Fertilization and Seeding Effects on Vegetative Cover After Wildfire in North-Central Washington State

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Abstract: Land surface treatments are often applied after severe wildfires to mitigate runoff and erosion threats. However, questions remain about treatment effectiveness, even as treatment costs continue to rise. We experimentally evaluated the effects of seeding and fertilization treatments on vegetative and total soil cover for two growing seasons after the Pot Peak wildfire in the eastern Cascade Mountains. Without treatments, vegetative cover averaged 15% the first year and 27% the second year after wildfire. Fertilization significantly increased vascular plant cover and reduced bare soil area in both years, but differences between low and high fertilization levels were not significant. Fertilization also increased cryptogam cover. Seeding alone was generally ineffective; however, the combination of fertilization with a seed mixture containing the native forb, yarrow (*Achillea millefolium* L.), produced the highest vascular plant cover and lowest bare soil area. Our results suggest that fertilization may be more effective than seeding, probably providing a degree of protection from erosion, especially the second year after fire. However, treatment effectiveness must be evaluated in context against costs and potential ecosystem impacts. FOR. SCI. 55(6):494–502.

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EVALUATING AND LIMITING soil erosion and flooding hazards are important watershed management objectives after high-severity wildfires in many forests and rangelands. High-severity wildfires kill vegetation and consume surface organic matter, exposing mineral soils to increased erosion (DeBano et al. 1998, Wondzell and King 2003, Neary et al. 2005). Wildfires can also increase soil water repellency, reduce infiltration rates, and increase rates of water and sediment delivery to streams (DeBano 2000, Benavides-Solorio and MacDonald 2001, Ice et al. 2004). Wildfire effects on runoff and soil erosion typically diminish as vegetation recovery replaces live plant and litter cover (Benavides-Solorio and MacDonald 2001), a process that can take from a few months to several years or more depending on vegetation type and fire severity (Wright and Bailey 1982). Although elevated levels of runoff and soil erosion are natural consequences of severe wildfires, they often present hazards to human health and property, particularly when fires occur in or near the wildland-urban interface.

To reduce erosion and flooding hazards and protect natural resources, managers of federal forest and range lands in the United States often prescribe land surface treatments as part of the burned area emergency response (BAER) process (Robichaud et al. 2000). Land surface treatments are designed to reduce rainfall runoff and soil erosion and 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 the growth and litter production of surviving and newly establishing plants by enhancing soil nutrient availability. Mulching seeks to directly replace surface organic matter. In all cases, treatments are expected to reduce flooding and erosion hazards without significantly retarding native vegetation recovery.

Annual costs for BAER land surface treatments have risen in recent years as a result of an increase in areas burned by high-severity wildfires, increased postfire threats to human health and property due to expansion of the wildland-urban interface (Hammer et al. 2007), and increasing use of costly mulching treatments. As costs have risen, pressure has increased to assess the effectiveness of current treatments, limit treatment application to areas of greatest need, and explore alternative land treatments that provide greater effectiveness and/or reduced costs. Recent studies have reported that rigorous testing and monitoring of BAER treatments has seldom occurred (Robichaud et al. 2000, US Government Accountability Office 2003), making it more difficult for agencies to justify continued expenditures.

For this study, we used a field experiment to examine the effects of four seeding treatments and three fertilization levels on the development of organic soil cover after the 2004 Pot Peak wildfire in north-central Washington State. We also assessed mulching effects at four of eight study

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sites where mulch was applied operationally during the BAER process. We sought to address the following questions:

1. How effective are seeding and fertilization treatments, alone and in combination, for accelerating the development of organic soil cover (live plants and plant litter) after severe wildfires?
2. How much do fertilization effects vary with application levels?
3. Which seeded plant species produced the most soil cover?
4. Did mulching alter seeding and fertilization effects or live plant cover?

To answer these questions, we examined treatment effects on four response variables: seeded species cover, total vascular plant cover, relative cover of cryptogams, and exposed bare soil.

Methods

Study Area

We conducted the study within the perimeter of the 2004 Pot Peak wildfire, part of the Pot Peak-Sisi Ridge wildfire complex, which burned over 19,000 ha along the southwest shore of Lake Chelan in north-central Washington State, USA (47°55′N, 120°20′W). Approximately 45% of the area burned in stand-replacing wildfire with significant soil heating. Postfire assessments concluded that soil erosion hazards were high for much of the study area because of the combined factors of high fire severity, steep topography, and erodible soils. Much of the study area had previously burned in a large, mixed-severity wildfire in 1970.

Vegetation and climate within the study area were typical of dry coniferous forests in much of the eastern Cascade Mountains region. Lower elevations supported dry coniferous forests dominated by ponderosa pine (*Pinus ponderosa* C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* (Mirbel] Franco), whereas higher elevations supported mixed-conifer forests dominated by lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Douglas-fir, and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). The climate features warm, dry summers and cold, relatively wet winters. Based on climate data from the nearby Entiat Experimental Forest (5–8 km to the southwest), we estimated mean annual precipitation within the study area to be 45–55 cm/year, with much of the precipitation falling as snow during the winter.

