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Comparison of Postfire Soil Water Repellency Amelioration Strategies on Bluebunch Wheatgrass and Cheatgrass Survival

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Abstract

Soil water repellency can limit postfire reseeding efforts and thus increase the susceptibility of a site to weed invasion. We evaluated the effectiveness of wetting agents and simulated anchor chaining for improving seedling growth and survival in water-repellent soil, for the native perennial bluebunch wheatgrass (*Pseudoroegneria spicata*) and invasive annual cheatgrass (*Bromus tectorum*). Research was performed in a glasshouse, on 20-cm-diameter soil cores that were excavated from underneath burned Utah juniper (*Juniperus osteosperma*) trees. The experiment was arranged as a randomized split-plot design, with the two grass species sown separately under four soil treatments: 1) no treatment (control), 2) simulated anchor chaining (hereafter referred to as “till”), 3) wetting agent, and 4) till plus wetting agent. Soil water content was highest in the wetting agent treatment, lower for till, and lowest in the control. Overall, the response of bluebunch wheatgrass and cheatgrass was similar among treatments. At the conclusion of the study, wetting agent cores had twice as many seedlings as the control, while the till and control were similar. Despite a lower number of seedlings, tilling in general resulted in the same level of biomass as the wetting agent treatment. Overall, biomass in the till and wetting agent treatments was at least twofold higher than the control. No benefit was found in applying both till and wetting agent treatments together in comparison to just applying wetting agent. Because of a lack of correlation between glasshouse and field settings the results of this study need to be interpreted with caution. Our data may indicate that if cheatgrass is not already present on the site, anchor chaining or treating the soil with wetting agent can increase establishment of seeded species.

Resumen

La impermeabilidad del suelo puede limitar los esfuerzos de resiembra posteriores a la aplicación del fuego y por lo tanto hacer más susceptible un sitio a la invasión de malezas. Evaluamos la efectividad de agentes humectantes y simulamos anclas encadenadas para mejorar el crecimiento y supervivencia de plántulas en suelos impermeabilizados para el pasto perenne nativo (*Pseudoroegneria spicata*) y el pasto invasor anual (*Bromus tectorum*). La investigación se desarrolló en un invernadero en una muestra de suelo de 20 cm de diámetro colectada debajo de árboles de (*Juniperus osteosperma*). El diseño experimental fue de parcelas divididas aleatorias con los dos pastos sembrados de manera separada en cuatro tratamientos de suelo: 1) control, 2) simulación de cadena de ancla (referido como “labranza”), 3) agente humectante y 4) labranza más agente humectante. El contenido de agua en el suelo fue mayor en el tratamiento con el agente humectante, menor para labranza y más bajo en el control. En general, la respuesta de los pastos (*Pseudoroegneria spicata*) y (*Bromus tectorum*) fue similar entre los tratamientos. Como conclusión de este estudio, el suelo con el agente humectante tuvo más del doble de plántulas que el control mientras la labranza y control fueron similares. Independientemente del bajo número de plántulas el tratamiento de labranza en general tuvo el mismo nivel de biomasa que el tratamiento del agente humectante. En general, la biomasa en los tratamientos del humectante y la labranza fueron al menos dos veces mayores que el control. No se encontró beneficio en aplicar los tratamientos del humectante y la labranza juntos en comparación con solo la aplicación del agente humectante. Debido a la poca correlación entre la propuesta del invernadero de cristal y el campo los resultados de este estudio necesitan ser interpretados con precaución. Nuestros datos podrían indicar que si el pasto *Bromus tectorum* no está presente en el sitio actualmente el uso de cadenas de anclaje o tratamiento en el suelo con agentes humectantes pueden aumentar el establecimiento de especies sembradas.

