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Effects of Topsoil Stockpiling on Soil Viability at Yucca Mountain, Nevada

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Management & Operating Contractor

Effects of Topsoil Stockpiling on Soil Viability at Yucca Mountain, Nevada

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) is evaluating the suitability of Yucca Mountain in Nye County, Nevada as a monitored geologic repository for spent nuclear fuel and high-level radioactive waste. The DOE is committed to reclaiming land disturbed by site characterization activities and has implemented a program to conduct habitat reclamation at Yucca Mountain. As part of the reclamation program, topsoil, a limited resource, has been salvaged from Yucca Mountain Project construction sites and stockpiled for subsequent use during reclamation.

Salvaging and stockpiling topsoil is important for habitat reclamation in the Mojave Desert because suitable soil material often is a major limiting factor. However, stockpiling topsoil can adversely affect soil viability (i.e., result in negative changes in the microbial, physical, and chemical properties of the soil) and hinder plant growth. However, much of the research documenting the effects of topsoil stockpiling on soil viability has been conducted in areas with different soils and more mesic conditions than those at Yucca Mountain. Currently, there is no information on how salvaging and stockpiling topsoil influences soil viability in desert ecosystems. Information also is lacking on how vegetation planted on stockpiles influence soil viability in desert ecosystems.

In May 1993, a study was initiated to determine the effects of revegetation treatment, stockpile depth, and duration of stockpiling on soil viability at Yucca Mountain. The study was implemented on the Exploratory Studies Facility (ESF) Borrow Pit topsoil stockpile. Topsoil was salvaged and stockpiled in March 1993, and vegetation was planted using four seed mixes (revegetation treatments) that differed in the proportions of shallow-rooted, deep-rooted, and legume species. These treatments were chosen so that the plants on different plots would have different rooting depth profiles.

Soil viability sampling began in May 1993, approximately 40 days after the stockpile was seeded. Three aspects of soil viability were considered: microbial biomass (active and total bacterial and fungal biomass; counts of vesicular-arbuscular mycorrhizae spores), percent soil moisture, and physical and chemical properties of the soil. Within each of the four revegetation treatments, soil samples were collected from five depth layers in the stockpile. Soil was also sampled from the surface layer of adjacent, undisturbed topsoil. Soil samples were collected approximately every month until December 1993 ($n = 7$) to determine short-term effects of stockpiling. During 1994 and 1995, three additional sets of soil samples were collected (approximately every six months) to determine longer-term effects of stockpiling. Weather conditions were monitored with a nearby meteorological station.

The density of seeded species was measured in April 1994, and species composition on all of the plots was found to be similar. Soil viability analyses revealed that none of the revegetation treatments was associated with consistently higher levels of microbial activity at any soil depth or over time. The lack of a treatment effect was attributed to similarities among vegetation on the plots. Also, after only one year, the plants may not have had time to establish deep roots.

No differences among soil depths were found in the amount of bacteria or fungus in the stockpile over time. However, the amount of bacteria and fungus in the stockpile differed from undisturbed topsoil during the first year of the study. These differences were attributed to the initial impact of topsoil salvage and the subsequent interactions between bacteria and fungi. During the first 110 days

in the stockpiled topsoil, fungal populations declined and bacteria became relatively more abundant. In undisturbed soil, fungi were more abundant than bacteria during this time. After 110 days, fungal populations in the stockpiled topsoil temporarily recovered, but then they again declined and bacteria became dominant during the remainder of the first year. During this same time, fungi remained the dominant form in undisturbed topsoil. The disparities in fungi and bacterial dynamics between stockpiled and undisturbed topsoil during the first year may be related to competitive interactions between these organisms. Other factors such as predation and substrate availability (that were not measured) also may have influenced the results.

During the second year, the amount of fungus and bacteria in the stockpiled topsoil generally was similar to that in the undisturbed topsoil. For total bacteria, no significant differences existed between stockpiled topsoil and undisturbed topsoil. Differences in the amount of active bacterial and fungal biomass were found between stockpiled and undisturbed topsoil during the second year of the study; however, the rates of change in these biomass components were similar over time, suggesting that the biomass of microbial populations in the stockpiled topsoil changed over time in ways that were similar to those in the undisturbed topsoil. Counts of vesicular-arbuscular mycorrhizae spores in the stockpiled and undisturbed topsoil did not differ until the end of the second year (when more spores were found in the stockpiled topsoil). Microbial populations in the stockpiled and undisturbed topsoil may have been more similar during the second year of the study because vegetation and soil moisture conditions were more similar than those found during the first year.

Soil physical and chemical properties generally were similar in the stockpile and adjacent undisturbed topsoil throughout the study. Thus, topsoil stockpiling had little effect on the physical properties of these desert soils.

The most important result, from a topsoil management standpoint, was that the stockpiled topsoil continued to have some microbial activity throughout the duration of this study (although activity in the stockpile differed somewhat from that in undisturbed soil) and at all depths in the stockpile. Thus, topsoil stockpiling did not appear to be detrimental to soil viability at Yucca Mountain, and changes in current management practices for stockpiling topsoil are not warranted.

CONTENTS

Page

CONTENTS (continued)

Page

FIGURES

Page

TABLES

1. INTRODUCTION

1.1 Project Overview

As required in the Nuclear Waste Policy Act (NWPA) of 1982 and the Nuclear Waste Policy Amendments Act of 1987, the U.S. Department of Energy (DOE) is characterizing Yucca Mountain, Nye County, Nevada for the potential development of a geologic repository for spent nuclear fuel and high-level radioactive waste. In keeping with requirements in the NWPA to conduct these investigations in an environmentally sound manner, DOE developed an Environmental Management Plan for the Yucca Mountain Site Characterization Project. As part of the environmental program, DOE has implemented habitat reclamation to reclaim lands disturbed by site characterization activities (DOE 1989). As part of reclamation, topsoil has been salvaged, removed from construction sites, and stockpiled for subsequent use during reclamation. Salvaging and stockpiling of topsoil is needed because the lack of suitable soil material is a major factor which can limit successful reclamation in the Mojave Desert (Wallace et al. 1980).

1.2 Previous Research

Research has shown the importance of adequate topsoil for plant growth and establishment (Power et al. 1976, Wallace et al. 1980, Schuman et al. 1985, Ostler and Allred 1987, Claassen and Zasoski 1993), as the lack of topsoil can prevent successful revegetation. Salvaging of even minimal amounts of topsoil in desert ecosystems is critical for successful reclamation (Ostler and Allred 1987).

Although salvaging topsoil is important for reclamation, research conducted on the effects of stockpiling topsoil generally suggests that salvaging and stockpiling adversely impact the physical, chemical, and microbial properties of soil that promote and sustain plant growth (i.e., soil viability). Physical properties of the soil that can be affected by topsoil salvaging and stockpiling include compaction of the soil (Ramsay 1986), increased bulk density (Abdul-Kareem and McRae 1984), and decreased water holding capacity (Miller and Cameron 1976). Effects of stockpiling topsoil on chemical properties of the soil also have been documented. In stockpiled soils having large percentages of clay, ammonium can accumulate due to inhibition of the nitrification process (Abdul-Kareem and McRae 1984, Harris and Birch 1987, Harris et al. 1989). Organic carbon in stockpiled soils has been found to decrease with increasing depth and age of the stockpile (Abdul-Kareem and McRae 1984, Harris and Birch 1987).

Microbial communities, which are partly responsible for the decomposition of organic matter and nutrient cycling, also can be affected by topsoil stockpiling. The amount of bacterial biomass in the soil can increase after stockpile construction as a result of incorporating organic matter (e.g., stems, leaves, roots of plants) into the soil during salvage operations (Harris and Birch 1990, Harris et al. 1989). Fungal biomass in the soil also can be affected. During topsoil removal, fungal biomass can be reduced by tearing, crushing, and breaking fungal hyphae (Harris et al. 1989). One major group of fungi that can be impacted by topsoil stockpiling is the vesicular-arbuscular mycorrhizal (VAM) fungi (Harris et al. 1987, Miller et al. 1985, Rives et al. 1980, Visser et al. 1984). VAM fungi are important because they form symbiotic relationships with plant roots and improve water and nutrient absorption by the roots (Salisbury and Ross 1992). Reductions in VAM fungi can negatively impact the establishment and persistence of plants that rely on these fungi (Stark and Redente 1987).

The depth of a topsoil stockpile, and the duration of stockpiling, are major factors that can influence the viability of soil in a stockpile. At a coal mine in North Dakota, soil bulk density increased, and water holding capacity decreased, with increasing depth in a topsoil stockpile (Miller and Cameron 1976). These effects were attributed to the compacting force from upper soil layers of the stockpile. Rives et al. (1980), in a study conducted at the same mine, found that viable inocula of VAM were reduced in a 3-year-old topsoil stockpile when compared to adjacent undisturbed areas. In England, there was less microbial activity (aerobic bacteria, fungal biomass, and total microbial biomass) in the deeper parts of a stockpile, and there was less microbial activity as the stockpile aged (Harris et al.1989). At another site in England, there were fewer fungal propagules and actinomycetes in deeper parts of a stockpile, especially when stockpile depths exceeded 1 m (Johnson et al. 1991). In New Zealand, Ross and Cairns (1981) compared soil from 10-year-old stockpiles with soil from adjacent undisturbed areas. At depths of greater than 1 m in the stockpile, they found less microbial biomass and more ammonium nitrate than in the undisturbed areas.

The recovery of microbial populations after topsoil has been salvaged appears to depend on the amount of organic matter present in the soil (Elkins et al. 1984, Visser 1985). Living vegetation provides a source of leaf litter and other organic matter that is available for decomposition (Fresquez et al. 1986, Visser 1985, Wilson 1965), therefore the presence of vegetation can be critical in the recovery of microbial populations. As a result of this, reclamation manuals generally recommended reestablishing vegetation on topsoil stockpiles as soon as possible after salvage (BLM 1992, Brown and Hallman 1984, USDA 1979). Vegetation also aids in stabilizing topsoil stockpiles by reducing wind and water erosion. It is also recommended that species used to revegetate stockpiles should be species that are compatible with the ultimate use of the topsoil (e.g., do not use exotic species if the topsoil will be used to reestablish native vegetation; BLM 1992, Brown and Hallman 1984, USDA 1979). However, there are no recommendations concerning which species are most beneficial for improving microbial recovery after topsoil salvage.

Much of the research documenting the effects of topsoil stockpiling on soil viability has been conducted in areas with environmental conditions more mesic than those at Yucca Mountain (e.g., North Dakota, England, and New Zealand), and there is no information on the effects of topsoil salvaging on soil viability in arid desert ecosystems. Although research has indicated that vegetation is critical for improving soil viability (e.g., Stark and Redente 1987), little research has been conducted in arid regions on the effects that different species of plants may have on the viability of stockpiled topsoil. Information on these matters would aid in improving soil viability after stockpiling, and they may aid in determining whether mitigation efforts (e.g., reinoculation, fertilization, etc.) are necessary before topsoil can be used to reclaim habitat in arid regions.

1.3 Objectives

The objectives of this study were to determine the effects of plant species composition, stockpile depth, and the duration of stockpiling on soil viability in an arid ecosystem.

2. METHODS

2.1 Study Area

Yucca Mountain is located in southwestern Nevada, approximately 150 km northwest of Las Vegas, Nevada, and 26 km north of Amargosa Valley, Nevada (formerly Lathrop Wells). The study site was located exclusively within lands controlled by the federal government. This study was conducted using a topsoil stockpile that was created during excavation of the Exploratory Studies Facility (ESF) Borrow Pit (Figure 2-1). Salvaging and stockpiling the topsoil began in late January 1993, and was completed by April 1, 1993. The upper 45 cm of the soil was removed from the borrow pit using bulldozers and scrapers. Upon completion, the stockpile was 95 m wide, 200 m long (1.9 ha), and was approximately 2 m deep.

Soils at the site were mixed alluvium and well- to excessively-well drained. The majority of the soils within the ESF Borrow Pit area were classified as Typic Haplocambids (Aridisols; CRWMS M&O 1997). Soils in the excavated area had an A-horizon that was generally 0-20 cm deep, a weakly defined B-horizon that was 20-40 cm deep, and a C-horizon that was 40-150 cm deep. Soil textures were sandy loams, and 25-40% of the material was composed of rock fragments.

The study site was in the Creosote-Bursage (*Larrea-Ambrosia*) vegetation association. The three dominant perennial shrubs at the site were creosotebush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*) and Nevada jointfir (*Ephedra nevadensis*).

2.2 Climate

Climate in the Yucca Mountain area was characterized by strong solar insolation, limited precipitation, low relative humidity, and large daily temperature ranges. DOE has collected more than 30 years of weather data at a weather station (4JA) located 12 km southeast of the study site (DOE Nevada Operations Office, unpublished data). Average annual precipitation during 1965-1995 at this weather station was 139 mm. Precipitation in the Yucca Mountain area was seasonal with most of the precipitation falling during winter and early spring. The amount of annual precipitation fluctuated from year to year, and precipitation occurred on relatively few days each year. Precipitation events greater than 0.2 mm only occur on approximately 30 days per year at the Nevada Test Site (Eglinton and Dreicer 1984). Temperatures, averaged over the 30-year period, were 35.6 °C during the warmest month (July) and 1.8 °C during the coldest month (December).

During the study, precipitation and temperature were recorded at Meteorological Station 1, a component of the Yucca Mountain meteorological monitoring network. This station was located approximately 2 km west-northwest of the study site. Precipitation during the study was above average during the winter and spring of 1993 and 1995, but it was below average during winter and spring of 1994 (Figure 2-2). Precipitation that fell during January and February 1993 (about 85 mm each month) while the topsoil stockpile was being constructed (late January through March 1993), was more than four times greater than the average for these months (about 20 mm). Temperatures were slightly warmer during the summer of 1994 than during the summer of 1993 (Figure 2-2).

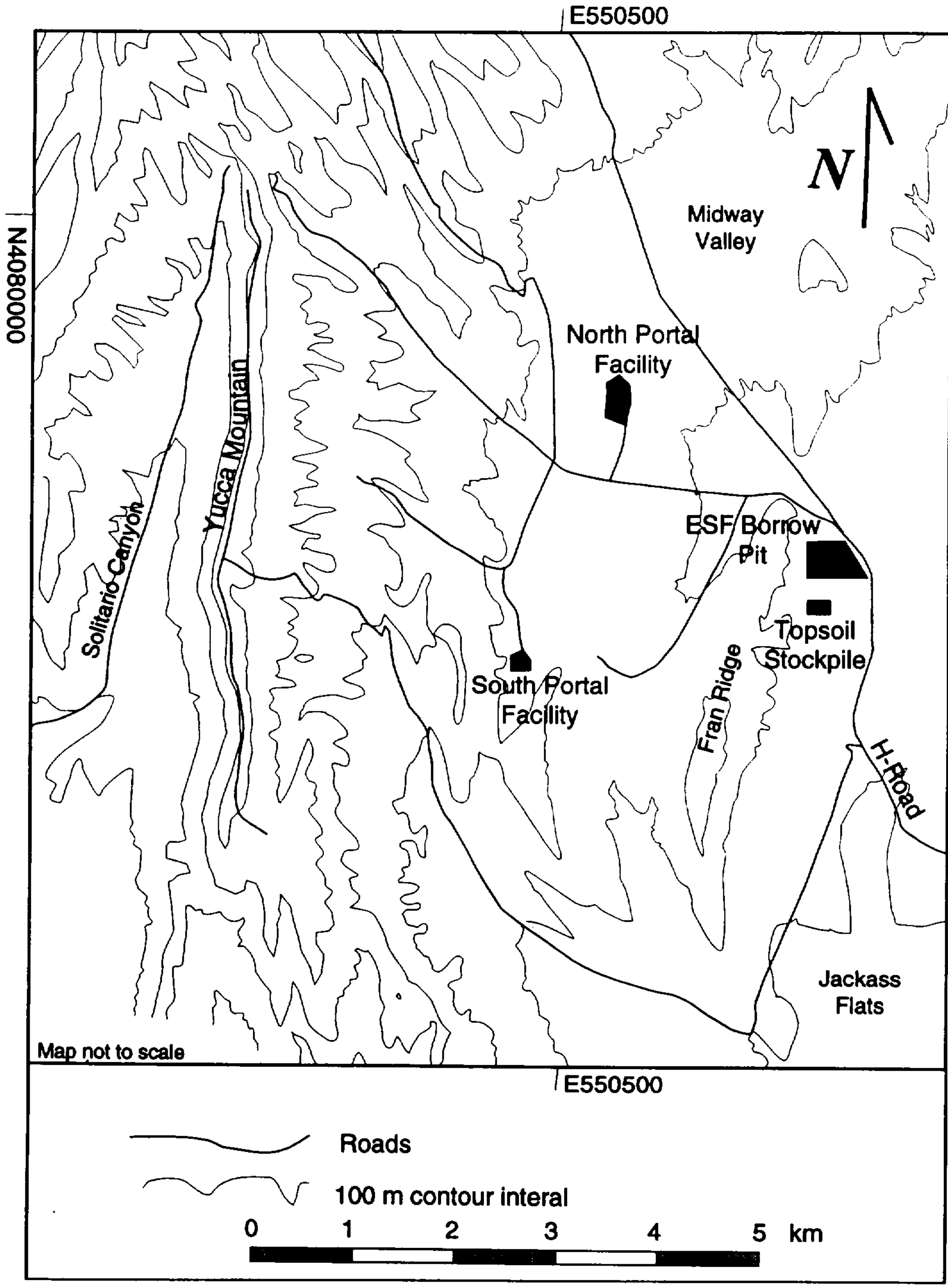

Figure 2-1. Location Exploratory Studies Facility Borrow Pit and topsoil stockpile at Yucca Mountain, Nevada.

