Assessing the Effectiveness of Seeding and Fertilization Treatments for Reducing Erosion Potential Following Severe Wildfires

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***Abstract**—Postfire slope stabilization treatments are often prescribed following high-severity wildfires on public lands to reduce erosion, maintain soil productivity, protect water quality, and reduce risks to human life and property. However, the effectiveness of slope stabilization treatments remains in question. For this study, tests were on effectiveness of seeding and fertilization treatments for increasing total live plant cover and reducing percent bare soil during the first 2 years following wildfire in dry mixed-conifer forests of north-central Washington State. Assessments were made on the effects of four seeding treatments (none, two perennial species mixes, and a winter wheat monoculture) and three fertilization levels (0, 50, and 100 lb N/acre) in factorial combination on percent bare ground, and plant cover using a generalized randomized complete block design at eight sites. Half of the sites also received aerially applied straw mulch. Surveys of vegetation responses during the first two summers following fire showed that seeding, fertilizing, and straw mulching all significantly influenced bare ground and/or live plant cover. Fertilizing alone increased mean live plant cover by 4 to 9 percent in 2005, and by 8 to 12 percent in 2006. Seeding alone increased mean live plant cover by only 1 to 2 percent in 2005 and 0 to 3 percent in 2006. Fertilizing and seeding together increased plant cover by up to 11 percent in 2005 and 20 percent in 2006 and reduced bare ground by up to 13 percent in 2005 and by 21 percent in 2006. Of the seeded species, two native perennial forbs, yarrow (*Achillea millifolium*) and fireweed (*Chamerion angustifolium*), contributed the most to total plant cover. Straw mulching increased litter cover by 10 to15 percent, but had little effect on live plant cover. Our results suggest that fertilization treatments can increase the effectiveness of seeding treatments and stimulate regrowth of surviving native vegetation following wildfires, particularly in forest types with understory vegetation dominated by species that resprout following fire. More work is needed to determine appropriate levels of fertilization and to better identify species and environmental factors that produce better results for seeding treatments.*

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Introduction

Controlling erosion and water runoff are important objectives for land managers following severe wildfires. High severity wildfires kill vegetation and consume surface organic matter, exposing mineral soils to increased erosion, particularly during intense rainfall events (DeBano and others 1998; Neary and others 2005; Wondzell and King 2003). Fires can also increase hydrophobicity in soils, thereby reducing water infiltration rates and increasing surface runoff, soil erosion, and sediment delivery to streams (Benavides-Solorio and MacDonald 2001; DeBano 2000). These fire-induced effects on soil erosion and water runoff typically diminish as vegetation recovers and replaces lost plant and litter cover (Benavides-Solorio and MacDonald 2001).

Although elevated levels of soil erosion and water runoff are natural ecosystem responses to severe wildfire, they can present unacceptable hazards to human health and property in lower parts of the affected watersheds. Increased sediment delivery to streams and/or loss of forest productivity may also be undesirable, even if human interests are not threatened, if fires are deemed uncharacteristically severe due to previous management activities (such as logging or fire suppression). To reduce erosion and flooding hazards and protect natural resources, land surface treatments are often applied on Federal forest and range lands following wildfires as part of burned area emergency response (BAER) or emergency stabilization and rehabilitation (ESR) efforts (Robichaud and others 2000).

Land surface treatments to reduce erosion and runoff can include seeding, fertilizing, and mulching. Seeding treatments seek to increase plant cover by promoting establishment of new plants, typically from fast-growing species and readily available seed stocks. Fertilization treatments seek to enhance growth and litter production of surviving and newly established plants by enhancing soil nutrient availability. Mulching seeks to directly replace surface organic matter while having little or no effect on vegetation recovery.

Annual costs for BAER/ESR land treatments have increased in recent years due to increased areas burned by high severity wildfires, increased postfire threats to human health and property due to expansion of the wildland-urban interface, and increasing use of costly mulching treatments. Despite escalating expenditures and widespread use, rigorous testing and monitoring of BAER rehabilitation treatments have seldom occurred (Robichaud and others 2000; Government Accountability Office 2003), making it more difficult for agencies to justify continued expenditures.