Key Words: anchor chaining, piñon-juniper, till, wetting agents, wildfire

INTRODUCTION

Large-scale catastrophic wildfires are becoming more frequent and severe within sagebrush ecosystems of the Intermountain West (Pellant 1990; D’Antonio and Vitousek 1992; Miller and Tausch 2002; Keane et al. 2008). After a fire, the ability of a site to recover is dependent on the degree that ecological processes have been altered both before and after the fire (Briske et al. 2005). Modifications to the soil’s ability to wet and retain water through the development or enhancement of a

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postfire water-repellent layer is one such alteration that has the potential to control site recovery (e.g., Osborn et al. 1967; Krammes and Osborn 1969; Madsen et al. 2011).

Soil water repellency is common in arid and semiarid climates where woody vegetation types with oil- or wax-rich leaves persist with associated thick litter layers (Doerr et al. 2000; Jaramillo et al. 2000; Madsen et al. 2008; Glenn and Finley 2009). Water repellency can be induced through the secretion of waxes, oils, and resins from plants, insects, and microorganisms (Neinhuis and Barthlott 1997; Doerr et al. 2000). These hydrophobic compounds are mainly long-chained fatty acids that can be subdivided into primarily aliphatic hydrocarbons and amphiphilic compounds (Doerr et al. 2000; Horne and McIntosh 2000).

During a fire, heat volatilizes organic substances in the litter and upper water-repellent soil layers. These volatilized compounds move downward into the soil, condensing around soil particles in the cool underlying soil layers, resulting in a shallow wettable layer at the soil surface and an intensified water-repellent zone below (DeBano et al. 1970; Doerr et al. 2009). Postfire water repellency decreases site stability by promoting wind and water erosion and impairing revegetation success (Doerr et al. 2000; Ravi et al. 2010). For example, during a rainfall event, water repellency impedes infiltration, leading to rapid saturation of the upper wettable layer. On steep slopes this saturation can enable water, soil, and debris to quickly flow downslope, resulting in extensive soil erosion, site degradation, and sediment pollution (DeBano 1981). Seeds that germinate in the upper wettable soil layer experience limited soil moisture availability as the water-repellent layer redirects soil moisture below the seedlings' root zone through breaks in the water-repellent layer (Madsen 2010).

Limited seedling establishment can expose a site to weed invasion (Young et al. 1976; Keeley et al. 2005) and subsequently impair ecological services (i.e., Arnold et al. 1964; D'Antonio and Vitousek 1992). In light of these effects and the large amount of public capital invested in postfire rehabilitation treatments (Knutson et al. 2009), it may be important for postfire restoration practices to utilize treatment strategies that help mitigate impacts from soil water repellency.

Broadcast seeding followed by one-way anchor chaining has been shown to improve establishment of aerial-seeded plants, which subsequently minimizes weed invasion and promotes ecological function (MacDonald 1999; Ott et al. 2003; Juran et al. 2008). This versatile technology allows land managers to reseed landscapes that are typically not treatable by other mechanical methods due to a wide range of surface conditions such as steep slopes, rocky terrain, and accumulation of large woody plant material (McKenzie et al. 1984). Anchor chaining is of particular value for reseeding burned pinyon-juniper (*Pinus* spp.–*Juniperus* spp.) (P-J) ecosystems. When applied to this system, the tilling action of the anchor chain is thought to improve seedling establishment by enhancing seed soil contact and helping to “break up” the water repellency within the soil (Utah State Legislature Natural Resources, Agriculture, and Environment Interim Committee 1997). While there has been substantial internal knowledge developed over the years by land management personnel, formal studies examining the mechanisms by which anchor chaining influences restoration efforts in water-repellent soils is lacking. Improving our understanding of how anchor chaining influences site recovery in the presence of

water-repellent soil will aid in the design and implementation of future restoration treatments.

