Evaluation of Forest Thinning Effects on Runoff, Infiltration, Sediment Yield, and Vegetative Cover in a Northern New Mexico Forest.

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INTRODUCTION

In New Mexico, competition is growing for fresh water, and there are increasing regulatory requirements for control of water quality. Better understanding of the effects of land use practices on runoff and water quality is needed for improved water resource management. Forests in particular represent opportunities and challenges for managing vegetation to affect runoff and water quality. Forests occupy approximately 21 percent, or 16.7 million acres of land in NM (O'Brien 2003). An increase in tree densities resulting from intensive grazing and a century of fire suppression has led to reduced water yields and herbaceous cover (Trimble and Weirch, 1987). Combinations of thinning and burning forests promise to increase water yields and forage while reducing wildfire danger. Studies have found that removing 15% of the basal area from the Rocky Mountain/Inland Intermountain region leads to a measurable increase in annual water yield (Stednick 1996).

Catastrophic fires have been an end result of overstocked forests (Weaver 1964). In New Mexico wildfires have burnt over 95,000 acres between 2000 and 2004. Wildfires are expensive and negatively impact the environment. These fires have led to an increased interest by forest managers to thin dense stands that are vulnerable to wildfires. It is of great interest to land mangers to research the effects of forest treatments to determine which treatments meet management objectives regarding infiltration, runoff, sediment yield, and vegetation.

Soil moisture is directly related to runoff. As soil moisture increases, soil pores become filled with water, as a result; infiltration is reduced and runoff increases

(Bowyer-Bower 1993, Azooz & Arshad 1996). More research is needed to determine how soil moisture changes over time during applied rainfall.

Increased sediment yield associated with forest treatments may be an important treatment limitation. Soil disturbance caused by forest treatments will typically lead to increases in soil erosion (MacDonald and Stednick, 2003). Forest treatments with greater soil disturbance will yield greater sediment yield. Generally the increase in soil erosion will be short term. As herbaceous fuels increase, erosion will decline because groundcover is negatively correlated with soil erosion (MacDonald and Stednick, 2003). More research is needed to assess short term effects on sediment yield and herbaceous cover.

In the southwest, a large amount of scientific research has been conducted on forest management, specifically in Arizona and Colorado. Little research has been conducted in New Mexico. Broad information relevant to New Mexico can be drawn from forest studies in these other states with similar conditions (McDonald & Stednick 2003). More research is needed to learn about the specific effects of forest treatments in New Mexico.

The purpose of this study was to determine the effects of forest thinning treatments in New Mexico forested watershed uplands on infiltration, runoff, sediment yield, and vegetative cover. This research will provide improved scientific knowledge to land and water managers which will help them to better manage our water resources. This information can aid land and water managers in selecting appropriate thinning prescriptions that will meet their goals. The primary objectives of this study were to:

1. Determine forest thinning treatment effects on runoff and infiltration.

2. Determine soil moisture interplay during applied rainfall.
3. Asses the short term effects of forest thinning treatments on sediment yield and herbaceous cover.

PREVIOUS WORK AND PRESENT OUTLOOK

Over the last century, tree densities have increased considerably leading to reduced water yields and herbaceous cover (MacDonald and Stednick, 2003). Two major factors have led to an increase in tree density: intensive livestock grazing and organized fire suppression (Swetnam, 1990; Touchan et al. 1995). Increases in tree density have reduced the amount of water yield and stream flow (Trimble and Weirch, 1987). These dense forests are in poor health and prone to wildfires. Recently the southwest has experienced destructive wildfires. Wildfires can negatively impact water quality. Prior to European settlement fire was frequent and widespread (Allen et al., 1995). Historically, frequent low-intensity surface fires thinned the forests and maintained open stand conditions (Swetnam and Baisan, 1996). Accounts of pre-settled forests describe ponderosa pine forests as open and park-like supporting a diverse herbaceous cover (Cooper, 1960). Thinning forest stands will improve forest health and reduce the potential of wildfires.