In this study, we used an experimental approach to examine the effects of seeding and fertilization treatments on plant cover and bare soil at eight sites within the Pot Peak Fire (2004) in the eastern Cascade Range of Washington State. The effects of mulching are also documented as mulch was operationally applied at half of the sites. Study objectives related to this report included:

1. Quantify the effects of seeding, fertilizing, and mulching on vascular plant cover and bare soil cover for 2 years following wildfire.
2. Assess differences among sites in rates of native vegetation recovery and treatment effectiveness after wildfire.

Methods

Study Site

The Pot Peak-Sisi Ridge wildfire complex burned 47,000 acres of coniferous forest along the southwestern shore of Lake Chelan in north-central Washington State during summer 2004. About 45 percent of the area burned was classified as moderate to high severity fire with respect to soil effects, and erosion hazards were considered high for about 90 percent of the total area burned due to combined effects of fire, topography, and soils. Much of the area burned by the Pot Peak Fire, which was the subject of this study, had previously burned in a large wildfire in 1970.

Forests within the Pot Peak Fire area are dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) at lower elevations and by lodgepole pine (*Pinus contorta*), Douglas-fir, and subalpine fir (*Abies lasiocarpa*) at higher elevations. Soils generally consist of volcanic ash and pumice deposited over colluvium or glacial till. The climate features warm, dry summers and cold, relatively wet winters. The majority of precipitation falls from October to March (much of it as snow), with occasional intense summer thunderstorms.

We selected eight study sites within areas of moderate and high fire severity, as identified by fire severity maps. The sites were well dispersed and represented a broad range of environmental settings (table 1). At each site, we identified a relatively uniform area of about 1 ha on which we established a grid of 96 study plots. Each plot was 4 m wide and 10 m long, with the long side oriented downslope. We left a 2-m wide untreated buffer between plots to reduce risks of across-plot contamination.

Table 1—Site characteristics for Pot Peak Study, including topographic setting (slope, aspect, and elevation), fire severity (soil effects), operational mulching treatment, mean total plant cover (percent) and shrub cover (percent) on untreated control plots.

Site	Slope (%)	Aspect (°)	Elevation (m)	Fire severity	Mulch†	Plant cover in 2005 (%)	Shrub cover in 2005 (%)
Hug me	35	280	1196	Moderate	No	40	27
Mouse	47	305	1221	High	Yes	9	9
Rainbow	57	360	1297	High	Yes	21	10
Stairway	45	325	1313	Moderate	No	14	13
Beast	68	90	1321	High	Yes	27	25
Big Tree	45	320	1380	High	Yes	3	2
Nice View	12	20	1393	Moderate	No	19	14
Squirrel	43	345	1507	High	No	7	5

† Denotes if mulch was operationally applied to the site.

Treatments

We tested the effects of four seeding treatments and three levels of fertilization in factorial combination on plant cover and bare soil at each site. Seeding treatments included a "warm" seed mix with three grasses and one forb species expected to do well in warmer and drier sites; a "cool" seed mix with two grasses and one forb species expected to do better on cooler and more moist sites; a monoculture of soft white winter wheat (Eltan) that is often prescribed as an operational treatment in this area; and a control treatment with no seeding (table 2). Most of the seeded species were natives (table 2), but local seed sources were not required. We designed the seeding treatments to provide an average of 60 seeds/ft^2 for the cool seed mix (20 seeds/ft^2/species) and the warm seed mix (15 seeds/ft^2/species), and an average of 15 seeds/ft^2 for the winter wheat treatment. By comparison, the local operational seeding treatment with winter wheat called for only six live seeds/ft^2. For the fertilization treatments, we applied an ammonium nitrate-ammonium sulfate (30-0-0-6) fertilizer mix at quantities calculated to provide 0, 50, or 100 lb of nitrogen per acre. The local operational treatment called for fertilizing at a rate of 50 lb N/ft^2. We applied both seed and fertilizer with a hand-held Whirlybird spreader, attempting to produce a relatively uniform application rate. Treatments were applied shortly after snowmelt in the spring following the wildfire.

Table 2—Seeded species information for the Pot Peak Study.