The application of wetting agents (surfactants) after fire has been shown to reduce soil erosion and improve vegetation establishment on water-repellent soils in the chaparral ecosystem (e.g., Osborn et al. 1967; Krammes and Osborn 1969; DeBano and Conrad 1974). Since the 1970s, wetting agents have had limited use in wildland systems even though they have been extensively applied in urban landscapes (e.g., turfgrass). This use in urban landscapes has led to improvements in the effectiveness of wetting-agent chemicals for treating soil water repellency (Kostka 2000; Kostka and Bially 2005; Soldat et al. 2010; Oostindie et al. 2011). Recent evaluations within a glasshouse setting by Madsen (2010) provided evidence that wetting agents can improve ecohydrologic properties required for plant growth within postfire pinyon-juniper plant communities. Madsen (2010) found that water-repellent soil treated with wetting agent had significantly higher infiltration rates, soil water content, plant density, and biomass than a water-repellent soil without wetting agents. Subsequently, wetting agents may also provide an innovative approach for alleviating the effects of soil water repellency and promoting establishment of desired species.

The primary objectives of this study were to 1) compare seedling emergence, survival, and growth of a native plant species “Anatone” bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) A. Löve] to that of cheatgrass (*Bromus tectorum* L.) in the presence of water-repellent soil; and 2) evaluate the effectiveness of wetting agents and soil tillage for ameliorating soil water repellency and improving soil water content, seedling density, plant survival, and plant biomass. Our hypothesis was that seedling emergence and growth of bluebunch wheatgrass and cheatgrass would be limited on water-repellent soils, and that the amelioration of soil water repellency through tillage or wetting agent application would benefit both species.

MATERIALS AND METHODS

Study Area

Effects of wetting agent application and simulated mechanical soil disturbance on postfire water-repellent soil were evaluated in a glasshouse experiment conducted from 10 February through 22 April 2009 at Brigham Young University (BYU), Provo, Utah. Soil used in the study was collected from the subcanopy of burned Utah juniper trees [*Juniperus osteosperma* (Torr.) Little], within the boundaries of the 2007 Milford Flat wildfire. This fire was ignited by lightning on 6 July 2007 and rapidly became Utah's largest wildfire on record, burning over 145 000 ha before its containment on 10 July 2007. Soil was collected 1 yr after the fire 13.7 km northwest of Milford, Utah (lat 38°26'12"N, long 112°51'46"W) at the base of the Mineral Mountain Range. At this site the soil is a coarse sandy loam, mixed, mesic Aridic Haploxerolls. Before the fire, the vegetation community at the study site was a Phase III, P-J woodland (i.e., “trees are the dominate vegetation and primary plant layer influencing ecological processes on the site”; Miller et al. 2005), with Utah juniper and singleleaf pinyon (*Pinus monophylla* Torr. & Frém.) as the predominant tree species. At the time of soil collection, the soil remained almost completely bare of live vegetation. Research

by Madsen (2010) found that the upper layer of the soil was wettable down to 1.7 ± 0.2 cm, after which the soil was water repellent, down an additional 4.5 ± 0.2 cm. Estimates of the severity of the water-repellent layer using the water drop penetration time test (Krammes and DeBano 1965) showed that on average it would take 87.6 ± 11.0 min (average and standard error of the mean) for a water drop to enter into the soil.

Study Design

Soil was collected with minimal disturbance by pressing large cylinders (20 cm diameter by 36 cm deep) into the soil with a front-end loader. Each cylinder or tube was then modified for use as a growing pot by fastening permeable ground cloth around the bottom to secure the core within the tube. In the glasshouse, pots were planted with either bluebunch wheatgrass or cheatgrass. Soil treatments included tilling, wetting agent application, both tilling and wetting agent application (till/wetting agent), and no amelioration treatment (control). The study was arranged in a randomized block design, with five blocks and three subsamples per treatment, for a total of a 120 pots in the study (2 species by 4 treatments by 5 blocks by 3 subsamples = 120 pots).

The tilling treatment was designed to mimic the effects of an Ely-style anchor chain (Vallentine 1989; Ott et al. 2003). Soil was tilled by pushing a handheld spade into the soil to a depth of 10 cm and then rotating on a horizontal plane, with the vertex at the soil surface, until the bottom of the spade emerged from the soil. This motion was repeated four times in each pot assigned to receive a till treatment.

