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Surface soil physical and hydrological characteristics in *Bromus tectorum* L. (cheatgrass) versus *Artemisia tridentata* Nutt. (big sagebrush) habitat

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ABSTRACT

Limited information exists of the differences in soil physical and hydrologic properties in invasive *Bromus tectorum* L. (*BT*) (cheatgrass) habitats versus native *Artemisia tridentata* Nutt. (*AT*) (big sagebrush) habitats. Our objective was to assess differences in soil physical and hydrological properties by comparing measures of soil particle size; aggregate stability; hydrophobicity; bulk density; penetration resistance; surface roughness; and infiltration (double-ring and mini-disk tension infiltrometer) between habitats. *BT* sites were sampled following *AT* stand replacing fires that resulted in near continuous *BT* establishment. Sites characterized by *AT*, and not burned, were sampled as controls. Significantly lower infiltration rates and surface roughness ratios in conjunction with statistically significant higher aggregate stability and penetration resistance suggest that *BT* sites have different surface physical characteristics from *AT* sites. Lower surface roughness and higher penetration resistance on *BT* sites may yield greater runoff, subsequently providing less available water for plant growth. However, higher aggregate stability and plant cover on *BT* sites may negate this effect. Higher percentage coarse sand fractions and lower percentage fine fractions, in conjunction with smoother, less permeable surfaces on *BT* sites, suggest the potential for soil erosion on *BT* sites. Further research is needed to elucidate the specific mechanisms responsible for the differences seen between *AT* and *BT* sites and whether post fire *BT* occupation, fire, or landscape differences are responsible.

1. Introduction

The ability of *BT* to out-compete native species for available nutrients and water, and its propensity to quickly colonize open niches in an ecosystem as a result of a disturbance event (e.g., fire, over-grazing), has greatly stressed the native *AT* shrub-steppe ecosystem in the northern Great Basin (Brooks et al., 2004). The extent of the problem is large too. West (1999) estimates that approximately half of the existing sagebrush steppe habitat in Western North America (44 million ha (Miller and Edelman, 2000)) has been invaded by *BT* and of this approximately 25% is dominated by *BT*. Areas invaded by *BT* have experienced a decline in native species floristic diversity (e.g., Knapp, 1996) and changes to fire regimes (e.g., Brooks et al., 2004) that have resulted in lower soil biota diversity and shifts in the structure of the soil food web (e.g., Belnap and Phillips, 2001). Soil change following *BT*'s invasion of native ecosystems has resulted in shallow, rapid cycling of soil organic matter leading to less soil organic matter and more NO_3^- N (Norton et al., 2004) and shifts in soil nutrient cycling leading to lower potential net N mineralization (e.g., Belnap and Phillips, 2001; Evans et al., 2001). Research comparing non-invaded soil to soil in areas invaded by *BT* (hereafter called *BT* soils) indicate invaded soils have different soil morphologies (Norton et al., 2004), have higher silt and lower sand fractions (top 10 cm of the soil sampled) and less biological diversity in the upper 10 cm as well as compared to control sites (Belnap and Phillips, 2001). Ground litter has also been found to decrease with *BT* invasion (Knapp, 1996). Soil surface changes due to *BT*'s invasion may be due to the tendency of the species to form more uniform, dense cover than vegetation native to the Great Basin (Knapp, 1996).

Changes in soil morphology and physical properties due to *BT* thus point to a transition in pedogenesis or pedodegradation from that which resulted in the native ecosystem and its soil. Such a change, while perhaps temporary, could be a very important factor in determining water movement within a soil system, especially since native Great Basin species compete less effectively for soil water as compared to invasive *BT* (Melgoza et al., 1990). Based on the work of Norton et al. (2004) and Belnap and Phillips (2001) it would appear that *BT* could change soil moisture in invaded areas due to changes in plant cover, surface characteristics, and soil morphology. For example, infiltration and overland flow are typically controlled by soil structure and/or aggregate stability (Debano et al., 1998; Weltz et al., 1998). As soil structure is broken down due to fire, or changed in response to *BT* invasion, soil could be more or less susceptible to transport by overland flow (Debano et al., 1998; Weltz et al., 1998; Abu-Hamdeh et al., 2006).

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The loss of soil structure can also decrease surface roughness (Mwendera and Feyen, 1994) (surface micro-topography), which allows water falling on the surface to flow more quickly across the landscape, decreasing infiltration (Debano et al., 1998; Zhang et al., 2007). Undisturbed soil has a combination of both micropores and macropores that allow for easy movement of water and air through the soil. Changes to the soil structure (and thus the pore sizes and distribution) will affect the distribution and extent of the soil's porosity (Mwendera and Feyen, 1994; Debano et al., 1998) and water movement.

Little research has been conducted to date on differences in soil properties and surface characteristics that can influence soil moisture in areas inhabited by *BT* versus native *AT*. Given the importance of soil moisture in arid environments and previous research showing *BT*'s invasive effect on soil and native species, our objective is to determine if differences exist in surface and near-surface soil physical and hydrological properties between *BT* (on former *AT* sites) and *AT* sites. Our data can then be used to better understand potential differences in soil surface physical and hydrological properties in the different habitats.