Soils in the study area are mostly gravelly sandy loams of the Palmich series (Natural Resources Conservation Service 2009). The parent material for these soils consists of volcanic ash and pumice deposited over colluvium or glacial till derived from granodiorite or rhyolite. Analysis of soil samples obtained after the wildfire and before treatment (five per site, 0–10 cm depth) indicated that soil bulk density averaged 0.83 g/cm^3, with 78% fine particles (<2 mm) on a mass basis (Table 1). Soil organic matter averaged 3.7% and soil pH averaged 6.85 (Table 1). Severe wildfires can significantly reduce total soil nitrogen in these soils through volatilization and ash convection (Grier 1975, Bormann et al. 2008). Soils in this region also appear to be sulfur deficient (Klock et al. 1971).

Within the study area, we selected eight sites that had burned in stand-replacing wildfire and for which wildfire effects were classified as moderate or high severity based on burned area reflectance classification maps produced by the US Forest Service and visual inspection of postfire soils. We selected sites that were broadly dispersed and represented a wide range of environmental settings within the wildfire (Table 1). At each site, we identified a relatively uniform area of about 1 ha and established a grid of 96 study plots. Plots were 4 m wide and 10 m long, with the long side oriented down-slope. We left 2-m wide untreated buffers between plots to reduce risks of cross-plot contamination.

Study Design and Treatments

We tested the effects of seeding and fertilizing on plant cover and bare soil by applying four seeding treatments and three levels of fertilization in factorial combination at each site in the spring following the wildfire (April–May 2005). We used a generalized randomized block design for the study (Hinkelmann and Kempthorne 1994). At each site, we randomly assigned seeding and fertilization treatments to plots in factorial combination so that each of the 12 unique treatment combinations would be replicated eight times. Treatment application errors on three sites led to as many as 10 replicates and as few as 7 replicates for some treatment combinations; however, we still replicated each fertilization

Table 1. Study site descriptions, including topographic position (slope, aspect, elevation), fire severity rating, soil properties (means based on five samples per site), mulching status, and mean plant and shrub cover on controls during the first year after wildfire

Site	Slope (%)	Aspect (°)	Elev. (m)	Fire severity	Soil bulk density (g/cm^3)	Soil fraction <2 mm (%)	Soil pH	Soil organic matter (%)	Mulch applied (yes/no)	Plant cover, 2005 (%)	Shrub cover, 2005 (%)
Hug Me	35	280	1196	Med.	0.87	67.7	6.8	3.5	No	40	27
Mouse	47	305	1221	High	0.80	79.4	6.8	3.8	Yes	9	9
Rainbow	57	360	1297	High	0.80	83.8	6.6	4.4	Yes	21	10
Stairway	45	325	1313	Med.	0.84	91.0	7.1	3.5	No	14	13
Beast	68	90	1321	High	0.87	79.9	6.9	4.0	Yes	27	25
Big Tree	45	320	1380	High	0.81	45.6	6.8	3.4	Yes	3	2
Nice View	12	20	1393	Med	0.85	88.6	7.1	3.4	No	19	14
Squirrelly	43	345	1507	High	0.80	87.2	6.7	3.8	No	7	5

treatment 32 times and each seeding treatment 24 times per site.

Seeding treatments included a monoculture of soft white winter wheat (Eltan; *Triticum aestivum* L.) that is often prescribed for operational seeding treatments in this area: a "warm" seed mix with three grasses and one forb species expected to do well on warmer and drier sites, a "cool" seed mix with two grasses and one forb species expected to do better on cooler and more mesic sites, and a control treatment with no seeding (Table 2). Most seeded species were natives (Table 2), and the seeds were purchased from local vendors, but seeds were not necessarily collected from local populations. We designed the warm and cool mix seeding treatments to provide 645 seeds/m^2, and the winter wheat treatment to provide 161 seeds/m^2 (due to larger seed mass). For the fertilization treatments, we applied an ammonium nitrate-ammonium sulfate (30-0-0-6) fertilizer mixture at quantities calculated to provide 0, 56, or 112 kg of nitrogen/ha. We applied seed and fertilizer with a handheld Whirlybird spreader, attempting to produce a relatively uniform application rate within each plot.

In addition to the experimental treatments, four sites received aerial application of wheat straw mulch as part of operational erosion control efforts. Contractors applied straw mulch by dropping loose bales of straw from helicopters during the fall and spring immediately after the wildfire; in most cases, mulching was complete before we applied our experimental treatments. Although mulching was not an experimentally applied treatment, we surveyed straw cover on all plots on the treated sites to assess the amount of soil cover produced and the potential effects of mulch on vegetation responses to seeding and fertilization treatments.

