norland, 2000). Seeding should occur prior to surface mulch application to allow the soil-to-seed contact necessary for germination (Dreesen, 2008). By providing shade and reducing evaporation, soil moisture can be conserved and soil temperature variation reduced (Norland, 2000; Davis, 2004; Whisenant, 2005; Mulumba & Lal, 2008). Additionally, the mulch protects the soil from the impact of raindrops, slows and reduces the amount of run-off, which in turn reduces nutrient loss (Mulumba & Lal, 2008). Higher mulch rates provide better erosion protection, but may inhibit seedling growth and establishment (Norland, 2000). Soil conditioners, particularly soil tackifiers, may be used to bind surface mulch in place to protect it from blowing away in the wind (Norland, 2000; Schor & Gray, 2007) a significant disadvantage in the windy and arid southwest. Although applying mulch to the soil surface has promising effects, incorporating mulch into the soil also appears to provide favorable conditions for reclamation, offers a different environment for seeds, and solves some of the problem with wind.

Incorporating mulch into the soil surface has been shown to improve the physical condition of soil and create advantageous conditions for seed germination (Biederman & Whisenant, 2009). Adding organic material directly into the soil can help to repair the nutrient cycle (Beare *et al*, 1992), reduce evaporation (Gill & Jalota, 1996) and retain soil moisture longer than surface mulch (Biederman & Whisenant, 2009). Biederman & Whisenant (2009) concluded that incorporating mulch maintained higher vegetation density during droughts when mulch was mixed into the soil at a higher rate and lower depth. Incorporating mulch improved the water holding capacity by creating a "moisture reservoir," which is especially important in arid climates (Wood & Buchanan, 2000; Biederman & Whisenant, 2009). Gill and Jalota (1996) found that mixing organic matter into the soil also depends on the soil texture and properties. Although incorporating mulch may not provide as much erosion protection as surface mulch, incorporated mulch does offer some erosion control by increasing rainfall interception and increasing infiltration, as compared to no mulch (Biederman & Whisenant, 2009). Incorporating mulch additionally increases soil roughness, which can create microsites, or safe sites, for seeds and seedlings (Winkel *et al*, 1991). When mulch is incorporated into the soil it offers different levels of erosion protection and soil conditions than surface mulch and bare soil (no mulch).

The susceptibility of soil to erosion depends on its physical characteristics, including texture, composition, topographic position, vegetative cover and organic matter content (Simanton *et al*, 1991; Weltz *et al*, 1998). Coarse texture soils may have high infiltration rates and greater deep percolation, while finer textured soils have lower infiltration rates and retain water closer to the surface (Whisenant, 2005). Silt, clay, and sand content influences the ability of the soil to resist erosion. Silt has the highest potential to erode while clay has the highest resistance to erosion, as it is binds together. Soils with coarse fragments high in sand have low runoff due to their high infiltration rates (NRCS, 2002). Organic matter binds soil particles together and forms aggregates, making the soil more resistant to erosion (Weltz *et al*, 1998; NRCS, 2004). Vegetative cover has been shown to intercept raindrops, reduce the impact to the soil surface, increase infiltration and decrease erosion (Weltz *et al*, 1998; NRCS 2004). Cover may be found in the forms of vegetation canopy cover, vegetation basal cover, mulch (plant litter), rocks, or bare ground. In general, the erosion rate increases as the amount of bare ground increases (Weltz *et al*, 1998). Revegetation and cover (mulch or rock) on a disturbed site may help to prevent erosion.

This study was designed to evaluate methods for reclamation including soil type, surface roughness and application of mulch. Different from other kind of revegetation, soil texture can often be controlled to some extent in reclamation but is unclear where the balance lies between suitability for plant growth and resistance to erosion. A smooth or rough surface can create different soil conditions and while a rough surface seems better for germination, establishment and decreasing erosion potential, it would not have to be significantly better than the smooth surface to be recommended because making the surface smooth costs more to install. Incorporated mulch appears to offer the best compromise by enhancing surface roughness while fastened into the ground but it offers less erosion protection than surface mulch. Surface mulch appears to be cheaper to apply and offers more erosion protection but is difficult to keep in place. However, the establishment of vegetation is the primary response variable of interest and the native, site adapted species selected for seeding may respond differently than expected from research and recommendations developed in other regions.

Present Study

Every site has unique ecological processes and physical challenges (Wood & Buchanan, 2000) that must be considered for reclamation. The present study was conducted for a proposed copper mine to be located in the Santa Rita Mountains of Southeast Arizona. This experiment was conducted to determine which methods are most likely to produce a stable site and a self-sustaining, self-repairing ecosystem that will promote hydrological functions to support post-mining use. Post-mining use includes ranching, wildlife habitat, and recreation. This project simulated planned reclamation by using similar slope inclinations, the predominant slope aspect, and soil replacement protocols with the two most common soil types of the area. The desired plant community, a semi-desert grassland with well-dispersed shrubs, is based on the historic climax plant community of the Rosemont area (NRCS, 2011a; NRCS, 2011b).

The reclamation test plots were located within the Madrean Basin and Range system (NRCS, 2011), on the east side of the northern portion of the Santa Rita Mountains, located approximately 30 miles southeast of Tucson, Arizona. The lower elevation was situated at approximated 1403 meters (4600 feet) in semi-desert grassland and the upper elevation site is located at approximately 1646 meters (5400 feet) in upland grasslands, bordering Madrean Oak Woodlands. The elevations represent the upper and lower elevations of the planned reclamation landform. These sites fall within NRCS ecological site descriptions of Major Land Resource Area (MLRA) 41, which were used to describe baseline conditions. The lower plot fits into the 30.5 – 40.6 cm (12 – 16-in) precipitation zone on limestone hills, while the upper plot fits in the 30.5 – 40.6 cm (12 – 16-in) and 40.6 – 50.8 cm (16 – 20-in) precipitation zone on granitic hills (NRCS, 2011a). These ecological site descriptions may be used evaluate seasonal distributions of vegetation, vegetation type and production.

Climate variables of the Rosemont area are described from the historic Rosemont Junction town and nearby sites of similar characteristics. Over 59 years of records were used to determine annual precipitation means, and records over the past 97 years were used to determine the mean minimum and maximum temperatures. A mean annual precipitation, minimum and maximum temperatures were taken from the Rosemont town from 1931 through 1970, Empire from 2007 through 2010, and the Rosemont weather station from 2008 through 2010 (Davis & Callahan, 1977; Wunderground, 2010). The site is described as an arid region, with a mean annual precipitation of 41.7 cm (16.4 in) per year, ranging from a mean annual precipitation from 27.2 cm (10.7 in) to 70.6 cm (27.8 in). There are two main seasons in which precipitation occurs: the cool season, and the warm season. The cool season, from October to April, produces about 40% of the annual precipitation in the form of a low intensity rain or snow. The warm season (otherwise referred to as the monsoon season), from May to September, produces about 60% of the annual precipitation in the form of high intensity thunderstorms (Winkel *et al*, 1991; NRCS, 2011a; NRCS, 2011b). The majority of the plant community thrives during the warm season when more water is available (Davis, 2004). Data from the Rosemont area ranging from 1914 through 2000 (WestLand Resources, Inc., 2007) resulted in mean minimum temperatures in the Rosemont area occurred in January [34° Farenheight (F) (1° Celcius (C))], while the mean maximum temperatures occurred in June (91° F (32.8° C)).

There are two main soils that this study focuses on: Arkose and Gila conglomerate, as named by the parent materials of the soils. These are the two main soil types found within the footprint of the future copper mine site. The Arkose is a sedimentary rock mixture of detrital (organic) and chemical material, including silicates. Arkose is classified by its mineral composition and assemblage; it is a siltstone, sandstone or conglomerate made up of quartz, feldspar, a small amount of impurities and kaolinitic clay often contains iron oxide and is generally red in color (Krynine 1948; Tetra Tech, 2007). The Arkose and Gila Conglomerate soil textures on the test sites were all classified as sandy loams, as a result of laboratory analysis by MotZZ Laboratory (Mesa, AZ). The Gila conglomerate, a type of sedimentary rock that is composed of pre-existing rocks that are cemented together, is composed of quartz sandstone, carbonates, argillite, hornfels, granitic rock, and quartz-feldspar. Although the soils have similar texture, their differences in mineral composition may influence the vegetation that will occur with revegetation.

The vegetation used in the seed mix should be suitable for the each soil type. A plant community may occur across multiple soil types, but each soil type is typically identified with a single plant community. A semi-desert grassland is represented in the 10 species native seed mix, shown in Table 1, which was chosen on the basis of a previous greenhouse study. The seed mix was based on the functional groups and seasonal characteristics of the target ecosystem and will support post-mining uses. The seed mix is commercially available, which is an important factor in large-scale projects. Seed availability may vary from year to year depending on climate conditions and demand; therefore, back-up species have been determined from the greenhouse study. I requested that the seed sources that have the most similar climate and site characteristics to the test plot sites, as they should be the best adapted and most suitable for revegetation (Whisenant, 2005; NRCS, 2006b). The seed mix is adapted to the climate, soils and conditions of the site and possesses the characteristics of a self-sustainable, self-repairable ecosystem.

Table 1. Rosemont native species seed mix.

Rosemont Copper Seed Mix	Scientific Name	Group	Species Composition
Arizona cottontop	*Digitaria californica*	WSPG	14%
Blue grama	*Bouteloua gracilis*	WSPG	14%
Curly mesquite	*Hilaria belangeri*	WSPG	14%
Green sprangletop	*Leptochloa dubia*	WSPG	14%
Plains Lovegrass	*Eragrostis intermedia*	WSPG	14%
Sideoats grama	*Bouteloua curtipendula*	WSPG	14%
Bottlebrush squirreltail	*Elymus elymoides*	CSPG	3%
Mexican gold poppy	*Eschscholzia californica ssp. Mexicana*	AF	8%
Desert marigold	*Baileya multiradiata*	PF	4%
Fairy Duster	*Calliandra eriophylla*	SH	0.1%
TOTAL			100%

*WSPG = Warm Season Perennial Grass; CSPG = Cool Season Perennial Grass; AF = Annual Forb; PF = Perennial Forb; SH = Shrub

The time of year in which seeding occurs may effect revegetation success. Seeding should occur immediately before optimal conditions present themselves to minimize the time that seeds are exposed to harsh environmental conditions and seed predators (Rennick & Munshower, 1985). In Southeast Arizona, optimal seeding time for the Rosemont seed mix corresponds to mid- to late-June, prior to the monsoon seasons, as it is composed of primarily warm season species (NRCS, 2011). When optimal conditions do not occur, seeds may remain dormant until favorable conditions for germination and survival occur (Andondakis & Venable, 2004), but often they germinate and die without establishing (Abbott & Roundy, 2003). The cool season species in the seed mix would be expected to remain dormant until the following winter. Rennick & Munshower (1985) showed that the time of seeding could have a lasting effect through at least the fifth growing season. Due to the climatic variability in arid regions, optimal conditions may not occur every year for establishment.

METHODS

Site Preparation

The reclamation plan of the proposed Rosemont mine is mimicked by the test plots in slope inclination and aspect (exposure) and soil replacement. All areas used for field-testing, including the soil borrow sites, were located on private property. To assist in reestablishing vegetation, two most common soil types were scraped off borrow sites and replaced at each site, a process known as top dressing (Wood & Buchanan, 2000). The same slope inclination and aspect were chosen due to the strong presence of slope effects in Southeast Arizona (Whittaker & Niering, 1964; Whittaker & Niering, 1968). The desired slope grade was an 18-degree, or 3:1 slope. This slope also offers site stability and the ability to drive agricultural equipment horizontally along the contour; arid land revegetation on 26-degree (2:1) or steeper slopes has shown to be uncommon (Wood & Buchanan, 2000).

The lower site was 1.6 ha (4 ac) in area and was originally located in the Mabray-Chiricahua rock outcrop association (NRCS 2010). Half of the original slope was approximately a 4:1 (14-degree) slope and the other half was slightly steeper than a 3:1 slope. In order to achieve the desired slope, modification was necessary. The northern portion of the slope was created using a cut-and-fill technique (Figure 1), where the lower portion of the area was cut, then moved to the top of the hill. The southern portion of the slope was created by pushing the top of the hill down to the bottom of the hill to fill, as this portion of the hill was steeper than 18-degrees. The upper site is approximately 1.6 ha (4 ac) in area and was originally located in Chiricahua cobbly sandy loam

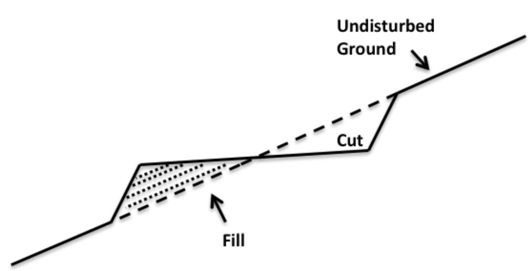


Figure 1. Cut and fill technique.

(NRCS 2010), an Arkosic soil. The original slope was approximately a 26-degree (2:1) slope, steeper than the desired 18-degree slope. In order to create the desired slope, material was cut from the side of the hill and filled in at the bottom of the desired area, as shown in Figure 1 (Schor & Gray, 2007). The cut at the top of the hill was as much as 25-feet below the original soil surface.

Soil Placement

Soil replacement is beneficial for revegetation as the soil contains seeds, microorganisms and favorable soil properties (Wood & Buchanan, 2000). Once the desired 3:1 slopes were created, the upper and lower test sites were divided into two equal areas to place Gila and Arkose soil to a depth of 30.5 cm (12 in). The Gila was scraped off of a site located on private property using an excavator then hauled to each site. Since the soil was directly hauled to the sites, the seed bank and microorganisms were assumed to be living when placed on the testing sites. The Arkose material was native to the upper site; therefore, material that was cut from the hillside during the cut-and-fill was used directly. Due to the amount of cutting that was required to create the slope, some sections were much rockier than others, with much less fine material mixed in. These soils likely had little soil development and few microbes in the soil, as it appears to be mainly parent material. The Arkose material used for the lower site was cut from the road to the upper site and consisted of shallower materials with more fine materials.

Experimental Design

Split block designs are often used for practical reasons when factors are difficult to change (Mead, 1994; Jones & Nachtsheim, 2009). A blocked split-split plot design was used for ease of soil replacement and to prevent soil compaction while creating seedbed treatments. Elevation was considered a block effect. Each site was divided into 24 equal-area sections, totaling 48 sections. Half of each site (12 sections) was Gila soil and the other half was Arkose soil. Limiting traffic by heavy machinery will reduce or prevent compaction. It is essential to prevent compaction because it has the ability to restrict infiltration, resulting in runoff and erosion, and nutrient loss (NRCS, 2003; NRCS, 2004). Each test plot was divided into rows along the contour so that the equipment could take long one-way passes across multiple sections in order to limit traffic and compaction. This prevented compaction caused by turning tractors around in small areas and it also helped to simulate the actions that would be taken in larger-scale projects. The rows were randomly chosen to be either rough or smooth using the Microsoft Excel random number generator, assigning values to rough and smooth. Half of each site had a rough surface, while the other half had a smooth surface. Each section was then randomly designated one of three mulch treatments (no mulch, incorporated mulch, or surface mulch). This is a blocked split-split plot design of 2 elevations X 2 soil types X 2 replicates of: (2 surface X 3 mulch)), for a total of 48 sections. See APPENDIX B for sequenced maps of the experimental design.

Sections were sufficiently large to allow for the use of equipment that would be used on a large-scale project. Each section at the lower site was 0.06 hectares (ha) (0.16 ac) and each section at the upper site was 0.05 ha (0.12 ac). Certified weed-free 22.9 cm (9 in) straw wattles and silt fences marked the boundaries of each section. Agricultural equipment was used to prepare the seedbed, mulch and soil tackifier treatments. At the upper elevation site, two sections were switched within the same soil type because the equipment applying the mulch was not able to navigate these sections safely. Prior to treatment application, all sites were considered to be equal and treatments were randomly assigned with the same sources of variation; therefore, switching two equally suitable sites is not expected to affect results.

An order of operations was created to limit disturbance and compaction while installing the treatments and to ensure that seeds were properly placed on top of the seedbed (Table 2). The soil had been compacted after the construction of the sites; therefore it was necessary to rip all soil. Since the Arkose and Gila soils were placed to a 30.5 cm (12 in) depth, the ripping depth was limited to 20- to 25-cm (8- to 10-in) to prevent mixing of the subsurface soils. All soil disturbance and seedbed preparation was completed before seeding to ensure that designated seeding depths were realized. Incorporating the straw mulch and soil roughness treatments preceded the broadcast seeding. Broadcast seeding was followed by surface mulch. Soil tackifier was then sprayed onto the surface mulch.

Table 2. Order of operations.

Order	Operation
1	Rip top 8- to 10-inches (20-25 cm) of surface to break up compaction on all sections
2	Incorporate straw mulch into top 6- to 8-inches (15-20 cm) of soil, in designated sections
3	Rip top 6- to 8- inches (15-20 cm) of soil on all sections to create rough surface
4	Drag a screen across soil surface of designated sections to create smooth surface
5	Broadcast seed across all sections
6	Blow straw mulch on soil surface of designated sections
7	Spray soil tackifier on top of surface mulched sections

Surface Treatments

Rough and smooth soil surfaces were chosen as possible surface textures that are commonly found in mined lands. Due to the high amount of traffic with heavy equipment used to construct the site, all sections of the plots were ripped approximately 20 cm (8 in) deep using a ripper bar dragged by a John Deer loader to break up any compacted layers within the reconstructed soil. The same ripper bar was used to create a rough surface and ripped to a 20 cm (8 in) depth. Ripping left lose ridges along the contour that were susceptible to wind and water erosion. To create the smooth surface treatment after ripping, a lightweight 4-foot X 6-foot screen made of expanded metal was dragged across the rips to knock down the high ridges into the low depressions. This created a more even soil surface while still benefitting from the ripping effects and was less susceptible to wind erosion. Although there were no noticeable ridges as there were on a rough surface, the smooth surface was only as smooth as the texture of the soil itself.

Mulch Treatments

After the initial ripping occurred, certified weed-free wheat straw mulch was mixed into the soil at the rate of 4.5 Mg ha^{-1} (2 t ac^{-1}) in the designated sections (Wood & Buchanan, 2000; Dressen, 2008). The mulch that was used for soil incorporation occurred in shorter lengths than the mulch that was used for surface mulch for ease of installment. Mulch was first blown onto the surface from a trailer pulled by a Case III MXM130 tractor with dual rear tires to minimize compaction (NRCS 2003). The trailer held two 0.5 t mulch bales, which were fed by a chain into 3 rows of saws that ground the bales and blew the mulch onto the surface. The first attempt to incorporate mulch was via disking, but it bunched the mulch and dragged it behind rather than incorporating into the soil. A rotary tiller, Rotadarion, was then dragged along the contour. When the soil was getting churned, gravity would move the soil and pile it up on the lower side of the rotor tiller. This would have affected the surface treatments, so this application method was discarded. The rotary tiller was ideal for incorporating mulch when used perpendicular to the contour (Wood & Buchanan, 2000). It fluffed up the soil evenly while churning the mulch into the soil. To prevent further compaction, the tractor made a loop using the test plot perimeter roads. In plots where no road was available, the tractor stayed along the section boundaries. Some mulch was pulled out of the soil when a rough surface was created by dragging the ripper bar across these sections.

A pneumatic mulch blower was used to apply surface mulch, followed by the soil tackifier application. Pneumatic blowers use air to spread mulch evenly and in close proximity to the soil surface without using water, which is limited in arid lands. Dry mulch blowers are able to cover large areas quickly, including steep slopes (Norland, 2000). On surface mulch sections, certified weed-free mulch was applied at the rate of 4.5 Mg ha^{-1} (2 t ac^{-1}) consistent with common practice (Wood & Buchanan, 2000; Dressen, 2008). Longer pieces of mulch were used so that it would have a greater chance to be held down with the tackifier. Mulch was blown onto the surface after seeding as previously described. Following the first application of surface mulch at the lower plot, high winds picked up before tackifier could be applied. This left mulch piled in clumps and some mulch was blown off of the test plot. The following day we manually spread the clumped mulch to bare areas or areas where mulch was too thin.

A soil tackifier was used to keep surface mulch in place. Soil conditioners, including soil tackifiers, are used to improve soil conditions and hydrological processes (Whisenant, 2005). Soil tackifier was used in sections where surface mulch was applied to keep the mulch fastened to the ground. The soil tackifier, EnviroTac II, was applied on top of the surface mulch treatments by spraying it with a Finn T330 hydroseeder. This truck holds 3,000 gallons of water and has 2 paddle mixers to agitate and mix the tackifier with the water. The EnviroTac II was manually mixed to the recommended ratio, 12 water: 1 tackifier (Environmental Products &

Applications, Inc., 2006). The discharge boom was used for areas that were accessible from the truck. For areas inaccessible by the boom, a hose was connected to the truck and sprayed onto the mulch at closer range. The lower site was applied at a higher rate as the contractors applied all of the tackifier-water mix before all surface mulch sections had been sprayed. Soil tackifier, like mulch, is used as a temporary aid in erosion control and vegetation establishment, and is broken down by environmental factors over time (Norland, 2000).

Nurse Crop

During the cool season, a nurse crop of wheat, *Triticum aestivum*, was inadvertently grown as a result of the wheat seeds brought in with the straw mulch. This nurse crop was seeded at the same time as the seed mix, in late December 2009, and grown in mulched sections. Generally, irrigation is needed to grow wheat in arid lands (Wood & Buchanan, 2000; Whisenant, 2005). Nurse crops are usually annual grasses that improve infiltration and provide erosion control while simultaneously improving environmental conditions for slower-growing perennial seedlings that are establishing and providing weed control (Stoddart, 1946; Whisenant, 2005). After the nurse crop dies, stubble mulch remains (stems and roots of wheat) and provides cover that continues to protect young seedlings. Its roots anchor the stubble mulch in place and have been shown to be effective for at least 1 year (Norland, 2000). Mulch may be sterilized by heating it in an autoclave, though it is more practical to use on a small-scale project. The many benefits of a nurse crop are desirable, though it is not likely that a nurse crop will establish often in an arid climate.