Water consumption, transpiration, and interception from plants have increased along with tree density (Swetnam, 1990). Transpiration is the loss of water through the plant stomata. Interception is the water that is caught by the plant canopy and evaporates into the atmosphere. Generally in areas where precipitation exceeds 18 to 20 inches, a reduction in tree cover results in increased water yield (MacDonald and Stednick, 2003).

Removing 15 to 30 percent of the basal area of a forest has been shown to lead to a detectible increase in water yield (Stednick 1996). Greater reductions in basal area should yield greater amounts of runoff. However reductions of basal area by forest treatments can lead to increases in sediment yield (MacDonald and Stednick, 2003). Soil disturbance caused by forest treatments will typically lead to increases in soil erosion (MacDonald and Stednick, 2003). Careful planning and implementation of forest treatments can minimize the negative effects of forest management. Generally the increase in soil erosion will be short term. As soon as herbaceous vegetation is established, erosion will be minimized (MacDonald and Stednick, 2003).

The effects of forest treatments on water yields have been studied by several scientists. Most studies show increases in water yield with tree clearing (Bosh and Hewlett, 1982). Different parameters affect water yield, including evaporation, transpiration, and infiltration (MacDonald and Stednick, 2003). Little research has been conducted to determine the contribution of the above parameters to increased water yields. More research is needed to assist land and water managers to manage for water quantity and quality.

EXPERIMENTAL PROCEDURES

Study Area

This study was conducted from August to September, 2004 in the Lincoln National Forest near Cloudcroft, NM. Mean annual precipitation ranges from 16 to 30 inches with two-thirds of the precipitation falling in the form of high intensity-short duration thunderstorms between March and October (Sylvester and Wright 2003). Winter precipitation is mainly in the form of snowfall (Sylvester and Wright 2003). The average annual temperature is about 45 degrees F with extremes of 26 degrees F below zero in the winter to 100 degrees F in the summer (Sylvester and Wright 2003). The average frost-free season is 80 to 145 days with the last killing frost in early May to early June and the first killing frost in early September to early October (Sylvester and Wright 2003). The topography is relatively steep with slopes ranging from 0-40 percent. Elevation ranges from 8800 feet to 9350 feet above sea level.

Cox Canyon is in the Pumphouse Grazing Allotment in the Lincoln National Forest. This allotment has been grazed during the summer season (mid May - mid October) for over thirty years (Rick Newmon, personal communication, January 27, 2005). For the past 20 years, stocking numbers have ranged from 56 to 64 cattle during the summer months (Rick Newmon, personal communication, January 27, 2005). Prior to this time, the grazing permit allowed grazing of 146 cattle for the same summer season (Rick Newmon, personal communication, January 27, 2005). The treatment areas mentioned have received only incidental use by cattle due to dense canopy and minimal forage production.

Runoff and sediment transport studies were conducted in a mixed conifer forest in Cloudcroft, NM. Steep slopes ranging from 17 to 27 percent were studied on three treatment areas. Representative vegetation and slope was determined from six permanent transects placed within each treatment area. Three different treatments were evaluated: 1) untreated control, 2) precommercial thin with slash piled, and 3) precommercial thin with slash scattered. Pile and scatter sites were harvested manually using a "Low Intensity Thin. This treatment harvests trees only less than 9 inches DBH. This level of stocking control reduces density only marginally. In most cases density will remain in excess of 40% of maximum (Rio Penasco II EA). The intent of this prescription is to provide for a short-term reduction in hazardous fuels (ladder fuel) (Rio Penasco II EA). This treatment does not require a timber sale. One major advantage of this prescription is that it can be applied across a wide range of landscapes, with or without a transportation system (Rio Penasco II EA).