Following the till treatment, all pots were seeded with 15 seeds of either bluebunch wheatgrass or cheatgrass, by hand-pressing the seeds just under the soil surface in each pot. Bluebunch wheatgrass seed was purchased from Granite Seed Company (Lehi, UT). Cheatgrass seed was collected within the boundaries of the Milford Flat fire near the area the soil cores were collected. Total germination was 65% for bluebunch wheatgrass and 99% for cheatgrass (as tested in 13-cm-diameter petri dishes using three replications of 100 seeds per species).

A non-ionic wetting agent from Aquatrols Corporation of America (Paulsboro, NJ), which is composed of a blend of alkylpolyglycoside and ethylene oxide/propylene oxide block copolymers, was applied at $0.012 \text{ ml} \cdot \text{cm}^{-2}$ when the pots were first watered. Throughout the course of the study a mist sprinkler system was used to water the pots at a rate of $2.7 \text{ cm} \cdot \text{h}^{-1}$. Each pot received 400 ml of water during the initial watering. To encourage seed germination, pots were watered over the next 6 d, as needed, in order to keep the surface soil moist. Following this period, we watered pots with 400 ml, every 7 d for the duration of the study. Temperature of the glasshouse was set at 23°C with a 12-h photoperiod.

Measurements

Variables measured to assess treatment effects included soil water content, plant density, and above- and below-ground biomass. For each of the different water repellency amelioration treatments and the control, we randomly selected five pots for soil water content measurements. Soil water content was recorded every half hour with EC-5 Soil Moisture Sensors in conjunction with Em5b data loggers (Decagon Devices, Pullman,

WA). We placed the soil probes within the wettable soil surface layer because it best represented growing conditions for newly emerged seedlings.

We measured plant density throughout the course of the study by recording the number of live seedlings every 3 d for all pots in the study. At harvest (61 d after seeding), we washed roots free of substrate and measured separately above-ground and below-ground biomass (dried at 65°C for 72 h).

Data Analysis

Data were analyzed using SAS (Version 9.1; SAS Institute 2002), with significance determined at the $P < 0.05$ level. The difference between the treatments for soil water content was investigated for each watering period, using repeated measures ANOVA analysis. A general linear model ANOVA for analyzing randomized complete block designs was used to determine differences among treatments and species for seedling density, above-ground biomass, and below-ground biomass. Seedling counts were analyzed at peak plant density (around 9–15 d after seeding depending on treatment and species) and at the conclusion of the study. We also compared the percentage of seedlings lost between peak density counts to the number of seedlings alive at the end of the study. A separate analysis was also performed on peak and final plant densities after normalizing the species densities by total germination percentage. When conducting pairwise comparisons species were treated as split-plot factors, with mean values separated using Fisher's Least Significant Difference test.

RESULTS

Treatment, watering period, and treatment by watering period interactions were significant for soil water content ($P < 0.001$). Differences among treatments for soil water content were generally greatest at the beginning of the study and decreased over time (Fig. 1). Water content of soil treated with wetting agent was significantly higher than all treatments for the first five watering periods. Beyond that point, soil treated with wetting agent differed only from the control. Water content in soils receiving the till/wetting agent treatment was higher than observed in soils receiving only the till treatment for the first three watering periods and was higher than the control for all watering periods except period 8. Soil water content response was mixed for the till treatment with relatively moderate increases during the initial part of the study (day 0–12) and final half of the study (day 35–61) (Fig. 1).

Species and treatment interactions for peak and final density were significant (Table 1; Fig. 2A). Cheatgrass seedling density was consistently 1.5 times greater than that of bluebunch wheatgrass across all treatments. When seedling densities were normalized by the percentage of germinable seeds, species was not a significant factor (Table 1; Fig. 2). The lowest peak seedling density values were associated with the till treatment. Wetting agent and till/wetting agent treatments had greater peak seedling density than the till treatment. The control showed intermediate values relative to till and wetting agent treatments (Fig. 2).