Broadcast Seeding

Broadcast seeding is often applied on rough terrains and to create a random, natural look; seeds were expected to be covered by natural conditions including wind and water erosion, (Wood & Buchanan, 2000) leaving the small seeds to be buried at their optimal planting depth (Yurkonis *et al*, 2010). The lower and upper elevation sites were broadcast seeded at the rate of 523 seeds m^{-2} (48.6 seeds ft^{-2}) (Dreesen, 2008), a high seeding rate to account for seeds that will not be situated at their optimal germination depth (Wilson *et al*, 2004). The seed mix was proportioned based on desired plant community. This amount was then converted to the number of seeds per pound, according to the species. Granite Seed (Lehi, Utah) supplied the certified weed-free seed mix by pure live seed and supplied bulk weights. The seed was weighed at the test site based on bulk weight and proportioned based on area of application. One species, *Calliandra eriophylla,* was recommended at a lower rate of 2,965 seeds ha^{-1} (1,200 seeds ac^{-1}) (NRCS, 2009). *Calliandra eriophylla* seed was weighed separately and was proportionately mixed into the overall seed mix manually. The broadcast seeder was towed behind a Case III MXM130 with dual- rear tires at a consistent speed to apply the same amount of seeds on all areas. The broadcast spinning device was tied into the drive shaft of the tractor, allowing for a consistent seeding rate. Broadcast seeding occurred on 21 December 2009 at the lower site and 30 December 2009 at the upper site.

Data Collection

Monitoring objectives were to evaluate and document progress towards declared goals, detect changes over time, and to use results for future management decisions. Variables of interest related to climate, soil properties, and vegetation (Table 3).

Table 3. Response variable monitoring, frequency and method.

Response variables	Frequency	Measurement Method/ Equipment
Climate		
Temperature Precipitation Wind Speed & Direction Evaporation Precipitation	15 minute intervals Event triggered, up to 20.3 cm (8 in) per hour 0.4 m/s trigger, 0 – 40 m/s Once per hour Event triggered, up to 12.7 cm (5 in) per hour	Weather Station Onset HOBO Rain Gauge RG3 & RG3-M event data logger
Soil Properties		
Soil Moisture	Until rain ceased after cool season	Field Scout TDR 100
Soil Temperature	15 minute intervals	HOBO pendant data logger
Soil Mycorrhizae	Initial, following warm season	Send to Lab
Soil Roughness/microtopography	Initial, following warm season	Pin meter or Surface Laser Scan
Soil Properties	Initial, following warm season	Send to Lab
Vegetation Attributes		
Vegetation Cover Density Aboveground Biomass Species Diversity Shannon-Wiener Index Species Composition	Peak of cool season (May - June) and warm growing seasons (September - October)	Quadrat Quadrat Harvest Density Density and Biomass Density and Biomass
Hydrological Attributes		
Erosion Vegetative Cover (Canopy, Basal), Mulch Cover, Rock Cover, Bare Ground	Following monsoon season (October) Peak of warm season (September – October)	Erosion Nails Silt Fence Tape Measures Point-Intercept

Weather

Instruments were installed at each site to monitor weather. The Rosemont weather station was installed in 2006, located approximately 0.8 km (0.5 mi) north of the upper testing site. The station measures temperature using a Campbell 107 Thermistor, precipitation using a tipping bucket Campbell TR-525USW, evaporation, and wind speed and direction. Temperatures from 21 July through 1 September 2010 came from the Empire Ranch weather station, when the Rosemont weather station was disabled. The Empire Ranch is located approximately 10.1 km (6.3 mi) from the lower test plot and 12.2 km (7.6 mi) from the upper test plot, with an elevation of 1416 m (4647 ft) above sea level (Wunderground, 2011). An Onset HOBO data-logging tipping bucket rain gauge was installed in the center of each of the test plots. Due to technical errors, the Rosemont weather station precipitation data was used from January to July 2010 and a USGS rain gauge was used for the lower site. The Barrel Canyon USGS rain gauge was located approximately 1.9 km (1.2 mi) from the lower test plots. Temperature & light pendant data loggers (Onset HOBO pendant loggers) were installed at each site. Eight data loggers measured light: one on the soil surface of each soil type and one at each mulch depth at each site. The dimensions of the loggers measure 58 x 33 x 23 mm (2.3 x 1.3 x 0.9 inches) and are easily placed under mulch. They measure a range of 0 to 320,000 lux (0 – 30,000 lux ft^{-2}) and recorded data every 15 minutes.

Soil

Soil Moisture

Soil moisture is key factor for revegetation in arid lands as water is a limiting resource. To determine the effectiveness of treatments on conserving soil moisture, measurements were taken with a soil moisture meter, a Field Scout TDR 100, with 7.6 cm (3 in) probes. In order to receive an accurate measurement, the probes must be fully inserted into the ground. When this was not possible due to rocks below the surface, the probes were moved and re-inserted into the soil until it was possible to insert the probes completely. Once the probe was inserted, 10 readings of percent volumetric water content were taken and averaged. The soil moisture readings were taken down hill of the 7 soil erosion nails in each section, but not close enough to disturb the nails. These nails were placed on each section randomly; when a nail could not be found, another random location was found and used for a soil moisture point. When possible, all measurements were taken within the same day. When it was not possible to obtain all measurements within a day, they were taken the following day. Soil moisture was collected during three points of time during the cool season: 31 January 2010, 26 February 2010, and 17 March 2010. The three points of time were averaged for data analysis to characterize the soils. No soil moisture measurements were taken during the warm season 2010 due to time constraints.

Soil Temperature

Temperature data loggers (Onset HOBO pendant loggers) were installed on the soil surface on each soil type and beneath one and two inches of mulch. They measure a range from -20° to 70° C (-4° to 158°F) and recorded readings every 15 minutes. Soil temperatures were not observed to compare differences between the rough surface and smooth surface treatments. Soil temperatures were observed at each elevation on each soil type and beneath mulch to determine the soil temperature differences with mulch depth. Surface mulch treatments were assumed to affect soil types equally because the surface mulch covers the soil surface completely. Due to cost, only one data logger was used at each location. More replications would be needed for a full analysis.

Soil Properties

A soil sample was collected from each treatment type and from reference sites. Samples were taken when the soil was initially placed on the test plots (17 December 2009), after the warm season (13 October 2010 to 11 November 2010) and from reference areas following the warm season (10 November 2010 to 22 November 2010). A 5.1 cm (2 in) diameter soil corer was used to extract samples to the depth of 15- to 20-cm (6- to 8-inches), when possible. Rocks below the surface would block the coring device from pressing deeper. When this occurred, the sample was taken to the depth in which the rock occurred or the corer was moved within the area quadrat area until a sample of sufficient volume could be collected. Moving the soil sample was not expected to affect results since the sample that was collected corresponded to vegetation data.

The initial soil analysis was used as a baseline to determine the differences between soils and to detect changes over time. The initial soil samples consisted of 10 subsamples that were randomly located within each soil type at each site. Soils were re-sampled between 13 October 2010 and 22 November 2010. Two soil samples were collected from every section. Each sample consisted of 2 subsample locations randomly located along each of 3 transects, totaling 6 subsamples per section. These locations corresponded to the quadrats used for vegetation data collection. Surface mulch was not collected in a soil sample; mulch was pushed aside and the soil sample was taken from the soil surface and below.

Reference areas had similar elevations, soils, slope aspect and inclination for comparison purposes, but were undisturbed native soils. Each sample consisted of 3 subsamples randomly located along a transect, which corresponded to the quadrat locations. The upper elevation reference site was located just west of the upper test site and consisted of Arkose soil. The lower elevation reference site was located just east of the lower test site and consisted of Mount Fagan rhyolite megabreccia. Although soil types were different, this site was the nearest geographic location while being constrained to private property where grazing had not yet occurred that season while meeting elevation and slope requirements.

Of the two samples collected at each location, one sample was sent to MotZZ Laboratories, Inc. (Tempe, Arizona) for a soil sample analysis, including nitrate (NO_3-N), phosphate (PO_4-P), potassium (K), organic matter and pH. The second sample was sent to BBC Laboratories (Tempe, Arizona) for a vesicular-arbuscular mycorrhizae (VAM) spore count. Each laboratory provided general descriptions of soil analyses (Table 4). To analyze VAM, the BBC Laboratories sieved and isolated VAM spores by sucrose gradient and microscopy enumeration; only viable spores that were in good condition were counted. Nutrients, organic matter, VAM and pH were averaged by soil type at each site.

Table 4. Soil analysis methods.

Test	Method
Nitrate (NO_3-N)	Cd-reduction
Phosphate (PO_4-P)	Olsen
Potassium (K)	NH_4OAc (pH 8.5)
Organic Matter	Walkey Black
pH	1 soil: 1 water
Vesicular-Arbuscular Mycorrhizae	Spore count

Soil Roughness

A pin meter or a laser surface scan can be used to measure the microtopography of the soil surface; due to the high costs of a laser surface scan, the pin meter was chosen. The pin meter used in this experiment consisted of 101 pins spaced 1 cm (0.4 in) apart with an aluminum backboard to form a 1-m (3.3 ft) transect (Bryant *et al*, 2007). The pins were dropped down to the surface of the soil and held in place with rubber grommets. The top of the pins are then measured to create a profile of the soil surface and photographed using a digital camera.

These photographs were taken from the same perspective and used to record individual pin heights. Measurements were visually estimated to the nearest 0.5 cm (0.2 in).

The pin meters were randomly placed perpendicular to the contour so that contour ripping effects could be quantified. Seven 1-m pin meter transects were measured in each treatment section at the lower test plot. Due to time constraints five 1-m (3.3 ft) pin meter transects were measured in each treatment section at the upper test plot. Pin meter measurements taken from 29 January through 6 May 2010. Of the 6 surface-mulch combination treatments, there were 24 pin meter measurements taken on each soil type.

To measure the surface roughness, h_{rms}, the soil surface was measured using the standard deviation, which is shown in the following formula:

$$h_{\mathrm{rms}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z_i - \bar{z})^2}$$

where *n* is the number of height measurements, z_i is a single measurement and z is the mean of the measurements (Bryant *et al,* 2007).

Mulch Depth

Mulch depth was derived from pin meter measurements taken from 29 January through 6 May 2010. Only surface mulch treatments were used in the mulch depth analysis. Measurements were taken on the surface of the mulch and at the soil surface. To obtain the depth of the surface mulch, the mulch surface measurement was subtracted from the soil surface measurement. Mulch depth corresponded to the application rate (Norland, 2000).

Vegetation Attributes

In order to determine which treatments established a healthy, sustainable, and desirable plant community to meet post-mining uses, biomass, density, cover and diversity were monitored at the peak of the cool and warm growing seasons. The cool season vegetation monitoring occurred between 25 May and 24 June 2010. The warm season vegetation monitoring occurred between 10 September and 30 October 2010. To measure the plant community, three- 40 x 40 cm (1.3 x 1.3 ft) quadrats were randomly located along 3 randomly placed 10 m transects, totaling 9 quadrats per section. A 1 m (3.3 ft) boundary around each section was excluded to eliminate edge effects. Data collectors had previous experience with rangeland monitoring or were trained prior to data collection in the field to improve upon accuracy. Each species was evaluated during the peak of their characteristic growing season. Some grasses had inflorescences at the time of vegetation measurements, which resulted in a positive identification, but most grasses were observed in their vegetative state. These grasses were identified to species based on vegetative characteristics to the best of the collector's abilities.

Harvesting plants to obtain their biomass is a time-consuming, but direct measure. Aboveground biomass was quantified by clipping plants 1 cm (0.4 in) above the ground surface. During the cool season, all species were pooled for biomass determination. During the warm season, biomass was separated according to species. No dead plants were collected. Harvested plants were placed in a paper bag, dried in an oven in the lab at 70° C (158° F) for a minimum of 3 days and weighed to the nearest 0.01 gram. Three quadrats were randomly placed along a randomly located 10 m (32.8 ft) transect, for a total of 9 quadrats per section. During the cool season the quadrats were placed below the transect line and during the warm season the quadrats were placed above the transect line. By placing the quadrats on different sides of the permanent transect, warm season biomass and cover measurements were not altered by previous harvesting.

Density was counted according to the number of stems of each species within the quadrat during both cool season and warm season monitoring. The edge rule was the following: if the plant basal area or stem was more than half way outside of the quadrat, it was not counted. If the plant basal area or stem was more than half way inside the quadrat, it was counted. If the plant basal area or stem was half in or out, every other plant would be counted. Species diversity and species composition were derived from this data.

Canopy cover, otherwise known as foliar or aerial canopy, is the projection of all aboveground vegetation onto the soil surface and basal cover refers to the area where vegetation intersects the soil surface (Elzinga *et al*, 2005). Canopy cover can be used to estimate the amount of erosion protection vegetation offers and, like biomass, is sensitive to climatic and biotic factors (BLM, 1999; Elzinga *et al*, 2005). Canopy cover should be estimated during the same time of year due to climatic influences while basal cover does not vary much with short-term variation in climatic and biotic factors. No livestock grazing was planned or expected during the experiment and native herbivores were not expected to influence cover observations. Cover measurements are quick, though it can be difficult to interpret vegetation trends over time (Elzinga *et al*, 2005). For example, it is possible to have an increase in the number of individuals or it is possible for few individuals to increase in biomass over time, which result in the same cover measurements. Basal cover was estimated and during the cool and warm season, canopy cover was estimated during the warm season. These measurements were visually estimated using nine- 40 x 40 cm (15.75 in) quadrats in each section to the nearest 5% by observing vegetation from directly above. These measurements were performed as a team when possible to improve upon accuracy.

Species richness and the Shannon-Wiener diversity index were used to describe species diversity. Species richness, or the number of species per given area, was described as species per square meter. The Shannon-Wiener diversity index is a measure of the distribution or evenness of the species in a section (per square meter). The following equation was used to determine the index:

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

where S is the total number of species, i is a single species, and p_i is the relative abundance of each species, or the proportion of individuals of a single species to the total number of individuals in the given plant community (Zar, 2010). Species that have a low index number indicates that few species dominate an area, or an index of 0 signifies that there is only 1 species within an area. Species are more evenly distributed with an increasing diversity index.

Species composition is the proportion of species or functional groups within a plant community used to evaluate range condition and allows for plant community comparisons (BLM, 1999). A similarity index compares the reclaimed site with a reference site to determine when goals have been met (Habich, 2001). Density, biomass, or cover can determine species and function group composition. The same attribute should be used to compare composition trends over time (BLM, 1999). Plant density data was used to determine functional group composition by pooling species into the following categories: annual forbs, perennial forbs, annual grasses, perennial grasses, shrubs, and vines.

Volunteer species are species that were not included in the seed mix. Possible sources of volunteer species may be seeds from the seedbank, from the seed mix, and dispersal from outside of the test plots. Due to direct hauling of the replacement soil, the seed bank was expected to remain viable (Wood & Buchanan, 2000). If the collector recognized the volunteer species, it was recorded to family, genus or species. If the collector was not able to identify the volunteer species, it was assigned a number and specimens were collected to use as a key. These samples were later taken to the University of Arizona herbarium to key out to a minimum of functional group or family, and genus or species, when possible.

Hydrological Attributes

Soil movement was estimated following the warm season (monsoon season) when it was most likely to occur due to the high intensity nature of the storms (NRCS, 2011a; NRCS, 2011b). Soil erosion nails are a common method to measure soil movement quickly and at low cost over a defined area. There were 7 randomly located nails located in each section that were measured in late October 2010. To minimize edge effects, no nails were located within 1 m (3.3 ft) of the edge of a perimeter boundary. To randomly locate each nail, an origin was located on the northwest corner of each section and a horizontal and vertical location was chosen with a random number table. The nails were hammered into the ground until the nail head was flush with the surface of the ground. The nails were marked by a rebar and cap above and offset from the nails, along with a marker flag. These flags were often destroyed by the sun and wind and were replaced. The nails were installed from 31 January to 3 March 2010.

Although precipitation had occurred within the installation time, the majority of soil movement was expected during the monsoon season. At the end of the monsoon season, the nails were measured to the nearest millimeter from the top of the nail head. If the nail was covered with soil, the depth of the soil on top of the nail head was measured as carefully as possible and assigned a positive value. When soil was eroded, a negative value was assigned. Due to the windy conditions at the site, some flags were torn apart and some nails were not located during this monitoring season.

As a second way to measure soil movement, fabric tape measures were faceted to a silt fence. The bottom of the tape measure was installed flush with the soil surface. To minimize edge effects, no tape measures were installed with within 1 m (3.3 ft) of any boundaries. Seven tape measures were randomly installed within a measured maximum distance using a random number table. The tapes were installed from 12 March to 20 May 2010. Although some erosion may have occurred before or during the installation, the majority of erosion was expected to occur during the monsoon season. Since the tapes measured the accumulation of soil, it was assumed to have been soil eroded from the test plot. The tapes were measured to the nearest 0.5 mm in late October 2010. The silt fences were intended to capture soil at the bottom of each section. However, in some cases water drained along the silt fences and even carried soil away. When the soil had been carried away it was assigned a negative value.

To determine the amount of protection the soil had from raindrop impact and soil movement, cover measurements were collected. Point-intercept measurements were taken using a metal rod, dropping the pin perpendicular to the ground at a 0.25 m (1.6 ft) interval along each transect and categorized as bare ground, rock, mulch, canopy or basal cover. Rocks were defined as 10 mm or larger. In cases where there were multiple layers of cover, only the uppermost layer was counted. During windy conditions, plant canopy cover was generally not stationary and measurements were taken to the best of the observer's ability. Three permanent transects were randomly installed along the contour in each section during the cool season monitoring. A 1 m boundary around each section was excluded to minimize edge effects. Cover was measured on the uphill side of the transect during the cool season and the downhill side of the transect during the warm season to avoid collecting inaccurate cover measurements due to plant harvesting during the cool season.

Statistical Properties

The JMP, version 8.0, software was used for data analysis. Probability analysis was set at 0.05 for significance. A blocked split-split design was used for treatment installation purposes. Each section was defined as a single experimental unit, a total of 48 units. There were 9 quadrat cover, density and biomass measurements per section. The responses were each averaged to one response per section. Cover was expressed in percent, density was converted to plants per square meter and biomass was converted to kilograms per hectare. Seeded density and seeded biomass (during the warm season) were derived from density and biomass data. Species richness and Shannon-Wiener diversity index values were derived from the 9 density measurements. Species richness was calculated from the total number of species per section and then converted to species per square meter. Each species was summed together and was taken in proportion to the total number of individuals in each section, according to the Shannon-Wiener diversity index formula. Each section was then analyzed as a single replicate of a treatment.

A multivariate analysis of variance (MANOVA) was conducted to determine the interrelatedness between the response variables as result of the treatments. The following response variables were used in the MANOVA: quadrat basal, quadrat canopy cover (warm season), density, seeded density, biomass, seeded biomass (warm season data), species richness, and Shannon-Wiener diversity index. A blocked split– split plot design of elevation, soil, mulch and surface treatments as the explanatory variables. Elevation was considered a block effect and other explanatory variables included soil type, surface (nested within soil), and mulch (nested with surface (nested within soil)). Elevation was crossed with each of the explanatory variables to determine if an interaction affected the response variables. The univariate Greenhouse-Geisser test was used to adjust for error associated with the split-split plot design. When an interaction occurs, the effect of one explanatory term has on the mean response depends on the value of the second explanatory term (Ramsey & Schafer, 2002); therefore, one factor cannot be discussed with the second factor.

The least square means models were run to address questions pertaining to individual response variables. A blocked split-split plot design was used for each response variable. Elevation was considered a block effect and other explanatory variables included soil type, surface (nested within soil), and mulch (nested with surface (nested within soil)). An interaction between elevation and each of the explanatory variables was used to examine response variables. To compare multiple means, the Student's t-test was used to compare up to 2 treatment levels and the Tukey's HSD (honestly significantly different) test was used to compare more than 2 treatment levels when effect results were statistically significant. To compare means within the levels of a single factor, the Student's t test was used.

The power to detect and explain statistical inferences within the data depends on the chance mechanism used to apply treatments and the number of replications of the treatment. If a treatment application or sample is selected randomly, each treatment or sample has an equal chance of being selected. A random sample allows us to make inferences from the data to a broader population (Ramsey & Shafer, 2002). In the current study, there was the least power to detect differences in elevation as there was only 1 replication of each elevation and it could not be randomly applied. This was followed by 1 replication of soil at each elevation. The placement of the soil was chosen at random at each site and had more power to detect differences than elevation. There were 2 rows, or 2 replications of seedbed treatments on each soil type. The seedbed treatment was randomly selected by the row and has more power to detect differences with 2 degrees of freedom than elevation and soil type. There were 2 replications of mulch on each soil type and within each seedbed preparation treatment. Mulch treatments were randomly selected and had the most power to detect differences with 8 degrees of freedom.

To determine how soil movement was influenced, erosion nails were averaged per section and analyzed using the least square means model. A positive value was assigned when soil accumulated and a negative value when soil eroded. When evaluating soil movement, the absolute value of soil accumulation and erosion was used. The experimental explanatory variables (elevation, soil, surface, and mulch treatments) were used to evaluate their affects on soil movement. Cover (rock, mulch, canopy, basal, and bare ground) was also used to evaluate their affects on soil movement. While cover is an attribute within the experimental treatments, this aspect is often analyzed due to its intricate relationship with soil movement.

