EFFECTS OF JUNIPER REMOVAL BY BULLDOZING AND SHEARING ON SEEDBED PREPARATION AND VEGETATION ESTABLISHMENT IN THE LAMPASAS CUT PLAIN, TEXAS

A Thesis

by

CHERYL K. MANNEL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Rangeland Ecology and Management

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Approved by:

Chair of Committee,	Fred Smeins
Committee Members,	Richard Conner
	Wayne Hamilton
	Cristine Morgan
Head of Department,	Steven Whisenant

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ABSTRACT

Effects of Juniper Removal by Bulldozing and Shearing on Seedbed Preparation and Vegetation Establishment in the Lampasas Cut Plain, Texas. (December 2007)

Cheryl K. Mannel, B.A., Southwestern University

Chair of Advisory Committee: Dr. Fred Smeins

Woody encroachment upon grasslands is a global trend that is cause for concern. In the Lampasas Cut Plain of Texas, Ashe juniper is the dominant woody invasive species. Grassland restoration is dependent upon proper seedbed preparation and seedling establishment. Shearing and bulldozing are common methods of juniper removal. Three hypotheses were tested in this experiment. The first was that bulldozing and shearing results in similar seedbed preparations. The second was that electrical conductivity (EC_a) models soil moisture storage heterogeneity across a landscape. The third hypothesis tested was that bulldozing and shearing result in similar seedling establishment. Eighteen plots were selected and three treatments were applied: 1) shearing, 2) dozing, and 3) control. After clearing with both juniper removal methods, the levels of soil disturbance and vegetation regrowth were measured. Point measures were used to describe soil surface disturbance, and at each point, presence and size of ground cover and surface depressions were recorded. After germination, when the plants were large enough to identify, vegetation was sampled at 20-24 locations in each plot. At each sample location a quadrat was placed on the transect, and total herbaceous, grass, forb, rock, litter, and bare soil cover were recorded in cover classes. All species were identified, seeded species were enumerated, and in the second vegetation sample, dominant species were assigned a cover class.

There was considerable variation between plots for all parameters measured. Bulldozing created a greater number of depressions in the soil than shearing. It also had a higher percent of large depressions. There was no difference in ground cover change between treatments except in the case of the largest litter category. EC_a was effective in modeling soil moisture storage patterns and had a lower coefficient of variation than manual soil depth measurements. There was no difference between sheared and dozed plots for any of the vegetation establishment parameters, but control plots had lower establishment in most categories. Overall, there was little difference between the two treatments in seedbed preparation and seedling establishment. The cost of shearing was 80% of the cost of dozing, which made it more desirable in this scenario.

DEDICATION

This thesis is dedicated to the hard working and conscientious landowners who strive to achieve a balance between sustainable land use and profit. My hope is that this work will contribute to achieving this challenging and worthwhile goal.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Smeins, for helping me to become a better scientist and writer. I have a long way to go, but thanks to you, I have come far. I would also like to thank my committee members, Dr. Conner, Mr. Hamilton, and Dr. Morgan, for their guidance and support throughout the course of this research. Thank you so much for being generous with your time and advice.

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I also want to extend my gratitude to Steve Manning and the Leon River Restoration Program, which provided the funding for this research, and the private landowner who was willing to participate in the study.

Finally, thanks to my mother and father Beth and Terry Keelin for their support and encouragement and to my husband Bobby for his patience and love.

NOMENCLATURE

C	Carbon
Ca	Calcium
CEC	Cation Exchange Capacity
K	Potassium
Mg	Magnesium
N	Nitrogen
Na	Sodium
P	Phosphorus
c	clay
cl	clay loam
l	loam
scl	silty clay loam
sl	silty loam

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CHAPTER I

INTRODUCTION

The Lampasas Cut Plain of Texas was historically grassland with small stands of juniper and mixed timber (Scifres 1980). Fires would burn in areas of heavy fuel accumulation and they would reduce juniper populations in all areas except where fuel levels were minimal such as rocky outcrops (Hinesley 1986). Continual heavy grazing on Texas rangeland has substantially reduced the amount of mulch, litter, and standing vegetation, which along with anthropological influences, has removed fire from the range (Hamilton and Ueckert 2004). The suppression of naturally occurring fires and continuous heavy grazing are likely causes of the rapid increase in stand density and the expansion of the range of Ashe juniper (*Juniperus ashei* Buchholz) in central Texas over the past century (Archer 1989; Hamilton and Ueckert 2004; Hinesley 1986).

Ashe juniper is a small evergreen, non-sprouting gymnosperm tree. Its distribution ranges from Southern Missouri to Arkansas and into Oklahoma as well as central Texas, Mexico, and Guatemala (Blomquist 1990; Hinesley 1986; Smeins and Fuhlendorf 1997). While the geographic distribution of Ashe juniper is similar to its historic range, community densities have increased dramatically in the past century (Smeins and Fuhlendorf 1997; Smeins and Merrill 1988). Ashe juniper tends to proliferate on slopes atop shallow limestone soils in areas under sub-humid to semi-arid moisture conditions (Blomquist 1990; Dallimore and Jackson 1967; Hinesley 1986; Scifres 1980).

This thesis follows the style of *Rangeland Ecology and Management*.

It frequently forms dense stands which diminish ecological diversity and overall herbaceous production (Blomquist 1990; Fuhlendorf et al. 1997; Hinesley 1986; Yager 1993).

The reduction in palatable herbaceous cover has led many ranchers to resort to brush control to restore range sites to grasslands suitable for ungulate grazing. The three main methods of juniper management are mechanical control, chemical control, and burning. In central Texas, most brush control programs are geared toward mechanical methods.

Though mechanical brush removal has undergone no major innovation in the last 30 years, it is and will remain a popular form of range treatment for a number of reasons including its nearly immediate results (Burroughs et al. 2004). One study found that mechanical brush removal had better overall results compared to burning (Young et al. 1948). Mechanical clearing is also favored by some landowners who are concerned with wildlife because it allows for specific treatment locations with minimal disturbance to untreated areas, as opposed to chemical or fire control methods which may drift into unintended treatment areas (Burroughs et al. 2004). When selecting a method of mechanical brush control, several factors must be considered including, 1) species characteristics (density, size, sprouting ability), 2) seedbed preparation and revegetation (soil disturbance, reseeding), 3) topography (accessibility, erosion hazards), 4) soil properties (fertility, water retention), and 5) cost/benefit (Vallentine 1971).

The three main objectives of this study are: 1) determine if juniper removal through shearing or dozing creates different types and amounts of soil surface disturbance and results in differential seedbed preparation, 2) determine if soil moisture heterogeneity across research plots can be predicted using soil bulk electrical conductivity measurements, and 3) determine whether the juniper clearing by bulldozer or shearing results in different seed germination and seedling establishment.

Study Area

Field experiments were conducted on a private ranch near Pearl, Texas, in the Lampasas Cut Plain region in Coryell County (Fig. 1) which is a mix of the Grand Prairie and Cross Timbers regions of Texas.

The area is typified by hot summers and mild winters with occasional cold surges . The mean temperature for July is 29.2˚C and for January it is 7.8˚C (McCaleb 1985). Precipitation is intermittent throughout the year with a slight spring peak. Total annual rainfall means 86 cm with 48 cm (55 %), occurring from April through September, which is the growing season for most plants in the area (Table 1) (McCaleb 1985).

Table 1. Monthly rainfall (cm) averages recorded by the Evant SSW 1 weatherstation from 1941 – 2003.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Average	4.2	5.3	5.5	7.1	10.1	8.6	5.2	5.4	7.0	7.7	5.8	4.4	77.9

The topography is marked by rolling hills with a dissected limestone plain atop hard and soft limestone (McCaleb 1985). The Eckrant-Rock outcrop series is a clayey-skeletal, montmorillonitic, thermic Lithic Haplustoll formed from limestone parent material. Coarse fragments and stones constitute up to 35-70% of the volume of the soil, increasing with depth. The Evant series, which is associated with the Cross Timbers region, is a clayey, montmorillonitic, thermic shallow Petrocalcic Paleustoll with clayey marine sediment parent material. Course fragments and stones comprise less than 15% of the soil volume. Both soils have gentle slopes (1-3 percent) and are well drained and clayey. While both soils series are relatively shallow, the solum of the Evant is deeper (36-50 cm) than the Eckrant-Rock outcrop series (15-38 cm). In both soils, plant productivity is limited by a shallow depth of the root-limiting layer (McCaleb 1985). The Eckrant-Rock outcrop series is typically characteristic of Low Stony Hill ecological sites, while the Evant series is characteristic of Redland ecological sites. The research plots for this study were established on transitional Low Stony Hill and Redland sites.

The fire climax vegetation structure is a live oak savannah with a canopy of 20 percent or less amidst stands of mid and tall grasses. The experimental sites have a history of heavy grazing and removal of naturally occurring fires which has caused a shift in the structure of the plant community (McCaleb 1985). The interpreted pre-European vegetation is 10 percent woody, 85 percent grasses, and 5 percent forbs (McCaleb 1985). Dominant woody plants of climax Redland and Low Stony Hill sites include live oak (*Quercus virginiana*), shinnery oak (*Quercus pungens* var. *vaseyana*), post oak (*Quercus stellata*), and greenbrier (*Smilax bonanox*) (McCaleb 1985). The herbaceous layer is comprised of little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), silver bluestem (*Bothriochloa saccharoides* var. *torreyanus*), Texas grama (*Bouteloua rigidiseta*), Texas wintergrass (*Stipa leucotricha*), and sideoats grama (*Bouteloua curtipendula*) (McCaleb 1985). Because of grazing and the absence of fire in the experimental plots, the woody community is dominated by Ashe juniper with frequent post oaks and Spanish oaks (*Quercus falcata* var. *falcata*). The herbaceous community is dominated by the seeded King Ranch bluestem (*Bothriochloa ischaemum* var. *songaricus*), Texas grama, pricklypear cactus (*Opuntia sp.*), Texas wintergrass, tall dropseed (*Sporobolis asper* var. *asper*), and silver bluestem (Hatch and Pluhar 1993).

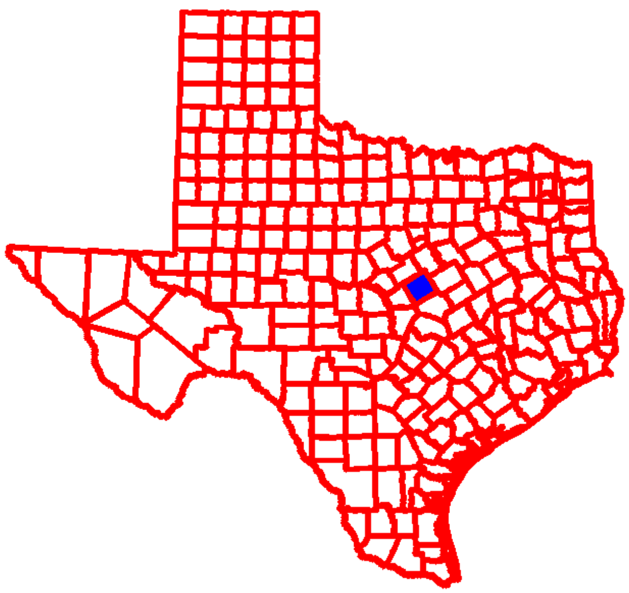

Figure 1. Location of Coryell County.

CHAPTER II

EFFECT OF MECHANICAL JUNIPER REMOVAL METHOD ON SOIL SURFACE DISTURBANCE AND SEEDBED PREPARATION

Introduction

One current trend in ecologically-sound brush removal focuses on individual plant treatments to reduce the cost of brush management and minimize the damage to desirable plants (McGinty and Ueckert 1997; Wiedemann 2004). This portion of the study will examine the effect of two plant selective mechanical types of control for Ashe juniper. One treatment will be juniper removal by uprooting plants with a bulldozer, while the other treatment will be shearing juniper at the ground level with hydraulic shears attached to a skid steer.

