Post-fire Erosion and the Effectiveness of Burned Area Rehabilitation Treatments, Colorado Front Range

L.H. MacDonald, D. Rough[1], J. Pietraszek[1], and J.W. Wagenbrenner[2]

[1]Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523; leemac@cnr.colostate.edu

[2]Forest Sciences Laboratory, U.S.D.A. Forest Service Rocky Mountain Research Station, Moscow, ID 83843; jwagenbrenner@fs.fed.us

INTRODUCTION

High-severity wildfires in the Colorado Front Range can increase runoff and erosion rates by several orders of magnitude relative to unburned conditions (e.g., Moody and Martin 2001). Burned area emergency rehabilitation (BAER) treatments are often implemented, but very few studies have quantified their effectiveness (Robichaud et al. 2000). Over the last five years we have been measuring sediment production rates and site conditions from both treated and untreated sites on seven wild and three prescribed fires of different ages in the Colorado Front Range (Figure 1; Table 1). The objectives of our work have been to: (1) quantify post-fire erosion rates; (2) determine the relative importance of different controlling factors; and (3) assess whether the rehabilitation treatments significantly reduce hillslope erosion rates relative to untreated areas. The results will help predict post-fire erosion rates and guide post-fire rehabilitation efforts.

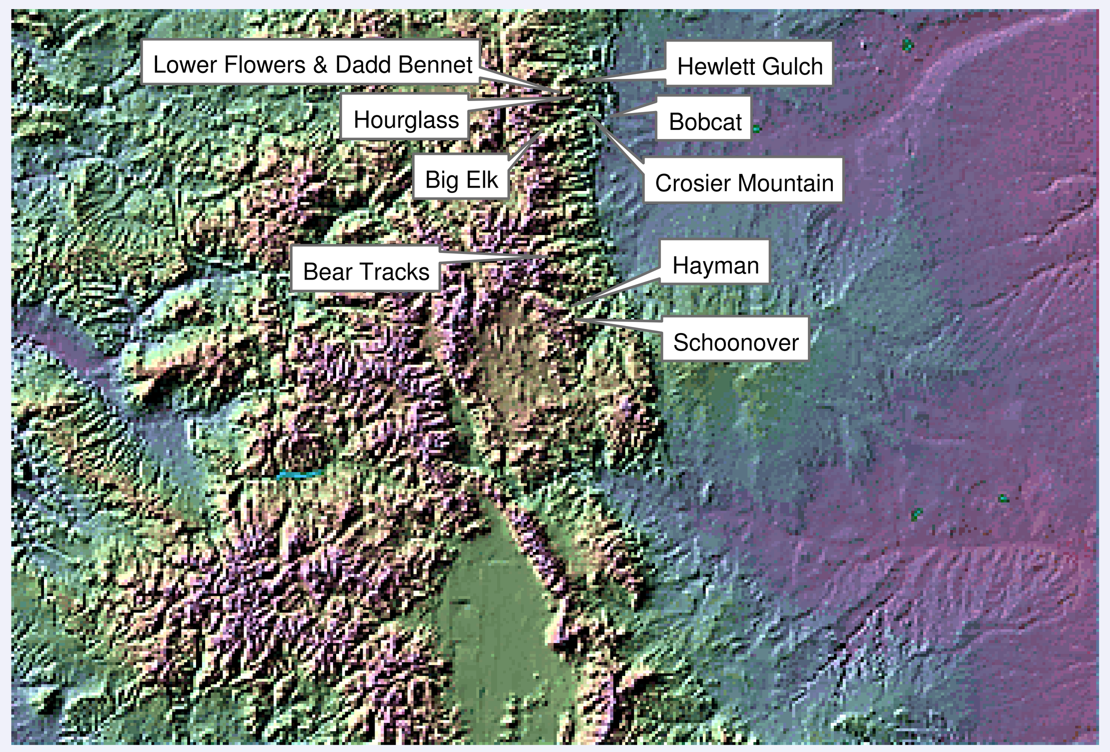

Figure 1. Locations of fires used in this study.

