Hillslope Treatment Effectiveness Monitoring on Horseshoe 2 and Monument Fires

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***Abstract**—Between February and July, 2011, over 360,000 acres burned across the Coronado National Forest during one of the most active fire seasons in recorded history. Burned Area Emergency Response (BAER) Teams evaluated post-fire watershed conditions and prescribed treatments based on threats to known values at risk. Hillslope stabilization treatments were prescribed and implemented for areas of high soil burn severity on both the Horseshoe 2 and Monument Fires. These treatments consisted of seeding on the Horseshoe 2 Fire and application of agricultural straw mulch and seed on the Monument Fire. Initial monitoring results indicated one of three seeded species (Hordeum vulgare) emerged in both burned areas, slightly improving effective ground cover in both treatments. However, seeding treatments failed to meet monitoring success criteria for the Horseshoe 2 and Monument Fires. Hillslope erosion was reduced where mulch treatment was applied correctly and where slope gradients were moderate on the Monument Fire, and appeared to contribute to seeded species cover. In the Horseshoe 2 Fire, hillslope erosion was high on the treatments transects and was not reduced by seeding alone. A need for additional monitoring in spring 2012 exists and would improve the current understanding of the effectiveness of hillslope treatments.*

Introduction

The summer of 2011 saw record wildfires across the southwestern United States. In southeastern Arizona, the Horseshoe 2 Fire burned approximately 222,954 acres in the Chiricahua Mountains (http://inciweb.org/incident/2225/), and the Monument Fire burned approximately 30,526 acres in the Huachuca Mountains (www.inciweb.org/incident/2324/) (fig. 1). Both fires burned watersheds that drain onto developed private lands and rural ranches. In Arizona, monsoon rains immediately follow wildfire season and are often how fires are ultimately extinguished. The quick, intense burst of rainfall from relatively common (<2-5 yr frequency) storms can generate large floods and debris flows in watersheds disturbed by wildfires. U.S. Forest Service (USFS) Burned Area Emergency Response (BAER) assessments were completed for both fires. Soil burn severity maps show 12% of the Horseshoe 2 Fire burned at high severity and 30% at moderate severity, while 7% of the Monument Fire burned at high severity and 39% at moderate severity. Moderate to high soil burn severity in both fires occurred on moderate to very steep slopes in the upper watersheds. The BAER teams conducted hydrologic analyses of post-burn conditions using a 5-year return-interval storm with an intensity of $^1/_2$ inch/hour. Results indicated an estimated increase of post-fire peak flows from 2-15 times in the Horseshoe 2 burned area (USDA 2011a), and from 3-10 times in the Monument burned area (USDA 2011b).

To mitigate predicted increases in post-fire runoff and consequential risks posed to life, property, and soil productivity within and near the burned areas, hillslope treatments were prescribed for selected areas of moderate and high soil burn severity on USFS-managed lands. Aerial seeding was applied to treatment areas in the Horseshoe 2 burned area from July 16 through July 18 and in the Monument Fire on July 29. Seed mixtures included *Hordeum vulgare* (annual barley), *Bouteloua gracilis* (blue grama) and *Pascopyrum smithii* (western wheatgrass) for the Horseshoe 2 Fire, and *H. vulgare*, *B. gracilis* and *Elymus trachycaulus* (slender wheatgrass) for the Monument Fire. The seeding was applied, with variable seed coverage, by fixed-wing aircraft. Agricultural straw mulch was applied over seeded units in the Monument Fire from August 2 to 17, 2011; no agricultural straw was used to stabilize hillslopes in the Horseshoe 2 Fire.

