

Effects of Soil Quality and Depth on Seed Germination and Seedling Survival at the Nevada Test Site

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Abstract—A study was developed to test the effects of soil quality and depth on seedling emergence and survival. Fifty-six plots were established and two treatments were tested. The first treatment compared native topsoil to subsoil imported from a borrow pit. The second treatment compared four different depth ranges of both soil types. All plots received identical seeding treatments. Seedling density was measured after emergence. Overall seedling densities averaged 10.3 ± 8.8 (SD) plants/m². Statistical analysis revealed a significant interaction between the two treatment factors. The subsoil had increasing densities from the deep soil depths to the shallow depths while the topsoil had increasing densities from the shallow soil depths to the deep depths.

As part of its commitment under the Nuclear Waste Policy Act 1983, as amended in 1987, the U.S. Department of Energy (DOE) has developed an environmental program (DOE 1989) that is to be implemented during site characterization at Yucca Mountain. A portion of this environmental program deals with reclamation of disturbed sites. The goal of reclamation is to return land disturbed by site characterization activities to a stable ecological state with a form and productivity similar to the predisturbed state.

Since limited information exists pertaining to Mojave Desert reclamation, DOE has implemented a series of feasibility studies to investigate the success of various reclamation techniques for the Yucca Mountain area. The most successful techniques will be used for stabilizing and revegetating temporary topsoil stockpiles, and reclaiming sites released for final reclamation.

Many of the sites disturbed in the early years of site characterization did not have topsoil salvaged for later use during reclamation. Topsoil is an important component of the desert environment. It serves as a nutrient source for plants (Great Basin Naturalists Memoirs 4 1980; Ostler and Allred 1987) and the top 5-10 cm (2-4 in) of soil contains the majority of the seed-bank and a large percentage of the organisms associated with nutrient cycling (Foth and Turk 1972). Therefore, soil may have to

be imported to these sites in order to meet the reclamation goals set by DOE. Because importing soil to a site is expensive, data needs to be collected to assess the minimum amount of soil necessary for reclamation.

The effects of topsoil depth have been studied by mining operations in semi-arid regions. Croft and others (1987) tested soil thicknesses of 0, 10, 20, 30, and 46 cm (0, 4, 8, 12, 18 in) and reported that plant cover and biomass did not appear to be affected by topsoil depth. However, Schuman and others (1985) tested soil depths of 0, 20, 40, and 60 cm (0, 8, 16, 24 in) and reported that production was greater for the 40 (16 in) and 60 cm (24 in) depths. Chambers (1989) recommends that 30 cm (12 in) of topsoil be applied to fine or medium-textured spoils while coarse-textured or rocky spoils may require up to 60 cm (24 in) of topsoil. Power (1978) found that red spring wheat yields increased as pure topsoil thickness increased up to 60-75 cm (24-30 in), at which point yields plateaued. Research conducted in California's San Joaquin Valley found that as little as 15 cm (6 in) of topsoil produced a 19-fold increase in production and a 4-fold increase in percent cover over a no-topsoil control (Anderson 1987).

Topsoil is a scarce resource in the desert so situations may arise where lower-quality soils may have to be used. The effects of topsoil quality on revegetation have not been studied extensively and findings have been mixed. Power (1978) concluded that red spring wheat yields were lowest on subsoil, followed by a subsoil and topsoil mix. Red spring wheat yields were highest for pure topsoil. Other experiments have shown that rough-graded subsoil can be superior to topsoil for grass and legume establishment, although subsoil moisture rather than the topsoil material was the primary factor responsible for the improved grass and legume establishment (Wright and others 1978). Information gained by studying soil depth and soil quality will aid in determining methods for reclaiming sites in the most cost-effective manner.

The objectives of this study were to determine the effects of soil quality and depth on emergence and survival of native plant species. The working hypotheses are: 1) seedling emergence will be higher in the topsoil in comparison to the imported subsoil; and 2) seedling emergence will be the same across all soil depths. This paper presents preliminary data. Field plots will be monitored for the next several years to determine plant survival as it relates to soil quality and depth. The working hypotheses for the long-term study are: 1) long-term plant density and survival will be higher in the native topsoil in comparison to the imported subsoil; and 2) long-term plant density and survival will have a direct relationship to soil depth.