Data Collection and Analysis

We surveyed plant cover during midsummer (July–August) in 2005 and 2006, when live plant cover was near its annual peak. At each plot, we estimated relative cover for each vascular plant species. We first visually estimated cover values for each plant species to the nearest percent using templates as visual guides (e.g., 1% cover). We recorded values less than 0.5% as "trace" amounts, using a constant value of 0.2% cover for subsequent analyses. We then summed individual species cover values to get total plant cover for each plot. We also estimated cover of bare soil, litter, straw mulch, woody debris (10-hour fuels and larger), cryptogams, and rock for portions of the plot not covered by live vascular plants, so that cover values summed to 100%.

We analyzed the effects of seeding, fertilizing, and mulching on seeded species cover, vascular plant cover, cryptogam cover, and bare soil using mixed-effects analysis of covariance (SAS PROC MIXED; Littell et al. 2006). Vascular plant cover values required square root transformations to normalize model residual errors, whereas seeded species and cryptogam cover values required a logarithmic transformation. We included the seeding treatment, fertilization treatment, and their interactions as categorical fixed factors in all statistical models. Because plots were measured in 2 consecutive years, we included "year" as a categorical time variable. We also included year-by-treatment interaction terms in all models to test for differences in seeding and fertilization effects between 2005 and 2006. We set a type I error rate of 5% ($\alpha = 0.05$) as our threshold for statistical significance. We included site (blocking factor) and site-by-treatment interactions as random effects in the model where significant ($P < 0.05$) to account for within-site similarities in plant cover values and possible site influences on treatment effects. We also included the individual plot (within a site) as a random effect to account for positive correlations among repeated measurements on the same plot. We used multiple comparison tests on pairs of least square means and linear combinations of least square means to make comparisons among individual seeding and fertilization treatments when treatment main effects or interactions were found to be significant.

To assess the effects of mulching on response variables and treatment effects, we included mulch cover as a potential continuous covariate in the models, along with mulch-year, mulch-seed, and mulch-fertilization interaction terms. Mulch cover values were transformed using the same transformation as the response variable for each model to avoid producing artificial nonlinear relationships between the mulch covariate and response variables. The mulch covariate and associated interaction terms were removed using a backward elimination procedure until all remaining mulch-related model predictors were statistically significant ($P < 0.05$).

Results

Seeded Species Cover

Seeded species cover on control plots averaged 1.6% in the first year and 2.5% in the second year across all sites. Seeded species cover on control plots consisted primarily of fireweed (*Chamerion angustifolium* [L.] Holub) and common yarrow (*Achillea millefolium* L.), with smaller (often

Table 2. Species composition of seed mixes (warm, cool, and wheat) used in seeding treatments

Seed mix	Species name	Common name	Life form	Origin
Warm	*Achillea millefolium*	Common yarrow	Forb	Native
	Elymus wawawaiensis	Snake River wheatgrass	Grass	Native
	Festuca ovina	Sheep fescue	Grass	Exotic
	Poa secunda	Sandberg bluegrass	Grass	Native
Cool	*Chamerion angustifolium*	Fireweed	Forb	Native
	Elymus lanceolatus	Thick-spike wheatgrass	Grass	Native
	Festuca idahoensis	Idaho fescue	Grass	Native
Wheat	*Triticum aestivum*	Common wheat	Grass	Exotic

trace) amounts of two grass species that could only be identified with confidence to the genus level (*Poa* L. and *Festuca* L.) because of small plant sizes. Wheat (*Triticum aestivum*) was also found across all seeding treatments, particularly on mulched sites where residual seed heads were often present in the wheat straw.

Fertilization and seeding treatments and their interactions significantly influenced seeded species cover (Table 3). The combinations of the warm seed mix and fertilization at either the low or high level produced significantly higher seeded species cover in both years than any other treatment combinations, increasing seeded species cover by approximately 4% the first year and 8–10% the second year compared with other seeding treatments with fertilization (Figure 1). Fertilization increased seeded species cover compared with no fertilization for all combinations of year and seeding treatments, except for the wheat seeding treatment in the second year after fire. However, effects produced by the high and low fertilization levels were not significantly different compared across seeding treatments and years. Seeding without fertilization did not significantly influence seeded species cover in the first year, and only the warm species mix produced significantly more seeded species cover than controls in the second year (Figure 1).

Among the seeded species, the two perennial forbs produced the most cover. Common yarrow (*Achillea millefolium*) was by far the most successful seeded species, with cover on plots seeded with the warm mix greatly exceeding that on other plots in both years (Figure 2). Fireweed cover was also relatively high in both years but was not significantly influenced by seeding (Figure 2). The remaining seeded species produced less than 1% additional soil cover on average in either year (Figure 2).