RESULTS

Weather

During the 2010 calendar year, the lower site received a total of 37.6 cm (14.8 in) precipitation: 14.9 cm (5.9 in) during the cool season (January to May) and 21.0 cm (8.3 in) during the warm season (June to October). The upper site received a total of 49.6 cm (19.5 in) precipitation: 23.6 cm (9.3 in) during the cool season and 23.1 cm (9.1 in) during the warm season. Precipitation that occurred in November and December 2010 pertain to the cool season of 2011 and did not influence vegetative or hydrological data collected. Monthly distribution of precipitation can be seen in Table 5. The lower site received approximately 59% of precipitation during the warm season, while the upper site received a nearly equal distribution of precipitation between seasons. The upper site received slightly more precipitation during the cool season. Surface mulch sections received additional water during the mulch tackifier installation, but was not quantified. No additional irrigation was provided in this experiment.

Table 5. Test plot precipitation during 2010.

	Precipitation (cm/in)			
Month	**Lower Site**		**Upper Site**	
January	7.0	2.8	10.9	4.3
February	4.6	1.8	8.3	3.3
March	1.8	0.7	2.8	1.1
April	1.4	0.5	1.5	0.6
May	0.0	0.0	0.0	0.0
June	0.0	0.0	0.6	0.3
July	8.6	3.4	9.6	3.8
August	9.5	3.7	8.5	3.4
September	1.4	0.6	3.2	1.3
October	1.5	0.6	1.1	0.4
November	0.0	0.0	0.0	0.0
December	1.7	0.7	3.0	1.2
TOTAL	37.6	14.8	49.6	19.5

According to the Rosemont weather station, in 2010 the lowest temperatures occurred in February (2.1° C (35.8° F)), which was above the historic average minimum temperature of 1° C (34° F). The warmest temperatures occurred in August (32.4° C (90.3° F)), which was below the historic average maximum temperature of 32.8° C (91° F). The lowest nightly temperature occurred on 23 February 2010 at -4.2° C (24.4° F). The highest daily temperature occurred on 23 June 2010 at 33.8° C (92.8 °F).

Table 6. Rosemont weather station temperatures during 2010.

Rosemont Weather Station, Temperature, °C			
Month	**Mean Maximum**	**Mean Minimum**	**Mean Temperature**
January	12.2	3.5	7.5
February	11.2	2.1	6.6
March	14.8	4.7	9.8
April	18.4	7.5	13.5
May	23.4	11.3	18.3
June	29.6	18.1	24.6
July	30.1	19.6	24.6
August	32.4	16.8	23.8
September	28.0	18.4	23.0
October	22.1	12.1	17.0
November	15.6	5.4	10.5
December	15.5	6.1	10.5

Soil

Soil Moisture

Over the cool season, I detected significant interactions (X) between elevation and soil type (written "elevation X soil;" F = 158.9; 1 df; SE = 0.7; P <0.0001). The highest soil moisture occurred in Gila soil (30.8% Volumetric Water Content (VWC) at the lower site, 30.7% VWC at the upper site). The Arkose soil at the lower site held significantly less soil moisture than the Gila soil, but 3-times more soil moisture than the Arkose soil at the upper site (Table 7). The Arkose at the upper site held the least amount of soil moisture with an average of 9.2% VWC.

Table 7. Least square means (±SE) for soil moisture (percent volumetric water content, "% VWC") associated with the interaction of elevation X soil.

Treatments		**Mean VWC** (Percent)
Elevation	**Soil**	
Lower	Arkose	26.5 ± 0.7 B
	Gila	30.7 ± 0.7 A
Upper	Arkose	9.2 ± 0.7 C
	Gila	30.8 ± 0.7 A

* Means followed by different letters indicate significant differences (*P* ≤ 0.05) based on Tukey's HSD test.

Soil Temperature

With one exception (upper site with 1 in of mulch), soil temperatures were higher when no mulch was present. The maximum Arkose soil temperature was equal at either site, while the Gila soil at the lower site raised an additional 27.2° F at the lower site. Maximum soil temperatures decreased as mulch depth increased. With 2.5 cm (1 in) of surface mulch, soil temperature decreased from 12.9 – 21.6° F, with the exception of Gila soil at the upper site (temperature increased by 2.8° F). When surface mulch was 5.1 cm (2 in) deep, soil temperatures decreased from 11.5 – 42.8° F. Table 8 provides an insight into how mulch affected soil temperature. Minimum soil temperatures increased as mulch depth increased. When surface mulch was 2.5 cm (1 in) deep, minimum soil temperatures increased from 3.7 – 6.4° F. When surface mulch was 5.1 cm (2 in) deep, minimum soil temperatures increased from 6.0 – 13.6° F. With increasing mulch, soil temperature variation (standard deviation) decreased.

Table 8. Soil temperatures from 10 July 2010 to 23 September 2010.

Elevation	Soil	Surface	Mulch	Mulch Depth (cm/in)		MAX (°F)	MIN (°F)	AVG (°F)	STD DEV (°F)
Lower	Gila	Rough	No Mulch	0	0	156.2	56.2	88.8	22.8
	Arkose					147.5	56.4	87.2	21.0
Upper	Gila					129.0	55.5	83.5	16.8
	Arkose					147.5	52.8	85.8	21.6
Lower	Gila	Rough	Surface Mulch	2.54	1	134.6	60.9	83.8	15.9
				5.1	2	113.4	62.4	81.1	10.6
Upper		Smooth		2.54	1	131.8	59.2	82.3	15.5
				5.1	2	117.5	66.4	80.1	9.3

Soil Properties

A MANOVA was conducted for nutrients, soil organic matter, mycorrhizae and pH (Table 9). The explanatory variables of the model were: elevation, soil, surface (nested within soil), mulch (nested within surface (nested within soil)), elevation X soil, elevation X surface (soil), and elevation X mulch (surface (soil)). Elevation, soil, and the interaction between elevation X soil were statistically significant ($F_{1.02, 24.5} = 18.53$; $P = 0.0002$).

Table 9. MANOVA table for soil response variables during warm season 2010.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F	P
Elevation	1.0209	24.501	7.0535	0.0133
Soil	1.0209	24.501	24.844	<0.0001
Elevation X Soil	1.0209	24.501	18.5303	0.0002
Surface (Soil)	2.0417	24.501	0.3712	0.6980
Elevation X Surface (Soil)	2.0417	24.501	1.7953	0.1868
Mulch (Surface (Soil))	8.167	24.501	2.1262	0.0714
Elevation X Mulch (Surface (Soil))	16.363	24.501	2.0463	0.0818

Soil Nutrients, Organic Matter & Mycorrhizae

Examining the soil property results in Tables 10 and 11, nitrate decreases from the initial soil placement to the warm season. Phosphate slightly decreases in both soils at the lower site while increasing in both soils at the upper site and potassium increases in all cases between the initial and warm season results. When comparing the warm season soil properties to the reference soil properties (Tables 11 and 12), the reconstructed soil contained fewer nutrients in almost all situations. Results in Table 11 have been pooled for comparison purposes. There were significant differences between the interactions of elevation X soil. More samples were needed to determine significant differences among the initial and reference samples.

Table 10. Initial soil properties associated with the interaction of elevation X soil in experiment.

Treatment		Nitrate-N,	Phosphate-P,	Potassium, K	Organic Matter	Vesicular Arbuscular	pH
Elevation	**Soil**	**NO_3-N** (ppm)	**PO_4-P** (ppm)	(ppm)	(Percent)	**Mycorrhizae** (Spores/g)	
Lower	Arkose	4.2	6.3	180	1.6	1	8.0
	Gila	1.9	2.4	130	3.6	1	8.6
Upper	Arkose	2.7	7.8	130	0.6	0	7.4
	Gila	5.0	3.1	140	4.0	1	8.3

Table 11. Least square means (±SE) for soil properties associated with the interaction of elevation X soil in experiment during warm season 2010.

Treatment		Nitrate-N,	Phosphate-P,	Potassium, K	Organic Matter	Vesicular Arbuscular	pH
Elevation	**Soil**	**NO_3-N** (ppm)	**PO_4-P** (ppm)	(ppm)	(Percent)	**Mycorrhizae** (Spores/g)	
Lower	Arkose	2.32 ± 0.28 A	6.11 ± 0.41 B	213 ± 5.89 A	0.87 ± 0.09 B	2.58 ± 0.38 A	8.04 ± 0.04 B
	Gila	0.60 ± 0.28 B	1.34 ± 0.41 C	158 ± 5.89 B	0.45 ± 0.09 C	0.42 ± 0.38 B	8.50 ± 0.04 A
Upper	Arkose	1.88 ± 0.28 A	9.72 ± 0.41 A	173 ± 5.89 B	0.56 ± 0.09 B C	0.17 ± 0.38 B	7.65 ± 0.04 C
	Gila	2.90 ± 0.28 A	3.22 ± 0.41 C	168 ± 5.89 B	1.43 ± 0.09 A	1.25 ± 0.38 A B	8.35 ± 0.04 A

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

Table 12. Reference areas soil properties associated with the interaction of elevation X soil in experiment during warm season 2010.

Reference		Nitrate-N,	Phosphate-P,	Potassium, K	Organic Matter	Vesicular Arbuscular	pH
Elevation	**Soil**	**NO_3-N** (ppm)	**PO_4-P** (ppm)	(ppm)	(Percent)	**Mycorrhizae** (Spores/g)	
Lower	**Mt Fagan Rhyolite Megabreccia**	2.98	7.44	275	2.19	13.6	7.4
Upper	**Arkose**	9.34	34.60	504	3.08	8.2	6.2

Organic matter decreased in all soils from the initial soil tests (17 December 2009) to the warm season soil analysis (13 October to 11 November 2010) (Tables 10 and 11). The Gila soil on the upper site contained the most amount of organic matter (1.43%) and the least organic matter was contained in the Gila at the lower site (0.45%). Despite mixing mulch into the soil in incorporated mulch sections, there were no statistically significant increases in organic matter. All test plot organic matter content was less than the reference sites.

Soil samples were analyzed for living vesicular arbuscular mycorrhizae (VAM) spores within soil samples (Tables 10, 11 and 12). The highest spore counts occurred in the undisturbed reference area and the least occurred after the warm season in Arkose at the upper site. All treatments increased from the initial treatment application to the warm season monitoring with the exception of the Gila soil at the lower site, which decreased from 1 spore per gram of soil to 0.42 spores per gram of soil.

Soil pH

All soils on the test plot are basic, ranging from pH 7.4 to 8.6 (Tables 10 and 11). Although pH values varied slightly, pH did not change from the initial sampling to the warm season sampling. The reference Arkose at the upper site is slightly acidic with a pH of 6.2. The lower reference site consists of a different soil type with a nearly neutral pH (7.4).

Mulching (surface (soil)) also caused significant differences in soil pH (Table 13). The Gila soil was more basic (8.30 – 8.55) than the Arkose soil (7.60 – 8.08). Both soil types revealed the same patterns: surface mulch was least basic, incorporated mulch more basic and no mulch was most basic. Rough surfaces were more basic than smooth surfaces.

Table 13. Least square means (±SE) for soil pH associated with mulch (surface (soil)) in experiment following the warm season 2010.

Treatment			Mean pH ± SE
Soil	**Surface**	**Mulch**	
Gila	Rough	No Mulch	8.55 ± 0.04 A
	Smooth		8.50 ± 0.04 A
	Rough	Incorporated Mulch	8.43 ± 0.04 A B
	Smooth		8.43 ± 0.04 A B
	Rough	Surface	8.35 ± 0.04 A B
	Smooth		8.30 ± 0.04 A B C
Arkose	Rough	No Mulch	8.08 ± 0.04 B C D
	Smooth		7.95 ± 0.04 C D E
	Rough	Incorporated Mulch	7.90 ± 0.04 D E
	Smooth		7.80 ± 0.04 D E
	Rough	Surface	7.75 ± 0.04 D E
	Smooth		7.60 ± 0.04 E

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

Surface Treatments

There was a statistically significant response in soil roughness (h_{rms}) with the interaction of elevation and soil ($F = 26.1620$; 1 df; SE = 0.25; $P < 0.0001$). The Arkose soil at the upper site had the roughest soil ($h_{rms} = 4.66$) (Figure 2). The least rough (or most smooth) soil surface occurred at the lower site on Arkose soil ($h_{rms} = 1.15$). There was no significant difference in soil roughness between surface treatments (Table 14), but the long time between observations made the data poorly suited to detect this difference.

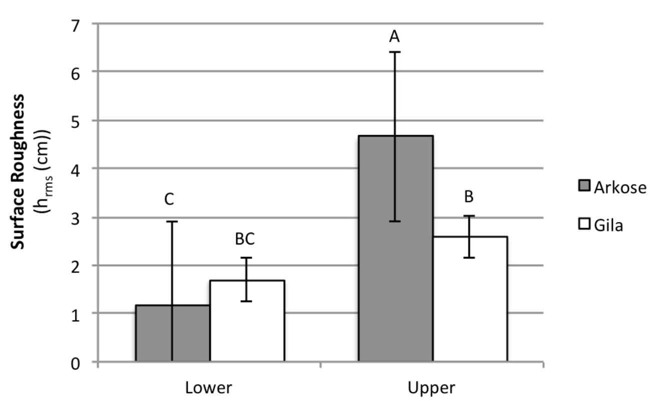


Figure 2. Least square means (± SE) for surface roughness associated with the interaction of elevation X soil in the experiment.

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

Table 14. Surface roughness associated with elevation, soil, surface and mulch treatments.

Factor	Elevation		Soil		Surface		Mulch		
Level	Lower	Upper	Arkose	Gila	Rough	Smooth	Incorporated Mulch	No Mulch	Surface Mulch
Mean Surface Roughness (cm)	1.43	3.67	2.91	2.2	2.55	2.56	2.24	2.57	2.85

Mulch Treatments

Mulch Depth

There was a statistically significant difference in surface mulch depth with elevation (F = 22.1564; 1 df; SE = 0.34; P= 0.0015). Mulch was applied at a significantly greater rate at the lower site and hence mulch depth on the lower site (3.41 cm ± 0.34 SE) was greater than that on the upper site (1.13 ± 0.34 SE) based on Tukey's HSD test.

Light

The most light occurred where no mulch was applied, light decreased as the mulch depth increased. On average, surface mulch with 2.5 cm (1 in) of mulch received a maximum of 3.0% of the light received under no mulch treatments. Surface mulch treatments with 5.1 cm (2 in) of mulch on the soil surface received a maximum of 0.7% of the light received as compared to no mulch treatments. With fewer lumens per square foot reaching the soil surface, surface mulch treatments showed less variation in light conditions than no mulch treatments.

Table 15. Light conditions on the soil surface from 10 July 2010 to 23 September 2010, presented in lumens per square foot.

Elevation	Soil	Surface	Mulch	Mulch Depth (cm/in)		MAX (lum/sq ft)	MIN (lum/sq ft)	AVG (lum/sq ft)	STD DEV (lum/sq ft)
Lower	Gila	Rough	No Mulch	0	0	26624	0	3114	4971
	Arkose					21504	0	2895	4570
Upper	Gila					25600	0	3167	5003
	Arkose					27648	0	4052	6562
Lower	Gila	Rough	Surface Mulch	2.54	1	992	0	63	98
				5.1	2	144	0	3	7
Upper		Smooth		2.54	1	512	0	52	80
				5.1	2	208	0	2	6

Vegetation Attributes

Table 16 summarizes significant factors and interactions between factors during the cool and warm season of 2010. For ease of viewing, nested effects are not displayed. Seeded biomass and canopy cover were not observed during the cool season 2010.

Table 16. Significant factors that influenced vegetation attributes in experiment during 2010.

Explanatory Variable	Cool Season 2010	Warm Season 2010
MANOVA	(Elevation X Soil)	(Elevation X Soil), (Elevation X Mulch)
Biomass	(Elevation X Soil)	(Elevation X Soil), (Elevation X Mulch)
Seeded Biomass	NA	Elevation, Soil
Density	None	Soil
Seeded Density	Soil, Mulch	Soil
Species Richness	(Elevation X Soil), (Elevation X Mulch)	Surface, (Elevation X Soil), (Elevation X Mulch)
Shannon-Wiener Index	(Elevation X Mulch)	Surface, (Elevation X Soil), (Elevation X Mulch)
Basal Cover	None	Surface, (Elevation X Soil)
Canopy Cover	NA	Surface, (Elevation X Soil), (Elevation X Mulch)
Functional Group Composition	Mulch	Soil, (Elevation X Mulch)

Cool Season MANOVA

A multivariate analysis of variance (MANOVA) of the cool season vegetation resulted in a statistically significantly interrelated by elevation, soil, and between the interactions of elevation X soil ($F_{1.065, 34.08}$ = 10.14; P = 0.0028) (Table 17). No other explanatory variables significantly affected vegetation.

Table 17. MANOVA table for vegetation response variables during cool season 2010.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F	P
Elevation	1.0602	25.446	19.2974	<0.0001
Soil	1.0602	25.446	6.8077	0.0138
Elevation X Soil	1.0602	25.446	10.1499	0.0033
Surface (Soil)	2.1205	25.446	1.4588	0.2515
Elevation X Surface (Soil)	2.1205	25.446	1.2811	0.2965
Mulch (Surface (Soil))	8.4820	25.446	1.5880	0.1750
Elevation X Mulch (Surface (Soil))	8.4820	25.446	1.0746	0.4124

Cool Season Summary of Data

The cool season data has been summarized in Table 18. Attributes are the means of the two replications of 9 quadrats collected in each section, where mulch (surface (soil (elevation))). Significant differences are graphed below and are explained within each vegetation attribute.

Table 18. Summary of cool season vegetation attributes.

Treatments				**Biomass** (kg ha^{-1})	**Density** (plants m^{-2})	**Seeded Density** (plants m^{-2})	**TRAE Density** (plants m^{-2})	**Species Richness** (Number of	**Shannon-Wiener Diversity Index** (H')	**Basal Cover** (percent)
Elevation	**Soil**	**Surface**	**Mulch**							
Lower	Arkose	Rough	Incorporated Mulch	2314.1	117.7	4.9	106.6	5.2	0.66	6.5
			No Mulch	2831.8	49.7	13.2	16.7	5.9	1.59	9.6
			Surface Mulch	3290.5	211.5	2.4	206.2	2.1	0.16	10.1
		Smooth	Incorporated Mulch	2435.7	141.7	1.0	137.8	2.4	0.14	5.3
			No Mulch	2894.4	37.8	13.2	11.1	5.6	1.56	7.1
			Surface Mulch	2814.5	116.0	6.2	101.0	3.1	0.54	9.9
	Gila	Rough	Incorporated Mulch	2199.4	281.2	8.7	272.2	2.1	0.21	10.2
			No Mulch	802.6	20.1	18.4	1.4	2.8	1.08	1.7
			Surface Mulch	1994.4	115.3	2.1	112.8	2.1	0.11	4.1
		Smooth	Incorporated Mulch	2911.7	344.4	1.4	341.0	3.1	0.07	7.7
			No Mulch	1619.2	58.3	42.7	15.3	4.2	1.54	3.2
			Surface Mulch	1730.4	151.4	0.3	150.0	1.4	0.06	3.2
Upper	Arkose	Rough	Incorporated Mulch	1421.1	75.7	7.3	66.7	2.1	0.41	5.3
			No Mulch	1337.7	126.7	6.2	120.1	1.7	0.64	7.5
			Surface Mulch	1150.1	26.0	3.5	22.6	1.7	0.44	1.4
		Smooth	Incorporated Mulch	1674.8	40.3	11.5	27.8	3.5	0.85	5.8
			No Mulch	1758.2	26.0	12.2	1.0	2.8	0.93	4.4
			Surface Mulch	2154.3	212.8	18.1	188.9	2.8	0.42	10.9
	Gila	Rough	Incorporated Mulch	1740.8	191.0	6.2	184.4	2.4	0.37	7.2
			No Mulch	1282.1	64.6	14.9	49.0	3.8	0.94	3.8
			Surface Mulch	1786.0	245.1	10.8	234.4	2.8	0.24	7.2
		Smooth	Incorporated Mulch	1723.4	48.3	10.1	38.2	2.8	0.73	3.8
			No Mulch	1633.1	67.4	21.5	44.8	4.2	1.18	5.0
			Surface Mulch	1928.4	91.0	34.0	56.2	4.9	1.19	8.8

***TRAE = *Triticum aestivum*, Common Wheat**

Cool Season Biomass

During the cool season, there was a statistically significant response in biomass (ANOVA; $F_{23, 47} = 2.7725$; P = 0.0081) with the interaction between elevation and soil (F = 10.18; 1 df; SE = 155; P = 0.0039). The most biomass was produced at the lower site on Arkose soil, yielding an average of 2763 kg ha^{-1} (Figure 3). Other treatments produced 1582 – 1876 kg ha^{-1} of biomass.

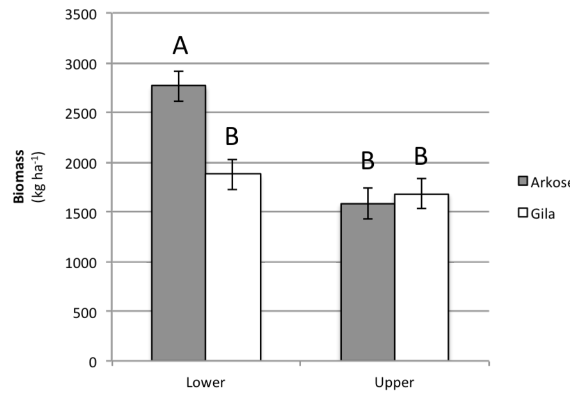


Figure 3. Least square means (±SE) for biomass associated with elevation X soil interaction in experiment during cool season 2010.

*Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

Cool Season Density

During the cool season, there were no statistically significant differences in density (ANOVA, $F_{23, 47} = 1.6433$, P = 0.1170). A noteworthy response in density occurred between elevation and mulch (Figure 4). No mulch

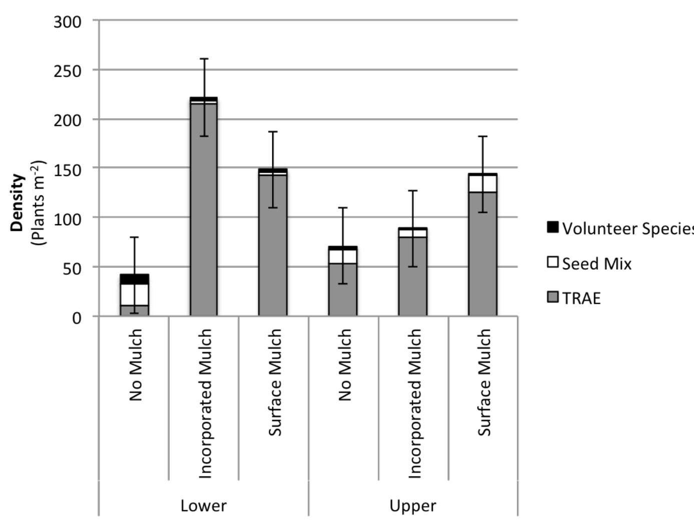


Figure 4. Density associated with elevation X mulch during cool season 2010. *TRAE = *Triticum aestivum*

treatments produced about a third of the density as compared to sections with mulch (No mulch: 56.4 plants m^{-2}, incorporated mulch: 155.1 plants m^{-2}, surface mulch: 146.1 plants m^{-2}).

Cool Season Seeded Density

There was a statistically significant response in seeded density (seed mix) (ANOVA; $F_{23, 47}$ = 2.2329; P = 0.0281; SE = 4.85) with soil (F = 4.54; 1 df; SE = 1.98; P = 0.0435) and mulch (surface (soil)) (F = 2.45; 8 df; SE = 4.85; P = 0.0424) during the cool season. Gila soil produced an average of 6.0 additional plants per square meter than Arkose soil (Figure 5). No mulch (smooth (Gila)) produced significantly more seeded plants per square meter than any other treatment. All no mulch treatments fell within the A or AB significant groups, in the top 50% of mulch treatments (Figure 6). The seed mix made up 4% of the density with

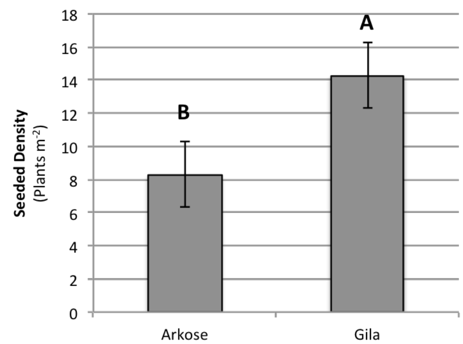


Figure 5. Least square means (±SE) for seeded density associated with soil in experiment from cool season 2010.
* Means followed by different letters indicate significant differences (*P* ≤ 0.05) based on Tukey's HSD test.

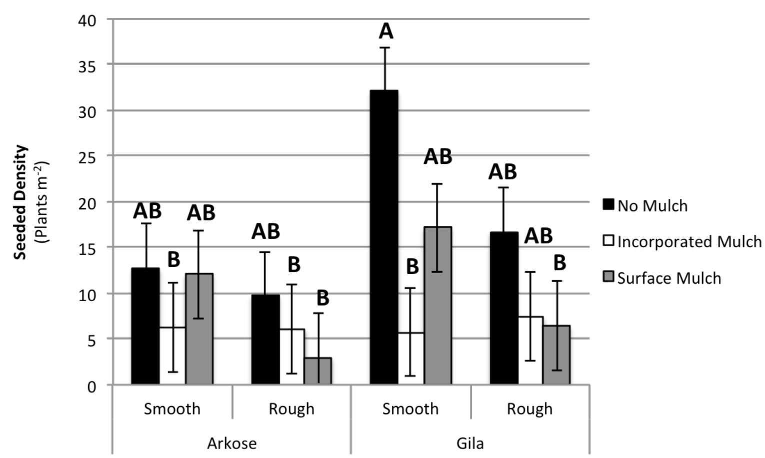


Figure 6. Least square means (±SE) for seeded density associated with mulch (surface (soil)) treatment in experiment during cool season 2010.

* Means followed by different letters indicate significant differences (*P* ≤ 0.05) based on Tukey's HSD test.

incorporated mulch, 31.6% of the density with no mulch, and 6.6% of the density with surface mulch.

Cool Season Species Diversity

Cool Season Species Richness

During the cool season, species richness was statistically significant different (ANOVA; $F_{23, 47} = 3.1563$; P = 0.0035) with elevation X soil, (F = 18.50; 1 df; P=0.0002) and elevation X mulch (F = 3.04; 8 df; P = 0.0164). The highest species richness was observed at the lower site on Arkose soil, producing an average of 4.1 species m^{-2} (Figure 7). The most number of species with elevation X mulch was observed at the lower site with no mulch, producing an average of 5.9 species m^{-2} (Figure 8).

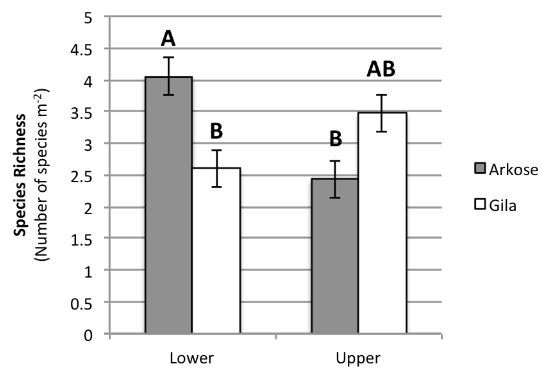


Figure 7. Least square means (±SE) for species richness associated with elevation X soil interaction in experiment during cool season 2010.

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

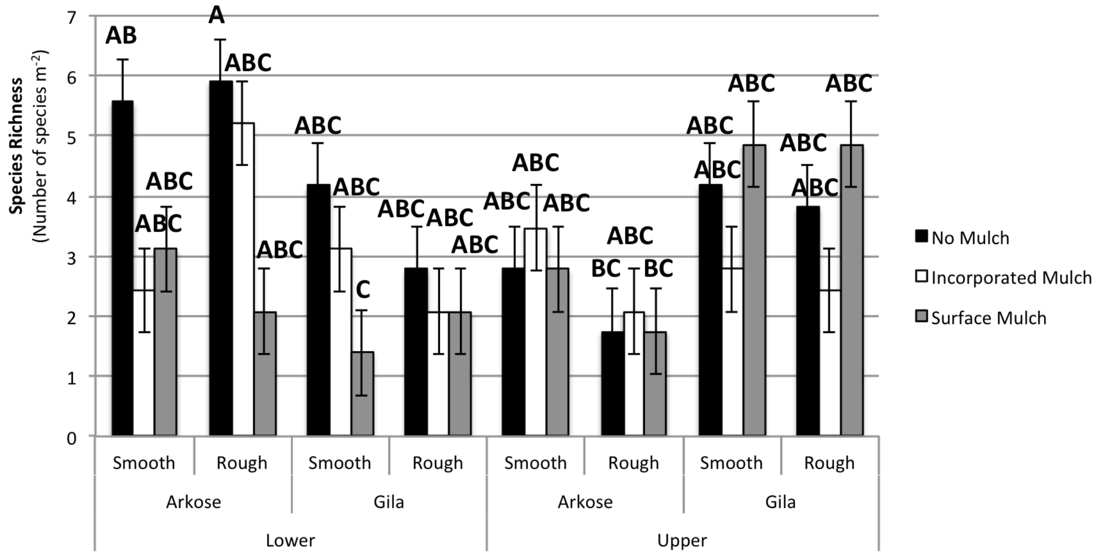


Figure 8. Least square means (±SE) for species richness associated with elevation X mulch (surface (soil)) interaction in experiment during cool season 2010.

* Means followed by different letters indicate significant differences (*P* ≤ 0.05) based on Tukey's HSD test.

Cool Season Shannon-Wiener Diversity Index

During the cool season, there were statistically significant differences in the Shannon-Wiener diversity index (H') (ANOVA; $F_{23, 47}$ = 3.4666; P = 0.0018) with the interactions of elevation X mulch (surface (soil)) (F = 2.608; 8 df; SE = 0.26; P = 0.0329). The most evenly proportioned number of species occurred at the lower site with no mulch (rough (Arkose)), producing an index of 1.60 (Figure 9). The least evenly proportioned number of species occurred at the lower site with surface mulch, producing an index of 0.06. This indicates that one species dominated the plant community with few other species present. All other treatments were not considered to be significantly different from one another.

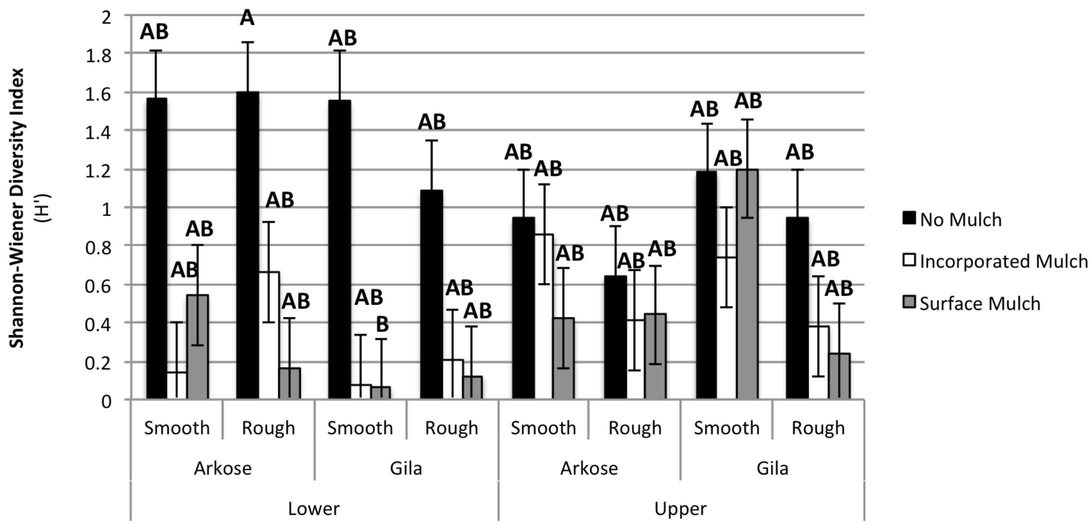


Figure 9. Least square means (±SE) for Shannon-Wiener Index associated with elevation X mulch (surface (soil)) treatment interaction in experiment from cool season 2010.

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

Cool Season Functional Group Composition

The majority of the plant community (all treatments) consisted of annual grasses (69.0%), followed by annual forbs (21.1%), perennial grasses (5.6%) and perennial forbs (4.3%) (Figure 10). Within the annual grasses, 99.9% of the grasses were wheat (*Triticum aestivum*), 64.5% of the annual forbs were seeded

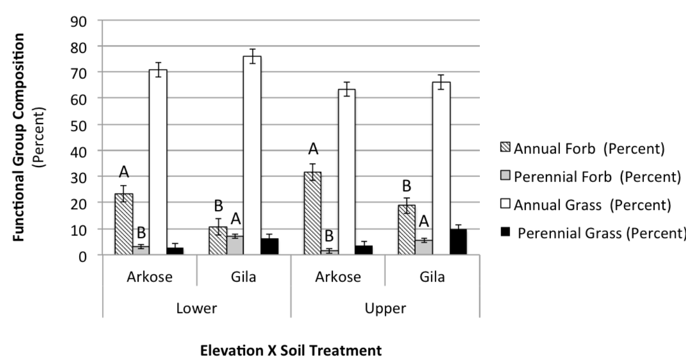


Figure 10. Least square means (±SE) for functional group composition associated with soil during cool season 2010.

* Means followed by different letters indicate significant differences ($P \leq 0.05$) based on Tukey's HSD test.

(*Eschscholzia californica* ssp. *mexicana),* 100% of the perennial grasses were seeded and 96.7% of the perennial forbs were seeded (*Baileya multiradiata*). All remaining vegetation was volunteer species. One volunteer species, *Chenopodium watsonii*, composed 31.8% of the annual forbs.

Table 19. MANOVA table associated with functional group composition during cool season 2010.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F	P
Elevation	1.1016	26.438	1.6973	0.2051
Soil	1.1016	26.438	2.4775	0.1251
Elevation X Soil	1.1016	26.438	0.0373	0.8699
Surface (Soil)	2.2031	26.438	1.3511	0.2776
Elevation X Surface (Soil)	2.2031	26.438	1.2126	0.3166
Mulch (Surface (Soil))	8.8126	26.438	5.9875	0.0002
Elevation X Mulch (Surface (Soil))	17.774	26.438	0.6525	0.7399

A MANOVA showed that the responses variables were statistically significantly interrelated by mulch (surface (soil)) ($F_{8.8126, 26.438}$ = 5.9875; P = 0.0002). Mulch significantly affected each functional group (Table 20) while annual forbs and perennial forbs were also significantly differed by soil type (Figure 10). Arkose soil was favored by annual forbs while Gila soil was favored by perennial forbs. Mulch affected the whole plant community; wheat (annual grass) composed the majority of the species in sections where mulch was present. Annual forbs composed a 27.5% or more of the plant community where mulch was not present; no mulch (smooth surface (Arkose soil)) made up a significantly greater amount of annual forbs than any other treatment (75.5%); of that treatment, *Chenopodium watsonii* composed an average of 40.3% of the total composition.

Table 20. Least square means (±SE) for functional group composition associated with mulch (surface (soil)) during cool season 2010.

Treatment			% Annual Grass	% Annual Forb	% Perennial Grass	% Perennial Forb
Soil	Surface	Mulch				
Arkose	Smooth	No Mulch	16.1 ± 13.2 B	75.5 ± 7.7 A	2.35 ± 4.5	6.08 ± 2.8 A B C
		Incorporated Mulch	83.0 ± 13.2 A B	14.4 ± 7.7 B C	0.85 ± 4.5	1.78 ± 2.8 C
		Surface Mulch	87.2 ± 13.2 A	12.4 ± 7.7 B C	0.22 ± 4.5	0.20 ± 2.8 C
	Rough	No Mulch	40.4 ± 13.2 A B	42.5 ± 7.7 A B	14.1 ± 4.5	3.08 ± 2.8 B C
		Incorporated Mulch	85.6 ± 13.2 A	12.7 ± 7.7 B C	0.00 ± 4.5	1.73 ± 2.8 C
		Surface Mulch	90.5 ± 13.2 A	7.20 ± 7.7 B C	1.58 ± 4.5	0.78 ± 2.8 C
Gila	Smooth	No Mulch	32.3 ± 13.2 A B	29.3 ± 7.7 B C	20.4 ± 4.5	15.0 ± 2.8 A
		Incorporated Mulch	86.5 ± 13.2 A	6.88 ± 7.7 B C	2.28 ± 4.5	4.38 ± 2.8 A B C
		Surface Mulch	74.0 ± 13.2 A B	16.0 ± 7.7 B C	7.00 ± 4.5	3.00 ± 2.8 B C
	Rough	No Mulch	42.1 ± 13.2 A B	27.5 ± 7.7 B C	16.9 ± 4.5	13.6 ± 2.8 A B
		Incorporated Mulch	91.2 ± 13.2 A	6.13 ± 7.7 B C	1.35 ± 4.5	1.33 ± 2.8 C
		Surface Mulch	96.5 ± 13.2 A	2.60 ± 7.7 C	0.53 ± 4.5	0.38 ± 2.8 C

* Means followed by different letters indicate significant differences (*P* ≤ 0.05) based on Tukey's HSD

Cool Season Basal Cover

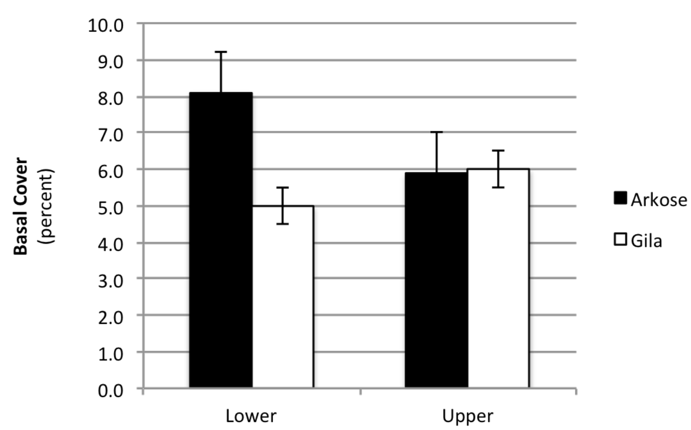


Figure 11. Basal cover associated with elevation X soil interaction during cool season 2010.

There were no statistically significant relationships with basal canopy to any of the explanatory variables (ANOVA; $F_{23, 47}$ = 1.1270; P = 0.3861). The largest basal cover occurred at the lower site on Arkose soil (8.1%), while the smallest basal cover was observed at the lower on Gila soil (5.0%) (Figure 11). Basal cover areas at the upper site were nearly identical (Arkose soil: 5.9%, Gila soil: 6.0%).

Warm Season MANOVA

A MANOVA was conducted using biomass, density, seeded density, species richness, Shannon-Wiener Index, and basal cover as the response variables and a blocked split-split design of the explanatory variables (Table 21). The response variables were statistically significantly interrelated by the interaction of elevation X soil ($F_{1.3033, 31.28}$ = 15.7171; P < 0.0001), and elevation X mulch (surface (soil)) ($F_{10.427, 31.28}$ = 2.55; P = 0.0209).

Table 21. MANOVA table for vegetation response variables during warm season 2010.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F	P
Elevation	1.3126	31.503	5.23	0.0210
Soil	1.3126	31.503	9.4374	0.0022
Elevation X Soil	1.3126	31.503	15.4526	<0.0001
Surface (Soil)	2.6523	31.503	0.2225	0.8562
Elevation X Surface (Soil)	2.6523	31.503	0.6874	0.548
Mulch (Surface (Soil))	10.501	31.503	1.5567	0.1633
Elevation X Mulch (Surface (Soil))	10.501	31.503	2.5563	0.0205

Warm Season Summary of Data

The warm season data has been summarized in Tables 22 and 23. Graphs denote significant differences and are explained within each vegetation attribute. Attributes are the means of the two replications of 9 quadrats collected in each section, where mulch (surface (soil (elevation))).

Table 22. Summary of warm season vegetation attributes. *CHWA = *Chenopodium watsonii*

Treatments				Biomass	Seeded Biomass	CHWA Biomass	Density	Seeded Density	CHWA Density
Elevation	Soil	Surface	Mulch	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(plants m^{-2})	(plants m^{-2})	(plants m^{-2})
Lower	Arkose	Rough	Incorporated Mulch	769.1	97.9	607.3	61.1	55.6	1.7
			No Mulch	1481.2	0.0	1481.2	16.0	0.0	15.3
			Surface Mulch	347.2	2.8	334.4	17.7	11.8	3.5
		Smooth	Incorporated Mulch	437.8	36.8	47.6	47.9	39.9	0.7
			No Mulch	1616.0	0.7	1579.5	36.8	20.8	12.8
			Surface Mulch	226.4	58.7	124.0	41.7	32.3	4.2
	Gila	Rough	Incorporated Mulch	55.2	47.9	0.0	84.4	81.9	0.0
			No Mulch	324.0	322.2	0.0	60.1	58.3	0.0
			Surface Mulch	19.4	18.1	0.0	22.2	17.7	0.0
		Smooth	Incorporated Mulch	31.6	30.6	0.0	82.6	80.6	0.0
			No Mulch	235.1	233.7	0.0	140.3	134.4	0.3
			Surface Mulch	59.0	59.0	0.0	31.6	31.6	0.0
Upper	Arkose	Rough	Incorporated Mulch	162.8	160.4	2.4	20.5	17.4	0.3
			No Mulch	79.5	79.5	0.0	18.4	18.4	0.0
			Surface Mulch	311.6	66.3	209.7	13.5	4.5	9.0
		Smooth	Incorporated Mulch	379.5	375.0	4.5	24.0	23.3	0.7
			No Mulch	174.3	79.5	94.8	38.2	33.7	2.8
			Surface Mulch	475.3	233.0	147.9	24.7	21.2	3.5
	Gila	Rough	Incorporated Mulch	286.8	463.2	0.0	75.0	69.8	0.0
			No Mulch	235.4	162.2	0.0	43.1	35.8	0.0
			Surface Mulch	465.0	76.7	0.0	57.6	46.2	0.0
		Smooth	Incorporated Mulch	293.7	278.5	2.1	59.4	54.2	0.3
			No Mulch	495.8	438.2	5.6	71.2	66.0	0.0
			Surface Mulch	605.6	523.3	0.0	107.6	99.0	0.0

Table 23. Summary of warm season vegetation attributes, continued.

Treatments				Species Richness	Shannon-Wiener	Canopy Cover	Basal Cover
Elevation	Soil	Surface	Mulch	(Number of species m^{-2})	Diversity Index (H')	(percent)	(percent)
Lower	Arkose	Rough	Incorporated Mulch	7.3	1.35	20.9	3.67
			No Mulch	1.4	0.20	39.7	2.56
			Surface Mulch	4.9	1.45	21.9	1.28
		Smooth	Incorporated Mulch	10.4	1.70	21.5	2.57
			No Mulch	4.5	1.15	44.2	2.94
			Surface Mulch	6.9	1.75	18.3	4.06
	Gila	Rough	Incorporated Mulch	5.9	1.40	12.7	3.44
			No Mulch	4.5	1.29	12.8	2.78
			Surface Mulch	3.5	0.65	4.8	1.50
		Smooth	Incorporated Mulch	5.9	1.38	16.9	7.06
			No Mulch	8.0	1.80	21.5	6.61
			Surface Mulch	3.5	1.30	2.8	1.00
Upper	Arkose	Rough	Incorporated Mulch	4.5	1.35	8.8	2.33
			No Mulch	1.7	0.70	5.3	1.33
			Surface Mulch	1.7	0.50	7.4	0.83
		Smooth	Incorporated Mulch	3.5	1.25	16.6	5.24
			No Mulch	5.9	1.50	11.2	2.72
			Surface Mulch	4.2	1.35	12.4	4.11
	Gila	Rough	Incorporated Mulch	9.7	1.50	23.2	6.98
			No Mulch	9.0	1.90	19.2	5.33
			Surface Mulch	10.1	1.90	16.1	4.81
		Smooth	Incorporated Mulch	8.3	1.60	15.3	6.11
			No Mulch	7.6	1.75	26.0	6.11
			Surface Mulch	12.2	1.95	25.0	9.22

Warm Season Biomass

During the warm season, there were statistically significant responses in biomass (ANOVA; $F_{23, 47} = 2.7298$; $P = 0.0089$) with the interactions between elevation X soil ($F = 18.15$; 1 df; $SE = 99.15$; $P = 0.0003$) and elevation X mulch (surface (soil)) ($F = 2.72$; 8 df; $SE= 99.15$; $P = 0.0275$). The most biomass produced was at the lower site on Arkose soil, which produced an average of 813 kg ha^{-1}; the least biomass produced was at the lower site on Gila soil, which produced an average of 121 kg ha^{-1} (Figure 12).

