

Revegetation of Disturbed Semiarid Grassland
in Canyonlands National Park

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A grassland restoration project was conducted in Canyonlands National Park on an area recently disturbed due to construction. Two native grasses (Oryzopsis hymenoides and Stipa comata) were seeded with 18 different soil treatments. Stipa density and relative mycorrhizal colonization were measured.

None of the soil treatments resulted in significantly greater Stipa density than the control treatment of seeding only plus water. There was very little correlation between Stipa density and mycorrhizal colonization based on the treatments ($r^2 = 0.01$, $p = 0.05$). Three treatments produced 3 to 5 times the VAM colonization as the control including spring cryptobiotic soil crusts, with and without sugar, and fall soil crusts with sugar and mulch. Factors influencing mycorrhizal colonization are discussed.

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INTRODUCTION

The southwestern portion of the United States is characterized in part by arid and semiarid deserts. Many of these landscapes have been severely overgrazed resulting in denuded soil surfaces and heterogeneity of soil resources (Schlesinger et al. 1990). Disturbance in arid climates may be followed by shifts in species composition as a result of reduced organic matter and soil moisture, and increased soil temperatures from loss of shade (Allen and MacMahon 1985). Re-establishment of vegetation on disturbed southwestern desert lands has been mildly successful, the resulting vegetation typically differing in composition, and many times not persisting to establishment (Thornburg and Fuchs 1978); the level of mycorrhizal fungi remaining in the soil appears to be an indicator of the type and rate of plant succession that will follow (Doerr et al. 1984). Failures in semiarid revegetation may be due in part to the focus on plant species to the exclusion of soil patterns and processes, plant-soil relationships, and the functioning of the ecosystem as a whole.

Revegetation research on disturbed arid lands has focused almost exclusively on mined lands, though 245 million hectares (27%) of land in the United States consists of rangeland pasture compared to 1.5 million hectares (.2%) of mined lands (Paone et al. 1978). Regardless of the cause

of disturbance, large areas of semiarid lands have lost their functional stability and are in need of rehabilitation (Box 1978). The systems and processes which create stability in semiarid deserts are not well understood.

Soil disturbance is a significant barrier to regeneration in semi-arid environments due at least in part to the fragile and easily damaged soil crusts which characterize these systems (Campbell et al. 1989, Dunne 1989). Cryptobiotic soil crusts, formed and held together primarily by cyanobacteria, lichens, mosses, bacteria and fungi in the southeastern Utah desert, are critical to soil stability, nutrient and water retention, water infiltration, and nitrogen fixation (Beymer and Klopatek 1992, Anderson et al. 1982 (1), Brady 1974, St. Clair et al. 1984, and MacGregor and Johnson 1971, Isichei 1990). Water absorption capacity and nutrient retention are particularly important in the semiarid West where precipitation and minerals, phosphate in particular, are limiting to plant growth (Williams and Aldon 1976). Disturbance to these crusts affects plant establishment and revegetation (Doerr et al. 1984). Soil crusts seem to be an appropriate area of focus for restoration, if taken in the context of the soil-plant connection, the effects on the rate of mycorrhizal colonization as a result of crust formation, and the resultant response of the host plants.

Most semi-arid grassland plants form vesicular-arbuscular mycorrhizae (VAM) (Trappe 1981). This symbiosis has been found to benefit both individual plants and ecosystem processes (Anderson 1987, Reeves 1987). VAM form a hyphal network through which material may be transferred between individuals of the same and different species in a community, which in turn stabilizes ecosystem nutrient fluxes (McNaughton and Oosterheld 1990, Perry et al 1992). Some of the functions which have been found to benefit VA mycotrophic as compared to nonmycotrophic plants include; increased absorption of water and nutrients, drought resistance, pathogen protection, maintenance of CO₂ uptake, reduced water loss, better absorption of mineral ions and increased plant growth (Molina and Amaranthus 1990, Huang et al. 1975, Miller 1987, Allen 1991). Plants in semiarid grassland communities are particularly influenced by VAM associations (Miller 1987).

The presence and distribution of mycorrhizal plants has been related to water availability, successional stages within a community, and mycorrhizal inoculum potential in the soil (Pendleton and Smith 1983). Mycorrhizal plants are more typical of undisturbed and later seral stages of semiarid habitats (Reeves et al. 1979). The establishment phase following disturbance is an important determinant of plant community due to the few seral stages typical of semiarid ecosystems (Kleiner 1983, Fowler 1986). Soil

disturbance has been found to reduce mycorrhizal inoculum potential (Warner et al. 1987) and favor nonmycorrhizal plants on semiarid disturbed land (Reeves et al. 1979, Allen and Allen 1987, El-Tayeb and Skujins 1989). When infected, mycorrhizal species have been found typically to establish more quickly than nonmycorrhizal species due to higher survival rates and greater production (Doerr et al. 1984).

This research is part of a larger project designed and implemented by Canyonlands National Park under the direction of Dr. Jayne Belnap. I participated in setting up the research plots, seeding and applying soil treatments, and measurement of seedling establishment and mycorrhizal colonization. This paper describes my part in the study, examining revegetation of disturbed soils with native grasses and their subsequent relative colonization of VAM.

The objectives of the study were to determine the affects of various soil treatments on 1) Stipa seedling establishment, and 2) relative colonization of VAM on Stipa. Two Stipa species were seeded and various soil amendments were applied. Relative VAM colonization of Stipa and Stipa density were measured.

Hypotheses and Rationale

Stipa Density

Hypothesis 1. Cryptobiotic soil crusts, sugar, straw mulch, hay and water will each increase Stipa establishment in

comparison to the control treatment of seeding only plus water.

Rationale. Topsoiling has been found to enhance plant establishment and growth in revegetation of semiarid mined sites (Packer and Aldon 1978). The presence of soil biota and organic matter may improve soil structure and plant growth (Forster 1990). Inoculation with healthy crusts may thus speed crust formation and the retentive functions the crusts provide. Sugar should affect nutrient availability through a chain-reaction series of responses; increased microbial activity, decreased available nitrogen to the annuals, greater establishment of perennials which have lower nutrient requirements (McLendon and Redente 1991). Straw mulch shades the plants which should reduce soil temperature, moisture loss and heat stress (Packer and Aldon 1978). Hay was added as a relatively low C/N source of organic matter that should improve soil water-holding capacity and provide aeration, reducing compaction of soil. Water should affect the ability of plants to use nutrients and thus encourage growth (Ries and Day 1978).

