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SOIL LOOSENING PROCESSES FOLLOWING THE ABANDONMENT OF TWO ARID WESTERN NEVADA TOWNSITES

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ABSTRACT.—Soil compaction was measured at four sites within two abandoned mining camps in the western Great Basin Desert, Nevada. Bulk density and macroporosity values were generated from soil samples collected in areas of different land use intensities in camps that had been abandoned for approximately 70 years. Results show that significant differences remain in bulk density values between abandoned roads and undisturbed areas in both towns, and that the areas around foundation peripheries are still significantly more compacted in one town. There were no significant differences between land use groups as measured by macroporosity. Estimated soil recovery, based on a linear model using bulk density values, suggests that approximately 100 to 130 years are necessary for complete loosening to occur for abandoned roads, and that 100 or fewer years are necessary for complete amelioration of the foundation periphery areas. The wetter townsite, with more freeze-thaw days, finer-grained soils, and greater plant cover, had shorter recovery estimates. These findings suggest that the results of human-use impacts in arid areas may still be apparent long after disturbances cease.

Key words: soil recovery, soil compaction, arid lands, Great Basin Desert, ghost towns.

Arid lands are undergoing environmental degradation processes at a rapid rate worldwide and are being severely disturbed by excessive soil erosion and salinization (Allen 1988, Goudie 1990). The explosion in human population levels in the last several decades in arid regions has been a major cause for land degradation, especially considering that arid regions are particularly sensitive to anthropogenic land use impacts (Goudie 1990). While the greatest extent of soil degradation has occurred in Sahelian Africa, other arid zones of the world are also vulnerable (Goudie 1990).

The arid American West is one such region where human use impacts have risen dramatically in the last several decades (Francis and Ganzel 1984). The increased popularity of backcountry visits by off-road vehicles, mountain bikes, backpackers, or horseback riders has had a considerable impact on the surrounding environment, either damaging or altering both the flora and soils of affected areas (Cole 1983, 1987, 1990, Lathrop 1983, Webb 1983, Prose and Metzger 1985).

Compaction of desert soils caused by backcountry activities can decrease infiltration rates, increase runoff, and impede plant root growth, which favors further soil degradation processes (Vollmer et al. 1976, Rowlands and Adams 1980, Hinckley et al. 1983, Lathrop 1983, Prose et al. 1987, Goudie 1990). While the impacts of backcountry activities have been documented over short time spans (often less than 30 years), little is known about long-term consequences of these activities (Knapp 1991). Few studies exist that document how well a disturbed area recovers following cessation of disturbances, particularly in areas traditionally considered to have little economic value, such as arid lands.

Recovery processes of compacted soils are not well understood (Webb et al. 1983, 1986) and have been conducted primarily in more mesic environments (Webb et al. 1983, Knapp 1989). Recovery estimates vary considerably, ranging from less than 10 years on Minnesota forest soils (Thorud and Frissell 1976), to 23 years on Idaho forest soils (Froehlich et al. 1985), to 50 years on forest soils in South Australia (Greacen and Sands 1980), and up to 200 years on soils in southwestern Montana (Knapp 1989).

The few studies that have examined soil recovery rates in the arid American West have been confined to the Mojave Desert (i.e., Webb and Wilshire 1980, Webb et al. 1983, 1986, 1988, Prose and Metzger 1985). Rates of soil recovery from these studies of abandoned mining camps ranged from 80 to 140 years and

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Fig. 1a. Terrill, ca 1920, looking northwest. Photo by Roly Ham, courtesy Special Collections, University of Nevada, Reno, Library.