Seedling mortality between peak density counts and that recorded at the end of the study was attributable only to

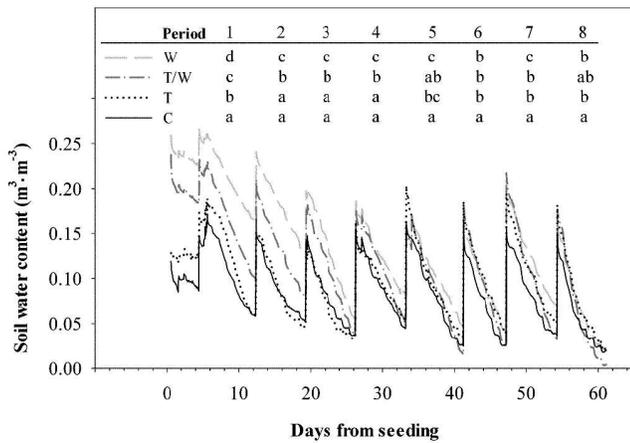


Figure 1. Average soil water content over the course of the study for control (C), till (T), wetting agent (WA), and till+wetting agent (T/WA) treatments. Significance is denoted by watering periods with different lowercase letters indicating significant differences among sampling periods ($P < 0.05$).

treatment main effects (Table 1). Over the course of the study, seedling density dramatically decreased in the controls with 53% and 63% of the seedlings from peak density counts desiccating by the end of the study, for cheatgrass and bluebunch wheatgrass, respectively (Fig. 3). In contrast, relatively few seedlings desiccated in the till, wetting agent, and till/wetting agent treatments, with seedling loss ranging between 8% and 22% depending on the treatment and species (Fig. 3). At the conclusion of the study, plant density was similar between the control and till treatments, while wetting agent and till/wetting agent treatments had significantly higher plant densities than the till treatment (Fig. 2).

Differences in above-ground and below-ground biomass were also attributable to species and treatment main effects (Table 1). The wetting agent, till/wetting agent, and till treatment all produced more above-ground biomass than the control for both species (Fig. 4). A similar response was found for below-ground biomass with wetting agent and till/wetting agent treatments having greater below-ground biomass than the control. The till treatment also had more below-ground biomass in comparison to the control for cheatgrass; however, bluebunch wheatgrass was similar between the till and control for this parameter.

Table 1. *P* values from mixed-model ANOVA analysis results on the effects of species, treatment, and species by treatment interactions. Significant *P* values are italicized.

Response variables	Species	Treatment	Species × Treatment
Peak density	<i>< 0.001</i>	<i>< 0.001</i>	0.745
Final density	<i>< 0.001</i>	<i>< 0.001</i>	0.335
Peak density normalized with germ.	0.471	<i>< 0.001</i>	0.923
Final density normalized with germ.	0.228	<i>< 0.001</i>	0.977
Above-ground biomass	<i>< 0.001</i>	<i>< 0.001</i>	0.862
Below-ground biomass	<i>< 0.001</i>	<i>< 0.001</i>	0.093