2.3 Experimental Design

The experimental design for this study had two phases. The first phase was to determine the best mix of plant species for maintaining soil viability, and the second phase was to compare soil viability parameters from the best treatment with those from undisturbed soils.

In the first phase, the assumption was made that the best revegetation treatment (i.e., mix of seeds) would be the one that resulted in the highest levels of soil viability at each depth in the stockpile over time. Therefore, the first phase was designed to determine if revegetation treatments affected soil viability. The experimental design for this phase was a two-factor repeated measures analysis of variance with five replicates. The first factor in the design was *Revegetation Treatment* (Table 2-1), and this factor had four levels: 1) *native mix* - a seed mix containing plant species in proportions comparable to that at which these species occur in native plant communities; 2) *shallow mix* - a seed mix containing the same species, but with proportionally more seeds of the shallow-rooted species than deep-rooted species; 3) *deep mix* - a seed mix containing the same species, but with proportionally more seeds of the deep-rooted species than shallow-rooted species; and 4) *legume mix* - a seed mix with shallow-rooted native species and exotic legume species. The second factor was *Soil Depth*. For this factor, samples of soil were taken from 5 depths: 1) 0-20 cm; 2) 50-70 cm; 3) 100-120 cm; 4)160-180 cm; and 5) 210-230 cm below the surface. The parameters measured (i.e., response variables) included active and total bacterial biomass, active and total fungal biomass, and a count of vesicular-arbuscular mycorrhizae (VAM) spores. Microbial biomass and VAM spores were measured repeatedly over time. A revegetation treatment was considered better than the others if it was associated with consistently higher levels of a specific response variable at each depth of the stockpile on each date of sampling.

If revegetation treatment (seed mix) did not affect a specific soil viability parameter at each depth or over time (i.e., no revegetation treatment proved better than the others), the measurements for revegetation treatments were averaged for each depth (across seed mix treatments) and sampling date. When possible, these averages were used in the second phase of the study.

The second phase was designed to determine if soil viability parameters associated with the best revegetation treatment differed from those in adjacent undisturbed soils (control). To make this determination, soil viability parameters were compared using a one-factor repeated measures analysis of variance with five replicates. This test included comparing samples taken from six treatment groups: soil from the five depths described for the topsoil stockpile, and soil taken from a depth of 0-45 cm in undisturbed soil adjacent to the stockpile. The parameters used in this phase included measures of the microbial community (as above), plus physical and chemical properties of the soil. These parameters were measured repeatedly over time.

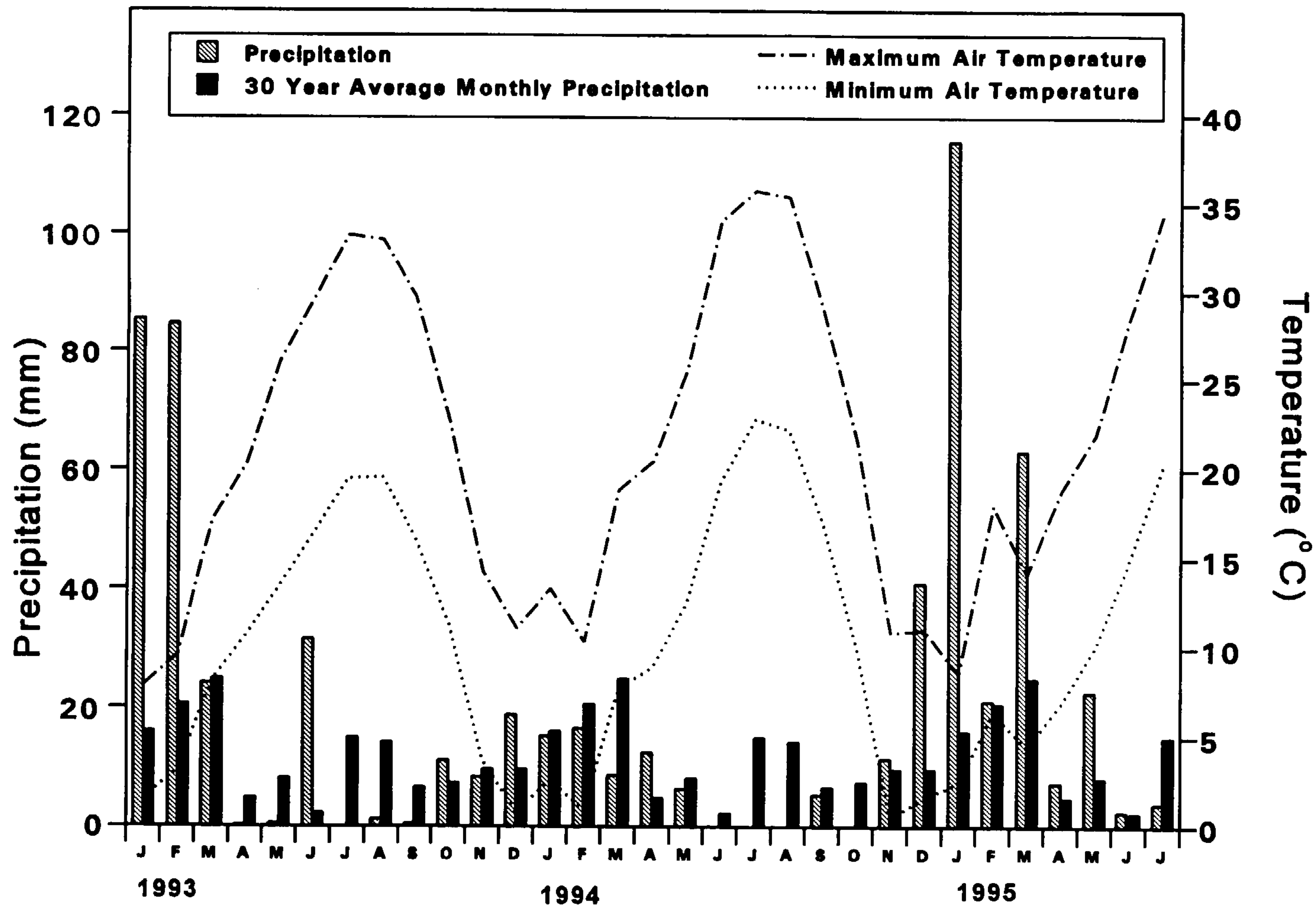

Figure 2-2. Monthly precipitation, maximum air temperature, and minimum air temperature at Meteorological Station 1 (located approximately 2 km west-northwest of the Exploratory Studies Facility Borrow Pit topsoil stockpile) collected from January 1993 through July 1995. Thirty-year average precipitation was determined from data collected at Weather Station 4JA, located approximately 12 km southwest of the Borrow Pit.

Table 2-1. Seed mixes used for revegetation treatments in the soil viability study at Yucca Mountain, Nevada. The amount of seed for each species is given as the percentage of pure live seed. Dashes (-) indicate that a species was not used in the seed mix. Seeding rate was 21 kg/ha PLS.

		(% of total number of pure live seeds)			
Common Name	Scientific Name	Deep Mix	Native Mix	Legume Mix	Shallow Mix
Shallow-rooted species					
Indian ricegrass	*Achnatherum hymenoides*	3.55	10.48	8.72	12.57
white bursage	*Ambrosia dumosa*	2.29	5.80	4.83	6.96
cattle saltbrush	*Atriplex polycarpa*	9.25	10.91	12.98	19.64
blackbrush	*Coleogyne ramosissima*	0.17	0.20	0.18	0.28
Nevada ephedra	*Ephedra nevadensis*	0.23	0.63	0.32	0.57
spiny hopsage	*Grayia spinosa*	2.58	5.33	2.72	4.79
winterfat	*Krascheninnikovia lanata*	1.00	1.57	2.10	2.47
Anderson's wolfberry	*Lycium andersonii*	12.61	29.73	26.51	38.22
desert globemallow	*Sphaeralcea ambigua*	3.86	4.55	4.06	4.09
Deep-rooted species					
green rabbitbrush	*Chrysothamnus viscidiflorus*	15.78	5.32	-	4.79
heathgoldenrod	*Ericameria nauseosa*	30.35	11.93	-	3.58
white burrowbush	*Hymenoclea salsola*	8.06	4.00	-	0.90
creosotebush	*Larrea tridentata*	10.26	9.55	-	1.15
Legume Species					
common deerweed	*Lotus scoparius*	-	-	16.42	-
alfalfa	*Medicago sativa*	-	-	7.66	-
yellow sweetclover	*Melilotus officinalis*	-	-	9.49	-
Coves' cassia	*Senna covesii*	-	-	4.01	-

2.4 Revegetation Treatment Installation and Monitoring

After construction of the stockpile was completed, the site was disked to alleviate soil compaction at the soil surface. After disking, twenty 36- by 17-m plots were established on the stockpile, and treatments (five replicates of each seed mix) were randomly assigned to the 20 plots. Plots were harrowed and drill seeded on April 1, 1993.

To assess the response of the revegetation treatments, plant density was measured in April 1994, about one year after planting. On each of the twenty plots, three transects were established lengthwise across the plot, and density was measured in ten 1-m^2 quadrats on each transect (n = 30 subsamples per plot). The 30 density estimates for each plot were then averaged, and this single average value was used as an estimate of plant density on each plot (treatment replicate) in statistical analyses (i.e., avoiding pseudoreplication).

2.5 Soil Viability Sample Collection and Analyses

Soil samples were collected from each of the 20 plots by digging a new 2.5-m deep trench with a backhoe on each sampling date (Table 2-2). The vertical trench walls were cleared of soil contaminated from upper depths, and depth ranges for sample retrieval were marked on the wall. Soil samples collected for microbial analyses were taken from within each depth range and placed in a container. Soil in the container was mixed, and large (>5 cm) gravel particles were removed. The soil was then placed in a plastic zip-lock bag, stored in a cooler, and shipped on the day of collection (via overnight mail) to a laboratory for analysis. Soil samples collected for physical and chemical analysis were taken from the appropriate soil depths and placed in a Tyvek storage bag. These samples were taken to a field laboratory, air dried, and shipped to a different laboratory for analysis. Soil samples were collected approximately once per month for the first six months of the study to assess short-term effects of stockpiling ($n = 7$), and after that, they were collected approximately every six months to assess longer term effects ($n = 3$; Table 2-2).

Because bacteria and fungi (microbes) are important in the decomposition of plant litter and organic matter in desert ecosystems (Rundel and Gibson 1996), soil viability analyses included measurements of total bacterial biomass, active bacterial biomass, total fungal biomass, active fungal biomass, and VAM fungal spores. Measurements of total microbial biomass provide an indication of the total amount of these components in the soil and includes all bacteria and fungi that are active, senescent, and moribund. Measurements of active microbial biomass provide an indication of the amount of biomass in the soil that is metabolically active (i.e., the amount of biomass that is actively respiring, decomposing plant litter, reproducing, etc.). Changes in microbial activity (i.e., changes in the percentages of total and active microbial biomass) and changes in biomass are good indicators of disturbance on microbial populations (Ingham and Coleman 1984). Measurements of VAM fungi spores can be used to assess inoculation potential of topsoil.

Soil was analyzed for the presence of microbes by the Soil Microbial Biomass Service (SMBS) in Corvallis, Oregon. SMBS determined active bacterial biomass, active fungal biomass, and total fungal biomass using the fluorescein diacetate (FDA) stained agar-soil suspension method (Lodge and Ingham 1991). Total bacterial biomass was determined using the fluorescein isothiocyanate (FITC) method (Babuik and Paul 1970). VAM spores were counted using the flotation-centrifugation technique (Allen et al. 1979). Soil moisture was determined gravimetrically.

Changes in the physical and chemical properties of soils can influence plant growth. Analyses of physical properties included determining the amount of organic matter (Walkley-Black Method), and sand, silt, and clay (Hydrometer Method) in the soil (expressed as a percent). Analyses of chemical properties included determinations of pH, electrical conductivity (EC), sodium adsorption ratio (SAR), nitrate nitrogen (Potassium Chloride Extraction), phosphorus (Olsen Sodium Bicarbonate Extraction), potassium (Ammonium Acetate Extract), zinc (Diethylene Triamine Pentaacetic Acid Extract), and iron (Diethylene Triamine Pentaacetic Acid Extract). These analyses were done by the Soil Characterization Laboratory at Colorado State University (first two sampling dates; Table 2-2) and by the Dellavalle Laboratories in Fresno, California (last sampling date; Table 2-2).

Table 2-2. Dates on which soil samples were collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile. Check marks (✔) indicate that soil analyses were conducted for that date.

		Type of Soil Analysis			
Sampling Date	**Days After Stockpile Completion**	**Total and Active Bacteria**	**Total and Active Fungi**	**VAM Spore**	**Physical and Chemical Properties**
May 11, 1993	40	✔	✔		✔
June 15, 1993	75	✔	✔		
July 20, 1993	110	✔	✔		
August 24, 1993	145	✔			
September 23, 1993	175	✔			
October 28, 1993	210	✔			
December 17, 1993	260	✔	✔	✔	
May 26, 1994	420	✔	✔	✔	✔
February 10, 1995	680	✔	✔	✔	✔
June 10, 1995	800	✔	✔	✔	

2.6 Statistical Analyses

Plant Density Data

Analysis of variance statistical procedures, computed with the SAS GLM procedure (SAS 1990), were used to determine if the density of seeded species differed among the revegetation treatments (i.e., did differences in the number of plants of each species on the plots reflect differences in the number of seeds of each species in the seed mix?). Fisher's Protected Least Significant Difference (LSD) procedure was used to determine whether differences in plant density among treatments were statistically significant ($\alpha = 0.05$).

Soil Viability Data

Soil data were analyzed using repeated measures analysis of variance statistical procedures with the SAS GLM program using the REPEATED option. Mauchly's-*W* was used to test the assumption of sphericity for repeated measured models (von Ende 1993). When data were non-spherical, degrees of freedom for the within subjects main effects and interactions tests were adjusted using the Huynh-Feldt epsilon (von Ende 1993). If the Huynh-Feldt epsilon value was greater than 1.0, an epsilon value of 1.0 was used as the for degrees of freedom adjustment (SAS 1990). Determinations of statistically significant differences among treatments and interactions were made using $\alpha = 0.05$. Prior to using the repeated measures analysis of variance procedures, microbial data were normalized using a *log +1* transformation (i.e., $Y^* = log(Y+1)$; Steel and Torrie 1980).

Multiple comparisons were conducted using Fisher's Protected Least Significant Difference (LSD) procedure to determine the significance of statistical results. LSD values were calculated using appropriate error terms for repeated measures designs (Milliken and Johnson 1984). Degrees of freedom for the LSD equations were adjusted using the Huynh-Feldt epsilon (Milliken and Johnson

1984). Bonferonni adjustments were used to adjust LSD α-values to maintain an error rate of $\alpha = 0.05$.

Profile analyses (PROFILE transformation in the SAS GLM procedure) were used to identify time intervals (i.e., days after stockpile completion) in which temporal changes in the response variables (e.g., biomass) differed at different depths. For example, given that one expects the total amount of bacterial biomass to change during the year as environmental conditions change, does the amount of biomass change in the same way at different depths in the stockpile? Profile analyses use individual analysis of variance tests and contrasts of the time intervals to produce F-tests. The results of these F-tests can be used to determine the significance of a temporal effect and to determine whether the slopes of the response variables at each level of the main factor are different (von Ende 1993). Bonferonni adjustments were used to adjust α-values to maintain an error rate of $\alpha = 0.05$ for the profile analyses (von Ende 1993).

Pearson's correlation coefficients (r) were used to assess the strength of the relationships among the soil viability parameters. Correlations were considered significant using an α-value of 0.05 and a Bonferonni-adjustment for multiple tests.

3. RESULTS

3.1 Revegetation Treatment (Seed Mix) Response

In the spring of 1994, one year after planting, the density of all seeded-species (i.e., including only those species included in the seed mix and excluding other native species) averaged approximately 3.0 plants/m^2, and there were no differences in total density among the revegetation treatments ($P = 0.43$).

When considering each seeded-species individually, densities of nine of the 17 species differed among treatments, and the differences were similar to the proportion of seeds sown. Thus, seeding at higher rates resulted in higher density of plants one year later. However, because of the large amount of variability in these data, many of the treatments were not statistically different (Figure 3-1).

Five of the species exhibiting differences were shallow-rooted species (white bursage, cattle saltbrush, winterfat, Nevada ephedra, and Indian ricegrass), two were deep-rooted species (heathgoldenrod and white burrowbush), and two were legumes (yellow sweetclover and alfalfa; Figure 3-1, Table 2-1). Densities of the deep-rooted heathgoldenrod and white burrowbush, and the shallow-rooted winterfat and white bursage were proportionally similar to the amount of pure live seed sown (i.e., a proportional increase in seeding rate for a species resulted in a proportional increase in density); however, these differences were only significant for one or two of the treatments (Figure 3-1). Three of the shallow rooted species (cattle saltbrush, Nevada ephedra, and Indian ricegrass) had densities that were proportionally dissimilar to the amount of seed sown (Figure 3-1). Although the remaining seeded species (Cove's cassia, green rabbitbrush, blackbrush, spiny hopsage, creosotebush, common deerweed, Anderson's wolfberry and desert globemallow) were seeded at varying proportions, measured densities were less than 0.05 plants/m^2, and no significant differences existed among the revegetation treatments (Figure 3-1).

