RESTORATION TREATMENTS IN THE MIDDLE RIO GRANDE BOSQUE: EFFECTS ON SOIL COMPACTION

Cody L. Stropki[1] and Roy Jemison[2]

The Rio Grande is a braided, slightly sinuous aggrading river with a shifting sand substrate (Crawford at el. 1993). In the past, floods commonly shifted the course of the river which was crucial for the survival of the cottonwood trees; however, today overbank floods no longer occur because river flow is regulated by a series of dams and levees. The severity and frequency of floods along the Rio Grande began to increase during the 1870s due to a variety reasons including increased and rapid runoff from the upper watersheds and an aggrading riverbed. The increased runoff is attributed to overgrazing by livestock and logging in the upper reaches of the watershed (Scurlock 1998). These were just a few of the changes that were to occur along the Rio Grande.

The Rio Grande was historically a "flood-river." However, due to the dense population surrounding the river today and the increased need for water in the region, it has been changed to a "reservoir-river." The building of dams can cause extreme variations to the natural hydrological cycle of river and riparian areas (Nilsson and Berggren 2000). The Middle Rio Grande bosque (riverside forest) is an area that is sensitive to variations in the hydrologic cycle. It flooded historically during the late spring and early summer as the snow in the upper watersheds melted. The floods would wash away dead and downed woody material as well as distribute seeds of native species. Current river regulation does not allow the dead and downed materials to be flushed out by floods. Likewise, without flooding the regeneration of native species has dramatically declined (Howe and Knopf 1991). Regulation creates additional problems such as increased fuel loading, which can lead to catastrophic fires and limited natural regeneration of native species. The lack of natural regeneration provides opportunities for invasion by exotic species.

The most invasive exotic species is *Tamarix ramosissima*, commonly known as salt cedar. This plant thrives in New Mexico, in part because it is native to Euro-Asia, which has similar climates and soil types to New Mexico (Scurlock 1998). Salt cedar was introduced into New Mexico in the early 1900s as an ornamental tree and for its ability to control erosion and silt on tributary streams to the Rio Grande (Scurlock 1998). Russian olive (*Elaeagnus angustifolia)* is another species imported in the early 1900s as an ornamental and for bank stabilization. By 1934, Russian olive and salt cedar had moved into the Rio Grande bosque and had become a dominant component of the ecosystem (Crawford et al. 1993).

Eradication methods used to control such exotic plants in the past have not been successful, which leads us to today's problems. How do we control species such as salt cedar and Russian olive without damaging the surrounding ecosystem? Starting in 2000, the Middle Rio Grande Conservancy District, the USFWS Bosque del Apache, the city of Albuquerque, and the USDA Forest Service Rocky Mountain Research Station developed a research project to determine the effectiveness of several treatments to control exotic species in the bosque. The main objective of the treatments is to reduce the fuel loads that can lead to catastrophic fires while limiting impacts to fauna. Fuel load can be defined as the total amount of fuel available for burning in a particular fire. Fuel loads can vary widely in magnitude depending on the types and amount of materials present. Fuel loading as defined by DeBano et al. (1998) is the measure of the potential energy that might be released by a fire. To facilitate the reduction of high fuel loads, a variety of machinery and vehicles are being driven into the bosque to remove debris and exotic vegetation. Other problems such as soil compaction could be created while addressing the issue of excess fuel loads.

[1]Rocky Mountain Research Station and UNM Water Resources Program, Albuquerque
[2]Rocky Mountain Research Station, Albuquerque

METHODOLOGY

In 1999, a study was initiated under a memorandum of agreement between several agencies to determine the effects of three treatments designed to reduce hazardous fuel loads in the Middle Rio Grande bosque on wildlife, native vegetation, and hydrologic resources. The USDA Forest Service Rocky Mountain Research Station (RMRS) worked with the different agencies to locate 12 suitable experimental units for research along the river in a randomized block study design (Figure 1; Kuehl 2000). Three blocks—Albuquerque Block (North), Los Lunas–Bernardo Block (Middle), and Lemitar-Bosque Del Apache Block (South)—each contained three treatments and a control site. The sites also met the following criteria: visibly high fuel loads as identified by landowners, relatively homogenous vegetation at least 20 hectares in size, cottonwood overstory and an understory with native and exotic woody plants, accessibility by road, permission from landowner for access and treatments, and relatively little disturbance from grazing, vehicles, and other uses (Finch et al. 2001).

