# Soil Resources Influence Vegetation and Response to Fire and Fire-Surrogate Treatments in Sagebrush-Steppe Ecosystems

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## Abstract

Current paradigm suggests that spatial and temporal competition for resources limit an exotic invader, cheatgrass (*Bromus tectorum* L.), which once established, alters fire regimes and can result in annual grass dominance in sagebrush steppe. Prescribed fire and fire surrogate treatments (mowing, tebuthiuron, and imazapic) are used to reduce woody fuels and increase resistance to exotic annuals, but may alter resource availability and inadvertently favor invasive species. We used four study sites within the Sagebrush Steppe Treatment Evaluation Project (SageSTEP) to evaluate 1) how vegetation and soil resources were affected by treatment, and 2) how soil resources influenced native herbaceous perennial and exotic annual grass cover before and following treatment. Treatments increased resin exchangeable $NH_4^+$, $NO_3^-$, $H_2PO_4^-$, and $K^+$, with the largest increases caused by prescribed fire and prolonged by application of imazapic. Burning with imazapic application also increased the number of wet growing degree days. Tebuthiuron and imazapic reduced exotic annual grass cover, but imazapic also reduced herbaceous perennial cover when used with prescribed fire. Native perennial herbaceous species cover was higher where mean annual precipitation and soil water resources were relatively high. Exotic annual grass cover was higher where resin exchangeable $H_2PO_4^-$ was high and gaps between perennial plants were large. Prescribed fire, mowing, and tebuthiuron were successful at increasing perennial herbaceous cover, but the results were often ephemeral and inconsistent among sites. Locations with sandy soil, low mean annual precipitation, or low soil water holding capacity were more likely to experience increased exotic annual grass cover after treatment, and treatments that result in slow release of resources are needed on these sites. This is one of few studies that correlate abiotic variables to native and exotic species cover across a broad geographic setting, and that demonstrates how soil resources potentially influence the outcome of management treatments.

**Key Words:** exotic annual grass, herbicide, mowing, prescribed fire, soil nutrients, soil water

## INTRODUCTION

Current paradigm suggests that resistance to exotic plant invasions is largely a function of resource limitation and biological resource partitioning. Ecosystems are believed to be relatively resistant to invasion if most available resources are utilized by the existing native vegetation through time and space (Veresoglou and Fitter 1984; Tilman et al. 1997; Duke and Caldwell 2001; Booth et al. 2003; James et al. 2008). Resistance to invasion decreases if increases in resource availability occur due to disturbance or other factors (Davis et al. 2000). Much less is known about the influence of inherent resource levels and resource fluctuations in ecosystems with persistent populations of invaders. Because vegetation management treatments designed to reduce invaders typically cause increases or pulses in resource availability, understanding the interactions of invasive species with the abiotic environment and native species in the vegetation community is essential for predicting outcomes.

Semi-arid shrub-steppe systems are often limited by one or more soil resources, typically water, nitrogen (N), or phosphorus (P) due to lack of consistent precipitation, poor soil development, low N-fixation and deposition, lack of organic matter, high carbonate content, or alkaline soil pH. Native species are well adapted to these conditions, and shrub-steppe ecosystems with intact native perennial woody and herbaceous species often have tightly coupled water and nutrient cycles that can increase resistance to invasion (James et al. 2008; Prevey et al. 2010; McGlone et al. 2011; Roundy et al. 2014). However, disturbance of semi-arid sagebrush (*Artemisia* L.) ecosystems in the intermountain United States due to inappropriate land uses or management practices can result in dominance of exotic annual grasses (e.g., cheatgrass; Knapp 1996).

Invasion of semi-arid sagebrush ecosystems is closely linked to changes in disturbance regimes and community composition

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that result in increased resource availability for growth and reproduction of exotic annuals (D'Antonio and Vitousek 1992; Pellant 1996). Introduction of domestic ungulate grazers to the Great Basin in the 1860s decreased native perennial herbaceous species cover, and likely altered soil resource availability throughout much of the region (Mack and Thompson 1982; Young et al. 1987; Melgoza et al. 1990). Native herbaceous perennials in the Great Basin are largely caespitose grasses that did not evolve with and are not tolerant of repeated intensive grazing (Branson 1953; Hickey 1961; Jewiss 1972; Mack and Thompson 1982). Removal of these grasses can increase soil nutrient and water availability in shrublands, which, in turn, can facilitate dense sagebrush stands with low resistance to exotic annual species (Dodd et al. 1998; Blank et al. 2007). Dense sagebrush stands are prone to high intensity fires that increase availability of soil nutrients and soil moisture, and because sagebrush are killed by fire, simultaneously decrease competition for soil resources (Blank et al. 2007; Leffler and Ryel 2012). Temporary pulses of soil N, P, K, micronutrients, and water in the absence of native perennial herbaceous species significantly reduce resistance to invasion (Blank et al. 2007; Chambers et al. 2007). Increases in resources following fire can persist for several years, prolonging the invasion window (Stubbs and Pyke 2005; Rau et al. 2007; Roundy et al. 2014).