The bulldozer is effective in the uprooting and piling of large Ashe junipers. Bulldozing is best suited for scattered stands of large trees, but not as efficient for large, dense stands of smaller plants because it is time-consuming to target individual plants with the bulldozer (Vallentine 1971). Bulldozing creates large pits from the uprooted trees which leave the soil disturbed. These pits may pond rainwater and become prime locations for seed germination, especially if water is extremely limited (Blomquist 1990). Bulldozing also brings rocks to the soil surface, altering the microtopography of a cleared site. One of the drawbacks to bulldozing is seed scattering, which may spreadjuniper to areas that were previously uninfected. Another is that the blade of a bulldozer may scrape the soil surface but not uproot very young junipers, thus leaving them standing and able to proliferate (Young et al. 1948).

An alternative method of individual mechanical juniper removal involves attaching hydraulic shears to a skid steer tractor, which is readily available and operates at a low cost. Bulldozing allows for a degree of specificity, but it falls short of the plant-selective potential of sheering. Brush control methods that employ brush cutting, as opposed to uprooting, are very effective in Ashe juniper management (Young et al. 1948). Skid steers cause considerably less soil disturbance, and currently there is debate as to whether that disturbance is sufficient to create an adequate seedbed. Many other methods of mechanical brush control such as disking, chaining, root-plowing, roller-chopping, and grubbing have proven effective, but bulldozing and shearing are the most common methods in central Texas (Scifres 1980; Vallentine 1971; Wiedemann 2004).

Proper seedbed preparation is vital to seed germination and effective seedling establishment of seeded species after brush removal. The clearing method selected must provide a suitable level of soil disturbance (Burroughs et al. 2004). Bulldozing creates a more irregular soil surface and exposes more rocks than shearing. Controversy exists over whether this degree of soil disturbance is beneficial or detrimental to the process of revegetation. Mutz (1978) found that aggressive soil disturbance impeded plant succession and created fluctuating forage production in mesquite invaded areas in south Texas. He also found that in the first two years, areas with minimal soil disturbance were at a more advanced successional stage and had higher forage production than those with a greater amount of soil disturbance. While greater soil disturbance led to fewer desirable herbaceous species, it did result in more effective long-term brush control (Mutz 1978).

In shallow soils, such as those of the Lampasas Cut Plain, increased surface rockiness is an important consequence of soil disturbance. Rock cover can protect the soil surface from raindrop impact and reduce aggregate breakdown (Hinesley 1986). Rocks may also harbor rainfall and offer protection from drought and herbivory (Hinesley 1986; Merrill and Young 1959). Data on the effects of rock cover on infiltration are contradictory, with some studies showing a positive correlation and some showing a negative relationship (Hinesley 1986). The effect of mechanical clearing method on surface rock cover is an important consideration in ashe juniper management.

As part of the Rural Investment Act of 2002, the Natural Resource Conservation Service (USDA) provides an Environmental Quality Incentives Program (EQIP) that offers cost sharing programs to farmers and ranchers (USDA 2005). In central Texas, one of these programs includes financial assistance to landowners who wish to use sound conservation practices to remove brush from their land. If a landowner agrees to follow specific guidelines and recommendations set by the government, they can significantly offset the cost of Ashe juniper removal. Bulldozing and shearing are both methods of mechanical brush removal supported by the EQIP program; however, if a rancher intends to receive EQIP funds to assist with the cost of reseeding after brush removal, bulldozing is the only mechanical method that they can use. This requirement is based on the assumption that bulldozing creates enough soil surface disturbance to create a good seedbed while shearing does not adequately manipulate the soil surface.

The goal of this aspect of the study was to compare the impacts of bulldozing and shearing juniper on seedbed preparation. The hypothesis tested was that removal of Ashe juniper by bulldozing or shearing will create similar soil surface topographies and soil surface conditions resulting in similar seedbed preparation.

Methods

Eighteen plots were selected for this experiment. They were chosen based on close proximity and similarity of vegetation, topography, and soil (Fig. 2). Plot areas ranged from 0.13-0.25 hectares. Prior to application of the treatments all plots were sampled to characterize the canopy, ground cover, and vegetation. Within each rectangular plot, a central lengthwise transect was established. Ten points separated by eight paces, a distance of approximately 8 m, were established on the transect leaving a buffer of three paces on either end to avoid edge effects. At each point on the central transect, a perpendicular secondary transect was made. On either side of the original transect, ten points separated by three paces were sampled on the secondary transect. In every plot, a total of two hundred points were sampled. At each point, a 0.4 mm metal pin was placed in the soil and the nearest herbaceous species and ground cover at the point (fine litter, rock, plant, or bare soil) were recorded. A vertical line was projected upward from the pin to record noting the overstory tree canopy species. This yielded a measure of the canopy and herbaceous composition as well as ground cover prior to treatment.

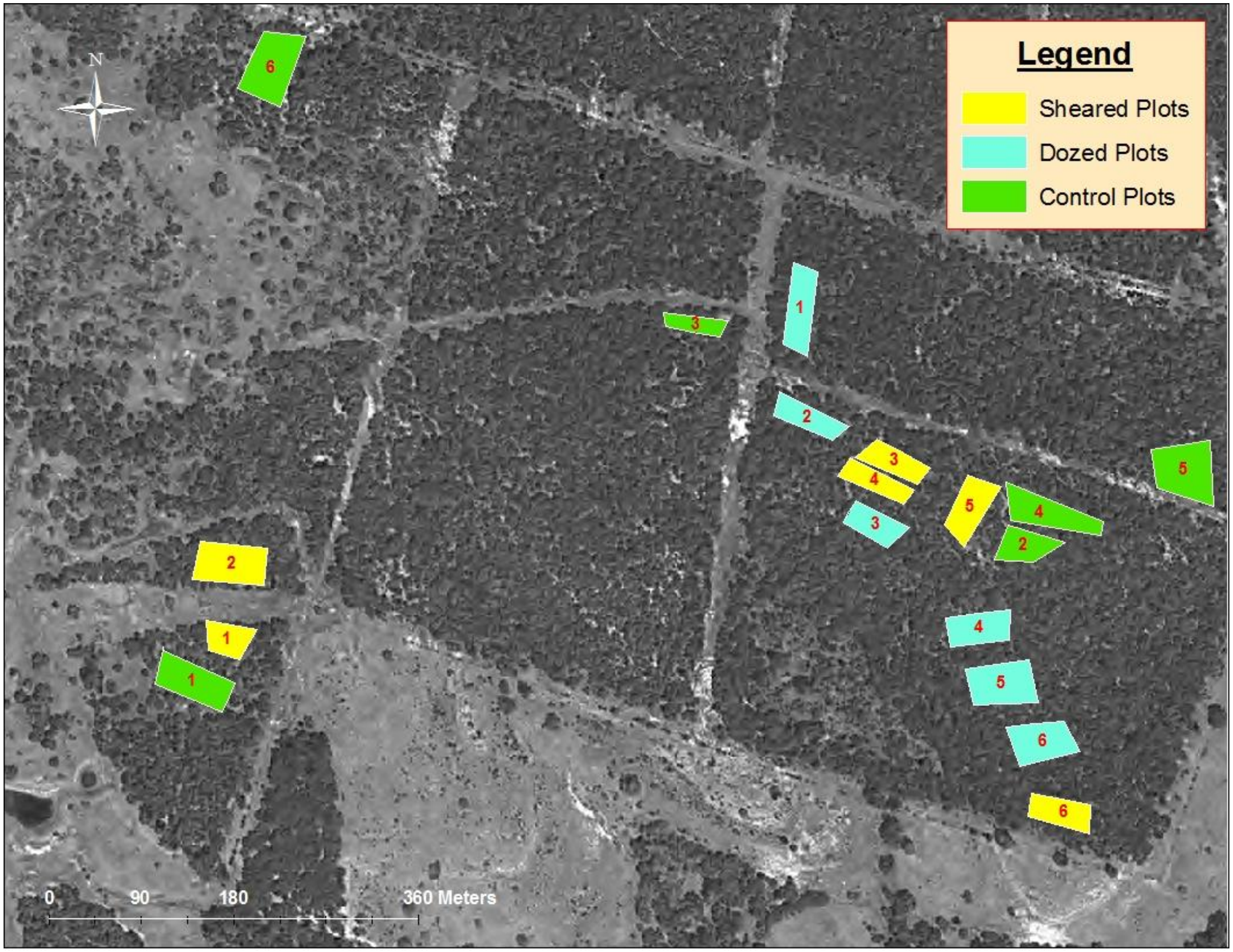

Figure 2. Map of study area, and research plots.

After the juniper clearing, soil samples were taken from all plots. The top six inches of soil were sampled from five locations in each plot, one from the center of each quadrant and one from the center of the plot. These were pooled to form one sample per plot. Analyses were conducted in the Texas A&M University Forest Science Laboratory which measured pH, potassium, calcium, magnesium, sodium, phosphorus, organic matter, organic carbon, soluble salts, exchangeable acid, base saturation, particle size distribution, and CEC (App. 1). The organic carbon measurement was refined by extracting and quantifying inorganic carbon for each sample at the Soil and Crop Sciences laboratory using the pressure calcimeter method.

Soil surface disturbance created by the brush removal process was measured by sampling 200 point samples per plot in plots that had juniper removal. For these samples, each plot had four lengthwise equidistant transects separated by eight paces leaving a buffer of three paces from the plot boundary to avoid edge effects. The transects were paced off and divided equally so that on each transect, fifty equidistant points could be measured. Beginning at one end of the transect, the central pin of a ten point frame was pushed into the ground at the determined number of paces. This process was continued throughout the transect. At each point, the ground cover was determined as fine or coarse litter, rock, vegetation, or bare ground. If fine or coarse woody litter was present, its diameter was recorded in diameter classes (Table 2). In addition, the presence and depth of depressions caused by a bulldozer or skid steer were recorded with depth classes (Table 3).

Table 2. Five diameter classes of course litter evaluated for each cleared plot.

Diameter Class	Diameter (cm)
1	0.1 – 0.3
2	0.4 – 1.3
3	1.4 – 2.5
4	2.6 – 7.6
5	> 7.6

Table 3. Four classes of depression in the surface soil evaluated for each cleared plot.

Depression Class	Depth (cm)
1	0.0 - 5.0
2	5.1 - 10.0
3	10.1 - 15.0
4	>15.0

In order to determine the effect of clearing method on the alteration of the soil surface, pre-treatment soil surface sampling results were compared with post treatment samples to estimate change in each of the ground cover categories. An exact binomials test with an experiment wise $\alpha = 0.05$ was conducted on the means of each ground cover and depression category for all sheared and dozed plots to determine if there was a significant difference in any of these characteristics due to brush clearing method. This statistical procedure was chosen because it was specifically designed to compare proportional measures, which is the form of the data for this portion of the experiement (i.e. fine litter occurred in 150 out of 200 point samples) (Ott and Longnecker 2001).

Results

Considerable variation of the surface soil parameters existed across treatment replications (Figs. 3A-3D). Change in total litter was compared between all treatment plots and between the two treatment means (Fig. 3A). There was no significant difference in total litter change due to treatment. The initial ground cover measurements of litter were almost entirely fine litter, which was all juniper needles, while the post-clearing measurements of litter varied from fine to very coarse litter. A more meaningful comparison of litter change due to treatment compares initial litter to post-treatment fine litter (Figure 3B). The difference in fine litter change between treatments was not significant. Because initial litter cover was all fine litter, we assumed that post-clearing coarse litter was all present as a result of the clearing method. There was no significant difference in treatment means of litter in classes L1, L2, L3, or L4; however, the frequency of L5 sized litter was significantly higher in the sheared treatment than in the dozed treatment. Change in total rock cover was examined (Fig. 3C), but there was no significant difference in mean change in rock cover between sheared and dozed treatments. Bare ground cover change from pre-treatment to post-treatment was also plotted (Fig. 3D) but was not significantly different between sheared and dozed treatments.

