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Anchor Chaining's Influence on Soil Hydrology and Seeding Success in Burned Piñon-Juniper Woodlands

M.D. Madsen [a,*], D.L. Zvirzdin [b], S.L. Petersen [b], B.G. Hopkins [b], B.A. Roundy [b]

[a] USDA – Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, OR 97720, USA
[b] Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT 84602, USA

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ABSTRACT

Broadcast seeding is one of the most commonly applied rehabilitation treatments for the restoration of burned piñon and juniper woodlands, but the success rate of this treatment is notoriously low. In piñon-juniper woodlands, postfire soil—water repellency can impair seeding success by reducing soil—water content and increasing soil erosion. Implementing anchor chaining immediately after seeding can improve establishment of seeded species by enhancing seed-to-soil contact and may improve restoration success by decreasing soil—water repellency through soil tillage. The objectives of this research were to 1) determine if anchor chaining in postfire pinyon-juniper woodlands diminishes soil—water repellency, and 2) determine meaningful relationships between soil—water repellency, unsaturated hydraulic conductivity [$K(h)$], and the establishment of seeded and invasive species. Research was conducted on two study sites, each located on a burned piñon-juniper woodland that had severe water repellency and that was aerially seeded. At each location, plots were randomly located in similar ecological sites of chained and unchained areas. At one location, anchor chaining considerably improved soil hydrologic properties, reducing the severity and thickness of the water-repellent layer, and increasing soil $K(h)$ 2- to 4-fold in the first 2 yr following treatment. At this same location, anchor chaining increased perennial grass cover 16-fold and inhibited annual grass and annual forb cover by 5- and 7-fold, respectively. Results from the second site only showed improvements in soil $K(h)$; other hydrologic and vegetative treatment responses were not significantly improved. Overall, this research suggests that anchor chaining has the potential to improve restoration outcomes, though additional research is warranted for understanding the direct impact of anchor chaining on soil—water repellency without the interaction of a seeding treatment.

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Introduction

Sagebrush (*Artemisia* spp.) ecosystems of western North America are rapidly declining (Davies et al., 2011). The expansion of piñon (*Pinus* ssp.) and juniper (*Juniperus* spp.) woodlands (Davies et al., 2011) represents a significant component in the loss of sagebrush communities. Estimates show that piñon-juniper woodlands currently occupy 40 million hectares (Romme et al., 2009). This represents a 10-fold increase from the pre-European settlement period (Miller and Tausch, 2001). As these woodlands mature, fuel loads and tree canopy cover increase, promoting large-scale, high-intensity wildfires (Miller and Tausch, 2001; Miller et al., 2008). The loss of shrubs and perennial grasses associated with advanced tree infilling and high-intensity fire reduce ecosystem resilience (Miller and Tausch, 2001; Miller et al., 2008). Lack of perennial shrubs and grasses encourages a shift to an introduced annual weed community (Bestelmeyer et al., 2009; Miller and Tausch, 2001). The domination by invasive annuals, such as cheatgrass (*Bromus tectorum* L.), increases the frequency and scale of wildfires, which further promotes invasion (D'Antonio and Vitousek, 1992); with this conversion, hundreds of sagebrush obligate species are declining or at risk of extirpation (Rowland et al., 2006). Loss of native vegetation is also affecting rangeland ecosystem goods and services, including national and regional food supplies, water quality, and recreation (Brunson and Tanaka, 2011).

Land managers can halt the shift to an introduced nonnative annual community by successfully seeding desired perennial species after a wildfire (Goodrich and Rooks, 1999; Ott et al., 2003). Where economic and site conditions allow, a rangeland drill can effectively distribute and sow seeds of perennial species (Monson et al., 2004). However, the presence of tree skeletons or steep and rocky soils can prohibit the use of a rangeland drill on many sites. Under these conditions, land managers are constrained to aerial broadcast seeding (Vallentine, 1989; Whisenant, 1999).

* Correspondence: Matthew Madsen, Eastern Oregon Agricultural Research Center USDA - Agricultural Research Service 67826-A Hwy 205 Burns, OR 97720, USA, Phone: (541) 573-8915 Cell: (801) 669-2812.
E-mail address: matthew.madsen@oregonstate.edu (M.D. Madsen).

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In low elevation (i.e., < 2 000 m) sagebrush communities where precipitation levels are low, broadcast seeding will often result in poor establishment of a perennial plant community (Allen, 1995; Lysne and Pellant, 2004; Ott et al., 2003; Tausch et al., 1995). With adequate precipitation, anchor chaining can improve the success of broadcast seeding efforts when implemented directly after the seeds are sown (Juran et al., 2008; Ott et al., 2003; Thompson et al., 2006). Anchor chaining is performed by pulling a 60—120-m—long anchor chain with 20—40-kg links between two heavy, continuous-tracked tractors traveling in the same direction. Swivels attached at both ends of the chain allow it to rotate and till the soil. Welding short 30—40-kg lengths of railroad iron across each link further increases disturbance; this type of chain is referred to as an "Ely Chain" (Cain, 1971; Fig. 1). Improvement in seeding success from anchor chaining has been primarily attributed to the technique's ability to 1) cover the seed (Ott et al., 2003), 2) increase the number of seed "safe sites" (Harper et al., 1965; Ott et al., 2003; Thompson et al., 2006), and 3) increase infiltration rates and decrease soil loss and sedimentation levels resulting from the redistribution of debris material from the burned trees (Roundy and Vernon, 1999).