In the fall of 2002, treatments were started to control the non-native species and to reduce the fuel load within each treatment plot. The goal of the fuels reduction project is to identify the most effective way to reduce the amount of fuels and exotic species while limiting the damages to cottonwood and other native trees and shrubs, while also limiting damages to the natural environment and having a positive or least-negative impact on native wildlife species (Finch et al. 2003). The three treatments and a control were (1) mechanical removal (described below) of dead, downed, and exotic woody plants, and treatment with herbicide; (2) partial mechanical removal of dead, downed, and woody exotics, treatment with herbicide followed by light prescribed fire; (3) mechanical removal of dead, downed, and woody exotics, treatment with herbicide, followed by revegetation with native plants; and (4) control, no treatment.

Taylor and McDaniel (2004, unpublished manuscript) described the mechanical removal technique of salt cedar and other woody exotics as follows: cut down the aerial growth using chainsaws,

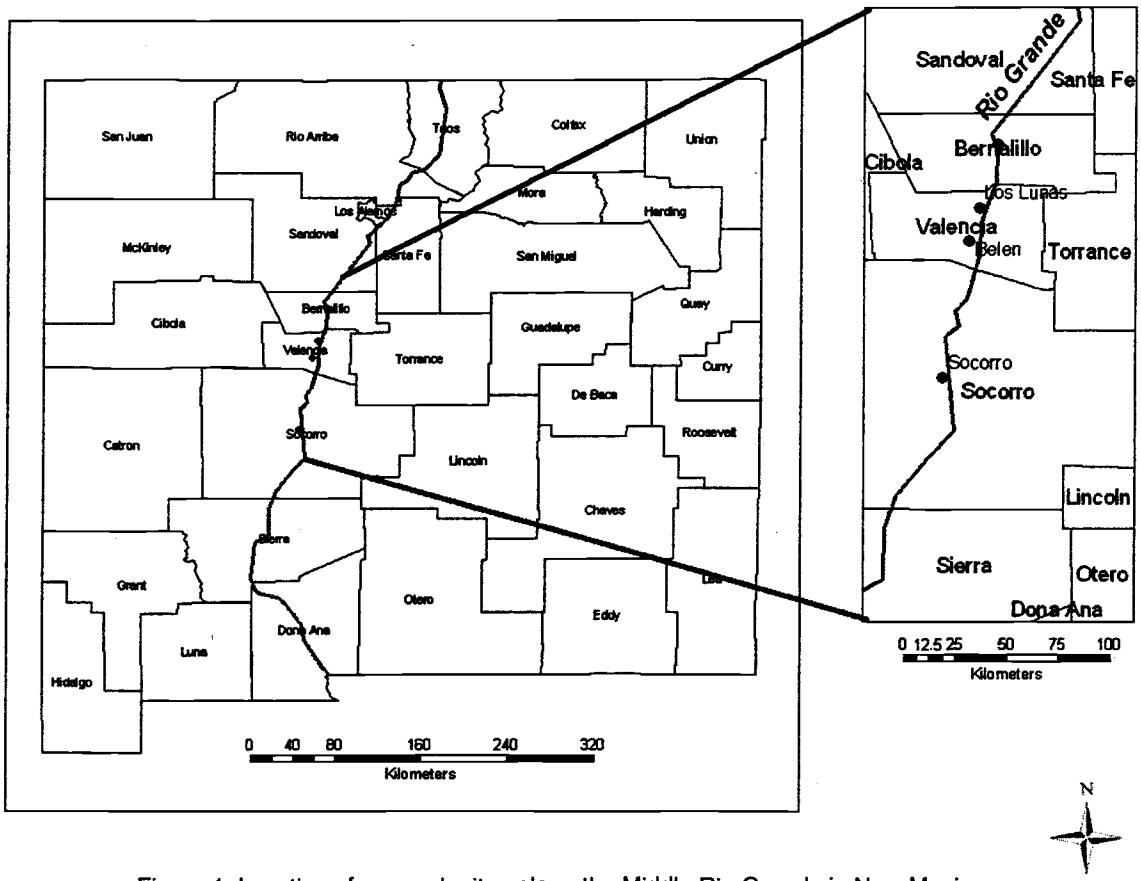

Figure 1. Location of research sites along the Middle Rio Grande in New Mexico.

then immediately apply herbicide to the cut stump using a low-volume backpack sprayer. The aerial trunks and stems are either chipped on site or hauled to access roads where they are removed as firewood by the public.

