THE EFFECTS OF LOGGING BURNED WOOD ON SOIL EROSION RATES

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The Rodeo-Chediski fire of June and July 2002 ravaged approximately 462,000 acres of Apache land and Apache-Sitgreaves National Forest in northeast Arizona, igniting a debate on both a local and state level about forest management techniques. Despite the strong opinion of all parties whether or not forests should be thinned, and what should happen to the burned areas, the assumption was voiced that burned areas, if logged, would have significantly higher erosion rates. However, no controlled scientific study until now has been undertaken to definitively measure or compare erosion rates in burned-logged versus burned-unlogged forests. Therefore a study was designed to determine the effects of logging and its consequences on soil erosion in the burned areas of the Rodeo-Chediski fire.

Three types of sites were studied: unburned areas served as a control to measure the natural erosion rates, burned-unlogged areas provided a control for natural erosion rates in high-severity burned areas, and the burned-logged sites provided data on the effects of logging in high-severity burned areas. These sites were chosen on the basis of their similarities in hillside location, original canopy cover, slope (5–13.5°), and drainage area (0.031–0.035 ha).

LOCATION

The study areas are located on the north-central portion of the Rodeo-Chediski burn area in central Arizona. The unburned (UB) sites are located approximately 6 km (3.7 mi) south adjacent to Lons Canyon (NW 1/4, Sec. 13, T10N, R20E). The burned-unlogged (B) and burned-logged (BL) areas are located approximately 2 km (1.25 mi) south of the town of Pinedale on the flanks of Turkey Hill (SE 1/4, Sec. 6, T10N, R19E). In the burned-logged areas, the fences were installed after the burned wood was logged in May of 2004. Sites were selected, however, on a "worst-case scenario" basis, in that the logging damage to the ground was noticeable. BL1 has a road on its upper part, BL2 has a skid path, and BL3 has large ruts in the middle of the drainage area that is evidence of the passage of heavy logging machinery.

METHODS

Silt fences (see Robichaud and Brown 2002) were used to catch sediment runoff. The drainage perimeter and the drainage area were calculated using GIS and slope was measured using a clinometer. Industrial red chalk was spread on the ground to a distance of approximately 60 cm into the drainage area from the silt fence to mark the original ground level. Rain Wise digital electronic rain gauges were installed at or near each silt fence. Rain data were collected with a HOBO and then downloaded using the program BOXCAR.

The line transect method (Wollenhaupt and Pingry, no date; Environmental Protection Agency 1994; Caratti, no date) was used to determine ground cover within each drainage area. Ground cover surveys recorded the amounts of branches, litter, rocks, herbs, shrubs, roots, trees, and bare soil. Ground cover surveys were conducted in October or September of 2003, 2004, and 2005.

Sediment behind the fence was collected generally in April and September of each year. Soil mass was determined with a PESOLA® 35 kg spring scale. A subsample of the soil was collected and air dried for a week to determine the soil's mass and the moisture content. Rates of erosion were based on the amount of sediment moved per hectare over a period of time. Two values are presented: the total amount of sediment moved in a year and the average amount of sediment moved during a month of precipitation. For the amount of sediment moved per year, totals for the summer and winter erosion periods were added together to give kilograms per hectare per year (kg/ha/yr).

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The average amount of sediment moved during periods of precipitation provides information as to when the majority of erosion is taking place and at what rate. The two main precipitation periods in Arizona are winter rains and snows (November to April) and summer monsoons (July to September). Thus, the kilograms per hectare were divided by the months that sediment was collected behind the silt fences.

Bivariate plots were used to compare erosion rates with the variable of interest (percent herb, soil, rock, etc.). Averages of the different types of sites were compared using a simple t-test. The numbers of sites are low (3 each), and the variability within the different types of sites made achieving significance difficult.

RESULTS

Table 1 and Figure 1A show that soil erosion rates for 2004-05 were relatively low in the unburned areas (79.5–356.1 kg/ha), highest in the burned areas (9842.8–27,234.2 kg/ha), and slightly lower in the burned and logged areas (924.2–14,074 kg/ha). The values for the winter of 2003-04 were not used because logging had not yet occurred. Average precipitation was 28.87 inches (733 mm) for the 2004-05 season and 11.85 inches (301 mm) for the 2005-06 season.