Simulator Design

A portable rainfall simulator (Wilcox et al. 1986) fitted with a ¼G10 full jet nozzle (Spraying Systems Co.,Wheaton, Ill.) was used to provide controlled conditions for evaluating infiltration, runoff, and sediment yield. This type of simulator was used on steep slopes in the Guadalupe Mountains; yielding drop sizes produced by the ¼G10 full jet nozzle are smaller than natural rainfall at the same intensity (Wilcox et al 1986). Due to the smaller size of drops produced by the ¼G10 full jet nozzle, kinetic energy of a simulated rainfall of 10 cm hr^{-1} is only about 36% of a natural rainfall event of the same intensity (Wilcox et al 1986). Rainfall simulations were conducted with the nozzle positioned vertically downward within a tripod at 175 cm above the soil surface.

Rainfall Application

Rainfall simulations were conducted in August and September, 2004 on square meter circular runoff plots, first under antecedent moisture conditions (dry run) and then about 24 hours later at field capacity (wet run). The average water application for the dry runs was 14.5 cm hr^{-1}, which was the minimum rate that consistently produced runoff on all plots when soils were dry. After the dry run, plots were covered with plastic to eliminate evaporation and ensure soils were at field capacity prior to wet runs. The average water application for the wet runs was 14.9 cm hr^{-1}. Ten plots were evaluated for each treatment for a total of 60 rainfall simulations, with both dry and wet runs lasting one hour. Two rain gauges were installed near the center of the plot and rainfall was measured at five minute intervals. Water was pumped from a 400 gallon water buffalo to the rainfall simulator through garden hose with a Pacer water pump powered by a 5.5 horsepower Briggs & Stratton engine.

Plot Selection

Plot locations were randomly selected by stretching out a tape along permanent transects previously installed for the vegetation study and randomly selecting a distance. This distance was found on the tape and a random direction was taken from the second hand of a watch. A distance of ten meters was measured in the random direction and the plot ring was located as close as possible to the ten meter mark, depending on trees and rocks. If the plot could not be installed at or near this point, a new random distance was selected. Due to the high amount of canopy closure plot rings were always placed under the canopy.

Plot Setup

The plot ring was placed with the runoff tray in the down slope direction and pounded into the ground with a sledge hammer, until the tray was level with the soil surface. During plot installation, soil approximately one centimeter or less above runoff tray was slightly disturbed. This narrow strip of soil was patted down to ground level to close the gap between the soil and the tray. A hand level one meter in length was used to measure the slope of each plot. A small screen was installed over the runoff tray to prevent pine needles and small twigs from entering the runoff collection tank. A 1.5 meter, clear 4.44 cm diameter (1-¾ inch) hose was clamped to the spout of the runoff tray at one end and laid into the collection tank at the other end. This ensured that overspray from the simulator was not collected as runoff. A pit was dug at the end of the clear runoff hose to insert the collection tank below the soil surface. The collection tank was always installed lower than the runoff spout to prevent any slowing of runoff. Time to runoff was recorded. Runoff was collected and measured every five minutes in collection tanks at the bottom end of the plot ring. Infiltration was calculated as the difference between the amount of water applied and the amount of runoff collected.

A small pit was dug at the outside center of the plot ring where an automated soil moisture probe "CS615" (Campbell Scientific, Logan UT.) was installed horizontally into the soil at a depth of five centimeters. Volumetric soil moisture was measured at one minute intervals. The soil moisture probe was connected to a "CR10X" Campbell Scientific data logger which was connected to a laptop computer. Monitoring infiltration by time through the use of these soil moisture probes was a key component of this project. Soil moisture probes allowed us to determine speed and depth of infiltration. A piece of plastic was used to cover the pit to ensure that water did not enter the pit, resulting in inaccurate readings of soil moisture.