Table 3. Type III tests of fixed effects from mixed-model analyses of seeding and fertilization treatment effects on seeded species and total plant cover

Response variable	Treatment effect	*P*
Seeded species cover	Seed	<0.001
	Fertilizer	<0.001
	Seed-by-fertilizer	<0.001
	Year	0.16
	Seed-by-year	<0.001
	Fertilizer-by-year	0.69
	Seed-by-fertilizer-by-year	<0.001
	Straw	0.001
Vascular plant cover	Seed	<0.001
	Fertilizer	<0.001
	Seed-by-fertilizer	0.24
	Year	<0.001
	Seed-by-year	0.27
	Fertilizer-by-year	0.64
	Seed-by-fertilizer-by-year	0.11
	Straw-by-fertilizer	0.02
Cryptogam cover	Seed	0.69
	Fertilizer	0.004
	Seed-by-fertilizer	0.63
	Year	<0.001
	Seed-by-year	0.31
	Fertilizer-by-year	0.06
	Seed-by-fertilizer-by-year	0.31
	Straw-by-fertilizer	<0.001
	Straw-by-year	<0.001
Bare soil area	Seed	<0.001
	Fertilizer	<0.001
	Seed-by-fertilizer	0.38
	Year	<0.001
	Seed-by-year	0.19
	Fertilizer-by-year	0.02
	Seed-by-fertilizer-by-year	0.29
	Straw	<0.001

Vascular Plant Cover

Total vascular plant cover was generally low during the first two growing seasons after the Pot Peak wildfire but was also highly variable among sites. On untreated control plots, vascular plant cover averaged 15% in the first year (Figure 3), with site means ranging from 4 to 39%. Second year plant cover averaged 27% on control plots, with site means ranging from 11 to 57%.

Seeding and fertilization treatments both significantly influenced vascular plant cover, but there were no statistically significant interactive effects among treatments (Table 3). Fertilization significantly increased vascular plant cover compared with no fertilization in both years, but the effects of low and high fertilization levels on plant cover were not significantly different. Fertilization treatment effects varied significantly among sites as indicated by a significant interaction between site (random variable) and fertilization treatment ($P < 0.001$); however, this random variability among sites was not correlated with the mapped fire severity classification. Seeding with the warm seed mix significantly increased live vascular plant cover compared with the other seeding treatments (Figure 3). However, the wheat and cool mix seeding treatments did not significantly alter vascular plant cover.

Cryptogam Cover

Cryptogam cover responded to fertilization but not to seeding (Table 3). Cryptogam cover averaged only 0.5% on control plots in the first year after the fire, increasing to 3% in the second year (Figure 4). Fertilization increased average cover of cryptogams to approximately 1.5% in the first year and 8% in the second year (Figure 4), with no significant difference in treatment effects between the low and high fertilization levels.

Bare Soil Area

As with vascular plants, bare soil area varied considerably among sites. Bare soil area on control plots averaged 75% the first year (Figure 5), with site means varying from 59 to 89%. Bare soil area on control plots declined by an average of 19% from the first to second growing seasons, with site means declining 10 to 30%.

Fertilization and seeding both significantly influenced bare soil area (Table 3). The warm seed mix treatment reduced bare soil area significantly more than the other seeding treatments. Likewise, fertilization reduced bare soil area significantly compared with no fertilization, but effects of the high fertilization level did not differ significantly from those of the low fertilization level (averaged across all seeding treatments). In the absence of seeding, fertilization