Treatments are being implemented by the agencies that own the land. These agencies are subtracting the labor to different companies, so the types of equipment being used vary somewhat, but in general are similar, including pickup trucks, small front-end loaders, trailer-mounted chippers, and hand-operated chainsaws.

Each of the 12 sites contains three sets of reptile and amphibian sampling arrays (i.e. herp arrays). The herp arrays are used to determine what effects the restoration treatments might have on the reptile and amphibian populations. The herp arrays served as reference points for bulk density and soil moisture reading locations. The four sites (of 12) used for this study were tested to gain a preliminary understanding of how the soils are responding to fuels reduction activities. Also, all treatments are not occurring at the same time; some of the sites will not be treated until 2005.

Data Collection

Bulk density and moisture content readings were taken 10 m apart in the direction of the branch of each array at each site (Figure 2). These readings were taken at five points for a total of 50 m out from the end of the array branch. It should be noted that the first reading was taken not at the end of the array but 10 m out from the end to avoid the effects of people walking around the arrays. At each point, bulk density and moisture content were measured at depths of 50 mm, 100 mm, and 150 mm, for a total of 45 readings per array (15 readings per branch x 3 branches per array = 45 readings).

Soil bulk density and water content were measured using a Campbell Pacific neutron probe, which measures bulk density by releasing Cesium-137 as gamma radiation from a source in the base of the instrument into the soil. The gamma radiation passes through the soil and is measured by a Geiger-Mueller detector located in a probe which is extended from the instrument into the ground at the desired depth. Soil with a low bulk density gives a high count of Cesium-137 per time of test, whereas soil with a high bulk density gives a low count of Cesium-137 for the same period of time (CPN International 1999).

In addition to bulk density measurements, soil taxon and soil horizons were determined for each site. The soils data were collected by soil scientists with the USDA Forest Service Southwestern Region. The data were recorded on Ecological Site Description form R3-FS-2500-6, along with other information such as vegetation, aspect, and drainage class (USDA Forest Service 2002). Soil texture is a major factor in determining how compacted a soil can become. Sandy soils for example are only slightly susceptible to soil compaction. If these soils experience a high degree of compactness, significant deterioration of their physical properties will not occur. Soils derived from silt, such as silty loams or clays, are easily compacted because of their weak structures, and when compacted their physical properties deteriorate (Kozlowski 1999).

Data Analysis

Soil bulk density data measured and recorded in the field with the neutron probe were downloaded to a personal computer for analysis. The data were first organized in Microsoft Excel, then analyzed with statistical analysis software (SAS) version 8.02 (SAS 2002). Paired t-tests were used to determine if there were significant differences in bulk densities before and after treatments. Tests with p-values less than 0.05 indicate significant differences between before and after bulk densities. The null hypotheses for the tests were that the differences between pre-treatment measurements and post-treatment measurements equaled zero.

RESULTS

Soil bulk densities for eight arrays on four of the sites used in the fuels reduction study were measured before and after restoration treatments to determine if the activities associated with the treatments caused significant changes in the bulk densities. A summary of the observed data is presented in Table 1 with the results of the paired t-test analyses. Significant changes in bulk density occurred at several sites and at different depths. The changes in bulk density were always increases, except on South 2 Array 1 at a depth of 50 mm, where there was a decrease in bulk density. Every soil type except sandy loam showed a significant change in bulk density. Soil moisture was less at every site during the post-treatment measurements than during the pre-test measurements.

DISCUSSION

Soil bulk density changed significantly from before to after treatments at several of the arrays monitored during this study, as determined by paired t-test analyses. Although these results are