Summer erosion rates for 2004 and 2005 showed a similar difference between the burned and unburned sites (Figure 1B; winter erosion rates are not discussed here due to space limitations). The burned sites on average had an erosion rate 32–111 times higher than the unburned sites. Summer 2005 erosion rates for unburned sites decreased to 82.2 percent of the previous summer. The burned-unlogged sites decreased to 32 percent of the previous summer erosion rates. Burned-logged sites decreased to 16.0 percent of the previous summer erosion rates.

The unburned sites had the most vegetation, such as litter, while both the burned-unlogged and burned-logged sites had less vegetation and much more exposed soil (Figure 2). The burned sites had more exposed rocks than the unburned sites due to less vegetation. Litter was the most predominant ground cover in unburned sites, and it increased through the years. The averages for exposed soil decreased. In the burned-unlogged and burned-logged sites the ground cover surveys conducted in 2005 revealed an average increase in litter (5.1%) and herbs (5.7%), as well as a decline in exposed soil (6.5%) and rocks (6.5%).

As mentioned, the climate in the White Mountain area has two rainy seasons: the winter between November and April and the summer monsoons between July and September (Figure 3). The major dry seasons are May–June and October–November. Snow constitutes the majority of winter precipitation, and summer precipitation is largely rain. The summer monsoon season brings higher intensities of rain as opposed to the slow melting of snow during the winter.

Each silt fence site received approximately the same amount of precipitation with only some minor variation. Rainfall was about the same as the historic average in the winter of 2003-04, summer of 2004 (slightly higher in August), and summer of 2005. Rainfall was nearly three times the historic average in the winter of 2004-05. In contrast, rainfall was nearly four times less in the winter of 2005-06, although the recorded amount is probably less due to deep snow (2–3 ft) slumping off the rain gauge in March.

The t-tests of the erosion rates suggest that there are significant differences between all the burned

Table 1. Seasonal and yearly soil erosion rates (kg/ha).

Site	Fall 2004	Summer 2004	Winter 04-05	Total 2004-05	Summer 2005	Winter 05-06	Total 2005-06
UB2	11.1	37.1	31.3	79.5	51	3.4	54.4
UB3	16.3	65.6	6.6	88.5	63.1	5.9	69
UB4	119.1	118.5	118.5	356.1	338.7	25.7	364.4
B1	2283.7	24364	586.5	27234.2	12363.4	508.9	12872.3
B2	1074.7	8808.4	121.8	10004.9	5499.4	130.7	5630.1
B3	845.7	8626.8	370.3	9842.8	4304.4	15.3	4319.7
BL1	1362.7	12569.8	141.7	14074.2	3972.3	164.7	4137
BL2	30.4	889.1	4.7	924.2	23.5	0	23.5
BL3	665.4	6998.6	809.3	8473.3	2922	161.6	3083.6