Soil Sampling

Prior to rainfall simulations, a soil core (0-5 cm depth) was taken next to each plot, and stored in a labeled plastic bag to determine gravimetric antecedent moisture content and bulk density. Bulk density samples were taken at a 0-5 cm depth following the core method (Blake and Hartage, 1986) and oven dried for 48 hours at 105C prior to weighing. A second soil sample was taken (~0.5 kg, 0 to 5 cm depth) to determine organic matter and soil texture. Organic matter was measured using the Walkley-Black procedure (Nelson and Sommers, 1982) by the New Mexico State University SWAT lab. Soil texture was measured using a Beckman-Coulter laser diffraction particle analyzer. Soil samples were prepared for texture analysis by crushing soil through a 2mm sieve and removing identifiable organic matter. Soil samples were then split down to a 10 gram sample. Initial results yield a sandy soil. This was much different from the texture estimated on a few samples using the Feel Method. The difference in texture was believed to be caused by soil aggregation due to high organic matter in these forest soils. Forest soils are generally rich in organic matter. An additional soil sample was crushed through a 2mm sieve and then treated for removal of organic matter following the oxidation using sodium hypochlorite method. In each plot surface roughness was measured north to south and east to west with a relief meter that contained 20 pins spaced 5.5 cm apart (Kincaid and Williams 1966). Surface roughness was calculated as the standard deviation of pin lengths from the relief meter frame to the soil surface. Runoff was thoroughly agitated and a 1-liter subsample taken to calculate sediment yield. This subsample was filtered, oven dried, weighed, and converted to sediment yield (mass of sediment per unit area, kg ha-^{1}) and sediment concentration (mass of sediment per unit volume of runoff, g L-^{1}).

Vegetation Sampling

Three transects were placed parallel across the square meter plots, and a measuring tape used to measure ground cover, basal cover, and aerial cover of grasses, forbs, and shrubs. Basal cover is the cross-sectional area of plants near the ground; it is usually measured at a height of 2.5 cm for herbaceous plants (Muir and McClaran 1997). Aerial cover is the area represented by the vertical projection of plant foliage onto the ground (Muir and McClaran 1997). Ground cover was broken up into the following categories: litter, rock, and bare ground. After wet runs litter depth was measured in the center of the plot and half way between the center and each side. Litter depth was measured with a ruler in centimeters including both litter and humus layers. Litter was collected in a burlap sack and dried for five days at 70C prior to weighing (kg m^{-2}). Grasses and forbs were clipped to the soil surface, collected in paper bags, oven dried for 48 hours at 70C, and weighed (kg ha^{-1}). Basal area of trees was measured with a ten factor prism using point sampling (Bitterlich 1948). Crown closure was measured with a spherical densitometer by taking the average of measurements when facing north, east, south, and west directions from the plot (Lemmon 1956).

Data Analysis

Terminal runoff rates were calculated by averaging the 55 and 60 minute runoff rates. The terminal infiltration rates were calculated by averaging the last 55 and 60 minute runoff rates. The time to five centimeter infiltration was calculated by graphing soil moisture against time and finding the point on the graph where the soil moisture started a distinct increase. Time to peak runoff was calculated by finding the time it took for runoff to peak. Change in soil moisture was calculated by subtracting the beginning soil moisture from the maximum soil moisture. Soil moisture was calculated by dividing the weight of water within the soil sample by the soil's weight after drying at 105C for 48 hours.

Statistical Analysis

Data was analyzed as a completely randomized design. Sites were compared using a one-way nonparametric analysis of variance (i.e., the Kruskal-Wallis test) (Ramsey and Schafer 2002). One-way nonparametric analysis ranks the data and determines if values in one group tend to be larger than values in other groups. In the presence of significant differences, post hoc analyses used the Wilcoxon test to compare pairs of sites. One square meter plots were treated as the experimental unit because they were independent of each other.

Data was first analyzed to determine if random effects were present (i.e., the Mixed Procedure) (Ramsey and Schafer 2002). Three random models were compared to a non-random model. Results showed that there was no difference among models (fit statistics or p-values). This analysis proved that the one square meter plots were independent of each other because there was no clustering of data among experimental units or transects. Before conducting the experiment we expected the one square meter plots to be representative of the treatment and independent of each other. This was confirmed when no correlations among experimental units or transects were found.