Scientific name	Seed mix	Common name	Lifeform	Origin
Achillea millefolium	Warm	common yarrow	Forb	Native
Chamerion angustifolium	Cool	fireweed	Forb	Native
Elymus lanceolatus	Cool	thick-spike wheatgrass	Grass	Native
Elymus wawawaiensis	Warm	Snake River Wheatgrass	Grass	Native
*Festuca idahoensis**	Cool	Idaho fescue	Grass	Native
*Festuca ovina**	Warm	sheep fescue	Grass	Exotic
*Poa secunda**	Warm	Sandberg bluegrass	Grass	Native
Triticum aestivum	Wheat	common wheat	Grass	Exotic

*Due to difficulties in identification of young plants, *Festuca* and *Poa* species were identified to genera only

In addition to the experimental treatments, four of the sites received aerial application of wheat straw mulch as part of a larger BAER treatment. Contractors applied the mulch by dropping loose bales of straw from helicopters in the fall (shortly after the wildfire) and spring. Although mulching was not an experimentally applied treatment, we made use of spatial heterogeneity in straw cover and depth to evaluate its effectiveness for reducing bare soil cover and its potential effects on vegetation recovery and vegetation responses to seeding and fertilization treatments.

Experimental Design

We used a generalized randomized block design for the study. We randomly assigned treatments in factorial combination so that each possible combination of fertilization and seeding treatments would be replicated eight times per site. Implementation errors on three sites led to as many as 10 replicates or as few as seven replicates for some treatment combinations; however, we still replicated each fertilization treatment 32 times and each seeding treatment 24 times on each site.

Data Collection and Summary

We collected plot data during midsummer (July to August) in 2005 and 2006, when total live plant cover was near its annual maximum. At each plot, we estimated relative cover for each plant species present, as well as cover of bare ground (soil), litter, mulch (straw), woody debris (10 hour fuels and larger), cryptogams, and rock for portions of the plot not covered by live vascular plants so that total cover summed to 100 percent. All cover estimates were based on visual assessment of what a raindrop would hit if falling straight down. In the case of overlapping vegetation, cover was attributed to the taller species. Similarly, plant cover took precedence over litter and so on. We estimated cover values to the nearest whole percent for values over 0.5 percent, and recorded values less than 0.5 percent as "trace" amounts (using a constant value of 0.2 percent cover for subsequent analyses). We summed species cover values to obtain total plant cover for each plot.

Statistical Analyses

Prior to analysis, we chose a Type I error rate of 10 percent ($P < 0.10$) as an acceptable threshold for statistical significance. We accepted a higher error rate than is traditional because we believe that managers are primarily interested in estimated effect sizes and would likely accept a higher false-positive error rate if the potential treatment benefit is high.

We analyzed the effects of seeding, fertilizing, and mulching on bare soil and total plant cover in 2005 and 2006 using mixed statistical models (SAS PROC MIXED, Littell and others 1996). We included the seeding treatment, fertilization treatment, and their interactions as categorical fixed factors in the statistical model, and mulch cover (as measured in 2005) as a continuous covariate. Because plots were measured in two consecutive years, we included "year" as a binary time variable, coding 2005 observations as zero and 2006 observations as one. We also included year-by-treatment interaction terms in the model to test for differences in seeding and fertilization effects between 2005 and 2006. We included "site" and site-by-treatment interactions as random effects at the site level, where at least marginally significant ($P < 0.10$), to test for site effects on mean plant cover (or bare soil) and/or treatment effects. We also included the plot (within site) as a random effect to account for correlations among the repeated measurements. Plant cover data required the use of a square-root transformation to normalize model residuals.

Results

Fertilization significantly increased mean live vascular plant cover during the first two growing seasons following the 2004 Pot Peak wildfire. On untreated control plots, plant cover averaged 15 percent in the first year and 27 percent in the second year. Fertilization alone increased mean plant cover in the first year from 15 percent on controls to 19 percent at 50 lb N/acre and to 24 percent at 100 lb N/acre (fig. 1). During the second year following fire, fertilization increased mean plant cover from 27 percent on untreated control plots to 34 percent on plots receiving 50 lb N/acre and 39 percent on plots receiving 100 lb N/acre (fig. 1). First year fertilization effects were maintained into the second year, but there was no consistent evidence for additional fertilization effects in the second year; there was, however, considerable variability among sites in this regard (see below).

