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Improving Reseeding Success after Catastrophic Wildfire with Surfactant Seed Coating Technology

Reference

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ABSTRACT

The application of soil surfactants in wildfire-affected ecosystems has been limited due to logistical and economic constraints associated with the standard practice of using large quantities of irrigation water as the surfactant carrier. We tested a potential solution to this problem that uses seed coating technology to harness the seed as the carrier. Through this approach, precipitation leaches the surfactant from the seed into the soil where it absorbs onto the soil particles and ameliorates water repellency within the seeds microsite. We evaluated this technology in a burned, highly water repellent, piñon-juniper woodland. Within a randomized complete block design, we separately seeded two bunchgrass

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species (Indian ricegrass and crested wheatgrass), whose seeds was either left uncoated or coated with a surfactant blend of alkylpolyglycoside and ethylene oxide/propylene oxide block copolymer. Plots were monitored through two growing seasons. In the spring after seeding, plant density and cover in the surfactant coated treatments were approximately 3-fold higher than the uncoated treatments. Two years after seeding, differences in plant density between the treatments decreased slightly, with the surfactant coated treatments having 2.8-fold higher density, as compared to the uncoated treatments. Over this same period, relative differences in cover between the treatments had increased, with surfactant coated treatments having 3.4-fold higher cover than the uncoated treatments. Overall, the results of this study demonstrate the ability of surfactant seed coating technology to improve seedling emergence and establishment. Future research is merited for evaluating the technology at larger-scales and within different ecosystems.

Keywords

seed-coating, water-repellency, surfactant, wetting agent, wildfire, reseeding, piñon-juniper

Introduction

Worldwide, many biomes have experienced increases in the intensity, size, frequency, duration, and seasonality of wildfires [1]. Catastrophic wildfires can leave ecosystems incapable of self-repair and subject to further ecological degradation. To facilitate recovery, land managers commonly seed desired species back into the system. Unfortunately, the success of these seeding efforts is typically less than desirable [2,3]. This is concerning as global climate change is anticipated to further limit restoration outcomes [4]. Consequently, there is an urgency to develop restoration tools that will improve seeding efforts and maintain the ecological integrity of wildfire-affected ecosystems.

Soil water repellency (or hydrophobicity) can be a formidable barrier to post-fire seeding efforts [5–7]. High intensity fires induce or increase soil water repellency as hydrophobic substances in the vegetation, litter, and soil volatilize and condense around soil particles within the cool underlying soil. This concentrates hydrophobic substances into a discrete layer a few mm to cm below the soil surface, dramatically reducing the ability of water molecules to infiltrate the soil matrix [8–10]. Water repellent soils can curtail seeding efforts by promoting the erosion of soil and seeds [11–13], and reducing soil water availability for seed germination and plant establishment [7,14].

The application of soil surfactants is a best management practice for the treatment of soil water repellency in golf courses and sports fields [15–17], and is becoming more popular in treating water repellency in various sectors of the agricultural industry [18,19]. Soil surfactants have also been evaluated in wildland systems for reducing post-fire erosion and improving reseeding success [5–7]. In general, these wildland studies have shown soil surfactants to be effective in mitigating the effects of post-fire soil water repellency. Despite this, the use of soil surfactants in post-fire restoration treatments has been limited. One of the main constraints is that irrigation water is typically used as a carrier in the delivery of soil surfactants. Such an approach can be logistically prohibitive in wildland systems where the surfactant needs to be applied across large land areas with steep and rugged terrain [20].

Madsen et al. [21,22] developed a potential solution for applying surfactants as a post-fire restoration treatment by using seed coating technology. Through this approach, the seed is used as a carrier for the soil surfactant. After planting, precipitation leaches the surfactant from the seed into the soil where it absorbs onto the soil particles and ameliorates water repellency within the seeds microsite. Laboratory research has indicated that surfactant seed coating (SSC) technology increases soil water infiltration, percolation, and retention in the area around the seed, which improves seedling emergence and plant survival [22].

The objective of this research was to evaluate SSC technology within a burned, highly water repellent, piñon-juniper (*Pinus-Juniperus*) woodland. We hypothesized that SSC technology would increase seedling emergence, growth, and plant establishment when compared to uncoated seeds.

