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Influence of Soil Color on Seedbed Microclimate and Seedling Demographics of a Perennial Bunchgrass☆,☆☆

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ABSTRACT

Perennial bunchgrasses are critical to maintaining sagebrush plant communities, but seeding of native bunchgrasses following fire has had limited success. Previous research indicated that blackened soils beneath burned sagebrush canopies have increased bunchgrass seeding success when compared with interspace locations. We investigated soil moisture and temperature across white, neutral, and black soils and tested the relationship between soil color and seedling demographics for bluebunch wheatgrass. We used a randomized block design with three treatments and five replications conducted in a Wyoming big sagebrush community in southeast Oregon. The study site was rototilled before establishing 50 x 50 cm plots in each of 2 yr. We installed soil temperature/moisture probes at 3-cm depth in each plot. Plots were seeded in November of each year with 125 viable seeds and covered in a < 1-mm layer of white, brown, or black aquarium sand. We counted emergent seedlings weekly through May of the year following planting. Soil moisture during the emergence period (March–May) was highest for white soils and lowest for black or neutral soils ($P < 0.001$); soil temperature was highest for black or neutral soils and lowest for white soils ($P < 0.001$). Year 1 was characterized by a relatively warm and dry emergence period, and year 2 was relatively cool and moist. Emergent seedling density was highest ($P < 0.05$) for white soils; surviving seedling density (on June 1) was highest ($P < 0.05$) for white soils in year 1 and black soils in year 2. Black soils had greater success in a year with lower soil temperatures and adequate soil moisture. When soil moisture was limited, and spring temperatures warmer, increased soil temperature on black soils led to seedling desiccation and death.

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Introduction

Ecological function of low- to mid-elevation sagebrush (*Artemisia tridentata* Nutt.) rangeland in the western United States is under serious and growing threat from invasive exotic annual grasses (Meinke et al. 2009; Davies et al. 2011). These species are now present to some degree across most of the low to middle elevation Great Basin region; Meinke et al. (2009) estimated a moderate to high probability of cheatgrass (*Bromus tectorum* Nutt.) dominance on 28 million ha in the Intermountain West of Idaho, Oregon, Nevada, Utah, and Washington. Annual grasses outcompete perennial seedlings and result in high fine fuel continuity, which has been associated with dramatic increases in both wildfire frequency and size (Chambers et al. 2007; Miller et al. 2013). Native perennial grass and shrub species in the sagebrush biome are ill adapted to frequent fire and decline or become locally absent over time (Boyd et al. 2015).

Key to preventing the spread of annual grasses is maintenance of perennial bunchgrasses. While perennial grass seedlings are poor competitors with annual grasses, mature perennial bunchgrasses serve to reduce site availability for annual grasses (Chambers et al. 2007; Davies 2008). Success in reestablishing perennial bunchgrasses from seed has lagged behind increases in the spatial extent of invasive annual grass cover. Previous research indicates that likelihood of establishment is not spatially homogenous and varies at scales ranging from plant communities to micro scales within plant communities (Boyd and Davies 2010, 2012a) and is strongly impacted by temporal variability in climatic factors (Boyd and Lemos 2015). We previously documented that postfire site characteristics associated with prefire undercanopy shrub locations experience increased emergence and biomass of planted seedlings relative to interspace locations and that this divergent performance is associated with darker soils, increased soil nutrient availability, and higher soil surface temperatures (Davies et al. 2009; Boyd and Davies 2010, 2012b). This work linked darker soils with warmer soil temperatures but was unable to test the impact of this relationship on seedling dynamics independent of altered soil nutrient characteristics associated with undercanopy locations.