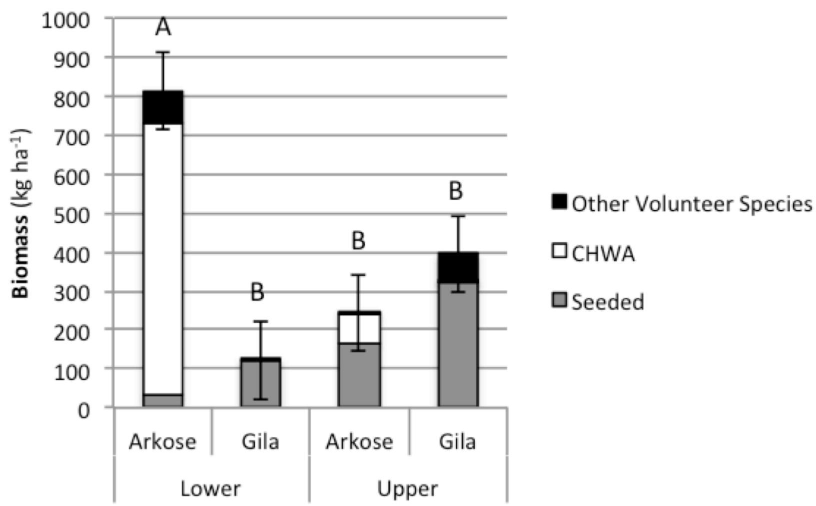


Figure 12. Least square means (±SE) for biomass associated with elevation X soil interaction during warm season 2010.
Columns labeled with different letters indicate statistically significant differences ($P \leq 0.05$) as indicated by Tukey HSD test.

Figure 12 displays the total biomass, biomass contributed by the seed mix (seeded biomass), and the biomass contributed by a volunteer species, *Chenopodium watsonii* (CHWA) in kilograms per hectare. There was a significant difference in CHWA biomass, which revealed the same differences as the total biomass. CHWA contributed to 85.5% of the biomass at the lower site on Arkose and nearly a third of the biomass at the upper site on Arkose. Where CHWA was less dominant, the seed mix contributed almost all of the biomass at the lower site on Gila, 68% of the biomass at the upper site on Arkose, and 82% of the biomass at the upper site on Gila.

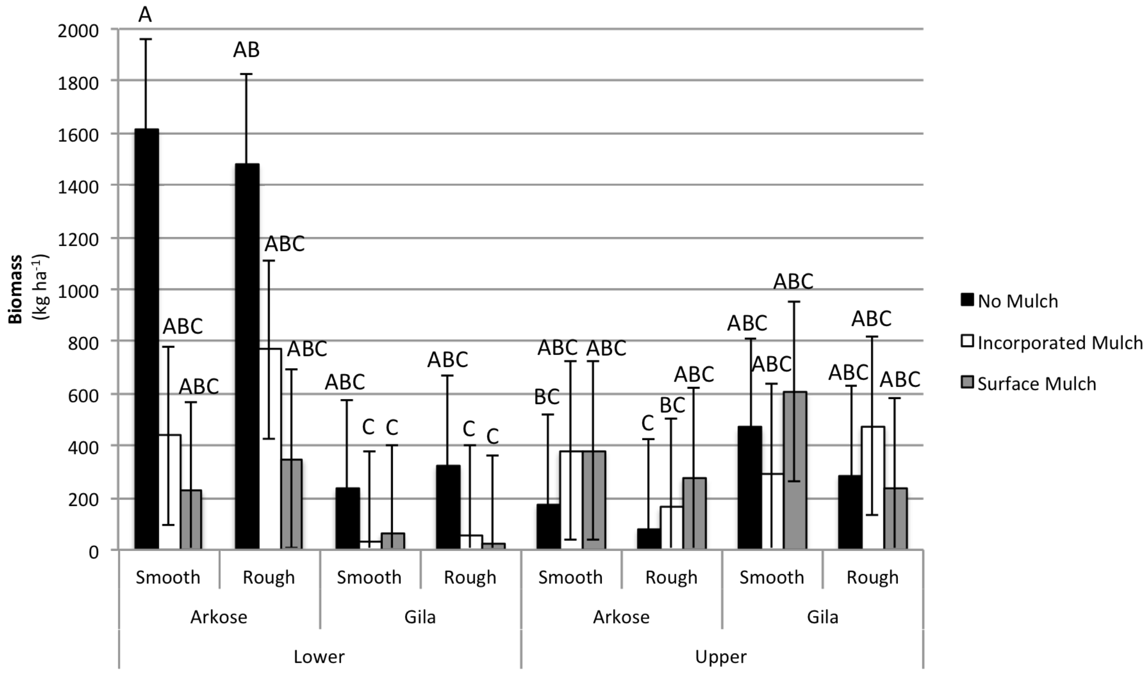


Figure 13. Least square means (±SE) for biomass associated with the interaction of elevation X mulch (surface (soil)) during warm season 2010.

Columns labeled with different letters indicate statistically significant differences (P ≤0.05) as indicated by Tukey's HSD test.

There was a statistically significant interaction in biomass with elevation and mulch (Figure 13). The most biomass was produced at the lower site with no mulch (smooth (Arkose)) with an average biomass of 1617 kg ha^{-1}. The least amount of biomass was observed at the lower site with surface mulch (rough (Gila)), which produced an average biomass of 19.5 kg ha^{-1}.

Warm Season Seeded Biomass

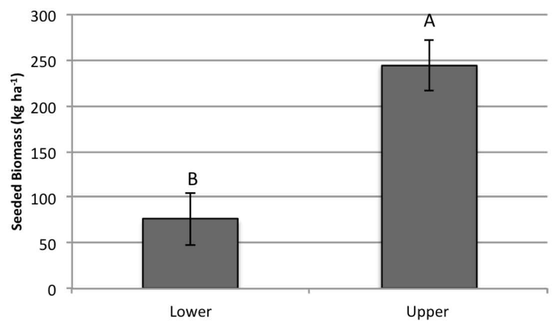


Figure 14. Least square means (±SE) for seeded biomass associated with elevation during warm season 2010.

Columns labeled with different letters indicate statistically significant differences (P ≤0.05) as indicated by Student's t-test.

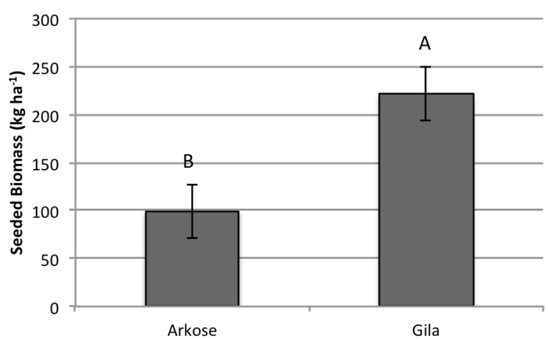


Figure 15. Least square means (±SE) for seeded biomass associated with soil during warm season 2010.

Columns labeled with different letters indicate statistically significant differences (P ≤0.05) as indicated by Student's t-test.

During the warm season, there were statistically significant responses in seeded biomass (ANOVA; $F_{23, 47}$ = 2.7372; P = 0.0087) with elevation (F=18.21; 1 df; SE = 28.01; P = 0.0003) and soil (F=9.48; 1 df; SE = 28.01; P = 0.0051). The most seeded biomass observed was at the upper site (Figure 14), producing an average of 245 kg ha^{-1}; Gila produced an average of 76 kg ha^{-1} (Figure 15). The most seeded biomass was observed in the Gila soil, producing an average of 221 kg ha^{-1} while the Arkose soil produced an average of 99 kg ha^{-1}.

Warm Season Density

During the warm season, there was a statistically significant response in density (ANOVA; $F_{23, 47}$= 1.5269; P = 0.1549) with soil (F=1.68; 1 df; SE = 7.5; P = 0.0010). The Gila soil produced an average 69.6 plants m^{-2}. The Arkose soil produced an average of 30.0 plants m^{-2} (Figure 16).

Warm Season Seeded Density

During the warm season, there was a statistically significant response in seeded density (ANOVA; $F_{23,47} = 1.6750$; $P = 0.1084$) with soil ($F = 16.41$; 1 df; SE = 7.22; $P = 0.0005$). The Gila soil produced an average of 64.6 seeded plants per square meter, contributing 92.8% of the total density on Gila (Figure 16). The Arkose soil produced an average of 23.2 seeded plants per square meter, 77.4% of the total density on Arkose. The seed mix composed the majority of the plants on the test plots, but did not contribute a large amount of biomass, indicating that the plants were relatively small.

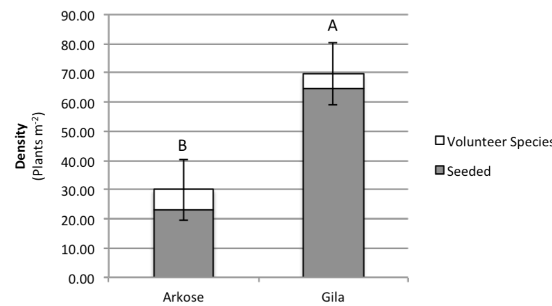


Figure 16. Least square means (± SE) for density associated with soil during warm season 2010.

Columns with different letters indicate significant differences ($P \leq 0.05$) based on Student's t-test.

Warm Season Species Diversity

Warm Season Species Richness

During the warm season, there was a statistically significant response in species richness (ANOVA; $F_{23, 47} = 5.4678$; $P < 0.0001$) with the surface treatment ($F=5.27$; 2 df; SE = 0.51; $P = 0.0127$), the interaction between elevation X soil ($F = 41.13$; 1 df; SE = 0.51; $P < 0.0001$) and elevation X mulch

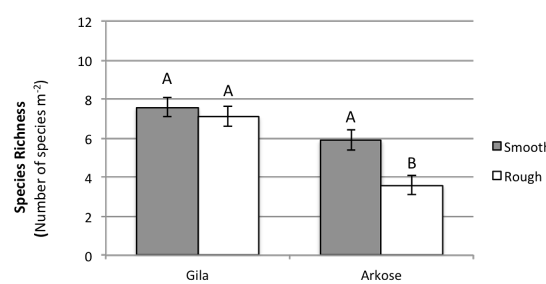


Figure 17. Least square means (± SE) for species richness associated with surface (soil) during warm season 2010.

Columns with different letters indicate significant differences ($P \leq 0.05$) based on Student's t-test.

(F = 3.50; 8 df; SE = 1.78; P = 0.0081). The soil surface significantly effected species richness (Figure 17). A smooth surface on Gila soil produced the most number of species with a mean of 7.6 species m^{-2}, while the least mean number of species occurred on a rough surface on Arkose with 3.6 species m^{-2}.

When assessing the elevation X soil interaction, there were significant variances at each treatment level. The upper site on Gila soil produced the most number of species, 9.5 species m^{-2} (Figure 18). The least number of species occurred at the upper site on Arkose soil, which produced 3.6 species m^{-2}.

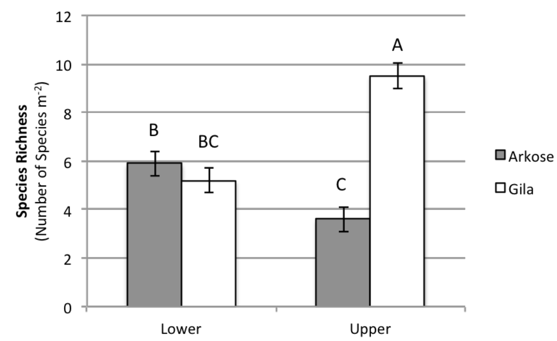


Figure 18. Least square means (± SE) for species richness associated with elevation X soil interaction during warm season 2010.

Columns with different letters indicate significant differences (P ≤ 0.05) based on Student's t-test.

The elevation X mulch (surface (soil)) interaction resulted in a range of 12.2 to 1.4 species m^{-2} (Figure 19). Following the elevation X soil interaction, the most number of species occurred at the upper site on Gila soil with a smooth surface and surface mulch. The least number of species occurred at the lower site with no mulch on Arkose soil with a rough surface.

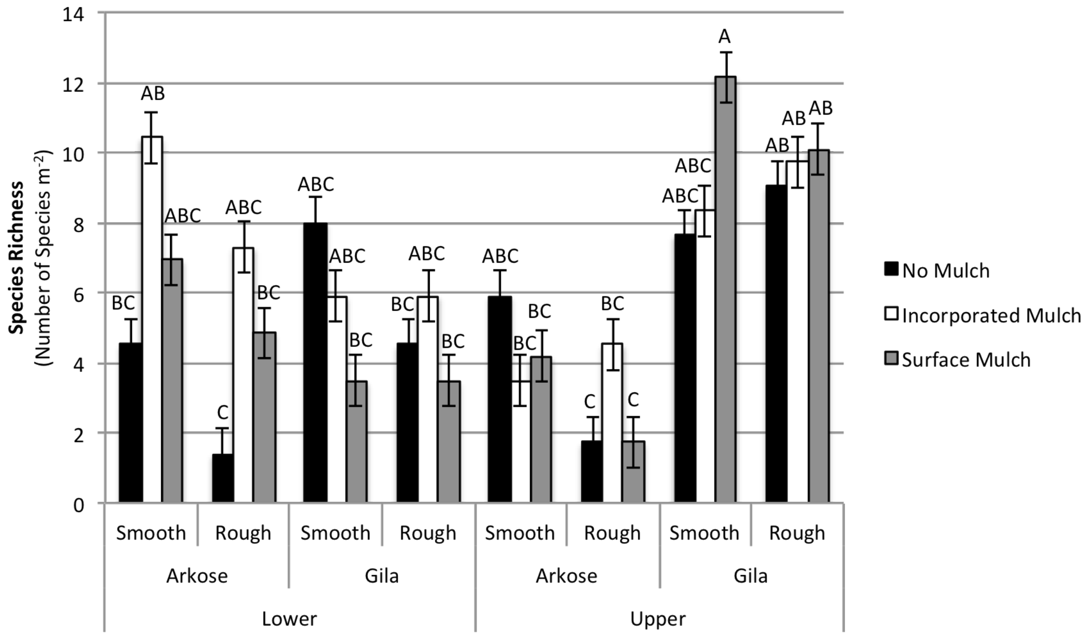


Figure 19. Least square means (±SE) for species richness associated with elevation X mulch (surface (soil)) interaction during warm season 2010.

Columns with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

Warm Season Shannon-Wiener Diversity Index

During the warm season, there were statistically significant responses in the Shannon-Wiener diversity index (H') (ANOVA; $F_{23, 47}$ = 3.5476; P = 0.0015) with the soil surface (F = 8.04; 2 df; SE = 0.10; P = 0.0021), the interaction of elevation X soil (F = 9.95; 1 df; SE = 0.10; P=0.0043) and elevation X mulch (F = 2.58; 8 df; SE = 0.34; P = 0.0344). The smooth surface on Gila soil produced an average index of 1.63, while

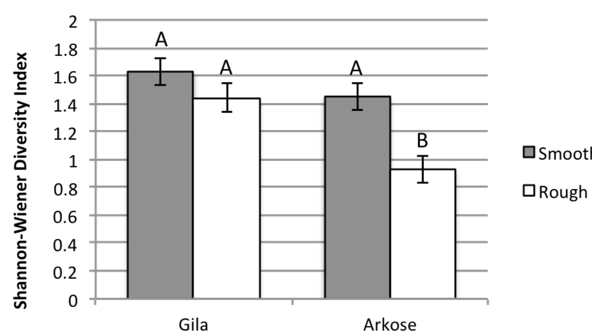


Figure 20. Least square means (±SE) for Shannon-Wiener Index associated with surface (soil) during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Student's t-test.

a rough surface produced an average index of 0.93 (Figure 20). The rough surface on Arkose soil produced significantly less evenly distributed species than the other surface (soil) treatments.

The most evenly proportioned number of species occurred at the upper site on the Gila soil with an average index of 1.77 (Figure 21); the species distributions are well proportioned. The remaining elevation X soil treatments were significantly less evenly proportioned.

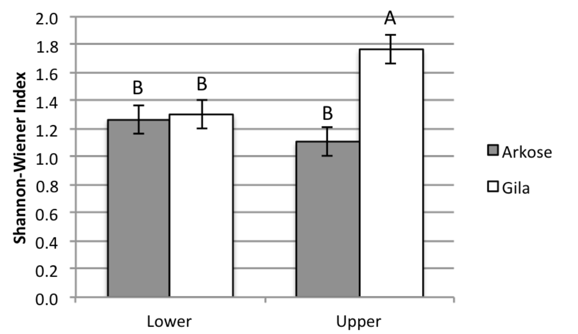


Figure 21. Least square means (±SE) for Shannon-Wiener Index associated with elevation X soil interaction during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Student's t-test.

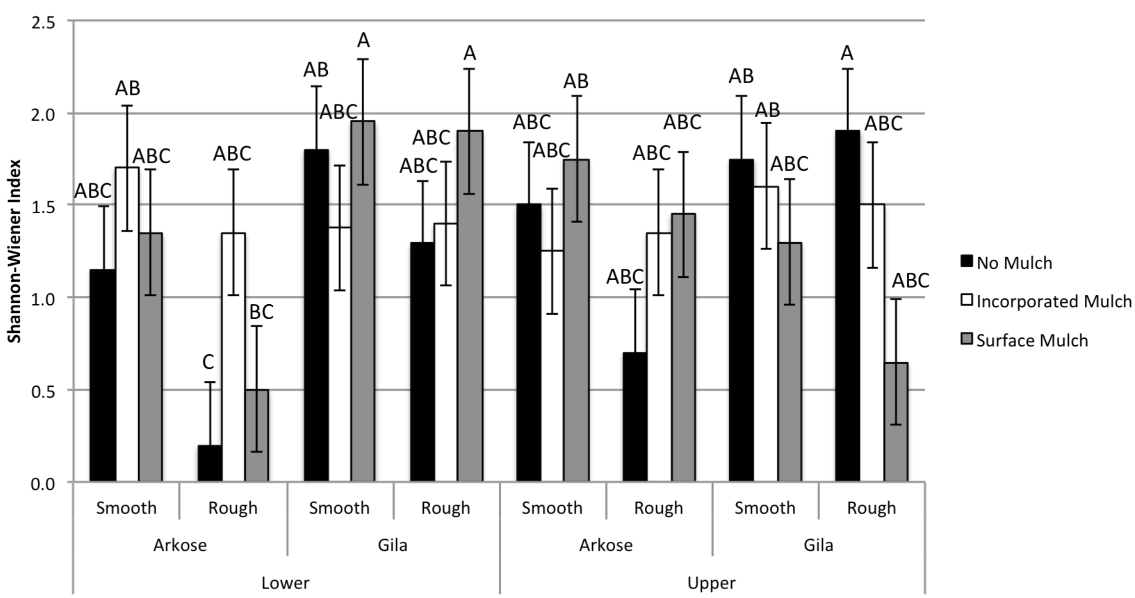


Figure 22. Least square means (±SE) for the Shannon-Wiener Index associated with elevation X mulch (surface (soil)) treatment interaction during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

When analyzing the elevation X mulch (surface (soil)) interaction, most treatments were well proportioned, with H' ranging from 1.80 to 0.65. The 3 most well proportioned species distribution occurred at the upper site on Gila soil (Figure 22). The highest Shannon-Wiener diversity index was on a smooth surface with surface mulch (H' = 1.95). The least well-proportioned treatment occurred at the lower site with no mulch (rough (Arkose)).

Warm Season Functional Group Composition

Functional group composition was evaluated during the warm season 2010, which was derived from density data (Table 24). Functional groups (all treatments) consisted of annual grasses (2.7%), annual forbs (20.6%), perennial grasses (70.9%), perennial forbs (3.2%), shrubs (2.1%) and vines (0.4%). Wheat (*Triticum aestivum*) composed 62.1% of the annual grasses, 41.1% of the annual forbs were seeded (*Eschscholzia californica* ssp*. mexicana),* 72.0% of the perennial forbs were seeded (*Baileya multiradiata*) and 97.0% of the perennial grasses were seeded. All remaining vegetation was volunteer species. One volunteer species, *Chenopodium watsonii*, composed 52.0% of the annual forbs.

Table 24. Least square means (±SE) for functional group composition associated with soil during the warm season 2010.

Soil	Mean Annual Grass (Percent) ± SE	Mean Annual Forb (Percent) ± SE	Mean Perennial Grass (Percent) ± SE	Mean Perennial Forb (Percent) ± SE	Mean Shrub (Percent) ± SE	Mean Vine (Percent) ± SE
Arkose	2.74 ± 1.17	33.9 ± 3.6 A	60.45 ± 4.5 B	2.58 ± 0.93	0.08 ± 2.94	0.25 ± 0.32
Gila	2.67 ± 1.17	7.38 ± 3.6 B	81.29 ± 4.5 A	3.86 ± 0.93	4.19 ± 2.94	0.63 ± 0.32

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

A MANOVA was conducted using the experimental treatments with functional group composition (Table 25). There was a significant affect between the functional groups and soil ($F_{1.6986,40.767}$ = 13.5959; P <0.0001), as well as the interaction between elevation X mulch (surface (soil)) ($F_{13.589, 40.767}$ = 2.5881; P = 0.0096). Using least square means, annual forbs and perennial grasses were significantly influenced by soil and the interaction of elevation X mulch (surface (soil)) (Figures 23 & 24). Annual grasses, perennial forbs, shrubs and vines were not significantly different among the test plot treatments.