The objective of this study was to evaluate the initial effectiveness of hillslope treatments within both burned areas. To evaluate if treatments were successful or not within the first year of application, the study plots were monitored to determine if (1) seeded species germinated and became established, (2) seeded species provide effective cover for soil stabilization, (3) straw mulch cover was uniform throughout Monument Fire treatment units, (4) straw mulch treatment

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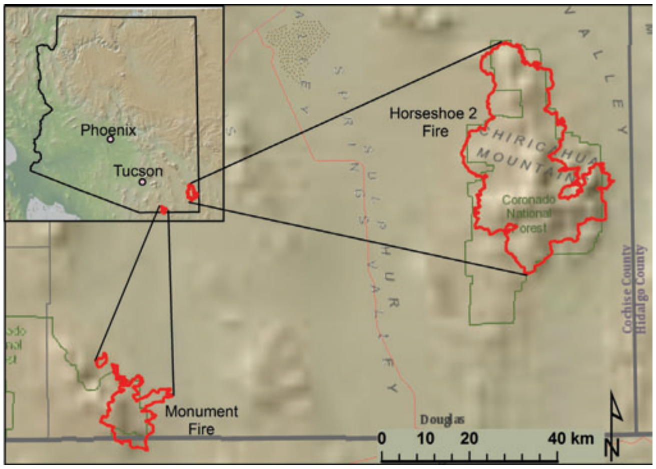

Figure 1—Location of Horseshoe 2 Fire and Monument Fire in south-eastern Arizona.

successfully reduced soil erosion in the Monument Fire, and (5) wind was a factor in moving the straw mulch in the Monument Fire.

Methods

Site Selection

Burned areas suitable for seeding and mulching treatments had moderate to high soil and vegetation burn severity with slope gradients between 40 and 60%. Appropriate areas for treatment were identified by the BAER teams (USDA 2011a,b,c). Within the treatment areas, preliminary transect locations were selected on the basis of soil burn severity (USDA 2011a,b) vegetation burn severity (USDA 2011c), aspect (table 1), and accessibility. Potential treatment and control transect locations were located in the field based on ArcGIS-derived UTM coordinates. Transects were established in areas that represented average hillslope conditions while avoiding natural drainages which may have contributed to pre-fire hillslope erosion that would not have been mitigated by treatments The number and location of control transects were limited as most of the potential treatment areas were seeded (Horseshoe 2) or seeded and mulched (Monument).

Data Collection and Analysis

Two rain gauges were installed on the Monument Fire and one was installed in the study area of the Horseshoe 2 Fire (northern half of the fire) in early July with a second gauge installed in late July. Rain fell on both fires before any of the hillslope treatments could be applied. The first significant rains fell on the Monument Fire on July 10 (table 2) and on the Horseshoe 2 Fire on July 11 (table 3). Both storms produced debris flows and floods. The NOAA Atlas 14 classifies both storms as a 2-year/30-minute frequency. During July and August, 10 storms on the Monument Fire (table 2) and 11 storms on the Horseshoe 2 Fire (table 3) produced enough runoff to generate either debris flows or floods with peak discharges sufficiently large to threaten or cause damage to values at risk based on reports from BAER team implementation teams and local residents.

Thirty-meter transects were established along contour to collect rill network density and effective ground cover data (fig. 2). For each transect, the width and depth of each rill was measured for the first 10 m, distance between rills was measured within the first 15 m, and total number of rills was tallied for the entire length. Average values for distance between rills and rill width and depth measurements for each fire were calculated to compare treatments with control sections. Rill cross-sectional areas, ranges, averages, and standard deviations were calculated by treatment for each fire.

Effective ground cover (EGC) data collected from 1 m square quadrats included native vegetative cover, seeded species cover and count, large woody debris, and litter (Brady and Weil 2000; DeBano and others 1998; Pannkuk and Robichaud 2003). Agricultural straw cover and clumps of agricultural straw within 1 m of treatment transects were also measured in the Monument Fire. Square meter quadrats were read every 3 meters for the length of each transect. Cover frequency index (CFI) was calculated for each EGC variable for treatment and control transects sampled in each burned area. This metric combines frequency of occurrence and absolute percent cover for each variable analyzed (Benkobi and Uresk 1996; USDA 2006). Ground cover was determined to be effective at reducing erosion when all variables measured contributed to 70% or greater cover (Pannkuk and Robichaud 2003; Robichaud 2005). Successful treatment implementation and germination of seeded species included the presence of all three seeded species, an average of greater than 20 seeded individuals in treatment quadrats, and a CFI of twice the overall vegetation CFI for treatment transects (Johnson 2004).