Methods

STUDY SITE DESCRIPTION

Research was conducted within the boundaries of the "Mustang" wildfire, located 38.3 km south of Saint George, UT (Lat: 36° 42'36.19" N, Long: 113° 38" 17.20" W, elevation 1589 m). Lightening ignited the fire on Aug. 8, 2010, and it burned 1081 ha. At the study site, slope is minimal (1 %–2 %). Soil texture is a gravelly-loam, with a taxonomic classification as a fine, smectitic, mesic Calcidic Haplustalfs [23]. Volumetric soil water content at −1.5 MPa (permanent wilting point) and −0.33 MPa (field capacity) are 19.6 and 29.9 %, respectively [23]. Prior to the fire, the plant community was a Phase III, piñon -juniper woodland, with Utah Juniper (*Juniperus osteosperma* (Torr.) Little), and singleleaf piñon (*Pinus monophylla* Torr. & Frém.) acting as the primary plant layer driving ecological processes [24]. Mean annual precipitation is approximately 352 mm [25]. Research was conducted within the tree mound zones of burned piñon and juniper trees.

At the initiation of the study, three random points per plot were selected for soil water repellency profiling. At each point, areas with water repellent soil were identified using the water drop penetration time (WDPT) test [9]. Soils were considered water repellent if WDPT exceeded 5 s. Where soil water repellency was found, thickness of the water repellent layer was determined by performing WDPT tests at 5 mm depth increments until water repellency was no longer found. To quantify the severity of the water repellent soil, a 20 ml sample of soil was taken from the center of the water repellent layer. In the laboratory, five replicate water drops were place on the soil and the time for each water drop to enter the soil was recorded. Across all points sampled for soil water repellency, the top 1.4 ± 0.13 cm (average ± standard error) of soil was wettable and primarily composed of ash material originating from burned litter and debris. Below this depth, water repellent mineral soil predominated and extended down an additional 2.6 ± 0.13 cm. Average water drop penetration time (WDPT); within the water repellent layer was 1.38 ± 0.16 h.

Experimental Design

The experiment was installed as a randomized complete block design with five blocks. Each block consisted of four circular plots with a 2.0 m radius (area 12.6 m^2) centered around the trunk of a piñon or juniper individual. Two plots were seeded with the native species Indian ricegrass (*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkwork), and the remaining two were seeded with the introduced species crested wheatgrass (*Agropyron cristatum* (L.) Gaertner). Both of these species are ecologically adapted to the study site and commonly used in local reseeding efforts. One plot within each species was sown with uncoated seeds, while the other was sown with seeds subjected to SSC treatment (2 species by 2 coating treatments = total of 4 treatments).

Seed coating was performed at the Eastern Oregon Agricultural Research Center (EOARC) in Burns, OR using a RP14DB rotary seed coater (BraceWorks Automation and Electric, Lloydminster, SK, Canada). A detailed description of the methods and materials used to apply SSC technology is described by Madsen et al. [21,22]. In the coating process, seeds were first coated with a base coating containing 6.0 % weight of product to weight of seed (w/w) of Selvol-205 (Sekisui Specialty Chemicals America, Dallas, TX), and 72 % w/w of the powder filler material, diatomaceous earth (EnviroTech Soil Solutions, Inc. Oregon City, OR). After the base coating was applied, ASET-4002 soil surfactant composed of a blend of alkylpolyglycoside and ethylene oxide/propylene oxide block copolymers (Aquatrols Corporation of America, Paulsboro, NJ) was coated onto the seeds at 127 % w/w. Diatomaceous earth was also applied during this step as a carrier for the surfactant at 108 % w/w. Plots were seeded Oct. 16, 2011, with 750 pure live seeds (PLS) m^{-2}.

DATA COLLECTION AND ANALYSIS

Long term and monthly precipitation estimates during the period of the study were derived from models developed by PRISM's (Parameter-elevation Regressions on Independent Slopes Model) Oregon Climate Service (PRISM Climate Group 2012). Annual average precipitation and temperature were estimated from 1980–2010.

Seedling density and cover were measured within each plot from 12 randomly placed 0.125 m^2 quadrates. Density was determined by counting the number of live plants; cover was ocularly estimated as the percentage of live biomass occupying the quadrate. Density was measured in the spring at peak emergence (May) and both density and cover were measured at the end of the growing season (August) of the first and second year.

Vegetative data were analyzed in SAS (Version 9.3; SAS Institute, Cary, NC) using a repeated measures, mixed model. The fixed effects were seeded species, seed treatment, sampling period, and their interactions. Block was considered a random factor. Correlations among the repeated measures were modeled with a first order, autoregressive, moving average covariance structure. The SLICE option was employed in the LSMEANS procedure to determine if means were statistically different between non-coated and SSC treatments. For all comparisons a significance level of $P < 0.10$ was used.