METHODS

Sediment fences are being used to measure sediment production on plots of 150-8640 m^2. Site characteristics measured at each plot include slope, soil texture, contributing area, and aspect. Percent cover is measured at the beginning and end of each growing season. Data from one or more tipping-bucket rain gauges at each fire are used to determine summer precipitation, rainfall intensity, and rainfall erosivity. The emergency rehabilitation treatments being evaluated include mulching, contour-felling, seeding, seeding and scarification, hydromulching, and the use of a polyacrylamide (PAM) soil binding agent. Treatment effectiveness is being tested between groups of treated and untreated swales, or with a replicated paired-swale design (Figure 2).

Most of the study sites and all of the treatments are on sites burned at high severity, as these are the areas of greatest concern (Table 1). At the end of 2003 we had 240 plot-years of data from untreated sites, and 142 plot-years of data from 40 treated sites. The most intensively studied fires are the June 2000 Bobcat fire, the May 2002 Schoonover fire, and the June 2002 Hayman fire (Figure 1; Table 1).

Figure 2. Paired swale design with adjacent control (left) and treated swales (right).

Fire (year)	Treatment	Severity	Number of Plots
Bobcat (2000)	Aerial and ground seeding	High	4
Bobcat	Dry mulching	High	7
Bobcat	Contour Felling	HIgh	11
Bobcat	Untreated	High; Moderate; Low	25; 2; 1
Hayman (2002)	Scarification and seeding	High	4
Hayman	Dry mulching with seeding	High	4
Hayman	Aerial hydromulching	High	4
Hayman	Ground hydromulching	High	4
Hayman	Untreated	High; Moderate; Low	31; 1; 0
Schoonover (2002)	Wet PAM	High	3
Schoonover	Dry PAM; New wet PAM	High	3; 3
Schoonover	Untreated	High	6
Big Elk (2003)	Untreated	High; Moderate; Low	3; 2; 1
Hewlett Gulch (2002)	Untreated	High; Moderate; Low	3; 0; 0
Dadd Bennett (1999)	Untreated	High; Moderate; Low	0; 3; 2
Lower Flowers (1999)	Untreated	High; Moderate; Low	4; 4; 2
Crosier Mountain (1998)	Untreated	High; Moderate; Low	4; 1; 0
Bear Tracks (1998)	Untreated	High; Moderate; Low	3; 0; 2
Hourglass (1994)	Untreated	High; Moderate; Low	5; 1; 1

Table 1. Number of untreated control plots and treated plots by treatment and fire severity.

RESULTS: *Untreated Plots*

Nearly all of the post-fire sediment production in the Colorado Front Range occurs as a result of summer rainstorms rather than snowmelt. Five millimeters of rainfall and rainfall intensities of only 10 mm hr^{-1} can induce overland flow and surface erosion on sites recently burned at high severity.

Both univariate and multivariate analyses show that percent bare soil is the dominant control on annual sediment production rates (Figure 3a). Percent bare soil is controlled primarily by burn severity and time since burning (Figure 3b). Multiple regresssion indicates that rainfall erosivity is the second most important factor (Table 2), and this factor is more important when the data are analysed on a storm-by-storm basis. Sediment production rates are higher on convergent hillslopes than planar hillslopes, and recent work has shown that this difference is due to greater rill incision in the swale axes. Most sites show a large decline in sediment production rates by the third summer after burning (Figure 4), but areas with coarser soils show a slower recovery in terms of both percent cover and sediment production.