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Materials and Methods

A disturbed area on the northern end of the Yucca Mountain crest was selected for this study due to the flat, homogeneous bedrock surface. Elevation at the site is approximately 1,450 m (4,750 ft). The undisturbed area surrounding the study site is dominated by blackbrush (*Coleogyne ramosissima*) and is characteristic of a transition desert shrub community between the lower elevation Mojave Desert and the higher elevation Great Basin Desert. In 1982, the area was scraped with a bulldozer and the soil was used in construction of a road. Minimal topsoil and subsoil remained on the exposed bedrock.

In November 1992, a road-grader was used to scrape off any remaining topsoil and subsoil and expose the bedrock at the study site. While most of the area was exposed bedrock, some soil remained in the cracks and undulations of the bedrock's surface. Fifty-six 5 x 7.5 m (16.4 x 24.6 ft) plots were marked out on the site in a completely randomized 2 x 4 factorial design with seven replications. The first factor, soil quality, had two levels: subsoil and topsoil. The subsoil originated from a borrow pit on the east side of Yucca Mountain. The topsoil was the material that remained on the site following the original disturbance. It was a mixture of topsoil and subsoil similar to material that would have been salvaged for future use. The second factor, soil depth, had four levels: 5 ± 5, 15 ± 5, 25 ± 5, and 35 ± 5 cm (2.5 ± 2.5, 6 ± 2.5, 10 ± 2.5, 14 ± 2.5 in) of soil. A front-end loader was used to spread the soil over each plot. Removal of large rocks and final leveling was accomplished by hand. Samples from both soil types were analyzed for the physical and chemical factors listed in Table 1.

Plots were seeded at a rate of 18.4 kg/ha pure live seed (PLS) (16.4 lb/ac PLS) with a mix of species native to Yucca Mountain (Table 2). All seed was drill-seeded except for winterfat (*Ceratoides lanata*) which was broadcast-seeded. Plots were mulched with wheat straw at a rate of 2,803 kg/ha (2,500 lb/ac). The straw was then tackified with a mixture of commercially available tackifier at a rate of 112 kg/ha (100 lb/ac) and wood fiber at a rate of 168 kg/ha

Table 1—Median comparisons of selected soil properties for the subsoil and topsoil soil types. Letters denote differences at the $p < 0.05$ level. Differences were calculated using the Wilcoxon two sample test.

Soil property	Subsoil (n = 5)	Topsoil (n = 4)
Nitrogen (ppm)	2a	11b
Phosphorus (ppm)	0.1a	2.4b
Potassium (ppm)	604a	514a
Percent organic matter	0.2a	1.5b
Percent gravel > 2mm	57a	44.5b
Percent sand	88a	64b
Percent silt	2a	24b
Percent clay	10a	13a
Soil type	Loamy sand	Sandy loam
Percent water at 1/10 bar	15a	22b
Percent water at 15 bars	9.2a	15.3b
Cation Exchange Capacity (CEC)	10.6a	21b
pH	8a	8a
Electrical conductivity	1.38a	0.8b

Table 2—Seeded and unseeded species counted during spring (1993) seedling density measurements.

Common name	Scientific name	Identification code
Seeded Species:		
Anderson desert thorn	<i>Lycium andersonii</i>	LYAN
blackbrush	<i>Coleogyne ramosissima</i>	CORA
California buckwheat	<i>Eriogonum californica</i>	ERCA
common snakeweed	<i>Gutierrezia sarothrae</i>	GUSA
desert mallow	<i>Sphaeralcea ambigua</i>	SPAM
fourwing saltbrush	<i>Atriplex canescens</i>	ATCA
galleta grass	<i>Hilaria jamesii</i>	HIJA
spiny hopsage	<i>Grayia spinosa</i>	GRSP
Nevada ephedra	<i>Ephedra nevadensis</i>	EPNE
shadscale	<i>Atriplex confertifolia</i>	ATCO
sticky leaf rabbit-brush	<i>Chrysothamnus viscidiflorus</i>	CHVI
white burrow-brush	<i>Hymenoclea salsola</i>	HYSA
white bursage	<i>Ambrosia dumosa</i>	AMDU
winterfat	<i>Ceratoides lanata</i>	CELA
Unseeded Species:		
wheat	<i>Triticum aestivum</i>	TRAE
white clover	<i>Melilotus alba</i>	MEAL
storksbill	<i>Erodium cicutarium</i>	ERCI
red brome	<i>Bromus rubens</i>	BRRU

(150 lb/ac). Approximately 0.64 cm (0.25 in) of supplemental water was applied to the plots after mulching.