Data were collected from September 22 through 27, 2011. Six treatment and three control transects were established in the Horseshoe 2 burn area and seven treatment and two control transects were established in the Monument burned area (table 1). One potential treatment transect in the Monument Fire was abandoned due to safety concerns.

Results

Rill Density

Measurements were collected along transects to obtain rill density and cross-sectional areas, although not all transects intersected rills. On the Horseshoe 2 Fire, rill measurements were collected on four of six of the treated transects and two of three of the control transects (tables 4 and 5, fig. 3). One control transect intersected a single rill beyond 15 m; therefore, no measurements were collected On average, there were a greater number of rills in the treatment transects, and rill cross-sectional areas were 64% lower for treatment transects than for control transects.

On the Monument Fire, rill measurements were collected on four of seven treated transects and two of two control transects (tables 6 and 7, fig. 4). One treated transect intersected three rills beyond 15 meters; therefore, no measurements were collected for this transect. On average, there were a greater number of rills in the control transects. However, rill cross-sectional areas were 37% lower for treatment transects than for control transects.

Effective Ground Cover

H. vulgare was the only seeded species observed during data collection. This grass species was present in 71% of Horseshoe 2 treatment quadrats, accounting for an average of 10.7% cover and 7.6 CFI (table 8), and in all Monument treatment quadrats, accounting for an average of 7.8% cover and 7.6 CFI (table 9). *H. vulgare* cover on the Horseshoe 2 Fire was highest where soil and vegetation burn severity was moderate and lowest where soil and vegetation burn

Table 1—Transect locations, soil burn severity, vegetation burn severity, aspect and transect sample type. (c = control, untreated)

Fire	Transect	Burn Severity: Soil[a]	Burn Severity: Vegetation[b]	Aspect[c]	Sample Type
Monument	1	moderate	high	east	treatment
	2	moderate	high	east	treatment
	3	moderate	high	north	treatment
	4	high	high	east	treatment
	5	high	high	north	treatment
	6c	moderate	high	north	control
	7c	high	high	east	control
	8	moderate	high	east	treatment
	10	high	high	north	treatment
Horseshoe 2	11	high	high	north	treatment
	12	high	moderate	south	treatment
	13c	high	high	south	control
	14	moderate	moderate	west	treatment
	15c	moderate	moderate	west	control
	16	mixed	mixed	west	treatment
	17	mixed	mixed	south	treatment
	18	high	high	north	treatment
	19c	high	high	north	control

[a]Soil burn severity derived from BAER Assessment Team's Final Soil Burn Severity GIS (USDA 2011a & b).
[b]Vegetation burn severity downloaded from USFS Remote Sensing Application Center, Salt Lake City, 09/17/2011.
[c]Aspect generated from 30 meter DEM in ArcMap 9.3.1 with Spatial Analyst (ESRI 2011).

Table 2—Significant rainfall events from two ALERT gauges within the Monument Fire burned area. Dates of hillslope treatments are shown in right column.

Miller Canyon ALERT Gauge				Ash Canyon ALERT Gauge			
Date	Storm Total (mm)	Storm Duration (h:mm:ss)	Average Storm Intensity (mm/hr)	Storm Total (in)	Storm Duration (h:mm:ss)	Average Storm Intensity (mm/hr)	Treatments
10-Jul	41.66	1:04:00	39.1				
20-Jul	29.46	1:17:16	22.9	6.1	2:14:48	2.7	
23-Jul	9.14	0:12:00	45.7	10.2	0:14:17	42.7	
26-Jul	8.13	0:35:32	13.7				
28-Jul	19.30	5:04:57	3.8	31.5	4:08:01	7.6	
29-Jul	2.03	0:42:31	2.9	11.2	1:20:20	8.3	Seeding Applied
31-Jul	12.19	4:43:42	2.6	31.5	4:01:28	7.8	
11-Aug	3.05	0:44:49	4.1	8.1	1:08:45	7.1	Straw Mulch Applied Aug 2-17
13-Aug	6.10	3:00:32	2.0	13.2	1:39:21	8.0	
20-Aug	22.35	1:00:07	22.3	17.3	0:21:18	48.7	
22-Aug	2.03	0:12:10	10.0	15.2	0:24:24	37.5	
23-Aug	9.14	0:11:22	48.3				

Table 3—Significant rainfall events from two gauges within the Horseshoe 2 Fire burned area. Dates of hillslope treatments are shown in right column.