One-way nonparametric analysis of variance was required after data were tested for normality and almost all variables did not exhibit a normal distribution. Side by side box plots revealed that the data was non-normal due to outliers, skew, and/or different variability among variables. Transformations were conducted to try and normalize the data but were unsuccessful for most variables.

Data was analyzed in SAS 9.1 (SAS Institute Inc). Treatment group distributions are summarized using both the 5-number summary and the mean and standard deviation. Statistical significance in the following text will interpret p-values as suggested by Ramsey and Schafer (2002).

RESULTS

Table 1. Five Number Summary Plus Mean and Standard Deviation for Dry Run Hydrologic Parameters from 30 Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Precipitation (cm/hr)	Control [a]	11.3	12.5	13.6	15.4	21.8	14.4	3.0
	Pile [a]	12.1	13.1	14.5	17.1	18.3	14.8	2.2
	Scatter [a]	11.5	13.6	15.0	16.6	22.7	15.4	3.1
Total Runoff (liters)	Control [a]	0.1	0.5	2.4	12.5	29.9	7.0	9.5
	Pile [a]	1.2	2.6	7.6	10.8	21.8	8.5	6.5
	Scatter [a]	0.5	2.9	4.6	8.7	15.7	6.0	4.6
Time to Runoff (seconds)	Control [a]	80	88	117	135	330	134	73
	Pile [a]	73	83	95	120	162	104	28
	Scatter [a]	57	98	153	183	226	144	53
Time to 5cm Infiltration (seconds)	Control [a]	2	2	3	4	5	3	1
	Pile [b]	3	3	4	5	26	6	7
	Scatter [a]	2	2	3	4	4	3	1

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 2. Five Number Summary Plus Mean and Standard Deviation for Wet Run Hydrologic Parameters from 30 Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Precipitation (cm/hr)	Control [a]	11.0	12.0	13.8	17.3	19.4	14.4	2.9
	Pile [a]	10.9	11.5	13.3	16.5	17.5	13.8	2.5
	Scatter [a]	12.1	13.9	16.7	18.5	20.6	16.4	2.9
Total Runoff (liters)	Control [a]	0.2	0.4	3.2	8.8	36.2	6.7	10.9
	Pile [a]	0.2	1.1	4.1	14.8	22.7	8.0	8.2
	Scatter [a]	1.4	2.5	6.8	9.3	29.9	8.9	8.9
Time to Runoff (seconds)	Control [a]	84	125	156	181	418	171	95
	Pile [a]	72	98	123	143	161	122	27
	Scatter [a]	80	108	132	155	284	141	60
Time to 5cm Infiltration (seconds)	Control [a]	1	2	3	3	5	3	1
	Pile [a]	2	3	4	5	8	5	2
	Scatter [a]	2	2	3	4	7	3	2

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 3. Five Number Summary Plus Mean and Standard Deviation for Soil Moisture Interplay during 30 Dry Run Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Soil Moisture	Control [a]	0.121	0.235	0.288	0.344	0.512	0.293	0.109
Beginning of dry run	Pile [a]	0.173	0.288	0.374	0.488	0.545	0.376	0.127
(%)	Scatter [a]	0.164	0.290	0.377	0.432	0.522	0.355	0.119
Soil Moisture	Control [a]	0.319	0.371	0.522	0.655	0.884	0.549	0.177
End of dry run	Pile [a]	0.478	0.616	0.696	0.817	0.911	0.705	0.133
(%)	Scatter [a]	0.317	0.545	0.678	0.753	0.924	0.651	0.169
Maximum Soil Moisture	Control [a]	0.319	0.373	0.522	0.655	0.884	0.550	0.177
(%) dry run	Pile [a]	0.478	0.665	0.702	0.817	0.911	0.715	0.130
	Scatter [a]	0.317	0.545	0.685	0.759	0.925	0.654	0.170
Change in Soil Moisture	Control [a]	0.074	0.798	0.239	0.289	0.569	0.256	0.133
(%)	Pile [a]	0.249	0.299	0.311	0.366	0.487	0.339	0.072
	Scatter [a]	0.153	0.257	0.280	0.308	0.493	0.298	0.091