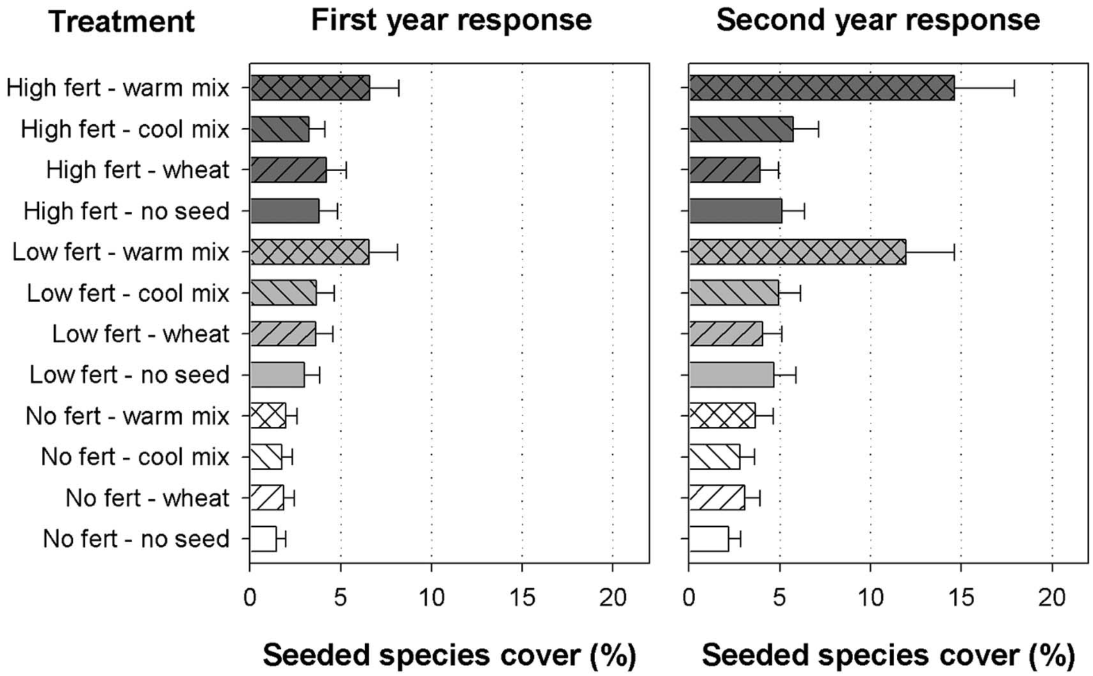

Figure 1. Fertilization and seeding treatment effects on seeded species cover in the first and second years after wildfire as estimated by model least-squares means estimated at 0% mulch cover. Treatment labels indicate the fertilization level (none, low, or high fert) followed by the seeding treatment (no seed, wheat, cool mix, or warm mix). Bar shading indicates fertilization levels, and crosshatching indicates seeding treatment. Error bars indicate standard errors.

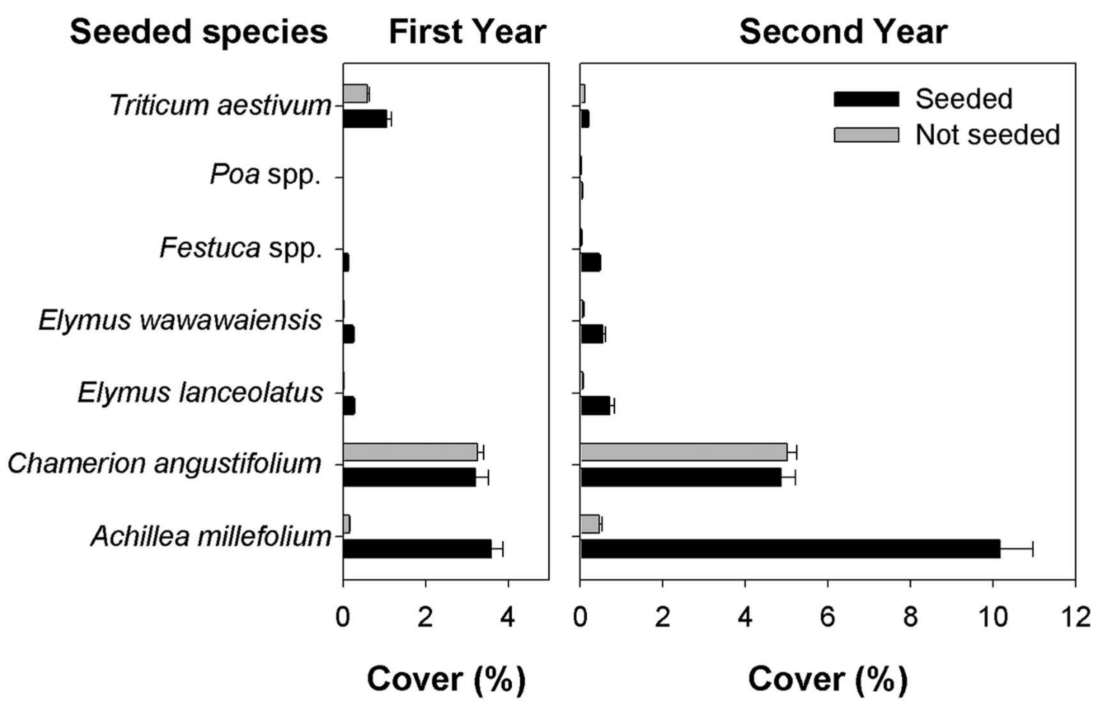

Figure 2. Comparison of mean seeded species cover on plots where species were seeded (24–48 plots/site) and not seeded (48–72 plots/site). Error bars indicate standard errors of arithmetic means.

reduced bare soil area in the first year by an average of 10% at the high application level and 4% at the lower application level (Figure 5). In the second growing season, fertilization without seeding reduced bare soil area by an additional 7% at the high level and by 8% at the low level (Table 3; Figure 5).