The site received approximately 20.7 cm (8.1 in) of precipitation during the period of November, 1992 through March, 1993, which postponed seeding until the end of March. Approximately 2.0 cm (0.8 in) of natural precipitation occurred between the time of planting (March, 1993) and when seedling density data was collected in June, 1993.

Seedling density data by species was obtained on June 3, 1993, by counting all seedlings (seeded and annual) within 1-m² quadrats. Ten quadrats were located along a transect centered within each replicate plot. Seedling density was calculated for each species as the number of seedlings/m².

Treatment differences and interactions were determined nonparametrically with an extension of the single factor Kruskal-Wallis method (Zar 1984), using ranked sums to determine sum of squares. Species differences according to treatment effect were determined with the single factor Kruskal-Wallis method (Zar 1984). Multiple comparisons within treatments and species were determined with a nonparametric analog to Student-Newman-Keuls mean comparison test (Zar 1984).

Results

Soil Analysis

Ten of the 13 soil properties analyzed were different between the topsoil and subsoil (Table 1). The topsoil's chemical properties were generally more conducive for plant growth and establishment, since it had higher amounts of nitrogen, phosphorus and organic matter. The topsoil also had a higher water-holding capacity at both -1/10 and -15 bar pressure.

Seedling Density of Seeded Species

Seedling densities across all treatments were low and variable, averaging 10.3 ± 8.8 (SD) plants/m². Replicates within the same treatment combination (soil type x soil depth) often had large ranges of means. Of the 14 species seeded, seven species did not emerge or had fewer than 12 individuals counted in all 560 sample quadrats. Two species, California buckwheat (*Eriogonum californica*) and winterfat made up 88.5% of the entire seeded species response.

Analysis showed the data to have a nonnormal distribution. Log₁₀ and square root transformations were unsuccessful in normalizing the data, so nonparametric methods were used for data analysis. Seedling densities were not different for the main treatments, soil type ($p > 0.50$) and soil depth ($p > 0.10$). The interaction of the two main treatments, however, was highly significant ($p < 0.0001$). For this reason, the remaining analyses of seedling density for each main treatment effect is presented within the levels of the other treatment factor as recommended by Sokal and Rohlf (1981).

Median seedling densities in the subsoil were high in the shallowest depths and low in the deeper depths (Figure 1A). Median densities in the 5 cm (2.5 in) and 15 cm (6 in) soil depths were different from each other ($p < 0.005$), and from the median densities in both the 25 cm (10 in) and 35 cm (14 in) depths ($p < 0.001$). The median densities in the 25 cm (10 in) and 35 cm (14 in) depths were not different from each other ($p > 0.05$). The median density trend for the topsoil was opposite (Figure 1B). The 25 cm (10 in) and 35 cm (14 in) depths had higher median densities than the two shallow depths ($p < 0.01$), but the 25 cm (10 in) and 35 cm (14 in) depths were not different from each other ($p > 0.05$).

Seedling densities were different between soil types within the same soil depth categories (Figure 1A and 1B), a result of the significant interaction. A minimum two-fold magnitude difference ($p < 0.0005$) is seen in median seedling densities between soil type for all soil depth levels.

Comparisons of individual species shows that the same six species responded best in both the subsoil and topsoil treatments (Figure 2A and 2B). Because the median values were mostly zeroes on the species level, the mean was used to see trends. The mean is an overestimation of the central point of the data because the data is positively skewed. For this reason the mean rank scores are also provided and multiple comparisons were determined from the mean rank scores. The response of individual species to soil type was generally the same; mean differences were never greater than one plant/m².