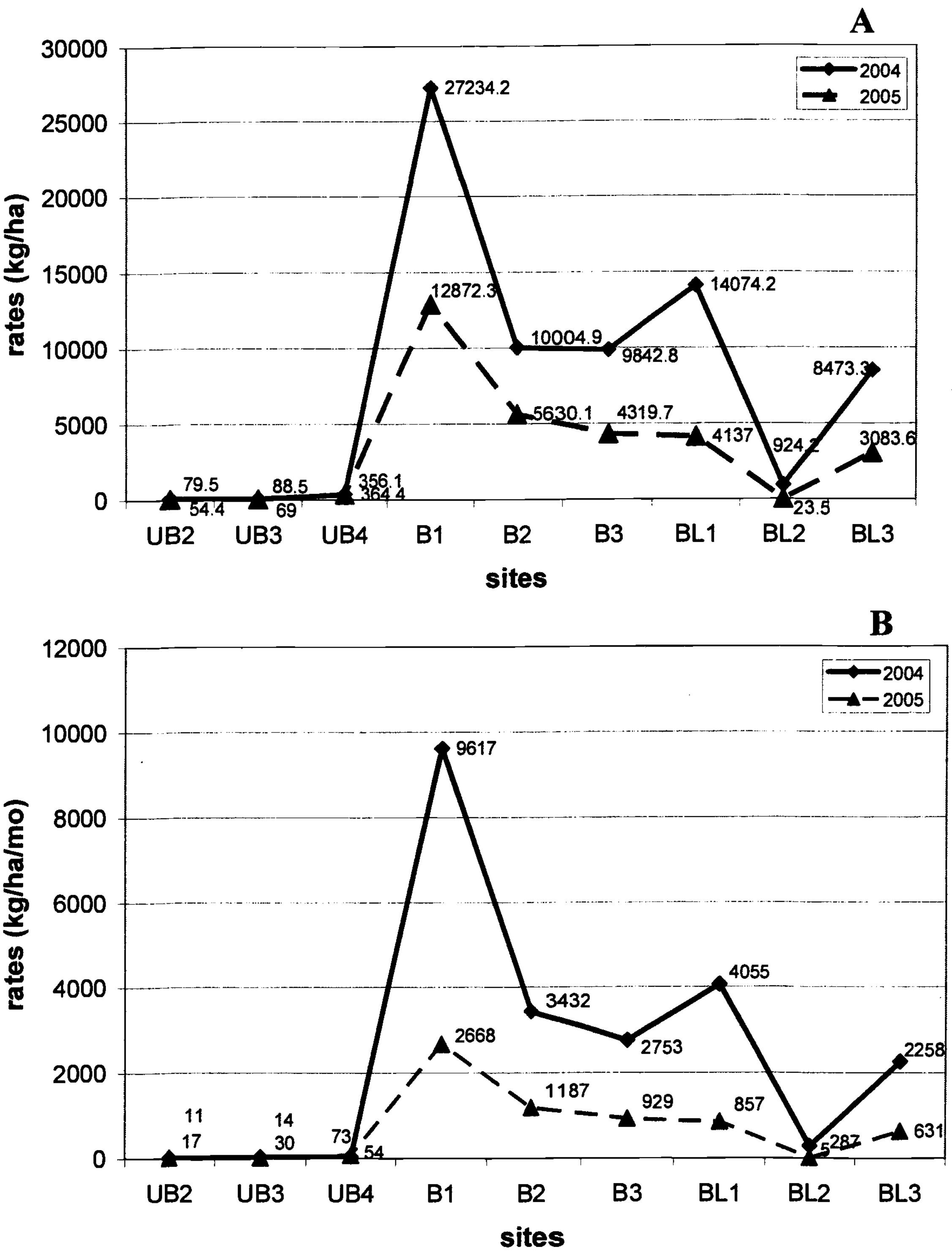

Figure 1. (a) Yearly erosion rates for 2004 (summer to winter 04-05) and 2005 (summer to winter 05-06); (b) summer erosion rates for 2004 and 2005.