Mulching Effects

For sites receiving the operational mulching treatment, mulch cover averaged 10.4%, with 95% of plot cover estimates falling within the range of 0.4 to 55.0% cover. Mulch

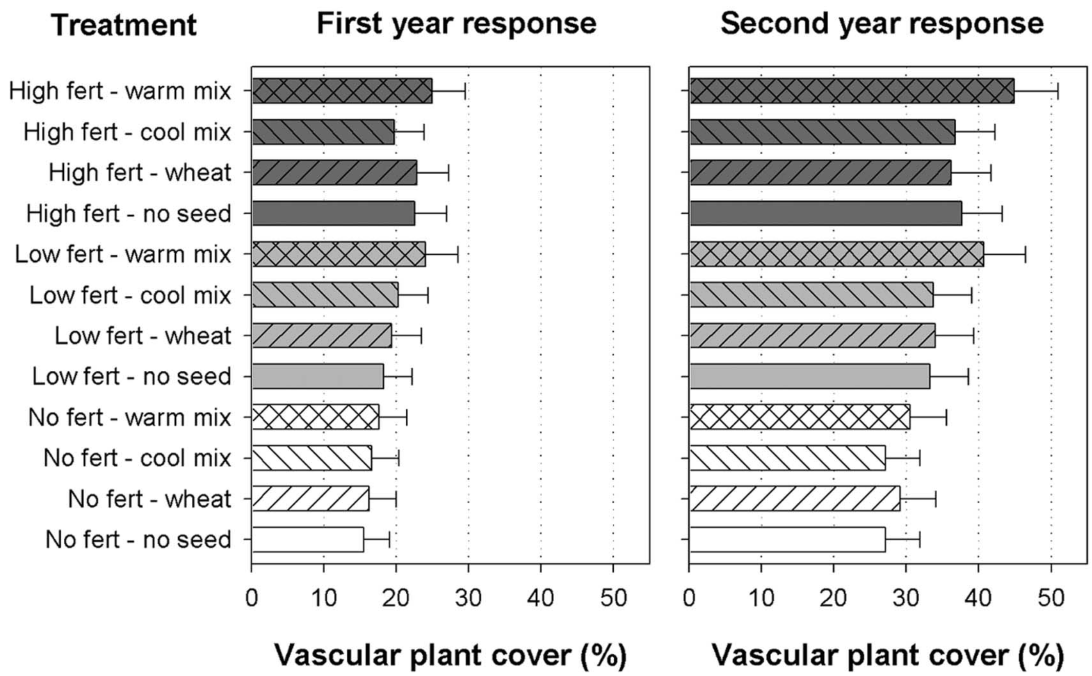

Figure 3. Fertilization and seeding treatment effects on vascular plant cover in the first and second years after wildfire as estimated by model least-squares means estimated at 0% mulch cover. Treatment labels indicate the fertilization level (no, low, or high fert) followed by the seeding treatment (no seed, wheat, cool mix, or warm mix). Bar shading indicates fertilization levels, and crosshatching indicates seeding treatment. Error bars indicate standard errors.

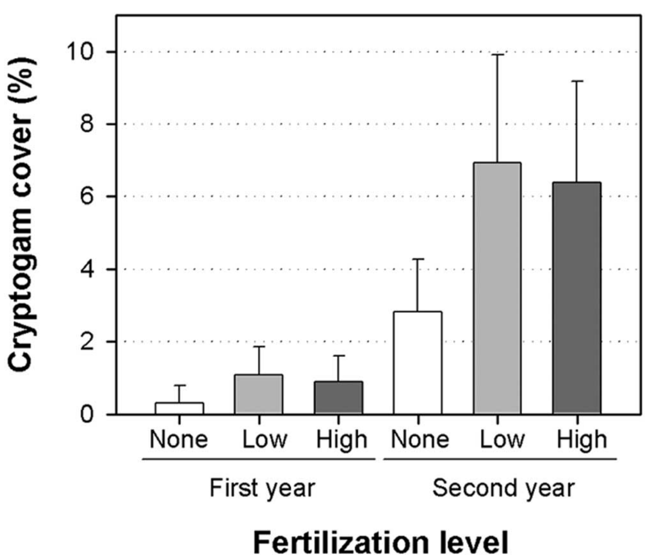

Figure 4. Fertilization effects on cryptogam cover in the first and second years after wildfire. Error bars indicate standard errors of model least-squares means.

cover was relatively consistent among sites, with site means ranging from 8.8 to 12.2% cover.

Mulching significantly reduced bare soil area on treated sites, consistent with the primary goal of the treatment (Table 3). However, mulching effects were not limited to providing physical cover, as mulching also influenced seeded species cover, total vascular plant cover, and cryptogam cover. Seeded species cover was positively correlated with mulch cover in both the first and second years after wildfire (Table 3). Straw mulching also influenced vascular plant cover, because vascular plant cover was positively correlated with mulch cover when mulching was combined with fertilization. Without fertilization, mulching did not significantly affect vascular plant cover. Cryptogam cover was positively correlated with mulch cover across all fertilization levels in the first year after the fire, although the response of cryptogam cover to mulching was more positive with fertilization than without fertilization. In the second year after the fire, cryptogam cover was positively correlated with mulch cover only on fertilized plots.