Table 25. MANOVA table associated with functional group composition during the warm season 2010.

Source	Numerator Degrees of Freedom	Denominator Degrees of Freedom	F	P
Elevation	1.6986	40.767	0.3696	0.6590
Soil	1.6986	40.767	13.5959	<0.0001
Elevation X Soil	1.6986	40.767	0.3351	0.6821
Surface (Soil)	3.3972	40.767	0.7089	0.5689
Elevation X Surface (Soil)	3.3972	40.767	0.9281	0.4452
Mulch (Surface (Soil))	13.589	40.767	1.5272	0.1465
Elevation X Mulch (Surface (Soil))	13.589	40.767	2.5881	0.0096

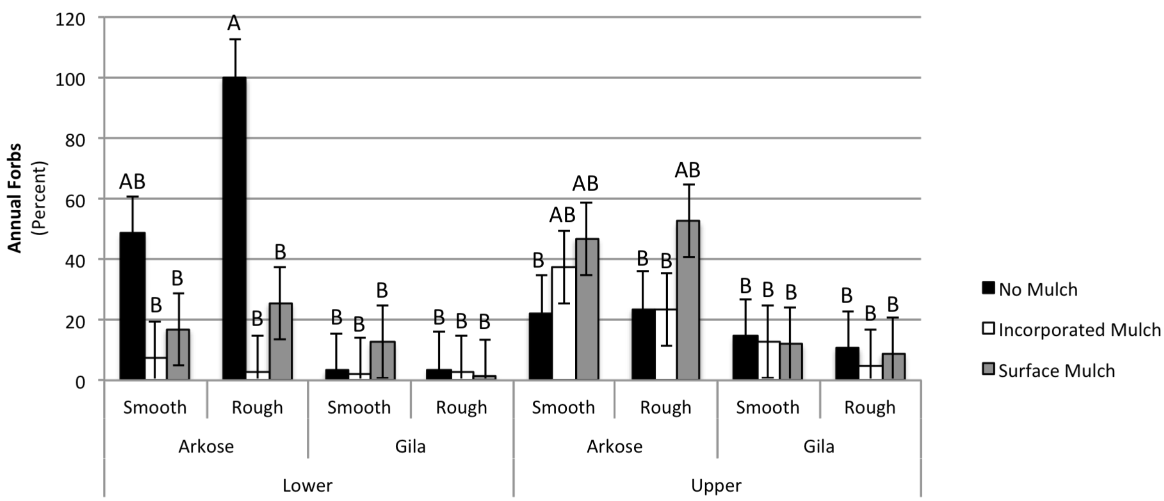


Figure 23. Least square means (±SE) for annual forb composition associated with elevation X mulch (surface (soil)) interaction during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

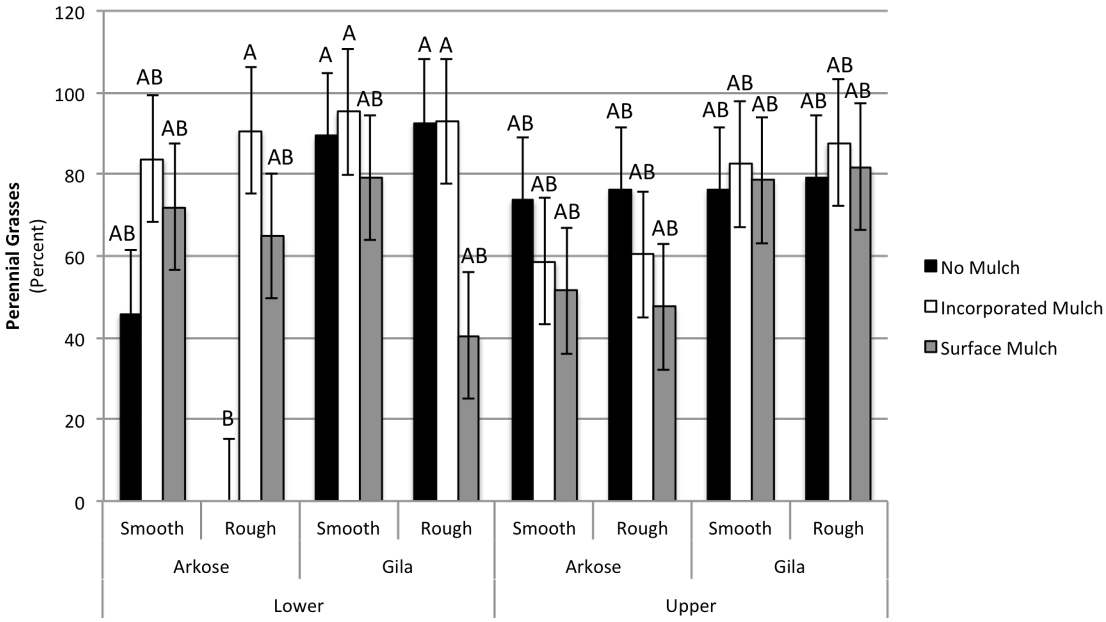


Figure 24. Least square means (±SE) for perennial grass composition associated with elevation X mulch (surface (soil)) interaction during the warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

Warm Season Canopy Cover

During the warm season, there were statistically significant responses in quadrat ocular estimates of plant canopy cover (ANOVA; $F_{23, 47}$ = 4.2644; P = 0.0004) with the interaction between elevation X soil (F = 45.39;

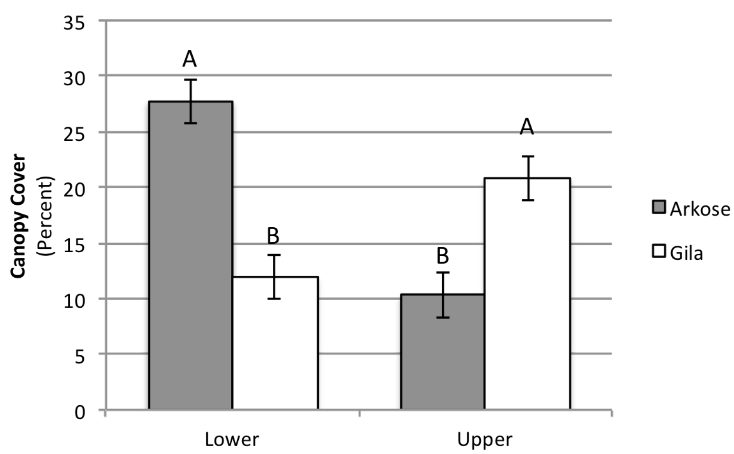


Figure 25. Least square means (±SE) for canopy cover associated with the interaction of elevation X soil during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

1 df; SE = 2.76; P <0.0001) and elevation X mulch (F = 3.06; df = 8; SE = 6.78; P = 0.0159). The highest mean canopy cover (27.8%) occurred at the lower site on the Arkose soil (Figure 25). The lowest mean canopy cover (10.3%) occurred at the upper site on Arkose soil.

The elevation X mulch (surface (soil)) interaction was significant (Figure 26). The highest canopy cover occurred at the lower site with no mulch on Arkose soil; the smooth surface produced slightly more canopy cover (44.2%) than the rough surface (39.8%). A quarter of the treatments produced a small amount of canopy cover, ranging from 2.9 – 11.2% cover (group C). The lower site with surface mulch (smooth (Gila)) had the lowest canopy cover.

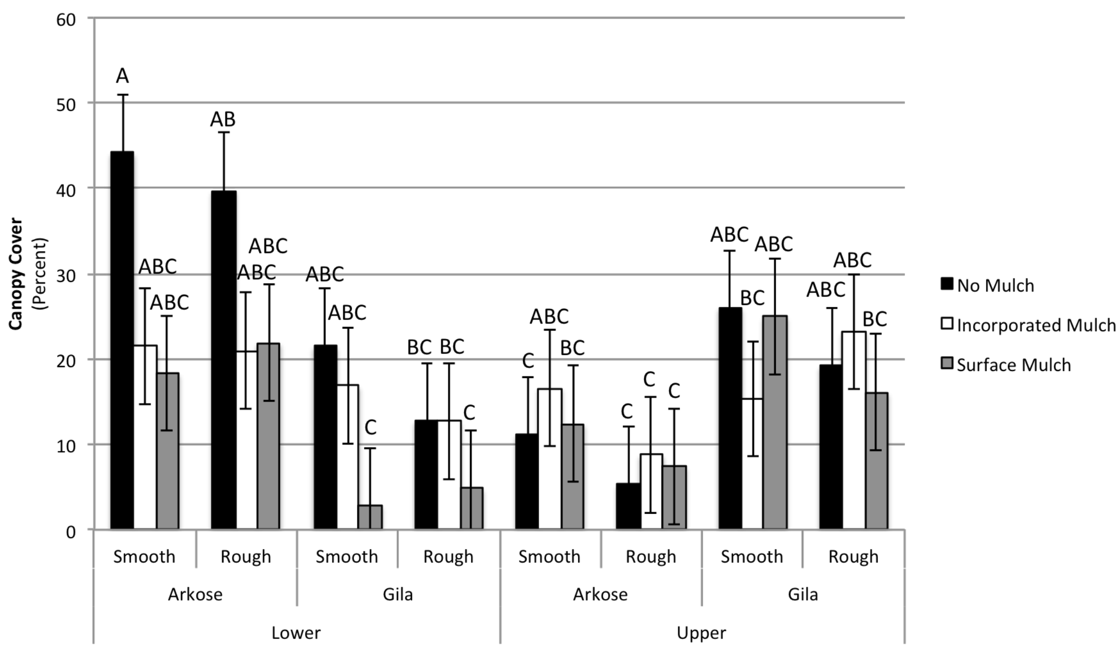


Figure 26. Least square means (±SE) for canopy cover associated with elevation X mulch (surface (soil)) interaction during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

Warm Season Basal Cover

During the warm season, there were statistically significant responses in quadrat ocular estimates of basal cover (ANOVA; $F_{23, 47}$ = 2.3886; P = 0.0194) with soil surface (F=4.30; 2 df; SE = 0.60; P = 0.0253) and the interaction between elevation X soil (F = 5.47; 1 df; SE = 0.60; P = 0.0280). A smooth surface on Gila soil produced the largest mean basal cover (6.0%) while a rough surface on Arkose produced the smallest mean basal cover (2.0%) (Figure 27). More basal cover was produced on the Gila soil than the Arkose soil, with differing surface roughnesses.

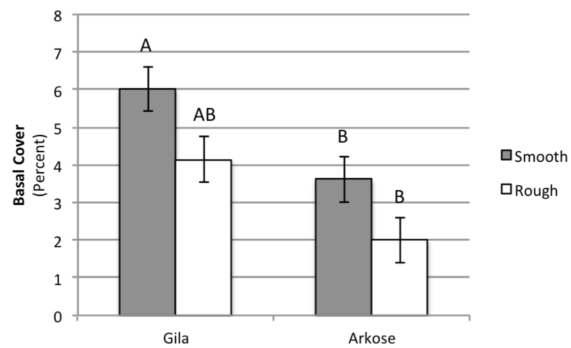


Figure 27. Least square means (±SE) for basal cover associated with surface (soil) during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Student's t-test.

The largest mean basal cover was observed at the upper site on the Gila soil (6.44%), significantly higher than all other elevation X soil treatments (Figure 28). The smallest mean basal cover was observed at the upper site on the Arkose soil (2.75%).

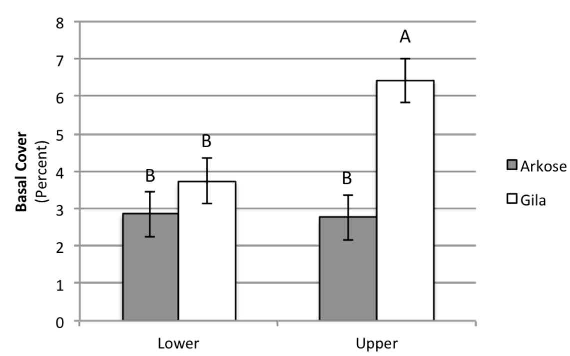


Figure 28. Least square means (±SE) for basal cover associated with elevation X soil interaction during warm season 2010.

Columns labeled with different letters indicate significant differences (P ≤ 0.05) based on Student's t-test.

Seed Mix Evaluation

Seeded density was significantly affected by soil type and favored the Gila soil (64.4 plants m^{-2}) over Arkose soil (23.2 plants m^{-2}) during the warm season. The seed mix composed the majority of the total density (77% on Arkose soil, 93% on Gila soil). When evaluating the individual species of the seed mix by density, soil had a significant influence on *Baileya multiradiata* (BAMU), *Bouteloua curtipendula* (BOCU), *Digitaria californica* (DICA), and *Hilaria belangeri* (HIBE), elevation X soil had a significant influence on *Bouteloua gracilis* (BOGR), and elevation X mulch had a significant influence on *Eragrostis intermedia* (ERIN) and *Leptochloa dubia* (LEDU). The broadcasted seed density was 21 seeds m^{-2} for BAMU and 74 seeds m^{-2} for each perennial grass (BOCU, DICA, ERIN, HIBE and LEDU). All species preferred the Gila soil (Table 26).

Table 26. Seed mix density in relation to soil during warm season 2010.

Soil	BAMU (Plants m^{-2})	BOCU (Plants m^{-2})	BOGR (Plants m^{-2})	DICA (Plants m^{-2})	ERIN (Plants m^{-2})	HIBE (Plants m^{-2})	LEDU (Plants m^{-2})
Arkose	0.4	15.1	1.0	0.5	0.1	2.3	1.6
Gila	2.7	31.3	6.9	1.4	1.5	6.4	10.4

BAMU: *Baileya multiradiata*, BOCU: *Bouteloua curtipendula*, BOGR: *Bouteloua gracilis,* DICA: *Digitaria californica*, ERIN: *Eragrostis intermedia*, HIBE: *Hilaria belangeri*, LEDU: *Leptochloa dubia*

Each species was evaluated to determine its establishment rate and rank within the seed mix. An average of 7.4% BAMU seeds established and was the sixth most abundant species in the seed mix during the warm season. BOCU was the most abundant species within the seed mix and established an average of 20% of BOCU seed on Arkose soil and 42% on Gila soil. BOGR was the fourth most abundant species in the seed mix. It was observed at its highest density at the lower site on Gila soil (11.5 plants m^{-2}), while the lowest density was observed at the upper site on Arkose soil (0.3 plants m^{-2}). On average, 1.4% of the DICA seeds established and was the seventh most abundant species in the seed mix. ERIN was the least abundant perennial grass of the seed as an average of 1.1% of the ERIN seeds established. ERIN preferred the upper site with surface mulch to all other treatments (2.7 plants m^{-2}, other treatments: 0.4 plants m^{-2}). HIBE had the highest density on Gila soil (6.4 plants m^{-2}) with 4.3% of the seed mix established. LEDU was the second most abundant species in the seed mix and preferred the Gila soil (10.4 plants m^{-2}). LEDU preferred the lower site with no mulch overall other treatments (12.8 plants m^{-2}, other treatments: 4.7 plants m^{-2}). No individuals of the Fairy Duster shrub, *Calliandra eriophylla* (CAER) were observed on the test plots during either growing season of 2010. CAER was the least abundant species in the seed mix.

Volunteer Species

During the cool season, 13 species were observed within quadrats observed in the test plots. During the warm season, 63 species were observed within the test plots, for a total of 76 volunteer species observed during the 2010 growing seasons. Wheat (*Triticum aestivum*) was not counted as a volunteer species. A list of volunteer species can be found in APPENDIX A.

Hydrological Attributes

Treatment Influence on Soil Movement

The least square means model resulted in a significant interaction between elevation X soil on the response of soil movement, as measured by nails ($F = 22.6222$; 1 df; $P < 0.0001$). Soil movement was indicated by the amount of soil accumulation above or lost from below nails whose heads were level with the soil surface at the beginning of the study at a single point.

Table 27. Least square means (±SE) for soil movement associated with the interaction of elevation X soil post-monsoon season 2010.

Treatment		Soil Movement (cm) ± SE
Elevation	Soil	
Lower	Arkose	0.96 ± 0.09 A B
	Gila	0.71 ± 0.09 B C
Upper	Arkose	0.49 ± 0.09 C
	Gila	1.11 ± 0.09 A

Means followed by different letters indicate significant differences (P ≤ 0.05) based on Tukey's HSD test.

When soil was lost, the response was assigned a negative value, or a positive value for soil accumulation. The absolute value of the response was used for analysis of soil movement. The least amount of soil movement occurred at the upper site on Arkose soil and the most amount of soil movement occurred at the upper site on Gila soil (Table 27).

Cover Influence on Soil Movement

A MANOVA was conducted to evaluate the effects of the test plot treatments on cover, as performed by point-intercept monitoring. There was a significant affect on cover by the interaction of elevation X soil ($F_{4, 51.389}$ = 21.2673; P <0.0001) and elevation X mulch ($F_{17.13, 51.389}$ = 2.7044; P = 0.0031). A least square means analysis was performed to evaluate which types of cover (bare ground, rock, mulch, canopy and basal cover) significantly influenced soil movement. Rock cover was the only type of cover that significantly influenced soil movement for the erosion nail measurements (F = 6.6008; 1 df; P = 0.0138).

Soil Movement as a Function of Cover

Bare ground, rock cover and mulch cover were plotted against soil movement at a single point to determine how soil movement responds as a function of cover (Figure 29). When soil movement was plotted against bare ground, soil movement increased as the amount of bare ground increased (0.0022 cm percent bare ground^{-1}). When soil movement was plotted against rock cover, soil movement decreased as the amount of rock cover increased (-0.1588 cm percent rock cover^{-1}). When soil movement was plotted against mulch cover, soil movement decreased as the amount of mulch cover increased (0.0002 cm percent mulch cover^{-1}).

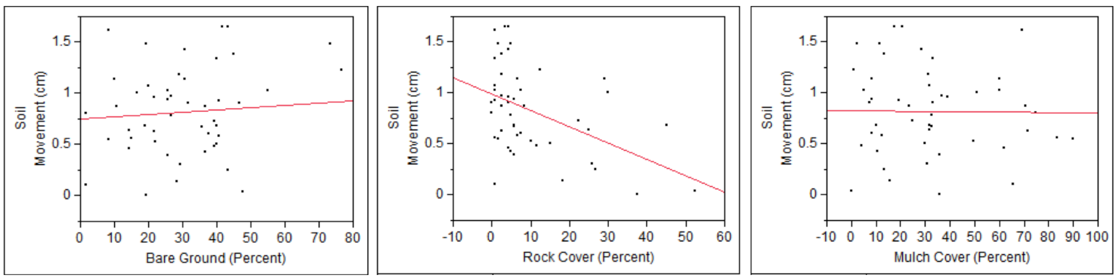


Figure 29. Soil movement response to bare ground, rock cover and mulch cover post-monsoon season 2010.

DISCUSSION

Climate variables were considerably different between the lower and the upper site. The upper site is 244 m (800 ft) higher than the lower site and less than 4.8 km (3 mi) apart, yet the upper site received 11.9 cm (4.7 in) more precipitation than the lower site. The cool season precipitation varied more than the warm season precipitation, as the upper site received 8.7 cm (3.4 in) more precipitation than the lower site in the cool season as opposed to 2.1 cm (0.8 in) difference during the warm season. It appears that elevation had a large effect on precipitation. Although snow depth was not measured, the upper site seemed to receive considerably more snow than the lower site by visual observation. During the warm season, another study site nearby (Walnut Gulch Experimental Watershed near Tombstone, Arizona) showed 2.5 cm (1 in) to 5.0 cm (2 in) variation in a 3 km (1.9 mi) distance within a single precipitation event (Renard & Simanton, 1975). It is not unusual for precipitation to vary significantly within a short distance in southeast Arizona and effect revegetation success.

Based on climate records, the 2010-year received an average amount of precipitation at the lower site (37.6 cm or 14.8 in) and above average at the upper site (49.5 cm or 19.5 in). Although a comparison of records indicate that the lower site received an average amount of precipitation, I believe the vegetation reflected an above-average amount of precipitation. Above-average precipitation is preferred for establishing vegetation in arid lands (Dernet *et al*, 2008), as water is usually the most limiting factor in arid lands (Stoddart, 1946). Neither average monthly temperature extremes were outside of the average temperatures at the Rosemont site. The lowest temperature occurred on 23 February 2010 at -4.2°C (24.4°F), which may have injured vegetation (Monteiro Brando & Durigan, 2004). However, the majority of the seed mix thrives during the warm season and had not germinated at this point in time. Temperature during the 2010 growing seasons was not expected to have significant effects on vegetation.

In this arid climate, it was recommended to seed prior to the warm season (Vallentine, 1980; Rennick & Munshower, 1985; Marietta & Britton, 1989), but the construction schedule prevented this from occurring. In this particular year, this worked in our favor as seeds were placed at the end of December and germination occurred by the end of January, which left the seeds exposed to the environment for a short amount of time. Unexpectedly some warm season species began to grow before the cool season monitoring, which began in May. Seeding in December as opposed to June or July may have given warm season species an advantage, as they were able to grow and increase in biomass as opposed to seeding prior to the monsoon rains in early July (Moghaddam, 1976). Some studies have shown that seeding in the cool season is advantageous as it allows warm season species to begin growth earlier and grow larger than seeding prior to the warm season (Jordan, 1981; Monsen & Stevens, 2004). It appears that cool season seeding was advantageous in this study. This may be worthwhile to test to determine the best time for seeding at the Rosemont site.