Hypothesis 2. Fertilizer will decrease Stipa establishment in comparison to the control treatment.

Rationale. Fertilizer increases available nutrients which tends to increase overall plant growth, though may encourage annual weeds which reduces nutrient availability for initial establishment of perennial grasses.

VAM

VAM formation should develop with the availability of root density (Allen 1992) and carbohydrates from the plants. Extent of colonization is typically correlated with plant growth (Harley and Smith 1983). Therefore, I expect colonization to increase with the same amendments as for Stipa density. Additional reasons for development and discouragement without regard for Stipa density are listed below.

Hypothesis 3. Cryptobiotic soil crusts, sugar, straw mulch, hay and water will each increase relative VAM colonization in comparison to the control treatment of seeding only plus water.

Rationale. The soil stabilization created by the cryptobiotic crusts may provide a more secure surface for mycorrhizal inoculum to locate roots for formation. Sugar should stimulate biological activity, including bacteria which stimulate mycorrhizal formation. Organic amendments have also been found to increase mycorrhizal development (Johnson and McGraw 1988). Mulch has been found to encourage VAM formation where nitrogen is adequate and phosphorus limiting (anecdotal observation, Wilson and Wilson 1992). Soil aeration (hay) and soil moisture have been associated with higher mycorrhizal inoculum potential (Allen 1992).

Hypothesis 4. Fertilizer will decrease relative VAM colonization in relation to the control treatment.

Rationale. Mycorrhizal abundance has been found to decrease as soil fertility increased in a natural ecosystem (McNaughton and Oosterheld 1990). High levels of inorganic fertilizers used for reclamation often have also been found to inhibit mycorrhizal formation (Allen 1992).

METHODS

Study Area

The study area, in Canyonlands National Park, Utah, is in a cold desert at 1370 m elevation characterized by seasonality of temperature and precipitation. Temperatures have an annual range of 55°C. Yearly precipitation of 32 cm mainly occurs from March to October, the highest months being July and August (Needles District Visitor Center records, Canyonlands National Park). The site is relatively flat with a general soil texture of 70% sand, 21% silt, 9% clay, and a pH of 8 (Loope 1978).

The study site is a 1.4-acre strip paralleling a paved road, severely disturbed due to construction in the Needles District of Canyonlands National Park. Prior to recent disturbance, the site supported two seeded grasses, Oryzopsis hymenoides and Stipa comata. Other pre-disturbance species include Aristida purpurea, Helianthus annua, Sphaeralcea coccinea, Ambrosia acanthicarpa, Stephanomeria exigua, Atriplex canescens, Gutierrezia sarothrae, Heterotheca villosa, Chrysothamnus nauseosus, Artemisia tridentata, Hilaria jamesii, Astragalus mollissimus, Aster machaeranthera, Mentzelia cronquistii, Cycloloma striplificifolia, Salsola kali, and Bromus tectorum.

The area was moderately grazed from the mid-19th century until early 1970's when creation of the National Park allowed

removal of cattle (Kleiner 1983). The area was consequently disturbed from overgrazing prior to the recent disturbance. The aim of the final product of the revegetated area is an imitation of an area of the park which was never grazed, and is dominated by native grasses and forbs with a minimal shrub component.

Soil Treatments and Rationale

The study site was divided into 126, 20.90 m² plots representing eighteen different treatments each replicated seven times in a randomized block design. The treatments are listed in Table 1 followed by the rationale.

Table 1. Soil treatments applied to 126, 20.90 m² plots replicated seven times in a randomized block design.

Treatment

Treatments with water:

- T1:** Cryptobiotic soil crusts, applied fall.
- T2:** Cryptobiotic soil crusts and sugar, applied fall.
- T3:** Cryptobiotic soil crusts, applied fall, and fertilizer, applied spring.
- T4:** Cryptobiotic soil crusts, applied fall, and straw mulch, applied spring.
- T5:** Cryptobiotic soil crusts, applied fall, fertilizer and straw mulch, applied spring.

T6: Cryptobiotic soil crusts and sugar, applied fall, straw mulch, applied spring.

T7: Cryptobiotic soil crusts and wheat hay, applied fall.

T8: Sugar, applied fall, and straw mulch, applied spring.

T9: Straw mulch and fertilizer, applied spring.

T10: Straw mulch, applied spring.

T11: Cryptobiotic soil crusts, applied spring.

T12: Cryptobiotic soil crusts and sugar, applied spring.

T13: Cryptobiotic soil crusts and fertilizer, applied spring.

T14: Cryptobiotic soil crusts and straw mulch, applied spring.

T15: Fertilizer, applied spring.

T16: Control: seed only.

Treatments without water:

T17: Seed, no water.

T18: Cryptobiotic soil crusts and sugar, applied spring, no water.

Rationale

Twelve treatments involved the application of cryptobiotic crusts to the soil surface in either the fall or the spring. Crusts were added to speed natural crust formation, stabilize soils from erosion, retain water and nutrients, and enhance water infiltration (Anderson et al. 1982 (1 & 2), Beymer and Klopatek 1992). Eleven of the 12 crust treatments were irrigated, and were combined with one of the following additional treatments: (a) none (crusts only)

(b) sugar spread on the soil surface (c) fertilizer (1:2:1 nitrogen, phosphorus, potash) (d) straw Hilaria mulch applied to the soil surface, or on top of the soil crusts in treatments with crusts, and (e) wheat hay mixed into the soil.

Amendments tested in isolation were compared to the control treatment of seed only plus water (T16) for analysis. To test the effects of sugar and hay comparisons were made of combinations of each with another amendment to the other amendment alone. The comparisons are listed in Table 3-1 and 3-2 in the Results section.

Procedures

The project began in May of 1991. Seeds of the Stipa and Oryzopsis species were collected in the Park during the summer of 1991 within two miles of the study site. The herbicide Roundup was applied to the corridor with a mechanical sprayer in June and August as an initial attempt to control the dominance of Salsola kali, a pervasive exotic in disturbed areas of the West (Beatley 1973). The intended rate of application was 3.5 L/ha, though the June application was erroneously put out at 28 L/ha, eight times the intended rate. The August application was applied at the original rate and resulted in 2.2 kg total. Following herbicide treatment, the corridor was turned with a tractor disk to a depth of 20.