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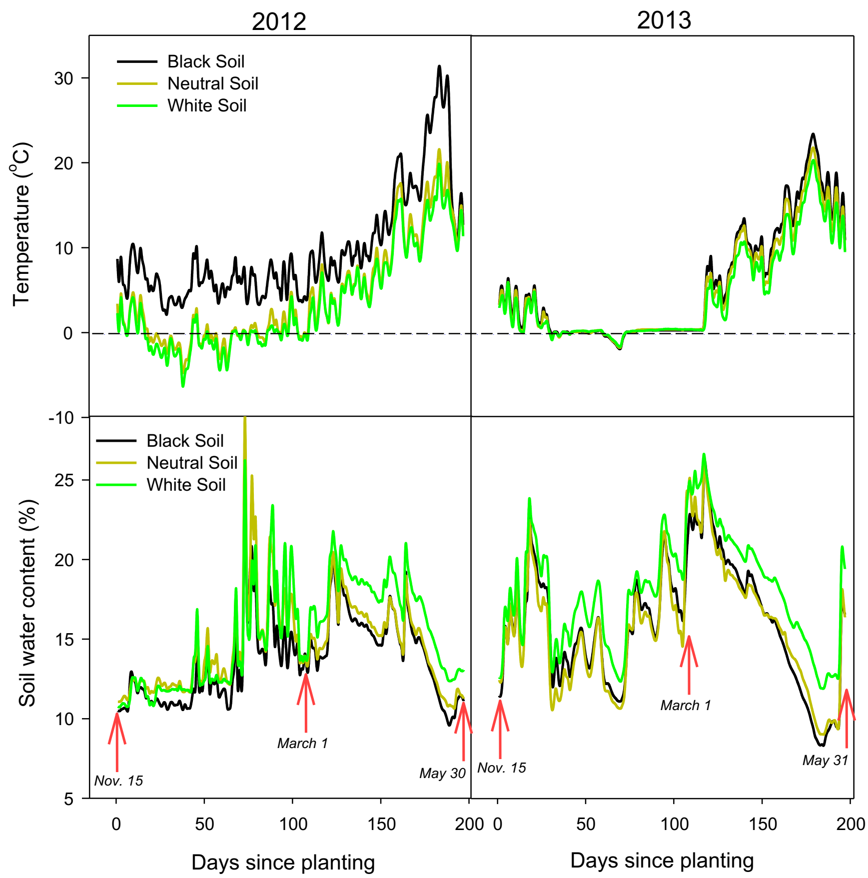

Figure 1. Soil surface temperature and moisture for plots with different colored soils in southeast Oregon during 2012 (left column) and 2013 (right column) as a function of days since planting. Plots were hand planted with bluebunch wheatgrass seeds in mid-November.

In this study, we examined the specific influence of soil color on soil temperature and moisture and subsequent performance of bluebunch wheatgrass seedlings. We hypothesized that darker soil color would result in elevated soil temperature and reduced soil water and that earlier seedling emergence of darker soils would be associated with increased emergent and surviving seedling density. We focused this research on emergence and near-term postemergence survival due to the importance of this demographic period in determining seedling fate of perennial bunchgrasses (James et al. 2011).

Methods

Study Area

Our study site was located at the Northern Great Basin Experimental Range, approximately 50 km west of Burns, Oregon (43.48 N, 119.72 W) at an elevation of approximately 1 400 m. Annual precipitation is highly variable but averages 286 mm with the majority falling as rain or snow during the October to May period (data file, Eastern Oregon Agricultural Research Center, Burns, OR). Soils were classified as a well-drained, Derallo Variant-Pernty complex with a surface horizon of fine sandy loam underlain by bedrock at approximately 75 cm (Lentz and Simonson 1986). Study plots were excluded from herbivory for the duration of the study using wire mesh fencing.

Plot Layout and Data Collection

We used a randomized complete block design with treatments (soil color) replicated over five blocks in each of 2 yr. Plots were instrumented with GroPoint soil moisture/temperature sensors ($\pm$0.01 m^3/m^3 accuracy) buried to approximately 3-cm depth (Environmental Sensors Inc., Sidney, BC). Sensors were programmed to collect readings on an hourly basis from the time of planting until 31 May of each year, and data were stored on a GroPoint GP-DL3T data logger. Soil colors included black, neutral, and white. In September of each year, we rototilled 50 × 50 cm plots and randomly assigned plot treatments. On 15 November of each year, plots were raked and hand-seeded with 125 viable Anatone bluebunch wheatgrass seeds (*Pseudoroegenaria spicata* [Pursh] A. Love; Lot LHSAD3-445-1, L&H Seeds, Inc.; Connell, WA). Seed viability was determined by placing 50 seeds on moist blotter paper (four replications) for 4 wk (21°C, 12 h light/12 h dark); seeds with a visible radicle were considered viable. Planted seeds were covered with approximately 1 cm of soil that had been sifted through a 3-mm mesh screen. Soil color was altered by applying an approximately 1-mm thick layer of black (grayscale value = 70), neutral (grayscale value = 185), or white (grayscale value = 220) aquarium sand immediately after planting (Petco Animal Supplies, Inc.; San Diego, CA). The "neutral" soil was meant to mimic the brownish hue of natural soils at the study site. Sand was reapplied as needed during snow-free periods from the time of planting until the final seedling density count on 1 June of each year.