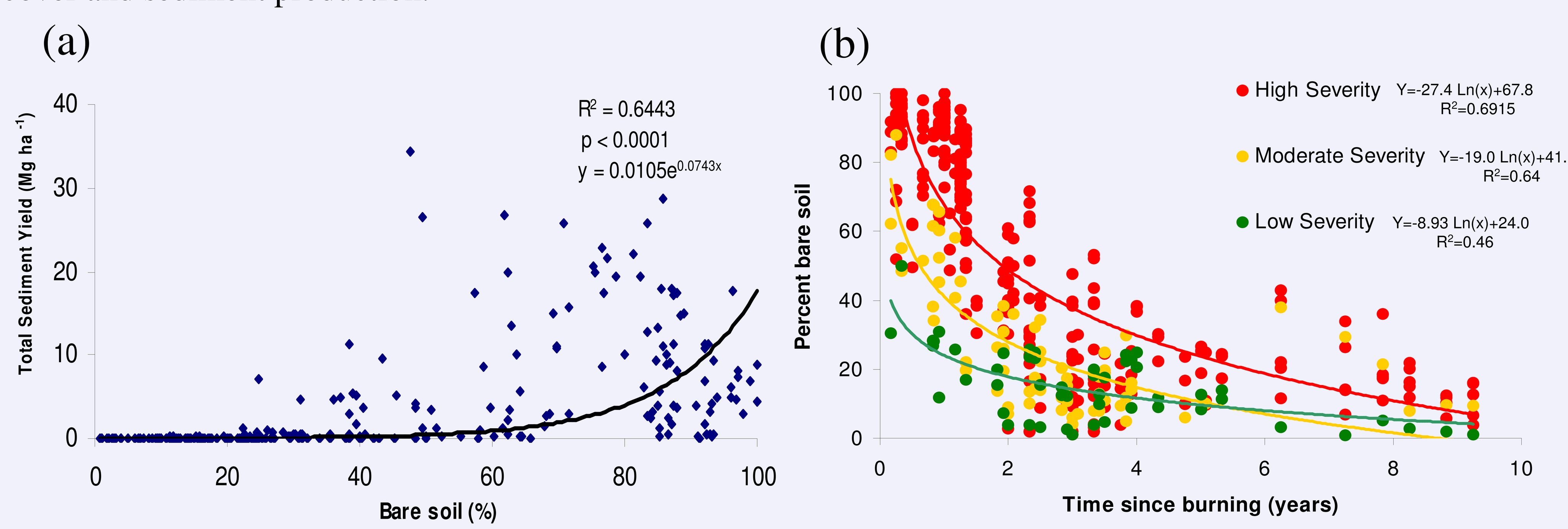

Figure 3. (a) Relationship between percent bare soil and sediment production. (b) Percent bare soil by time since burning and fire severity.

Parameters	Partial R^2	p-value
Bare soil (%)	0.58	<.0001
Summer erosivity (MJ mm ha^{-1} hr^{-1})	0.05	<.0001
Hillslope position (swales, planar)	0.05	<.0001
Soil D_{84} (mm)	0.04	0.04
Average I_{30} (mm hr^{-1})	0.01	0.002
Time since burning (years)	0.01	0.004
Aspect (degrees)	0.01	0.013
Soil D_{16} (mm)	0.01	0.026

Table 2. Significant parameters for a multivariate model predicting post-fire erosion.

RESULTS: *Effectiveness of Treatments*

None of the treatments applied after the June 2000 Bobcat fire significantly reduced sediment yields in the first year because a 48-mm storm caused 12 of the 16 sediment fences to overtop. The dry mulch treatment did significantly reduce sediment yields in the second year after burning (p=0.0001), but not in the third and fourth years due to the high variability on the untreated plots (Figure 4a). On the Hayman fire, the dry mulch and aerial hydromulch treatments each reduced sediment yields by more than 90% in the first and second years after burning (p<0.05), but not in the third year (Figure 4b). The ground hydromulch treatment did not significantly reduce sediment yields in any year (Figure 4b).

Neither seeding nor seeding with scarification significantly reduced sediment yields for any year on either fire (Figures 4a,b). The effectiveness of the contour-felling treatment was inconsistent, as the treatment installed after the 48-mm storm significantly reduced sediment yields in the following (second) year after burning but not in the third year (Figure 3a).

The wet PAM treatment reduced sediment yields by 66% in the first year after burning (p=0.05) (Figure 4b), while the dry PAM treatment had no significant effect on sediment yields. In the second year after burning a new wet PAM treatment was applied to the plots where the dry PAM had been shown to be ineffective, but this new wet PAM treatment did not significantly reduce sediment yields in either of the next two years (Figure 4b).