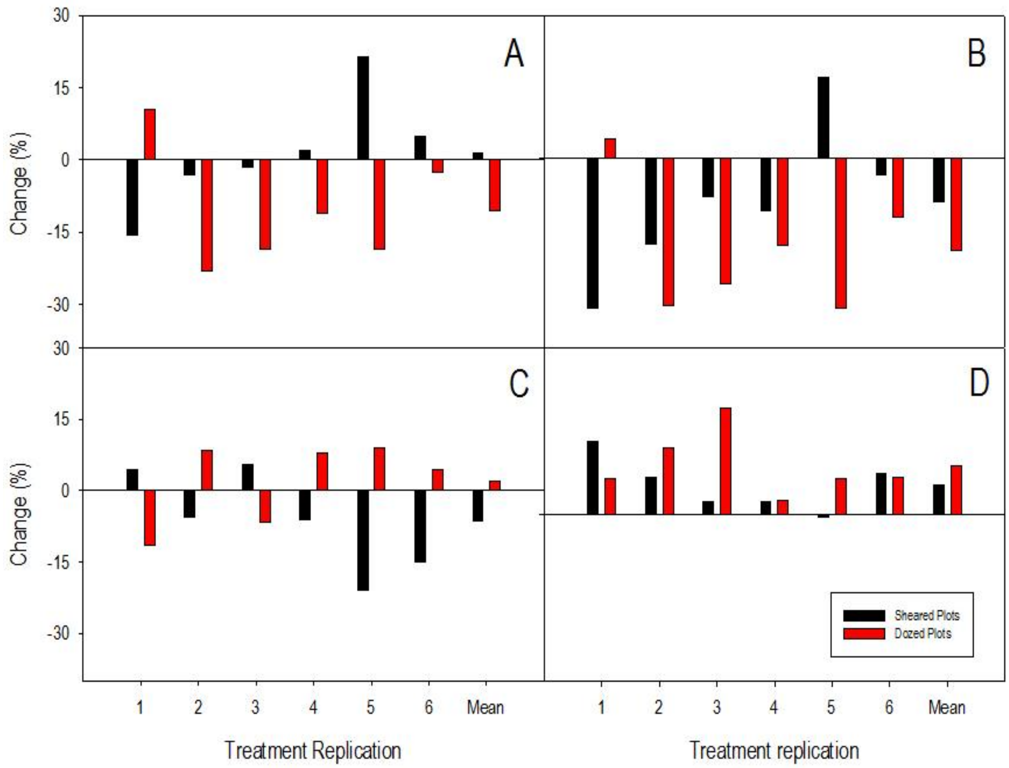

Figure 3. Percent change in A) total litter, B) fine litter, and C) rock cover on the soil surface as well as D) bare soil following juniper removal. Fine litter is defined as litter between 0.1 – 0.3 cm in diameter.

Presence and depth of depressions were compared to learn if the surface topography of the research plots was different due to the implement used to remove the juniper (Fig. 4). Depressions were found on 5.8% of the surfaces of sheared plots, while 17.1% of the surfaces of dozed plots had depressions. The dozed plots had more depressions than sheared plots, but the mean difference was not significant. There was also treatment difference in the size distribution of depressions. In sheared plots, depressions of class D1 (0-5 cm) comprised 90% of all depressions, while in dozed plots, D1 class depressions only represented 75% of all depressions. In all three cases, dozed plots had more depressions than sheared plots, however the differences in treatment means were not significant.

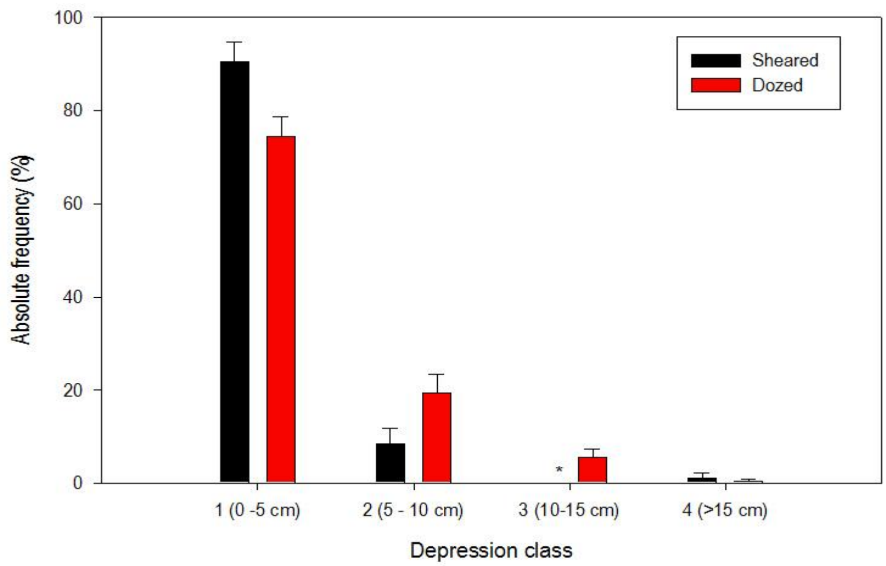

Figure 4. Absolute frequency of each depression class by treatment.

The soil chemical properties were fairly uniform across all plots, however, three characteristics had noteworthy variation. Clay content ranged from 21.5 – 51.3%, however most values were between 25 – 35%. There were also four plots that exhibited very low CEC, 21.1 – 33.4 meq · 100g soil, and low Ca, ranging from 15.9 – 30.2 meq · 100g soil, when most other plots had CEC and Ca above 60 meq · 100g soil. Measurements of other cations were much lower, so the differentiation of these four plots was less pronounced. The plots were D-5, D-6, and S-6; and they all adjacent to one another and on sites that were more characteristic of Redland sites than Low Stony

Hill sites. Finally, in all plots, soil organic matter content, and thus organic carbon content, was high, with values >10% and >5%, respectively.

Discussion

Mechanical juniper clearing by bulldozing and shearing resulted in similar seedbed preparation, thus supporting the hypothesis. Because of a high degree of variation between plots, even plots that received the same treatment, there was no significant treatment difference in any of the ground cover descriptives (i.e. – litter, rock, etc.). For instance, the fourth sheared replication was the only plot that increased in fine litter following treatment. The same plot had the greatest decrease in rock cover, and bare soil also decreased in this plot. One explanation for these differences in soil surface change following treatment in this plot is that the fine litter may have been distributed in piles rather than evenly; and clearing spread out the litter thus covering rocks and bare soil and making more sample points fall on litter.

One soil surface characteristic that may have been under-represented by the sampling method was the surface rockiness that was produced by each clearing method. Rockiness was not measured in size classes as litter was; so rocks were only recorded as present or not present. Visual inspection of the plots reveals that bulldozing brought more medium to large rocks to the surface than shearing. This probably did impact seedbed preparation, but the sampling scheme assigned small pebbles the same weight measure as large rocks, so this treatment difference was not documented.

There was no pre-treatment measure of the soil surface smoothness due to inaccessibility. Though pre-treatment assessment of the soil surface was not conducted, we assumed it was fairly even. Bulldozing did create a greater amount of depressions on the soil surface, though the difference was not significant at $\alpha = 0.05$; and the bulldozer had a greater percent of depressions with depths > 5cm than the skid steer. The difference may be attributed to the physical uprooting of the trees by the bulldozer, which leaves large holes. Additionally, the bulldozer blade scraped the soil surface, which may have caused disturbance to large rocks, leaving impressions in the soil surface where the rocks were removed. Neither of these disturbances occurred when clearing brush with a skid steer. This differential level of soil surface disturbance may lead to differential seedling establishment success.

Soil chemical parameters were varied, and it is unknown if that variation had an effect on seedling establishment. Organic carbon varied slightly between plots, but was uniformly high for a grassland. The research site is more appropriately examined as a juniper grove with occasional oaks, however, since the site was cleared recently. In 50 year juniper groves, soil carbon is typically between 4-10%, which is very similar to what was found in the research plots, and those numbers are even higher below oak species (Jessup 2003). The decline of soil carbon is slow, so we would expect a recently cleared juniper grove's soil carbon content to resemble that of a standing juniper grove for 10+ years after conversion to grassland. Variation CEC would result in lower amounts of available Ca, K, Mg, and Na; which would affect seedling establishment. A difference in clay content may alter soil moisture storage, which would certainly have an effect on seedling establishment. In this region, soil moisture is the most limiting factor for plant growth, and therefore, it merits investigation to determine if there is significant variation in soil moisture storage within and between research plots.

CHAPTER III

MODELING SPATIAL VARIATION OF DEPTH TO AN IMPENETRABLE LAYER USING ELECTRICAL CONDUCTIVITY MEASUREMENTS

Introduction

Woody species are encroaching upon grasslands across the globe (Archer 1989). On the Lampasas Cut Plain region of central Texas, the dominant woody invasive is Ashe juniper. Success of grassland restoration efforts on these landscapes is dependent not only on the quality of the restoration plan, but also on abiotic factors that can be spatially variable across the landscape to be restored. Measuring and accounting for this spatial variability can aid in the development of a restoration plan that is tailored to a specific study area. Within our study area, soil depth is relatively shallow (0.3-1.0 m deep) and highly variable because of limestone outcrops and rock fragments of the limestone parent material. This spatial heterogeneity of soil depth has an effect on the composition and structure of the plant community (Molinar et al. 2002).

A soil's capacity to store plant available water is key to the success of the vegetation that it supports (Hinesley 1986; Morgan et al. 2000). When soils within an area are fairly similar in texture, soil volume determines the water holding capacity (Boettinger et al. 1997; Coupland 1979; Hinesley 1986). Measurements of soil depth to limestone bedrock provide an approximate estimate of this soil volume. Knowledge of the extent and distribution of soil volume variation can be useful in grassland recovery efforts following woody plant removal because it allows the identification of production zones that are best suited for recovery efforts (Boettinger et al. 1997; Kitchen et al. 2005).

Measuring soil depth by manually inserting a metal probe into the soil can be inaccurate, difficult, and time consuming, particularly when the soil contains substantial amounts of rock fragments (Hinesley 1986). A rapid and non-invasive technique for estimating soil depth, such as measuring bulk soil electrical conductivity (EC_a), provides a method that is faster and has the capacity to collect information about soil variation at a high spatial resolution. Soil EC_a measurements primarily respond to changes in soil salinity, clay content and type, and moisture. If soil salinity is negligible and percent clay and clay type are consistent across the measurement area, then EC_a primarily responds to soil moisture storage within the soil profile (McNeill 1980a; Morgan et al. 2000; Sheets and Hendrickx 1995). Because bedrock has little pore space and is generally not conductive, shallower soils should have lower and deeper soils higher EC_a values (Boettinger et al. 1997; McNeill 1980a). The change in EC_a due to variation in soil moisture across a landscape is a reliable measure because soil moisture is relatively stable during a one to two day measuring period. Therefore, EC_a is useful for delineating zones of different soil moisture retention capacity (Kitchen et al. 2005).

Soil bulk electrical conductivity can be measured using two commercially available instruments, one requires soil contact via a probe inserted into the soil, the VERIS (Veris Technologies Salina, KS) and the other is non-invasive, the EM38 (Geonics Ltd Missoula, Canada). The EM38 was used because there were frequent rock outcrops and rock fragments within the soil, and the non-invasive properties of the

EM38 make it ideal for rocky soils. The EM38 is lightweight, portable, and does not disturb the soil or the plant community. It can be connected to a data recorder and a GPS unit so that large numbers of data points can be recorded and georeferenced.

In the EM38, a transmitter coil emits an AC current creating a magnetic field which induces secondary currents in the soil. These secondary currents generate a secondary magnetic field in the soil. A receiver coil located one meter from the transmitter coil on the same instrument senses both the primary and secondary magnetic fields, and their ratio is the apparent conductivity of the soil (Fig. 5) (Corwin and Rhoades 1990; McNeill 1980b; Rhoades and Corwin 1981).

Figure 5. Diagram of EM38-DD.

When used in the vertical dipole position, this non-invasive measurement averages soil EC_a in approximately a 1.0 m horizontal radius and to a potential depth of

1-2 m (Sheets and Hendrickx 1995). Because 75% of the response comes from the upper 190 cm, EC_a-based soil moisture estimates correspond with the zone of influence for most plant roots (Corwin and Lesch 2005; Corwin and Rhoades 1990; Rhoades and Corwin 1981).

The use of the EM38 to determine soil apparent conductivity is advantageous because it is non-invasive and the data collected is automatically georeferenced; and because it collects data points rapidly and in great number, a higher degree of spatial resolution can be achieved faster than with conventional manual measurement techniques. There are some limitations, however, including difficulty zeroing, drift from temperature changes, and limited dynamic range such that readings from very conductive and very resistive soils are not as accurate as they are at less extreme values (McNeill, 1980).