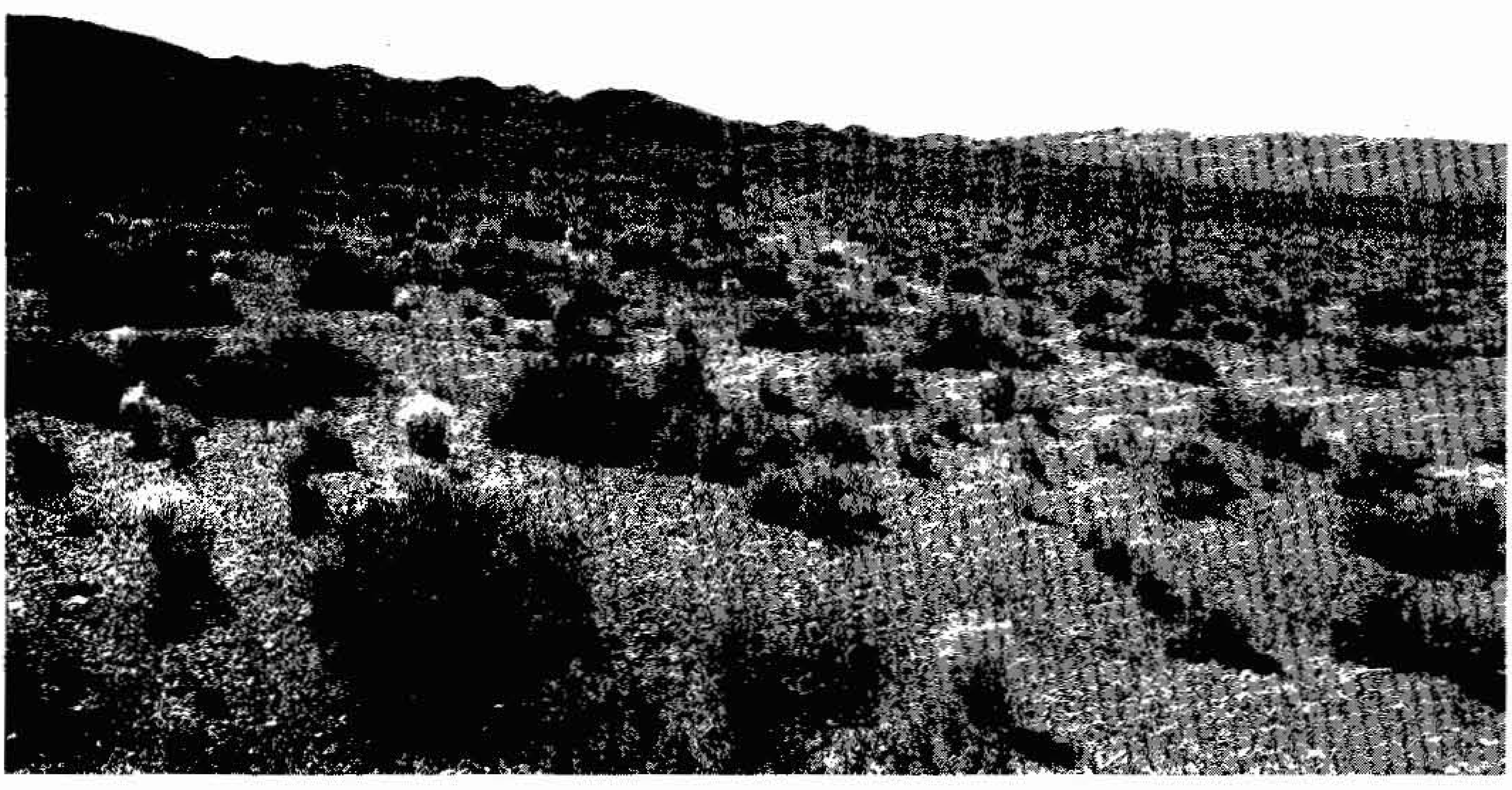

Fig. 1b. Terrill, 1990. Photograph by author.

averaged 100 years. Comparable studies have yet to be conducted in the Great Basin Desert.

Ghost towns abandoned in the early twentieth century in the western Great Basin Desert showcase the long-term effects of soil compaction. Built because of the discovery of valuable ores such as gold and silver, these towns were short-lived as the ores became too scarce to extract profitably (Paher 1970, Carlson 1974, Shamberger 1974). These towns have been

TABLE 1. Climatic and soils data for the two selected Great Basin Desert townsites.

Townsite	Elevation (m)	Est. annual precipitation (mm)	Est.* mean Jan. temp. (°C)	Est.* mean July temp. (°C)	Soil type	Sand, silt and clay (%)
Terrill	1305	125	−0.8	22.8	loamy sand	84/12/4
Wonder	1740	250	−3.9	20.5	sandy loam	46/50/4

*Source of estimate: Houghton et al. 1975.

exposed to a variety of environmental impacts, including trampling by livestock, humans, and vehicles, and have shown a variety of vegetation recovery responses (Knapp 1992). The purpose of this paper is to examine the effects of soil recovery in two abandoned mining towns in the Great Basin Desert in similar fashion to those studies conducted in the Mojave Desert.

STUDY AREAS

Two measures of soil compaction, bulk density and percentage macroporosity, were gathered from Terrill and Wonder. Terrill (39°05′N, 118°46′W) and Wonder (39°35′N, 118°04′W) were abandoned in ca 1915 and ca 1925, respectively (Figs. 1a, 1b). Both sites lie at the base of north-south trending fault-block mountain ranges in central western Nevada, although Terrill's elevation (1305 m) is substantially lower than Wonder's (1740 m). Terrill is the drier site, receiving approximately 130 mm of precipitation annually with the estimated mean January and July temperatures being −0.8 C and 22.8 C, respectively (Houghton et al. 1975; Table 1). The vegetation in Terrill is a salt desert scrub habitat type (Tueller 1989), and common species are the shrubs *Sarcobatus baileyi*, *Atriplex confertifolia*, and *Tetradymia spp.*; the grasses *Oryzopsis hymenoides* and *Bromus tectorum*; and the forb *Sphaeralcea ambigua*. Ground cover in Terrill is approximately 20% (Knapp 1992). Wonder receives approximately 250 mm of annual precipitation, has mean January and July temperatures of −3.9 C and 20.5 C, respectively (Houghton et al. 1975; Table 1), and supports a sagebrush/grass habitat type (Tueller 1989) with approximately 35% ground cover (Knapp 1992). Common species in Wonder are the shrub *Artemisia tridentata* and the grasses *B. tectorum* and *Sitanion hystrix*.