Seedling Density of Non-seeded Annual Species

Thirty-three non-seeded annual species were identified and counted within the seedling density quadrats. Three common desert perennials: rubber rabbitbrush (*Chrysothamnus nauseosus*), needle leaf rabbitbrush (*Chrysothamnus teretifolius*) and Indian rice grass (*Oryzopsis hymenoides*) were also counted but were not included in the analysis. Non-seeded annual species responded differently to soil

type ($p < 0.005$) but not soil depth ($p > 0.25$). The interaction was also significant ($p < 0.001$).

For both soil types, median annual species' densities in the two shallow soil depths were different than the densities in the two deeper soil depths (subsoil $p < 0.001$; Figure 3A and topsoil $p < 0.005$; Figure 3B), but the median density trends for the two soil types were opposite. This response is very similar to that seen from the seeded species. Annual species densities across soil types were not different ($p > 0.05$) for the two shallow depths as they were for the seeded species. Only in the two deeper soil depths were annual species densities different for soil type ($p < 0.0001$).

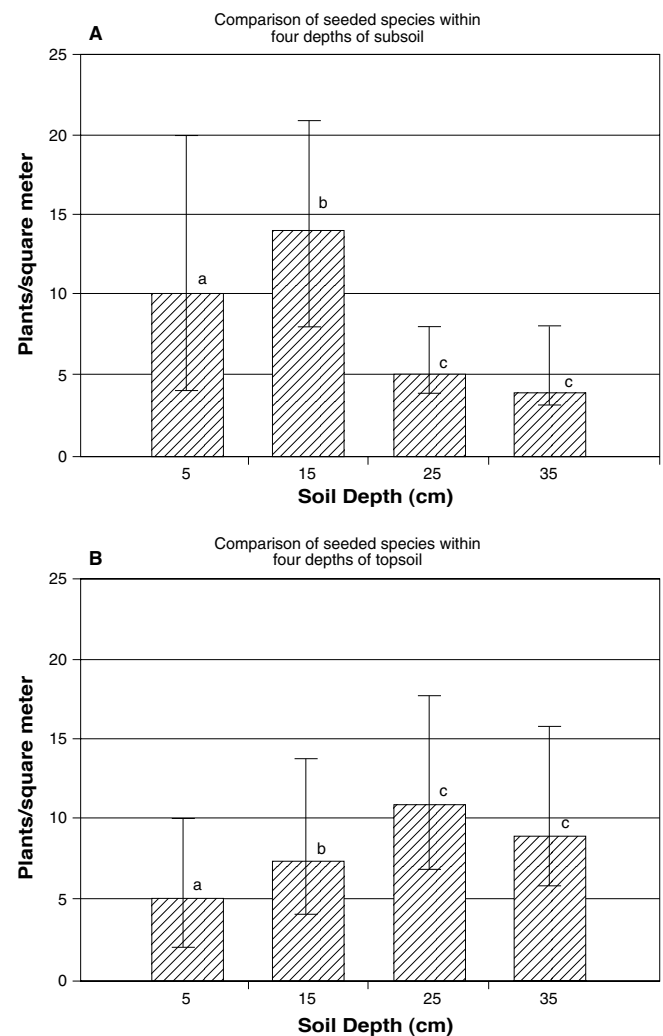


Figure 1—Median plant densities of all seeded species for two soil types, subsoil (A) and topsoil (B) at four soil depths. Differences among soil depths were measured using the Kruskal-Wallis method (Zar 1984). Multiple comparisons were determined using a nonparametric analog to the Student-Neuman-Keuls test (Zar 1984). Letters denote differences ($p < 0.05$). Vertical bars represent the 25%-75% quartile range. Sample size (n) equals 70.