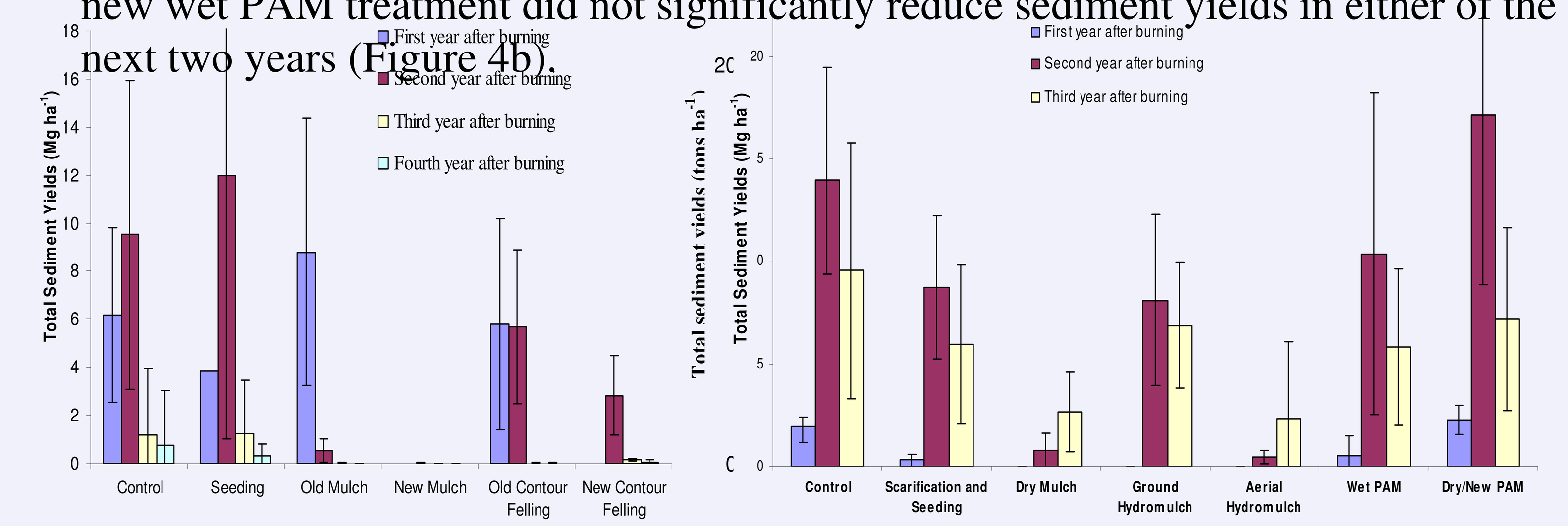

Figure 4. Mean sediment yields for eight treatments in: (a) the Bobcat fire, and (b) the Hayman and Schoonover fires. Error bars represent one standard deviation.