Seeding was done in the fall to take advantage of accumulated moisture of the summer rains (Plummer 1977).

Seeding began in October of 1991. Oryzopsis hymenoides was drill-seeded at an average depth of 7.5 cm to avoid losing seed to herbivory (SCS 1988, Fulbright et al. 1982). Oryzopsis hymenoides was drilled at the rate of 215 seeds/m² resulting in 8.2 kg total seed drilled. Oryzopsis hymenoides was then hand broadcast at the rate of 54 seeds/m², in addition to the drilling to avoid visual rows of grass resulting from the lines the tractor seeded. Stipa comata was hand broadcast at the rate of 110 seeds/m², except for the first 23 plots of the corridor (all treatments of the first replicate and treatments 3, 4, 11, 13 and 14 of the second replicate) where it was erroneously seeded at 160 seeds/m². Stipa comata was not drill seeded because germination typically occurs the first season after planting (SCS 1988), and seed was not subject to herbivory for as long a period of time as Oryzopsis hymenoides. The entire corridor was hand-raked to cover seed.

All fall treatments to the corridor occurred during October and November of 1991. Fall soil treatments were applied in the order of hay, sugar and cryptobiotic soil crusts. Sugar was hand-distributed on top of the soil at a rate of 660 kg/ha. Hay was mixed into the soil 15 cm deep and applied at a rate of 1/2-bale per plot.

Cryptobiotic soil crusts were removed from a site slated for future disturbance, within 1 km of the study site, and re-applied within hours. Vegetation on the site where soils

were collected was similar to the mixed grassland/shrubland adjacent to the study site described under Study Area. The Stipa and Oryzopsis species seeded were inclusive of this community, in addition to other native grasses and forbs. Some exotic species existed there, though there was no evidence of Salsola kali, the most noxious of the local weeds, and the non-native species that did exist were a minor part of this community. The top 15 cm of soil were shovelled into a pile on the bed of a pickup truck. The top 5 cm consisted of cryptobiotic crusts, while the remaining 10 cm was the underlying topsoil, included for ease of spread. This depth should have included the mycorrhizal fungi thought to be confined to the rooting zone of vegetation (Safir 1987), the surface 20 cm in semiarid ecosystems (Sparling and Tinker 1978). The mixture was scooped into 19-liter buckets with four buckets applied to each plot. This resulted in a 1:3 mixture of crusts to topsoil. 2.3 kg of crusts and 6.8 kg of topsoil were broadcast across the surface for a total of 9.1 kg crusts and soil per plot.

Spring soil treatments of sugar, fertilizer, and cryptobiotic crusts were applied in March of 1992 followed by mulch in May. Sugar was applied by hand as during fall treatments. Fertilizer was applied in May for all inclusive treatments, fall and spring alike. Spring application was done to avoid loss of nutrients with precipitation. 1.1 kg of fertilizer was hand spread across each plot. The fertilizer

consisted of a 1:2:1 ratio of nitrogen, phosphorus and potash. Spring cryptobiotic soil crusts were collected from the same area and applied to plots in a similar manner as in the fall. The mulch consisted of straw Hilaria jamesii and was spread on top of crusts to a depth of 5 cm for 90% coverage. Two to three bales per plot were used to accomplish this coverage.

Sugar treatments were re-applied in March, May, July and September of 1992 and will continue every other month between March and November throughout the 3-year study period.

Irrigation was initiated at the beginning of July 1992 and will continue monthly contingent upon rainfall in comparison to a 90-yr monthly precipitation average of 8.5 cm. The amount of water released bi-monthly is figured to equal the 90-yr average. One-half cm of water is released in a 10-minute watering event.

Measurement

Measurement consisted of counting *Stipa* stems, and determining the colonization rate and genera of vesicular-arbuscular mycorrhizae on the *Stipa* sp. *Stipa* density was used as the indicator of establishment. Aseptate mycorrhizal hyphae and VAM vesicles were examined to determine colonization rate while spores were sieved from soil samples to identify VAM genera.

Stipa Establishment

Stipa stems were counted in July and September of 1992. Plants were counted in 5 random square meter quadrats chosen from a 16-m² quadrat within each plot. On all plots, Stipa stems were counted in the same quadrats within each of the July and September sampling periods.

Vesicular-arbuscular Mycorrhizae

In June of 1992, five samples of Stipa sp. roots were excavated from each plot for determination of VAM colonization. For each sample, enough stems were pulled to collectively include at least 20 rootlets. The species counted was assumed to be Stipa comata due to the 2-3 year lag for germination typical of Oryzopsis hymenoides (SCS 1988). Random samples were chosen by walking to the center of the plot and selecting the closest grasses to the collector, in any direction, starting at the center and moving to the outside of the plot until sufficient roots were obtained. Small grasses were chosen to maximize success of pulling entire roots; soil compaction from construction and rainfall made long grass roots harder to obtain in entirety. Samples were not taken for VAM analysis from T17, the unwatered treatment; spring rainfall was above average (Needles District Visitor Center records, Canyonlands National Park) and irrigation had not yet been installed, so all treatment plots received equal water up to this point eliminating the

difference between T16 and T17. Subsamples were stored in 20 dram vials with 1:1 ethyl alcohol and water.

Samples were cleared and stained with Trypan Blue (Koske and Gemma 1989) within 1 wk of being pulled. Roots were heated in 2.5% KOH for 25 minutes at 90°C in a water bath. They were then rinsed with three changes of water: two with tap water and the final rinse with distilled water. Roots were acidified in 1% HCl for 1 hour. Staining the roots involved storage with acidic glycerol/Trypan blue for 20 minutes at 90°C in the water bath, rinsing with three water changes (two of tap water, one of distilled water), and destaining in acidic glycerol without Trypan blue where they remained until microscopic examination.

Roots were examined under a compound microscope and mycorrhizal colonization classed in 1 of 5 categories as follows:

<u>Category</u>	<u>Colonization Rate</u> <u>(% root length colonized)</u>
1	No Infection
2	>0 - 25%
3	>25 - 50%
4	>50 - 75%
5	>75 - 100%

VAM colonization was determined two ways; (a) definite colonization - percent root length occupied by aseptate hyphae in the presence of vesicles, and (b) probable colonization - percent root length occupied whether vesicles were present or not (Jim Trappe, personal communication). For definite colonization the colonization rate was recorded as category 1,

no colonization, in the absence of vesicles. Where vesicles were observed the colonization rate was recorded as estimated percent of root length occupied by hyphae. For probable colonization percent occupied by hyphae was the sole consideration for category placement.