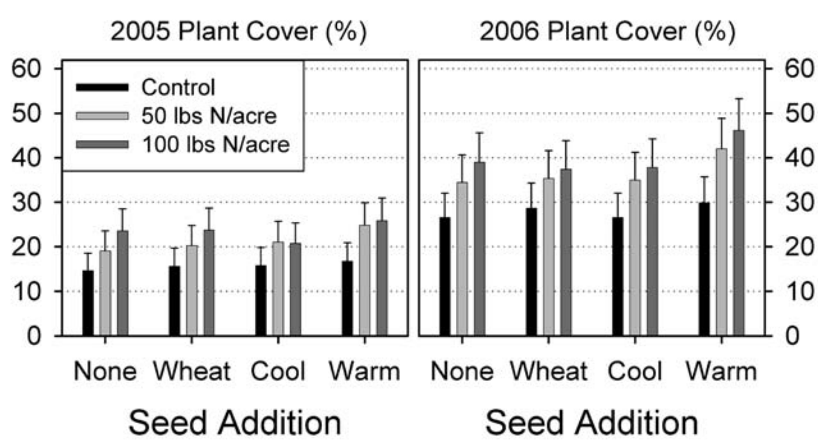

Figure 1—Effects of seeding and fertilization, and their interaction on live plant cover during the first two growing seasons following wildfire (2005 and 2006). Error bars indicate standard errors for the estimated treatment means.

Seeding treatments also increased live vascular plant cover, but the effects were relatively small. Without fertilization, mean plant cover in the first year increased from 15 percent on unseeded controls to 16 percent on plots receiving the winter wheat or cool seed mix and to 17 percent on plots receiving the warm seed mix (fig. 1). In the second year, plant cover averaged 27 percent on untreated controls and plots receiving the cool species mix, 29 percent on plots receiving the wheat seed, and 30 percent on plots receiving the warm species mix (fig. 1).

The most effective treatment combination included seeding with the warm species mix and fertilizing with 100 lb N/acre; it produced a net increase in mean plant cover of 11 percent in 2005 and 21 percent in 2006 (fig. 1). Interactions between the seeding and fertilization treatments were statistically insignificant, indicating that treatment effects on live plant cover could be treated as being additive.

By increasing live plant cover, fertilization and seeding reduced percent cover of bare soil during the first 2 years following fire (2005 and 2006). For plots without active seeding, fertilization reduced average percent bare soil in the first year from 76 percent on unfertilized plots to 71 percent on plots receiving 50 lb N/acre and to 66 percent on plots receiving 100 lb N/acre (fig. 2). In the second year, fertilization reduced bare soil from 56 percent on unfertilized plots to 44 and 39 percent at 50 and 100 lb N/acre, respectively. Unlike plant cover, fertilization produced an additional effect on bare soil in the second year after fire, as indicated by a significant year-fertilization interaction (table 3). Both active fertilization treatments produced an additional net reduction of about 7 percent bare soil in the second year, relative to controls.

As with live plant cover, seeding treatments produced only a small reduction in bare soil in the first year after fire, and no significant additional effect in the second year after fire. Individually, seeded species varied considerably in their effectiveness, although most added little cover. Of all the seeded species, yarrow (*Achillea millifolium*) appeared to be the most effective for increasing plant cover and reducing bare soil. Statistical tests found no evidence for any significant interactions between seeding and fertilization treatments.