Both townsites have alluvially deposited, volcanic sandy-loam to loamy sand soils (Stewart and Carlson 1978; Table 1). The soils in Terrill are sandy, mixed, Typic Calciorthids, while Wonder's soils are fine-loamy, mixed, Typic Calciorthids (USDA-SCS 1975). Organic matter was estimated to be less than 1% at both townsites.

Terrill and Wonder have been subjected to minimal human-caused impacts since abandonment because of their remote locations. Little grazing by domestic animals has occurred in Terrill because of the lack of a nearby water source. Wonder has experienced greater grazing pressures by sheep, cattle, and feral horses. Neither sheep nor cattle have grazed the Wonder area since 1980 (A. Anderson, District Range Conservationist, BLM, personal communication, 1990).

METHODS

Soil samples for bulk density and macroporosity measurements were gathered at four different land use categories at each town. Data were collected from active roads (to get a theoretical upper limit of compaction), abandoned roads (representing prior high-intensity land use), areas within 5 m of foundation peripheries (representing prior moderate-intensity land use), and control plots (areas of minimal disturbance located near [<2 km] the townsite). All efforts were made to ensure that the four different land use groups within each townsite were similar to each other in terms of slope, aspect, soil texture, elevation, and parent material so that accurate comparisons could be made. Trails caused by either feral horses or small mammals were avoided.

Soil data from the controls, active roads, and abandoned roads were gathered using a stratified, unaligned sampling method. Thirty 5-m line transects were set parallel to both the active and abandoned roads, and one soil core was gathered at a random point along each line transect. Soil cores from control plots were gathered at a random point on each of forty 5-m line transects. Soil cores were also gathered at a

TABLE 2. Bulk density and macroporosity values, and recovery period estimates for abandoned townsites.

Site	Bulk Density[a] (g/cm^3)	Macroporosity (% by vol.)	Recovery period (years)	
			Bulk density	Macroporosity
		Terrill		
Active road	1.65 ± 0.04[b]	19.7 ± 2.4[b]		
Abandoned road	$1.51^{\#*} \pm 0.05$	$21.6^{\#} \pm 2.3$	130	120
Foundation peripheries	$1.47^{\#} \pm 0.07$	$21.9^{\#} \pm 2.7$	100	100
Control plot	$1.41^{\#\$} \pm 0.03$	$22.7^{\#} \pm 2.4$		
		Wonder		
Active road	1.59 ± 0.08	17.3 ± 2.0		
Abandoned road	$1.48^{\#*} \pm 0.07$	$20.3^{\#} \pm 1.9$	100	80
Foundation peripheries	$1.46^{\#} \pm 0.07$	$20.8^{\#} \pm 0.8$	85	70
Control plot	$1.42^{\#} \pm 0.06$	$21.1^{\#} \pm 1.1$		

[a]Bulk density data with exception of active roads and standard deviation values are from Knapp 1992.
[b]One standard deviation.
$^{\#}$= Significantly different (p = .05) from active road based on Tukey test.
*= Significantly different (p = .05) from control plot based on Tukey test.
$^{\$}$= Significantly different (p = .05) from foundation peripheries based on Tukey test.

random point on each of forty 5-m line transects that were set perpendicular to the foundation periphery sides. The cores were oven-dried overnight and then weighed for bulk density (Blake 1965). One-fourth of the cores also were kept intact for macroporosity readings that were measured under 30 cm of tension using a tension-table (Orr 1960). Soil texture was measured using the micro-pipette method (Miller and Miller 1987).

Analysis of variance (ANOVA) was used to examine whether differences in either bulk density or macroporosity values existed between land use categories (abandoned roads, foundation peripheries, and control plots) for each town (Zar 1984, SAS 1985). Where significant overall differences existed, Tukey multiple comparison tests were used to determine between which groups these differences occurred (Zar 1984). Soil recovery was considered complete when no significant differences existed between disturbed sites and their respective control plots.