Taxonomic identification of VAM fungi was accomplished by sieving spores from a soil sample and examining microscopically. The soil sample was collected as a conglomerate from five randomly chosen plots in the top 10 cm of soil during July of 1991. Spores were sieved using four screen sizes; sieving progressed through smaller screens in the order of 850 μm , 0.246 mm, 90 μm and 53 μm . No spores were found in the 53 μm sieve. Genera of mycorrhizal fungi were identified using keys by Schenck and Perez (1990).

Statistical Analyses

Data on VAM colonization and Stipa density was analyzed using multivariate analysis with Multiple Linear Regression tests. Mean densities of July and September Stipa measurements were log transformed to meet assumptions of normality and constance. Residuals of VAM measurements were distributed normally on an untransformed scale. The mean of each treatment was compared to the control of seed only plus water (T16) using an LSD multiple range test. Planned comparisons were made for treatments involving sugar and hay including each amendment in combination with other amendments

compared to the other amendments alone. Two analyses of VAM colonization were performed, one in which vesicles were required to indicate amount of VAM colonization greater than 0, and one in which aseptate hyphae were taken to indicate "probable" VAM (Jim Trappe, personal communication). Definite VAM colonization was regressed at July Stipa density to determine whether the treatments had the same pattern of effects and whether VAM colonization could be partially attributed to Stipa density. Definite VAM was then regressed at probable VAM colonization to determine whether similar factors determine hyphal colonization as vesicle formation. Both correlations were run with a Simple Linear Regression.

RESULTS

Stipa establishment

Stipa densities are reported for July and September measurements in Tables 2 and 3, respectively. None of the treatments produced significantly greater Stipa densities than the control treatment of seed only plus water (T16), while treatments with mulch resulted in significantly lower densities from both July and September measurements. Spring crust plus fertilizer (T13) had a significant negative effect in September and not in July. Likewise spring crust alone (T11) developed a fairly significant negative effect in September that was not demonstrated in July.

Several planned comparisons were made to identify effects of amendments not tested in isolation (Table 4). None of the comparisons for sugar or hay showed significant differences for July or September measurements.

The grass species on which density measurements were made could not be determined at this early stage of growth. Seed heads and more developed leaf structure are necessary to make positive species identification. It is probable, however, that Stipa comata was the species measured due to a 2-3 year delay of germination typical of Oryzopsis hymenoides (SCS 1988).

Vesicular-arbuscular mycorrhizae

Relative probable (aseptate hyphae) and definite VAM colonization (presence of vesicles) among treatments are reported in Tables 5 and 6, respectively. Six treatments increased definite VAM colonization by three to over five times above that of controls, and with a probability of 0.05 or greater: spring crusts alone (T11) and spring crusts with sugar added (T12), fall crusts with mulch added (T4) and with both mulch and sugar added (T6), mulch plus fertilizer (T9), and mulch plus sugar (T8). Of these, by far the strongest effect statistically ($p < 0.001$) was with spring crusts, spring crusts plus sugar, and fall crusts plus sugar and mulch. Spring crusts and spring crusts plus sugar did not differ from one another, indicating the effect was due solely to crusts.

Planned comparisons for effects of sugar and hay are listed in Table 7. Fall crusts plus sugar (T2) differed from fall crusts alone (T1) for definite and probable VAM, the sugar affecting definite VAM negatively and "probable" VAM positively. There was a difference between the combinations of fall crusts, mulch and sugar (T6) and fall crust plus mulch (T4), the sugar adding a synergistic positive effect. A difference also existed for probable VAM between sugar and mulch (T8) and mulch alone (T10), the sugar having a negative effect. There was no difference for the comparisons of spring

crust and sugar (T12) to spring crust alone (T11) nor for hay plus fall crusts (T7) to fall crusts alone.

The genus of VAM mycorrhizal fungi found in the soil and presumed to be associated with Stipa sp. was Acaulospora, forming endomycorrhizae with lobed vesicles (Schenck and Perez 1990). There was an insufficient number of spores to identify species, however the samples examined appeared related to A. longulata from the pale yellow coloring, the spore size in the 75 - 90 μm range, and the mucilaginous spore wall (Schenck and Perez 1990).

Definite VAM colonization and July Stipa density were highly uncorrelated from a Simple Linear Regression ($r^2 = 0.01$, $p = 0.05$). Definite and probable VAM colonization also did not show the same pattern of effects based on Simple Linear Regression ($r^2 = 0.0625$, $p = .05$).

Table 2. Mean July Stipa density for treatment groups. Treatments include water unless indicated otherwise. Significant differences were determined with the LSD multiple range test (* indicates difference from control (T16) at 0.05 level; LSD= 0.51 for 0.05 difference between two means).

<u>Treatment</u>	Mean No. <u>Stipa stems</u>
9 - mulch, fertilizer *	3.04
14 - s. crust, mulch *	3.10
8 - f. sugar, mulch *	3.43
5 - f. crust, fertilizer, mulch *	3.49
6 - f. crust, f. sugar, mulch *	4.30
4 - f. crust, mulch *	4.99
10 - mulch *	5.04
13 - s. crust, fertilizer	7.12
12 - s. crust, s. sugar	7.16
18 - s. crust, s. sugar, no water	7.73
7 - f. crust, hay	7.83
15 - fertilizer	8.47
11 - s. crust	8.58
3 - f. crust, fertilizer	9.76
16 - control: seed only	9.84
1 - f. crust	10.15
17 - seed, no water	11.22
2 - f. crust, sugar	11.34

Table 3. Mean September Stipa density for treatment groups. Treatments include water unless indicated otherwise. Significant differences were determined with the LSD multiple range test (* indicates difference from control (T16) at 0.05 level; LSD= 0.66 for 0.05 difference between two means).

