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Preemergent Herbicide Protection Seed Coating: A Promising New Restoration Tool[☆,☆☆]

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ABSTRACT

Invasive annual grasses such as cheatgrass (*Bromus tectorum* L.) outcompete native grasses, increase fire frequency, and impact the functionality and productivity of rangeland ecosystems. Preemergent herbicide treatments are often used to control annual grasses but may limit timely restoration options due to negative effects on concurrently planted desired seeded species. We tested the efficacy of activated carbon-based herbicide protection coatings applied to individual bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love) seeds for protecting seedlings from injury associated with pre-emergent herbicide (imazapic) application in a laboratory environment. Emergence of coated seed averaged 57% ± 5% compared with bare seed, which had 14% ± 10% emergence with imazapic application. Seedling height for coated seed averaged 7.56 ± 0.6 cm compared with 2.26 ± 0.4 cm in uncoated bare seed in the presence of imazapic. Coated seeds produced 87% more plant biomass than uncoated seeds. Our laboratory results suggest that treating individual seeds with an activated carbon-based coating dramatically reduces negative effects of pre-emergent herbicide on desired seeded species. Field studies are needed to confirm these results in an applied restoration context.

Introduction

The invasion of exotic annual grasses such as cheatgrass (*Bromus tectorum* L.) has impacted ecosystem function across millions of acres in US sagebrush (*Artemisia* L.) steppe, and these species are now present throughout most of the Great Basin region (Davies et al. 2011). Exotic annual grasses can outcompete native perennial bunchgrasses, increase fire ignition and frequency, and degrade soils by modifying fundamental nutrient cycling processes (Norton et al. 2004; Reed-Dustin et al. 2016), making restoration efforts extremely expensive and challenging (Mata-Gonzalez et al. 2008). Given the impact of annual grass invasion on resource uses and values within the Great Basin ecosystem, as well as the spatial extent of the problem, more effective methods for controlling cheatgrass and restoring degraded plant communities are imperative to maintaining ecosystem services.

Research has shown that an effective method for reducing annual grass abundance is to apply pre-emergent herbicide (Davidson and Smith 2007; Sheley 2007). However, pre-emergent herbicide application can have adverse effects on seedlings of desired species (e.g., native perennial bunchgrasses) since the herbicide will injure or kill all emergent seedlings (Davies et al. 2014). Consequently, managers must wait up to a year following pre-emergent herbicide application before seeding desired species. In that time, exotic annual grasses can reestablish, reducing efficacy of the previous herbicide application (Davies et al. 2014). If a single-entry herbicide approach (i.e., simultaneously spraying herbicide and seeding desired species) were possible, this would significantly decrease costs relative to a double-entry approach and would afford seeded species the maximum window of opportunity to establish in a relatively competition-free environment (Sheley 2007).

In previous studies, the use of activated carbon (AC) in the form of pellets or herbicide protection pods (HPPs) incorporated with seeds of desired species was successful in protecting seedlings of

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seeded species from pre-emergent herbicide injury (Davies et al. 2017; Davies 2018; Clenet et al. 2019). Activated carbon in HPPs has a high surface area, which promotes adsorption, effectively making the herbicide locally inactive (Foo and Hameed 2010). These products allow desired seeds to be seeded simultaneous with application of herbicide (i.e., a true single-entry system). Although effective, these products can be difficult to produce without specialized equipment. Furthermore, activated carbon pellets, likely because of their size and compaction, have been shown in the absence of herbicide to decrease emergence and growth of seeded species (Clenet et al. 2019). To combat these issues, individual grass seeds have been coated in previous studies, unfortunately, with low success (Madsen et al. 2014). Getting enough activated carbon to adhere to each seed has proven to be difficult and resulted in poor protection from herbicide. In this paper, we evaluate the potential for a new method of coating individual grass seeds with a herbicide protection formula containing more activated carbon compared with previous studies and determine the potential for seed germination and initial seedling establishment as affected by coating and by varying rates of imazapic pre-emergent herbicide. We hypothesized that 1) seed coating would not influence seedling emergence in the absence of herbicide and 2) in the presence of herbicide, coated seed would have increased seedling emergence, shoot height, and aboveground biomass compared with bare seed, but 3) efficacy of the seed coating would decrease as herbicide amount increased.