2. Study area

2.1. Physiography

Study sites (Table 1A) are located in the northern extent of the Basin and Range province near Winnemucca, Nevada. All study sites occur on alluvial aprons late Pleistocene in age; the surface at one site is believed slightly older in age than other study sites but still late Pleistocene (Hawley and Wilson, 1965). Site elevations range from 1361 m to 1500 m above mean sea level on mostly southwest to northwest aspects and 0–4% slopes (Table 1A). Mean annual precipitation across the study area is 210 mm year^{-1}, mean annual temperature is 9.5 °C as measured at Winnemucca Municipal Airport, Winnemucca, Nevada (WRCC, 2006), and all soils are moderately alkaline (Table 1B).

2.2. Site selection

All potential study sites were identified and final ones selected based on known habitat type, fire history, and desired soil characteristics (soils chosen for the study were taxonomically similar across treatments according to soil survey maps and field observations). Sampling was conducted on four sites occupied by *BT* and four sites occupied by *AT* (Table 1A). *BT* sites were chosen from areas that were known to have been in *AT*, undergone a single stand replacing fire, and subsequently colonized by *BT* the following year of the fire (sites had been recorded as *AT* by Mike Zielinski, BLM Winnemucca, unpublished data). The earliest a plot was burned was in 1985 with other sites subsequently having fires in 1987, 1998, and 2002. To minimize the effects observed due to multiple fires, all *BT* study sites were selected where no fires have taken place since the original *AT* stand replacing fire. All study sites were located on open rangeland with particular care taken to avoid any study site that showed evidence of concentrated cattle usage or other obvious disturbance. All sites were located away from fences, water tanks, salt licks, and trees.

At each study site, soils were examined and sampled by pedologists including the mapping specialist who conducted the NRCS Soil Survey for the study area. At each site, soils were initially examined via four shallow excavations to 50 cm along a 100 m transect to insure similarity in soil morphologic properties (soil color, horizon depth and thickness, % rock fragments, root distribution, presence or absence of duric features) within the study site and to other study sites. From these holes, a single 1 m pit was hand excavated and a field description was made (Table 1B) (Schoeneberger et al., 2002) that was closely compared to the other study sites to ensure that soils chosen for the study were taxonomically similar across treatments. Study site soils are characterized as well drained and having formed from a mix of ash mantled alluvium derived from mixed rock sources and eolian parent materials. All soils sampled in the study were classified as xeric haplodurids (NRCS, 2006). The remaining three holes had 4 kg of soil sampled from the depths: 0–5 cm, 5–10 cm, and 10–15 cm. We assumed that over the time period of *BT* establishment considered in this study, most soil differences due *BT* would be seen first within the surface/A horizon. Since the majority of *BT* roots observed in this study were found to occur within the A horizon, it was deemed appropriate to evaluate potential differences due to *BT* by staying within 0–15 cm depth (A horizon). It was also apparent that the majority of the differences in site litter layer and soil structure, which would have a large effect upon water movement into the soil profile, would occur near the surface. On *AT* sites, soils were sampled underneath the drip line of *AT* foliage rather than completely underneath the shrub or in an interspace.

Field sampling was completed over the course of 2 years. *BT* sites were sampled in June 2005 for bulk density, and particle size analysis (percent sand, silt and clay and sand fractions). In June 2006, infiltration rate, hydraulic conductivity, surface roughness and aggregate stability were measured on the same four *BT* sites. On *AT* sites, soils were sampled and/or measured in June 2006. During sampling there were no extreme weather events, site disturbances or

Table 1A
Site characteristics

Site	Fire year	Elevation m	Aspect °	Slope %	Easting m	Northing m
*BT*1[a]	1985[b]	1452	194	3	426279[c]	4524682
*BT*2	1987	1361	35	2	429209	4515027
*BT*3	1998	1428	108	3	438405	4529049
*BT*4	2002	1500	345	2	448289	4537555
*AT*1	None	1418	199	4	438460	4528762
*AT*2	None	1420	210	3	438462	4512979
*AT*3	None	1431	223	3	437749	4528360
*AT*4	None	1425	212	3	439209	4528532

[a] *BT*=*B. tectorum*, *AT*=*A. tridentate*.
[b] Year of initial fire or None=no fire.
[c] NAd 83, UTM zone 11N.

Table 1B
Example pedon from pit at each site

Horizon	Depth cm	Color dry[a]	Consistence/Stickiness/Plasticity[b]	Structure[b]
A	0 to 14	10YR 6/2	Soft, friable/non-sticky/non-plastic	Weak, thick platy
Bw1	14 to 35	10YR 6/3	Lightly hard, friable/nonsticky/non-plastic	Weak fine and medium subangular blocky structure
Bw2	35 to 58	10YR 6/4	Soft, friable/nonsticky/nonplastic	Medium subangular blocky structure
Bkq	58 to 105	10YR 6/4	Soft, friable/nonsticky/nonplastic	Medium subangular blocky structure to massive
Horizon	**Field pH[c]**		**Roots[b]**	**Carbonates present¶**
A	7.4–7.6		Many, very fine to fine roots, throughout	Weakly effervescent
Bw1	7.4–7.7		Many very fine and few fine roots, throughout	Weakly to moderately effervescent
Bw2	8.1–8.3		Common very fine, few fine and medium roots, throughout	Moderately effervescent
Bkq	8.7–9.1		Common very fine, few fine and medium roots, throughout	Violently effervescent

¶Effervescence measured in the field with 1N HC1 per Schoeneberger et al. (2002).
[a] Site B2 had a 10YR 6/4 in the top horizons and a 10YR 7/2 in the two bottom horizons.
[b] per Schoeneberger et al. (2002).
[c] Field pH taken with colometric dye, range across all sites provided.