<u>Treatment</u>	Mean No. <u>Stipa stems</u>
9 - mulch, fertilizer *	3.42
14 - s. crust, mulch *	3.56
8 - fall sugar, mulch *	3.58
10 - mulch *	4.86
5 - f. crust, fertilizer, mulch *	5.45
4 - f. crust, mulch *	5.78
6 - f. crust, f. sugar, mulch *	6.10
13 - s. crust, fertilizer *	9.42
11 - s. crust	9.34
3 - f. crust, fertilizer	11.19
15 - fertilizer	12.53
2 - f. crust, f. sugar	12.95
18 - s. crust, s. sugar, no water	14.22
12 - s. crust, s. sugar	15.49
1 - f. crust	16.68
7 - f. crust, hay	17.76
16 - control: seed only	18.38
17 - seed, no water	27.99

Table 4. Planned comparisons for July and September Stipa measurements.

X = significant difference, 0 = no significant difference (at 0.05 level).

For sugar effect:

July

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
2- f. crust,	f. sugar	1 - f. crust	0
12- s. crust,	s. sugar	11 - s. crust	0
6- f. crust,	mulch, f. sugar	4 - f. crust, mulch	0
8- f. sugar,	mulch	10 - mulch	0

September

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
For sugar effect:			
2- f. crust,	f. sugar	1 - f. crust	0
12- s. crust,	s. sugar	11 - s. crust	0
6- f. crust,	mulch, f. sugar	4 - f. crust, mulch	0
8- f. sugar,	mulch	10 - mulch	0

For hay effect:

July

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
7- f. crust,	hay	1 - f. crust	0

September

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
7- f. crust,	hay	1 - f. crust	0

Table 5. Mean definite colonization of VAM on *Stipa*. Treatments include water unless indicated otherwise. Significance was determined with the LSD multiple range test (* indicates difference from control (T16) at 0.05 level; LSD=14 for 0.05 difference between two means).

<u>Treatment</u>	<u>Mean % definite VAM Colonization</u>
2 - f. crust, f. sugar	6
16 - control: seed only	10
10 - mulch	11
15 - fertilizer	19
7 - f. crust, hay	20
18 - s. crust, s. sugar, no water	21
14 - s. crust, mulch	24
3 - f. crust, fertilizer	26
1 - f. crust	26
5 - f. crust, fertilizer, mulch	26
13 - s. crust, fertilizer	29
9 - mulch, fertilizer *	31
4 - f. crust, mulch *	31
8 - f. sugar, mulch *	37
12 - s. crust, s. sugar *	44
11 - s. crust *	47
6 - f. crust, f. sugar, mulch *	54

Table 6. Mean probable colonization of VAM on *Stipa*. Treatments include water unless indicated otherwise. Significance was determined with the LSD multiple range test (* indicates difference from control at 0.05 level; LSD=19 for 0.05 difference between two means).

<u>Treatment</u>	Mean % probable VAM <u>Colonization</u>
16 - control: seed only	35
15 - fertilizer *	51
14 - s. crust, mulch *	56
18 - s. crust, s. sugar, no water *	60
1 - f. crust *	61
3 - f. crust, fertilizer *	61
7 - f. crust, hay *	61
13 - s. crust, fertilizer *	62
9 - mulch, fertilizer *	64
8 - f. sugar, mulch *	65
5 - f. crust, fertilizer, mulch *	65
11 - s. crust *	68
10 - mulch *	68
4 - f. crust, mulch *	69
6 - f. crust, f. sugar, mulch *	74
12 - s. crust, s. sugar *	75
2 - f. crust, f. sugar *	78

Table 7. Planned comparisons for Definite and Probable VAM formation.

X = significant difference, 0 = no significant difference (at 0.05 level).

For sugar effect:

Definite

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
2- f. crust,	f. sugar	1 - f. crust	X
12- s. crust,	s. sugar	11 - s. crust	0
6- f. crust,	mulch, f. sugar	4 - f. crust, mulch	X
8- f. sugar,	mulch	10 - mulch	0

Probable

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
2- f. crust,	f. sugar	1 - f. crust	X
12- s. crust,	s. sugar	11 - s. crust	0
6- f. crust,	mulch, f. sugar	4 - f. crust, mulch	0
8- f. sugar,	mulch	10 - mulch	X

For hay effect:

Definite

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
7-f. crust,	hay	1 - f. crust	0

Probable

<u>Treatment a</u>	<u>compared to</u>	<u>Treatment b</u>	<u>Difference</u>
7-f. crust,	hay	1 - f. crust	0

Discussion

Stipa establishment

For both measurement periods, all treatments with mulch resulted in lower Stipa density than the control, whereas no other treatment differed from control. By September, most treatments with fertilizer also had significantly lower Stipa density than controls. Analysis of treatments is discussed with regard to each amendment below.

Straw mulch

The negative effect of mulch is in contrast with the literature and was a surprising result. Mulch has been found important in moderating moisture in semiarid systems (Wilson and Wilson 1992) for reasons including reduced moisture loss, lowered soil temperatures, reduced raindrop impact, and slower soil and water movement (McKell 1978). Other benefits of mulch have included retention of seed and fertilizer, inhibition of soil-borne pathogens (Wilson and Wilson 1992) and reduced wind velocity (Kay 1978, Hodder 1977). In this experiment the mulch may have created soil pathogen activity, causing damping off of seedlings. Soil temperatures and light may have also limited seedling establishment from excessive cover.

Competition from annual weeds imported with the mulch may deter its benefits (Gould et al. 1975), as may have happened in this experiment. The Hilaria seed heads of the mulch were purportedly removed, though Hilaria seedlings

germinated, which may have reduced Stipa density in treatment plots with mulch. The mulch may have created environmental conditions which were unfavorable to Stipa establishment for the first growing season. The organic matter and carbon added to the soil may be favorable for establishment of Stipa sp. in following years.

Cryptobiotic soil crusts

Adding topsoil has been favorable in semi-arid restoration in providing a soil micro-organism inoculum and native seed source (McKell 1978), re-establishing desirable plant species (Skujins and Allen 1986), increasing infiltration rates (Hodder 1978), and encouraging establishment of all plant cover (Cotts et al. 1991). Cryptobiotic crusts have been found to stabilize soil in arid systems (Campbell et al. 1989); the physical improvement and protection of arid soils may enable rehabilitation of arid lands (Isichei 1990). The singular cryptobiotic crust treatments (T1 and T11) in this study did not lead to increased Stipa density as predicted, though the effects of trampling may have impeded their effect. Fall crusts alone had no effect in either season while spring crusts had a negative effect at the 0.07 significance level.