Emergence status of plots was checked weekly following planting, and no fall emergence was encountered. We began counting emerging seedlings coincident with first emergence following planting (late March). Following initial emergent seedling count, counts were made on an approximately weekly basis through 1 June. For the initial count, emergent seedlings were marked with a toothpick (uniquely colored by week) and for subsequent counts, toothpicks were removed for dead seedlings and added for new seedlings. Current and historical precipitation and temperature data were collected at an existing nearby

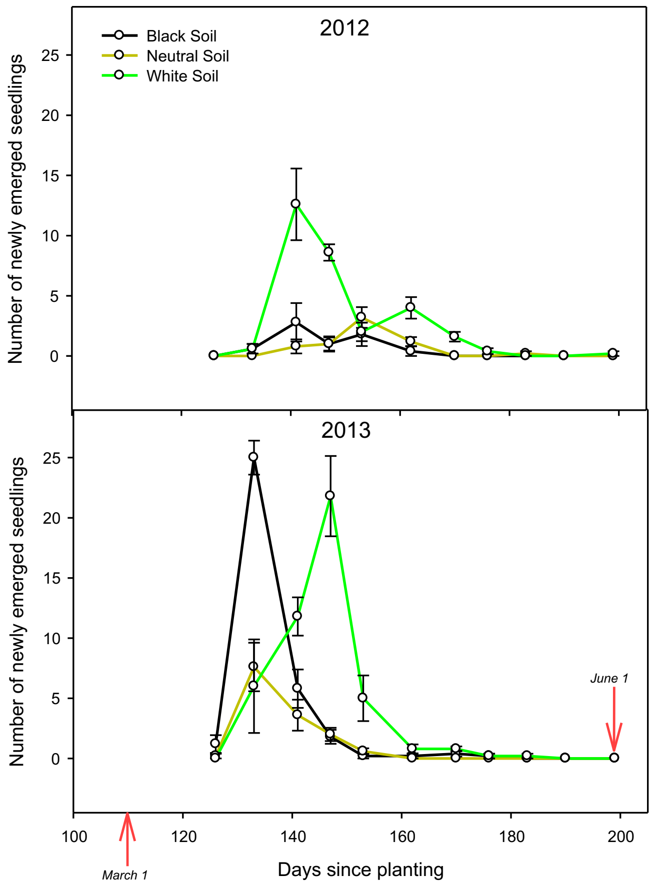

Figure 2. Means and standard errors for density of emergent seedlings for plots with different colored soils in southeast Oregon during the 2012 (top) and 2013 (bottom) growing seasons as a function of days since planting. Plots were planted with bluebunch wheatgrass seeds in mid-November. Scores represent the number of newly emergent seedlings on an approximately weekly basis from the time of first emergence (late March in each year) until May 31 (197 days since planting).