Materials and Methods

Study Site and Materials

Soil was obtained from a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S.L. Welsh) steppe community type, located at the Northern Great Basin Experimental Range, 16 km southwest of Riley, Oregon. Excavated soil was sifted (1.62-mm mesh) to remove remaining seeds and used to fill pots that were placed in a grow room at the Eastern Oregon Agriculture Research Center, Burns, Oregon. Bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love) seed was used in this study (Anatone, Granite Seed, Inc., Lehi, UT) and is a major component of native plant communities in sagebrush steppe ecosystems (and restoration efforts therein) of western North America (Madsen et al. 2014; Rodhouse et al. 2014; Clenet et al. 2019). Germination potential of bluebunch wheatgrass was 92% as determined using five replicates of 25 seeds in a petri dish containing moistened blotter paper and maintained for 19 d at 22°C and a 12-h light/dark cycle.

Seed Coating

Approximately 200 g of bluebunch wheatgrass seeds were first coated with 192 g of powdered activated carbon (Darco GroSafe, Cabot, Billerica, MA) and 255 mL of an 8% partially hydrolyzed polyvinyl alcohol binder (Selvol-205; Sekisui Specialty Chemicals, Dallas, TX) using a 14" commercial rotary seed coater (SedPell RP14-DB, BraceWorks Automation and Electric, Lloydminster, SK, Canada) and standard coating protocols. This base layer provided a surface for adhesion of herbicide protection material. Seed was subsequently coated with a herbicide protection formula consisting of 33% activated carbon, 14% compost, 6% worm castings, and 45% bentonite clay by weight, which was mixed with a 4% partially hydrolyzed polyvinyl alcohol binder (Selvol-205) using a new coating method referred to as “vortexing.” This method is composed of layering rotary-coated seed, powdered herbicide protection material, and atomized 4% partially hydrolyzed alcohol binder on a vibrating plate and hand mixing for approximately 1 min. Seed is then dried on a forced air dryer at 26°C for 1 h, and the process is repeated until the desired application rate is achieved. For a step-by-step protocol, please see Appendix S1 (available online at [insert URL here]). The development of this method was required to overcome the small particulate size of the herbicide protection formula, specifically the activated carbon. This alternative method is less abrasive than traditional rotary coating and allows additional layers of material to be added until a desired amount is coated on each seed.

Study Design

We used a randomized-block 2×3 factorial design with five blocks. Treatments were coated or bare (noncoated) seed, and growing pots ($14 \times 14 \times 15$ cm) were sprayed with a high herbicide application of imazapic (Plateau BASF Corporation, Research Triangle Park, NC) at 198.4 g ai·ha^{-1}, a low herbicide application rate at 99.2 g ai·ha^{-1}, or not sprayed with herbicide (control). The coating method was not precise, and each seed did not coat evenly. Because of this, we divided coated seeds by size class and amount of activated carbon per size class was calculated. Coating material was estimated by weighing subsets of 25 seeds and averaging their weight. This weight was compared with the average weight of uncoated seed to determine coating material attained per seed and then multiplied by 33% (the amount of activated carbon in the coating material). For purposes of this study, 12 mg of activated carbon per seed were used to protect seeds from herbicide application. Seeds in the 4-mm size class had at least 12 mg (12–15 mg) of activated carbon and were used in this study. Samples were placed in a climate-controlled common grow area (16°C–22°C) under Platinum LED P1200 lights (Platinum LED Lights, LLC, Kailua, HI) with a 12-h light/dark cycle.