Success of exotic annual grasses like cheatgrass (*Bromus tectorum* L.) is largely a function of high growth and reproductive rates and the capacity to take advantage of increases in resource availability. Cheatgrass can germinate from autumn to spring depending on soil water availability (Mack and Pyke 1983; Roundy et al. 2007); is capable of root elongation and growth at relatively cold temperatures (Melgoza and Nowak 1990; Aguirre and Johnson 1991); and exhibits a high growth rate allowing it to complete its lifecycle early in the growing season. Early growth and high rates of resource uptake make it competitive for available resources, which decrease resources for native perennial herbaceous species (Melgoza et al. 1990; Booth et al. 2003). Mature native species are capable of effectively competing with cheatgrass (Booth et al. 2003; Chambers et al. 2007; Blank and Morgan 2012), but seedlings of native species are not (Booth et al. 2003; Monaco et al. 2003; James et al. 2011). Therefore, mature native herbaceous perennial species represent the best defense against invasion (McGlone et al. 2011).

Managers are seeking effective methods for reducing fuels, increasing abundance of perennial native herbaceous species, and decreasing annual grass dominance in sagebrush-steppe ecosystems to protect biological diversity and maintain ecosystem function. Restoration of sagebrush-steppe has focused on reducing competition from woody species and increasing perennial herbaceous species abundance through prescribed fire, mechanical and chemical treatments, and seeding of perennials. To date, these treatments have met with variable success, and exotic annual grasses continue to expand their range (Pyke et al. 2013). Many of these treatments tend to increase soil resources and may actually be facilitating exotic annual grass invasion (Prevey et al. 2010). Much of the research surrounding annual grass invasion and sagebrush-steppe restoration has focused on soil water and N with significantly less attention being given to other nutrients and the interacting effects of abiotic factors (Kay and Evans 1965; Wilson et al. 1966; Melgoza et al. 1990; Booth et al. 2003; Lowe et al. 2003; Monaco et al. 2003; Vasquez et al. 2008). The purpose of this research is to examine the set of vegetation, soil, and abiotic factors likely to influence resilience to management treatments (recovery potential) and resistance to cheatgrass in Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) ecosystems. We use fuel reduction treatments across a large geographic area in the interior western United States to ask how inherent abiotic factors, vegetation composition, and soil resources influence relative abundance of native perennial herbaceous species and cheatgrass in sagebrush ecosystems before and after treatment. We address specific questions: (1) How are vegetation cover and soil resources (N, P, K, soil water) influenced by vegetation management treatments? And (2) How are native perennial herbaceous species and cheatgrass cover related to soil resources before and after treatment? The experiment is part of the Sagebrush Steppe Treatment Evaluation Project (www.sagestep.org), which was established to examine effectiveness of fuel reduction treatments for maintaining resilient sagebrush-steppe ecosystems that can resist cheatgrass invasion. Several other articles describing the SageSTEP study deal more extensively with initial vegetation response to treatment and cover a larger number of sampled sites (Chambers et al. 2014; Pyke et al. 2014). However, annual soil nutrient availability, moisture, and temperature data are only available for a subset of sites within the larger study. Vegetation data included in this study describes the general vegetation response to treatment on this subset of sites, and sets the context for our evaluation of interactions between soil resources, vegetation, and management treatments. This study represents one of the few observational studies to correlate abiotic factors with vegetation cover across a broad region, and is one of even fewer studies that attempt to determine the factors that relate treatment success to a broad range of biotic and abiotic variables.

## METHODS

### Experimental Area and Design

We focused on four of the seven arid Wyoming big sagebrush sites (McIver and Brunson 2014; [Onaqui, Utah; Roberts, Idaho; Rock Creek, Oregon; Saddle Mountain, Washington]) that encompassed a range of soil and weather patterns (Table 1). These are the only four Wyoming big sagebrush sites within the study where annual soil nutrient, soil moisture, and soil temperature data were collected in conjunction with vegetation data. The experiment was a randomized complete block split-plot design with repeated measures. Each of the four sites was a replicate block that contained four core treatment plots (20–80 ha). Core treatment plots were on similar soils and supported vegetation that was dominated by perennial grass and shrub cover with variable amounts of cheatgrass cover (0–50% areal cover). This mix of vegetation represents sites that may currently be stable, but are at risk of becoming dominated by annual grasses. At each site, four treatments were implemented, one per treatment plot: 1) prescribed fire, 2) mowing sagebrush at a blade height selected to reduce sagebrush cover $\approx$ 50%, 3) tebuthiuron herbicide applied at a rate selected to thin