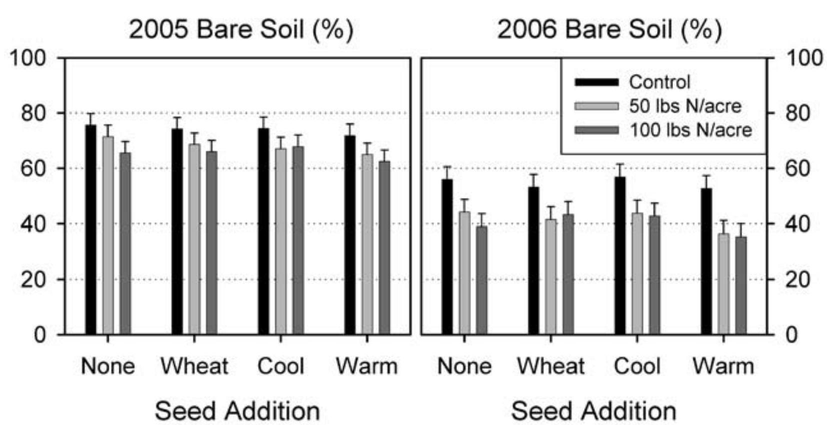

Figure 2—Effect of seeding and fertilization, and their interaction on bare soil cover during the first two growing seasons following wildfire. Error bars indicate standard error for the estimated treatment means.

Table 3—Type 3 tests of significance tests for fixed effects in mixed model analysis of treatment effects on live vascular plant cover.

Fixed effects	Num DF	Den. DF	F-value	Pr. > F
Live vascular plant cover:				
Seeding	3	1168	6.57	**0.000**
Fertilizing	2	15	29.98	**0.000**
Seeding x Fertilizing	6	1168	1.59	0.147
Year	1	7	99.09	**0.000**
Year x Seeding	3	736	1.37	0.251
Year x Fertilizing	2	15	0.67	0.526
Year x Seeding x Fertilizing	6	736	1.62	0.140
Mulching	1	1177	3.01	**0.083**
Year x Mulching	1	743	2.22	0.137
Bare soil cover:				
Seeding	3	1257	4.28	**0.005**
Fertilizing	2	1257	30.42	**0.000**
Seeding x Fertilizing	6	1257	0.75	0.609
Year	1	7	192.81	**0.000**
Year x Seeding	3	33	1.16	0.339
Year x Fertilizing	2	17	5.80	**0.012**
Year x Seeding x Fertilizing	6	717	1.03	0.403
Mulching	1	1246	616.10	**0.000**
Year x Mulching	1	703	117.32	**0.000**

Mulching reduced bare soil cover by 10 to 15 percent in the first year after fire on the four sites receiving the operational mulching treatment. Vegetation cover increased slightly with increasing mulch cover in the first year after fire ($P = 0.083$) but was not affected by mulching the following year.

Site factors significantly influenced first year live plant cover and second year fertilization effects. First year live plant cover varied from 4 to 37 percent and mean bare soil cover varied from 57 to 91 percent (table 1). Fertilization treatment effects on bare soil did not vary significantly among sites in the first year ($P > 0.10$) but did vary significantly in the second year ($P = 0.02$). From 2005 to 2006, reductions in bare soil on unseeded plots ranged 12 to 26 percent at 0 lb N/acre, 21 to 33 percent at 50 lb N/acre and 16 to 31 percent at 100 lb N/acre. Seeding treatment effectiveness did not vary significantly among sites.

Discussion

Fertilization Effects

We found that fertilization accelerated the development of live plant cover following severe wildfire, thereby reducing bare soil cover and, presumably, water runoff and soil erosion. Fertilization effects varied with treatment intensity (0 to 100 lb N/acre), with the 100 lb N/acre treatment increasing plant cover more than the 50 lb N/acre treatment. This indicates that soil N availability was at least partially limiting native vegetation recovery after the Pot Peak wildfire and suggests that higher levels of fertilization may have produced even larger increases in plant cover.

We expected fertilization effects to be greatest on sites with high densities (or cover) of sprouting shrubs and other fire-adapted species that could rapidly take up and use the additional nutrients. However, we found no evidence to support this notion. Fertilization effects were not significantly correlated with first-year plant cover or bare soil, suggesting that plant uptake capacity did not limit the effectiveness of the fertilization treatments, at least on these sites and at these fertilization levels. With only eight sites, however, our power to detect site differences in treatment effects was limited, and there was some evidence to suggest that fertilization effects declined somewhat at higher levels of plant cover.

