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Using Activated Carbon to Limit Herbicide Effects to Seeded Bunchgrass When Revegetating Annual Grass-Invaded Rangelands☆

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ABSTRACT

Revegetation of exotic annual grass—invaded rangelands is challenging as annuals rapidly reinvade after control treatments. The most effective control of exotic annual grass is usually achieved with pre-emergent herbicides; however, species seeded simultaneously with these herbicides will likely experience nontarget damage. Thus, seeding often occurs 1 yr later to reduce herbicide effects to seeded vegetation, but by this time annual grasses may already be reinvading and limiting revegetation success. Activated carbon can be used to protect seeded species from herbicide damage because it has a high absorption capacity that can deactivate many herbicides. A pot study in a grow-room suggested that a pod containing activated carbon and seeds, herbicide protection pods (HPPs), may allow desired species to be seeded simultaneously with annual grass control with the pre-emergent herbicide imazapic. However, HPPs have not been field tested. We evaluated two seeding treatments (crested wheatgrass (*Agropyron desertorum* [Fisch.] Schult.) incorporated into HPPs and bare seed, simultaneously with an imazapic application to control annual grasses at two sites invaded by cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski). Crested wheatgrass abundance was 300% greater with HPPs compared with bare seed in late June. Imazapic application reduced exotic annual grass density at both sites by approximately half. These results suggest that HPPs can be used to allow desired species to be seeded simultaneously with imazapic application. This will allow seeded species a longer window to become established before experiencing pressure from exotic annuals and enable a single-entry approach compared with multiple entries currently employed to revegetate annual grass—invaded rangelands. Though further field testing is needed, in particular with multiple species and higher herbicide applications rates, these results suggest that HPPs could improve our ability to restore and revegetate exotic annual grass—invaded rangelands.

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Introduction

Exotic annual grass invasion and dominance is a critical threat to rangelands throughout the world (Purdie and Slatyer, 1976; Mack, 1981; D'Antonio and Vitousek, 1992; Brooks et al., 2004). Invasive exotic annual grasses are converting perennial-dominated plant communities into annual-dominated communities at an alarming rate. Invasion of exotic annual grasses increases fine fuel continuity and amounts (D'Antonio and Vitousek, 1992; Brooks et al., 2004). Exotic annual grasses also dry out earlier than native vegetation (Davies and Nafus, 2013). These alterations to fuels increases fire frequency, which favors exotic annual grasses over perennial vegetation and creates an annual grass-fire cycle (D'Antonio and Vitousek, 1992; Rossiter et al., 2003). Fires often start in annual grass communities and spread into adjacent uninvaded areas, thereby promoting exotic annual grass invasion of the uninvaded area. It is paramount that perennial vegetation be reestablished in these exotic-invaded rangelands to return ecologic and economic services and break the annual grass-fire cycle. Efforts, however, to establish perennial vegetation in exotic annual grasslands often fail. Thus, there is a critical need for seed enhancement technologies to overcome limitations to seedling establishment (Madsen et al., 2016).

In the sagebrush steppe ecosystem, invasion by cheatgrass (*Bromus tectorum* L.), medusahead (*Taeniatherum caput-medusae* [L.] Nevski), and other exotic annual grasses has increased fire frequency, degraded wildlife habitat, and reduced biodiversity (Mack, 1981; Davies, 2011). Exotic annual grasses are one of the primary threats to the sagebrush ecosystem and fauna dependent upon it. Reestablishing perennial grasses in exotic annual grass infestations is critically needed to protect the sagebrush ecosystem. Established perennial grasses are highly competitive with exotic annual grasses because of overlap in resource acquisition patterns (James et al., 2008). Perennial grasses can limit the spread of exotic annuals (Davies, 2008; Davies et al., 2010) and prevent reinvasion by exotic annual grasses after herbicide control treatments

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(Davies, 2010; Davies et al., 2015). At the seedling stage, however, perennial grasses are outcompeted by faster growing exotic annual grasses (Clausnitzer et al., 1999; Vasquez et al., 2008).

To revegetate or restore exotic annual grass-invaded rangelands, exotic annuals must be controlled to allow perennial grass seedlings to establish. Exotic annual grass can be effectively controlled with preemergent herbicides (Monaco et al., 2005; Kyser et al., 2007, 2013). Imazapic is a common preemergent herbicide used to control exotic annual grasses in the sagebrush ecosystem (Sheley et al., 2007; Davies and Sheley, 2011; Kyser et al., 2013). Seeding of perennial vegetation is often postponed for 1 yr after imazapic application to limit nontarget herbicide damage to seeded species. However, control of exotic annual grasses is finite as they quickly redominate the site if resources are not used by perennial vegetation (Davies, 2010; Sheley et al., 2012; Davies et al., 2015). Logically, it would be advantageous to seed perennial vegetation at the same time as imazapic application to give perennial vegetation a longer window to establish before experiencing significant pressure from exotic annuals. Efforts to establish perennial vegetation from seed at the same time as imazapic application have produced variable results, with success generally being limited likely due to imazapic-induced mortality of seeded species (Sheley et al., 2012; Davies et al., 2014).

In this situation, herbicide toxicity is prospectively a limitation to seedling establishment. Seed enhancement technologies designed to overcome this specific barrier to seedling establishment would likely improve revegetation success. Activated carbon can be used to deactivate herbicides as it has a high adsorption capacity for many organic compounds, including many herbicides, because of high surface area per unit volume and a system of submicroscopic pores (Bovey and Miller, 1969; Coffey and Warren, 1969). In row crops, activated carbon has been applied in a band as a slurry over seeded rows to protect the crop from the herbicide (Lee, 1973). Applying activated carbon as a band does not allow for full control of weeds as weeds within the band are protected from the herbicide (Lee, 1973). Alternatively, applying activated carbon as a seed coat has been proposed to protect seeded species from herbicides (Hagon, 1977; Scott, 1989). Seed coating, in contrast to banding, provides herbicide protection only to the seed and a relatively thin layer around the seed. This thin layer of activated carbon may not prevent herbicide uptake by the seeded species as the radical extends into the soil where the herbicide is still active (Madsen et al., 2014).