3.2 Soil Microbial Response

Repeated measures analysis of variance, used to determine whether revegetation treatments affected soil microbial populations at different soil depths and over time, showed that revegetation treatments had no effect on the microbes (interaction between revegetation treatment, stockpile depth, and days after stockpile completion, $P > 0.05$; Appendix A). Because there was no effect of revegetation treatment, data were averaged for each soil depth and sampling date. These averages were used in a one factor repeated measures analysis of variance test to determine if soil viability parameters at the various depths differed from those in the adjacent undisturbed area over time. Generally, for all of the soil microbial parameters, there was an interaction between depth and days after stockpile completion ($P < 0.05$; Appendix B) which indicates that differences existed in stockpile depths and the undisturbed areas over time.

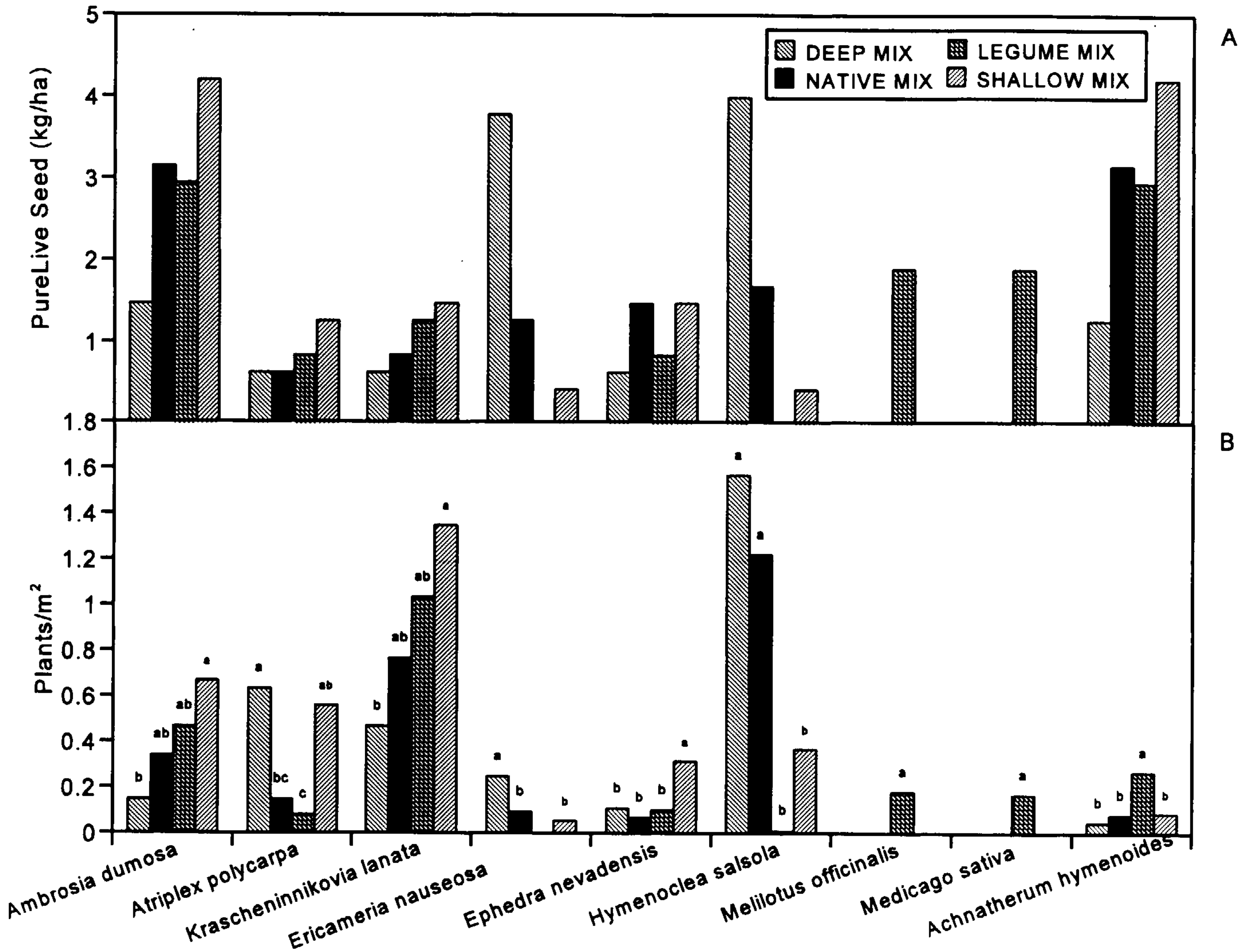

Figure 3-1. A) Seeding rates (pure live seed kg/ha) for species seeded at the Exploratory Studies Facility (ESF) Borrow Pit topsoil stockpile, and B) mean densities of seeded species in April 1994. Means for species with the same letter were not different ($P > 0.05$) using Fisher's Least Significant Difference.

Bacteria

Total Bacterial Biomass

Total bacterial biomass in the stockpile and in the undisturbed soil ranged from 1.86 to 16.95 μg/g of dry soil throughout the study period. Within the topsoil stockpile, total bacterial biomass did not differ among depths ($P > 0.05$; Figure 3-2) and temporal increases and decreases were similar at all depths. The total amount of bacterial biomass in the stockpile was similar to that in the adjacent undisturbed topsoil on most of the sampling dates ($P > 0.05$), and this was especially true for soil in the stockpile at depths of 0-160 cm (Figure 3-2).

During the first 110 days after the stockpile was constructed, the total amount of bacterial biomass in the stockpile declined, and that amount was not significantly different from that in undisturbed topsoil (Figure 3-2). During days 110-210, the total amount of bacterial biomass increased in the stockpile and in the undisturbed topsoil (Figure 3-2). Profile analysis indicated that the rate of increase in total bacterial biomass was similar at all soil depths (Days 110-145, $P = 0.59$; Days 145-170, $P = 0.90$; Days 170-210, $P = 0.56$), indicating that total bacterial biomass in the stockpiled topsoil was responding to environmental changes similarly to that in the undisturbed soil.

During days 210-260, the total amount of bacterial biomass in the stockpile decreased at all depths. However, during this same period, the amount of biomass in the undisturbed topsoil increased to almost four times more than the biomass in the stockpile (Figure 3-2).

During days 260-420, the total amount of bacterial biomass in the undisturbed topsoil declined while that in the stockpile increased. By Day 420, there were similar amounts of bacterial biomass in the stockpile and undisturbed topsoil (Figure 3-2).

After Day 420, the total amount of bacterial biomass in the stockpile was similar to that in the undisturbed topsoil (Figure 3-2), and no significant differences existed in the rates of decrease (Days 420-680, $P = 0.21$) or increase (Days 680-810, $P = 0.32$) in the stockpiled and undisturbed topsoil.

In general, the total amount of bacterial biomass in the topsoil stockpile and in the undisturbed soil responded to environmental or other conditions and fluctuated in similar ways. This suggests that the amount of bacterial biomass in the stockpiled topsoil was not negatively impacted by construction of the stockpile.

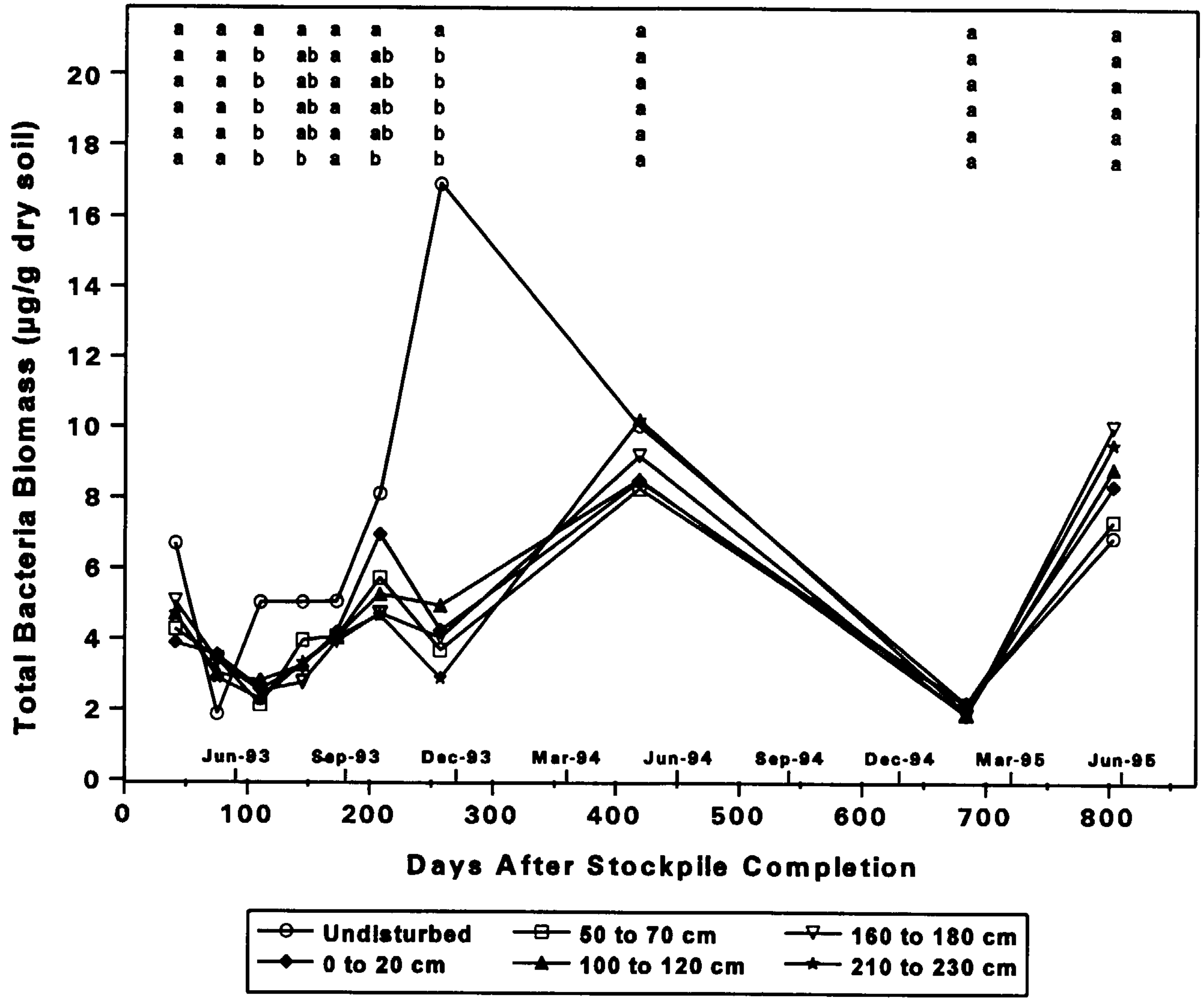

Figure 3-2. Total bacteria biomass (µg/g dry soil) from five depths in the stockpiled and undisturbed topsoil collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. Significant differences among means for each depth were determined using Fisher's Protected Least Significant Difference. Means with the same letter on a sampling date were not significantly different. Means and standard errors are presented in Appendix D.

Active Bacterial Biomass

The amount of active bacterial biomass ranged from 0.143 to 2.16 μg/g of dry soil throughout the study. At Day 40, there was less than half as much active bacterial biomass in the stockpile as there was in the undisturbed topsoil (Figure 3-3). However, by Day 75, active bacterial biomass had increased at all depths in the stockpile and undisturbed soil (Figure 3-3). The rate of increase was greater in the stockpile than in the undisturbed topsoil, especially at depths of 0-70 cm, resulting in similar amounts of active bacterial biomass in the stockpile and undisturbed topsoil at this depth (Figure 3-3).

During the next period (Days 75-110), the response of active bacterial biomass in the stockpile was different from that in the undisturbed topsoil (Figure 3-3). During this time, the amount of active bacterial biomass declined more rapidly in the stockpile than in undisturbed topsoil. By Day 210, there were similar amounts of biomass in the stockpiled and undisturbed topsoil.

After day 210, the amount of active bacterial biomass generally increased at all depths in the stockpile and in the undisturbed soils; however, the amount of active bacterial biomass generally was higher in the undisturbed soils. Profile analysis indicated that there were significant differences in the rates of change between stockpiled and undisturbed topsoil during the period from Day 210 to 420 (Days 210-260, $P = 0.001$; Days 260-420, $P = 0.005$). However, during Days 420-810, the rates of change between stockpiled and undisturbed topsoil were similar (Days 420-680, $P = 0.19$; Days 680-810, $P = 0.37$). This indicates that during this period, the stockpiled topsoil was responding to environmental conditions in a manner similar to that in the undisturbed topsoil. On Day 810, the amount of active bacterial biomass in the upper 120 cm of the stockpile was similar to that in the undisturbed topsoil (Figure 3-3).

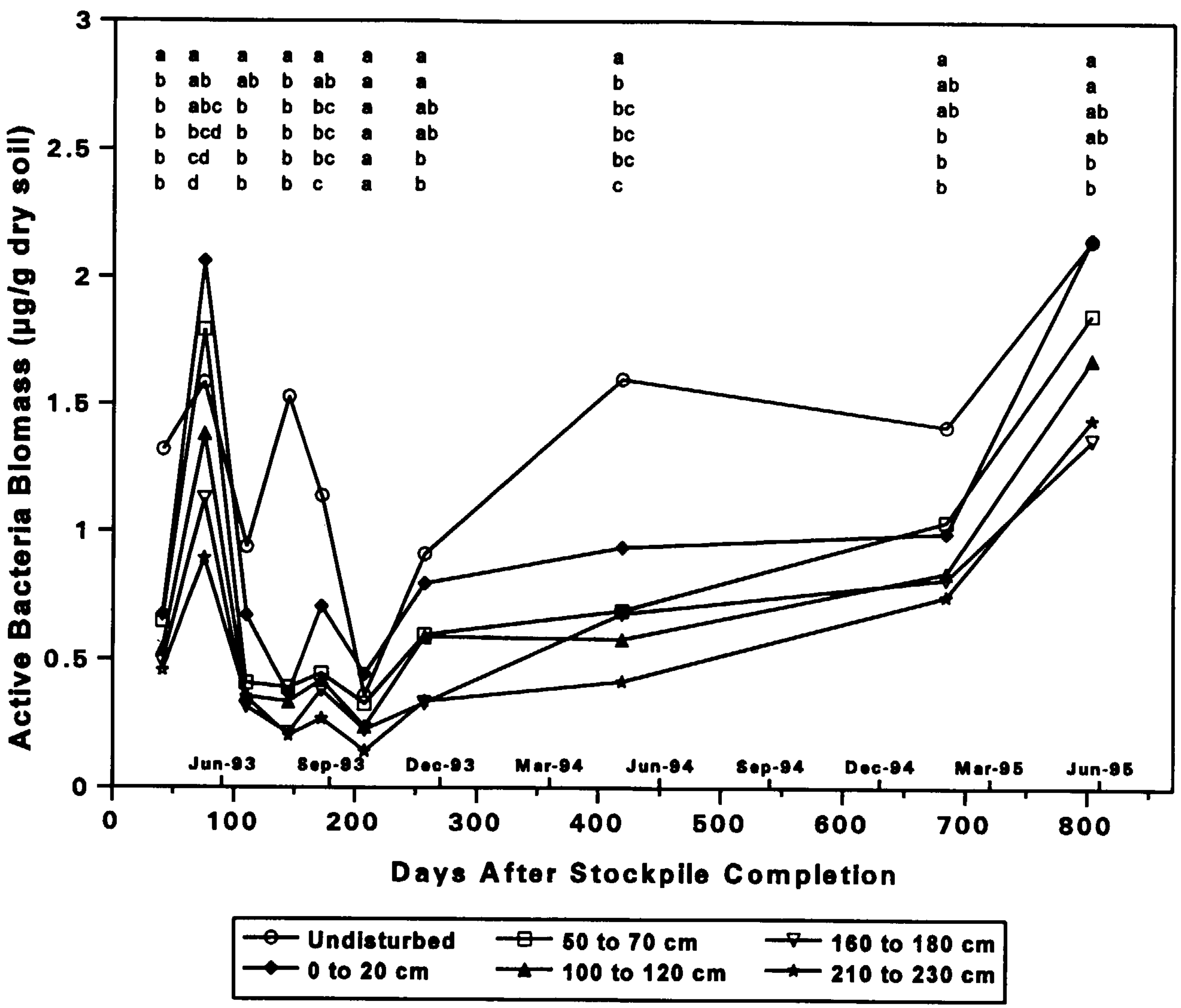

Figure 3-3. Amount of active bacterial biomass (µg/g dry soil) at five depths in the topsoil stockpile and in undisturbed soil collected during ten sampling sessions at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. Significant differences among depths were determined using Fisher's Protected Least Significant Difference. Means with the same letter on a sampling date were not significantly different. Means and standard errors are presented in Appendix D.