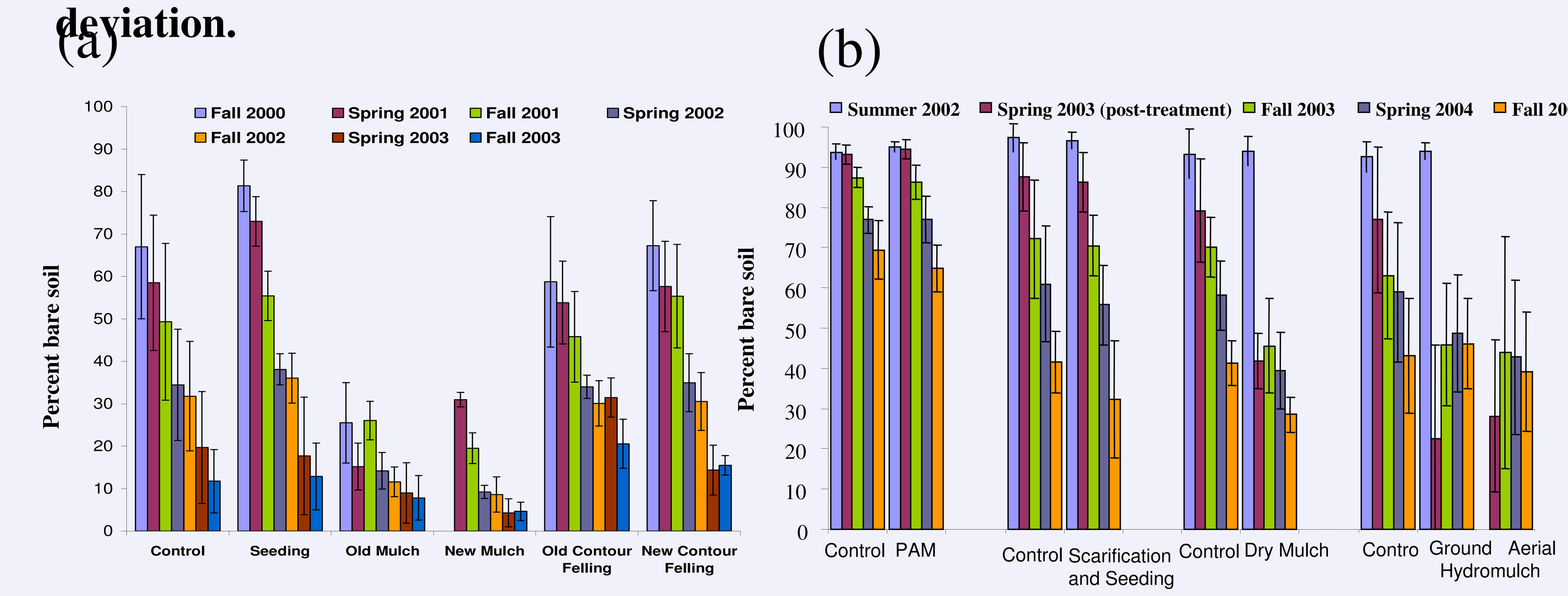

Figure 5. Mean percent bare soil by treatment in: (a) Bobcat fire, and (b) Hayman and Schoonover fires. Error bars represent one standard deviation.

DISCUSSION

The dry mulch and aerial hydromulch treatments were the most effective treatments in terms of reducing erosion because they immediately reduced the amount of bare soil relative to the control plots (Figure 5). For both the Bobcat and Hayman fires, the mulched plots in the first year after burning averaged less than 10% bare soil as compared to more than 90% bare soil in the untreated control plots. Mulching also increased the rate of vegetative recovery, and this compensated for the losses of mulch by overland flow, wind, or in situ decay. Three or four years are needed before revegetation on the control plots reduces the percent bare soil to the same levels as the mulched plots (Figure 5a), and this is why the mulch treatments did not significantly reduce sediment yields in the fourth year after burning (Figure 4a). The ground hydromulch treatment applied at the end of the first year did not significantly reduce the amount of bare soil, and this probably explains its ineffectiveness in reducing post-fire sediment yields.

Intensive monitoring on the Hayman and Schoonover fires indicates that rill erosion can account for approximately 80% of the measured sediment production in untreated areas. The only treatment with significantly lower rill densities was the dry mulch treatment (0.12 vs. 0.18 rills/m^2). This indicates that the mulching can reduce both hillslope and rill erosion, at least for the magnitude of the storm events observed in this study.

The varying effectiveness of the contour-felling treatment can be attributed to the size and magnitude of the subsequent storm events. The large storm in August 2000 effectively filled the sediment storage capacity behind the first contour-felling treatment, and the subsequent lack of storage capacity explains why this treatment was not effective in reducing sediment yields in the second year after burning. On the other hand, the contour-felling treatment installed after this large storm had sufficient capacity to store the sediment produced in an average year. Hence the second contour-felling treatment was able to significantly reduce sediment yields in the second summer after burning.

The reasons for the varying effectiveness of the wet and dry PAM treatments are being investigated. Lab experiments suggest that the PAM preferentially binds with the residual ash. Both the wet and dry PAM are subject to chemical breakdown induced by exposure to solar radiation. These results suggest that the wet treatment is most likely to be effective when the PAM is quickly washed below the soil surface and there is little or no residual ash.