UA/B2 Chiri Gauge & NWS KC2CPZ1 Weather Station				Treatments
Date	**Storm Total (mm)**	**Storm Duration (h:mm:ss)**	**Average Storm Intensity (mm/hr)**	
11-Jul	54.4	1:38:31	33.1	
12-Jul	8.6	0:35:52	14.4	Seeding Applied July 16-18
26-Jul	13.0	0:32:45	23.7	
28-Jul	7.9	0:59:29	7.9	
3-Aug	6.4	0:13:17	28.9	
9-Aug	6.0	0:11:35	31.1	
11-Aug	24.6	2:40:59	9.2	
13-Aug	18.0	1:25:56	12.6	
15-Aug	24.6	0:51:04	28.9	
24-Aug	10.9	0:47:38	0.54	

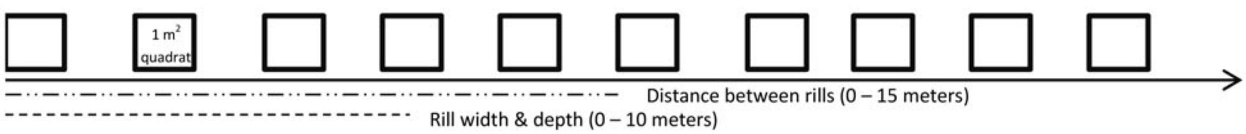

Figure 2—Transect sample design. Total number of rills were recorded for the length of transects and effective ground cover variables measured from quadrats.

Table 4— Distance between rills for the Horseshoe 2 Fire.

Transect	Number of rills (0.00- 15.0 m)	Distance between rills (m)	
		Range	Average
Treatment	14	0.1 to 3.85	0.83
	0	NA	NA
	0	NA	NA
	5	0.12 to 1.55	0.57
	7	0.5 to 5.75	2.00
	18	0.08 to 2.05	0.52
Control	0	NA	NA
	3	0.15 to 6.3	2.29
	0	NA	NA

Table 5— Rill density and cross-sectional area measurements for the Horseshoe 2 Fire.

Transect	Number of rills (0.00- 10 m)	Rill width (m)		Rill depth (m)	
		Range	Average	Range	Average
Treatment	9	0.15 to 0.7	0.31	0.005 to 0.04	0.02
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	5	0.07 to 0.12	0.10	0.005 to 0.03	0.02
	4	0.05 to 0.02	0.12	0.02 to 0.03	0.02
	11	0.09 to 0.6	0.28	0.005 to 0.06	0.02
Control	0	NA	NA	NA	NA
	3	0.3 to 1.3	0.67	0.03	0.03
	0	NA	NA	NA	NA

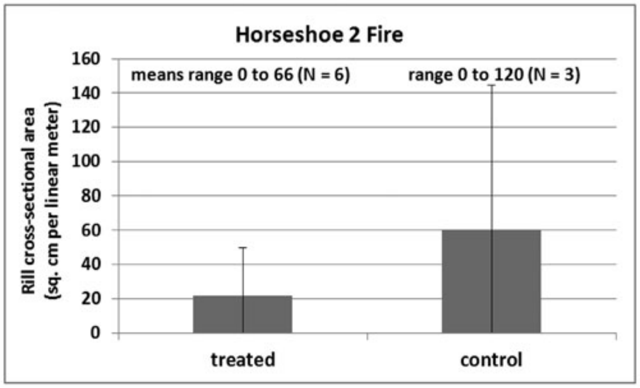

Figure 3—Horseshoe 2 average rill cross-sectional area with error bars for treatment and control samples.