Fungi

Total Fungal Biomass

The total amount of fungal biomass in the topsoil stockpile did not differ among soil depths during the study ($P > 0.05$; Figure 3-4). However, there generally was less total fungal biomass in the stockpile than there was in the undisturbed soil ($P < 0.05$ for most sampling dates). Rates of change in the amount of total fungal biomass between sampling dates generally differed in the stockpile and undisturbed topsoil (all except Days 110-260, $P = 0.12$, and Days 680-810, $P = 0.08$; Figure 3-4). At the end of the study (Day 810), there was less fungal biomass in the stockpile than that in the undisturbed topsoil; however, the difference was not significant ($P > 0.05$; Figure 3-4).

Active Fungal Biomass

There were similar amounts of active fungal biomass at each depth in the topsoil stockpile throughout the study ($P > 0.05$; Figure 3-5). During the first 75 days after the stockpile was constructed, the amount of active fungal biomass in undisturbed topsoil was greater than that found in the stockpile, but because of a high degree of variability in the samples, these differences were not statistically significant ($P > 0.05$; Figure 3-5).

During Days 110-680, there was more active fungal biomass in the undisturbed topsoil than at any soil depth in the stockpile (Figure 3-5). Although the undisturbed soil had greater active biomass, profile analyses indicated similar rates of change in active biomass at all depths in the stockpiled topsoil and in the undisturbed soil (Days 110-260, $P = 0.46$; Days 260-420, $P = 0.28$; Days 420-680, $P = 0.94$). Similar changes in the amount of active fungal biomass in the stockpiled and undisturbed topsoil suggest that the microbes were responding to environmental changes in similar ways.

At the end of the study, Day 810, the amount of active fungal biomass in the undisturbed topsoil and in all depths in the stockpiled topsoil were similar.

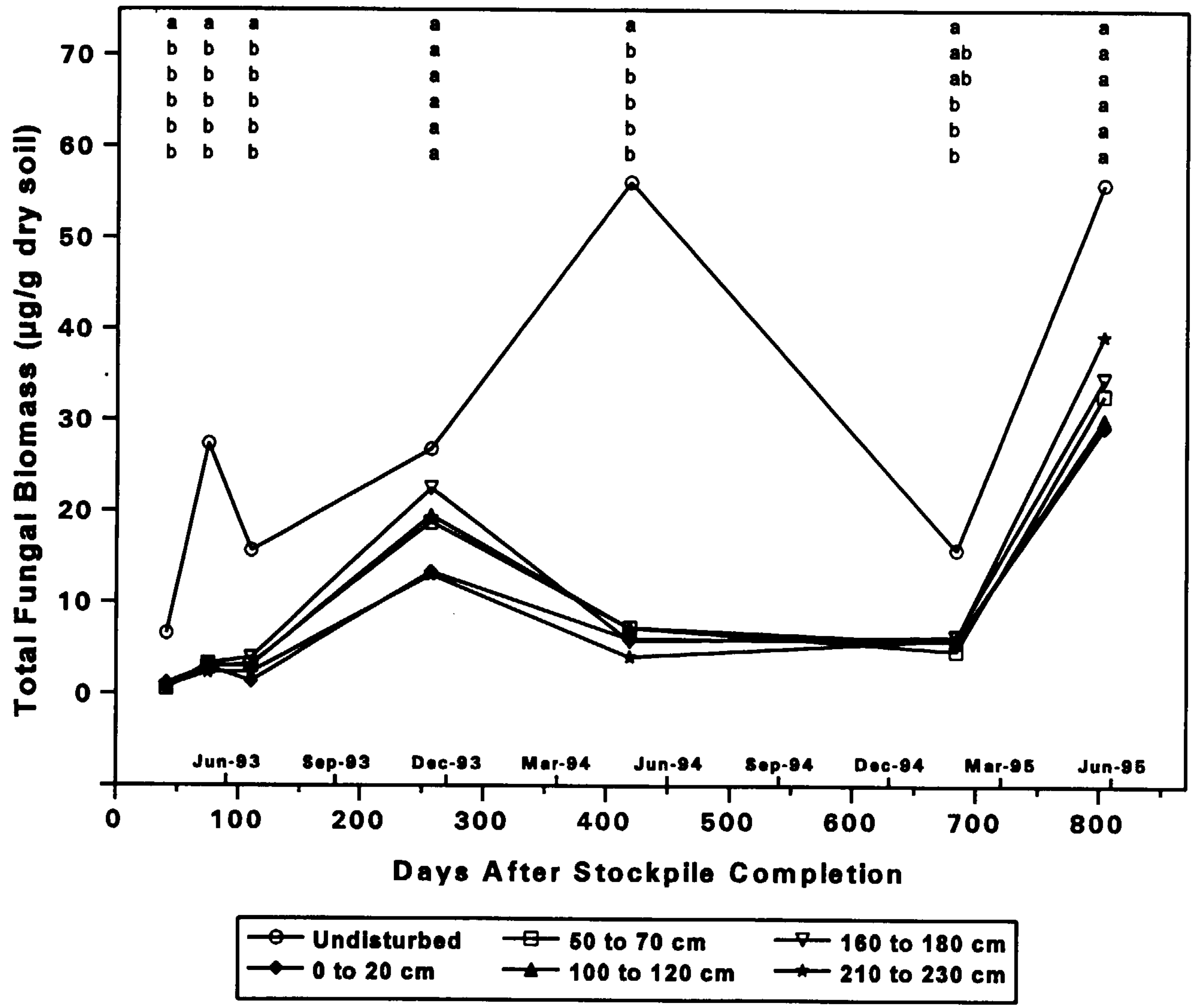

Figure 3-4. Total fungal biomass (µg/g dry soil) from five depths in the topsoil stockpile and in undisturbed soil collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. Significant differences among means were determined using Fisher's Protected Least Significant Difference (see Appendix B for analysis of variance table). Means with the same letter on a sampling date were not significantly different. Means and standard errors are presented in Appendix D.

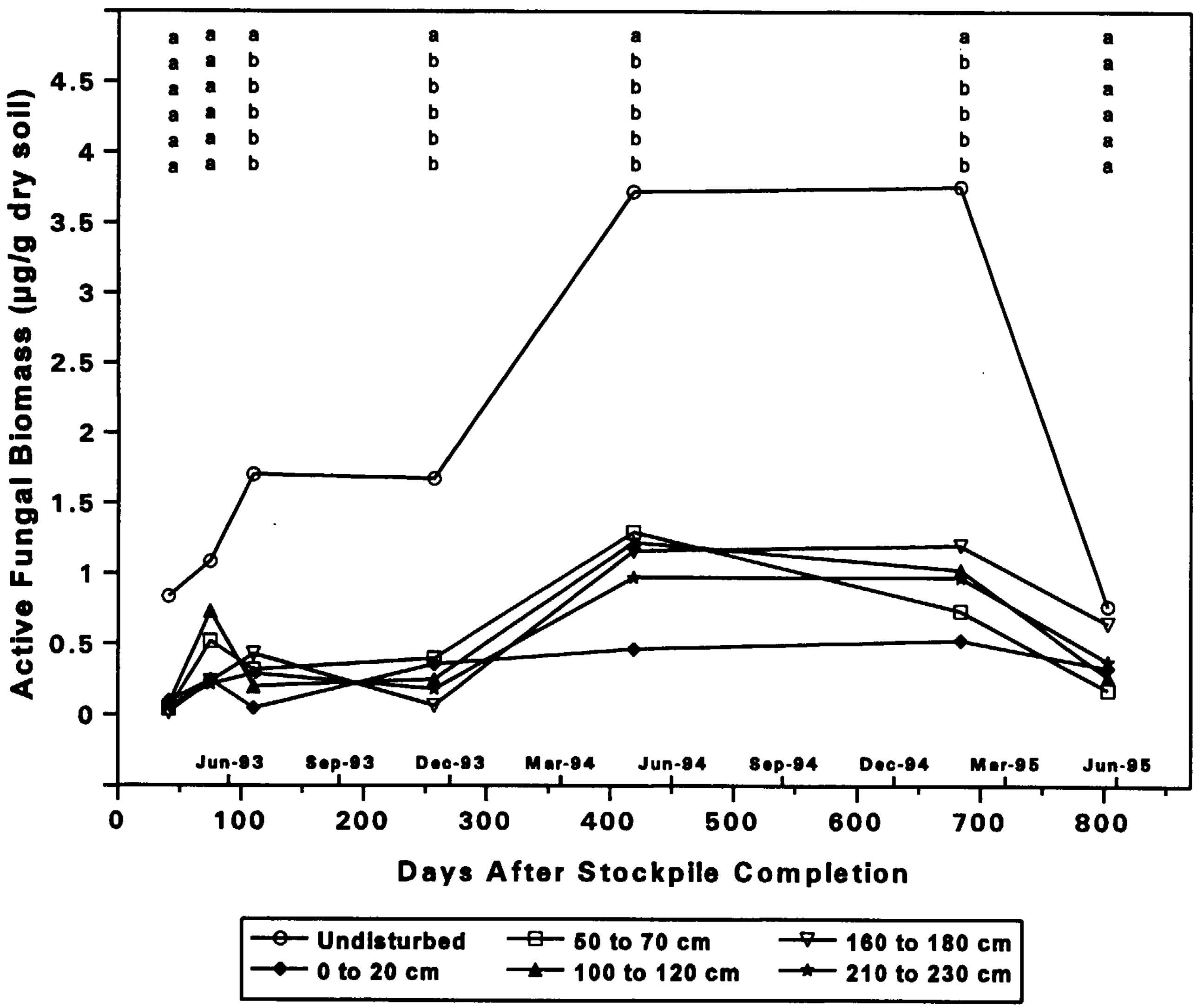

Figure 3-5. Active fungal biomass (µg/g dry soil) from five depths in the topsoil stockpile and in undisturbed soil collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. Significant differences among depths were determined using Fisher's Protected Least Significant Difference (see Appendix B for analysis of variance table). Means with the same letter on a sampling date were not significantly different. Means and standard errors are presented in Appendix D.

Vesicular-Arbuscular Mycorrhizae (VAM) Spores

The first measurement of VAM spores was made on Day 260. On this day, VAM spores in the stockpiled topsoil ranged from 8.8 (210-230 cm) to 14.6 spores/g of dry soil (0-20 cm; Figure 3-6). In the undisturbed topsoil there were 13.1 spores/g of dry soil, and this number was not different from those in the topsoil stockpile ($P > 0.05$; Figure 3-6).

From Day 260 to 420, VAM spores declined to approximately 1.5 spores/g of dry soil at all depths in the stockpile topsoil and in the undisturbed topsoil (Figure 3-6). Profile analysis indicated that the rates of decline were similar in the stockpile and undisturbed soils ($P = 0.92$). Additionally, no differences existed among the soil depths ($P > 0.05$; Figure 3-6).

During Days 420-810, VAM spore counts increased in the stockpiled topsoil while spore counts in the undisturbed topsoil remained relatively unchanged (Figure 3-6). On Day 810, VAM spores at all depths in the stockpile were greater than those in the undisturbed soil ($P < 0.05$).

Fungal and Bacterial Dynamics

Correlations between the amount of fungal and bacterial biomass were used to assess trends and interactions between these components of the decomposer community. Ratios of fungal to bacterial biomass were examined to assess changes in the proportions of these components over time and differences in changes in the stockpiled and undisturbed soil. Changes in microbial populations can reflect shifts in dominance from fungi to bacteria (and vice versa) and stresses to the system.

Microbial Interactions

During the first year of the study, trends in the ratio of fungal to bacterial biomass in stockpiled and undisturbed topsoil were generally opposite of one another (Figure 3-7). On the first sampling date (Day 40), no significant differences existed in the ratio of total fungal to total bacterial biomass (Figure 3-7). However, on Day 75, the ratio of total fungal to bacterial biomass in the undisturbed topsoil was 12, indicating that there was 12 times more fungal biomass than bacterial biomass. The ratio ranged from 0.8-1.0 at all depths in the stockpiled topsoil, indicating that the amount of bacterial biomass was similar to that of fungal biomass (Figure 3-7). During Days 75-260, fungi generally became more abundant in the stockpile, but they were less abundant in the undisturbed topsoil (Figure 3-7). The opposite trend occurred during Days 260-420 (Figure 3-7).

After Day 420, fungi became increasingly more abundant in the undisturbed and stockpiled topsoils (Figure 3-7). Profile analysis indicated that the rates of change in the ratios of fungal to bacterial biomass were similar during Days 420-800 days (all $P > 0.05$ with Bonferonni adjustment). This indicates that the rates of change in the proportions of fungi to bacteria were similar, and suggests microbial populations in the stockpiled and undisturbed topsoil fluctuated in a similar manner.

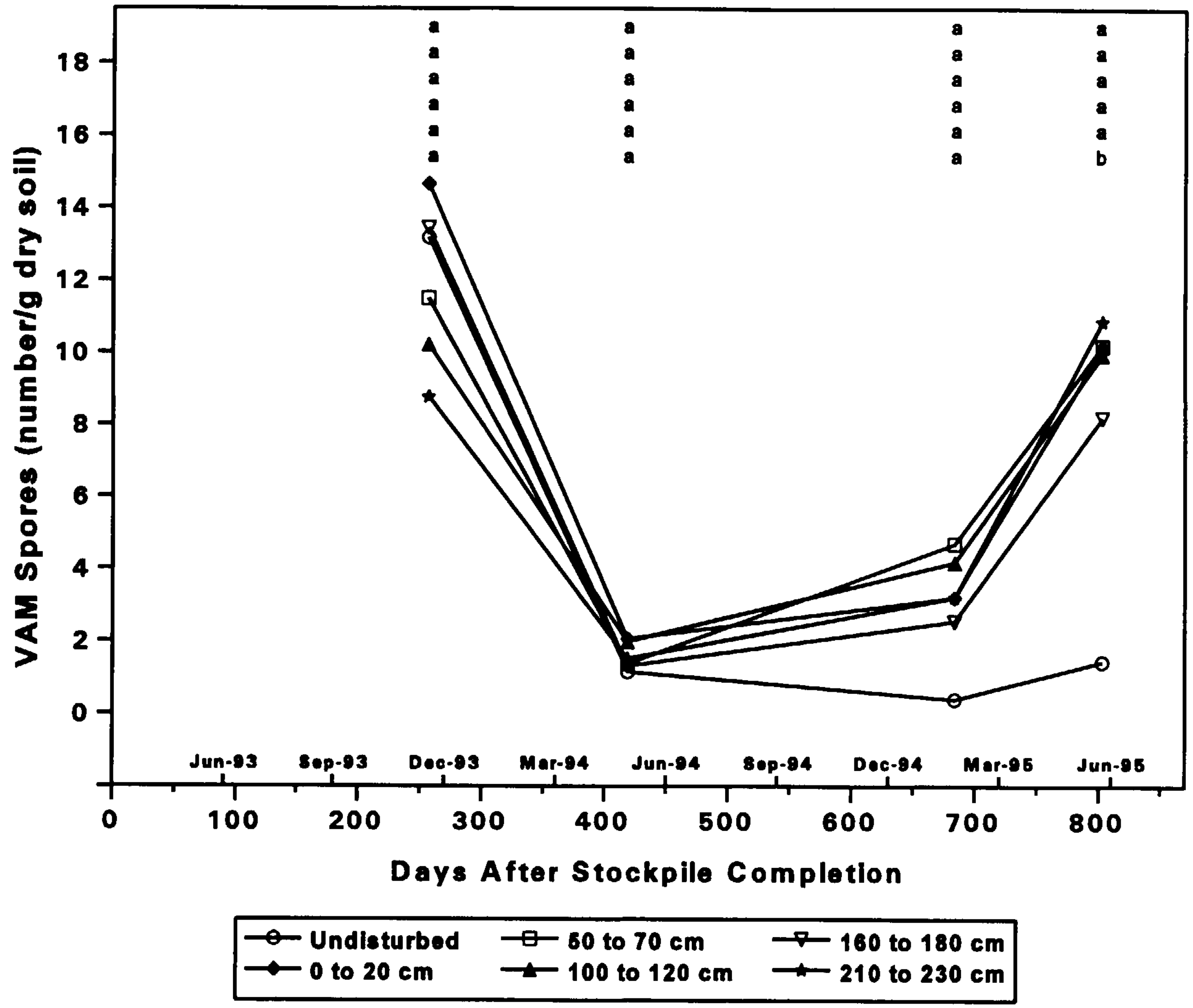

Figure 3-6. Vesicular-arbuscular mycorrhizae (VAM) spores (number/g dry soil) from five depths in the topsoil stockpile and undisturbed soil collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile, Yucca Mountain, Nevada. Significant differences among means were determined using Fisher's Protected Least Significant Difference (see Appendix B for analysis of variance table). Means with the same letter within a sampling date were not significantly different ($P > 0.05$). Means and standard errors are presented in Appendix D.