Each growing pot was watered to field capacity and planted with 25 bluebunch wheatgrass seeds. Seeds were placed on the soil surface, and a small amount of field-collected soil was sprinkled over the top until seeds could no longer be seen. After planting, pots were sprayed with their designated herbicide application rate using a hand-operated backpack sprayer (Solo, Newport News, VA) and allowed to air dry outside for 1 h before being brought back inside the grow room. This was done to decrease contamination of unsprayed pots. Throughout the study, pots were kept moist and hand watered as needed. Following a 4-wk period, total seedling emergence was counted for each pot. Living and dead bluebunch wheatgrass seedlings were counted separately. Seedlings were considered living if they had any remaining green tissue and were considered dead if they did not contain any green tissue. Seedling blade height of live seedlings was measured and averaged by pot, and aboveground biomass of live and dead seedlings was calculated per pot. Analysis of variance was used in R to compare the response of measured variables across treatments. When significant treatment or interactive effects were found, means were separated using the Tukey honestly significant difference method and reported with their associated standard errors. Differences were considered significant at $P \leq .05$.

Results

Coating and herbicide application interacted to affect seedling emergence ($P \leq .001$; Fig. 1). Percent emergence was similar across herbicide levels for coated seeds, but for bare seed, herbicide application reduced emergence approximately fivefold (see Fig. 1). Coating and herbicide application also interacted to affect seedling height ($P = .006$; Fig. 2). Seedling height decreased with herbicide application for both coated and noncoated seeds, but coated seeds were approximately twofold taller than noncoated seeds. Plant

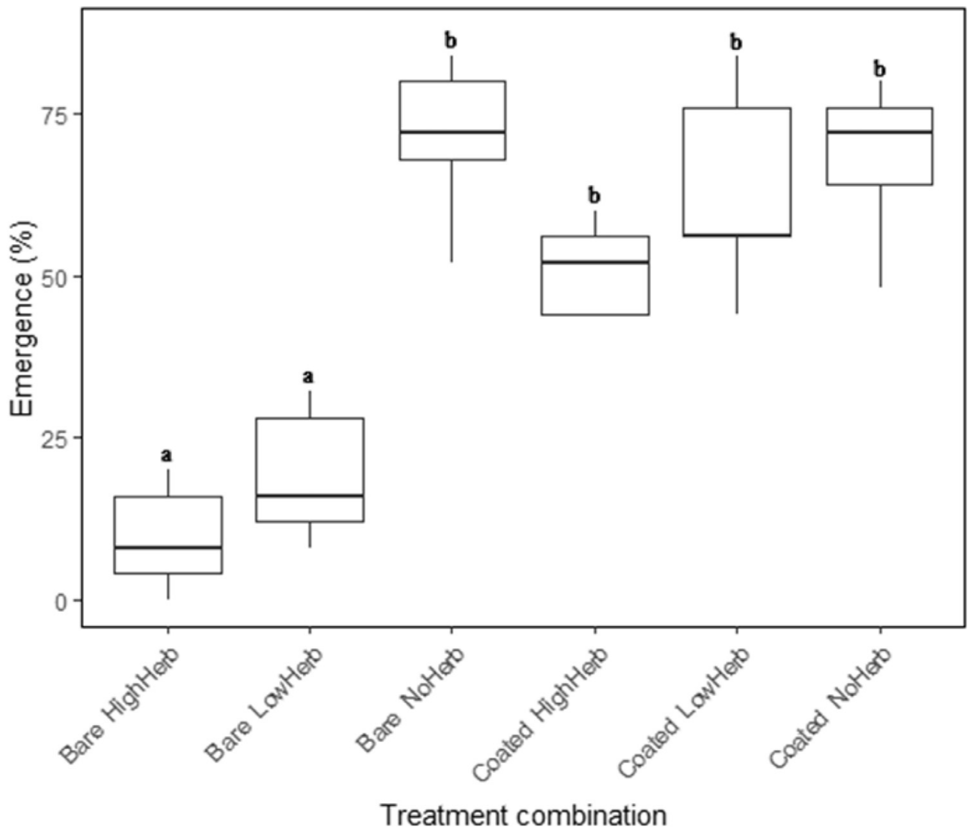

Figure 1. Box and whisker plots showing percent emergence of seedlings by treatment type (Bare = uncoated bare seed, Coated = herbicide protection coated seed; HighHerb = high herbicide treatment (198.4 g ai·ha^{-1}), LowHerb = low herbicide treatment (99.2 g ai·ha^{-1}), NoHerb = no herbicide application treatment). Boxes in each treatment combination represent the 25th through 75th percentiles, and each whisker represents the minimum and maximum data points. The line in the middle of the box shows the median. Treatments without a common letter are different ($P \leq .05$).