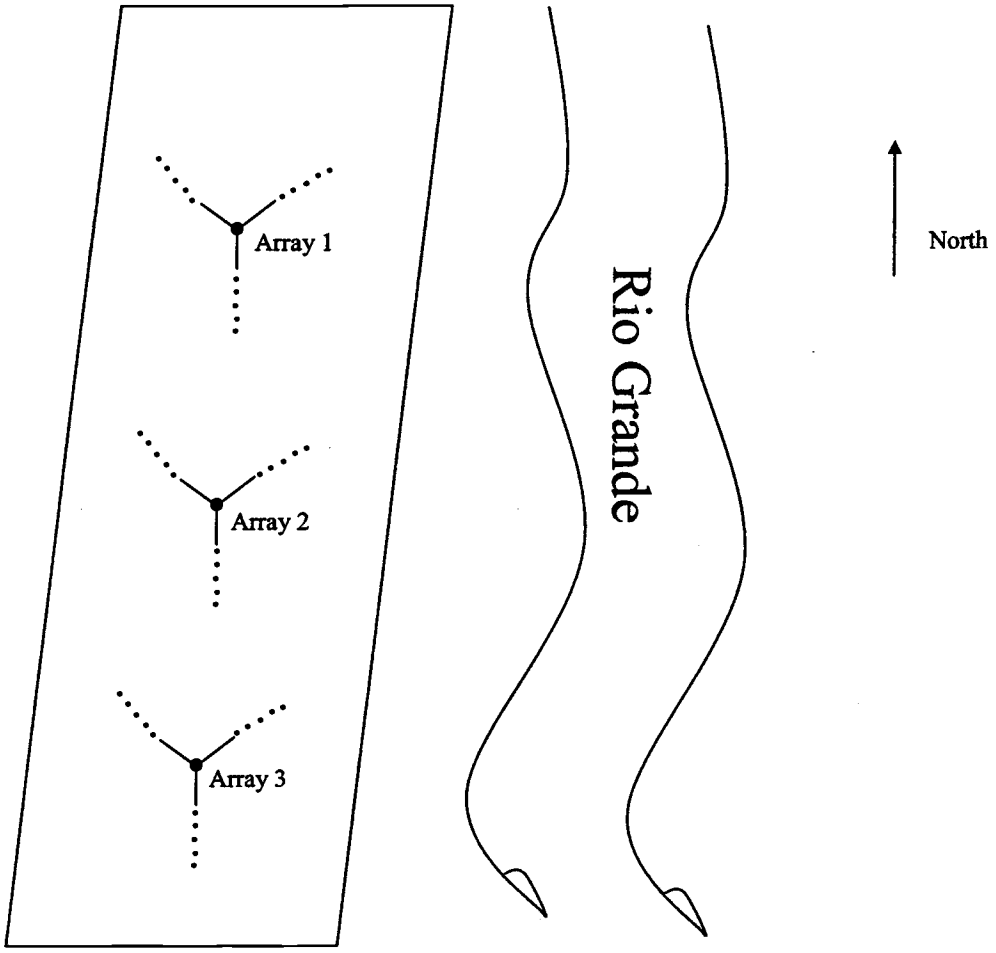

Figure 2. General outline of a site showing the location of the arrays with respect to the river. Readings were taken every 10 m and extended out ~50 m from the end of each arm of the array as represented by the black dots.

significant statistically they should not be taken as proof that soil bulk density responded this way across an entire site. The sampling done at the arrays in this study should be considered site specific. What can be drawn from these results is that the sampling and analysis methods can be used effectively to test for significant changes between pre and post soil bulk densities. To determine how soil bulk density changed across an entire site in response to treatment activities, an appropriately sized sample of arrays would need to be measured.

Looking at the results, several factors may help explain the observed changes from the pre to post bulk density measurements. Soil bulk density can increase when stress applied to the surface exceeds the internal strength of the soil (Horn et al. 1995). The different types of trucks, equipment, and human activities involved in the mechanical removal process of the dead, downed, and exotic species in the study areas could have applied enough excess stress at times to promote changes in bulk density. The weight of the vehicles, their loads, tire pressures, and track styles were not documented as part of this study. This information would be useful in determining the affects of the equipment on soil compaction and hence changes in bulk density.

Texture and moisture are properties that play a significant role in determining a soil's ability to be compacted (Baker et al. 2004; Brady 1974). Texture refers to the amount of sand, silt, and clay in a soil.

Table 1. Average bulk density measured with the neutron probe and the results of paired t- test analyses.