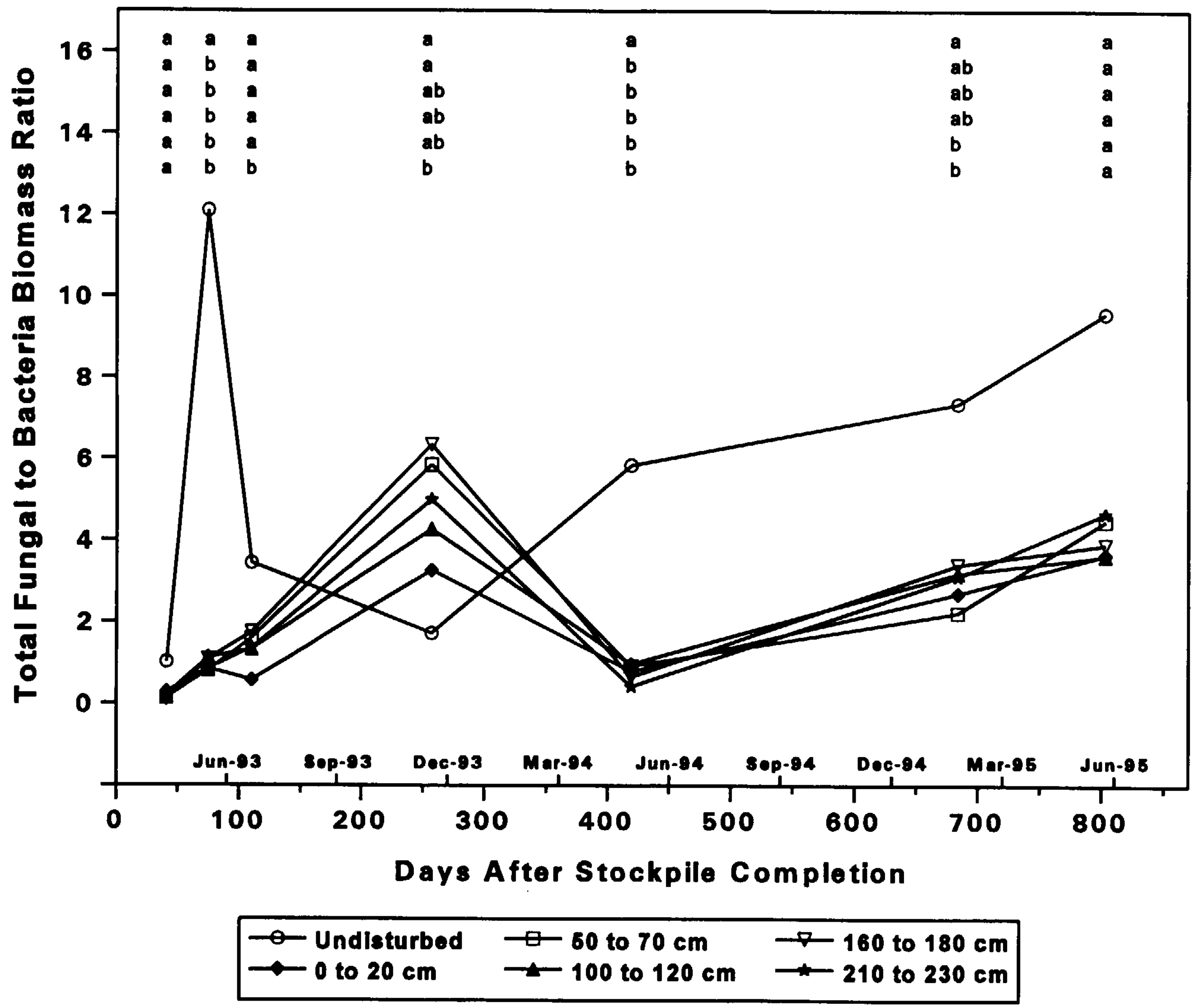

Figure 3-7. Ratio of total fungal biomass to total bacterial biomass at five depths in the topsoil stockpile and in undisturbed soil at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. Significant differences among depths were determined using Fisher's Protected Least Significant Difference (see Appendix B for analysis of variance table). Means with the same letter within a sampling date were not significantly different. Means and standard errors are presented in Appendix D.

Similarities in the bacterial and fungal population dynamics in the stockpiled and undisturbed topsoils also were reflected in correlations between these variables. Active bacterial biomass was positively correlated with total fungal biomass in all depths of the stockpile and in the undisturbed soil, but the relationship was statistically significant only in the uppermost and lowermost layers ($P < 0.05$; Table 3-1). The relationship was strongest in the stockpiled soils at a depth of 210-230 cm ($r = 0.70$), but perhaps more importantly, it was statistically significant in the upper layers of both areas ($r = 0.54$-0.62; $P < 0.05$)

Total bacterial biomass was weakly positively correlated with total fungal biomass, but the relationship was statistically significant only in the stockpiled soils at a depth of 100-120 cm (Table 3-1). Active fungal biomass was not correlated with either of the bacterial biomass variables or with total fungal biomass for any of the stockpile depths or for the undisturbed soil (Table 3-1). Temporal changes in the numbers of VAM spores in the stockpiled and undisturbed topsoils appeared to be unrelated to changes in the amount of active and total fungal biomass (all $P > 0.05$; Table 3-2).

Table 3-1. Relationships between bacterial and fungal parameters within each soil depth class expressed as Pearson's correlation coefficients (r, $n = 35$). Asterisks (*) indicate correlations that were significant at a Bonferonized value of $\alpha = 0.05$.

Measurement	Depth (cm)	Active Bacteria	Total Bacteria	Active Fungi
Stockpiled Topsoil				
Active Bacteria	0-20			
Total Bacteria		0.352		
Active Fungi		0.142	0.262	
Total Fungi		0.539 *	0.531	0.169
Active Bacteria	50-70			
Total Bacteria		0.234		
Active Fungi		0.018	0.294	
Total Fungi		0.430	0.482	-0.060
Active Bacteria	100-120			
Total Bacteria		0.185		
Active Fungi		0.025	0.070	
Total Fungi		0.489	0.541 *	-0.208
Active Bacteria	160-180			
Total Bacteria		0.378		
Active Fungi		0.195	0.201	
Total Fungi		0.379	0.483	0.053
Active Bacteria	210-230			
Total Bacteria		0.358		
Active Fungi		0.048	0.244	
Total Fungi		0.700 *	0.461	0.043
Undisturbed Topsoil				
Active Bacteria	0-45			
Total Bacteria		-0.131		
Active Fungi		0.286	0.091	
Total Fungi		0.620 *	0.170	0.265

Table 3-2. Pearson's correlation coefficients (r, n = 20) between counts of vesicular-arbuscular mycorrhizae (VAM) fungi spores and selected soil viability variables by soil depth class. None of the correlations were statistically significant at a Bonferonni-adjusted α- value of 0.05.

	Soil Depth Class					
Variable	0-20 cm	50-100 cm	100-120 cm	160-180 cm	210-230 cm	Undisturbed
Active Bacteria	0.177	0.203	0.357	-0.223	0.480	-0.368
Total Bacteria	-0.021	-0.176	0.216	-0.133	0.007	0.516
Active Fungi	-0.079	-0.450	-0.646	-0.553	-0.506	-0.198
Total Fungi	0.395	0.545	0.610	0.486	0.653	-0.154

Soil Moisture Interactions

Soil moisture differed in the stockpiled and undisturbed topsoil (Figure 3-8). The amount of moisture in the undisturbed topsoil (Figure 3-8) generally increased and decreased in response to yearly rainfall patterns (Figure 2-2). Soil moisture in the stockpile generally was higher than that in the undisturbed soil, especially during the first year. Soil moisture in the upper 120 cm of the stockpile fluctuated in response to seasonal precipitation patterns as it did in the undisturbed soil, but there was no seasonal effect at depths of 160-230 cm. The higher soil moisture in the stockpile likely was the result of constructing the stockpile during a spring rainy season when precipitation was almost four times greater than the 30-year average (Figure 2-2). Consequently, the topsoil was wet during construction, and much of the moisture remained in the stockpile for an extended period of time, especially at the deepest levels (Figure 3-8).

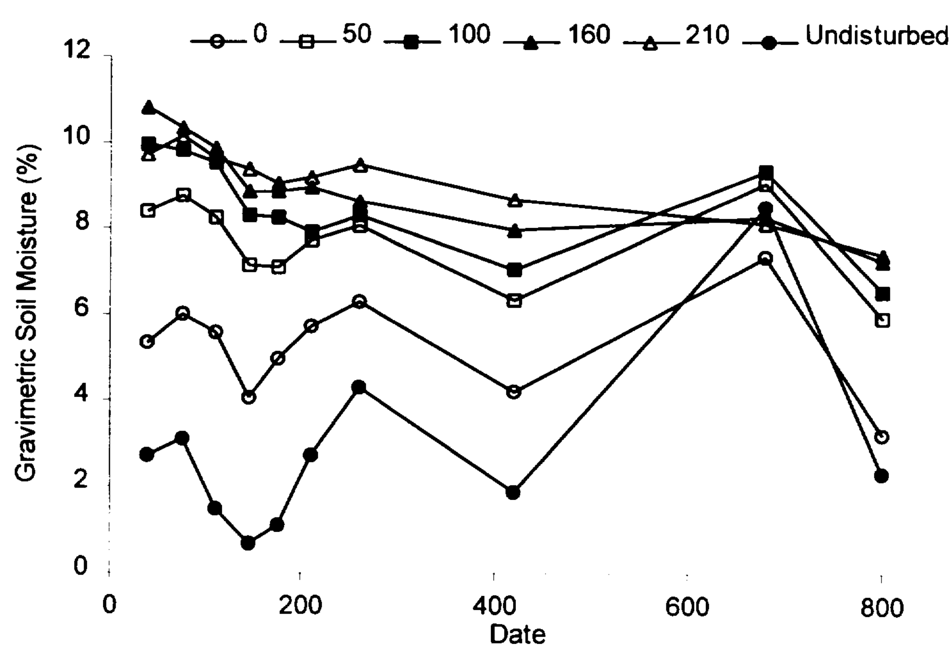

Figure 3-8. Gravimetric soil moisture (%) from five depths in the topsoil stockpile and in undisturbed soil collected at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada.

3.3 Soil Physical and Chemical Properties

Physical characteristics of the soil generally were unaffected by stockpiling the topsoil. As would be expected, textures were similar between the stockpiled and undisturbed soils (both were classified as sandy loams). The percentage of sand was slightly lower, and the percentage of silt and clay were slightly higher (75%, 14%, and 10%, respectively) in the stockpile when compared to the undisturbed topsoil (83% sand, 11% silt, and 6% clay). These slight differences likely resulted from soil heterogeneity across the landscape, soil mixing during stockpiling, and statistical sampling error. There were similar amounts of organic matter in the stockpiled and undisturbed topsoil (approximately 0.64% in each).

Some of the chemical characteristics of the soil differed in response to the effects of topsoil stockpiling. The sodium adsorption ratio (SAR) values in the stockpiled topsoil always were higher than those in the undisturbed topsoil ($P < 0.05$; Appendix E). Electrical conductivity in the stockpiled topsoil always was higher than it was in the undisturbed soil; and on some dates and at some depths, it was substantially higher (e.g., Day 420, depth = 0-20; EC = 1.46 vs. 0.42; Table 3-3). Other characteristics of the soil chemistry were similar in the stockpiled and undisturbed topsoils. For example, soil pH was similar in the stockpile (8.0 to 8.11) and undisturbed topsoils (8.07; Appendix E).

On Days 40 and 680, similar amounts of nitrogen, potassium, calcium, magnesium, and sodium were found at each depth in the stockpile and in the undisturbed topsoil (Table 3-3). However, on Day 420, differences were found in the amounts of these soil chemicals. For each chemical, there was at least one depth-class at which significantly more, or significantly less, of the chemical was found when compared against the other depth-classes or compared against the undisturbed soil (Table 3-3).

There always was more total phosphorus, and less sodium, in undisturbed topsoil than in the stockpile, but the differences generally were not significant (Table 3-3). There generally was less zinc in the undisturbed soil than in the stockpile, but this differences also generally was not significant (Table 3-3). There were similar amounts of iron in the undisturbed and stockpiled topsoils (Appendix E).

Table 3-3. Mean values of selected soil chemical properties sampled from five depths in the topsoil stockpile and from topsoil of an undisturbed area at the Exploratory Studies Facility Borrow Pit topsoil stockpile at Yucca Mountain, Nevada. For each day, sample means with the same letter were not significantly different using Fisher's Protected Least Significant Difference. Only those soil chemical properties with significant differences over time are presented. All means and standard errors are presented in Appendix E.

	Depth (cm)					
Days Since	Stockpile					Undisturbed
Completion	0-20	50-70	100-120	160-180	210-230	0-45
			Electric Conductivity (mmhos/cm)			
40	0.72 a	0.54 a	0.58 a	0.68 a	0.54 a	0.48 a
420	1.46 a	0.48 b	0.78 b	0.59 b	0.59 b	0.42 b
680	0.54 a	0.64 a	1.06 a	0.77 a	0.64 a	0.52 a
			Nitrate Nitrogen (ppm)			
40	0.50 a	0.50 a	0.50 a	0.50 a	0.50 a	1.00 a
420	27.60 a	3.60 b	4.20 ab	5.60 ab	3.40 ab	3.00 ab
680	4.00 a	5.75 a	16.25 a	6.50 a	4.75 a	2.20 a
			Total Phosphorus (ppm)			
40	1.56 a	1.98 a	1.80 a	2.08 a	2.36 a	2.64 a
420	2.28 ab	0.84 b	2.00 ab	2.12 ab	2.18 ab	5.06 a
680	3.00 a	2.75 a	3.00 a	3.25 a	2.25 a	5.00 a
			Potassium (ppm)			
40	472.80 a	505.20 a	529.60 a	523.20 a	525.60 a	505.60 a
420	501.20 ab	488.80 ab	504.00 a	478.60 ab	440.20 ab	388.40 b
680	626.25 a	585.00 a	563.75 a	672.50 a	608.75 a	791.00 a
			Calcium (meq/l)			
40	4.50 a	3.00 a	4.08 a	4.64 a	3.26 a	3.74 a
420	10.08 a	2.61 b	5.19 b	3.46 b	3.39 b	3.02 b
680	3.68 a	4.05 a	7.73 a	5.03 a	4.30 a	3.90 a
			Magnesium (meq/l)			
40	1.28 a	0.96 a	1.26 a	1.44 a	1.08 a	1.18 a
420	2.90 a	0.97 b	1.76 ab	1.32 ab	1.19 b	1.12 b
680	1.00 a	1.23 a	2.40 a	1.58 a	1.43 a	1.36 a
			Sodium (meq/l)			
40	2.10 a	1.74 a	1.86 a	2.06 a	1.38 a	0.56 a
420	2.26 a	0.77 b	1.74 ab	1.08 ab	1.57 ab	0.50 b
680	3.40 a	2.10 a	1.93 a	2.45 a	1.93 a	1.18 a
			Zinc (ppm)			
40	0.28 ab	0.26 ab	0.46 a	0.32 a	0.42 a	0.14 b
420	0.10 a	0.12 a	0.18 a	0.16 a	0.12 a	0.16 a
680	0.40 a	0.50 a	0.45 a	0.53 a	0.48 a	0.36 a

4. DISCUSSION

4.1 Revegetation Treatment Effects

The lack of an effect of revegetation treatment (seed mix) on soil viability may have been due to similarities in final species composition among the revegetation treatments. Although density estimates, measured after one year, revealed that several of the seeded species had densities comparable to the amount of seed sown, many of these densities did not differ among revegetation treatments (Figure 3-1). A possible reason for the similarities in density among the revegetation treatments was that seeds were planted on the stockpile late in the growing season (April 1, 1993), and many of the species may not have experienced environmental conditions sufficient to meet their germination requirements (e.g., dormancy breaking or cold chill). Also, little rain fell during April and May after planting (Figure 2-2), and therefore the seedlings that did germinate may not have received rainfall adequate for survival.

Another factor which might have influenced the results of this study (i.e., lack of revegetation treatment effects on soil viability) was that the plants growing on the stockpile during the first year probably did not root deeply. During the first year, when trenches were dug in the stockpile to sample the soil, roots of most species were found only in the upper 50 cm of the soil. However, during the second year, the roots of some plants extended to almost 180 cm. Because the roots did not extend into the deeper soils during the first year, any effect of revegetation treatment on soil viability would likely have been confined to the upper soil layers.

4.2 Effects of Stockpiling on Bacteria and Fungi

From a soil management perspective, the most important result regarding the effects of stockpiling on bacteria and fungi in the soil was that these microbes remained active in the stockpiled topsoil throughout the study.

Effects of Stockpile Depth

Several generalizations can be made about the effects of topsoil stockpiling on the bacteria and fungus in the soil. First, no differences were found in the amount of bacterial and fungal biomass among the five soil layers in the stockpiled topsoil over time (Figures 3-2 through 3-6). This result is contrary to the work of Ross and Cairns (1981), Johnson et al. (1991), Harris et al. (1989), and Harris and Birch (1990). These researchers found less microbial activity in deeper parts of stockpiles than in shallower parts, and they attributed the difference to the formation of anaerobic conditions in the deeper portions of a stockpile. For example, Harris et al. (1989) reported that samples of spores from aerobic microbes (collected at stockpile depths of 250-300 cm) contained only 19% as much bacteria, and 0.01% as many fungal spores, as were found in the upper portion of a stockpile (48 months after construction). They attributed the difference to anaerobic conditions that prevented aerobic microbes from producing new biomass in the deeper stockpiled soils.