Table 1
Plant biomass (g) as affected by herbicide application level and seed coating. High herbicide = 198.4 g ai·ha^{-1}, low herbicide = 99.2 g ai·ha^{-1}. Treatments without a common letter are different ($P < .05$).

Herbicide level (g)		Coating (g)	
No herbicide	0.37 ± 0.16a	Coated seed	0.23 ± 0.16a
Low herbicide	0.08 ± 0.07b	Uncoated seed	0.12 ± 0.06b
High herbicide	0.08 ± 0.11b		

biomass was affected by coating ($P = .008$) and herbicide application rate ($P \leq .001$; Table 1). Coated seeds produced 87% more plant biomass than uncoated seeds.

Discussion

Our results indicate individual bluebunch wheatgrass seeds coated with herbicide protection material were moderately protected from imazapic herbicide application. Vigor of seedlings grown from bare seed was decreased by herbicide application, as evidenced by decreased emergence, seedling height, and biomass in comparison with coated seed. In support of our first hypothesis, coating did not influence seedling performance in the absence of herbicide. Our second hypothesis was also supported since plant height and emergence were higher in coated seed than uncoated seed in the presence of herbicide. Our third hypothesis, however, was not supported given that measures of seedling performance did not vary by herbicide amount among coated seeds.

Although there was no difference in emergence between herbicide and no herbicide treatments in coated seed, there was a difference in coated seed plant height. Coated seed without herbicide treatment was twice as high as coated seed in the presence of herbicide. This suggests the herbicide is having a negative effect on vigor of coated seeds. We suspect some seeds had slightly less coating (protecting material) than others even though on average they had the same amount of coating per seed. The coating method used in this study does not coat each seed evenly and therefore results in some seeds attaining more protection material than others. Since activated carbon protects seed by an adsorption effect (Foo and Hameed 2010), seeds with less coating were likely more susceptible to injury from herbicide. Thus, greater amounts of activated carbon may be needed around seeds to increase the level of herbicide protection. In addition, once seedlings begin emergence and root elongation, they may come into contact with herbicide in the soil (Clenet et al. 2019).

For this study, the herbicide application rates were chosen based on the US Environmental Protection Agency's (EPA's) recommendations for rangeland use. According to the EPA, 66.1 g ai·ha^{-1} to 99.2 g ai·ha^{-1} of imazapic is enough to control cheatgrass in rangelands but 198.4 g ai·ha^{-1} is the maximum amount of herbicide allowed for use on rangelands (US EPA 2016). This study used 99.2 g ai·ha^{-1} for the low herbicide and 198.4 g ai·ha^{-1} for the high herbicide rate, meaning coated seed was still offered some protection at the maximum herbicide rate allowed for rangeland use.

Results of this study add to literature showing advantages of using activated carbon in seed enhancement technologies to reduce effects of pre-emergent herbicide on seeded species. Increasing the amount of activated carbon (protection material) on individual grass seeds in this study offered more protection from herbicide than observed by Madsen et al. (2014) with half