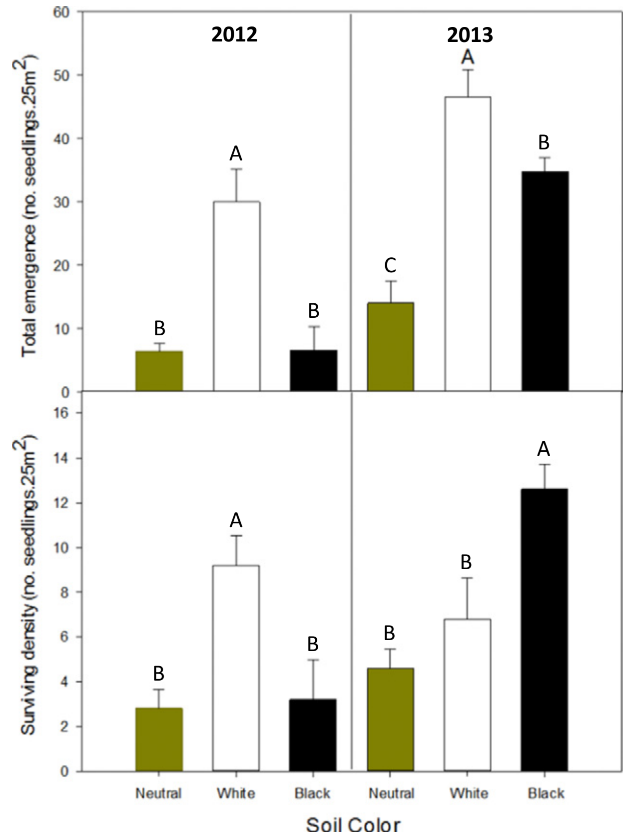

Figure 3. Means and standard errors for total emergence (top) and surviving seedling density (bottom) for plots in southeast Oregon during the 2012 (left column) and 2013 (right column) growing seasons. Plots were planted with bluebunch wheatgrass seeds in mid-November of each year, and density data were collected the following spring; total emergence represents the total number of seedlings emerging until June 1, and surviving density represents the number of live seedlings present on June 1. Within a graph, bars without a common letter are different ($\alpha = 0.05$).

(< 2 km) weather station (data file, Eastern Oregon Agricultural Research Center, Burns, OR). Snow cover data were from Burns, Oregon, approximately 60 km from the study site (NOAA 2015).

Data Analysis

Hourly values for temperature and precipitation were averaged or compiled within day. We summed the number of days with snow cover data, within year, from the day of planting (15 November) through 31 May. Data for seedling counts were summarized within year by emergent seedling density (total number of seedlings that emerged for a plot) and surviving seedling density (number of seedlings that survived to the last count date). We used analysis of variance (SAS Institute Inc., Cary, NC) to evaluate the effect of soil color on cumulative emergent seedling density and surviving seedling density. We used repeated measures analysis of variance (SAS Institute Inc., Cary, NC) to determine the influence of soil color on soil moisture and temperature over time and weekly emergence patterns. Covariance structure was selected as detailed by Littell et al. (1996). All models were constructed within year. Data not meeting ANOVA assumptions were weighted by the inverse of the treatment variance. Block and the block × treatment interaction were considered random effects. When significant effects were found, we used a Tukey procedure to determine differences among treatment means. The critical value for statistical significance was set at $\alpha = 0.05$. Means are reported with their associated standard errors.

Results

Precipitation from the time of planting through May 31 was 55% and 74% of the long-term average for 2012 and 2013, respectively. In 2013, the majority (56%) of the November–May precipitation fell as snow during December and January, compared with 27% of total precipitation in 2012. This is reflected in 49% of days with measureable snow cover during the November–May period in 2013 as compared with 18% of days in 2012. Air temperature was 2.0°C and 1.0°C lower than the long-term November–December mean in 2012 and 2013 and equal to or 0.2°C warmer than the March–May long-term mean in 2012 and 2013, respectively.

Soil temperature and soil water content varied by color ($P < 0.001$), time ($P < 0.001$), and the color × time interaction ($P < 0.001$) in both 2012 and 2013. Patterns of soil temperature over time suggest that in 2012, black soils were warmest, averaging 9.7°C ± 0.46°C, followed by neutral (4.32°C ± 0.43°C) and white (3.5°C ± 0.42°C) soils (Fig. 1). In 2012, black, neutral, and white soils experienced 0, 52, and 69 days with an average soil temperature < 0°C. Soil temperatures were much closer between colors in 2013, particularly during the period from 15 November to 1 March (see Fig. 1); temperatures averaged 5.6°C ± 0.48°C, 5.0°C ± 0.44°C, and 4.4°C ± 0.40°C for black, neutral, and white soils, respectively. In 2013, black, neutral, and white soils experienced 18, 22, and 21 days with soil temperature < 0°C. In both years, differences in soil water content between colors were roughly inverse of those observed for temperature, with white soils generally having highest values and black or neutral soils lowest (see Fig. 1). In 2012 water content averaged 13.7% ± 0.19%, 14.6% ±

0.20%, and 15.4% ± 0.23%, and in 2013 it was 15.9% ± 0.28%, 15.8% ± 0.27%, and 18.1% ± 0.27% for black, neutral, and white soils. This pattern of divergence in water content between colors was particularly evident as soil temperatures warmed during the April–May timeframe (137–197 d since planting).