Discussion

In the absence of direct measurements of erosion and flooding, the effectiveness of land surface treatments must be judged by their effects on total soil cover and bare soil area. Previous studies have demonstrated that sediment production after fire is positively correlated with bare soil area and negatively correlated with total soil cover (Johansen et al. 2001, Benevides-Solorio and MacDonald 2005, Wagenbrenner et al. 2006). However, the relationship between bare soil and sediment production is nonlinear (Johansen et al. 2001, Benevides-Solorio and MacDonald 2005), and thresholds may exist for bare soil area below which sediment production is not significantly different from background levels. These thresholds are typically estimated to be between 40 and 60% bare soil, with true thresholds expected to vary with rainfall intensity, soil properties, and topography (Orr 1970, Robichaud et al. 2000, Johansen et al. 2001, Wagenbrenner et al. 2006).

Did the soil cover produced by land surface treatments in this study reduce postfire soil erosion by a meaningful amount? The most effective treatment combination tested, the combination of the warm seed mix and fertilization, produced 11–13% additional soil cover in the first year and

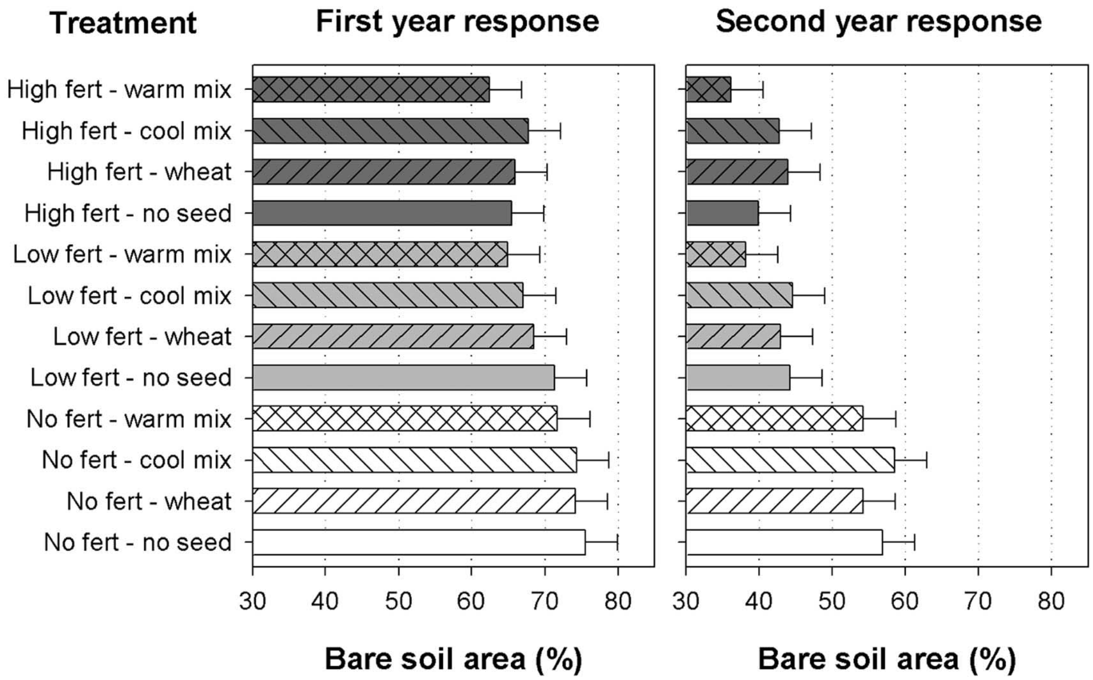

Figure 5. Fertilization and seeding treatment effects on bare soil area in the first and second years after wildfire as estimated by model least-squares means estimated at 0% mulch cover. Treatment labels indicate the fertilization level (no, low, or high fert) followed by the seeding treatment (no seed, wheat, cool mix, or warm mix). Bar shading indicates fertilization levels, and crosshatching indicates seeding treatment. Error bars indicate standard errors.

19–21% additional soil cover in the second year after fire, reducing bare soil by like amounts. None of the treatments in this study reduced bare soil area to less than 60% in the first year, so the soil erosion potential probably remained high relative to unburned areas across all treatments; however, at these high levels, a 10% reduction in bare soil area could significantly reduce sediment production. By the second year after fire, the most effective treatment combinations reduced bare soil area to less than 40%, and mean bare soil area approached 40% for all of the treatments that included fertilization. If 40% bare soil is indeed the level at which soil erosion rates begin to approach background levels, then fertilization would have reduced postfire soil erosion by a meaningful amount by the end of the second year.

With increased soil cover as an effectiveness indicator, fertilization proved to be more effective than seeding for increasing total plant and litter cover and reducing bare soil area in this study. Fertilization reduced bare soil area by stimulating growth and litter production in understory vegetation (including cryptogams). Fertilization also improved the effectiveness of some seeding treatments, particularly the warm seed mix containing yarrow, a small-seeded forb. We did not find significant differences in treatment effects between the high and low fertilization levels, suggesting that the lower dosage is probably adequate to overcome nitrogen and/or sulfur limitations on vegetation growth after fire and that higher dosages are unlikely to be cost-effective given similar soil conditions.