Results

PRECIPITATION AND TEMPERATURE

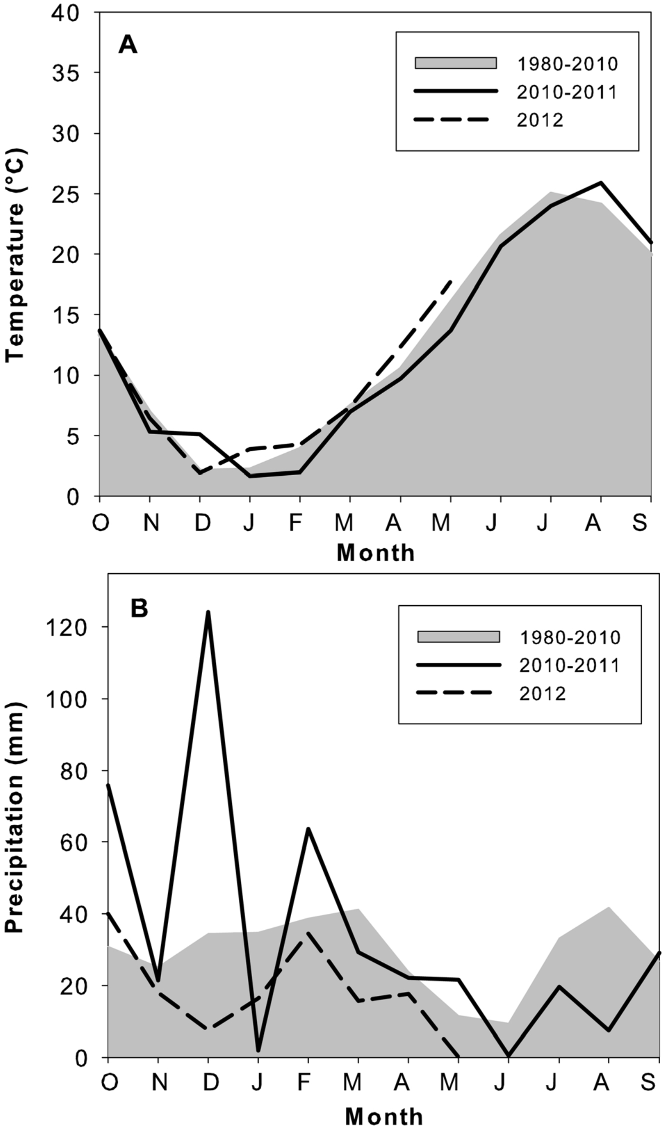
Average monthly temperatures throughout the study period generally mirrored the 30-year average (**Fig. 1(*a*)**). The primary exceptions were December 2010, February 2011, and January 2012. Average daily temperatures in December 2010 and January 2012 were 149 and 79 % higher than the 30-year average, while temperatures in February 2011 were 49 % lower. Precipitation in both 2011 and 2012 varied strongly from the 30-year average (**Fig. 1(*b*)**). Overall, precipitation was 18 % higher in 2011 and 38 % lower in 2012 (for the first eight months of the water year).

PLANT DENSITY AND COVER

Plant density was primarily influenced by SCC treatment and sampling period (**Table 1**). In the initial spring assessment, seedling density for both species combined was 3.2-fold higher in the SSC treatments as compared to the uncoated treatments, with an average density of 7.7 and 2.4 plants m^{-2}, respectively (**Fig. 2(*a*)**). By the end of the growing season in the first year, plant density in the SSC treatments had decreased to 1.2 plants m^{-2}, 4.5-fold higher than the 0.27 plants m^{-2} observed in the uncoated treatments. At the end of the growing season in the second year, differences between the treatments decreased, with the SSC treatment retaining a 2.8-fold higher plant density as compared to the uncoated treatments.

While repeated measures analysis did not indicate significant differences between the species for plant density, analysis by species within a sampling period showed that while both species benefited from the SSC treatment, the difference between coating treatments was only significant for Indian ricegrass (**Table 1**, **Fig. 3**). In the initial spring sampling, the Indian ricegrass SSC treatment produced 4.9-fold higher plant density as compared to uncoated seed of the same species, these treatments had average densities of 11.7 and 2.4 plants m^{-2}, respectively (**Fig. 3(*a*)**). At the end of the growing season in the first year, plant density had decreased to 1.9 and 0.33 plants m^{-2} in the SSC and uncoated treatments, respectively, increasing the difference between the SSC and uncoated treatments. At the end of the growing

FIG. 1 Average monthly (a) temperature and (b) precipitation for the Mustang wildfire study site. Data was extracted from the PRISM Climate Group database (prism.oregonstate.edu).



season in the second year, plant density in the SSC treatment decreased to 1.2 plants m^{-2} while the control plots maintained 0.33 plants m^{-2}. In the second year, plant density for the Indian ricegrass SSC treatment was 3.6-fold higher than the uncoated treatment.