Soil compaction and crust debility resulting from human travel over the soil from numerous measurements is a possible explanation for the failure of crusts to enhance Stipa establishment. All treatment plots were measured the

same number of times, so this effect applies to all treatments, though the predicted effect may have been reduced due to trampling. Past studies have recorded loss of total crust cover (Beymer et al. 1992) and cryptobiotic species diversity (Anderson et al. 1982) as a result of livestock grazing. Machinery compaction and tillage systems such as rotary and chisel plow have also reduced the rate of water infiltration in arid land agricultural fields (Abo-Abda and Hussain 1990).

Trampling appeared to compact the soil which may have limited infiltration and/or the water- and nutrient-retention capacity of the crusts. Stipa establishment may have subsequently been reduced due to small roots without the capacity to access nutrients and water (SCS 1988). However, neither fertilization nor watering improved Stipa establishment suggesting that nutrients and water were not limiting at this stage of the experiment. It is also possible that nutrients and water were not able to infiltrate down to the level of the roots, and may have evaporated on the surface before plants could utilize them.

Cryptobiotic crusts accumulate significant amounts of soluble carbon in fall and less so in spring, attributable to carbohydrates generated by the crust during photosynthesis (Beymer and Klopatek 1991). Various species of cyanobacteria have been associated with excretion of carbon, which have also been closely associated with

bacteria that assimilate the excreted material (Bauld and Brock 1974). Carbohydrate contents of crusts has been found to peak two days after the major spring thaw in Antarctica (Tearle 1987). Mosses have also exhibited carbohydrate leakage in a brief pulse for a few minutes following desiccation and rehydration (Beymer and Klopatek 1991). The contribution of carbon by crust organisms has been found nearly double in concentration in the fall as the spring (Beymer and Klopatek 1991). This may reflect carbon accumulation from photosynthesis over the summer.

Above-average spring rains would have been thought to increase available carbon to the soil from the crusts and encourage microbial activity. Soluble carbon has been found to move to lower levels in the soil within 10 days of photosynthesis (Beymer and Klopatek 1991). It seems logical to conclude that soluble carbon must thus be quickly utilized following availability or may be leached out of the plant-soil system.

Fertilizer

Desert soils are typically limited by nitrogen, phosphorus (Bauer et al. 1978) and potassium (Khudairi 1969) as well as characterized by low C-N ratios (Cundell 1977). Fertilizer was added here to supply limiting nutrients to the system with the expectation that the competing annual plants would use the nutrients to the detriment of perennial grasses.

Fertilization of plant communities occupying highly infertile sites has repeatedly been found ineffective for plant establishment and growth in infertile environments. Moderate nutrient additions (a 50% increase in annual nutrient flux) may be immobilized by inorganic adsorption and chemical solubility on infertile sites (Chapin III et al. 1986). This may also make a site infertile by tying up nutrients that seasonally become available. High fertilization has decreased the relative abundance of Stipa comata on a native range in Alberta (Johnston et al. 1967). In another study nitrogen increased production of Bromus tectorum, a weedy annual, and reduced production of perennial grasses in central Washington (Sneva 1963). A study in southeastern Oregon similarly found a 50% depression of a native grass, Agropyron spicatum, while Bromus tectorum increased by 600% over a 4-year period with repeated ammonium application (Kay 1966).

For my study, average Stipa density for the fertilizer only treatment (T15) was 30% lower than the control for the September measurement, however the difference was not statistically significant. With more replications we might have demonstrated the hypothesized fertilizer effect.

Sugar

Disturbed grasslands are typically characterized by increased nitrifying activity (Rice and Pancholy 1973), encouraging annual weeds which can rapidly absorb available

nutrients (Costello 1944). This was expected to be countered with the addition of sugar; sucrose was added as a rapidly utilizable energy source for the purpose of increasing decomposer biomass, temporarily decreasing available soil nitrogen. Addition of sucrose as an amendment to semiarid systems in the past has had marginal to no success increasing the density of perennial grasses and forbs: Sugar had no impact on the growth of Artemisia tridentata in a Great Basin study (Miller et al. 1991), lowered the decomposition of litter in a semiarid prairie (Coleman et al. 1990), and only marginally increased the success of perennial grasses at a semiarid sagebrush site (McLendon and Redente 1991).

Stipa densities in this experiment similarly did not respond to added sugar. Planned comparisons to test the effect of sugar include fall crust plus sugar (T2) with fall crust (T1), spring crust plus sugar (T12) with spring crust (T11) and fall crust, sugar and mulch (T6) with fall crust plus mulch (T4). In none of these cases did added sugar result in a significant difference.

Hay

The hay mixed into the soil was intended to provide aeration and a source of carbon with decomposition. Hay with fall crusts (T7), the only treatment involving hay, did not produce a significant difference in Stipa density in

relation to the control treatment nor in relation to fall crusts alone (T1).

Water

Suprisingly, the highest average Stipa densities were in unwatered control treatments in September, although they did not differ significantly from the watered controls. Above-average rainfall occurred during months of March and May (11 cm between March and May versus the average 8.7 cm, Needles District Visitor Center records, Canyonlands National Park). The added water may have increased plant growth of all treatments and mitigated the comparison of watered and unwatered treatments.

Water is thought to be a major limiting factor to nutrient capture and plant productivity in the Great Basin (Skujins and Allen 1986, Allen and Allen 1984), and often determines the success or failure of reclamation efforts (Thames 1977). Irrigation has generally been recommended as a safeguard against drought in the early years of revegetation of arid lands (McKell 1978). Increasing soil moisture has facilitated nutrient uptake and plant growth in past studies (Ries and Day 1978), and increased the relative abundance of perennial grasses over S. kali in a dry grassland system (Lauenroth et al. 1978). Establishment of Stipa comata has been improved in past research with increased soil moisture (Costello 1944).

Analyses of field studies classically produce unexpected results due to a multitude of confounding factors, as did this study. Factors which may have influenced differences in Stipa density not accounted for by treatments include differences in substrate textures and depth, pre-existing micro-organisms, and the effect of rabbits clipping the stems, though there is no evidence these effects differed among treatments and the randomized block design should have accounted for differences. The length of this study may be insufficient to determine the eventual relative Stipa density or its role in community dynamics. Past studies of semiarid grassland restoration and rehabilitation have been measured for 2- to 3-year periods (Reeves et al. 1979, Allen and Knight 1984, Piemiesel 1951). Further monitoring of the study plots may provide more conclusive evidence of Stipa dynamics.