Several studies have used variation in bulk soil electrical conductivity to describe and map spatial variability of soil moisture properties and other soil characteristics. Studies in central Missouri found that EC_a was highly correlated to observed depth of claypans, and this information was used to successfully map the topography of the claypan (Doolittle et al. 1994). In a study of soils within a wide range of textures in Canada, soil apparent conductivity explained 96% of spatial variation in soil water content regardless of texture when they contained low levels of dissolved electrolytes. At depth intervals of 0.5 m or less, the standard error of estimation of soil water content was 0.02 m^3 m^{-3} (Kachanoski et al. 1988). Morgan et al. (2000) found that EC_a mapped depth of a loess cap to within 12 cm of accuracy based on plant available water distribution. They found that EC_a predictions are most effective when used on large fields that have a high degree of variation in soil moisture storage.

This research project was originally established to examine the effect of two different methods of cedar removal, dozing and shearing, on seedbed preparation and seedling establishment. Eighteen total research plots were established and randomly assigned to one of three treatments; 1) ashe juniper shearing, 2) ashe juniper dozing, and 3) no juniper removal. While every attempt was made to select homogenous research plots, there is an inherent level of variability in the volume of soils in this area, which was apparent after Ashe juniper removal. A measure of the variability of soil volume, and therefore soil moisture storage across plots, explains some of the differences in vegetation growth not due to the juniper removal treatment. The objective of this study was to map soil depth heterogeneity to an impenetrable layer between and within research plots in which juniper was removed. Soil depth variation was used to estimate soil moisture storage. The hypothesis tested the ability of bulk electrical conductivity (EC_a) to effectively predict soil-depth variability within and between twelve 0.13-0.25 ha. research plots.

Methods

Soil bulk electrical conductivity was measured using an EM38-DD (Geonics Ltd Mississauga, Canada). The EM38-DD is composed of two EM38 ground conductivity meters attached so that they simultaneously measure vertical and horizontal ground response (Geonics Ltd Mississauga, Canada). The EM38-DD was connected to an

Allegro data collector (Juniper Systems North Logan, UT) as well as a backpack Trimble GPS unit (Trimble Sunnyvale, CA). Therefore, all data were georeferenced to an accuracy of approximately 3 m.

The EM38-DD was carried, by hand, at a height of approximately 7-8 cm above the surface of the soil along established transects referred to in Chapter II and measurements were logged at one second intervals. This process was conducted when the soils were approximately at field capacity. Once electrical conductivity data were collected for all treatment plots, the data were entered into GIS and a digital electrical conductivity map was created using inverse distance weighted interpolation of the second power and a cell size of 1 m.

To determine if a correlation existed between soil depth and bulk electrical conductivity, soil depth was measured manually. Locations for the soil depth measurements were selected using a stratified random design across all research plots. To identify locations for manual depth measurements, the EM38-DD readings from the vertical dipole were log transformed, to establish normality, and divided into ten strata (Table 4). The strata were selected in a manner that we intended to yield approximately the same number of observations in each stratum. An error was made in that process and two strata were combined which resulted in only nine strata, one of which had twice the number of observations as the other eight. From each stratum, five EC_a measurements were randomly selected. Soil depth was measured by driving a rod of 41/40 oxidized steel 0.64 cm in diameter into the ground until it hit bedrock or could not be driven further into the soil. A total of forty-five locations had manual soil depth measurements, and at each location four soil depths were measured within a one meter radius and averaged.

Table 4. EC_a strata along with their ranges, midpoints, and the number of data points per stratum that were used to determine depth classes for manual measurement.

Stratum	Range of log EC_a ($mS \cdot m^{-1}$)	Stratum midpoint ($mS \cdot m^{-1}$)	Number of data points
1	-0.602 - 0.641	0.20	418
2	0.642 - 0.720	0.72	375
3	0.721 - 0.805	0.76	422
4	0.806 - 1.016	0.91	806
5	1.017 - 1.122	1.07	411
6	1.123 - 1.237	1.18	401
7	1.238 - 1.320	1.28	408
8	1.321 - 1.415	1.37	405
9	1.416 - 1.686	1.60	401

Upon initial review, four points appeared not to follow the overall trend between EC_a and soil depth. Three of the four points occurred in the second replicate sheared plot, causing concern about the universality of the relationship. The EC_a map for this plot revealed that the areas randomly selected for depth measurements in that plot were in transition zones that bordered strata representing different soil depths. Because the GPS unit was only accurate to 3 m, we suspected that the manual measurements may have been taken at a location other than where the specific EC_a reading was taken, and therefore possibly in another EC_a zone. To address the question of whether or not this plot had a different EC_a-soil depth response, an additional nine locations were selected for more manual depth measurements. The additional measurements were selected, nonrandomly, for their position within the middle of a sizeable area of a particular EC_a range. There were nine areas of uniform log EC_a strata that met those criteria within the plot, thus, nine locations were selected.

Analysis of variance was conducted at 95 % confidence intervals for the means of the measured and predicted soil depth for each plot to discern any significant differences of soil depth between plots and between treatments (SPSS, SPSS Inc., Chicago, IL).

Results

Average soil depth values collected from manual measurements were plotted as a function of one of the nine EC_a strata (Fig. 6A). Residuals suggest that soil depth data are normal and that data spread is greater as log EC_a, and measured soil depth, increases (Fig. 6B). The minimum and maximum soil depth measurements were 0.5 cm and 84.0 cm, respectively, the median was 23.3 cm, and the average soil depth was 30.0 cm. The maximum depth penetration of the manual depth measurement instrument was 84.0 cm, so the true maximum soil depth may have been greater. There were no instances in which EC_a estimated soil depths greater than 84.0 cm, so accuracy below that depth was not necessary in determining the prediction power of EC_a.

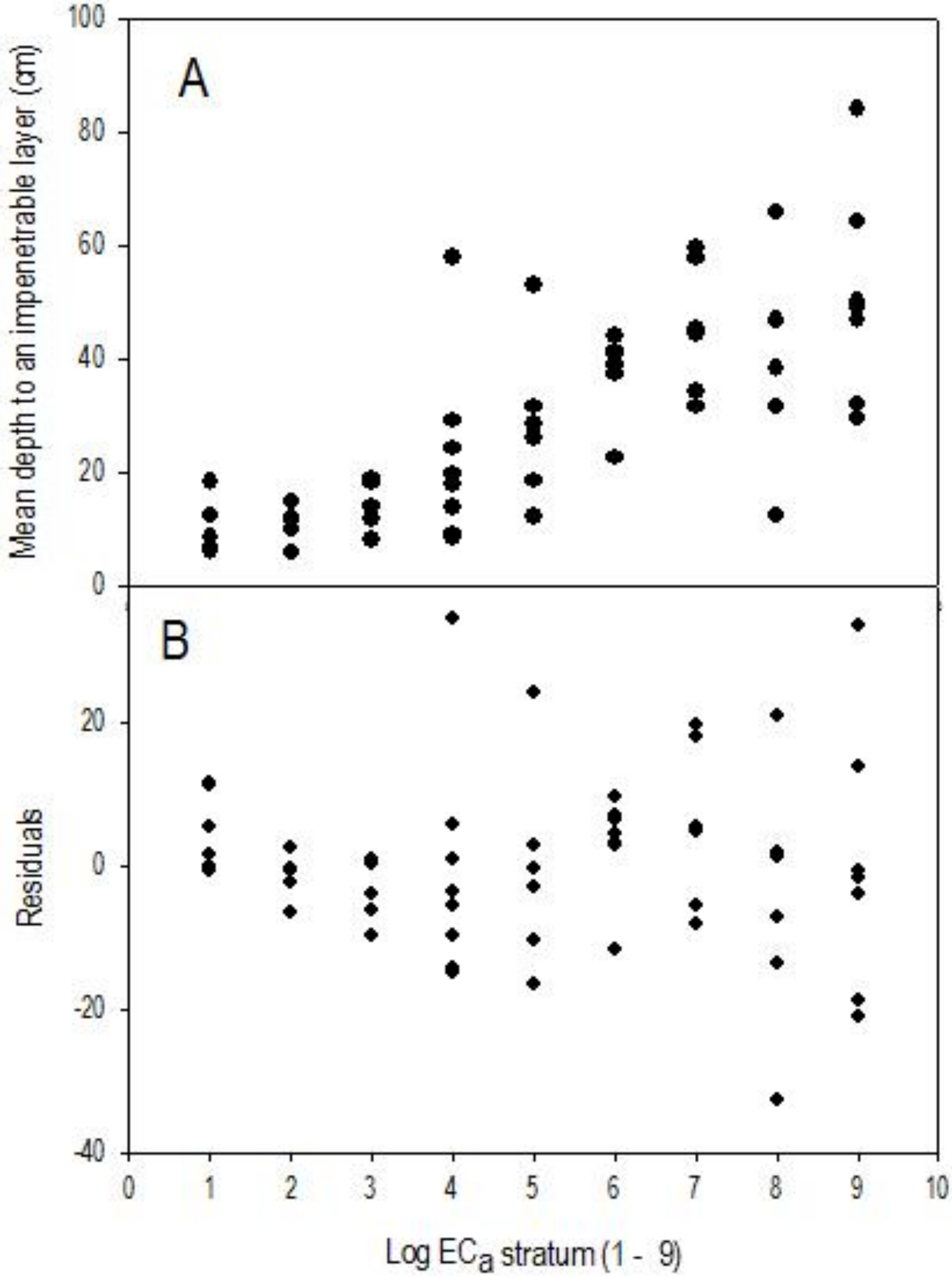

Figure 6. Mean measured depth to an impenetrable layer vs. the log EC_a stratum from which the measurement was taken. The data include the additional sample locations from the second sheared replication. The residuals show that the data appears normal and there is a quadratic relationship between the manual soil depth measured and log EC_a stratum.

A total of 4047 EC_a measurements were collected in a single sampling event over a period of approximately 2.5 hours. The EC_a values ranged from 0.25 mS · m^{-1} to 48.5 mS · m^{-1} with a median value of 10.5 mS · m^{-1} and an overall average of 13.13 mS · m^{-1}. The data were log transformed to establish normality. After log EC_a values were interpolated to a 1 m^2 grid, a minimum of 1147 values were used to estimate an average predicted depth to bedrock and coefficient of variation in each plot (Table 5).

Table 5. Mean soil depth as measured and as predicted by regressions formed from log EC_a measurements with all final data and with all final data without GPS outliers. An asterisk indicates that a value was not computed.

Treatment - Replication	Mean depth (cm)	CV	Mean predicted depth from regression of data without GPS outliers (cm)	CV	Mean predicted depth from regression including GPS outliers (cm)	CV
D – 1	43.1	0.57	40.6	0.16	43.7	0.13
D – 2	9.0	0.56	18.0	0.18	21.6	0.17
D – 3	12.9	0.42	16.2	0.32	19.4	0.31
D – 4	16.2	0.59	14.4	0.51	17.0	0.48
D – 5	37.3	0.41	32.5	0.28	36.1	0.25
D – 6	39.3	0.32	38.6	0.17	41.8	0.15
S – 1	31.4	0.69	29.2	0.07	33.2	0.06
S – 2	45.0	0.52	30.5	0.15	34.5	0.13
S – 3	8.7	0.58	12.8	0.32	15.5	0.32
S – 4	11.1	0.52	13.9	0.33	16.8	0.34
S – 5	14.1	0.61	12.3	0.34	14.8	0.36
S – 6	45.8	0.40	48.6	0.04	50.8	0.03
All Dozed	25.9	0.73	26.7	*	29.9	*
All Sheared	33.3	0.71	24.6	*	27.6	*
All Plots	30.0	0.73	26.9	0.49	30.1	0.44

A Games-Howell test of equality of means revealed that treatment means to measured depth to an impenetrable layer were not significantly different, but mean differentiation between plots were significantly different (Table 6). While the dozed replicates 2, 3, and 4 were not significantly different from the sheared replicates 3, 4, and 5 (their means range from 9.0 - 16.2 cm), they were significantly different from virtually all of the other plots because all other mean depths were above 31.0 cm.

Table 6. Comparison of significantly different measured and predicted plot mean depth to an impenetrable layer. (* = significantly different measured mean depth, shading = significantly different predicted mean depth).