Seed viability was 92.5% in 2012 and 90.9% in 2013. Seedling emergence varied by color ($P < 0.001$), time ($P < 0.001$), and color × time interaction ($P < 0.001$) in both years. Seedling emergence in both years began during the week of 18 March (126 d since planting, Fig. 2). In 2012, white soils had a strong emergence peak beginning 2 wk after first emergence but black and neutral soils had low weekly emergence (< 4 seedlings) without a strong peak over time. In 2013, black soils, and to a lesser extent neutral soils, had a strong emergence peak 1 wk after first emergence and plots with white soil showed a strong peak 3 wk following first emergence. In both years, emergence was minimal after about 162 d since planting (April 24). Total number of seedlings emerging until June 1 varied by color in both 2012 ($P = 0.003$) and 2013 ($P < 0.001$; Fig. 3). In 2012, emerging seedling density for white soils was approximately fivefold higher ($P < 0.05$) than neutral or black soils. Total emergent seedling density was 35% and 2.5-fold higher ($P < 0.05$) on white soils in 2013 as compared with black and neutral soils, respectively. Surviving seedling density varied by color in 2012 ($P < 0.001$) and 2013 ($P = 0.008$; see Fig. 3). Surviving seedling density was approximately threefold higher ($P < 0.05$) on white soils than black or neutral soils in 2012, and in 2013 surviving density on black soils was approximately twofold and threefold higher than white or neutral soils.

Discussion

Factors influencing germination of bluebunch wheatgrass seeds are well studied, but less is known about the relationship between environmental factors and seedling emergence (Hardegree et al. 2003). Results from this study indicate black soils have potential for increased seedling density at the end of the emergence period (end of May), and that the timing and amount of soil water availability and spring temperatures appear to mediate this relationship. Consistent with our prediction, soil temperature was elevated and soil water content was generally reduced with darker soils. Divergence in soil water content between colors was particularly notable during the seedling emergence period (March–May). During this period, water content ranged up to approximately 28% for all soil colors in 2013, whereas only white soils topped 20% during the same period in 2012 (see Fig. 1); high soil water content during the early emergence period in 2013 was associated with snow melt. Abundant snow cover also helped to moderate variability in soil temperature in 2013 compared with 2012, which had comparatively little snow cover.

Emergent and surviving seedling density did not consistently relate to soil color between years. In 2012, precipitation from time of planting to final density count was approximately 50% of the long-term average. We suspect that relatively low soil moisture in 2012 favored increased emergence and surviving seedling density on white soils because this soil color had relatively higher soil water content during the critical emergence period. This is supported by the fact that black and neutral soils never had a strong emergence peak in 2012 (see Fig. 2). In contrast, warmer soil temperatures on black soils during 2013 were associated with relatively high (compared with 2012) soil water content at the beginning of the emergence period and an early and strong emergence peak. Given declining soil water from March to May, this early emergence, coincident with high soil water content, may have allowed seedlings on black soils to develop to a phenological stage capable of persisting until our final density count. This is in contrast to white soils in 2013, which had a later emergence peak and high density of emerging seedlings but lower surviving seedling density than black soils. This is also consistent with our field observations that seedlings on white soil plots in 2013 were initially vigorous but desiccated over time with decreasing soil moisture. Our results indicate that soil color alone can alter seedling performance in the absence of alteration of soil nutrients associated with postfire under shrub canopy locations (Boyd and Davies 2012b).

We expected neutral soils would have intermediate seedling emergence and survival; however, data from 2012 suggested equal performance to black soils, and 2013 data indicated lowest scores for seedling emergence and survival. Soil water content of neutral soils closely tracked that of black soils in 2012, and water limitations may have reduced emergence performance. Reasons for relatively low emergence performance of neutral colored soils are less clear in 2013, but we suspect that soil temperatures may not have been warm enough for a strong emergence peak and that ensuing soil desiccation limited later emergence.

Implications

Soil color can influence emergence and early survival of bluebunch wheatgrass seedlings. From a management standpoint, blackened soils associated with burned shrubs are readily visible on postfire landscapes and may represent locations that need to be reseeded due to increased fire-related perennial bunchgrass mortality (Boyd et al. 2015). Our current and previous work (Boyd and Davies 2010, 2012b) suggests that increased soil temperature associated with blackened postfire soils could be expected to promote increased perennial bunchgrass seeding success with sufficient precipitation.

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