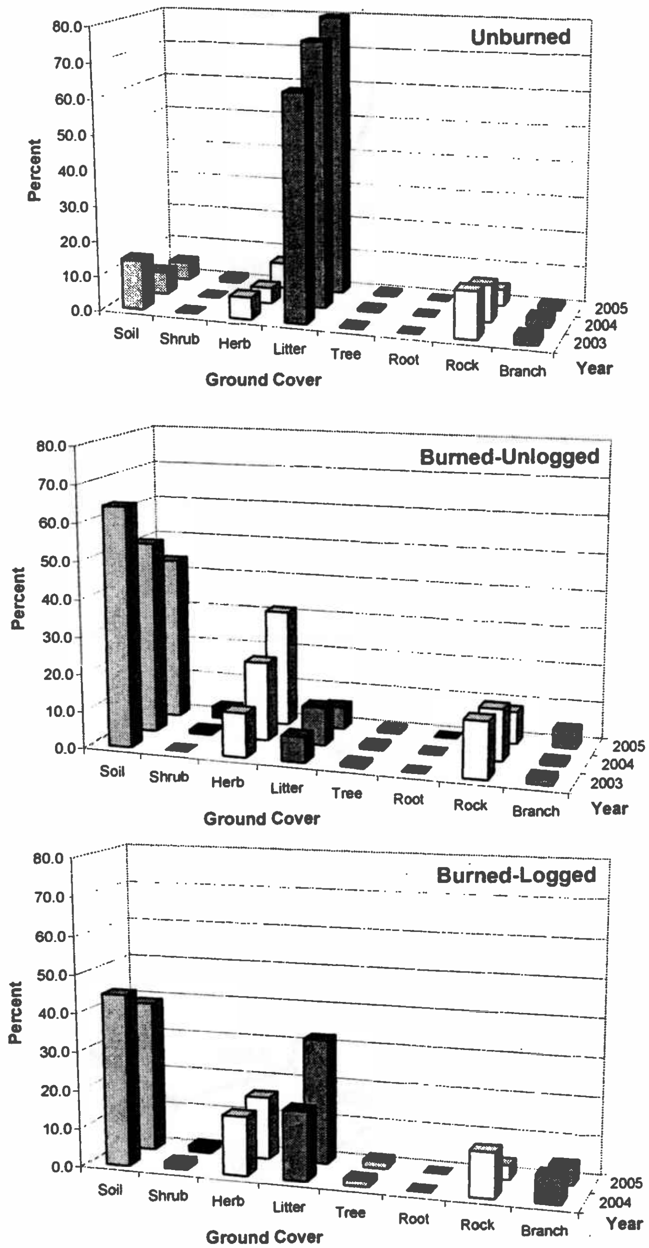

Figure 2. Average yearly changes in ground cover for all study areas.

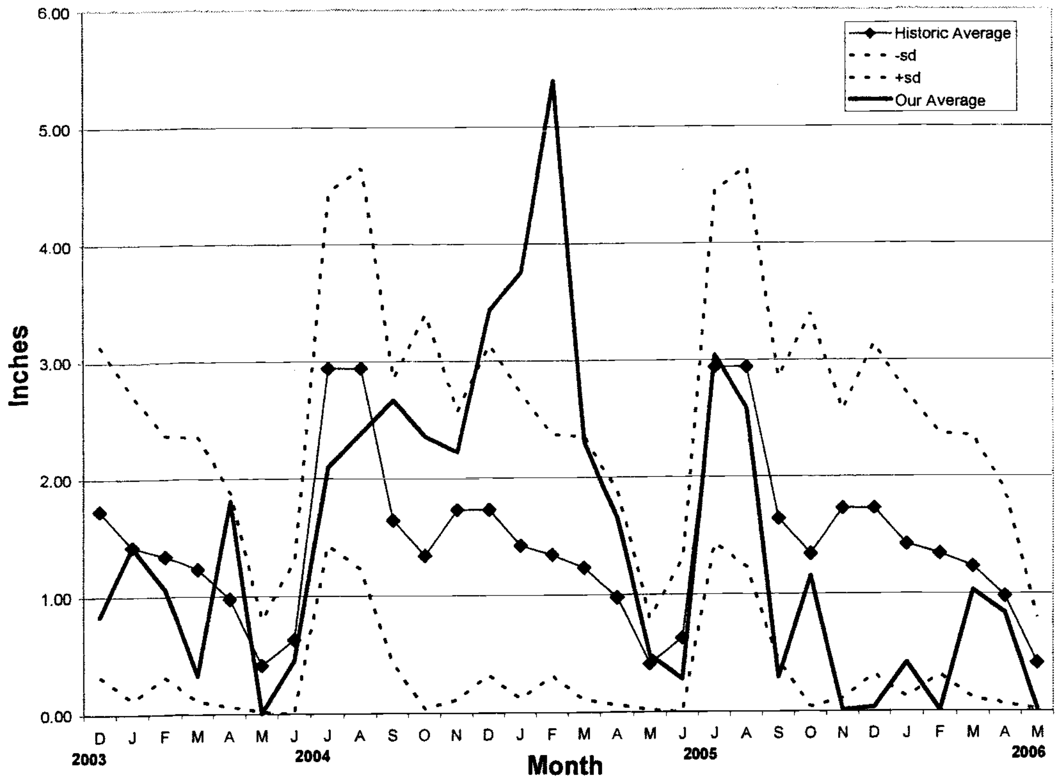

Figure 3. Rainfall during the study period (sd = standard deviation of historical amounts).