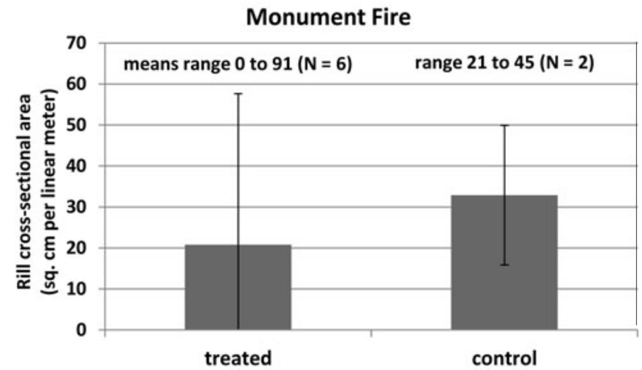

Figure 4—Monument Fire average rill cross-sectional area with error bars for treatment and control samples.

Table 6—Distance between rills for the Monument Fire.

Transect	Number of rills 0- 15 m	Distance between rills (m)	
		Range	Average
Treatment	15	0.04 - 6.3	0.68
	0	NA	NA
	0	NA	NA
	22	0.04 - 2.92	0.55
	0	28.35	NA
	0	NA	NA
	0	NA	NA
Control	19	0.09 - 2.95	0.69
	12	0.06 - 2.5	0.83

Table 7—Rill density and cross-sectional area measurements for the Monument Fire.

Transect	Number of rills 0- 10 m	Rill width (m)		Rill depth (m)	
		Range	Average	Range	Average
Treatment	11	0.08 - 0.48	0.26	0.015 - 0.06	0.03
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	8	0.05 - 0.39	0.2025	0.005 - 0.035	0.013
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
Control	11	0.07 - 0.24	0.13	0.0025 - 0.03	0.01
	10	0.11 - 0.65	0.32	0.005 - 0.03	0.019

severity was high. The highest and lowest *H. vulgare* cover on the Monument Fire were recorded where soil burn severity was moderate and vegetation burn severity was high. Four treatment transects on the Horseshoe 2 Fire and one treatment transect on the Monument Fire had an average of less than 20 individuals per quadrat. Average percent cover was less than 20% on all treatment transects.

Other vegetative cover was comprised primarily of native species. No invasive species were observed during data collection. The CFI of other vegetation was 10.0 for treatment and 4.8 for control transects on the Horseshoe 2 Fire and 6.3 for treatment and 2.5 for control transects on the Monument Fire. Non-vegetation effective ground cover was comprised of litter and rock with the addition of straw on the Monument Fire. Total non-vegetation effective ground cover CFI was 22.8 for all treatment transects combined and 11.5 for all control transects combined (table 9). The total number of straw clumps within 1 m of a treatment transect ranged from zero to eight on four of seven transects, indicating poor treatment application on some of the treatment areas. Non-vegetative ground cover for both fires had higher CFI for treatment and controls than overall vegetation CFI.

Seeding Success Criteria Evaluation

Treatments failed to meet success criteria for seed treatment application for both fires (table 10). Success criteria were based on monitoring methods of the Nuttall Complex on the Coronado National Forest (Johnson 2004) and Santiago Fire on the Cleveland National Forest (Wohlgemuth and others 2010).

Discussion

Both the Horseshoe 2 and Monument Fire burn areas experienced significant precipitation prior to hillslope treatment implementation. Following treatment implementation, the treated areas were exposed to numerous other storms. These precipitation events varied in intensity and location, and contributed to hillslope erosion before and after treatment implementation.

After initial data collection in September of 2011, 33% of seeded species (mostly *H. vulgare*) had established in treatment units in both burned areas. Although *Bouteloua gracilis* (blue grama) and *Pascopyrum smithii* (western wheatgrass) were absent from treatment transects, these species may yet emerge following 2011-2012 winter

Table 8—Horseshoe 2 Fire effective ground cover variables cover frequency index by sample type.