Vesicular-arbuscular mycorrhizae

VA mycorrhizae are thought beneficial in arid ecosystems for many reasons, including increasing water- and nutrient-absorption capacity, particularly phosphate-absorbing surfaces of perennial grass roots in low-phosphate soils (Allen 1991). VAM are believed to require a relatively continuous cover of host plants in order to persist in soils, and soil disturbance has been shown to significantly reduce VA inoculum potential (Allen

and Boosalis 1983). There was a poor correlation between Stipa density and mycorrhizal colonization. This is in contrast to what was predicted, in that extent of colonization is typically correlated with nutrient absorption of the plant and consequent growth (Harley and Smith 1983, Clapperton and Reid 1992).

All treatments resulted in greater probable VAM formation (presence of aseptate hyphae only). However, definite VAM (vesicles present), was significantly increased ($p = 0.05$) by only six treatments: spring crusts, either with or without sugar; fall crusts with mulch or with mulch and sugar; mulch with sugar; and mulch with fertilizer. Some treatments had quite different effects on probable and definite colonization. For example, fall crusts plus sugar did not influence definite colonization at all, but had a very strong effect on probable colonization. Mulch followed a similar pattern. Since vesicles are generally formed sometime after initial colonization (Harley and Smith 1983), it is reasonable to assume that the presence of vesicles in this study indicate colonization that occurred earlier in the growing season. Except for fertilizer, I will discuss treatment effects primarily in terms of carbon either as a source of energy and structure (cryptobiotic crusts, mulch, hay) or solely as an energy source (sugar). My discussion will focus on definite colonization.

Carbon as an energy source - Sugar

Sugar adds an immediate energy source which may have activated the micro-organisms. A number of comparisons were made to isolate the effects of sugar. Fall crusts plus sugar (T2) compared to fall crusts alone (T1) differed for definite and probable VAM. The effect of adding sugar to fall crusts was extremely negative for definite VAM and extremely positive for probable formation. Bacteria have been found to inoculate host plants simultaneously with mycorrhizal fungi. The presence of bacteria and microflora in the soil in general may enhance or suppress mycorrhizae and plant growth (Linderman 1987). Some types of bacteria require an external source of amino acids and/or vitamins secreted by plant roots in an undisturbed ecosystem (Richards 1987). Microflora also contribute to the production of exudates in the rhizosphere. Sugars have been identified as exudates, with glucose being one of the most abundant. The sugar added may have stimulated bacteria which encourage mycorrhizal formation, though later than formation without sugar. The positive effect on possible VAM would then reflect increased hyphal development and the negative definite VAM would be reflective of later initiation of formation not yet to the point of vesicle development.

A comparison of fall crust plus sugar and mulch (T6) to fall crust plus mulch (T4) differed for definite VAM.

Treatment T6 created a synergistic effect where the additive effects of fall crust plus sugar and fall crust plus mulch (6% + 31% = 37%) is less than the treatment with all three (54%). The synergism produced an extra 17% colonization that cannot be explained as additive effects of the treatments. The mulch provided a slower, more continuous energy supply, some nutrients from decomposing Hilaria, as well as vitamins, amino acids, or other organic acids, normally provided by plant secretions or decomposition (Richards 1987). The sugar provided a quick energy source which may have stimulated bacteria that encourage formation. The mulch may have also provided aeration and water-holding capacity.

Spring crust plus sugar (T12) compared with spring crust alone (T11) did not differ for definite or probable VAM, indicating the spring crusts were responsible for the positive effect. Sugar plus mulch (T8) compared to mulch alone (T10) differed for probable but not definite VAM. Sugar probably stimulated VAM-enhancing bacteria, though probably the formation developed later. Though the mechanism is not directly discernible, it can be inferred that sugar can be expected to lead to increased VAM colonization.

Carbon as energy and structure

Desert ecosystems are characterized in part by low organic matter (Cundell 1977), the retention of which is

critical to preserve nutrients and reduce erosion (Paul 1976). The presence of organic matter is thought key to developing structure in sandy soils, while the amount and constituents of the pool of organic matter is vital to the functioning of an ecosystem (Forster 1990). Treatments with straw, hay, and cryptobiotic crusts potentially provided structure to physically hold together the soil particles, and carbon as utilizable energy as the filamental structures broke down.

High organic matter usually promotes VAM establishment and persistence (St. John and Coleman 1983, Harinikumar et al. 1990), though when carbon is a major limiting factor the fungus has been found to act more as a pathogen than mutualist (Behlenfalvay et al. 1982). Many micro-organisms increase soil organic matter. Cyanobacteria, a major component of the cryptobiotic crusts, fix atmospheric nitrogen which stimulates the growth of micro-organisms. The diversity of a microbial population is site-specific, reflective of the organic matter content (Alexander 1965). Utilization of cyanobacteria and other nitrogen-fixing organisms of the soil biota has been recommended for improved arid land revegetation though the manipulation of soil biota has not been greatly undertaken (El-Tayeb and Skujins 1989).

Mulch

The soil ecosystem is thought to greatly benefit from any organic mulch, leading to stimulated mycorrhizal fungi and a root system protected from deleterious infection (Levisohn 1956). VA fungi have also colonized more heavily with the greater aeration and breakdown products of bacteria and other micro-organisms mulch provides (Wilson and Wilson 1992). Mulch alone did not increase definite colonization, nor in combination with spring crust, or fall crusts and fertilizer. Though mulching did not improve mycorrhizal formation, environmental conditions created by the mulch may have been beneficial to the overall ecosystem. These conditions include temperature reduction from shading, a physical impediment to erosion, and protection of the root system from infection (Levisohn 1952).

Hay

Hay plus fall crusts (T7) did not differ from fall crusts (T1) for definite or probable colonization.

Cryptobiotic soil crusts

Spring crusts had a strong positive effect on VAM, while fall crusts did not have an effect unless amended with sugar and/or mulch. I discuss crusts in relation to VAM, followed by possible differences of spring versus fall crusts.

Mycorrhizal inoculum may have been imported with the crusts. The inoculum potential has rarely been retained as

a result of topsoil retention when stockpiling interceded removal and replacement (Miller 1987). Long fallow periods have been found to reduce levels of mycorrhizal colonization and growth of Helianthus annuus (Thompson 1987). The soil crusts should have also improved water retention and reduced erosion forming a protective blanket for the soil ecosystem (Anderson et al. 1982, (1)). Spores could have then been trapped by the crusts and been in closer contact with the Stipa increasing inoculum potential. Immediate re-application should have saved the micro-organisms from desiccation (McKell 1978) for the spring crusts in this experiment.