Site	Treatment	Depth (mm)	Soil Type[2]	Avg Bulk Density (g/cm^3) and Standard Deviation[3]			Paired T-Test ($\alpha = 0.05$)		Avg % Water by Volume			Sample Dates	
				Pre-Treatment	Post-Treatment	Change	t	P	Pre-Treat	Post-Treat	Change	Pre-Treat	Post-Treat
North 2 Array 1	A	50	L	1.157 (0.129)	1.258 (0.133)	0.101	-2.04	0.0609	26.0	17.9	-8.1	11/13/02	4/17/03
		100	L	1.274 (0.107)	1.423 (0.104)	0.149	-4.24	**0.0008**	23.1	16.5	-6.6		
		150	L	1.316 (0.085)	1.467 (0.102)	0.151	-4.72	**0.0003**	20.8	14.4	-6.4		
North 2 Array 2	A	50	L	1.198 (0.128)	1.231 (0.134)	0.033	-0.85	0.4121	26.9	22.4	-4.5		
		100	L	1.327 (0.096)	1.425 (0.123)	0.098	-2.60	**0.0209**	23.2	18.3	-4.9		
		150	L	1.373 (0.084)	1.490 (0.105)	0.117	-3.27	**0.0056**	21.5	16.9	-4.6		
South 2 Array 1	A	50	SC	1.140 (0.081)	1.045 (0.111)	-0.095	2.77	**0.0151**	24.8	22.5	-2.2	1/15/03	7/4/03
		100	SC	1.227 (0.058)	1.218 (0.093)	-0.009	0.32	0.7532	22.8	10.7	-12.0		
		150	SC	1.277 (0.051)	1.288 (0.084)	0.011	-0.34	0.7388	21.6	9.5	-12.1		
South 2 Array 3	A	50	SL	1.049 (0.080)	1.049 (0.104)	0.000	0.00	0.9985	19.7	11.2	-8.5		
		100	SC	1.165 (0.042)	1.246 (0.066)	0.081	-3.63	**0.0027**	19.2	9.4	-9.8		
		150	SC	1.196 (0.034)	1.330 (0.056)	0.134	-8.54	**<0.0001**	16.8	8.5	-8.3		
South 3 Array 2	B	50	SC	1.254 (0.085)	1.183 (0.098)	-0.071	2.03	0.0620	19.7	14.8	-4.9	11/14/02	4/1/03
		100	C	1.368 (0.063)	1.324 (0.079)	-0.044	1.72	0.1083	17.4	12.8	-4.6		
		150	VFSL	1.396 (0.057)	1.371 (0.059)	-0.025	1.20	0.2502	16.8	12.2	-4.5		
South 3 Array 3	B	50	SC	1.167 (0.101)	1.292 (0.083)	0.125	-3.89	**0.0016**	22.2	14.8	-7.4		
		100	C	1.284 (0.088)	1.410 (0.087)	0.126	-4.20	**0.0009**	17.4	12.8	-4.6		
		150	VFSL	1.317 (0.087)	1.429 (0.110)	0.112	-3.34	**0.0049**	16.8	12.7	-4.1		
South 4 Array 1	C	50	SL	1.112 (0.122)	1.046 (0.126)	-0.066	1.75	0.1018	16.7	14.8	-1.9	11/14/02	4/1/02
		100	SL	1.261 (0.103)	1.226 (0.096)	-0.035	1.03	0.3193	14.6	12.2	-2.5		
		150	SL	1.341 (0.096)	1.315 (0.075)	-0.026	0.96	0.3550	12.0	10.9	-1.1		
South 4 Array 2	C	50	VFSL	1.274 (0.072)	1.150 (0.063)	-0.124	1.29	0.2182	22.2	16.7	-5.5		
		100	VFSL	1.378 (0.065)	1.404 (0.056)	0.026	-1.06	0.3052	19.5	14.4	-5.1		
		150	VFSL	1.411 (0.072)	1.444 (0.060)	0.033	-1.33	0.2041	18.3	13.9	-4.4		

[1]Treatment A: Removal of dead, downed, and exotic species, treatment of exotic stumps with herbicide, followed by revegetation with native species. Treatment B: Removal of dead, downed, and exotic species, treatment of exotic stumps with herbicide, followed by light prescribed burn. Treatment C: Removal of dead, downed, and exotic species, treatment of exotic stumps with herbicide.

[2]Soil type: L = loam, C = clay, SC = silty clay, SL = silty loam, VFSL = very fine sandy loam.

[3]Average bulk density and standard deviation of 15 samples measured around each array by depth as illustrated in Figure 2.