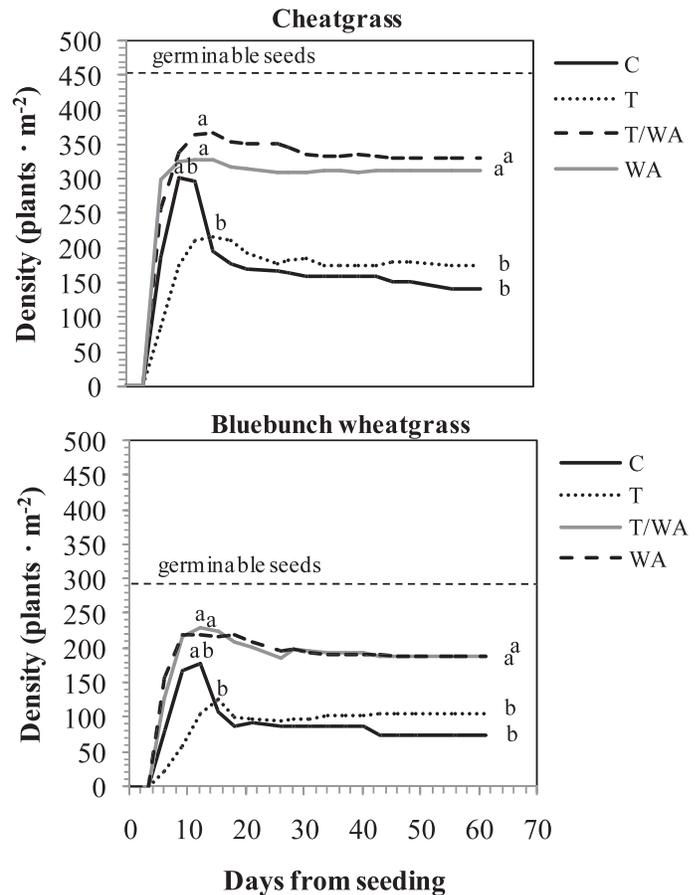


Figure 2. Seedling density of cheatgrass and bluebunch wheatgrass for the treatments control (C), till (T), wetting agent (WA), and till+wetting agent (T/WA). Statistical analysis was performed at peak density (about 9–15 d after seeding depending on treatment and species) and final density. Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

DISCUSSION

The results of this study support earlier observations that wetting agents can ameliorate postfire water repellency and subsequently help restore ecohydrologic function, in conjunction with reseeding efforts (e.g., DeBano et al. 1967; Osborn et al. 1967; DeBano and Rice 1973; DeBano 1981). For example, the wetting agent treatment more than doubled plant density and tripled biomass production of bluebunch wheatgrass. Increases in seedling emergence, survival, and biomass production may be specifically related to higher soil water contents and therefore longer periods of available soil moisture during periods when emergence and early growth occurred (Figs. 1 and 2). In this study, differences in soil water content between wetting agent and non-wetting agent-treated soil was most pronounced at the beginning of the study, with the treatments becoming more similar over the study period (Fig. 1). The decreasing difference in soil water content between the treatments as the study progressed may be a result of higher plant water use associated with greater plant density and growth in the wetting agent treatment compared to the control (Fig. 1).

Soil tillage designed to simulate anchor chaining showed mixed results. Tillage had lower peak density values than both

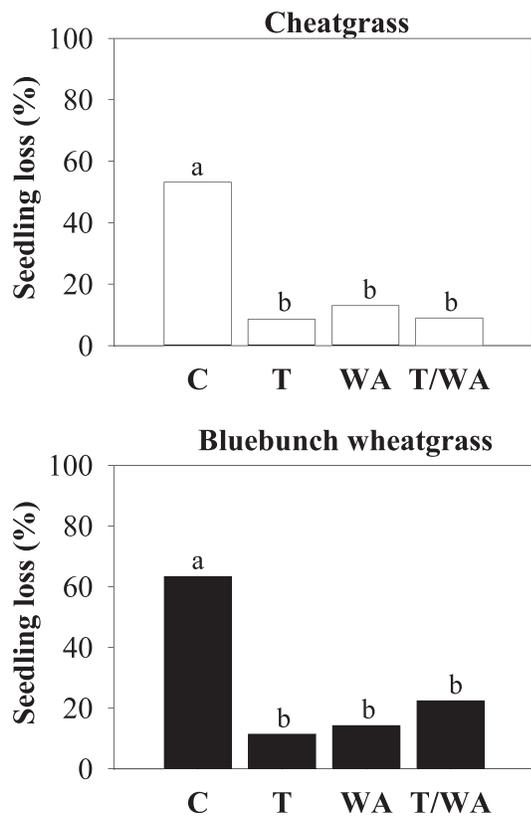


Figure 3. Seedlings lost over the course of the study for control (C), till (T), wetting agent (WA), and till + wetting agent (T/WA). Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