Soil moisture is a key driving force for revegetation in an arid climate and may be influenced by elevation and soil properties including soil texture (Stoddart, 1946; Davis, 2004). The Gila soil moisture at both sites was similar (31% Volumetric Water Content (VWC)), but the Arkose soil moisture content upper site held approximately one-third of the soil moisture of other soils (9.2% VWC). The Arkose soil at the upper site contained much larger particle fragments because during the construction of this site, the soil was cut from parent materials and only mixed with small amounts of developed soils from the original soil surface. The large particle sizes potentially allowed water to infiltrate deeper into the soil, leaving little soil moisture in at least the top 7.6 cm (3 in), the depth in which the soil moisture was measured. The difference in soil moisture in the Arkose soil at the upper site was reflected in the vegetation growth. Soil was the only significant influence on plant density. On average, the Arkose soil supported 39.6 fewer plants per square meter than Gila soil, which decreased the number of species found (-2.6 species m^{-2}). With fewer species, the evenness of species also decreased significantly decreased (H' = 0.93). Seeded density, species from the seed mix, was significantly affected by soil type, also favoring the Gila soil (64.4 plants m^{-2}) over Arkose soil (23.2 plants m^{-2}). For future studies, a soil moisture data logger would be ideal to track soil moisture availability. It is not recommended that large rock fragments with few fine particle soil be used for revegetation, as it appeared to not be able to retain sufficient moisture.

Direct hauling soil and soil depth influences viable seeds and microorganisms that can contribute to revegetation (Rennick & Munshower, 1985). Soils that are located deep in the soil profile do not contain seeds or contribute to species diversity. By using soils that are located near the current soil surface, or mixing soil from different depths of the soil profile, species diversity should be promoted. The second and third lowest species richness and Shannon-Wiener diversity index occurred at the upper site Arkose with a rough surface and no mulch or surface mulch (no mulch: 1.74 species m^{-2}, H' = 0.70, surface mulch: 1.74 species m^{-2}, H' = 0.50). This soil was located in particularly coarse-fragmented parent materials with very little soil formation, low amounts of soil moisture (9.2%), soil microbes (0.17 spores g^{-1}) and organic matter (0.56%). Under poor soil conditions, seedbed treatments and mulch did not promote species diversity. Direct hauling soil and the original soil depth used can influence revegetation success.

The heavy disturbance implicit in reconstructed soils can further limit nutrients from their already low levels (Shuman *et* al, 1991). Due to the close relationship of nutrients, organic matter and mycorrhizae, it is difficult to discuss one resource apart from another. From the initial- to the post-treatment soil analyses (post-warm season), organic matter and nitrates decreased (-1.62%, -1.53 ppm) while phosphates, potassium and VAM increased (0.20 ppm, 33 ppm, 0.36 spores g^{-1}). During the construction of the test plots and treatment installations, all soil was disturbed and mixed, many soil aggregates were broken apart and organic matter was exposed. Bacteria and fungi likely decomposed organic matter, which leads to increased microbial populations. Microbes also mobilize phosphorous and release plant available forms of nutrients. In a study by Mummey *et al* (2002), similar trends were observed where plants would deplete nitrogen and plant litter decomposed while bacteria, fungal and total microbial biomass increased. Mummey *et al* (2002) inferred that this was indicative of poor root exploration by vegetation. The establishment of vegetation parallels to the decreased nitrates and phosphates, which implies the decline is due to plant uptake of nutrients.

Reconstructed soils often begin with low levels of microbial activity (Norland, 2000). The post treatment average VAM spore count in disturbed soils was 10.1% of the spore count of the average of the reference sites (1.11 spores g^{-1}; references: 10.9 spores g^{-1}). The Arkose soil at the upper site contained the least amount of vegetation and VAM (23.2 plants m^{-2}, 0.17 spores g^{-1}; other treatments: 58.6 plants m^{-2}, 1.42 spores g^{-1}). VAM were likely harmed and populations decreased during the construction, but the small numbers of VAM that survived increased by an average of 0.36 spores g^{-1} with the establishment of vegetation on all soils. Rangelands display a large amount of diversity in microbial activity. Microbial activity may be high under shrubs and there may be almost no activity in the bare spaces between plants (Call &

Roundy, 1991; Mummey *et al*, 2002). No soil samples were collected under shrubs or grasses, so actual VAM counts under plants may be much greater than the area between vegetation that were observed in the warm season 2010 collection. Soil properties vary with season due to organic matter input when grasses or leaves die, temperature and moisture fluctuate and over long periods of time (Mulumba & Lal, 2008). Long-term monitoring will provide a better understanding of the microbial health of the soil.

Mulch had a significant influence on soil pH. Sections with no mulch were the most basic (pH 8.27), incorporated mulch was less basic (pH 8.14) and surface mulch was least basic (pH 8.00). Adding wheat straw mulch into or onto the soil appeared to neutralize the basic soils. Shen & Shen (2001) confirm that wheat straw is acidic, with a pH of 6.3. Alkaline soils can be treated with acid or acidic materials to neutralize soil (Tiedemann & Lopez, 2004). In this case, mulch treatments improved soil pH, which may have been beneficial for nutrient availability for vegetation.

During seedbed preparation, a rough surface was expected to create more microsites, or safe sites, to provide favorable conditions for seed germination and establishment for multiple species with slightly different germination site preferences (Table 28). The actual surface roughness of each treatment was not captured, despite attempts using a pin meter. The measurements were time consuming and could not be completed before rainfall had reduced the soil roughness (e.g. Guhza, 2004). Dragging a metal screen was used to create a smooth surface, but the final surface roughness was dependent on the soil texture. This resulted in a significantly rougher surface on the Arkose at the upper site (H_{rms} = 4.66) because of the amount of rocks in that part of the site as compared to all other soils (H_{rms} = 1.81). Methods to create a smooth surface appeared to be an ineffective method on large particles and more effective on smaller particles like the Gila soil.

Table 28. Surface treatment advantages and disadvantages.

Treatment	Advantage	Disadvantage
Rough Surface	Costs less than smooth surface	Increased potential for local erosion
	Decrease erosion by reducing the velocity of flowing water	Small seeds may get buried too deep
	More available microsites	-
Smooth Surface	Less local erosion may bury small seeds at favorable depth	Additional cost for added effort
	Provides good soil-to-seed contact	Increased potential for compaction
	Significantly favorable species diversity (species richness, Shannon-Wiener index)	Increased potential for erosion
	Significantly favorable basal cover	Decreased soil moisture

The smooth surface proved favorable for species richness, Shannon-Wiener diversity index, and basal cover as compared to the rough surface treatment. Though smooth surfaces were not statistically different than rough surfaces, means were higher for all vegetation attributes during the warm season. There was no clear trend in soil moisture in relation to the surface treatments. A rough surface was constructed of ridges and troughs from the ripping process. Erosion from wind and water on the ridges moved soil particles into the troughs. This may have buried more of the small grass seeds at a less ideal depth than the smooth surface, causing a loss in potential vegetation (i.e. Call & Roundy, 1991). Additional soil topography measurements may confirm the amount of erosion that occurred on the surface treatments over time. Although a smooth surface appeared to be favored, only species diversity and basal cover were significantly better than a rough surface. This does not warrant the additional costs and efforts that are necessary to install the smooth surface (Table 27). Additional traffic also increases the potential for compacted layers. During periods with less precipitation, surface treatment differences may have been more strongly expressed. In other studies a rough surface provided more microsites for seeds, as well as less evaporation, in comparison to a smooth surface. For these reasons, a rough surface is recommended over a smooth surface.

Mulch is commonly used to ameliorate harsh environmental conditions to promote vegetation establishment. Other studies have shown that mulch increases soil moisture, provides nutrients, increases organic matter, reduces temperature extremes and provides shade to seedlings (Norland, 2000; Mulumba & Lal, 2008; Biederman & Whisenant, 2009). In the current study, mulch did not make a significant difference in soil moisture, nutrients, or organic matter. However, surface mulch treatments contributed to reduced temperature extremes, less variable soil temperatures and reduced the light availability at the soil surface. In other studies, the benefits of mulch are best seen during droughts (Biederman & Whisenant, 2009). Mulching benefits could not be expected to be most strongly expressed due to the already favorable conditions.

A nurse crop of wheat, *Triticum aestivum*, was inadvertently grown as a result of the straw mulch. Average and above-average precipitation in 2010 provided adequate moisture for the wheat crop to establish. The source of the wheat seeds were within the wheat straw mulch, which explains why wheat was more abundant in mulched sections. Wheat seeds are relatively large as compared to native seeds, and appear to establish better when buried (incorporated mulch) in comparison to applied on the soil surface (surface mulch). Mulch was incorporated into the top 20.3 cm (8 in) of soil or less, and provided a more ideal burying depth and may be more likely to establish in future reclamation efforts. When mulch was applied on the soil surface it is likely that many wheat seeds did not have good seed-to-soil contact and may have been suspended above the soil surface. Light may have been limited under surface mulch and provided less ideal conditions for nurse crop establishment. Wheat was still observed in sections where no mulch was applied, most likely due to wind dispersal of mulch and seeds.

During the cool season, wheat appeared to out-compete the seeded cool season species. Density and species composition data show that wheat composed the majority of the vegetation (87.6% of all vegetation; perennial grasses and forbs: 12.4%). The bulk of the seed mix, or seeded density, was considered to be warm season species so we did not expect a high density of seeded species to have germinated during the cool season. Where wheat was present, it was the dominant species. Where no mulch was applied, an average of 1.1 additional species m^{-2} occurred with a more even distribution of species (no mulch: 3.9 species m^{-2}, $H' = 1.2$; incorporated mulch: 3.0 species m^{-2}, $H' = 0.4$; surface mulch: 2.6 species m^{-2}, $H' = 0.4$). When looking at wheat density and seeded density, as wheat density decreased, seeded species density generally increased. Low densities of the seeded cool season perennial grass, *Elymus elymoides* (ELEL), and the seeded annual forb, *Eschscholzia californica* ssp*. Mexicana* (ESCA), were observed in incorporated or surface mulch treatments. ELEL and ESCA were more abundant in sections with no mulch (ELEL: 1.0 plants m^{-2}, ESCA: 8.9 plants m^{-2}), followed by surface mulch (ELEL: 0.7 plants m^{-2}, ESCA: 7.2 plants m^{-2}) and were observed least in sections with incorporated mulch (ELEL: 0.5 plants m^{-2}, ESCA: 4.4 plants m^{-2}). Wheat followed the opposite trend, being most abundant in incorporated mulch, followed by surface mulch and the least abundant with no mulch. The benefits of nurse crops may be outweighed by competition in arid lands and during droughts, causing death or growth hindrance to the seeded species due to a lack of soil moisture and light (Stoddart, 1946). Though the seeded cool season species may have suffered from competition, the benefits of the nurse crop during the warm season outweighed the disadvantages.

The nurse crop provided erosion control and weed control (Stoddart 1946), which benefitted the seeded warm season species. While the wheat was alive, the wheat protected bare ground from precipitation impact and its roots held together soil to prevent erosion. After the wheat died in late May, stubble mulch remained and continued to provide erosion control, while its roots anchored the stubble mulch in place. It is likely that without the nurse crop, Watson's Goosefoot (*Chenopodium watsonii)*, a native annual forb, would have been more abundant in mulched sections in Arkose soil. The seeded warm season species were not able to establish well when Watson's Goosefoot was present, but were able to establish well with the nurse crop. The effect of the nurse crop may become more apparent in the future as benefits may take time to be expressed. Though a wheat nurse crop is not likely to establish often in an arid climate, when possible, it is recommended to control erosion and control weedy plants.

No mulch was necessary to establish vegetation during 2010. Soil moisture conservation using mulch was not needed due to the sufficient amount of precipitation. Without the use of mulch, these sites are vulnerable to invasive species. Biomass, density and species diversity displayed a trend where Watson's Goosefoot outcompeted the seed mix during this warm season likely by using resources such as soil moisture, nutrients, and light. Watson's Goosefoot was most prevalent in treatment sections with Arkose soil, no mulch, and particularly at the lower site where soil moisture was retained (biomass: 1549 kg ha^{-1}, canopy cover: 41.9%). Watson's Goosefoot did not thrive in the Arkose soil at the upper site likely because it was not able to retain adequate soil moisture. The biomass paired with density data indicated that the individual plants were large, as was visually observed. The lowest species richness and

Shannon-Wiener diversity index occurred at the lower site on Arkose with no mulch and a rough surface (1.4 species m^{-2}; H' = 0.20). This indicates that when Watson's Goosefoot is present, it is the dominant species.

The upper reference plot determined that the source of the Watson's Goosefoot seeds was within the Arkose soil. These plots contained an usually high amount of annual forbs (84.0% of the total density), in which Watson's Goosefoot composed 89.6% of the annual forbs, which further demonstrates the weedy characteristics of this species. Even within an established plant community, it is able to establish high densities of plants. As compared to the upper reference site, Watson's Goosefoot produced approximately 70.8% of the biomass observed on the lower test plot on Arkose soil (lower site: 693 kg ha^{-1} upper reference site: 493 kg ha^{-1}). During 2010, where Watson's Goosefoot established, the seeded species did not establish well and species diversity was limited. However, Watson's Goosefoot provided erosion control with its canopy cover and roots. Watson's Goosefoot may be a pioneer species, which is likely to be replaced with a stable plant community. Additional monitoring should give us a better understanding about the competitive ability of Watson's Goosefoot. No mulch treatments are vulnerable to weedy plant invasions, which do not appear to support the desired seed mix.

To further evaluate no mulch treatments to other mulch treatments (incorporated and surface), Arkose soils were not considered. No mulch treatments produced the best results for all vegetative attributes (density, seeded density, biomass, seeded biomass, species richness and Shannon-Wiener index) at the lower site on Gila soil during this year of above-average precipitation. A corrected application rate surface mulch application rate is needed for a more accurate comparison. At the upper site on Gila soil, surface mulch treatments produced more favorable results than no mulch treatments. It appears that when soils are capable of growth and a correct application rate for the Rosemont site is applied, surface mulch produced the most promising plant community. Due to the unpredictable climate and priority to conserve soil, mulch use should be considered for its benefits of soil moisture conservation and erosion protection.

Incorporated mulch provided the most consistent results, where it was neither the best nor the worst choice. Due to the complex conditions of the test sites, direct comparisons cannot be made without additional considerations (Arkose soil structure at the upper site, Watson's Goosefoot invasions on Arkose soil, different mulch rate applications at each site, low nutrients on Gila soil at lower site). The Gila soil at the upper site looks to be the best site for mulch comparisons. On Gila soil at the lower site, incorporated mulch consistently produced more favorable vegetation results (density, seeded density, biomass, seeded biomass, species richness and Shannon-Wiener index) than surface mulch when applied at a rate that is too high. If surface mulch had been applied at a lower rate on the lower site, I suspect that vegetation results would have been more similar to incorporated mulch.

Other benefits from other studies were not observed (enhanced soil roughness, improved soil properties). Incorporated mulch affects may be more strongly expressed in times of drought (Biedermann & Whisenant, 2009) or over time. The churning of the soil during the installation likely increased infiltration, though it was not measured. Using the rotary tiller to incorporate mulch may be detrimental to the equipment or impossible to use in rocky soils. Installation and cost may determine its practicality.

Although the surface mulch was planned to have an equal application at each site, measurement of surface mulch depth revealed differences. Using Norland's translation, a mulch rate was derived of 4.64 Mg ha^{-1} (2.06 t ac^{-1}) at the lower site and 1.54 Mg ha^{-1} (0.68 t ac^{-1}) at the upper site. After the surface mulch was applied at the lower site, high winds carried some mulch off the lower testing site. An additional light mulch application was blown onto the soil surface, which resulted in a slightly heavier application of mulch than desired (2 t ac^{-1}). Due to contractor error at the upper site, a lighter application of mulch was applied. Mulch treatments were observed later at the upper site than the lower site, which may have given more time for mulch to blow away, also contributing to less mulch at the upper site. Differences in soil temperatures and light conditions were reflected in vegetation.

Surface mulch provided shade to the soil surface, resulting in less light available to seedlings. With increasing surface mulch, less light was available to seedlings. Mulch 2.5 cm (1 in) deep allowed approximately 3% of available light to reach the soil surface while 5.1 cm (2 in) of mulch allowed almost no light to reach the soil surface (0.6%). Since the lower site surface mulch application was 3.41 cm (1.3 in), the mean amount of light received at the soil surface was between 0.6% and 3% of available light. The upper site surface mulch application was 1.13 cm (0.4 in), with the mean amount of light at the soil surface permitting more than 3% of the available light to the soil surface. Studies found that mulch depths of more than 5 cm begin to negatively impact germination and emergence of seedlings (Norland, 2000). The mulch application rate not only relies on the climate, but also on the species of plants seeded. Plants with small seeds, including many grasses, may not have adequate energy to penetrate the surface mulch layer and may not germinate in darkness (Norland, 2000). All seeds in the Rosemont seed mix were small and did not establish well with surface mulch at the lower site (lower site, surface mulch: 23.3 plants m^{-2}; lower site, other mulch: 58.9 plants m^{-2}). With a lower application of surface mulch at the upper site, the mulch barrier did not inhibit seed mix establishment resulting in a higher density than the lower site (surface mulch: 50.9 plants m^{-2}, other treatments: 43.7 plants m^{-2}). This rate appears to produce favorable revegetation. A surface mulch rate less than 2 t ac^{-1} is recommended for the Rosemont site.

A uniform application of surface mulch is difficult to establish, though an uneven application of surface mulch may produce a more diverse plant community. Since mulch tackifier did not last, mulch moved around with wind and a uniform application was not sustained. Water was needed to apply the tackifier, which is a limited resource in an arid land and may also affect germination. A study by Abbott & Roundy (2003) showed that some native perennial grasses would germinate after an initial storm event, then die without following storm events while fewer Lehmann's Lovegrass would germinate for an initial storm event, leaving more seeds in the seedbank. If the surface mulch tackifier was installed prior to the warm season, the native perennial grasses that compose the majority of the seed mix may have germinated and then died. Other methods to fasten surface mulch to the ground should be explored. Additionally, it was difficult to spray an even application of tackifier onto the mulch. With the heat and windy conditions of the site, the tackifier appeared to break down quickly and allowed mulch movement. With a suitable mulch rate and an uneven application of surface mulch, diverse environments for germination and establishment were created which resulted in higher species richness and a more diverse plant community. During the warm season 2-times more species per meter and a more evenly distributed plant community occurred in surface mulch sections at the upper site on Gila soil as compared to other treatments (upper site, surface mulch: 11.1 species m^{-2}, $H' = 1.93$; other treatments: 5.6 species m^{-2}, $H' = 1.31$). By promoting diversity of environments, species diversity should also be promoted.

Table 29. Mulch treatment advantages and disadvantages.

Treatment	Advantage	Disadvantage
No Mulch	Lowest cost	High potential for erosion
	No installation necessary	No weed control, vulnerable to invasive species
		Soil moisture depends on soil properties
		High potential for evaporation
		Seeds exposed to full environment and seed predators
Incorporated Mulch	More consistent results	Greatest difficulty to install, particularly in rocky soils
	Provides moisture reservoir in times of drought (Biedermann & Whisenant, 2009)	Likely highest cost
	Inserts carbon directly into the soil	Takes the most amount of time to install
	Anchored into the ground, no tackifier necessary	
	No water necessary to install	
	Enhances soil roughness	
	More available microniches	
Surface Mulch	Quicker to install than incorporated mulch	Correct application rate may be difficult to determine (Too thick: inhibits growth, Too thin: may not conserve sufficient soil moisture)
	Can install on steep slopes with pneumatic blower	Higher cost than no mulch
	Likely lower cost than incorporated mulch	Difficult to maintain (wind, water); soil tackifier requires water for installation
	Varying mulch depths may promote diversity	
	Conserves soil moisture	
	Protection from seed predators	
	Provides erosion protection	
Nurse Crop	Provides weed control	Competition with cool season species (water, nutrients, light)
	Provides erosion control	

Each of the mulch treatments (no mulch, incorporated mulch, and surface mulch) may be able to produce successful revegetation under varying climatic conditions. Due to the unpredictability of precipitation in the arid Southwest, mulch applications are recommended due to the potential of erosion and invasive species. In years of above-average precipitation, as was the case in 2010, no mulch was needed for revegetation due to already favorable conditions. Bare ground (no mulch treatment) is susceptible to weedy plant invasions and erosion, while mulch treatments provide protection from both threats. Between the mulch treatments, incorporated mulch and surface mulch will likely reveal differences more clearly during average or below-average precipitation years (Table 29). A lighter application rate of surface mulch at the lower site may have produced well-defined results, though my results from 2010 confirmed that an application rate that is too high likely inhibits germination and / or establishment. Additional testing should be conducted to determine the best method to attach the mulch to the soil surface. Despite positive outcomes in vegetation at the lower site in response to incorporated mulch, surface mulch treatments appear more promising with a correct application rate (2.2 Mg ha^{-1} (1 t ac^{-1})). The surface mulch installation is more cost-effective, requires less mulch materials, is quicker and easier to apply, and can be easily applied to rocky soils and steep slopes.

The seed mix was evaluated by individual species during their preferred growing season to determine its ability to establish during reclamation. All species preferred the Gila soil over the Arkose soil (Gila soil: 64.4 plants m^{-2}, Arkose soil: 23.2 plants m^{-2}). *Elymus elymoides* was not as abundant as other perennial grasses, as it was seeded at a lower rate (15.8 seeds m^{-2}), but may have also been affected by the nurse crop. *Escholzschia californica* ssp. *mexicana* favored the upper site (upper site: 9.1 plants m^{-2}, lower site: 4.6 plants m^{-2}), likely due to the additional 8.6 cm (3.4 in) of precipitation and less competition with the nurse crop. *Eschscholzia californica* ssp. *mexicana* prefers full sunlight and the genus is known to thrive following above-average winter precipitation (Epple, 1995). On average, 1.1% of the *Eragrostis intermedia* (ERIN) seeds established. There may have been errors with identification as some vegetative characteristics were shared with *Bouteloua curtipendula* or *Hilaria belangeri*. ERIN may prefer more moisture and nutrients as it favored the upper site with surface mulch to all other treatments (2.7 plants m^{-2}, other treatments: 0.4 plants m^{-2}). Additional monitoring when plants have matured and inflorescences are present may help to determine the success of this plant. No individuals of *Calliandra eriophylla* were observed. Poor seed quality is suspected, but shrubs may take longer amounts of time to establish (Stevens, 2004). All other species in the seed mix appeared to establish sufficiently.