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 4. Five Number Summary Plus Mean and Standard Deviation for Soil Moisture Interplay during 30 Wet Run Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Soil Moisture	Control [a]	0.225	0.289	0.405	0.457	0.607	0.397	0.123
Beginning of wet run	Pile [a]	0.173	0.288	0.373	0.488	0.545	0.376	0.127
(%)	Scatter [a]	0.164	0.290	0.377	0.432	0.522	0.355	0.119
Soil Moisture	Control [a]	0.377	0.387	0.540	0.665	0.841	0.552	0.161
End of wet run	Pile [a]	0.478	0.616	0.696	0.817	0.911	0.705	0.133
(%)	Scatter [a]	0.317	0.545	0.678	0.753	0.924	0.651	0.169
Maximum Soil Moisture	Control [a]	0.377	0.424	0.545	0.665	0.841	0.564	0.153
(%) wet run	Pile [a]	0.478	0.665	0.702	0.817	0.911	0.715	0.130
	Scatter [a]	0.317	0.545	0.685	0.759	0.925	0.654	0.170
Change in Soil Moisture	Control [a]	0.064	0.135	0.168	0.209	0.234	0.167	0.052
(%)	Pile [a]	0.099	0.173	0.221	0.237	0.326	0.215	0.060
	Scatter [a]	0.029	0.110	0.164	0.228	0.272	0.162	0.076

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 5. Five Number Summary Plus Mean and Standard Deviation for Dry Run Erosion Parameters from 30 Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Sediment Yield (kg/ha)	Control [a]	0.306	0.486	0.783	1.407	3.213	1.117	0.907
	Pile [a]	0.916	0.988	1.425	2.665	8.153	2.260	2.186
	Scatter [a]	0.103	1.316	1.907	2.416	3.141	1.774	0.926
Sediment Concentration	Control [a]	0.031	0.049	0.078	0.141	0.321	0.112	0.907
	Pile [a]	0.092	0.099	0.143	0.267	0.815	0.226	0.219
	Scatter [a]	0.010	0.132	0.191	0.242	0.314	0.177	0.093

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 6. Five Number Summary Plus Mean and Standard Deviation for Wet Run Erosion Parameters from 30 Rainfall Simulation Plots within Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Sediment Yield (kg/ha)	Control [a]	0.058	0.249	0.359	0.497	0.958	0.427	0.288
	Pile [b]	0.101	0.608	0.828	1.296	4.435	1.280	1.300
	Scatter [b]	0.297	0.597	0.897	1.265	1.766	0.951	0.453
Sediment Concentration	Control [a]	0.006	0.025	0.036	0.050	0.096	0.043	0.029
	Pile [b]	0.010	0.061	0.083	0.130	0.444	0.128	0.130
	Scatter [b]	0.030	0.060	0.090	0.127	0.177	0.095	0.045

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 7. Five Number Summary Plus Mean and Standard Deviation for Vegetation Characteristics Measured at 30 Plots for Three Forest Treatment Sites.