the control and wetting agent treatments; however, fewer seedlings desiccated over the period of study (Fig. 3), which resulted in the till treatment having, at least on average, higher seedling densities compared to the control (Fig. 2). Decreased seedling emergence in the till treatment was associated with lower soil water content near the soil surface. When the tilling treatment was implemented, water-repellent soil was brought to the soil surface. In this treatment we suspect that at the seed scale, soil water availability may have been limited for seeds in contact with the water-repellent soil, which resulted in relatively low seedling emergence. However, within this same treatment, there may have also been seeds that were associated with breaks in the water-repellent zone from the tilling of the soil. These breaks potentially created conditions favorable for seedling emergence and survival by creating a zone where the seedlings could be connected with the underlying soil moisture reserves. This study also indicates that mechanically tilling water-repellent soil enhances plant growth. Lack of significance between the control and till treatment for seedling density (Fig. 2) but greater above-ground biomass in the till over the control (Fig. 4) suggests that growth of surviving seedlings was increased by increased root zone water availability associated with tilling.

In general there did not appear to be any significant benefit to applying both till and wetting agent treatments together over just adding wetting agent alone. In this study wetting agent application appears to be superior for increasing seedling emergence and plant density in comparison to tilling the soil. However, possible dissimilarities between glasshouse and field