Postfire anchor chaining may also improve seeding success by mitigating the effects of soil—water repellency as this condition is well documented in piñon-juniper woodlands (Jaramillo et al., 2000; Madsen et al., 2008; Madsen et al., 2012a; Roundy et al., 1978; Scholl, 1971; Zvirzdin, 2012). Although soil—water repellency is often present prior to fire, burning can increase its severity and spatial consistency (Doerr et al., 2000). During a fire, heat volatilizes hydrophobic molecules in the litter and upper soil layers; pressure gradients then force the material deeper into the soil where it condenses upon the cooler underlying soil particles (DeBano et al., 1976). This process of volatilization and condensation can intensify water repellency by increasing the continuity of hydrophobic substances across the profile (Letey, 2001) and changing the nature of these substances, such that they bind tighter to soil particles and repel water more effectively (Doerr et al., 2009). The most clearly shown effect of soil—water repellency is the negative relationship between soil—water repellency and infiltration (DeBano, 1971; Doerr et al., 2003; Madsen et al., 2011; Pierson et al., 2008). The reduction of water infiltration by soil—water repellency has many secondary effects, including reduced soil—water content near the soil surface (Madsen et al., 2011, 2012a; Wallis et al., 1990) and increased runoff and erosion (Benavides-Solorio and MacDonald, 2001; DeBano and Rice, 1973; Leighton-Boyce et al., 2007; Martin and Moody, 2001). Decreased soil moisture content and site stability impairs seeding efforts by reducing seed germination and establishment success (Letey, 2001; Madsen et al., 2012a; Wallis et al., 1990).

Observations by land management personnel have attributed improvements in restoration success from anchor chaining to the ability of the practice to disrupt the water-repellent layer with the tilling action of the chain (Utah State Legislature Natural Resources, Agriculture, and Environment Interim Committee, 1997). However, research is lacking that verifies this hypothesis and examines the mechanisms by which anchor chaining improves seedling germination and establishment in the presence of water-repellent soils.

The objectives of this research were to 1) determine if anchor chaining in postfire piñon-juniper woodlands diminishes soil—water repellency; and 2) determine meaningful relationships between soil—water repellency, hydraulic conductivity, and the establishment of seeded and invasive species. We hypothesize that anchor chaining will reduce soil—water repellency levels, which will increase soil hydraulic conductivity, and aid in the establishment of seeded perennial species and prevention of non-native annual weeds.

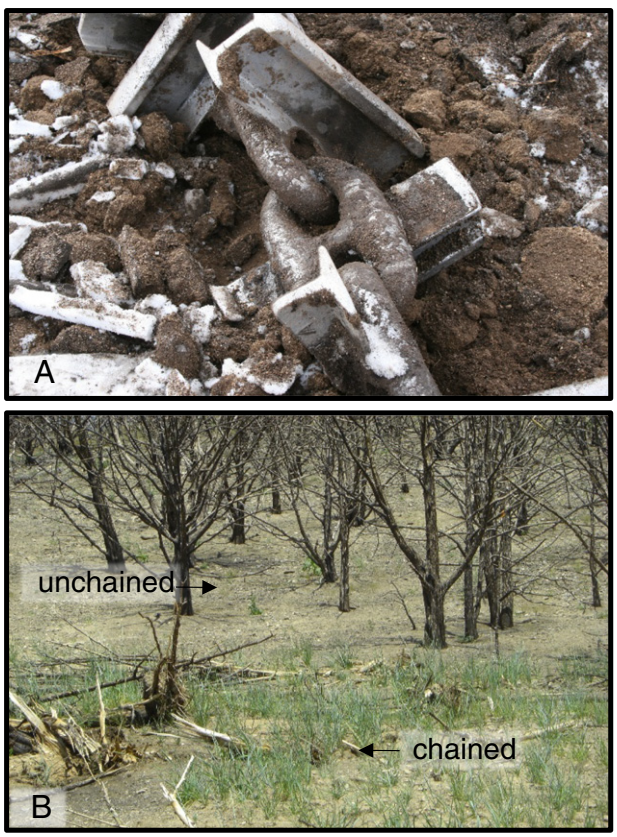

Fig. 1. A, Photo showing soil tillage created by an Ely-style anchor chain, and **B,** revegetation success between chained and unchained sites 2 yr after the Cedar Fort wildfire in Utah.

Methods

Study Site Description

We established study sites at the Cedar Fort and Milford Flat wildfires, located in central and south-central Utah, USA, respectively. The Cedar Fort fire was ignited by lightning on 3 August 2007 and burned 9 500 ha. Research at the Cedar Fort fire was conducted 4.3 km North of Cedar Fort, UT, USA (Lat: 40° 22' 10" N, Long: 112° 6' 6" W, elevation 1 841 m). The research site is predominantly southwest facing, and at the base of the Oquirrh Mountain Range. Prior to the fire, the plant community was in a Phase III juniper woodland development phase (Miller et al., 2008), with Utah juniper (*Juniperus osteosperma* [Torr.] Little) acting as the primary plant driving ecological processes. Soil parent material is alluvium derived from limestone and sandstone and is loamy-skeletal, carbonatic, mesic, shallow Petrocalcic Palexerolls (2—8% slope) (Soil Survey Staff, 2009). Soil pH is 8.5, organic matter content 1.5%, volumetric soil—water content at −1.5 MPa (permanent wilting point) and −0.33 MPa (field capacity) is equal to 6.2%, and 17.5%, respectively. Mean annual precipitation is approximately 330 mm (Soil Survey Staff, 2009). In October 2007, the State of Utah aerially seeded the site and portions of the fire boundary were anchor-chained with a single pass by an Ely-style chain. A seed mix of native and introduced species was applied at 13 $kg \cdot ha^{-1}$ of bulk seed. Particularly for the more arid and/or degraded sites in the Great Basin, nonnative species are commonly included in the seed mix to aid in soil stabilization and weed control (Monson et al., 2004). At this site, the native shrub Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle & Young) was sown. Native grasses seeded included slender wheatgrass (*Elymus*