Fertilization has been considered a possible but unproven postfire erosion control treatment, being generally applied only in combination with seeding. Tiedemann and Klock (1973, 1976) tested the effectiveness of fertilization with nitrogen and sulfur as a supplemental treatment to seeding after the Entiat wildfire killed most of the trees on the Entiat Experimental Forest, less than 10 km southwest of our study. Fertilization with seeding did not significantly increase first year vegetative cover compared with seeding alone; however, fertilization appeared to increase second year vegetative cover and the vigor of seeded species (Tiedemann and Klock 1973). Robichaud et al. (2006) found that live vegetative canopy cover was 19% higher on fertilized plots than on unfertilized plots (74% versus 55%) 4 years after high-severity wildfire on the North 25 wildfire (5–10 km north of our study area). Their larger fertilization effect after 4 years (despite a lower initial fertilization level of 31 kg/ha) suggests that the divergence in mean vascular plant cover we observed between fertilized and unfertilized plots in this study (8–10% after 2 years) could continue to expand.

In deciding when and where to apply fertilization treatments, fire severity and residual plant density are important considerations. High-severity wildfires have been estimated to dramatically reduce total soil nitrogen pools through volatilization (DeBano et al. 1998), probably increasing nutrient limitations on postfire plant productivity. The 1970 Entiat fire reduced soil N by an estimated 855 kg/ha (Grier 1975), and the 2003 Biscuit fire reduced soil N by 690 kg/ha (Bormann et al. 2008). Although less severe wildfires often produce flushes of increased N availability, despite losses in total N due to volatilization, such flushes of increased nutrient availability may be limited or absent after high-severity wildfires that produce prolonged soil heating (Elliott and White 1987, Covington and Sackett 1992, DeBano et al. 1998, but see also Keyser et al. 2008). Fertilization after high-severity wildfires could replace or supplement these natural pulses of nutrient availability and promote more rapid vegetation growth, as we observed in this study.

Fertilization effectiveness also depends on plant uptake and use of nutrients. Grogan et al. (2000) reported that ash residues from a wildfire in a bishop pine ecosystem in California stimulated biomass production in understory vegetation, particularly herbs and sprouting shrubs. Similarly, much of the response to fertilization in our study came from sprouting shrubs and perennial grasses and forbs that survived the fire. Where residual and colonizing plants are absent or present only at low densities, fertilization effects may be limited by plant uptake, and some type of seeding may be required to increase plant densities and realize the full benefits of fertilization.

Plant species are typically chosen for use in seeding treatments based on availability of seed (in large quantities), rapid early growth and development of soil cover, and small or ephemeral impacts on native vegetation recovery and biodiversity (Beyers 2004). Wheat has been used in postfire seeding treatments in the Pacific Northwest in the last 15 years or more largely because it is readily available, has produced good cover in some cases (e.g., the 1994 Hatchery Fire; Schoennagel and Waller 1999), and rarely persists beyond the second or third year. However, wheat seeding tends to be unreliable, producing very little cover after the 1998 North 25 Fire (Robichaud et al. 2006), the 2002 Deer Point Fire (Dodson and Peterson 2009), and in this study, with climate, soil conditions, and seed predation by small mammals all potentially contributing to failures. Where wheat seeding has produced high levels of plant cover, it has reduced the cover and species richness of native plants (Keeley 2004), demonstrating tradeoffs between effectiveness for erosion control and impacts on native vegetation recovery and biodiversity.

Of the plant species tested in this study, yarrow clearly produced the most organic soil cover, both alone and in combination with fertilization. Although not as readily available as wheat, yarrow seed is becoming more available because of its use in restoration projects. Despite its small seed size, yarrow produced significant cover the first year, with further gains the second year. Cover of yarrow increased with fertilization, indicating its ability to capture and use soil resources shortly after establishment. As with wheat, however, there appears to be a tradeoff between cover attained and impacts on native vegetation cover and biodiversity (Dodson et al. 2009). The success of yarrow does suggest, however, that production of rapid cover depends more on relative growth rate in the seeded environment than on seed size and energy reserves.

Experimental studies such as this are useful for comparing the effects of competing treatments on common sites and identifying promising treatments but are necessarily limited in their ability to extrapolate results to sites with environmental conditions not encountered within the study area. It is also difficult to quantify the influence of climatic variability on postfire vegetation recovery and responses to treatments. Assessing the robustness of treatments to site and climate conditions will probably require more of an adaptive management approach in which promising treatments are applied operationally and effectiveness monitoring (including adequate controls) is used to assess treatment effects. Meta-analyses of treatment effects spanning a wide range of sites and years could then provide the information needed to target treatments to sites where they are most needed and are most likely to be effective. Further studies relating soil cover (or bare soil) to soil erosion rates would also be helpful for testing and improving soil erosion models, defining threshold soil cover levels, and helping watershed managers to better determine when the potential benefits of land surface treatments are likely to be sufficient to justify application costs and provide the desired protections for human health and property.

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