Organic volatiles serve as the sole energy and carbon source for some microbes (Stotzky and Schenck 1976). Numerous organic volatile substances have inhibitory and stimulative effects on both microbial activity and plant growth. The volatiles are produced by biotic and abiotic sources. Biotic producers include soil microbes, seeds, living and dead plant matter, and animals, while the major abiotic sources include combustion of fossil fuels, industrial processes, burning and pesticides. Fungi produce a great diversity of volatiles (Stotzky and Schenck 1976), though the end effect is difficult to determine due to a great number of organisms and factors which may have an influence.

The effect of volatiles on mycorrhizal colonization cannot be determined without collective information about all volatiles affecting this system. The interactions of microbes in the rhizosphere are selective for each set of organisms (Azcon et al 1989). Ethylene has been found to form in soils as a result of microbial activity, encourage fungistasis in soil and adversely affect plant growth (Lindberg et al. 1979), though other volatiles are likely influential on growth dynamics as well. The great diversity of possible effects of volatiles further illustrates the complexity of the ecosystem.

Greater colonization of spring versus fall crusts may have to do with increased biological activity of the soil biota in the spring (Beymer and Klopatek 1991). Organisms in the fall crusts probably became less active shortly after application. The fall crusts effectively were "stockpiled" over the winter resulting in reduced inoculum potential and colonization.

Spring is the season of maximum precipitation in the Great Basin desert (Loope 1978), which in combination with increasing day length and warmer temperatures triggers biological activity and micro-organisms in the soil environment become active. The simple carbohydrates and amino acids given off by cryptogamic plants would stimulate microbial activity. Rhizosphere bacteria likely to stimulate VAM formation are also more common in the spring

(Richards 1987). The resulting crusts the following spring may not contain as many viable organisms as the more recently transferred spring crusts.

The addition of organic matter to the system under study may have affected plant establishment and mycorrhizal colonization by providing limiting nutrients, vitamins, amino and/or organic acids, stimulating mycorrhizal colonization, and/or instigating production of volatile substances which may be either inhibitory, stimulative or have no effect on both plant growth and fungal activity.

Fertilizer

The response of VAM formation to the nutrient environment has been found to be curvilinear, in which formation increases with stressful environmental conditions to a point, and then declines (Allen 1991). At the low end of the curve there may be fewer or less nutrient-rich plants to support formation, and less inoculum potential. The nutrient increase would support more colonization until the plant cover is dense enough that resource allocation to the fungi is no longer biologically worthy with mounting competition from other plants.

Fertilizer alone did not result in greater colonization. The lack of response for fertilizer further supports the curvilinear relationship where the nutrient level of the soil may have been near the point of maximal formation before the fertilization. The nutrients added may

have not been assimilable to the plants before leaching from the upper soil layers (Beymer and Klopatek 1991). Even if in the soil long enough for absorption, the addition of fertilizer also may not have resulted in more nutrient-rich plants; there is evidence that plants accustomed to nutrient-poor environments do not assimilate artificial fertilization (Chapin III et al. 1986).

The inhibition of mycorrhizal colonization from inorganic fertilization concurs with results of past studies. High rates (Skujins and Allen 1986) and intensive use of inorganic fertilizers have drastically inhibited VAM formation (Haymen 1982). Fertilization has resulted in decreased root colonization of Andropogon gerardii, an arid-land grass (Hetrick et al. 1988), as well as decreased microbial biomass, soluble organic carbon, and soil organic matter (Klein 1989).

Water

Above average spring rainfall partially reduces the extent of water exclusion, as with Stipa density. The control treatment for water with seed only and no water (T17) was not measured for definite or probable VAM colonization. By the month of June when VAM measurements were taken, spring rainfall had been great enough to not allow for a valid comparison. This was not true for the Stipa measurements when drying out of the non-water treatments had been allowed to occur. The one treatment

without water measured for VAM analysis (T18) resulted in a marginal increase above the control compared to the other treatments. Results are hypothesized for years of average rainfall.

A significant reduction in mycorrhizal colonization would be expected without irrigation based on past research, though irrigation in arid ecosystems can also induce salinity and inhibit establishment of VAM (Hirrel 1981). Another possibility for a year with average rainfall is a waterlogging effect which may reduce colonization from excessive water. The numbers of hyphal entry points on roots hairs have been found to be lower in wet soil, especially in dry habitats (Harley and Smith 1983). Desiccation of mycorrhizal fungi is common in arid ecosystems, requiring resistant propagules to survive drought (Gray and Williams 1971). Fungal colonization may be less affected by lack of water than Stipa density as less moisture has been found necessary for spores than plant seeds to germinate (Johnson 1977).

Revegetation

The measurements taken in this experiment are two assessments of ecosystem health, implicating above- and below-ground functions. The volume and diversity of organisms and relationships which act on this system make the possibility of knowing and understanding all of them

unlikely. Identifying organisms, functions and processes critical to maintaining the physiological processes which make up the ecosystem may provide the initiative needed to rehabilitate and/or restore the vast quantity of disturbed arid lands.

While identification of deterministic ecological functions spans a range of elements, actors and processes which may influence each other, as in a food web, improvement of an ecological system may require a total systems approach encompassing as much information about deterministic parts of the ecosystem as is feasible. In that naming and understanding the function of every member of the soil biota is neither possible nor likely useful to replication, protection of a system must assume every organism is essential and protect the land in entirety. Determination of which organisms have a synergistic effect on reproduction and persistence of the ecosystem is the issue for rehabilitation of land already denuded.

Techniques involving manipulation of soil biota have been recommended for arid land rehabilitation. Included are utilization of available organic matter, cyanobacteria and other N-fixing members of the soil biota, and mycorrhizae for improved revegetation efforts (El-Tayeb and Skujins 1989). From this study the addition of sugar, mulch and soil crusts provided a favorable environment for mycorrhizal colonization, while fertilizer did not add significantly to

formation. Fertilization is not recommended for disturbed areas where nutrients are limiting and competition by annuals is probable, while the use of renewable organic amendments is encouraged.

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