<table>
<tr><th colspan="2">EFG variable</th><th>Treatment</th><th>Control</th><th>Treatment</th><th>Control</th></tr>
<tr><td rowspan="3">Seeded species (treatment)</td><td>Hordeum vulgare</td><td>7.62</td><td>NA</td><td rowspan="4">21.64</td><td rowspan="4">4.85</td></tr>
<tr><td>Bouteloua gracilis</td><td>0</td><td>NA</td></tr>
<tr><td>Pascopyrum smithii</td><td>0</td><td>NA</td></tr>
<tr><td colspan="2">Other vegetation</td><td>10.02</td><td>4.85</td></tr>
<tr><td colspan="2">Litter</td><td>4.85</td><td>27.14</td><td rowspan="2">40.58</td><td rowspan="2">50.75</td></tr>
<tr><td colspan="2">Rock</td><td>32.49</td><td>23.26</td></tr>
</table>

Table 9—Monument Fire effective ground cover variables cover frequency index by sample type.

<table>
<tr><th colspan="2">EFG variable</th><th>Treatment</th><th>Control</th><th>Treatment</th><th>Control</th></tr>
<tr><td rowspan="3">Seeded species (treatment)</td><td>Hordeum vulgare</td><td>7.59</td><td>NA</td><td rowspan="4">6.46</td><td rowspan="4">2.54</td></tr>
<tr><td>Bouteloua gracilis</td><td>0</td><td>NA</td></tr>
<tr><td>Elymus trachycaulus</td><td>0</td><td>NA</td></tr>
<tr><td colspan="2">Other vegetation</td><td>6.26</td><td>2.54</td></tr>
<tr><td colspan="2">Straw</td><td>36.39</td><td>NA</td><td rowspan="3">22.78</td><td rowspan="3">11.54</td></tr>
<tr><td colspan="2">Litter</td><td>2.96</td><td>1.15</td></tr>
<tr><td colspan="2">Rock</td><td>32.34</td><td>50.35</td></tr>
</table>

Table 10—Seeding treatment success matrix.

<table>
<tr><th>Fire</th><th>Success criteria</th><th>Treatment transects meeting criteria (%)</th></tr>
<tr><td rowspan="3">Horseshoe 2</td><td>Average of 20 seeded individuals in quadrats</td><td>33</td></tr>
<tr><td>Seeded species CFI twice the overall vegetation CFI</td><td>33</td></tr>
<tr><td>Germination of all seeded species</td><td>0</td></tr>
<tr><td rowspan="3">Monument</td><td>20 seeded individuals in treatment quadrats</td><td>86</td></tr>
<tr><td>Seeded species CFI of twice the overall vegetation CFI</td><td>42</td></tr>
<tr><td>Germination of all seeded species</td><td>0</td></tr>
</table>

rains. Germination of seeded species was somewhat successful as only two of three seeded species were observed. Seeding slightly improved EGC on hillslope treatment units on both fires where seeds remained onsite following exposure to rainfall and slopes were moderate (closer to 40%). Overall treatment CFI was higher than controls and was attributed to both seeded and non-seeded species cover. Lack of consistently high emergence or high CFI of seeded species across treatment transects was attributed to seed mobilization during rainstorm events as high *H. vulgare* cover was observed on roads and in riparian areas downslope and downstream from treatment units in both burned areas (C. Gibson, personal observation). Agricultural straw mulch over seeding treatment on the Monument fire is assumed to have contributed to the higher average number of *H. vulgare* individuals because of higher number of individuals and more even distribution than observed in the Horseshoe 2 treatment quadrats (C. Gibson, personal observation). Site conditions such as steeper slopes (closer to 60%) and more concentrated runoff may have contributed to poor vigor and lower cover of *H. vulgare* in this burned area when compared to post-treatment conditions in the Horseshoe 2 burned area (C. Gibson, personal observation).