Treatment - Replication	D - 1	D - 2	D - 3	D - 4	D - 5	D - 6	S - 1	S - 2	S - 3	S – 4	S - 5	S - 6
D - 1		*	*	*					*	*	*	
D - 2	*				*	*	*	*				*
D - 3	*				*	*		*				*
D - 4	*				*	*		*				*
D - 5		*	*	*					*	*	*	
D - 6		*	*	*					*	*	*	
S - 1		*							*			
S - 2		*	*	*					*	*	*	
S - 3	*				*	*	*	*				*
S - 4	*				*	*		*				*
S - 5	*				*	*		*				*
S - 6		*	*	*					*	*	*	

The initial data for the correlation between depth to an impenetrable layer and log EC_a appeared linear, therefore a linear regression was performed and had an r^2 = 0.58. Based on visual inspection and the residuals plot of the linear fit, a quadratic function was fit and performed better (Fig. 7A). A plot of residual versus fitted values confirms that a quadratic fit satisfies the assumptions of regression better than a liner fit

(Fig. 7B). The adjusted R^2 value of the quadratic regression was 0.56, and the RMSD was 12.6 cm.

Most of the data points fell close to the regression line; however, there were four prominent outliers that may have been the result of GPS error. When the four outliers were removed, the overall characteristics of the quadratic curve and residuals did not change; however, as expected the adjusted R^2 increased to 0.76 (Fig. 7A and 7B).

After manually measuring nine additional soil depths in the second sheared replication plot, these points were added to the regression so that the potential outliers could be examined. With all of the original and new data points included (n=54), the R^2 was 0.54 and RMSD was 12.5 cm, which is very similar to the original data set which had an R^2 value of 0.59 and a RMSD of 12.6 (Fig 8A). The incorporation of the nine additional points from plot two did not significantly change the fit of the overall dataset. More importantly, eight of the nine new points fit well within the overall trend of the data. This result supports our idea that the original outliers were likely because of GPS error. One data point out of the nine additional points did not fit the overall trend. However, this point was measured beneath a tall post oak, which may have diminished the accuracy of the GPS unit. Though the idea of GPS outlier was not thoroughly tested, the inclusion or exclusion of the outliers does not change the soil depth prediction, it only affects estimation of the prediction error. If all five outliers attributed to suspected GPS error were removed, four from the original data and one from the additional data, the R^2 increased to 0.75 and RMSD is 7.7 cm (Fig. 8A and 8B).

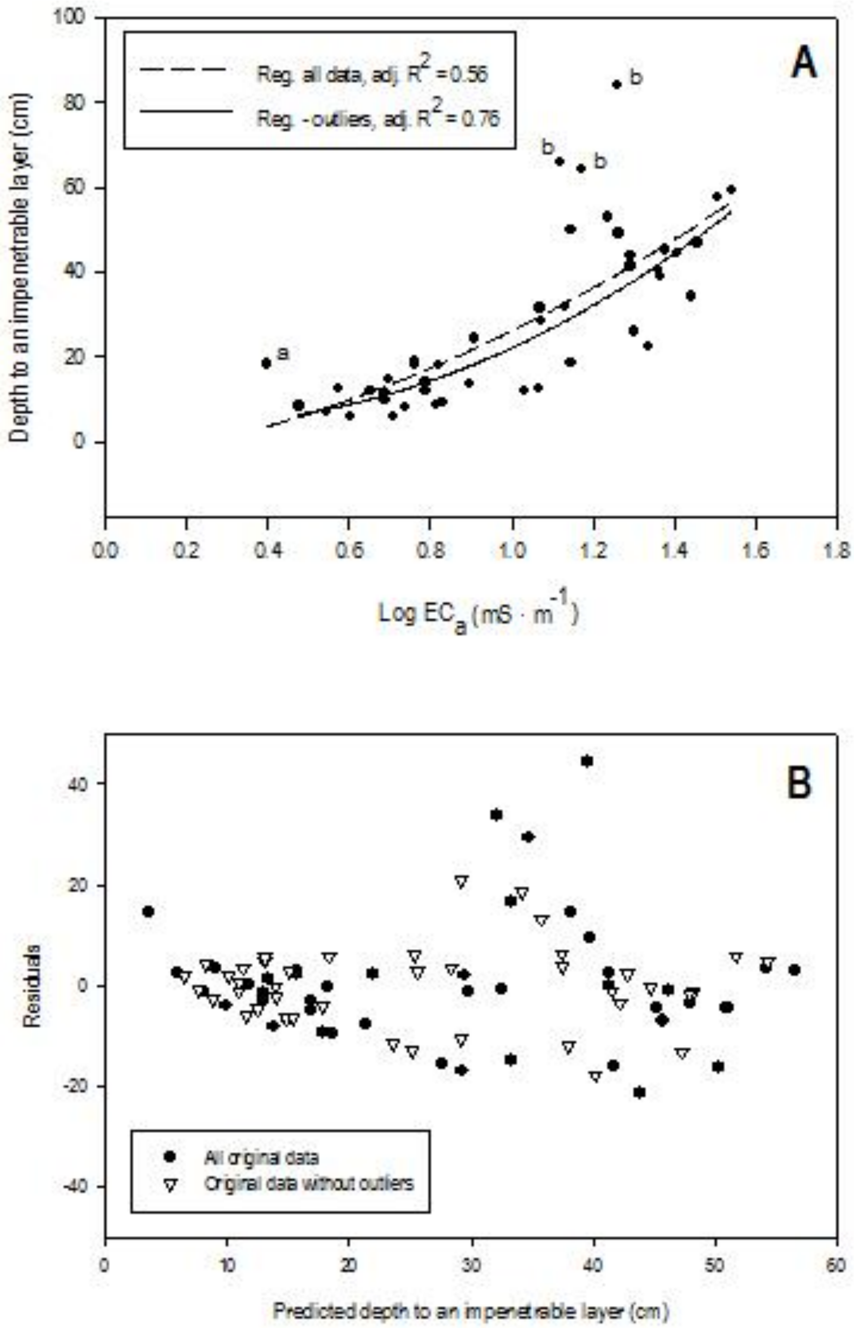

Figure 7. Regression of depth to an impenetrable layer vs. log EC_a with and without outliers. Data point marked “a” refers to the manual depth measurement next to a rock outcrop and data points marked “b” refer to depths sampled in transition zones within the second sheared replication plot. The removal of the GPS outliers has little effect on the residuals, which appear to have a normal distribution.

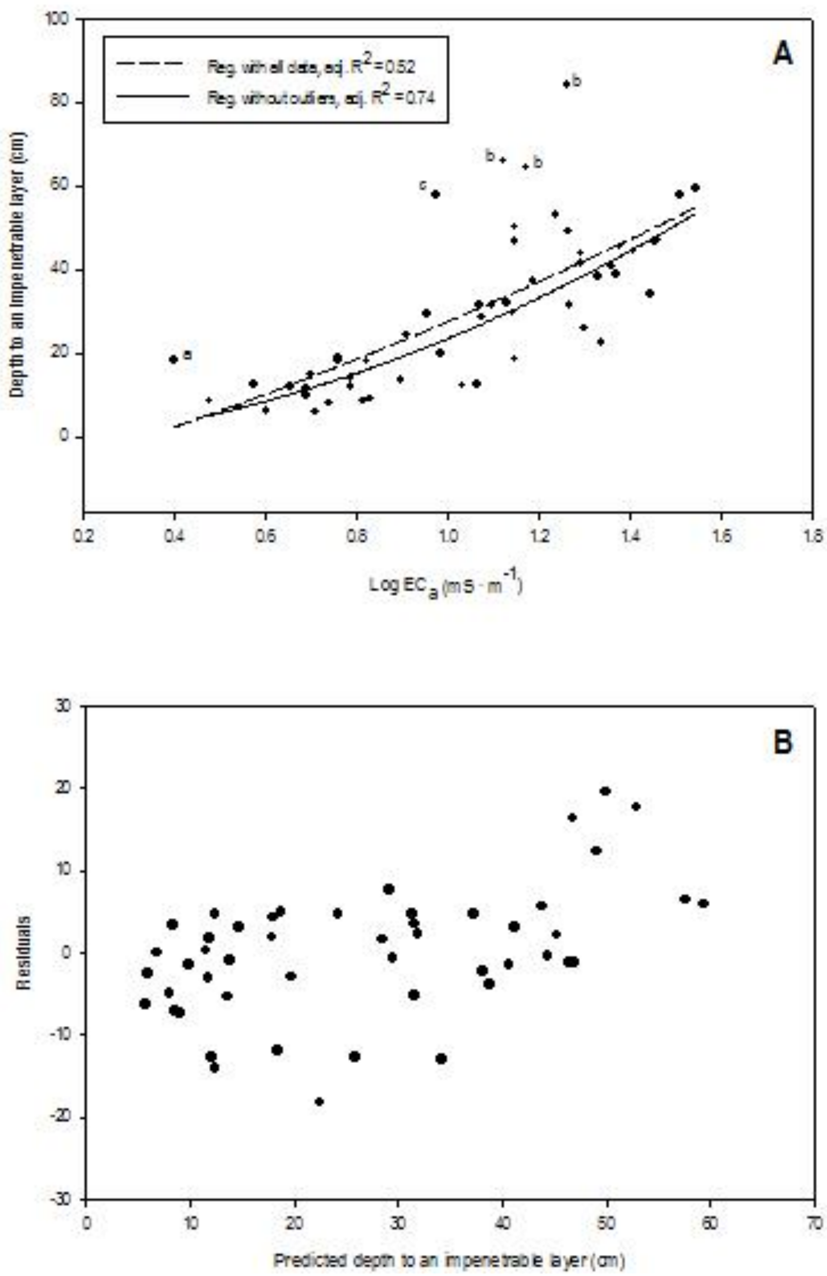

Figure 8. Regression of depth to an impenetrable layer vs. log EC_a for all data points and for all data points except outliers due to GPS error. Data point marked “a” refers to the soil depth sampled next to rock, data points marked “b” refer to the soil depths sampled in transition zones, and data point marked “c” refers to the soil depth measured beneath the tree. The residuals appear to have a normal distribution.

The quadratic regression equation derived from all of the log EC_a and manual soil depth data as well as the equation created from the log EC_a and soil depth data without the five probable GPS outliers were used to predict soil depth within each plot. The interpolated log EC_a values were used to predict the interpolated soil, and those values were averaged to obtain a mean soil depth for each plot (Table 5). Mean predicted soil depth from the equation without outliers ranged from 12.3 cm to 48.6 cm, with a median average soil depth of 23.6 cm. Average predicted soil depth from the equation with all of the data ranged from 14.8 cm to 50.8 cm, with a median average soil depth of 27.4 cm. Mean predicted soil depth was significantly different in all plots (Table 6).

Discussion

The manual soil depth measurements prove that there was significant soil depth variation between and within plots. The small number of manually-collected sample points makes confidence low for assumptions about between and within plot variability of soil depth. In some cases, there were only a dozen or fewer measurements within an entire plot. The time-consuming nature, high coefficient of variation, and small number of data points collected made manual rod-based measurement of soil depth undesirable for high resolution representation of the plots. To gain a finer spatial resolution of the spatial pattern of soil depth the EM38-DD provided a better tool, with some loss of accuracy.

The soil depth estimations from the interpolated log EC_a values were supported by more measurements, with an average of 300-400 EC_a measurements in each plot. The high number of soil depth values in each plot gives a more thorough picture of within-plot variability than manual soil depths. The predictions from log EC_a values provided more spatial resolution than the manual soil depth measurements for between and within plot variation and provided a useful map of where and how soil depth varies. While R^2 values were very different in regressions that included all of the data and regressions that excluded outliers, the average soil depth predictions were similar. Therefore, one could use either regression to predict soil depth and get approximately the same value. The RMSDs, 12.5 and 7.7 respectively, indicate that the EM38 can predict soil depth to an accuracy of 13 and 8 cm respectively, but the true predictive power of EC_a is most likely somewhere between 8 -13 cm.