Activated carbon herbicide protection pods (HPPs) may be an ideal medium between banding and seed coating (Madsen et al., 2014). Activated carbon is incorporated into a dough mixture containing seeds, water-sensitive binders, and other additives and then extruded through a rectangular die. The extruded dough mixture is then cut into strips and dried (for more details see Madsen et al., 2014). In a pot study in a grow room, HPPs protected a seeded perennial grass from imazapic at all applications rates (70 − 210 g acid equivalent · ha^{-1}) (Madsen et al., 2014). Thus, this seed-enhancement technology has potential applicability for revegetation of exotic annual grass − invaded rangelands but needs to be field tested.

The objective of this study was to determine if HPPs could protect a commonly seeded bunchgrass, crested wheatgrass (*Agropyron desertorum* [Fisch.] Schult.), from imazapic applied to control exotic annual grasses. We evaluated using HPPs with a simultaneous imazapic application on a cheatgrass-dominated site and another site dominated by medusahead. We expected that 1) exotic annual grasses would be controlled with the imazapic application and 2) seeded bunchgrass abundance would be greater when seeded as HPPs compared with bare seeded.

Methods

Study Sites

The study was conducted in southeast Oregon at two study sites that were formerly Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & A. Young)—bunchgrass plant communities. Climate is characteristic of the northern Great Basin with cool wet winters and hot dry summers. Both sites were invaded by exotic annual grasses, and perennial vegetation was limited, though native perennial bunchgrasses and forbs were more abundant on Site 2 than Site 1. Site 1 was 67 km southeast of Burns, Oregon at 1045 m above sea level. This site was relatively flat (<2% slope) with clay loam soil. The ecological site is SR Clayey 9 − 12 PZ (R010XC021OR). Long-term (1981 − 2010) average annual precipitation was 267 mm. Crop-year (1 October to 30 September) precipitation was 274 mm (104% of long-term average). Medusahead was the dominant vegetation at Site 1. Site 2 was 7 km north of Burns, Oregon at 1288 m above sea level. This site was on a south aspect with 30% slope with loam soil. The ecological site is South Slopes 10 − 12 (R023XY300OR). Long-term (1981 − 2010) average annual precipitation was 306 mm. Crop-year precipitation was 277 mm (90% of long-term average). Cheatgrass was the dominant vegetation at Site 2. Both sites were fenced to exclude livestock during the experiment.

Experimental Design and Measurement

This study was implemented at two sites, and at each site treatments were arranged in a randomized block design and replicated four times. Treatments were 1) HPPs and imazapic application (HPPs), 2) bare seed and imazapic application (bare seed), and 3) untreated and unseeded control (control). Treatments were randomly assigned to 1 × 3 m plots with a 1-m buffer between plots. Both seeded treatments (HPPs and bare seed) were seeded with crested wheatgrass at 400 PLS·m^{-2} using a Kincaid Push Planter (Kincaid Equipment Manufacturing, Haven, Kansas). Drill rows were 3 m long running parallel to the long edge of the plot and spaced at 25, 50, and 75 cm on the short edge of the plot. Pure live seed was 75% and determined using the petri dish germination method. The formulation for the HPPs by dry weight was 34% activated carbon, 42% Ca Bentonite, 4% worm castings, 12% compost, 4% super absorbent powder, 1.6% super absorbent fine granules, and 2.4% seed. Each HPPs contained on average 8 PLS of crested wheatgrass. Dry materials were thoroughly mixed, and then liquid Selvol-205 prepared with a 1% solid content was incorporated to create a dough. Dough material was pushed through an extruder (Model 468, Lem Products, West Chester, OH) with an 8 × 16 mm die. Extruded dough was cut into 16-mm lengths, resulting in 8 × 16 × 16 mm pods. On 22 September 2015, immediately after seeding the HPPs and bare seed, imazapic (Panoramic 2SL, Alligare, Opelika, AL) was applied at a rate of 87.5 g ai·ha^{-1} with a handheld CO_2 sprayer (R&D Sprayers, Opelousas, LA) with a tank pressure of 206.8 kPa. During imazapic application, temperatures were 19°C and 31°C, relative humidity percentages were 27% and 17%, and average wind speeds were 2 and 7 km·hr^{-1} at Sites 1 and 2, respectively.

Density of crested wheatgrass seedlings was determined by counting all seedlings in drill rows in March (early) and June (late) of 2016. Leaf density, plant height, leaf length, and leaves per seedling were only sampled in March due to sampling error in June. Herbaceous vegetation density was measured in June using ten 0.2-m^2 quadrats. The 0.2-m^2 quadrats were placed evenly along two transects that were placed at the 25 and 75 cm locations on the short edge of the plot and paralleled the long edge of the plot. Density for perennial vegetation was measured by species by counting all individuals rooted in the 0.2-m^2 quadrats. Density of annuals was determined by counting by species all individuals rooted in the 10% segment of the 0.2-m^2 quadrats.

Statistical Analyses

We used repeated measures analysis of variance (ANOVA) using the PROC MIX method in SAS v. 9.4 (SAS Institute, Cary, NC) to evaluate seedling density response to treatments. The appropriate covariance structure, compound symmetry, was selecting using Akaike's Information

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