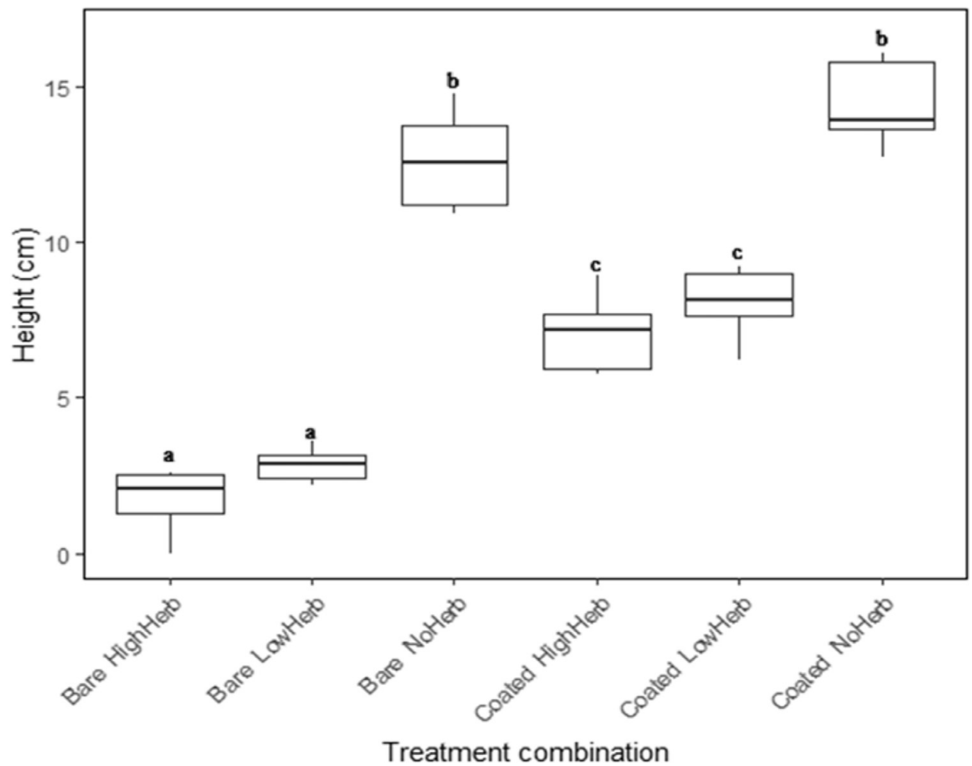

Figure 2. Box and whisker plots showing height of seedlings by treatment type (Bare = uncoated bare seed, Coated = herbicide protection coated seed; HighHerb = high herbicide treatment (198.4 g ai·ha^{-1}), LowHerb = low herbicide treatment (99.2 g ai·ha^{-1}), NoHerb = no herbicide application treatment). Boxes in each treatment combination represent the 25th through 75th percentiles, and each whisker represents the minimum and maximum data points. The line in the middle of the box shows the median. Treatments without a common letter are different ($P \leq .05$).

the amount of activated carbon coating. This study is the first to coat individual seeds with the herbicide protection formula rather than activated carbon alone. This protection formula, as well as the increase in activated carbon coated on individual seeds, resulted in higher emergence than seeds coated individually with activated carbon only (Madsen et al. 2014). Our study begins to delineate how much activated carbon or protection material is needed to protect seeds from herbicide, which is much lower than previously thought. Similar to our grow room study, field studies that used HPPs containing activated carbon demonstrated that use of activated carbon limited the effects of herbicide use on seeded species (Davies et al. 2017; Davies 2018; Clenet et al. 2020). Activated carbon seed enhancements are clearly an effective tool to reduce effects of pre-emergent herbicide on seeded native vegetation and warrant further refinement.

Management Implications

This proof of concept study shows individually coated seeds can be protected from herbicide under controlled conditions. We recommend field studies to determine success rates in natural environments. If effective in the field, activated carbon-based seed coatings could be a cost-effective alternative for restoration of annual grass—invaded landscapes of the sagebrush steppe ecosystem.

Use of herbicide protection coated products (seeds, pellets, or pods) allows for the possibility of performing seeding and weed control at the same time, which can save a year or more in restoration projects (Davies et al. 2017; Davies 2018; Clenet et al. 2019). This extra year will allow time for additional desired species growth with relatively minimal competition from exotic annual grasses, resulting in optimal restoration conditions (Madsen et al. 2014). In addition, although some loss of seedling vigor was evident for herbicide protection coated seeds exposed to herbicide (e.g., reduced seedling height), use of individually coated seed in an applied restoration context may be an attractive management option relative to pellets or pods due to less material needed, potentially reduced negative effects from pellet compaction and size on emergence and growth, and better flow through in machinery used for seed planting (e.g., rangeland seed drills).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2021.02.005.

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