areas (B and BL) and the unburned areas (UB) for the summer erosion rates (Table 2). Several differences are obvious between the burned sites and the unburned sites, which may explain the difference in summer erosion rates. The t-test conducted on the major variables (Table 3) illustrates that the amounts of litter, herbs, and soil are significantly different between the burned and unburned sites. In contrast, the burned-unlogged and burned-logged areas had significantly different amounts only of litter in 2004 and only herbs in 2005. Further discussion of the results is limited to only the areas that have been burned-unlogged and burned-logged.

The results discussed here do not include the site B1 which is an outlier in erosion rates (see Figure 1). In addition, ground cover variables are only discussed in relationship to summer erosion rates due to the high values of these rates when compared to winter. Regression analyses of the data for 2004 and 2005 revealed that the soil exposure and herbs + litter variables stood out as major contributors to summer erosion rates (Table 4). As a combined unit, herbs + litter was the most influential ground cover variable, with an R^2 value of 0.6331. Regression analyses illustrate a negative correlation of erosion rates to the percentage of litter and herb cover (Figure 4A). Another important factor is soil exposure, with an R^2 value of 0.6157. There is a strong positive correlation of the percentage of bare soil to erosion rates (Figure 4B). The other ground cover variables have low R^2 values.

Other factors that appear to control the summer erosion rates in the burned areas (B and BL) include slope angle and amount of rain. In 2004, the summer erosion rates showed a strong correlation to hillside slope (Figure 4C); in 2005, the erosion rates showed less of a correlation to hillside slope (Figure 4D). Summer rain decreased in 2005 when compared to 2004. This decrease corresponds to a decrease in erosion rates (Figure 4E).

DISCUSSION

An obvious difference exists in erosion rates between the unburned and burned sites. The most obvious physical difference between these sites is the large amount of litter and the small amount of

Table 2. The p values from t-test of erosion rates.

Type of treatment	Winter 2003-04	Winter 2004-05	Summer 2005-6	Summer 2004	Fall 2005	Fall 2004
All burned vs. unburned	0.351	0.074	0.099	0.035	0.038	0.022
Burned-unlogged vs. burned-logged	—*	0.860	0.548	0.299	0.169	0.728

*There are no winter values for burned-logged.

Table 3. The p values from t-test of the major ground cover types in the different treatment areas; bold values are significantly different.

Comparison	Branch	Rock	Tree	Litter	Herb	Shrub	Soil
B vs. UB 2003	0.5712	0.8297	0.0480	**0.0010**	0.0571	0.5091	**0.0075**
B vs. UB 2004	0.5982	0.6402	0.2992	**0.0005**	**0.0058**	0.1655	**0.0023**
B vs. UB 2005	**0.0174**	0.6278	0.1208	**0.0002**	**0.0086**	0.5698	**0.0001**
B vs. BL 2004	0.1573	0.8358	0.6004	**0.0343**	0.4123	0.6524	0.6954
B vs. BL 2005	0.9958	0.3452	0.9694	0.0580	**0.0142**	0.3329	0.6026

Table 4. The R^2 values for the different ground cover types vs. erosion rates in the burned-unlogged and burned-logged sites combined for different years and seasons and combined seasons. Site B1 was not included in the regression analysis.

Factor	Winter 03	Winter 04	Winter 03-04	Summer 04	Summer 05	Summer 04-05
Soil	—*	0.0775	0.0369	0.7802	0.5046	0.6157
Herb	—	0.0006	0.0000	0.1933	0.6124	0.0310
Litter	—	0.0490	0.1106	0.4059	0.7421	0.1511
Herb & Litter	—	0.0286	0.0122	0.6706	0.5617	0.6331
Branches	—	0.2381	0.1373	0.0423	0.1195	0.0016
Rocks	—	0.3341	0.3546	0.1987	0.4072	0.0149
Slope	—	0.0204	-	0.9682	0.7023	-

*Only two sites.

bare soil present at the unburned sites (Table 3, Figure 2), which is probably the reason for the difference in erosion rates.