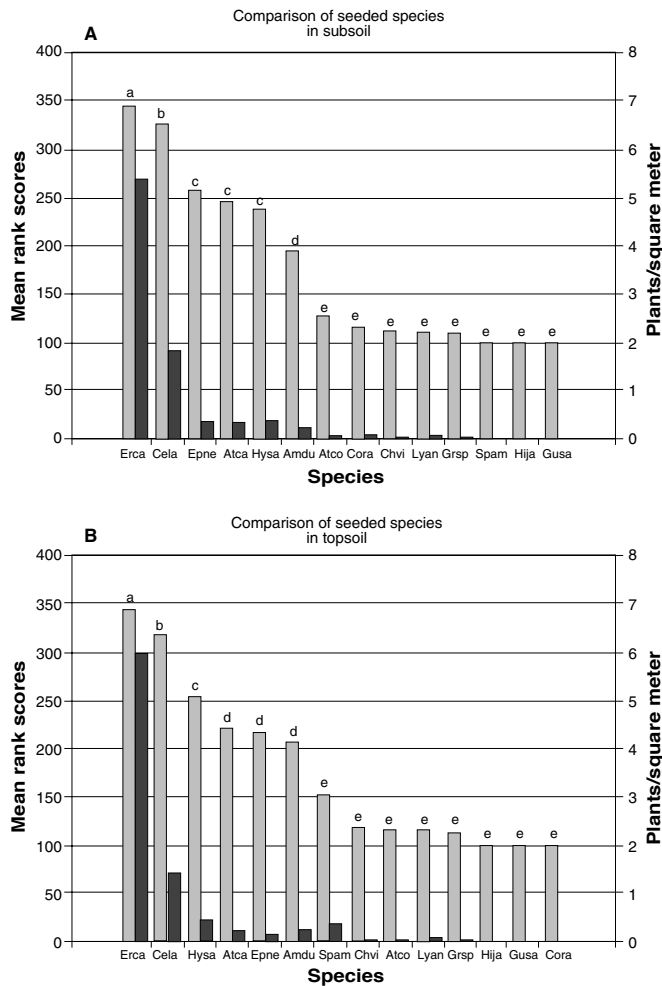


Figure 2—Response of 14 seeded species in two soil types, subsoil (A) and topsoil (B). The left bar is the mean rank score and the right bar is plant density/m². Differences among species were measured using the Kruskal-Wallis method (Zar 1984). Multiple comparisons were determined with a nonparametric analog to the Student-Neuman-Keuls test (Zar 1984). Letters denote differences ($p < 0.05$). Sample size (n) equals 280. Plant codes are defined in Table 2.

The response of annual species to soil type and depth was determined for the most abundant species. The densities of annual species varied. Twenty of the 33 annual species identified in the 560 sample quadrats were counted fewer than 10 times, while some species were counted more than 500 times. An annual species was considered separately if it was found in greater than 25% of the plots and more than 100 individuals were counted. Five species, storksbill (*Erodium cicutarium*), red brome (*Bromus rubens*), wheat (*Triticum aestivum*), white clover (*Melilotus albus*) and an unknown grass met this criteria. The remaining species were grouped together. Wheat and white clover were the most common annual species in both soil types (Figure 4A and 4B). Both wheat and white clover were also non-native annual species.