Sources of error when using EC_a to predict soil depth include human error, instrument error, and heterogeneity of soil properties other than soil moisture. A source of possible error from this experiment occurred in the second replicate of the sheared treatment, where four outliers were identified. That plot had much denser and taller vegetative cover than all of the other plots at the time of the EC_a measurement. The density and height of the vegetation complicated the maintenance of the EM38-DD at uniform height, which may have caused the instrument to be maintained at a greater height above ground and less consistently than in plots with lower vegetation densities. EC_a measurement is dependent on consistent instrument height; and elevating the instrument to avoid thick patches of grass would result in lower EC_a measurements.

Additionally this vegetation could have dried the soil profile out more than the other plots, resulting in lower EC_a values in relatively deeper soil depths. These complications may explain why the EC_a predictions for soil depth were less than the true depth of the soil. It is worth noting that the presence of thick ground cover most likely did not alter the EC_a measurement. Boettinger et al. (1997) found that plant cover did not affect apparent conductivity in a sagebrush-grass landscape; however, they suggest that more investigations are needed for landscapes with different levels of plant biomass such as rainforests. They also found that the presence of unconsolidated material may cause EC_a readings to be higher than expected at a certain soil depth. Unconsolidated parent material has a greater soil moisture capacity than soil, therefore, the EC_a value at a location with a relatively shallow soil atop a limestone outcrop bedrock with a large amount of saturated unconsolidated material below may have a higher EC_a value than a deeper soil without a significant amount of unconsolidated material within the range of the EM38-DD depth penetration. Textural variation, such as percent clay, may or may not significantly influence EC_a values in this specific case. One study found that in non-saline soils EC_a accurately predicted 96% of the spatial variation in soil moisture regardless of texture, which ranged from 2.5 to 44% clay (Kachanoski et al. 1988). On the other hand, the capacity for soil moisture is dependent on clay content, so a drastic change in clay content when soils are drying out may alter EC_a response to soil depth. This is unlikely in our case because EC_a was measured while the soils were at field capacity.

GPS error is the most likely cause for variation within the data. While GPS error impacted the results in this study, it would not pose a great problem in areas where the soil varies more gradually, such as over a 5-10 m range. It is still a reasonable method for most restoration efforts as they are usually conducted on larger scale than this study. Additionally more expensive survey-grade GPS systems, such as DGPS-RTK, are available and though they cost more, they have a horizontal accuracy of 2 cm. Disregarding error due to GPS inaccuracy, EC_a does appear to accurately predict variations in soil depth to bedrock on this research site. Other studies have had similar results examining depth to root-limiting horizons based on soil moisture distribution and response.

In a study of soil depth to a petrocalcic horizon in a semi-arid rangeland in Utah, researchers found that soil depth was strongly correlated (R^2=0.70) with vertical ECa measurements. In that study, the predictive power of EC_a was only accurate in discerning simple classifications such as <50 or >50 cm. Our research found that EC_a predicted soil depth within 13 cm in the worst scenario, while it predicted soil depth within 8 cm when the data points due to GPS error were disregarded. Moreover, at soil depths <50 cm its predictive power was even greater. Accuracy at shallow depths is the most important attribute for restoration in this ecosystem because limitations in water storage are the primary impedance to successful rangeland restoration. If the soil is deeper than 50 cm, it can retain water enough to sustain plant communities adapted to the area, and the accuracy of depth prediction is not an important factor.

CHAPTER IV

SEEDLING ESTABLISHMENT AND VEGETATION DEVELOPMENT FOLLOWING ASHE JUNIPER REMOVAL BY BULLDOZING AND SHEARING

Introduction

At a height of 1m, a juniper starts to alter the herbaceous community beneath its canopy (Blomquist 1990). Once juniper stands form, the competitive ability of herbaceous plants is greatly reduced because of poor light penetration through the dense canopy (Blomquist 1990; Fuhlendorf et al. 1997) and competition for water and nutrients (Rowan and Conner 1994). This competition for nutrients and water is especially notable in shallow soils where water and nutrients are scarce (Blomquist 1990). The presence of thick Ashe juniper stands significantly reduces the amount of grazeable land for livestock and wildlife because not only do they reduce herbaceous density and diversity, they also create a physical barrier which limits access to more desirable plant species (Smeins and Fuhlendorf 1997).

It is hypothesized that removal of Ashe juniper by bulldozing or shearing produces similar results in the re-establishment of seeded and volunteer herbaceous communities.

Methods

The eighteen plots and the pre-treatment sampling methods referred to in Chapter II apply to this aspect of the study as well. There were 6 sheared plots, 6 dozed plots, and 6 control plots which received no juniper treatment.

Once the juniper removal was completed, all of the plots were seeded with a mix of grasses and forbs (Turner Seed Co. Breckenridge, Texas). The seed mix consisted of five native grasses and forbs as well as *Sorghum almum* which was used as a nurse species (Table 7). The seeding rate was 3.4 kg/plot which slightly exceeded the manufacturer's recommendation of 3.0 kg/acre. A broadcast seeder was mounted on the back of a jeep which distributed the seeds to each plot. The jeep dragged a large juniper behind it during seeding to increase seed-to-soil contact.

A laboratory germination trial was conducted to verify the distributor's projected germination rate. Two hundred seeds of each species were removed from the bag of mix used to seed the experimental plots and were divided into four replications of fifty seeds for each species. These seeds were germinated in Petri dishes in a controlled chamber with 12 hours of daylight at 20˚C for one month. Petri dishes were monitored twice weekly throughout the experiment, and germinated seeds were counted and removed (Table 7).

Table 7. Percent germination of seeded species as provided by the distributor and as determined in the laboratory as well as pounds of live seed of each seeded species that were seeded per acre.

Common name	Latin name	Distributor's germination	Laboratory germination	Pounds live seed · $acre^{-1}$
Green sprangletop	*Leptochloa dubia*	92	57	0.11
Illinois bundleflower	*Desmanthus illinoensis*	94	31	0.40
Indiangrass	*Sorghastrum nutans*	96	44	0.72
Little bluestem	*Schizachyrium scoparium* var. *scoparium*	86	7	0.27
Sideoats grama	*Bouteloua curtipendula*	78	53	1.17
Sorghum almum	*Sorghum almum*	73	68	4.00

Rainfall was recorded by a tipping bucket rain gauge located near one of the control plots for the duration of the experiment to compare year to year change in precipitation. Fifty year average rain data collected at a nearby weather station were used for comparison with actual rain values collected for the duration of the experiment (Figure 9).

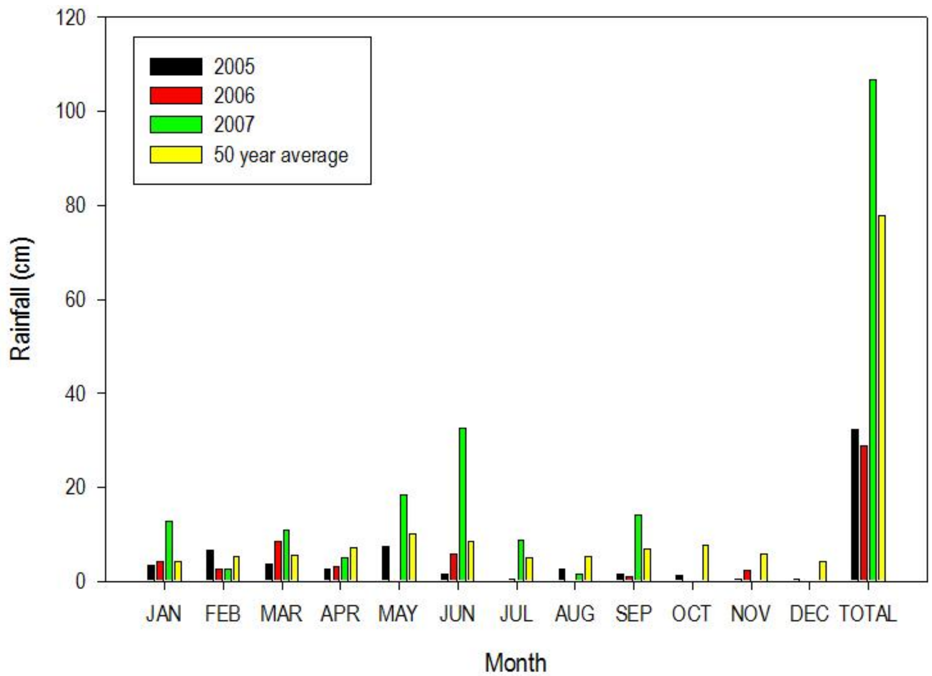

Figure 9. Rainfall measured on research plots for 2005, 2006, 2007, and 50 year average as measured by a nearby weatherstation. Data collection ended in September of 2007, therefore, there is no rainfall data for October-December of 2007.

The first sampling event (26 June 2006 – 27 June 2006) was conducted after initial germination when the vegetation was mature enough for identification. The four transect lines established for sampling the soil surface disturbance measurements which were described in Chapter II were used for all post-germination sampling. On each transect, five 0.25m (0.5m x 0.5m) quadrats were sampled, yielding a total of twenty quadrats per plot. A pre-selected random number of paces separated each quadrat sampled along a transect. Cover classes (Table 8) were assigned to rock, litter, bare ground, foliar cover of each species, total foliar cover, and total cover (defined as all non-bare ground) for each quadrat and individuals of each seeded species present were counted.

Table 8. Cover classes, ranges, and class midpoints used for post-treatment vegetation surveys.

Cover Class	Percent Cover	Midpoint
1	0.0 - 5.0	2.5
2	5.1 - 25.0	15.0
3	25.1 - 50.0	37.5
4	50.1 - 75.0	62.5
5	75.1 - 95.0	82.5
6	95.1 – 100.0	95.0

As the plant community structure and composition shifted over time the sampling system adjusted as well. The second sample of the plant community occurred from 11 June 2007 through 14 June 2007. The number of quadrats sampled per transect was increased from five to six, yielding a total of 24 sample quadrats per plot. All species were identified and recorded and the two dominant species in both the grass and forb categories were assigned a cover class. All seeded species were again enumerated and were additionally assigned a cover class.

Percent cover measurements were compared to predicted soil depth from EC_a measurements, referred to in Chapter III, to examine the relationship between cover and soil depth and to ascertain if soil depth variation explained variation in cover not due to treatment effect.

All experimental data were analyzed as a Completely Randomized Design. The treatment means for pre-treatment canopy cover, and seeded and volunteer species frequency were compared using an exact binomial test with an experiment-wise $\alpha = 0.05$ (Ott and Longnecker 2001). This test was selected because it is designed for comparison of proportional measurements which is the category of most of the data collected for this experiment (i.e. – sorghum almum was present in 4 out of 24 plots). Mean percent cover of seeded species and mean richness for each treatment was compared with an independent samples t-test with $\alpha = 0.05$.

Results

Pre-treatment woody plant canopy covers were compared to establish similarity of the initial woody cover, specifically, similar juniper cover, across treatments (Fig 10). The dozed treatment had greater mean woody canopy cover than the sheared treatment, and the control treatment had greater mean woody canopy cover than both the sheared and dozed treatments. None of the mean values for total canopy cover, juniper cover, oak cover, or all non-juniper cover were significantly different.

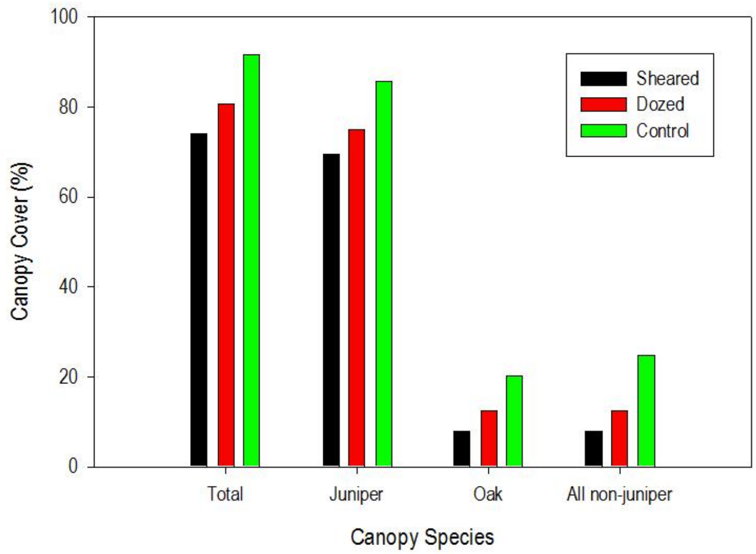

Figure 10. Pre-treatment percent woody species canopy cover. In many instances, canopy consisted of both juniper and oak species, and both were counted. Therefore, the combined canopy cover values for juniper and oak species may exceed the total cover values in some instances.