Soil recovery estimates were based on the equation (corrected from Webb et al. 1986):

$$T = [(I_a - I_u)/(I_a - I_t)] * T_A$$

where I_t = townsite (either abandoned road or foundation periphery)
I_u = undisturbed soils (control plots)
I_a = active road
T_A = time since abandonment of townsite

The data collected from active roads were used only for estimates generated by this equation. This equation generates rough estimates of soil recovery times. Webb et al. (1986) state that an exponential decay model might give more realistic soil recovery estimates, although only one abandonment time per site excludes the use of the exponential decay model.

RESULTS

Bulk density measurements for the abandoned road (1.51 g/cm^3) and foundation peripheries (1.47 g/cm^3) were significantly greater than for the control plot (1.41 g/cm^3) in Terrill, but in Wonder only the abandoned road (1.48 g/cm^3) had significantly greater bulk density values than the control plot (1.42 g/cm^3) (Table 2). Macroporosity measurements in both Terrill and Wonder were not significantly different between land use categories.

Estimated recovery times ranged from 85 to 130 years when based on bulk density measurements, and from 70 to 120 years when based on macroporosity measurements (Table 2). All measurements were greater on abandoned roads than on foundation peripheries and were comparatively longer in Terrill than in Wonder. While these values are derived by a linear recovery model, it is most likely that soil recovery follows more of a nonlinear path with rapid recovery early, then recovery rates slowing.

Heinonen (1977) has suggested that the bulk density of soils may decrease to a certain point, then level off without reaching predisturbance conditions.

DISCUSSION

Soil loosening is dependent upon shrink-swell, freeze-thaw, and biological activity processes (Larson and Allmaras 1971, Akram and Kemper 1979, Webb 1983, Webb et al. 1986, Knapp 1989). These processes in turn may be a function of soil type, climate, and biological activity. The recovery times for Terrill and Wonder show a relationship to all three of these processes, with recovery times in Terrill being longer than those in Wonder.

Soil texture is important because finer-grained soils are more prone to freeze-thaw and shrink-swell loosening processes than are coarser-grained soils (Webb et al. 1986). Fine-textured soils have more total pore space and have a higher water-holding capacity, thereby providing the soils of Wonder, that are more fine-grained than Terrill, more opportunities for expansion-contraction processes to occur (Millar et al. 1958). While percentages of clay may also be important, particularly if the clay has a high shrink-swell ratio, total amounts of clay at the two towns were the same and should not have a greater effect at one place than at the other.

Climate plays an important role in soil loosening processes, particularly where there is a high frequency of wetting and drying, freezing and thawing, or heating and cooling processes. Three climatic features favor faster soil loosening processes in Wonder than in Terrill. First, Wonder is 435 m higher than Terrill and Wonder has a shorter freeze-free period by approximately a month to a month and a half (J. James, Nevada State Climatologist, personal communication 1991). Second, Wonder lies at the base of a bowl-shaped depression and receives maximum cold-air drainage. Typical diurnal temperature contrasts for Wonder range from 22 to 28 C, with the greatest contrasts occurring in the summer and the least contrast in the winter (Houghton et al. 1975, J. James, personal communication, 1991). Terrill, on the other hand, experiences a 16.5 to 22 C diurnal temperature range (Houghton et al. 1975, J. James, personal communication, 1991). These differences in diurnal temperature range suggest that the heating-cooling and expansion-contraction processes are more pronounced for Wonder. Third, Wonder receives approximately twice as much annual precipitation as Terrill; therefore, the freezing-thawing and wetting-drying processes should occur more often in Wonder, facilitating the soil loosening processes.

Biological activity through plant root growth can also ameliorate soil compaction. Grasses and forbs are particularly effective for loosening of topsoil because they have many diffuse, shallow roots that penetrate the topsoil with subsequent minimal increases in soil strength, but leave behind small channels after the roots die (Webb et al. 1983). Plants such as shrubs, with a central taproot, however, cause localized compaction around the root, yet have fewer roots per unit volume and are less effective for soil loosening (Webb et al. 1983). Total plant cover in Wonder was substantially (approximately 20%) greater than in Terrill, especially with the grasses *Bromus tectorum* and *Sitanion hystrix*, which both have extensive, shallow root systems. Therefore, it appears that if soil loosening can be attributed to biological activity, it would be more pronounced in Wonder than in Terrill, although controlled, detailed experiments are necessary for confirmation.

CONCLUSIONS

After 75 years of recovery, significant differences remain between disturbed and undisturbed sites in Terrill as measured by bulk density. Estimates for recovery based on bulk density are from 100 to 130 years. In Wonder, after 65 years of recovery, significant differences remain only between abandoned roads and control plots. Estimated recovery for the abandoned road is 100 years. These results are in close agreement with similar, previous studies that examined soil recovery times in the Mojave Desert (e.g., Webb and Wilshire 1980, Webb et al. 1986) and suggest that the results of soil compaction processes that occur in arid environments are long-lived, but are not irreversible.

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