Sandy soils are generally course textured, well drained, and less subject to compaction than finer textured loam and clay soils (Brady 1974). Clay soils have smaller pore spaces, more surface area, and greater internal strength; they can retain more moisture and can be compacted more than coarse soils (Brady 1974). The organic matter, roots, and rocks in the soil also affect its bulk density and determine how it responds under different conditions (Brady 1974).

Soil texture at a given site generally remains constant from year to year unless altered by natural and human disturbances such as erosion or tillage. Soil moisture on the other hand can vary greatly over short periods of time in response to precipitation, flooding, and capillary rise and the fate of the water on the site. Sources of soil moisture on the arrays during this study were precipitation and potentially some capillary rise, during periods when groundwater levels were elevated. Avenues by which water left the arrays included percolation, evaporation, transpiration by plants, and runoff.

Precipitation that fell on the arrays during the study is summarized in Figure 3. A comparison of the pre and post sampling dates with the dates when precipitation was recorded shows that it is possible that treatment activities took place close to and on days when precipitation occurred. Of course it does not rain every day during the rainy seasons, and the soils in the arrays, by their classification, tend to be well drained (Table 1). However, it is possible that restoration activities took place while the soils were still wet from precipitation events, in which case they would have been more susceptible to compaction.

Soils when dry have a greater resistance to compaction than when wet (Horn et al. 1995). If restoration activities that have the potential to compact soils are conducted during the dry season in New Mexico, which is typically late spring to early summer, the probability of compacting soils when wet could be reduced. Alternatively, if treatments must be conducted during the summer monsoon and winter rainy seasons, a wait period following an event could be established to avoid

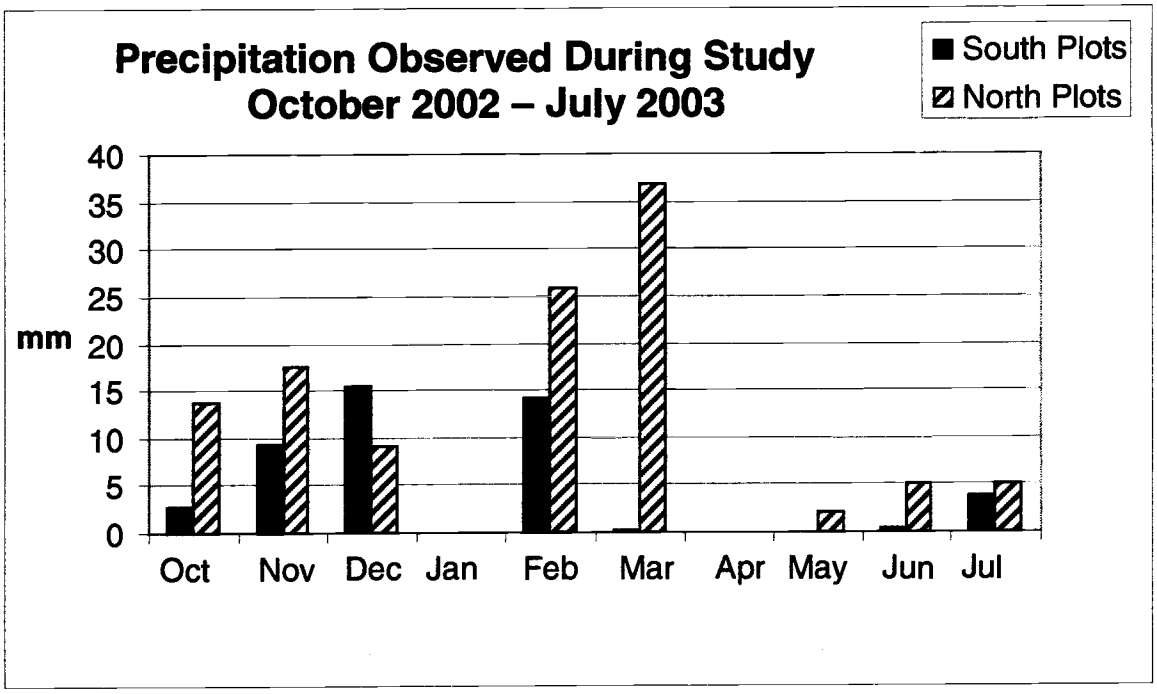

Figure 3. Monthly precipitation during the study.

the potential of compacting soils in areas where it could be a problem (Startsev and McNabb 2001; Brady 1974). Presently, there are no guidelines regarding soil moisture conditions and when restoration treatments should occur.