The factor with the most influence on erosion in the burned-unlogged and burned-logged areas was the steepness of slope. Erosion rates seem to have a moderate-high correlation to slope. Previous studies (see DeBano et al. 2005, Table 2.10) have shown that slope strongly influences erosion rates. The erosion rates of the relatively low slopes (8–24%) in the Pinedale study area were 1–27 kg/ha (for the second year), compared to the correspondingly higher erosion rates (first year rates of 72–370 kg/ha; DeBano et al. 2005) of steeper slopes (43–78%). Slope had a lower correlation to erosion rate and a lower slope of the regression line for summer 2005. This decrease is probably the result of the higher increase in correlation in combined percentage of herbs + litter and the decrease in exposed soil at the burned sites.

Other significant factors that influenced the erosion rates in the burned-unlogged and burned-logged areas were ground cover, exposed soil, and rainfall. The increase in ground cover from 2004 to 2005 was probably in part the reason for the decrease in erosion rates during the summer storms. The reduction in erosion rates, however, cannot be clearly attributed to the increase in ground cover. Rainfall during the summer of 2005 amounted to approximately 3 inches, whereas rainfall in the

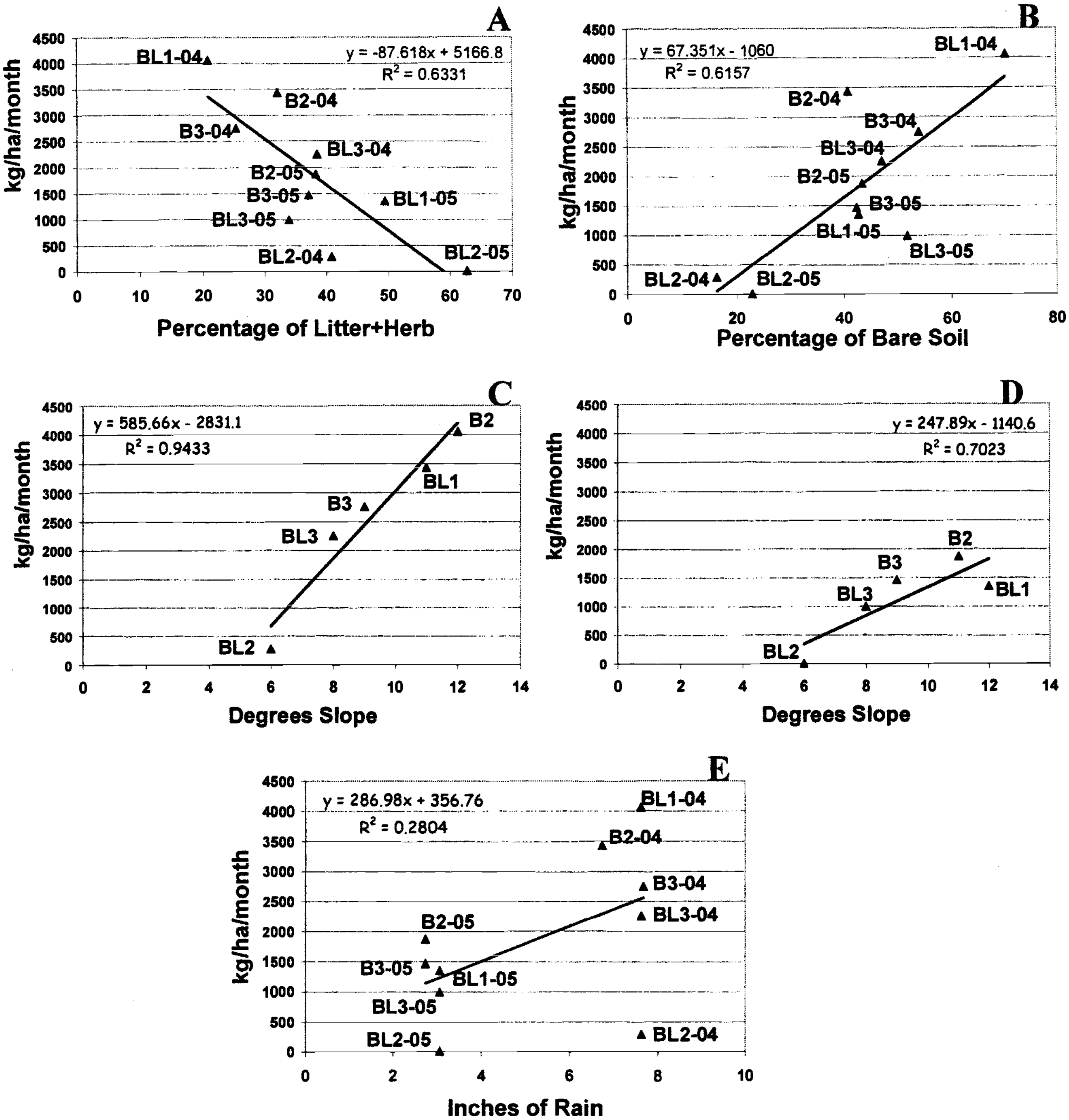

Figure 4. Bivariate plot of the summer erosion rates and the combined percentage of (a) litter and herbs, (b) percent bare soil, (c) slope 2004, (d) slope 2005, and (e) inches of rain in burned-unlogged (B) and burned-logged (BL) areas for 2004 and 2005. Note the lower slope and R^2 values for 2005.

summer of 2004 was about 7.5 inches. Thus the reduction in erosion rates for the summer of 2005 was probably also the result of decreased rainfall.

Site B1 had extreme erosion rates; for example, in the summer of 2004 the erosion rate was 9617 kg/ha/mo. B1 was thus eliminated from the analyses because it is an outlier. The high amount of erosion at B1 may have been due to the amount of rock on the surface.