Two years after the stockpile was constructed at Yucca Mountain, it does not appear that bacterial and fungal populations had been inhibited by anaerobic conditions. Harris and Birch (1990) state that anaerobic conditions are most likely to develop in soils with loam and clay textures, and they state that sandy soils become only slightly anaerobic at a depth of 200 cm. Sandy soils are more likely to remain aerobic than loam or clay soils because bulk density of sandy soils is lower, coarse pore spaces are larger, and these soils are better drained (Abdul-Kareem and McRae 1984). The texture of the soil at the ESF Borrow Pit was classified as sandy loam; thus, anaerobic conditions may not have developed during this study.

Effects of Time

A second generalization that can be made from this study about the effect of topsoil stockpiling on microbial populations is that changes in bacterial and fungal biomass (i.e., population dynamics) in the stockpiled topsoil generally were different from those in the undisturbed topsoil during the first year of the study. However, changes in the amount of microbial biomass were similar during the second year of the study. During the first year, both forms (active and total) of bacterial and fungal biomass exhibited periods where biomass was increasing in the stockpiled topsoil while decreasing in the undisturbed topsoil, and vice versa (Figures 3-2 through 3-5).

There are a number of reasons for why the bacterial and fungal population dynamics differed in the stockpiled and undisturbed topsoil during the first half of the study. Some of these may be related to the initial soil disturbance (i.e., scraping and bulldozing the soil into a pile), increased organic matter in stockpiled soils, and interactions between bacterial and fungal populations.

Fungal hyphae can be quite long, and these likely were torn, crushed, and broken by the shearing forces of heavy equipment used to salvage topsoil (Harris et al. 1989). Damaged hyphae can lead to the death of fungal cells and their subsequent decomposition by bacteria (Harris et al. 1993). The ratio of total fungal biomass to total bacterial biomass indicated that during the first 110 days after stockpile completion, the amount of bacterial biomass in the stockpile generally exceeded that of the fungal biomass, while the opposite was true in the undisturbed soil (Figure 3-7). Differences in the ratio of total fungal to total bacterial biomass during this period may have been due to reductions in the number of living fungal cells during the initial stockpiling of topsoil.

An increase in organic matter (from dead fungal cells and from plant matter incorporated into the soil during topsoil salvage) was given as the reason for an increase in bacterial biomass during the first 100 days after stockpile construction in other studies (Harris et al. 1989, Harris et al. 1993, Johnson et al. 1991). In this study, the amount of active bacterial biomass increased in the stockpile during Days 40-75 (Figure 3-3). This initial flush of active bacterial biomass may have resulted from increased amounts of organic matter in the stockpile as compared to the undisturbed topsoil. During Days 75-210, the amount of bacterial biomass in the stockpile declined. Harris et al. (1989) observed a similar decline in the amount of bacterial biomass after the early phase of their study, and they attributed this result to the depletion of available organic matter by the bacteria.

The ratio of total fungal biomass to total bacterial biomass indicated that fungal biomass became more abundant in the stockpile during Days 110-260 (Figure 3-7), while it became less abundant in the undisturbed soil. Apparently, conditions in the stockpile favored an increase in fungal biomass. A similar increase in fungi was reported by Harris et al. (1993), and they attributed it to the recovery of fungi in the stockpiled topsoil as they exploited dead plant material that had been incorporated into the soil during stockpiling. This could have been the case in this study. However, after this period (during Days 260-420), bacterial biomass became more abundant in the stockpiled topsoil indicating that the recovery of fungi in the stockpile was short lived (Figures 3-6, 3-7). During this same period, fungal biomass again became dominant in the undisturbed topsoil. The disparities in fungal and bacterial dynamics between stockpile and undisturbed soils during the first year of this study cannot be fully explained. Apparently, complex interactions between these components and other factors that were not measured (e.g., predation and substrate availability) played a role.

While the amount fungal and bacterial biomass in the stockpiled and undisturbed topsoils changed in different ways during the first year (e.g., one increasing while the other was decreasing), the amounts of microbial biomass in these two areas changed in similar ways during the second year (e.g., both up or both down). In addition to similar fluctuations during the second year, the amount of biomass also generally was similar during the second year. For total bacterial biomass, amounts in the stockpiled and undisturbed topsoils were similar after Day 420 (Figure 3-2), and the other measures of microbial activity were similar by the end of the study (Figures 3-3 through 3-5). For active bacterial and active fungal biomass, significant differences existed between the stockpiled topsoil and undisturbed soil during part of the second year, but the rates of change in these biomass components over time were similar (Figures 3-3, 3-5). Counts of vesicular-arbuscular mycorrhizae spores in the stockpile were similar to counts in the undisturbed topsoil until Day 800, at which time there were more VAM spores in the stockpile than in undisturbed topsoil (Figure 3-6). Although the ratios of fungal to bacterial biomass in the stockpile and undisturbed topsoils were different after Day 420, the rates of change in the stockpiled topsoil were similar to those in the undisturbed soil (Figure 3-7), indicating that, on a proportional basis, the fungal and bacterial biomass in the stockpiled and undisturbed topsoils were changing in similarly ways.

Effects of Vegetation

There were large differences in the amount of vegetation on the stockpile during the first and second years of this study. During the first year, the plants on the stockpile generally were shallow-rooted seedlings, but during the second year, these plants were more mature and they were rooted more deeply. The more mature vegetation present on the stockpile during the second year may have contributed to the comparable rates of change in microbial biomass in the stockpiled and undisturbed topsoils. Vegetation on the stockpile may have provided a stable source of organic matter that the microbes could exploit, thus allowing conditions to be more similar to those in the undisturbed area during the second year. The presence of plants (with the associated plant litter and root decomposition) on stockpiles is considered critical for providing a stable source of organic matter for microbes (Fresquez et al. 1986, Visser 1985, Wilson 1965). In the case of VAM fungi, which forms symbiotic relationships with plant roots, the establishment of host plants is critical in maintaining VAM fungi in stockpiled topsoil (Miller et al. 1985).

Additional evidence for the effect of vegetation on soil conditions was the change in soil moisture at the middle layers (50-120 cm) of the stockpile (Figure 3-8). Changes in soil moisture at these depths likely represent the removal of soil moisture by vegetation. As plants became established and their roots grew deeper, the plants were able to remove moisture from the deeper layers during the latter part of the study. Had vegetation not rooted to these depths (50-120 cm), the soil moisture content at these depths likely would have remained more similar from one sampling session to the next and declined gradually as it did at depths of 160-230 cm. Evidence of the effect of plants on soil moisture also was found in the upper-most levels (depths of 0-50 cm) of the stockpile. Soil moisture in this layer followed dry-downs patterns that were more similar to those in the undisturbed soil than they were to those from deeper soil layers in the stockpile (Figure 3-8).

4.3 Effects of Stockpiling on Soil Physical and Chemical Properties

Overall, there was little difference in the physical and chemical properties of the stockpiled and undisturbed soils. No differences were found in the physical properties, but in four cases, chemical differences were found between the surface layer of the stockpile (0-20 cm) and the undisturbed topsoil (0-45 cm). The fact that vegetation grew on the stockpile suggests that, despite the statistical differences, topsoil stockpiling did not have a detrimental biological effect on the chemical properties of the soil.

Other researchers (e.g., Abdul-Kareem and McRae 1984, Gee and Bauer 1976) noted that stockpiling generally did not negatively impact chemical properties of the soil. Abdul-Kareem and McRae (1984) found that in stockpiles of varying age and textural classes, the levels of nutrients were acceptable for agricultural purposes and that stockpiling did not adversely affected the chemical fertility of the soil. Gee and Bauer (1976) reported that stockpiling caused a high degree of variability in chemical properties (both within and between topsoil stockpiles), but that it did not negatively impact the growth potential of plants.

5. CONCLUSIONS

- After two years, topsoil stockpiling had not been detrimental to soil viability.
- At a given soil depth, there was little difference in soil microbial populations among plots at any one time.
- At a given time, there was little difference in soil microbial populations among soil depths.
- The amount of microbial biomass in the stockpiled topsoil and undisturbed topsoil generally differed over time, but they were similar by the end of the study.
- Temporal changes in the amount of microbial biomass in the stockpiled and undisturbed topsoils generally were different during the first year of the study, but they were more similar during the second year.
- The vegetation that was planted on the stockpile may have been a factor in generating the similar responses of the microbial populations in the stockpiled and undisturbed topsoils during the second year of the study. Vegetation may have stabilized the amount of organic matter available for the microbes in the stockpile, thus allowing conditions to be more similar to those in the undisturbed area.
- None of the revegetation treatments (seed mix) resulted in a consistently higher response by the soil microbes (i.e., none had more active or total bacterial biomass, more active or total fungal biomass, or higher counts of vesicular-arbuscular mycorrhizae spores) across depths in the stockpile or over time. This result may be due to the similarities in final species composition and density across revegetation treatments.
- Soil physical and chemical properties generally did not differ in the stockpiled and undisturbed topsoils over time. When differences were detected, they often were at depths of 0-20 cm in the stockpile. Stockpiling topsoil did not result in any changes in the chemical properties of the soil that prevented the growth of plants.
- Based on the results of this study, no changes in the current practices for managing topsoil stockpiles at Yucca Mountain are warranted.

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APPENDIX A

Repeated Measures Analysis of Variance Tables for the Revegetation Effects on Soil Microbial Response Variables at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada.

Appendix A

Repeated measures analysis of variance table for revegetation treatment effects on Active Bacterial Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
REVEGTRT	3	0.4254	0.1418	2.9100	0.0394	
DEPTH	4	7.2913	1.8228	37.4600	0.0010	
DEPTH*REVEGTRT	12	0.5028	0.0419	0.8600	0.5887	
Within Subject Effects						
DAYS	9	54.7445	6.0827	171.1200	0.0001	0.0001
DAYS*DEPTH	36	1.8859	0.0524	1.4700	0.0381	0.0381
DAYS*REVEGTRT	27	4.7688	0.1766	4.9700	0.0001	0.0001
DAYS*DEPTH*REVEGTRT	108	3.7412	0.0346	0.9700	0.5558	0.5558

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0940

Repeated measures analysis of variance table for revegetation treatment effects on Total Bacterial Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
REVEGTRT	3	5.7519	1.9173	7.7500	0.0001	
DEPTH	4	0.8752	0.2188	0.8800	0.4775	
DEPTH*REVEGTRT	12	1.2473	0.1039	0.4200	0.9514	
Within Subject Effects						
DAYS	9	120.9468	13.4385	62.7600	0.0001	0.0001
DAYS*DEPTH	36	5.3510	0.1486	0.6900	0.9125	0.9113
DAYS*REVEGTRT	27	28.3825	1.0512	4.9100	0.0001	0.0001
DAYS*DEPTH*REVEGTRT	108	14.5875	0.1351	0.6300	0.9984	0.9983

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.9904

Repeated measures analysis of variance table for revegetation treatment effects on Active Fungal Biomass.

Source	DF	Type III SS	Mean Square	F	P	Adj P[1]
Between Subject Effects						
DEPTH	4	0.7556	0.1889	1.7700	0.1431	
REVEGTRT	3	0.9557	0.3186	2.9900	0.0361	
DEPTH*REVEGTRT	12	2.2390	0.1866	1.7500	0.0720	
Within Subject Effects						
DAYS	6	19.9471	3.3245	25.0800	0.0001	0.0001
DAYS*DEPTH	24	4.0926	0.1705	1.2900	0.1659	0.1773
DAYS*REVEGTRT	18	3.3709	0.1873	1.4100	0.1200	0.1313
DAYS*DEPTH*REVEGTRT	72	8.8991	0.1236	0.9300	0.6344	0.6251

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.8903

Repeated measures analysis of variance table for revegetation treatment effects on Total Fungal Biomass.

Source	DF	Type III SS	Mean Square	F	P	Adj P[1]
Between Subject Effects						
DEPTH	4	5.2091	1.3023	3.4100	0.0127	
REVEGTRT	3	2.0585	0.6862	1.8000	0.1545	
DEPTH*REVEGTRT	12	4.0069	0.3339	0.8800	0.5748	
Within Subject Effects						
DAYS	6	614.4420	102.4070	207.9100	0.0001	0.0001
DAYS*DEPTH	24	14.6390	0.6100	1.2400	0.2025	0.2025
DAYS*REVEGTRT	18	21.6587	1.2033	2.4400	0.0009	0.0009
DAYS*DEPTH*REVEGTRT	72	26.7913	0.3721	0.7600	0.9287	0.9287

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0919

Repeated measures analysis of variance table for revegetation treatment effects on Vesicular-Arbuscular Mycorrhizae (VAM) Spores.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	4	3.9718	0.9929	1.2700	0.2879	
REVEGTRT	3	4.2316	1.1405	1.8100	0.1526	
DEPTH*REVEGTRT	12	8.9531	0.7461	0.9600	0.4971	
Within Subject Effects						
DAYS	3	130.3658	43.4553	74.7600	0.0001	0.0001
DAYS*DEPTH	12	4.0769	0.3397	0.5800	0.8538	0.8538
DAYS*REVEGTRT	9	16.3167	1.8130	3.1200	0.0015	0.0015
DAYS*DEPTH*REVEGTRT	36	15.8357	0.4399	0.7600	0.8410	0.8410

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.1492

APPENDIX B

Repeated Measures Analysis of Variance Tables for Topsoil Depth Effects on Soil Microbial Response Variables at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada.

Appendix B

Repeated measures analysis of variance table for Active Bacterial Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	5.4953	1.0991	47.94	0.0001	
Within Subject Effects						
DAYS	9	15.4258	1.7140	145.94	0.0001	0.0001
DAYS*DEPTH	45	1.8446	0.0410	3.49	0.0001	0.0001

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0496

Repeated measures analysis of variance table for Total Bacterial Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	2.9645	0.5929	15.4500	0.0001	
Within Subject Effects						
DAYS	9	39.6902	4.4100	80.2300	0.0001	0.0001
DAYS*DEPTH	45	9.3102	0.2069	3.7600	0.0001	0.0001

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0669

Repeated measures analysis of variance table for Soil Moisture.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	0.9644	0.1929	372.0900	0.0001	
Within Subject Effects						
DAYS	9	0.1408	0.0156	80.9900	0.0001	0.0001
DAYS*DEPTH	45	0.1694	0.0038	19.4900	0.0001	0.0001

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.1697

Repeated measures analysis of variance table for Active Fungal Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	10.4443	2.0889	21.6000	0.0001	
Within Subject Effects						
DAYS	6	11.4716	1.9119	26.4500	0.0001	0.0001
DAYS*DEPTH	30	1.0171	0.1339	1.8500	0.0089	0.0089

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.1936

Repeated measures analysis of variance table for Total Fungal Biomass.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	42.4775	8.4955	63.6200	0.0001	
Within Subject Effects						
DAYS	6	161.8179	26.9696	134.6400	0.0001	0.0001
DAYS*DEPTH	30	14.1188	0.4706	2.3500	0.0004	0.0004

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0013

Repeated measures analysis of variance table for Vesicular-Arbuscular Mycorrhizae (VAM) Spores.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	12.0443	2.4089	8.2500	0.0001	
Within Subject Effects						
DAYS	3	44.2169	14.7390	47.5700	0.0001	0.0001
DAYS*DEPTH	15	5.7232	0.3815	1.2300	0.2695	0.2895

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.7440

Repeated measures analysis of variance table for Total Fungal to Bacterial Ratios.

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	14.1020	2.8204	43.1500	0.0001	
Within Subject Effects						
DAYS	6	49.7957	8.2993	61.6400	0.0001	0.0001
DAYS*DEPTH	30	16.4076	0.5469	4.0600	0.0001	0.0001

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.8812

APPENDIX C

Repeated Measures Analysis of Variance Tables for Topsoil Depth Effects on Soil Properties at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada.

Appendix C

Repeated measures analysis of variance table for electric conductivity (EC).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	3.0796	0.6159	5.3200	0.0032	
Within Subject Effects						
DAYS	2	0.1953	0.0977	0.8000	0.4567	0.4567
DAYS*DEPTH	10	2.9024	0.2902	2.3800	0.0267	0.0267

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.2465.

Repeated measures analysis of variance table for Nitrate Nitrogen (NO_3-N).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	5.1737	1.0347	2.8100	0.0457	
Within Subject Effects						
DAYS	2	76.2797	38.1399	115.6300	0.0001	0.0001
DAYS*DEPTH	10	20.5316	2.0532	6.2200	0.0001	0.0001

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.0608

Repeated measures analysis of variance table for Phosphorus (P).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	4.5605	0.9121	2.9800	0.0376	
Within Subject Effects						
DAYS	2	4.0290	2.0145	4.4800	0.0180	0.0189
DAYS*DEPTH	10	2.8412	0.2841	0.0630	0.7776	0.7738

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.9742

Repeated measures analysis of variance table for Potassium (K).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	0.0414	0.0083	0.2700	0.9220	
Within Subject Effects						
DAYS	2	1.5100	0.7550	36.5100	0.0001	0.0001
DAYS*DEPTH	10	0.5148	0.0515	2.4900	0.0209	0.0209

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.1527

Repeated measures analysis of variance table for Calcium (Ca).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	3.0190	0.6038	4.3100	0.0086	
Within Subject Effects						
DAYS	2	0.3323	0.1662	1.3500	0.2722	0.2722
DAYS*DEPTH	10	3.6007	0.3601	2.9200	0.0082	0.0082

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.2699

Repeated measures analysis of variance table for Magnesium (Mg).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	2.0014	0.4003	4.1200	0.0105	
Within Subject Effects						
DAYS	2	0.4303	0.2152	1.9200	0.1599	0.1599
DAYS*DEPTH	10	3.0347	0.3035	2.7100	0.0128	0.0128

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.2246

Repeated measures analysis of variance table for Sodium (Na).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	14.5554	2.9111	6.7300	0.0009	
Within Subject Effects						
DAYS	2	5.4254	2.7127	5.5500	0.0077	0.0091
DAYS*DEPTH	10	6.1054	0.6105	1.2500	0.2933	0.2973

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.9354

Repeated measures analysis of variance table for Iron (Fe).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	3.2935	0.6587	1.6500	0.1952	
Within Subject Effects						
DAYS	2	2.7355	1.3677	3.1400	0.0547	0.0547
DAYS*DEPTH	10	3.6981	0.3698	0.8500	0.5865	0.5865

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.2828

Repeated measures analysis of variance table for Zinc (Zn).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	2.0750	0.4150	1.6800	0.1884	
Within Subject Effects						
DAYS	2	17.7907	8.8953	96.4900	0.0001	0.0001
DAYS*DEPTH	10	3.1464	0.3146	3.4100	0.0029	0.0029

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 1.1613

Repeated measures analysis of variance table for Sodium Adsorption Ratio (SAR).