Fertilization as an erosion control treatment has received little study, and, where it has been studied, results have been mixed (Robichaud and others 2000). In the Interior Pacific Northwest, Klock and others (1975) reported that fertilization increased establishment and cover of species seeded for erosion control. More recently, Robichaud and others (2006) found that fertilization increased total plant cover after the North 25 Fire (close to our study site), with plant cover on fertilized plots being 8 percent higher during the first year after fire and 13 percent higher during the second year, though these effects were not judged to be statistically significant. In Colorado, nutrients applied after wildfire in the form of biosolids also increased plant cover and biomass (Meyer and others 2004).

Results from this study suggest that fertilization could be an effective method for accelerating development of live plant and litter cover and reducing erosion hazards following wildfires. Further study is needed to test the possible additional benefits of higher levels of nitrogen addition, and to test the potential benefits of adding other nutrients, such as phosphorous and potassium. Implementation on sites with diverse soil, climate, and vegetation characteristics would also be helpful to assess the consistency of fertilization effects.

Seeding Effects

Compared to natural vegetation recovery and fertilizer effects, seeding treatment effects on live plant cover and bare soil were small. Some other studies have found seeding to be ineffective at increasing ground cover or reducing erosion (Wagenbrenner and others 2006; Robichaud and others 2006). Yet, there are also examples where seeding has produced larger amounts of cover after wildfire, even to the point of negatively affecting recovery of native vegetation (Beyers 2004; Keeley 2004; Schoennagel and Waller 1999).

Developing a better understanding of the causes of this variability in seeding success is important if seeding is to continue as a land surface treatment. Some variability may be due to uncontrollable variables such as year-to-year variability in precipitation and soil moisture. However, more consistent results may also be attained if seeded species were better matched with biophysical environments or, perhaps, if seeding were restricted to environments where it is generally successful. In this study, yarrow provided greater benefits than winter wheat, the normally prescribed seeding treatment. Is this because yarrow is better adapted to the biophysical settings, established better on burned soils, produced faster initial growth, was less susceptible to seed predation, or all of the above? The answer is unclear. However, further study appears warranted to identify species for seeding that perform consistently well, or to better match seeded species to the environments in which they can be expected to perform well. It will also be important to address questions about tradeoffs between the practical advantages of seeding highly available nonnative species and possible biodiversity benefits of seeding native species (from either local or distant seed sources).

Mulching Effects

Mulching was effective at reducing bare soil cover during the first year after fire, as has been documented previously (Robichaud and others 2000). Our analysis indicated that mulching reduced bare soil cover at a rate that slightly exceeded the rate of mulch application, perhaps due to germination and growth of residual wheat seed in the straw. A potential problem with mulching is that it may affect long-term vegetation recovery by introducing exotic species (Kruse and others 2004) or interfering with plant establishment (Robichaud and others 2000). We found no evidence that mulching reduced live plant cover in either year. However, mulch cover was low overall in this study (less than 15 percent average cover on mulched sites) and may have been below the threshold needed to influence plant cover. We have not yet examined possible mulching effects on plant community composition or exotic species.

Site Variability

In the absence of treatments, first year plant cover is determined by prefire plant cover and fire severity (in terms of mortality). In this study, first year plant cover was highly dependent on sprouting shrubs and, on one site, grasses. Understory plant cover generally declined with increasing elevation, probably because lower elevation sites had lower overstory canopy densities that supported higher understory plant cover and biomass before the fire. Low elevation plant communities may also be better able to survive wildfires. Causes for variability in site responses to fertilization are not yet clear but are certainly of interest. We are hopeful that clearer patterns of variation in treatment effectiveness will emerge in the future as results from similar studies on other wildfire areas become available.

Conclusions

Fertilization is a potentially effective treatment for increasing plant cover and reducing bare soil during the first 2 years following wildfire, but more work is needed to determine optimal application rates, formulations, and variability in effectiveness across a range of climates, fire severities, and soil and vegetation types. Seeding was not very effective in this study, suggesting that it may not be the best choice for erosion control in this area. The performance of yarrow, however, suggests that seeding effectiveness may be improved by choosing different species or species mixtures for seeding. Mulching significantly reduced bare soil cover, but it is not clear whether the reductions in erosion risk were large enough to justify the high application costs and elevated risks of exotic species introduction.

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