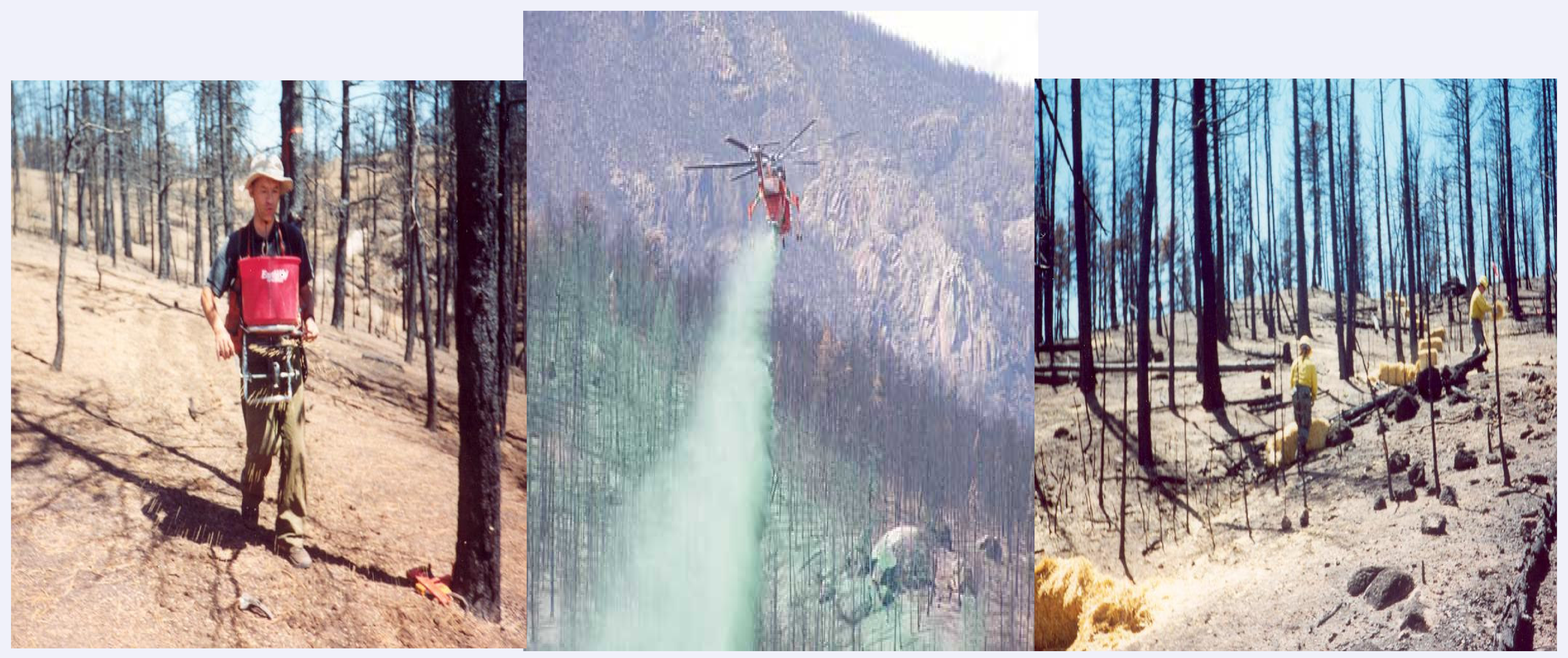

Figure 6. Application of seeding, aerial hydromulch, and dry mulch treatments.

CONCLUSIONS

- Percent bare soil is the primary control on post-fire sediment production rates. Dry mulch and aerial hydromulch reduced post-fire sediment production rates by more than 90% because these treatments immediately increased the amount of ground cover.
- Revegetation rates and sediment yields were not significantly reduced by seeding, seeding and scarification, or ground hydromulching.
- Contour-felling treatments became ineffective as the sediment storage capacity was exceeded.
- Rill incision in convergent areas can account for most of the sediment production at the hillslope scale, and rill density is positively correlated with sediment yields (R^2=0.42).
- Dry mulch was the only treatment that significantly reduced rill densities (p=0.001).
- PAM is generally ineffective in reducing post-fire sediment yields, and this can be attributed to the tendency to bind with ash and the degradation of PAM over time.

REFERENCES

Benavides-Solorio, J. de Dios, 2003. Post-fire runoff and erosion at the plot and hillslope scales, Colorado Front Range. Ph.D. dissertation, Department of Earth Resources, Colorado State University, Ft. Collins, CO. 218 pp.

MacDonald, L.H., and Huffman, E.L. 2004. Post-fire soil water repellency: persistence and soil moisture thresholds. *Soil Science Society of America Journal* 68: 1729-1734.

Moody, J.A. and Martin, D.A., 2001. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. *Earth Surface Processes and Landforms* 26: 1049-1070.

Robichaud, P.R., Beyers, J.L. and Neary, D.G., 2000. Evaluating the effectiveness of postfire rehabilitation treatments. USDA Forest Service, General Technical Report RM-GTR-63. Fort Collins, CO. 85 pp.

Wagengbrenner, J., 2003. Effectiveness of burned-area emergency rehabilitation treatments, Colorado Front Range. M.S. thesis, Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO. 103 pp.