Pre-treatment herbaceous cover was calculated, and the mean herbaceous cover was less than 1.5% across all treatments (Fig. 11). During the first growing season herbaceous cover increased from pre-treatment levels across all treatments following juniper removal (Fig. 11). Mean total herbaceous cover was not significantly different in any treatment in 2006. During the second growing season mean total herbaceous cover increased in sheared and dozed treatments, but mean herbaceous cover in the control treatment decreased (Fig. 11). Mean total herbaceous cover of the control treatment in 2007 was significantly lower than in sheared and dozed treatments ($p < 0.001$), but there was no significant differences in the mean total herbaceous cover of the sheared and dozed treatments.

Grass cover and forb cover were distinguished in the vegetation survey conducted in the second growing season (Fig. 11). The control treatment had significantly lower mean grass and forb covers than the sheared and dozed treatments, $p < 0.001$, but there was no significant difference between the sheared and dozed treatments' mean grass or forb covers.

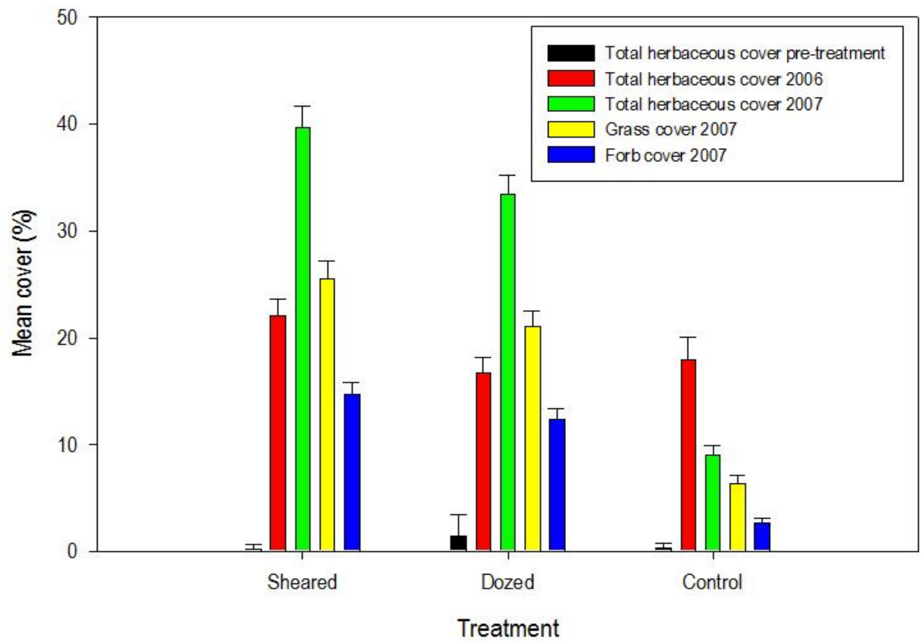

Figure 11. Total herbaceous cover pre-treatment, in 2006, and in 2007 as well as the contributions of grass and forb cover to the total cover for 2007. Cover classes were used to record percent cover in the field and midpoints of those cover classes were used for analysis. This may have resulted in overestimating cover, therefore, the sum of grass and forb cover may exceed the total cover value in some instances.

The laboratory germination trial had lower overall percent germination than the distributor's germination predictions. The seed had been stored in an uncontrolled environment for several months before the laboratory germination trials. Though storage conditions were unfavorable, the seeds proved to be robust and germinated. Because of the storage conditions, we cannot assume that there was any defect in the seed that would cause failure in germination in the field. In the research plots, *Sorghum almum* had the greatest density of the six seeded species in 2006, while sideoats grama had the greatest density in 2007 (Fig. 12A). The control treatment had significantly lower mean density of S*orghum almum* and sideoats grama than sheared and dozed treatments in 2006 ($p = 0.006$ and $p = 0.019$, respectively). Control mean density was significantly lower than sheared and dozed treatments for sideoats grama ($p = 0.005$) and Illinois bundleflower ($p = 0.01$) in 2007. Mean densities for all of the other seeded species were negligible across all treatments.

Of the species that were seeded, sideoats grama and *Sorghum almum* were present with greatest frequency (Fig. 12B). Green sprangletop was the only other species that showed a notable frequency, and it was present in approximately 20% of the quadrats in treatment plots in both years with the exception of the 2007 sheared treatment in which it averaged < 10% frequency. The only seeded species that occurred in the control plots were sideoats grama and Illinois bundleflower, and they were probably volunteers from the native seedbank and present before the onset of this research. There were no significant differences in frequency of any seeded species between sheared and dozed treatments in either year. The control treatment had significantly lower frequencies of *Sorghum almum* and sideoats grama in 2006 compared to sheared and dozed plots, and the frequency of *Sorghum almum*, sideoats grama, little bluestem, and green sprangletop was significantly lower in the control treatment than in the sheared and dozed treatments in 2007.

Cover measurements of seeded species in 2007 showed that sideoats grama had the highest mean percent cover at about 8% in sheared plots and 11% in dozed plots (Fig. 12C). *Sorghum almum* was the only other seeded species that occupied more than one percent mean cover, and it averaged 2% cover in the sheared treatment and 3% cover in the dozed treatments. Mean cover was not significantly different between sheared and dozed treatments for any of the seeded species. The control treatment had significantly lower mean cover of sideoats grama, little bluestem, and green sprangletop (p-values of 0.006, 0.00, and 0.030, respectively). The cover values for the other seeded species were so low in sheared and dozed plots that they were not significantly different from the mean cover in the control treatment where they were almost entirely absent.

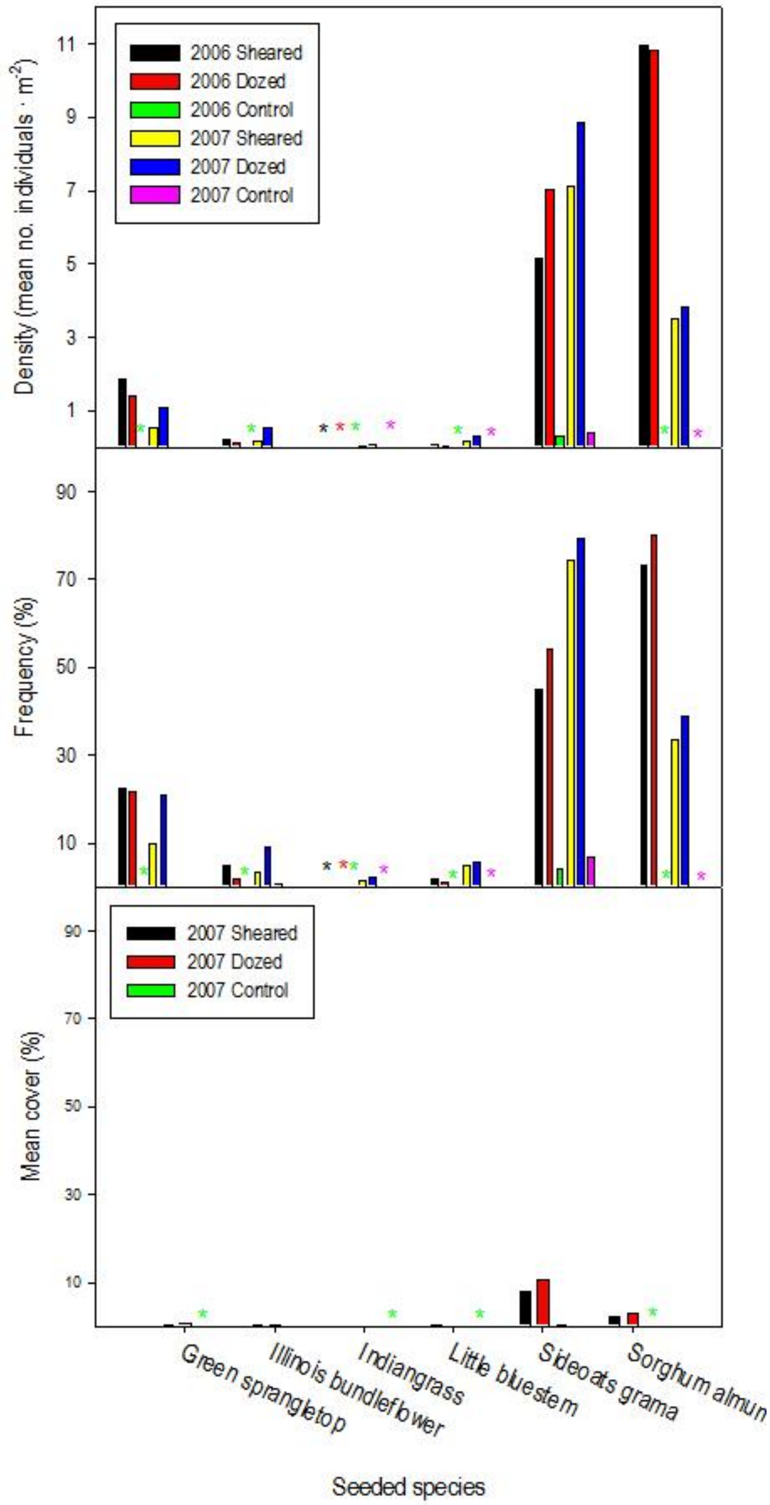

Figure 12. Mean density, frequency, and mean cover of seeded species. Individuals in controls were volunteer species present before seeding. (* = a zero value).

Absolute frequency was calculated for all species identified within the scope of either vegetation survey. A total of 91 species were identified (Table A-2) and the species that had the ten highest frequencies within a specific year and treatment twice or more were selected for closer scrutiny (Table 9).

Cedar sedge was found primarily in shaded areas, and its presence in the sheared and dozed treatments was the result of carryover from pre-treatment conditions. Dakota verbena increased considerably in 2007, which had unusually high amounts of rainfall, in sheared and dozed treatments. Ozark dropseed may have been misidentified in 2006 as Texas grama because it was so scarce vegetatively. The increased rainfall in 2007 resulted in taller and fuller vegetation, which made differentiation between the two species possible. Hedeoma, lesser chickweed, beggar’s lice, and noseburn all increased considerably in 2007; however, they did not contribute significantly to the total herbaceous cover as they were generally present in only trace amounts.

Table 9. Species among the top ten most frequent in at least two of the treatments.

	Common name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
Volunteer Grasses							
Perennial							
	Cedar sedge	28	10	40	16	15	48
	Hairy erioneuron	4	3	8	1	0	0
	King Ranch bluestem	36	17	28	45	45	18
	Ozark dropseed	0	0	0	43	11	8
	Scribners rosettegrass	10	4	11	28	10	9
	Tall dropseed	28	15	1	26	16	28
	Texas wintergrass	8	9	0	9	13	6
	Tumble windmillgrass	4	3	0	0	0	0
Volunteer Forbs							
Annual							
	Hedeoma sp.	0	0	0	44	34	7
	Lesser chickweed	0	0	0	53	63	5
	Texas croton	26	9	20	68	55	20
Perennial							
	Beggar's lice	0	0	0	52	43	9
	Dakota verbena	3	<1	0	38	33	7
	Yellow neptunia	4	4	0	0	0	0
	Knotweed leafflower	0	0	0	21	24	8
	New Mexico verbena	0	0	0	4	3	0
	Noseburn sp.	14	15	10	24	29	22
	Sida sp.	4	3	0	10	5	4
	Yellow oxalis	0	0	0	30	29	4

The three volunteer species with the highest frequencies that also exhibited cover dominance were King Ranch bluestem, tall dropseed, and Texas croton (Fig. 13). The frequency of King Ranch bluestem was not significantly different in any treatment in 2006 or 2007; however in 2007, its frequency in the sheared and dozed treatments was greater than in the control treatment. Tall dropseed was not significantly different in any treatment for either year, and in fact it exhibited virtually no change in frequency in sheared and dozed treatments from 2006 to 2007. However, tall dropseed's frequency increased in the control treatment of 2007. Texas croton had no significant difference in frequency in any treatment in 2006, and in 2007, only the control treatment mean was significantly different.