Source	DF	Type III SS	Mean Square	*F*	*P*	Adj *P*[1]
Between Subject Effects						
DEPTH	5	10.4291	2.0858	6.2500	0.0014	
Within Subject Effects						
DAYS	2	4.8059	2.4029	6.2600	0.0045	0.0076
DAYS*DEPTH	10	5.0509	0.5051	1.3200	0.2575	0.2709

[1] Significance test with degrees of freedom adjusted for Huynh-Feldt Epsilon = 0.8292

APPENDIX D

Means and Standard Errors for Soil Microbial Response Variables for Topsoil Depth Classes at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada.

Appendix D

Active Bacterial Biomass (µg/g dry soil)

	Soil Depth Class											
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.674	0.039	0.649	0.049	0.542	0.094	0.487	0.085	0.457	0.059	1.319	0.198
75	2.063	0.082	1.793	0.137	1.380	0.061	1.125	0.047	0.893	0.056	1.584	0.299
110	0.671	0.111	0.408	0.083	0.356	0.071	0.316	0.058	0.353	0.068	0.938	0.103
145	0.368	0.088	0.390	0.100	0.335	0.081	0.213	0.022	0.203	0.036	1.528	0.176
175	0.707	0.060	0.445	0.077	0.419	0.053	0.381	0.049	0.269	0.024	1.138	0.207
210	0.442	0.072	0.327	0.046	0.238	0.030	0.227	0.035	0.143	0.022	0.360	0.052
260	0.796	0.068	0.596	0.057	0.588	0.057	0.332	0.074	0.338	0.026	0.912	0.149
420	0.938	0.076	0.691	0.069	0.580	0.067	0.680	0.065	0.415	0.038	1.599	0.160
680	0.994	0.104	1.039	0.132	0.840	0.114	0.815	0.122	0.747	0.134	1.411	0.068
810	2.155	0.126	1.856	0.140	1.680	0.123	1.361	0.122	1.441	0.064	2.148	0.254

Total Bacterial Biomass (µg/g dry soil)

	Soil Depth Class											
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	3.893	0.366	4.282	0.322	4.723	0.246	5.067	0.370	4.718	0.578	6.705	0.964
75	3.551	0.265	3.460	0.250	3.025	0.403	3.391	0.418	2.898	0.407	1.873	0.194
110	2.584	0.280	2.138	0.233	2.818	0.488	2.529	0.244	2.287	0.406	5.036	0.793
145	3.216	0.414	3.965	0.912	3.269	0.408	2.773	0.385	3.336	0.482	5.042	0.499
175	4.193	0.467	4.076	0.560	4.052	0.626	3.933	0.651	4.056	0.600	5.072	0.007
210	6.966	1.168	5.729	0.839	5.269	0.418	4.726	0.386	4.673	0.774	8.121	0.892
260	4.247	0.505	3.692	0.707	4.950	1.226	4.039	0.904	2.900	0.346	16.954	2.762
420	8.476	0.617	8.267	0.665	8.528	0.834	9.199	0.541	10.212	0.480	10.052	1.097
680	2.198	0.045	2.177	0.128	1.890	0.158	1.866	0.150	1.957	0.095	2.215	0.169
810	8.353	0.864	7.349	0.421	8.846	0.842	10.021	1.675	9.521	1.569	6.895	1.087

Active Fungal Biomass (µg/g dry soil)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.097	0.033	0.043	0.016	0.079	0.038	0.017	0.017	0.061	0.043	0.838	0.308
75	0.247	0.130	0.520	0.247	0.732	0.257	0.235	0.115	0.217	0.102	1.085	0.835
110	0.046	0.036	0.319	0.155	0.202	0.095	0.431	0.232	0.292	0.122	1.704	0.562
260	0.360	0.159	0.401	0.099	0.251	0.036	0.067	0.046	0.184	0.099	1.674	0.387
420	0.466	0.029	1.293	0.656	1.221	0.383	1.162	0.173	0.973	0.176	3.718	0.464
680	0.529	0.047	0.737	0.131	1.027	0.180	1.201	0.344	0.974	0.055	3.753	0.240
810	0.334	0.098	0.179	0.065	0.270	0.195	0.648	0.214	0.381	0.175	0.769	0.476

Total Fungal Biomass (µg/g dry soil)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.202	0.541	0.581	0.286	0.983	0.324	0.594	0.308	0.816	0.244	6.593	1.001
75	2.945	1.247	2.916	0.776	3.044	0.748	3.281	1.013	2.334	0.992	27.370	17.976
110	1.385	0.352	3.192	1.020	3.069	0.669	3.910	0.823	2.375	0.722	15.663	4.482
260	13.368	1.904	18.799	1.941	19.545	2.591	22.530	2.768	13.014	3.453	26.803	7.947
420	6.046	2.297	7.248	1.300	7.259	2.165	5.807	1.013	4.080	0.885	56.100	6.013
680	5.823	0.838	4.782	0.688	5.743	0.549	6.323	1.100	6.037	0.284	15.797	1.211
810	29.255	4.037	32.808	2.925	30.163	1.454	34.604	2.863	39.316	2.810	55.938	10.721

Vesicular-Arbuscular Mycorrhizae (VAM) Spores (number/g dry soil)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
260	14.643	1.788	11.494	2.379	10.209	2.008	13.434	2.545	8.757	2.366	13.166	5.721
420	2.054	0.317	1.369	0.154	1.977	0.429	1.303	0.133	1.503	0.399	1.143	0.412
680	3.204	0.768	4.690	2.547	4.173	1.446	2.545	0.641	3.203	1.048	0.392	0.144
810	10.165	1.740	10.194	1.723	9.940	3.149	8.201	1.707	10.868	1.182	1.430	0.612

Total Fungal to Bacterial Biomass Ratio

Days	Soil Depth Class: 0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.284	0.111	0.134	0.067	0.208	0.072	0.106	0.052	0.168	0.046	1.015	0.148
75	0.855	0.365	0.811	0.203	1.119	0.320	1.084	0.393	0.842	0.299	12.096	6.479
110	0.574	0.172	1.594	0.632	1.334	0.435	1.737	0.576	1.355	0.577	3.434	1.187
260	3.249	0.407	5.835	1.137	4.260	0.351	6.329	1.014	4.984	1.900	1.711	0.438
420	0.787	0.357	0.921	0.229	0.971	0.372	0.650	0.126	0.418	0.117	5.832	0.854
680	2.686	0.450	2.215	0.341	3.184	0.560	3.395	0.553	3.096	0.127	7.347	0.892
810	3.638	0.609	4.464	0.284	3.612	0.566	3.885	0.691	4.651	0.959	9.565	2.508

APPENDIX E

Means and Standard Errors for Soil Physical and Chemical Properties for Topsoil Depth Classes at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada.

Appendix E

Soil moisture (%)

Days	0-20 cm Mean	0-20 cm ±SE	50-70 cm Mean	50-70 cm ±SE	100-120 cm Mean	100-120 cm ±SE	160-180 cm Mean	160-180 cm ±SE	210-230 cm Mean	210-230 cm ±SE	Undisturbed Mean	Undisturbed ±SE
40	5.65	0.24	9.21	0.52	11.04	0.36	12.15	0.40	10.76	0.45	2.78	0.21
75	6.38	0.12	9.59	0.24	10.89	0.42	11.53	0.28	11.32	0.25	3.57	0.19
110	5.94	0.45	9.00	0.38	10.55	0.32	10.96	0.19	10.65	0.19	1.52	0.24
145	4.21	0.25	7.69	0.22	9.07	0.18	9.72	0.32	10.40	0.25	0.66	0.11
175	5.23	0.24	7.63	0.35	9.03	0.45	9.73	0.27	9.97	0.25	1.09	0.14
210	6.05	0.08	8.37	0.23	8.59	0.70	9.85	0.46	10.15	0.51	2.78	0.14
260	6.74	0.21	8.76	0.35	9.09	0.50	9.45	0.18	10.49	0.72	4.49	0.36
420	4.39	0.36	6.77	0.34	7.61	0.26	8.68	0.46	9.54	0.41	1.90	0.21
680	7.97	0.75	9.96	0.30	10.32	0.48	9.05	0.49	8.84	0.54	9.24	0.22
810	3.29	0.18	6.30	0.19	7.01	0.30	7.82	0.34	8.03	0.42	2.36	0.19

Soil Depth Class

Zinc (ppm)

Days	0-20 cm Mean	0-20 cm ±SE	50-70 cm Mean	50-70 cm ±SE	100-120 cm Mean	100-120 cm ±SE	160-180 cm Mean	160-180 cm ±SE	210-230 cm Mean	210-230 cm ±SE	Undisturbed Mean	Undisturbed ±SE
40	0.280	0.020	0.260	0.025	0.460	0.081	0.320	0.073	0.420	0.124	0.140	0.040
420	0.100	0.000	0.120	0.020	0.180	0.037	0.160	0.040	0.120	0.020	0.160	0.025
680	0.400	0.058	0.500	0.041	0.450	0.119	0.525	0.111	0.475	0.048	0.360	0.025

Soil Depth Class

Sodium Adsorption Ratio

Days	0-20 cm Mean	0-20 cm ±SE	50-70 cm Mean	50-70 cm ±SE	100-120 cm Mean	100-120 cm ±SE	160-180 cm Mean	160-180 cm ±SE	210-230 cm Mean	210-230 cm ±SE	Undisturbed Mean	Undisturbed ±SE
40	1.260	0.025	1.240	0.129	1.100	0.205	1.140	0.191	0.940	0.108	0.340	0.025
420	0.954	0.127	0.594	0.169	0.850	0.196	0.708	0.050	1.002	0.154	0.348	0.055
680	2.200	0.942	1.325	0.298	0.925	0.111	1.325	0.189	1.150	0.096	0.700	0.167

Soil Depth Class

pH

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	8.040	0.040	8.180	0.049	8.060	0.040	8.120	0.073	8.120	0.058	8.100	0.055
420	8.100	0.045	8.120	0.049	8.040	0.051	8.060	0.075	8.120	0.049	8.060	0.060
680	8.175	0.048	7.975	0.048	7.900	0.071	7.900	0.041	8.000	0.041	8.060	0.025

Soil Depth Class

Phosphorus (ppm)

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.560	0.349	1.980	0.252	1.800	0.321	2.080	0.225	2.360	0.339	2.640	0.681
420	2.280	0.980	0.840	0.112	2.000	0.311	2.120	0.595	2.180	0.810	5.060	2.419
680	3.000	0.408	2.750	0.250	3.000	0.707	3.250	0.629	2.250	0.629	5.000	0.949

Soil Depth Class

Potassium (ppm)

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	472.800	14.087	505.200	23.756	529.600	16.366	523.200	12.901	525.600	31.709	505.600	38.516
420	501.200	16.129	488.800	24.309	504.000	35.878	478.600	30.237	440.200	43.550	388.400	36.486
680	626.250	42.787	585.000	38.676	563.750	25.526	672.500	79.726	608.750	51.453	791.000	82.952

Soil Depth Class

Calcium (meq/l)

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	4.500	0.948	3.000	0.336	4.080	0.655	4.640	1.253	3.260	0.068	3.740	0.337
420	10.082	2.462	2.614	0.178	5.188	2.458	3.460	0.345	3.394	0.582	3.024	0.462
680	3.675	0.193	4.050	0.233	7.725	1.991	5.025	0.095	4.300	0.436	3.900	0.493

Soil Depth Class

Electric Conductivity (mmhos/cm)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.720	0.132	0.540	0.068	0.580	0.092	0.680	0.156	0.540	0.025	0.480	0.020
420	1.456	0.302	0.476	0.056	0.784	0.330	0.588	0.052	0.588	0.112	0.420	0.063
680	0.543	0.034	0.638	0.050	1.063	0.265	0.773	0.026	0.640	0.039	0.522	0.084

Iron (ppm)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.880	0.086	2.020	0.203	2.540	0.397	2.360	0.344	3.120	0.564	2.180	0.521
420	1.780	0.198	3.160	1.107	9.580	3.366	5.520	2.196	3.880	2.106	2.020	0.139
680	7.300	4.911	5.000	0.560	3.325	0.760	6.825	4.077	5.475	2.525	2.040	0.133

Magnesium (meq/l)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.280	0.222	0.960	0.108	1.260	0.163	1.440	0.304	1.080	0.037	1.180	0.120
420	2.896	0.677	0.968	0.061	1.760	0.695	1.316	0.122	1.194	0.216	1.118	0.104
680	1.000	0.071	1.225	0.095	2.400	0.644	1.575	0.048	1.425	0.144	1.360	0.250

Sodium (meq/l)

Days	Soil Depth Class											
	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	2.100	0.207	1.740	0.147	1.860	0.484	2.060	0.638	1.380	0.174	0.560	0.051
420	2.258	0.183	0.770	0.214	1.744	0.841	1.084	0.079	1.570	0.373	0.502	0.098
680	3.400	1.545	2.100	0.460	1.925	0.075	2.450	0.357	1.925	0.103	1.180	0.381

Nitrate Nitrogen (ppm)

	Soil Depth Class											
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.500	0.000	0.500	0.000	0.500	0.000	0.500	0.000	0.500	0.000	1.000	0.000
420	27.600	7.947	3.600	1.077	4.200	1.715	5.600	1.435	3.400	1.364	3.000	0.548
680	4.000	1.000	5.750	0.946	16.250	7.227	6.500	0.646	4.750	0.854	2.200	0.490

Organic Matter (%)

	Soil Depth Class											
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm		Undisturbed	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.600	0.045	0.600	0.071	0.620	0.037	0.500	0.045	0.580	0.020	0.640	0.040
420	0.300	0.032	0.260	0.040	0.320	0.020	0.280	0.037	0.300	0.032	0.360	0.051
680	0.973	0.029	0.935	0.044	0.980	0.085	1.093	0.159	0.878	0.034	0.910	0.058

APPENDIX F

Means and Standard Errors for Total Bacterial Biomass by Revegetation Treatment, Topsoil Depth Class, and Days after Stockpile Completion for Soil Samples Collected at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada. See Table 2-1 for Explanation of Revegetation Treatments.