There were fewer plants per square meter on the test plots as compared to the seeded amount and reference sites. When broadcast seeding, it is recommended to seed at a higher density than the desired as many seeds will not be placed at its ideal burial depth or establishment conditions. Overall, there was an average establishment rate of 8.4% of the seeded rate, excluding volunteer species. Due to the amount of annual forbs present at the upper reference site, the lower reference site appears to be a healthier plant community to use for a baseline. The Gila soils are approaching a healthy plant community density (Gila soil: 69.6 plants m^{-2}, lower reference: 94.0 plants m^{-2}). There were 8.5 less perennial forbs m^{-2}, 13.7 more perennial grasses m^{-2}, and 11.8 less shrubs m^{-2}, as compared to the lower reference site. A lower density of shrubs and higher density of perennial grasses are desired for the new plant community, as wood plant encroachment has been observed in the Rosemont area and a grassland is desired. Since a low amount of seeds established and the reference plant communities contain a higher density of plants, a minimum seeding rate of 523 seeds m^{-2} (48.6 seeds ft^{-2}) is recommended when broadcast seeding.

Soil movement was influenced by the interaction of elevation by soil, as a result of rock cover. Soil movement was defined as the depth of accumulation or erosion at a single point.

There were differences in the soil roughness of the Arkose soil at the upper site (Arkose, upper site: h_{rms} = 4.66 cm; other treatments: h_{rms} = 1.81 cm), which was noticeable by visual inspection. An uneven (rough) surface has been shown to reduce the velocity of runoff and the amount of erosion, as compared to a smooth surface. The most amount of soil movement occurred on Gila soil at the upper site (Gila soil, upper site: 13.4 cm; other treatments: 8.6 cm). Gila soil is generally composed of smaller particles. Less energy is required to move small particles as compared to large particles, making the Gila soil more susceptible to soil movement. The upper site also received 2.1 cm (0.8 in) more precipitation than the lower site, contributing a greater volume of water to move soil particles. It is also possible that soil movement may have occurred due to the soil settling from the soil placement.

Of the 5 types of cover measured (bare ground, rock, mulch, canopy and basal cover), rock cover was the only type of cover to significantly influence soil movement. Cover disrupts raindrop impact and water flow, which usually results in less soil movement. Bare ground implies that there are no disruptions between the path of a raindrop and the soil and is more susceptible to soil movement than soils with cover (Weltz *et al*, 1998). Soil movement as a function of bare ground explains that as the amount of bare ground increases, the rate of soil movement increases (e.g. Weltz *et al*, 1998). For every percent of bare ground, soil movement increased at the rate of 0.0022 cm (accumulated or eroded). Rocks on the soil surface can absorb the energy of raindrop impacts. The rock position was not observed, but has the potential to affect soil movement (Poesen & Ingelmo-Sanchez, 1992). As rock cover increased, the amount of soil movement significantly decreased (0.0159 cm accumulation or erosion per percent rock cover). Rock cover appeared to be an effective method to prevent soil movement and is less vulnerable to erosion. The rock content in soils should be considered when accounting for erosion. Soils that contain lower rock content may increase mulching rates, or higher rock content may decrease mulching rates. Soil erosion must be prevented to maintain soil, nutrients, and microbes at the site.

Mulch can be used as a temporary aid to establish vegetation, with the added benefit of preventing erosion (Norland, 2000). The mulch at the Rosemont site showed that as mulch cover increased, the amount of soil movement decreased (-0.0002 cm accumulation or erosion depth per percent mulch cover). With a higher application of mulch, it is likely that mulch would have made a significant impact on soil movement. When mulch is applied for the purpose of erosion protection, it is usually applied at a higher rate of approximately 6.7 Mg ha^{-1} (3.0 t ac^{-1}) (Norland, 2000). However, a higher application of mulch would not support revegetation. There were no noticeable erosion features at either site during 2010. The establishment of vegetation should increase infiltration and prevent soil movement. During the first year of revegetation there appeared to be sufficient cover and site stability to prevent problematic erosion. A lower mulch rate is recommended as a trade-off to promote vegetation establishment, yet offer some erosion protection.

CONCLUSIONS

Proper soil management is necessary for revegetation. The Gila soil at the lower site and Arkose soil at the upper site came from deep within the soil profile, which resulted in lower amounts of nutrients and microorganisms. The soil that came from the upper portions of the soil profile (lower site Arkose soil and upper site Gila soil) appeared to be more developed and contained viable microorganisms and seed banks. The Arkose soil at the upper site was composed of larger soil particles, which did not hold sufficient soil moisture in the upper 7.6 cm (3 in) of the soil, where seeds and grasses utilize the moisture. Since water is a limiting factor in an arid system, is it essential that the soil is able to retain adequate soil moisture. Vegetation followed similar trends to soil moisture. Both Arkose soil and Gila soil are capable of supporting vegetation, given that there are sufficient fine particles to retain soil moisture and nutrients. Direct hauling soil placement is recommended to retain nutrients and to keep the seedbank and microorganisms alive. The Gila soil supported more vegetative growth and diversity during the warm season and is the preferred choice for revegetation.

The seedbed and wheat straw mulch treatments provided promising effects for successful reclamation in the arid southwest with correct application rates. Seedbed preparation methods that will promote infiltration and prevent run-off should be used for ecological and hydrological repair. Compaction should be prevented whenever possible by minimizing heavy traffic. A ripper mechanically destroys compacted layers, increases infiltration and creates a rough surface. A rough surface may not be maintained on fine-textured soils and a smooth surface may not be created on coarse-textured soils. Despite our efforts to capture the soil roughness, we were not able to collect all measurements before precipitation events occurred. Although many vegetation attributes were positively influenced by ripping followed by a smooth surface, differences were not significant and do not warrant the extra costs and efforts. A rough surface is recommended for future practices.

With above-average precipitation, no mulch was needed for revegetation during 2010, but is recommended for less favorable years. Bare soils (no mulch treatments) are more susceptible to erosion and generally do not preserve moisture as well as mulched treatments. As a result of the mulch, a nurse crop was grown and provided weed and erosion control. When surface mulch was applied at 4.6 Mg ac^{-1} (2 t ac^{-1}), grass seedlings were not able to break through the mulch barrier. Incorporated mulch appeared to be slightly more favorable for revegetation than surface mulch. However, with a correct application rate of 2.2 Mg ha^{-1} (1 t ac^{-1}), surface mulch is recommended, as it is more practical than incorporating mulch due to the costs, installation time and ability to apply on rocky soils and on steep slopes.

Amendments used for reclamation should consider the susceptibility of soil to erosion. The Gila soil is more susceptible to erosion than the Arkose soil. Rock cover significantly decreased the amount of erosion. Rock particles may be placed onto the soil surface to provide more protection from erosion, yet permit adequate soil moisture to support vegetation growth. Mulch applications may also be applied at a higher rate on more susceptible soils. It is imperative to conserve the soil and nutrients by preventing erosion on highly erosion-susceptible soils in order to establish vegetation in years of favorable conditions.

Our long-term goals of creating a self-sustainable, resilient ecosystem cannot be effectively monitored over one year. To determine the sustainability of the ecosystem and hydrological repair, yearly monitoring is planned during the peak growth of the warm season. Rangeland health monitoring should include the same variables evaluated during the 2010 warm season. Sustainability of the ecosystem will be determined as the ecosystem is able to reproduce and persist while maintaining a healthy condition. As with natural succession, the site is expected to experience seral stage changes until it reaches a stable or climax plant community.

APPENDIX A. VOLUNTEER SPECIES.

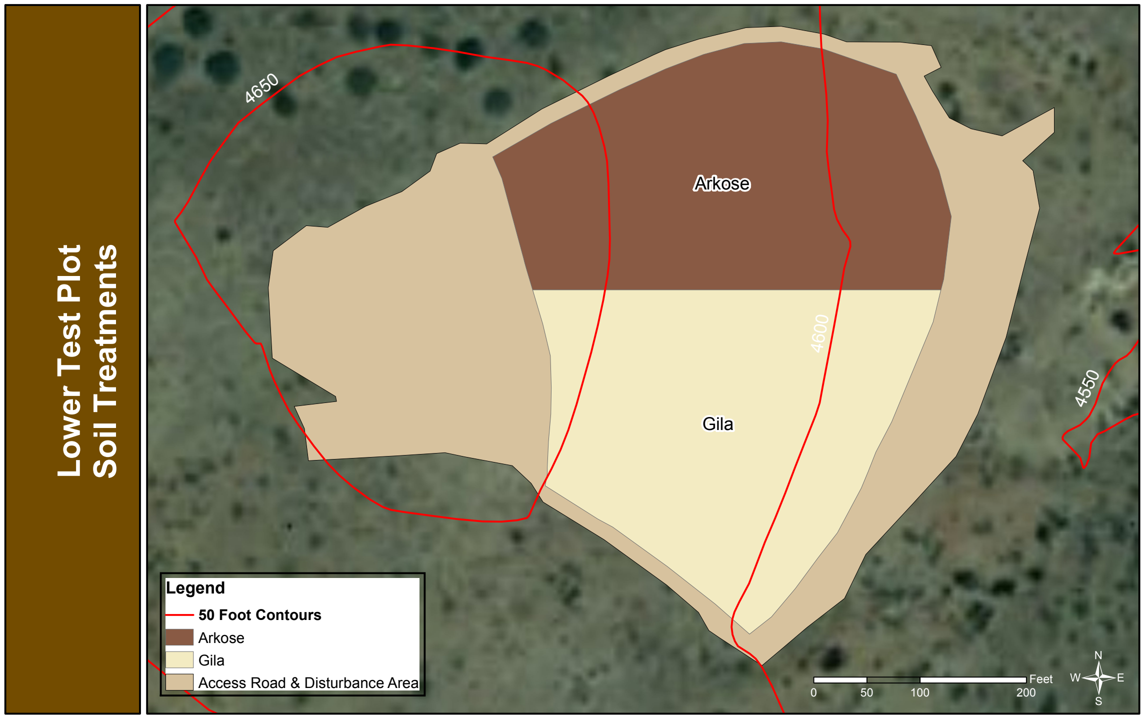
	Species	Common Name	Functional Group*	Season**
1	*Chenopodium watsonii*	Watson's Goosefoot	AF	CS & WS
2	*Astragalus nuttallianus*	Smallflower milkvetch	AF / PF	CS
3	*Phalaris minor*	Littleseed Canarygrass	AG	CS
4	*Atriplex elegans*	Wheelscale Saltbush	AF / PF	CS
5	Caryophyllacea	Forb	AF	CS
6	*Astragalus desperatus*	Rimrock milkvetch	PF / SH	CS
7	*Lotus humistratus*	Foothill Deervetch	AF	CS
8	*Sonchus asper*	Spiny sowthistle	AF / BF	CS
9	*Phacelia coerulea*	Skyblue Phacelia	AF	CS
10	*Descuriania pinnata*	Flixweed	AF	CS
11	*Gymnosperma sp (Asteracea)*	Forb	AF / PF	CS
12	*Dalea pogonanthera*	Bearded Prarie Clover	PF	CS
13	*Avena fatua*	Wild Oat	AG	CS
14	*Phemeranthus aurantiacusm*	Orange Fameflower	PF	WS
15	*Heliomeris* longifolia	Longleaf False Goldeneye	AF	WS
16	*Aristida ternipes*	Spidergrass	PG	WS
17	*Panicum arizonica*	Arizona Signalgrass	AG	WS
18	*Galium sp. (Rubiaceae)*	Forb	AF / PF	WS
19	*Ipomoea costellata*	Crestrib morning-glory	AV	WS
20	*Euphorbia hyssopifolia*	Hyssopleaf sandmat	AF	WS
21	*Carlowrightia arizonica*	Arizona wrightwort	SH	WS
22	*Panicum hirticaule*	Mexican panicgrass	AG	WS
23	*Crotalaria pumila*	Low rattlebox	AF	WS
24	*Amaranthus palmeri*	Amaranth	AF	WS
25	*Setaria leucopila*	Bristlegrass	PG	WS
26	*Astragalus nothoxys*	Sheep loco weed	PF	WS
27	*Malvaceae* sp.	Mallow	PF	WS
28	*Aristida adscensionis*	Six weeks Threeawn	PG	WS
29	*Chloris* virgata	Feather Fingergrass	AG	WS
30	*Dalea pogonethera*	Bearded Prarie Clover	PF	WS
31	*Fouquieria splendens*	Ocotillo	SH	WS
32	*Ipomoea cristulata*	Transpecos morning-glory	AV	WS
33	*Mollugo verticillata*	Green Carpetweed	AF	WS
34	*Giura gracilis*	Forb	AF	WS
35	*Sida abutifolia* or *S. procumbens*	Spreading fanpetals	PF	WS
36	*Malva neglecta*	Common Mallow	AF	WS
37	*Portulaca ambraticola*	Purslane	AF	WS
38	*Drymaria* sp.	Drymary	AF	WS

APPENDIX A. VOLUNTEER SPECIES – *Continued*

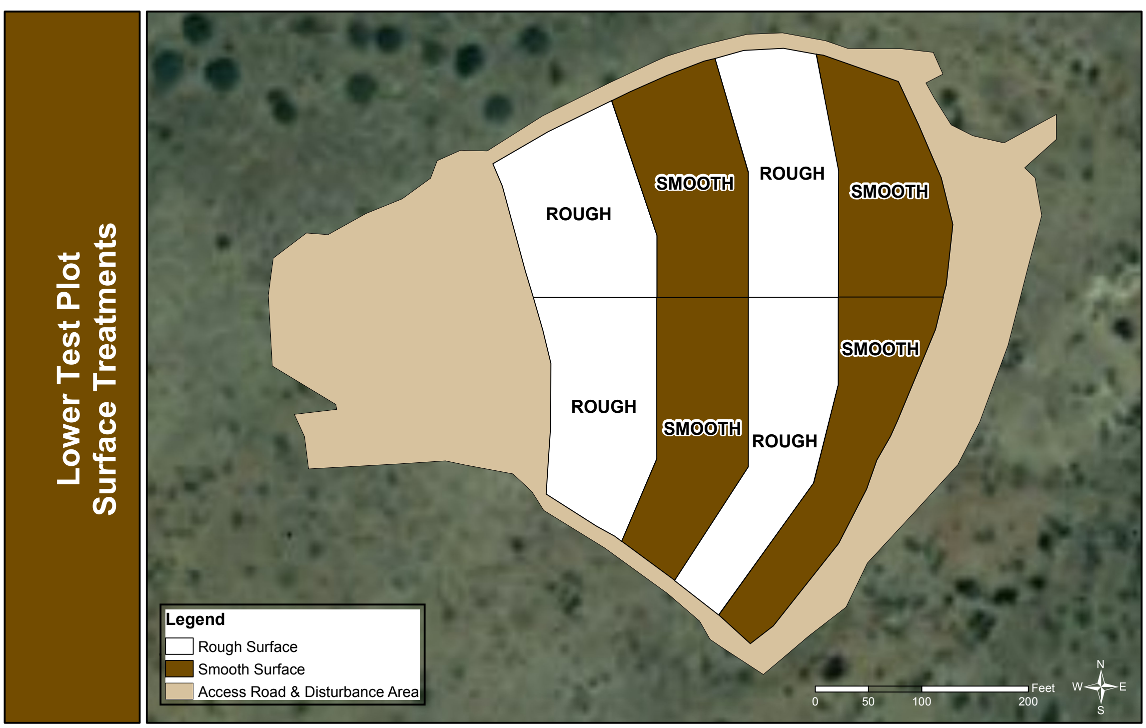
Species		Common Name	Functional Group*	Season**
39	*Ariochloa lemoni*	Cut grass	AG	WS
40	*Rhyncosida physoclyax*	Snoutbean	PF	WS
41	*Dalea procra*	Dalea	PF	WS
42	*Bouteloua aristidoides*	Needle Grama	AG	WS
43	Poaceae	Perennial Grass	PG	WS
44	*Muhlenbergia porteri*	Bush Muhly	PG	WS
45	*Eriogonum wrightii*	Bastardsage	PF / SH	WS
46	*Amaranthus palmeri*	Amaranth	AF	WS
47	*Bouteloua Aristoides*	Needle Grama	PG	WS
48	*Lycurus phleoides*	Wolftail	AG	WS
49	*Sanvitalia abertii*	Albert's creeping zinnia	AF	WS
50	*Desmodium procumbens*	Western trailing ticktrefoil	AF	WS
51	*Kallstroemia californica*	California caltrop	AF	WS
52	*Boerhavia erecta*	Erect spiderling	AF	WS
53	*Mentzelia asperula*	Oregon Mountain Blazing Star	AF	WS
54	*Melampodium leucanthum*	Plains Blackfoot Daisy	PF / SH	WS
55	*Salvia reflexa*	Lanceleaf sage	AF	WS
56	*Diodia teres*	Poorjoe	AF	WS
57	*Artemisia ludoviciana*	White sagebrush	PF / SH	WS
58	*Asteracea sp*	Forb	AF / PF	WS
59	*Dasyochloa* pulchella	Low Wollygrass	PG	WS
60	*Pappophorum vaginatum*	Whiplash Pappusgrass	PG	WS
61	*Amaranthus blitoides*	Mat amaranth	AF	WS
62	*Jatropha macrorhiza*	Ragged Nettlespurge	PF	WS
63	*Kallstroemia grandiflora*	Arizona Poppy	AF	WS
64	*Eriogonum abertianum*	Abert's Buckwheat	AF	WS
65	*Salsola tragus*	Prickly Russian Thistle	AF	WS
66	*Solanum rostratum*	Buffalobur Nightshade	AF	WS
67	*Phacelia crenulata*	Purplestem Phacelia	AF	WS
68	*Lepidium lasiocarpum*	Shaggyfruit Pepperwood	AF / BF	WS
69	*Cenchrus incertus*	Coastal Sandbur	AG	WS
70	*Argemone pleiacantha*	Southwestern Prickly Poppy	PF	WS
71	*Datura* sp.	Sacred Datura	AF	WS
72	*Bouteloua chondrosoides*	Sprucetop Grama	PG	WS
73	*Polygala obscura*	Velvetseed milkwort	PF	WS
74	*Eragrostis lehmanniana*	Lehmann's Lovegrass	PG	WS
75	*Eragrostis echinochloidea*	African Lovegrass	PG	WS
76	*Atriplex canescens*	Four-wing Saltbush	SH	WS

*AF (Annual Forb), BF (Biennial Forb), PF (Perennial Forb), AG (Annual Grass), PG (Perennial Grass), AV (Annual Vine), SH (Shrub). Species noted within multiple functional groups can be found in either form.
** CS (Cool Season), WS (Warm Season)

APPENDIX B. TEST PLOT DESIGN

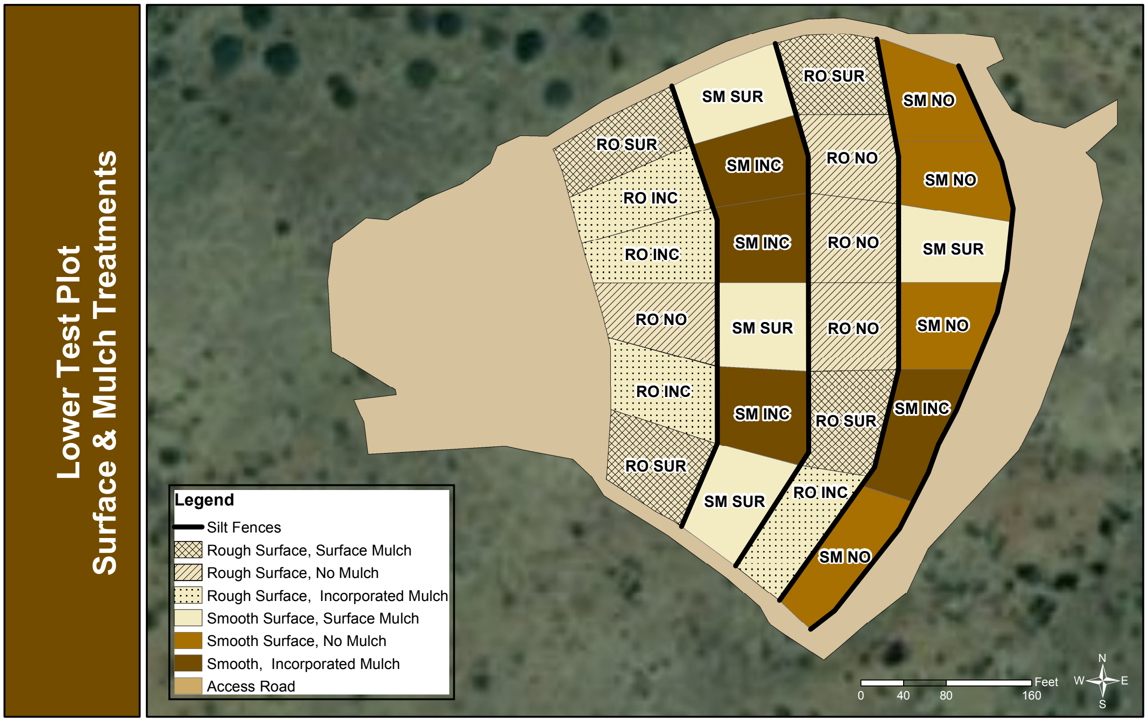


APPENDIX B- Figure 1. Lower site soil placement.



APPENDIX B- Figure 2. Lower site surface treatment design.

APPENDIX B. TEST PLOT DESIGN - ***Continued***



APPENDIX B - Figure 3. Lower site surface and mulch treatment design.

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