CONCLUSIONS AND RECOMMENDATIONS

Fuel reduction treatments in the Middle Rio Grande bosque have become important because of large amounts of excess woody fuels and a high potential for wildfire. The close proximity of fires to urban populations has highlighted the negative effects of catastrophic fires on riparian ecosystems and private property.

The results of this research show that changes in bulk density can be detected at site-specific locations with the sampling and analyses methods used. Paired t-test analyses for the eight arrays (site-specific locations) sampled showed significant changes in bulk density across soil types and depths. The results from this study are conclusive only for the arrays studied, due to the small sample size. Sample sizes that represent the extent and diversity of soils at each site must be determined to accurately portray the effects of the treatments across entire sites. Soil properties that figure into how bulk density can change during the treatments include texture, depth, and moisture. Timing of the treatments in relation to the rainy seasons also plays a role. Future studies should take a broader look at internal and external factors that can contribute to changes in soil bulk density during treatment activities. Internal factors include soil structure, organic matter, and moisture content during the treatments, not just before and after. External factors include vehicles types and weights, equipment types, material loads, tire pressures, and track styles.

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REFERENCES

Baker, M. B., Jr., P. F. Ffolliott, L. F. DeBano, and D. G. Neary, editors. 2004. Riparian areas of the southwestern United States: Hydrology, ecology, and management. Lewis Publishers, Boca Raton FL.

Brady, N. C. 1974. The nature and properties of soils, 8th ed. MacMillan, New York.

Crawford, C., A. Cully, R. Leuthenser, M. Sifuentes, L. White, and J. Wilber. 1993. Middle Rio Grande ecosystem: Bosque biological management plan. U.S. Fish and Wildlife Service, Albuquerque NM.

CPN International Inc. 1999. CPN MC-3 Portaprobe Operating Manual. Pacheco CA.

DeBano L. F., D. Neary, and P. Ffolliott. 1998. Fire's Effects on Ecosystems. John Wiley and Sons, New York.

Finch D., A. Chung-MacCoubrey, J. Kelly, R. Jemison, B. Pendleton, and R. Pendleton. 2001. Effects of fuels-reduction and exotic plant removal on vertebrates, vegetation, and water resources in Southwestern riparian ecosystems. Proposal to Joint Fire Science Program: RFP 2001-1. USDA Forest Service, Rocky Mountain Research Station, Albuquerque NM.

Finch D., R. Jemison, A. Chung-MacCoubrey, J. Galloway, M. Means, and D. Hawksworth. 2003. Progress report for Middle Rio Grande fuels reduction study 2000–2002. USDA Forest Service, Rocky Mountain Research Station, Albuquerque NM.

Howe, W. H., and F. L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. The Southwestern Naturalist 36(2): 218–224.

Horn, A., H. Domzial, A. Slowinska-Jurkiewicz, and C. van Ouwerkerk. 1995. Soil compaction processes and their effects on the structure of arable soils and the environment. Soil and Tillage Research 35: 23–36.

Kozlowski, T. T. 1999. Soil compaction and growth of woody plants. Scandinavian Journal of Forest Research 14: 596–619.

Kuehl, R. 2000. Design of experiments: Statistical principles of research design and analysis. Duxbury Thomas Learning Press, London.

Nilsson, C., and K. Berggren, 2000. Alterations of riparian ecosystems caused by river regulation. Bioscience 9: 783–792.

Scurlock, D. 1998. From the Rio to the Sierra: An environmental history of the Middle Rio Grande Basin. USDA Forest Service, Rocky Mountain Research Station, Fort Collins CO.

SAS. 2002. SAS/STAT Users Guide. Release 8.2 edition. Cary NC.

Startsev, A. D., and D. McNabb. 2001. Skidder traffic effects on water retention, pore-size distribution, and van Genuchten parameters of Boreal soils. Soil Science Society American Journal 65: 224–231.

Taylor, J. P., and K. C. McDaniel. 2004. Salt cedar control and riparian habitat restoration. Unpublished manuscript on file at Bosque del Apache National Wildlife Refuge, U.S. Fish and Wildlife Service, Socorro NM.

USDA Forest Service. 2002. Ecological site description. Form R3-FS-2500-6. Southwestern Region. Albuquerque NM.