	Site	Minimum	25th Percentile	Median	75th Percentile	Maximum	Mean	Standard Deviation
Litter Cover	Control [a]	99.7	100.0	100.0	100.0	100.0	99.9	0.1
(%)	Pile [b]	61.7	88.0	92.5	95.0	96.7	89.0	10.4
	Scatter [b]	90.3	92.7	93.5	95.0	98.0	93.9	2.3
Grass Cover	Control [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(%)	Pile [b]	0.0	1.0	3.0	4.7	16.3	3.9	4.7
	Scatter [b]	0.7	1.3	1.8	2.7	3.0	1.9	0.9
Forb Cover	Control [a]	0.0	0.0	0.0	0.0	0.3	0.0	0.1
(%)	Pile [b]	0.0	0.0	3.5	5.3	20.3	4.7	6.1
	Scatter [b]	0.7	2.0	4.2	6.0	7.0	4.2	2.2
Shrub Cover	Control [a]	0.0	0.0	0.0	0.0	0.3	0.0	0.1
(%)	Pile [a]	0.0	0.0	0.0	0.0	15.3	1.7	4.8
	Scatter [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rock Cover	Control [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(%)	Pile [a]	0.0	0.0	0.0	0.0	4.0	0.6	1.3
	Scatter [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare Ground	Control [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(%)	Pile [a]	0.0	0.0	0.0	0.0	2.0	0.2	0.6
	Scatter [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aerial Grass Cover	Control [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(%)	Pile	0.0	1.3	6.5	8.0	17.3	6.3	5.2
	Scatter	1.3	4.3	5.0	6.7	9.3	5.0	2.4
Aerial Forb Cover	Control [a]	0.0	0.0	0.0	0.0	1.3	0.1	0.4
(%)	Pile [b]	0.0	0.7	2.0	4.3	5.0	2.3	1.9
	Scatter [b]	1.0	2.0	4.3	8.7	12.7	5.6	4.1
Aerial Shrub Cover	Control [a]	0.0	0.0	0.0	0.0	1.0	0.1	0.3
(%)	Pile [a]	0.0	0.0	0.0	0.0	21.7	2.6	6.8
	Scatter [a]	0.0	0.0	0.0	0.0	5.7	0.6	1.8

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 8. Five Number Summary Plus Mean and Standard Deviation for Biomass and Litter Characteristics Measured at 30 Plots for Three Forest Treatment Sites.

	Site	Minimum	25th Percentile	Median	75th Percentile	Maximum	Mean	Standard Deviation
Grass Biomass[1] (kg/ha)	Control [a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pile [b]	11.1	15.0	30.9	34.0	68.1	28.9	17.4
	Scatter [b]	0.0	9.5	12.3	26.1	45.1	16.9	13.9
Forb Biomass (kg/ha)	Control [a]	0.0	0.0	0.0	0.8	64.1	7.4	20.1
	Pile [b]	0.0	7.9	11.9	25.3	65.5	18.5	19.2
	Scatter [b]	0.0	10.3	13.9	23.8	38.0	16.2	12.8
Litter Depth (cm)	Control [a]	2.8	3.0	4.0	4.5	4.9	3.9	0.7
	Pile [a]	1.7	2.5	3.9	4.7	5.6	3.7	1.4
	Scatter [b]	1.7	2.4	2.8	3.0	3.2	2.6	0.5
Litter Mass[2] (kg/m^2)	Control [a]	4.9	6.4	7.8	9.1	9.6	7.6	1.6
	Pile [a]	5.4	6.6	7.3	8.1	11.0	7.5	1.7
	Scatter [b]	4.3	4.6	5.9	6.6	8.0	5.8	1.2

[1] Biomass was oven dried for 48 hours at 70C prior to weighing (kg ha-^{1}).
[2] Litter was oven dried for five days at 70C prior to weighing (kg).
[a, b]: within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 9. Five Number Summary Plus Mean and Standard Deviation for Forest Stand Characteristics Measured at 30 Plots for Three Forest Treatment Sites.

	Site	Minimum	25th Percentile	Median	75th Percentile	Maximum	Mean	Standard Deviation
Basal Area (m2/ha)	Control [a]	27.6	43.6	45.9	50.5	55.1	45.7	8.4
	Pile [b]	20.7	25.3	31.4	36.7	41.3	31.5	7.4
	Scatter [b]	25.3	25.3	27.6	32.1	52.8	30.8	8.3
Crown Closure (%)	Control [a]	77.0	86.0	95.5	97.0	98.0	92.1	6.9
	Pile [b]	74.0	83.0	88.0	91.0	91.0	86.4	5.6
	Scatter [b]	76.0	80.0	82.5	86.0	98.0	83.5	6.5

[a, b]: within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

Table 10. Five Number Summary Plus Mean and Standard Deviation for Soil Characteristics Measured at 30 Plots for Three Forest Treatment Sites.