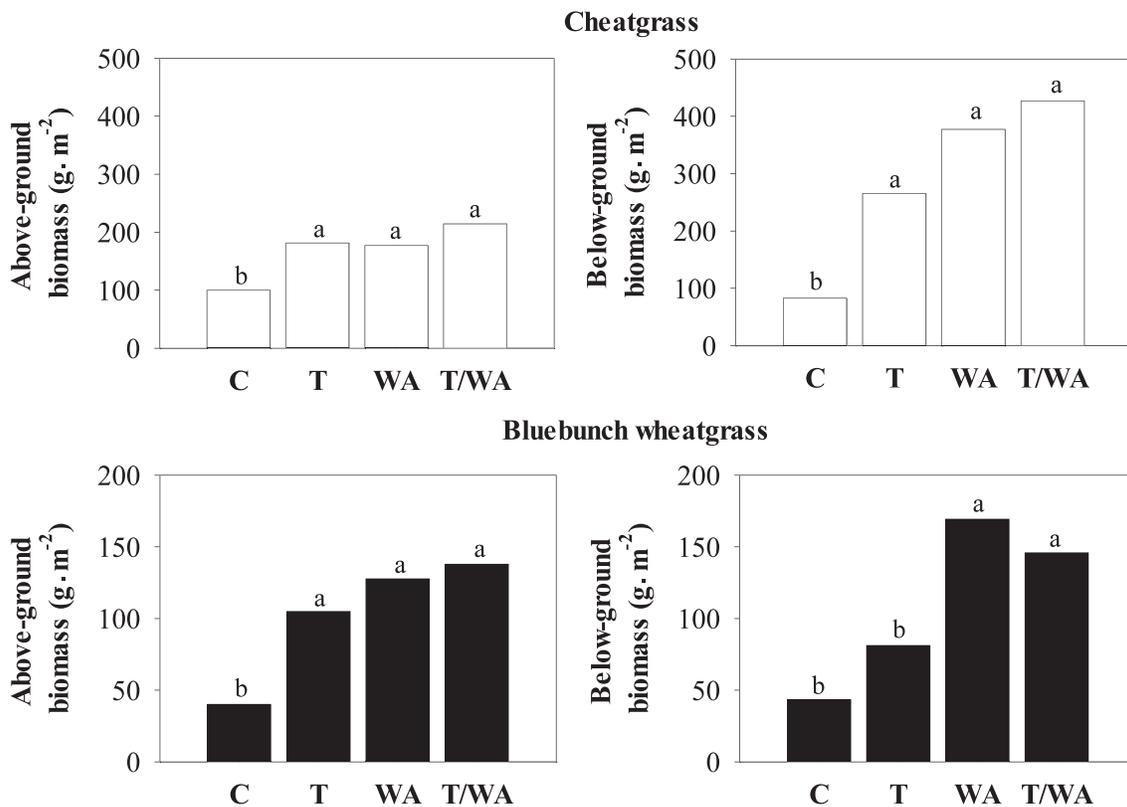


Figure 4. Above- and below-ground biomass of cheatgrass, and bluebunch wheatgrass grown on water-repellent soil, for control (C), till (T), wetting agent (WA), and till + wetting agent (T/WA) treatments. Different lowercase letters indicate significant differences among treatments ($P < 0.05$).

conditions, treatments, and effects require that the results of this study be interpreted with caution. The tilling treatment implemented in this study was designed to replicate soil disturbance from an anchor chain, but our methods failed to capture other perceived benefits associated with the anchor chain treatment. For example, aerial seeding of low elevation rangeland systems usually requires some form of seed coverage to be successful (Whisenant 1999). A perceived benefit to anchor chaining not realized in this study is that the anchor chain can be an effective tool for covering broadcast seed (Ott et al. 2003; Juran et al. 2008). In addition, as the anchor chain is dragged across the ground, it increases the number of “safe sites” (i.e., microtopographic locations with increased duration and amount of soil moisture; Harper et al. 1965) by making depressions in the soil, knocking over trees, and distributing debris over the soil surface (Farmer 1995; Roundy and Vernon 1999; Ott et al. 2003). Consequently, the full utility of anchor chaining is not realized in this study; field work is merited for comparing anchor chaining, wetting agents, and a combination of the two for improving seedling emergence and plant survival.

This study also suggests that water repellency limits establishment success of bluebunch wheatgrass in a similar manner as cheatgrass. Consequently, restoration treatments applied to treat soil water repellency has the potential to also promote the establishment of cheatgrass and possibly other invasive weeds. Whether wetting agents or anchor chaining will promote weed invasion may be dependent on the presence of weed seed. Catastrophic wildfires provide invasive species the opportunity to spread into new areas, by increasing resource availability (Davis et al. 2000). Thus, reseeding efforts are implemented to establish desired species before invasive species can invade (USDI-BLM 1999; Epanchin-Niell et al. 2009; Knutson et al. 2009). When reseeding efforts are successful the desired species can be effective at preventing cheatgrass invasion (Thompson et al. 2006; Jessop and Anderson 2007). However, if postfire water repellency decreases seeding success, this soil condition could lead to dominance by cheatgrass and other invasive weeds. The potential negative effect of water repellency on survival of seeded species immediately after a wildfire may provide an opportunity for weed invasion after soil water repellency has dissipated one or more years after the fire. Therefore, if wetting agents or anchor chaining can increase establishment of desired species in water-repellent soil, there is a potential for both of these treatments to indirectly decrease weed invasion.

MANAGEMENT IMPLICATIONS

Results of this study indicate that soil water repellency can impair seedling survival and plant growth of bluebunch wheatgrass and cheatgrass. Our data support the use of wetting agents as an effective means for mitigating the effects of soil water repellency and promoting establishment of bluebunch wheatgrass seeds and potentially other seeded species. This study did not show that soil tillage through anchor chaining would improve seedling density, but demonstrated that this treatment can enhance survival and biomass of those seedlings that do emerge. Wetting agents and anchor chaining also have the potential to promote establishment of weed species, suggesting

that caution be used when implementing these treatments. Future research is merited for repeating this study in the field to evaluate the long-term effects of wetting agent application and anchor chaining on reseeding success.

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