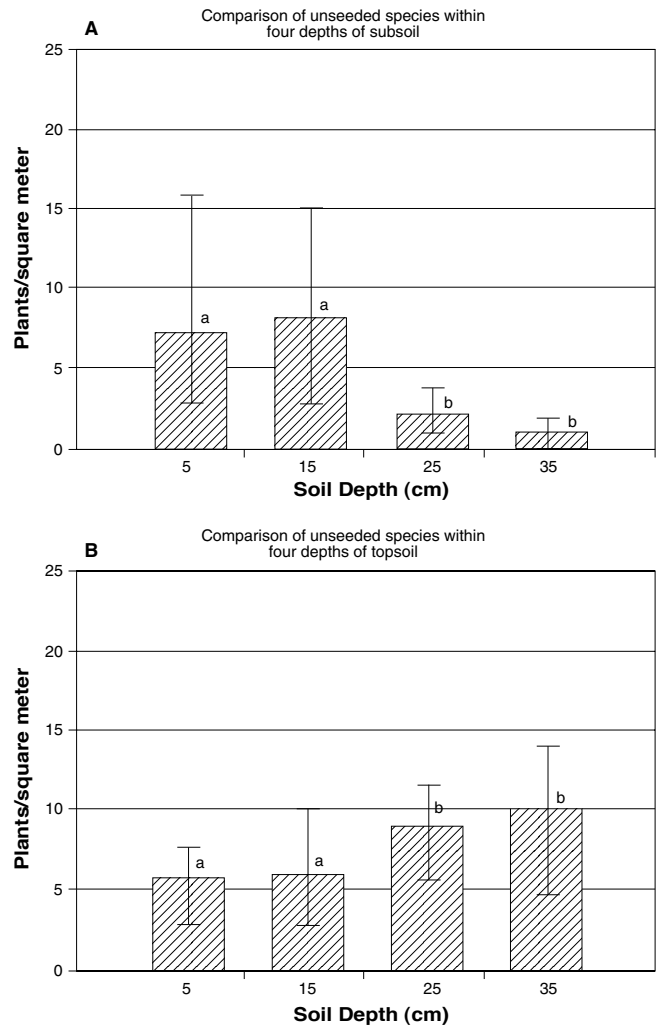


Figure 3—Median plant densities of all unseeded annual species for two soil types, subsoil (A) and topsoil (B) at four soil depths. Differences among soil depths were measured using the Kruskal-Wallis method (Zar 1984). Multiple comparisons were determined using a nonparametric analog to the Student-Neuman-Keuls test (Zar 1984). Letters denote differences ($p < 0.05$). Vertical bars represent the 25%-75% quartile range. Sample size (n) equals 70.

Discussion

The low seedling densities measured during this study could have been a result of several factors. Wester (1991) summarized 212 different papers that covered 11 different factors influencing seed germination. Most of these studies focused on three main factors, moisture, light, and air temperature. Germination requirements for many species indicate that a combination of factors affect seed germination and that these requirements sometimes conflict between species. For example, the germination profile of common snakeweed (*Gutierrezia sarothrae*) suggests that this species germinates best at cooler temperatures ($<70^{\circ}$ Fahrenheit) under low moisture stress (Kruse 1970). In contrast, spiny hopsage (*Grayia spinosa*) collected from the Mojave

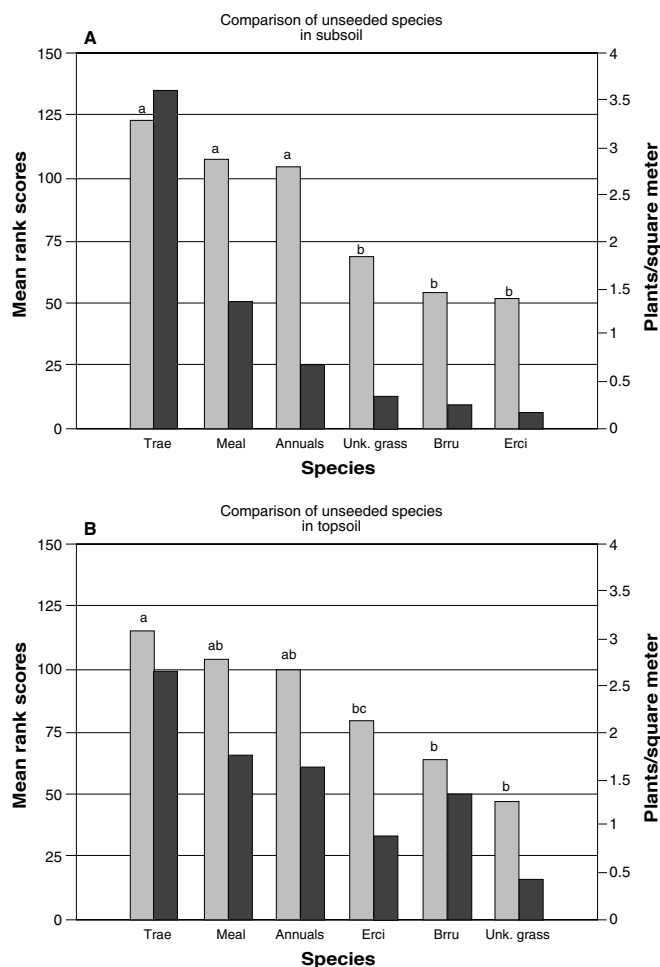


Figure 4—Response of 5 separate unseeded annual species and the pooled species (Annuals) in two soil types, subsoil (A) and topsoil (B). The left bar is the mean rank score and the right bar is plant density/m². Differences among species were measured using the Kruskal-Wallis method (Zar 1984). Multiple comparisons were determined with a nonparametric analog to the Student-Neuman-Keuls test (Zar 1984). Letters denote differences ($p < 0.05$). Sample size (n) equals 280. Plant codes are defined in Table 2.