TABLE 1 Results from repeated measures mixed model.

Effect	Density		Cover	
	F	Pr > *F*	*F*	Pr > *F*
Species	1.81	0.185	12.47	**0.002**
Treatment	3.85	**0.056**	7.4	**0.011**
Sample period	5.86	**0.005**	18.54	<**0.001**
Species X treatment	1.81	0.185	4.42	**0.045**
Species X sample period	1.06	0.356	10.77	**0.003**
Treatment X sample period	1.59	0.214	5.65	**0.025**
Species X treatment X sample period	1.04	0.363	3.12	**0.088**

[a] Significant P values are highlighted in bold ($P < 0.10$).

FIG. 2 (a) Combined seedling density produced from non-coated (control) and surfactant seed coatings (SSC) in the spring (May) of the first year after planting, and summer (August) one and two years after planting. (b) Plant cover produced from the control and SSC seed in the first and second year after planting. * Denotes significant differences between control and SSC treatments within a sampling period.

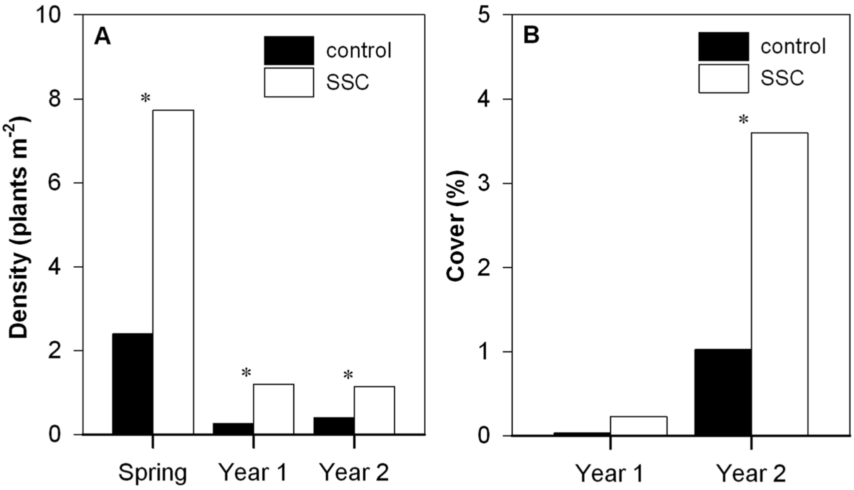
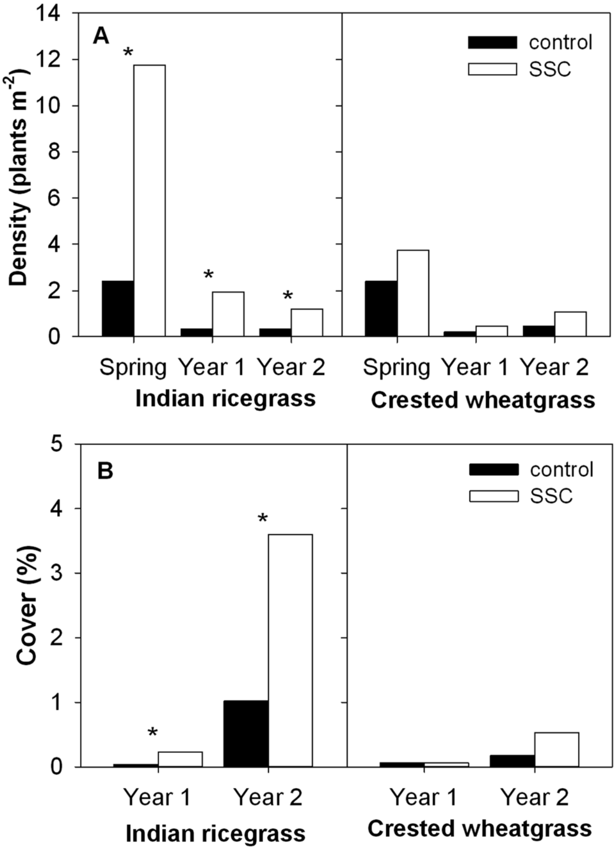


FIG. 3 (a) Seedling density of Indian ricegrass and crested wheatgrass produced from non-coated (control) and surfactant seed coatings (SSC) in the spring (May) of the first year after planting, and summer (August) one and two years after planting. (b) Plant cover produced from the control and SSC seed in the first and second year after planting. * Denotes significant differences between control and SSC treatments within a sampling period.