APPENDIX F

Total Bacterial Biomass (µg/g dry soil): Deep Mix Revegetation Treatment

	Soil Depth Class									
Days	**0-20 cm**		**50-70 cm**		**100-120 cm**		**160-180 cm**		**210-230 cm**	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	3.980	0.784	4.829	0.596	5.740	0.863	5.715	0.648	4.870	0.934
75	2.423	0.171	1.824	0.149	1.527	0.186	1.731	0.200	1.868	0.221
110	1.822	0.487	1.254	0.388	1.551	0.528	1.717	0.527	1.370	0.460
145	3.046	0.701	2.138	0.471	2.849	0.579	2.590	0.663	1.911	0.636
175	3.562	1.064	3.505	1.164	3.525	1.179	3.558	1.180	4.539	0.975
210	7.942	1.557	7.244	1.875	6.161	1.699	5.066	1.286	6.692	1.662
260	3.534	1.665	2.215	0.401	1.948	0.496	3.407	1.506	1.552	0.200
420	8.732	1.627	6.701	0.946	8.258	1.399	9.590	1.612	10.337	2.008
680	2.311	0.138	2.489	0.356	2.156	0.409	2.258	0.207	2.138	0.196
810	6.202	1.396	3.055	0.389	6.905	1.991	4.861	2.468	5.287	2.792

Total Bacterial Biomass (µg/g dry soil): Native Mix Revegetation Treatment

	Soil Depth Class									
Days	**0-20 cm**		**50-70 cm**		**100-120 cm**		**160-180 cm**		**210-230 cm**	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	6.182	1.280	6.253	1.402	6.029	1.123	6.200	1.813	5.747	1.603
75	1.877	0.314	2.782	0.381	3.174	0.926	3.253	0.924	2.371	0.850
110	2.228	0.296	3.376	0.602	4.220	1.042	3.033	0.661	3.701	0.675
145	4.081	0.460	5.600	2.098	4.087	1.279	2.677	0.464	4.773	1.739
175	4.011	0.766	3.714	1.038	3.914	0.917	3.720	1.064	3.656	1.130
210	8.292	2.950	5.173	1.248	6.910	0.647	4.870	1.489	5.090	1.719
260	3.931	0.993	2.849	1.198	6.283	2.198	3.959	0.716	4.061	1.963
420	6.872	0.327	9.788	1.670	9.203	1.629	9.214	2.187	9.188	1.719
680	2.477	0.103	2.383	0.290	2.057	0.204	1.870	0.377	2.251	0.178
810	7.992	1.556	5.795	1.760	8.348	2.216	9.824	2.070	8.980	1.229

Total Bacterial Biomass (µg/g dry soil): Legume Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	2.145	0.252	2.877	0.998	3.419	1.057	4.578	0.846	4.053	0.923
75	5.137	1.167	4.757	0.944	2.598	0.394	4.624	1.544	4.332	1.617
110	3.700	1.037	1.860	0.071	2.868	0.872	2.380	0.255	2.117	0.512
145	3.001	0.732	6.152	3.751	3.310	0.780	3.185	0.851	3.455	0.900
175	5.254	0.526	5.229	0.677	4.764	0.721	4.470	0.720	4.334	0.897
210	8.088	3.213	7.726	2.950	4.973	1.444	4.649	1.731	3.507	1.555
260	6.265	1.176	5.189	2.154	7.195	2.346	4.264	1.261	3.108	1.131
420	10.678	1.293	9.543	1.244	9.777	1.792	9.724	1.544	13.096	3.130
680	1.986	0.115	1.848	0.223	1.637	0.059	1.789	0.169	1.546	0.183
810	6.817	2.347	6.416	1.797	4.124	1.081	10.538	3.831	15.004	2.988

Total Bacterial Biomass (µg/g dry soil): Shallow Mix Revegation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	3.266	0.516	3.168	1.039	3.703	0.803	3.774	0.810	4.200	0.751
75	4.766	1.004	4.476	0.913	4.800	1.802	3.954	0.693	3.021	0.884
110	2.585	0.572	2.062	0.300	2.635	0.753	2.986	0.839	1.958	0.518
145	2.737	0.507	1.970	0.323	2.831	0.514	2.639	0.554	3.206	0.507
175	3.943	0.830	3.857	0.915	4.006	0.867	3.983	0.924	3.694	1.128
210	3.542	0.858	2.771	0.732	3.030	0.665	4.318	1.694	3.403	1.464
260	3.258	0.973	4.515	0.826	4.375	0.817	4.526	1.939	2.877	0.639
420	7.621	1.208	7.038	0.586	6.875	0.548	8.268	0.733	8.228	1.598
680	2.017	0.098	1.990	0.208	1.710	0.167	1.548	0.078	1.893	0.198
810	12.401	1.948	14.132	1.832	16.008	3.419	14.861	3.263	8.833	3.714

APPENDIX G

Means and Standard Errors for Active Bacterial Biomass by Revegetation Treatment, Topsoil Depth Class, and Days after Stockpile Completion for Soil Samples Collected at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada. See Table 2-1 for Explanation of Revegetation Treatments.

APPENDIX G

Active Bacterial Biomass (µg/g dry soil): Deep Mix Revegetation Treament

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.674	0.207	0.772	0.307	0.592	0.221	0.479	0.221	0.338	0.125
75	2.113	0.173	1.640	0.212	1.247	0.285	1.085	0.124	0.837	0.127
110	0.747	0.185	0.405	0.086	0.295	0.095	0.172	0.090	0.172	0.070
145	0.425	0.099	0.646	0.192	0.547	0.172	0.346	0.128	0.254	0.068
175	0.841	0.062	0.242	0.086	0.350	0.167	0.395	0.148	0.285	0.099
210	0.541	0.100	0.380	0.071	0.225	0.037	0.222	0.079	0.139	0.043
260	0.594	0.050	0.479	0.080	0.448	0.148	0.232	0.047	0.277	0.090
420	1.284	0.192	0.574	0.159	0.501	0.140	0.747	0.228	0.442	0.093
680	0.958	0.164	0.942	0.238	0.918	0.243	0.872	0.194	0.763	0.154
810	2.376	0.356	2.625	0.192	2.038	0.342	1.417	0.192	1.820	0.496

Active Bacterial Biomass (µg/g dry soil): Native Mix Revegetation Treatment

Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.861	0.077	0.768	0.079	0.731	0.174	0.643	0.118	0.743	0.113
75	1.261	0.149	1.931	0.324	1.386	0.341	1.136	0.227	0.833	0.217
110	0.708	0.168	0.469	0.182	0.349	0.113	0.358	0.082	0.566	0.153
145	0.315	0.124	0.343	0.127	0.305	0.184	0.223	0.096	0.291	0.125
175	0.796	0.110	0.493	0.099	0.370	0.038	0.515	0.131	0.232	0.093
210	0.256	0.050	0.240	0.018	0.235	0.045	0.228	0.059	0.125	0.019
260	0.855	0.246	0.572	0.048	0.531	0.120	0.256	0.093	0.357	0.065
420	0.753	0.161	0.686	0.155	0.542	0.099	0.759	0.151	0.431	0.089
680	0.989	0.074	1.158	0.160	0.702	0.120	0.719	0.104	1.076	0.077
810	2.507	0.359	1.948	0.497	2.051	0.248	2.242	0.117	1.583	0.169

Active Bacterial Biomass (µg/g dry soil): Legume Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.587	0.074	0.553	0.160	0.486	0.119	0.414	0.101	0.282	0.053
75	1.859	0.154	1.048	0.216	1.114	0.181	0.849	0.089	0.975	0.188
110	0.371	0.065	0.308	0.069	0.398	0.156	0.470	0.098	0.336	0.073
145	0.341	0.113	0.278	0.104	0.306	0.117	0.161	0.066	0.158	0.074
175	0.659	0.084	0.504	0.093	0.608	0.095	0.483	0.065	0.400	0.112
210	0.656	0.084	0.500	0.108	0.277	0.051	0.192	0.083	0.171	0.052
260	0.870	0.056	0.771	0.120	0.805	0.151	0.378	0.110	0.370	0.115
420	0.583	0.162	0.688	0.151	0.613	0.209	0.616	0.173	0.285	0.097
680	1.038	0.165	0.941	0.125	0.951	0.205	0.854	0.156	0.504	0.135
810	1.537	0.264	1.348	0.228	0.860	0.108	1.122	0.079	1.084	0.206

Active Bacterial Biomass (µg/g dry soil): Shallow Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.574	0.218	0.501	0.172	0.359	0.123	0.410	0.140	0.463	0.183
75	3.018	0.129	2.552	0.232	1.775	0.129	1.432	0.277	0.927	0.164
110	0.858	0.168	0.449	0.060	0.381	0.065	0.263	0.055	0.341	0.092
145	0.392	0.110	0.295	0.077	0.183	0.102	0.121	0.082	0.110	0.065
175	0.531	0.259	0.542	0.328	0.350	0.196	0.130	0.053	0.157	0.044
210	0.315	0.066	0.190	0.067	0.215	0.070	0.266	0.060	0.134	0.061
260	0.865	0.234	0.562	0.091	0.569	0.152	0.462	0.199	0.349	0.146
420	1.130	0.097	0.815	0.133	0.663	0.081	0.596	0.159	0.504	0.075
680	0.993	0.220	1.114	0.204	0.787	0.077	0.816	0.199	0.645	0.218
810	2.201	0.171	1.501	0.430	1.769	0.338	0.920	0.121	1.277	0.223

APPENDIX H

Means and Standard Errors for Total Fungal Biomass by Revegetation Treatment, Topsoil Depth Class, and Days after Stockpile Completion for Soil Samples Collected at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada. See Table 2-1 for Explanation of Revegetation Treatments.

APPENDIX H

Total Fungal Biomass (µg/g dry soil): Deep Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.116	0.705	0.000	0.000	0.946	0.946	0.393	0.289	0.288	0.288
75	2.593	0.767	1.391	0.545	3.588	2.036	0.771	0.516	1.167	0.316
110	0.093	0.093	0.945	0.393	2.870	0.815	2.880	0.337	1.996	0.526
260	21.838	7.686	31.437	8.166	24.963	7.504	31.207	10.922	22.915	11.198
420	3.806	1.517	8.582	2.088	14.161	7.932	7.222	2.210	3.550	0.348
680	6.587	1.549	2.879	1.012	4.392	1.502	8.306	0.289	4.422	0.688
810	30.527	8.783	41.044	3.441	37.619	2.496	45.027	6.622	37.060	6.121

Total Fungal Biomass (µg/g dry soil): Native Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.410	0.897	1.275	0.927	2.215	0.710	1.078	0.858	1.535	0.848
75	3.921	2.401	2.901	1.355	2.545	1.381	5.371	2.602	4.824	2.714
110	0.914	0.698	2.653	0.406	3.146	1.099	5.636	3.515	2.539	1.224
260	5.239	2.232	10.987	2.360	18.950	6.581	24.514	9.300	13.463	3.798
420	3.582	1.074	7.960	2.706	4.178	0.480	5.306	1.444	6.066	1.501
680	5.743	0.511	4.290	1.313	5.390	1.247	5.507	2.047	4.523	1.411
810	41.995	8.541	33.857	3.471	29.426	9.227	28.281	2.033	49.015	8.901

Total Fungal Biomass (µg/g dry soil): Legume Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	1.471	0.557	0.545	0.362	0.100	0.064	0.100	0.100	1.345	1.079
75	2.459	1.214	3.207	1.671	2.573	0.971	3.616	2.251	0.504	0.504
110	1.096	0.532	5.651	3.035	3.305	1.214	2.208	0.421	1.824	0.439
260	13.594	3.404	17.450	4.118	21.286	7.158	19.799	5.150	8.207	2.908
420	14.469	9.616	6.601	2.392	6.338	1.482	5.511	1.468	2.399	1.080
680	5.725	1.220	8.358	1.391	7.569	1.448	8.080	2.321	8.507	1.441
810	22.058	3.663	33.192	9.959	28.066	2.376	35.430	2.946	44.897	7.695

Total Fungal Biomass (μg/g dry soil): Shallow Mix Revegetation Treatment

	Soil Depth Class									
Days	**0-20 cm**		**50-70 cm**		**100-120 cm**		**160-180 cm**		**210-230 cm**	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.812	0.812	0.503	0.369	0.671	0.471	0.804	0.443	0.095	0.095
75	2.804	1.484	4.165	1.815	3.470	0.807	3.365	1.057	2.839	1.421
110	3.437	1.352	3.519	1.283	2.955	1.766	4.918	2.069	3.142	1.602
260	12.802	2.999	15.324	4.891	12.981	4.889	14.201	7.269	7.473	2.292
420	2.326	0.941	5.849	1.995	4.361	1.801	5.190	1.786	4.303	2.646
680	5.238	2.165	3.600	1.051	5.621	1.840	3.400	0.814	6.695	1.028
810	22.439	5.742	22.058	5.392	25.541	4.626	31.364	7.013	26.293	4.651

APPENDIX I

Means and Standard Errors for Active Fungal Biomass by Revegetation Treatment, Topsoil Depth Class, and Days after Stockpile Completion for Soil Samples Collected at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada. See Table 2-1 for Explanation of Revegetation Treatments.

APPENDIX I

ActiveTotal Fungal Biomass (µg/g dry soil): Deep Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.109	0.058	0.000	0.000	0.051	0.051	0.000	0.000	0.000	0.000
75	0.503	0.232	0.312	0.206	1.029	0.861	0.068	0.068	0.073	0.073
110	0.000	0.000	0.171	0.171	0.289	0.178	0.000	0.000	0.234	0.197
260	0.683	0.232	0.471	0.282	0.241	0.159	0.080	0.038	0.408	0.345
420	0.326	0.209	2.762	1.506	1.158	0.723	2.088	0.784	1.298	0.382
680	0.910	0.202	0.930	0.284	1.353	0.593	0.461	0.128	1.235	0.347
810	0.607	0.325	0.000	0.000	0.624	0.624	0.891	0.468	0.674	0.524

ActiveTotal Fungal Biomass (µg/g dry soil): Native Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.118	0.079	0.046	0.023	0.181	0.127	0.000	0.000	0.177	0.177
75	0.000	0.000	0.177	0.132	0.547	0.466	0.068	0.068	0.109	0.070
110	0.000	0.000	0.182	0.112	0.081	0.052	1.404	0.884	0.104	0.104
260	0.128	0.095	0.301	0.147	0.271	0.138	0.000	0.000	0.118	0.084
420	0.341	0.152	0.350	0.184	1.277	0.707	0.627	0.412	1.731	1.047
680	0.400	0.194	0.614	0.248	0.603	0.157	0.943	0.398	1.386	0.518
810	0.259	0.174	0.499	0.263	0.177	0.177	0.177	0.084	0.179	0.179

ActiveTotal Fungal Biomass (µg/g dry soil): Legume Mix Revegetation Treatment

Soil Depth Class										
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.161	0.073	0.094	0.071	0.049	0.033	0.000	0.000	0.065	0.065
75	0.198	0.132	0.621	0.469	0.552	0.277	0.693	0.439	0.135	0.135
110	0.000	0.000	0.051	0.032	0.285	0.175	0.246	0.142	0.155	0.103
260	0.608	0.420	0.506	0.179	0.349	0.147	0.187	0.151	0.107	0.107
420	0.747	0.277	0.919	0.387	1.305	1.026	2.040	0.729	0.161	0.161
680	0.342	0.095	1.021	0.365	1.311	0.147	2.301	0.987	0.881	0.468
810	0.261	0.107	0.126	0.088	0.189	0.189	1.162	0.471	0.219	0.102

ActiveTotal Fungal Biomass (µg/g dry soil): Shallow Mix Revegetation Treatment

Soil Depth Class										
Days	**0-20 cm**		**50-70 cm**		**100-120 cm**		**160-180 cm**		**210-230 cm**	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
40	0.000	0.000	0.033	0.033	0.036	0.036	0.067	0.067	0.000	0.000
75	0.288	0.194	0.969	0.610	0.800	0.197	0.111	0.072	0.548	0.465
110	0.186	0.142	0.872	0.475	0.154	0.103	0.072	0.050	0.676	0.415
260	0.020	0.020	0.324	0.244	0.144	0.120	0.000	0.000	0.104	0.104
420	0.449	0.318	1.143	1.105	1.011	0.817	0.165	0.165	0.704	0.314
680	0.463	0.128	0.381	0.219	0.839	0.181	1.099	0.313	0.393	0.267
810	0.208	0.097	0.090	0.090	0.091	0.091	0.363	0.363	0.452	0.286

APPENDIX J

Means and Standard Errors for Vesicular-arbuscular Mycorrhizae Spores by Revegetation Treatment, Topsoil Depth Class, and Days after Stockpile Completion for Soil Samples Collected at the Exploratory Studies Facility Borrow Pit Topsoil Stockpile, Yucca Mountain, Nevada. See Table 2-1 for Explanation of Revegetation Treatments.

APPENDIX J

Vesicular-Arbuscular Mycorrhizae Spores (number/g dry soil): Deep Mix Revegetation Treatment

	Soil Depth Class									
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
260	22.333	6.653	8.728	3.248	12.519	3.555	13.637	7.323	9.860	5.828
420	2.118	0.873	1.329	0.269	2.609	1.217	1.650	0.260	0.707	0.235
280	6.764	2.723	12.639	10.039	6.909	4.013	4.505	2.082	8.256	4.286
810	7.822	2.753	8.677	1.768	7.186	2.623	5.545	1.090	7.729	2.425

Vesicular-Arbuscular Mycorrhizae Spores (number/g dry soil): Native Mix Revegetation Treatment

	Soil Depth Class									
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
260	6.162	1.083	11.481	2.973	6.051	2.001	6.730	3.115	12.324	1.726
420	1.169	0.194	0.941	0.376	1.503	0.446	0.993	0.399	1.561	0.519
280	4.095	1.223	3.794	0.777	5.206	1.732	2.807	1.125	2.041	0.871
810	10.090	3.758	5.287	1.297	11.357	3.129	5.512	3.351	12.618	4.444

Vesicular-Arbuscular Mycorrhizae Spores (number/g dry soil): Legume Mix Revegetation Treatment

	Soil Depth Class									
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
260	13.617	4.112	11.271	2.297	8.261	4.139	11.732	6.887	9.330	3.292
420	2.670	0.339	1.600	0.725	1.695	0.661	1.487	0.192	2.440	1.437
280	0.916	0.328	1.050	0.305	0.846	0.165	0.709	0.224	1.097	0.473
810	5.365	2.301	10.839	5.335	4.568	1.257	6.729	3.059	14.897	10.405

Vesicular-Arbuscular Mycorrhizae Spores (number/g dry soil): Shallow Mix Revegetation Treamtent

	Soil Depth Class									
Days	0-20 cm		50-70 cm		100-120 cm		160-180 cm		210-230 cm	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
260	16.458	3.223	14.495	3.075	14.007	4.582	20.232	3.576	3.515	1.426
420	2.259	0.514	1.606	0.573	2.099	0.608	1.083	0.359	1.304	0.438
280	1.042	0.314	1.276	0.479	3.732	2.024	2.161	1.626	1.418	0.526
810	17.382	7.426	15.973	5.357	16.650	8.739	15.018	7.235	8.227	5.312