Desert appeared to germinate best in warmer temperatures ($>86^{\circ}$ Fahrenheit) but wasn't affected by moisture stress down to -12 bars (Wood 1976). The late planting date for this study may have been one reason why seedling density was low. Not all germination requirements may have been met for all species. Although overall densities were low, the response of California buckwheat was good, averaging over 5 plants/m². This favorable response would suggest that the germination requirements of California buckwheat were present.

The observed interaction between soil type and soil depth is difficult to explain. Although California buckwheat's response may have been the greatest contributor to the interaction, the response of five other seeded species and the annual species also follow a similar trend. This indicates that there was a consistent effect across all

plots that caused seedling emergence of most species to react similarly.

The first working hypothesis stated that soil type would affect seedling emergence. It was anticipated that the topsoil may have slightly higher densities than the subsoil. Two variables may be responsible for creating differences in seed germination and seedling emergence across soil types: 1) soil water-holding capacity (created by differences in soil texture) and 2) the seed's ability to absorb available water (created by differences in soil chemistry). Soil chemical properties such as salt content affect this by creating an osmotic pressure that inhibits the seed's ability to absorb water. Both water-holding capacity and salt content based on electrical conductivity are different between soil types; however, the electrical conductivities of both soils are probably not high enough to affect soil water availability to the seed. Soil water-holding capacities of the two soil types may have been different enough to cause differences in seedling emergence; however, the bedrock tended to hold water near the surface of the shallow subsoil plots providing adequate moisture for germination and thus overcoming the main treatment effect of soil type.

The second hypothesis stated that the different soil depths would not influence seedling emergence. Differences in seedling emergence across soil depth for a soil type can only be attributed to different amounts of soil water being held by different volumes of soil because both soil chemistry and soil particle size are identical. It was anticipated that the seedlings would not grow fast enough to be limited by soil water even at the shallowest depth. Although the topsoil showed a direct relationship between seedling density and soil depth, it is not likely that soil water depletion is the cause because the subsoil with a lower water-holding capacity showed higher density in the shallower plots. The data suggest that shallow subsoils and deep topsoils are the combinations that give the highest seedling emergence. However it seems reasonable that another variable may be responsible for the result seen.

One possible explanation results from a shallow bedrock surface's influence on soil water movement when rainfall occurs. Precipitation events prior to planting were observed to saturate the shallow soils (both in the experimental plots and in undisturbed areas) while the deeper soils were able to absorb water without becoming saturated. The topsoil in the deeper plots also seemed to hold this moisture for quite a long time while the subsoil in the deeper plots had dried 20 to 25 cm below the soil surface. Because the study was located on exposed bedrock, the shallow soils would naturally reach water-holding capacity more quickly than the deep soils during a precipitation event. This may have caused seedling germination in the shallow topsoil to be limited by anaerobic conditions or seed rot caused by a saturated soil profile. Although the shallow subsoil also reached the saturation point quickly, due to its larger particle size distribution, soil saturation may not have lasted long enough to cause anaerobic conditions or seed rot, thus allowing seeds to germinate. Conversely, water in the deep subsoil infiltrated and may have drained away so quickly that seeds did not have time to absorb water for germination. The native soils in the deeper plots may have held the water in the seed zone long enough for germination to occur but not long enough for germination to be limited. To determine if

the combined effects of a shallow bedrock surface and rainfall actually caused the results found, daily soil moisture data would have been required before and during the time of germination and emergence.

Conclusions

Preliminary results show an interaction of the two main treatments, soil type and soil depth for both seeded perennial species and non-seeded annual species. The cause of this interaction is not known; however, it may result from the shallow bedrock surface's influence on soil water movement when rainfall occurs. This study will continue for the next several years so that a final determination can be made.

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