Comparison of the erosion rates in the Pinedale study area to other areas in Arizona is limited due to the few available comparative studies. DeBano et al. (2005, Tables 2.9 and 2.10) reported first year erosion rates of 0.1–1.3 mg/ha in low- to high-severity wildfire areas in a ponderosa pine forest. These rates are less than either second or third year erosion rates (1–27 kg/ha) in the high-severity burned areas at Pinedale. In contrast, first year erosion rates in chaparral areas are generally higher after wildfires (29–204 kg/ha).

CONCLUSION

Should salvage lumbering be allowed in badly burned areas of national forest, and will this increase the erosion rates in logged areas? Results of this study do not support the hypothesis that erosion rates will change as a result of some types of lumbering activities. Instead, the differences in erosion rates at these sites has been tentatively found to be more closely tied to the slope of the drainage areas, the amount of herbs and litter, and the amount of rocks on the surface.

Limitations of this study included the small number of study sites (3 silt fences erected in each of the three areas—burned-unlogged, burned-logged, and unburned), and the fact that this study was not begun immediately after the 2002 fire, but instead began in 2003. The most significant erosion tends to occur in the first year after the fire. This reduction in erosion, however, can be seen from the erosion rates of 2004 to 2005, but this reduction may be in part due to the reduction in rainfall between the two monsoon seasons.

ACKNOWLEDGMENTS

We would like to thank Vince Causey, Carl DeCeaser, and Ed Collins, Lakeside District, Apache-Sitgreaves National Forest, for providing access to the study area and assistance in the location of the sites, and for providing GPS and GIS information. Dr. Pete Robichaud, Rocky Mountain Research Station, Moscow, Idaho, provided advice and the initial equipment to begin the fire erosion project. This study was initially funded by APS/Phoenix Suns Energy and Environmental Mini-Grant (2003) and later by National Science Foundation Grant EAR 0402648. Our thanks is also extended to the Show Low School District school board, administration, and students for their assistance in obtaining funding or participation in the project.

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