Plant cover was affected by species, coating treatment, sample period and the interactions between these fixed affects (Table 1). When cover for both species were combined, there were no significant differences between the SSC and uncoated treatments in the first year, but in the second year, plant cover was 3.4-fold higher in the SSC treatments as compared to the uncoated treatments (Fig. 2(*b*)). Comparison of coating treatments by species showed a response similar to that found for plant density: Indian ricegrass significantly benefited from the SSC treatment, whereas crested wheatgrass only benefitted slightly. In the first year, Indian ricegrass cover in the SSC treatment was 6.9-fold greater than in the uncoated treatment. In the second year, plant cover for all treatments increased greatly, though differences between the coating treatments decreased; the SSC treatment had 3.5-fold higher Indian ricegrass cover as compared to the uncoated treatment at the end of the study.

Discussion

As hypothesized, SSC technology improved reseeding success through increased seedling emergence and plant establishment. Restoration success was most likely enhanced as a result of the surfactant in the coating overcoming soil water repellency and improving soil water availability within the microsite surrounding the seed. Results obtained from our field study are consistent with those observed by Madsen et al. [22] under controlled laboratory experiments. Madsen et al. [22] conducted soil column experiments on a severely water repellent soil obtained from a burned piñon-juniper woodland and found SSC decreased runoff by 59 %, and increased the amount of water retained in the soil column by 68 %. Madsen et al. [22] further showed that through the amelioration of water repellency with SSC technology, seedling survival under drought conditions could be increased by 36 %.

It should be noted that the differences between coating treatments observed in our study were not quite as dramatic as those reported by Madsen et al. [22] for some metrics. Atypical climatic variability is one factor that may have affected the apparent SSC treatment effect, particularly for crested wheatgrass. In December 2011, two months after seeding, the average minimum temperature was around 1°C, which is approximately 5°C above the 30-year average. This month of above normal temperature coincided with several rainfall events that delivered 124 mm of precipitation, four times the amount of normal for December. Rawlins et al. [26] found that for crested wheatgrass and many other non-dormant perennial grass species, 50 % germination is reached within 20–25 days when seeds are incubated at 5°C. Daily average temperatures at our study site averaged 5°C throughout December 2011, and while diurnal flux limits a direct correlation, temperatures were well above the minimum for crested wheatgrass germination [27]. While not quantified, we observed high numbers of newly emerged seedlings growing from the crested wheatgrass plots at the end of December. Immediately following this warm and wet period, temperatures dropped dramatically, January and February 2012 were 30 % colder than the norm. In addition, precipitation in January totaled just 1.8 mm. We hypothesize that these conditions resulted in the widespread mortality of emerged crested wheatgrass seedlings.

It is unlikely that Indian ricegrass was as strongly affected by the December 2011 climate anomaly. This species typically has a very low fresh germination rate (i.e., as low as 8 %) [28] and employs a number of dormancy strategies to increase temporal variation in germination [29–31]. We expect that these characteristics suppressed germination in the fall and early winter periods, which limited losses during the subsequent cold and dry conditions of winter. For this species, SSCs ability to overcome soil water repellency and increase soil water availability most likely aided in seed stratification, seed germination, and plant establishment.

Irrespective of species-specific differences, one of the strongest findings in the support of our conclusion that SSC improves seeding success is the overall greater plant density and cover observed two years after seeding. Standards for a successful seeding can vary by region and management objectives. Within the region this research took place, a seeding could be considered successful when there is at least one established plant per square meter [32]. Although precipitation in 2011 was 18 % above normal, precipitation in 2012 was 38 % below the 30-year norm. We would expect such low precipitation to limit seeding success; however, plant density across all SSC treatments in the second year surpassed general thresholds of "seeding success," while non-coated seed failed to meet management standards. In the wake of current and predicted climate change impacts, which is suspected to cause higher temperatures and increase variability in precipitation, SSC technology may provide land managers with an important tool for maintaining the ecological integrity of wildfire-affected ecosystems [4,33]. Future research is merited for further evaluation of the technology.

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