	Site	Minimum	25 Percentile	Median	75 Percentile	Maximum	Mean	Standard Deviation
Slope (%)	Control [a]	17	19	19	20	25	20	2
	Pile [a]	18	19	22	25	27	22	3
	Scatter [a]	18	18	19	21	23	20	2
Soil Moisture (%) (dried & weighed	Control [a]	17.0	20.5	41.3	50.4	89.9	41.5	21.8
	Pile [a]	13.8	29.8	40.6	52.3	69.1	41.4	16.1
	Scatter [a]	14.4	31.2	38.4	48.3	61.7	38.1	14.9
Bulk Density (g/cc)	Control [a]	0.103	0.142	0.166	0.179	0.198	0.160	0.028
	Pile [a]	0.103	0.163	0.173	0.181	0.227	0.171	0.038
	Scatter [a]	0.142	0.159	0.186	0.200	0.214	0.181	0.023
Field Sand (%)	Control [a]	47.9	54.8	63.2	65.2	68.5	60.6	7.2
	Pile [a]	52.4	53.7	58.9	61.8	64.2	58.5	4.1
	Scatter [a]	45.0	49.8	55.7	59.8	62.0	55.0	5.7
Field Silt (%)	Control [a]	27.9	31.2	33.0	39.0	46.6	35.0	6.3
	Pile [a]	32.0	34.4	37.4	40.0	43.0	37.3	3.6
	Scatter [a]	34.1	36.3	39.7	45.2	49.7	40.5	5.2
Field Clay (%)	Control [a]	3.4	3.6	4.0	5.5	6.1	4.4	1.1
	Pile [a]	3.2	3.8	4.0	4.3	6.3	4.2	0.8
	Scatter [a]	3.7	4.2	4.4	5.1	5.3	4.5	0.6
Actual Sand (%)	Control [a]	8.2	11.5	11.9	13.3	16.0	12.3	2.2
	Pile [a]	9.5	11.1	12.9	14.8	15.1	12.6	2.0
	Scatter [a]	10.8	12.1	14.5	15.6	18.3	14.4	2.6
Actual Silt (%)	Control [a]	74.6	74.9	77.1	77.8	79.9	76.8	1.7
	Pile [a]	74.8	75.7	77.3	79.4	79.4	77.3	1.8
	Scatter [a]	71.0	73.7	75.5	76.8	79.4	75.4	2.6
Actual Clay (%)	Control [a]	9.1	10.3	10.6	11.6	13.7	10.9	1.4
	Pile [a]	9.2	9.8	10.0	10.2	11.1	10.1	0.6
	Scatter [a]	9.2	9.7	10.1	10.7	11.0	10.1	0.6
Surface Roughness (SD)	Control [a]	0.53	0.63	0.69	0.88	1.41	0.77	0.26
	Pile [a]	0.64	0.72	0.80	0.90	1.79	0.88	0.33
	Scatter [a]	3.37	3.67	4.39	5.53	9.35	5.18	2.06
Organic Matter	Control [a]	4.43	6.1	9.04	9.69	17.16	8.928	3.4985
	Pile [a]	5.9	6.35	8.85	11.2	12.03	8.94	2.45
	Scatter [a]	5.91	6.94	8.49	12.05	13.21	9.03	2.55

[a, b] within a variable, sites sharing the same letter do not differ significantly at the 0.05 alpha level.

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APENDIX

Figure 1 Study site: Cloudcroft, NM

Figure 2 Control Thinning Treatment

Figure 3 Precommercial Thinning Treatment + Slash Piled

Figure 4 Precommercial Thinning Treatment + Slash Scattered