Rill densities were high and distance between rills low on several treatment transects. This may indicate that treatment implementation was not entirely effective at stabilizing soil and reducing hillslope erosion for either burned area. The timing of initial rill development, however, occurred during the first significant storms and prior to treatment. It is not possible to definitively say what effect treatments had on hillslope stabilization because rills were not measur ed prior to and after the treatments. Seeded species that established on the hillslopes appeared to provide some effective ground cover on upper and lower slopes. On the Horseshoe 2 Fire, rock and litter contributed more to total EGC than all vegetation combined. Rock was the overall highest contributor to EGC for treatment and control transects. Treatment transects had higher overall vegetative cover than control transects, but this is likely due to the high frequency and cover of other vegetation detected in frames of treatment transects and low total number of control transects. Although *H. vulgare* increased EGC, uniform establishment and healthy vigor was inconsistent among treatment transects. This was particularly evident on steep slopes and where soil burn severity was high as *H. vulgare* was seldom detected in these locations and lacked robust stature that would contribute to litter cover following senescence.

On the Monument Fire, the application of agricultural straw mulch over the seed treatment contributed to EGC and slope stabilization. When considering all treatment and control transects, hillslope seeding treatment failed to meet criteria for improving EGC and has not sufficiently mitigated hillslope erosion. However, agricultural straw mulch did improve overall EGC and appeared effective at reducing hillslope erosion where slopes were gentle to somewhat moderate. Overall non vegetative effective ground cover CFI for treatments was double that of controls, indicating agricultural straw mulch treatment was successful.

The low total number of samples and the variety of slope characteristics encountered where transects were established contributed to variable hillslope results. This is particularly evident by the range of rill densities measured on treatment and control transects. It is uncertain whether hillslope rill characteristics were the result of a particularly intense localized storm or hillslope-treatment failure since data were collected following several significant storms and monsoonal moisture is highly variable. Despite a clear reduction in rill dimensions, on average, there is no significant (statistical) difference between treatment and control. A higher sample size may show the trend to be valid, but a more precise estimate of the difference is necessary to assess treatment and cost effectiveness.

Conclusions and Recommendations

Published studies of the effectiveness of post-fire seeding treatments have occurred in southern California chaparral and in various conifer ecosystems of the western United States (Beyers 2004; Robichaud 2005). Mulching (60% cover or greater) has been shown as the most effective treatment for reducing erosion, especially when protection is needed from the first storms that occur after fire (Beyers 2004). Seeding is likely to provide effective control of erosion during the first year only a third of the time (Beyers 2004). The effectiveness of seeding in Arizona may be even less due to the intensity of rainfall during monsoonal storms. Moody and Martin (2009) showed post-fire sediment yields during the first 2 years following fire are strongly tied to rainfall intensity. Rainfall regimes based on the 2-year 30-minute rainfall intensity place southeastern Arizona into the 2 highest categories (Arizona High – Horseshoe 2 Fire, and Arizona Extreme – Monument Fire) for the entire western United States (Moody and Martin, 2009). It is common that rains occur prior to treatment implementation as seen on these fires because monsoon and wildfire season overlap in Arizona. Thus, it is essential to understand if hillslope treatments are effective for this area of the country.

Initial monitoring results show that mulching on the Monument Fire appeared to be effective in reducing rill development and hillslope erosion on gentle slopes (closer to 40%) but additional field data are needed to verify this. No evidence of wind dispersal was observed, however, poor application of straw (clumps) was observed. Implementation reports indicated some of the straw bales were not properly prepared for dispersal, which resulted in straw clumps.

Initial observations suggest that seeding does not appear to be effective in this environment especially if the objective is slope stabilization prior to first damaging storm event. To improve the current knowledge of appropriate hillslope treatments and seeding species for burned landscapes in southeastern Arizona, further data collection from transects established in September of 2011 is strongly recommended for the second and third year post-fire. In addition to data collection from the 2011 transects, establishment of additional treatment and control transects is highly recommended to provide sufficient information for comparison of treated and untreated areas within the Horseshoe 2 and Monument Fires. Additional transects of both treatment and controls will aide in identifying whether or not results are statistically significant. Measurements specific to slope degree and length will aide in identifying appropriate slope characteristics for future post-fire hillslope seeding and agricultural straw mulch treatments. This will also provide an opportunity to determine whether *Bouteloua gracilis*, *Elymus trachycaulus* or *Pascopyrum smithii* emerge in seeded sites. This is particularly important in the case of *P. smithii*, which is a rhizomatous grass that is capable of displacing native vegetation.

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