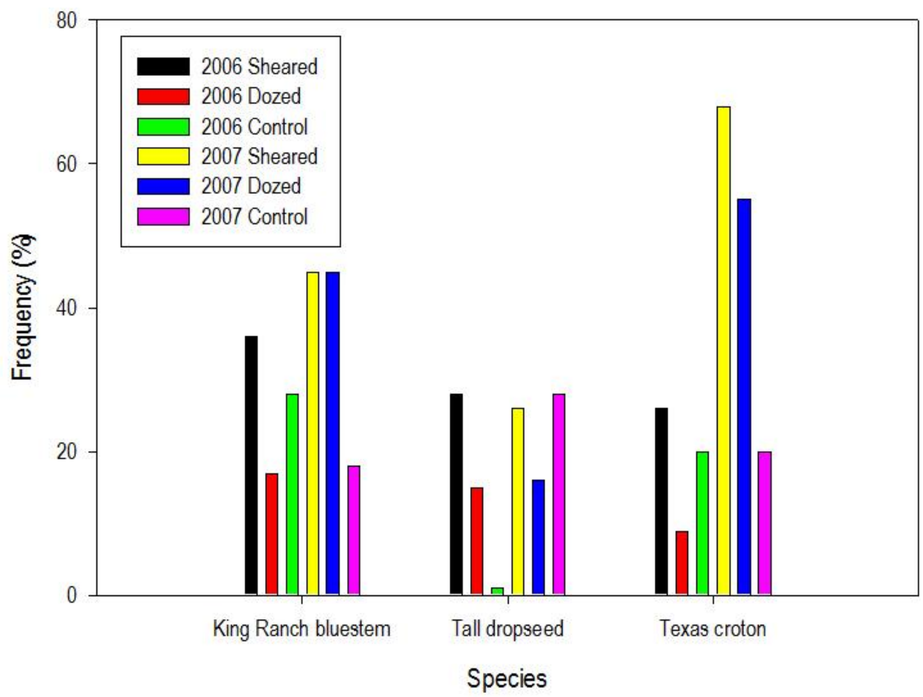

Figure 13. Frequency of the three most commonly occurring volunteer species.

Species richness in 2006 was greatest in the sheared treatment and lowest in the control treatment, with a mean of 16 and 9 species per plot, respectively (Fig. 14). The mean number of species in the control treatment plots was significantly lower (p =

0.035), than the mean number of species in plots that received the sheared treatment but it was not significantly different from the dozed treatment. The following year, richness increased across all treatments with sheared and dozed treatment plots both having a mean of 41 species and the control treatment plots averaging 21 species. Richness in the control treatment was significantly lower, p = 0.014, than in the sheared and dozed treatments, however, there was not a significant difference in richness between sheared and dozed treatments.

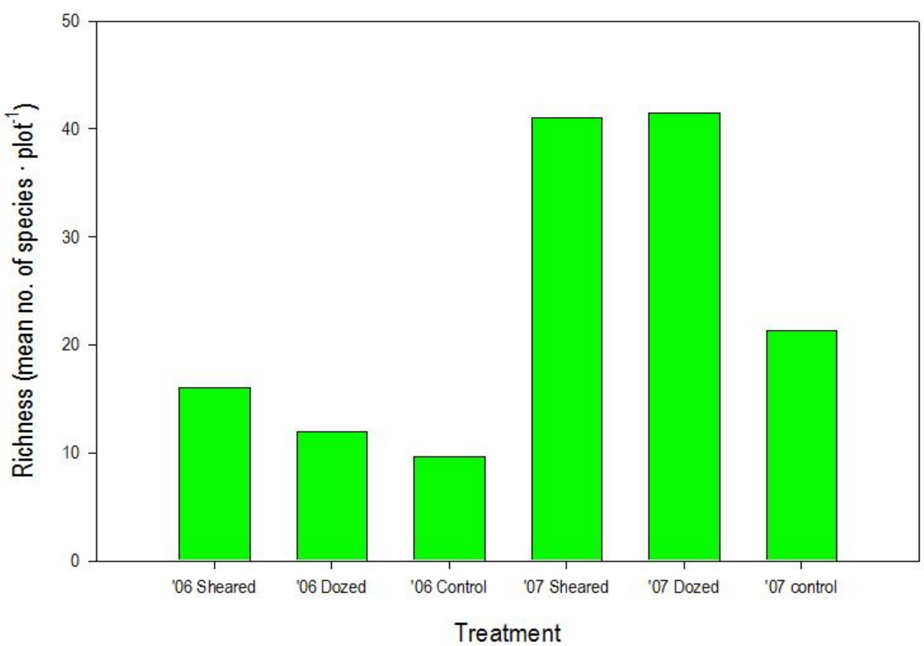

Figure 14. Species richness by treatment and year.

There was no correlation between total herbaceous cover and predicted soil depth or cover of the seeded species and predicted soil depth except in the case of sorghum almum (Figs. 15A – 15C). Sorghum almum was found at low covers (<3%) at all predicted depths of soil, but at greater covers (>10%), it was found only in soils with a predicted depth to an impenetrable layer of 10.0 cm or greater. When it was present in abundance (> 30% cover) it was almost always found in soils deeper than 30.0 cm. There was one instance in which sorghum almum was found at greater than 60% cover in a soil with a predicted depth of 0.0 cm. This point was unique because it was the only occasion in which *Sorghum almum* was present at such a high percent cover, making it an uncharacteristic for the plot and treatment. There may be a small fracture in the bedrock that allowed for deeper rooting and access to plant available water. More likely, the high cover of *Sorghum almum* is due once again to GPS error, which would explain the low soil depth prediction for the location when the site has proven to be capable of retaining enough plant available water to support that amount of vegetation.

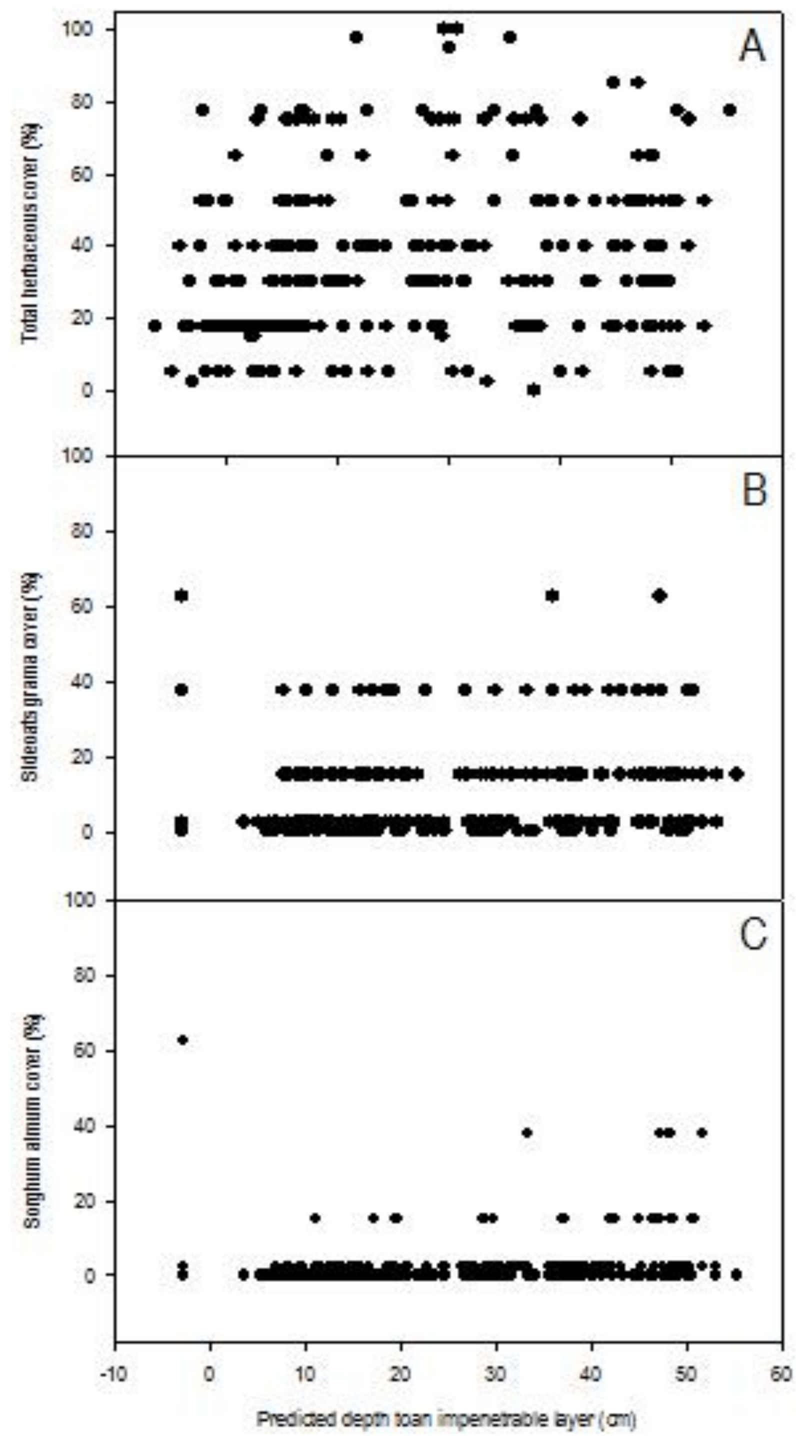

Figure 15. Total herbaceous cover, sideoats grama cover, and sorghum almum cover vs. predicted depth to an impenetrable layer.

Discussion

Method of juniper clearing had no significant effect on total cover, grass cover, forb cover, or seeded species cover, frequency, or density. Mean richness of sheared and dozed treatments was virtually identical.

In both sheared and dozed treatments, mean total cover, mean seeded species frequency and density, and mean plot richness increased from 2006 to 2007. The low amount of cover in 2006 and the subsequent increase cover and frequency of most species in 2007 is likely due to the abnormally low precipitation in 2006 and the unusually high amount of precipitation in 2007. Treatment effect may be masked in the two years of this study by the two consecutive years of uncharacteristic rainfall. In the first year, drought stress was so great that seedling establishment was impaired to the point that only a few species successfully established, while in the second year there was almost no water stress and many species flourished.

The decline in mean density and frequency of *Sorghum almum* in 2007 is likely due to the fact that it is a weak perennial. It establishes well, but it is a weak competitor. It was used as a nurse species to establish quickly following clearing and act as a cover crop; however it was also chosen because it would decline quickly and make resources and space available for the volunteer and seeded native species once they were established.

There appeared to be no relationship between total herbaceous cover and predicted soil depth from EC_a measurements. The exception to this is the pattern of increased sorghum almum cover with increased depth. The lack of expression of differential vegetative cover due to soil depth variation may also be attributed to the unusually high amount of rain in 2007. It is expected that shallow soils would have less cover than deeper soils because they do not retain water as long as the deep soils, and therefore cannot sustain as many plants. However, since precipitation was frequent and abundant in 2007, water stress was not a factor in determining herbaceous cover. The *Sorghum almum* probably exhibits the trend when other species do not because it is not adapted to water stress as the native species are, so even minimal stress, as was the case in 2007, would affect its cover distribution. In subsequent years, the effect of soil depth and water storage potential should result in differentiated herbaceous cover for more speci**es.**

CHAPTER V

CONCLUSIONS

Juniper removal by bulldozing and shearing does result in different levels of soil disturbance and thus, they create different seedbeds. The small difference in course litter most likely did not affect the seedbed, and the extent to which differential soil surface topography affected water storage in this situation is not known.

Soil apparent electrical conductivity was a useful measure to predict variations in soil depth which served as indicators of soil moisture patterns in this system. In future rangeland restoration projects this method may be valuable in discerning suitable sites for restoration that have the capacity to support healthy vegetative communities from areas that do not have sufficient soil to warrant restoration efforts. In future studies, EC_a would prove valuable at the onset of research or restoration efforts to locate homogenous sites. In this case, the study was already underway, and soil moisture patterns were used to factor out variation in soil moisture retention and enable researchers to discern differences in plant response due to juniper removal treatment.

Despite differences in soil surface topography created by clearing method, there was no difference in vegetation establishment between the two treatments. The short duration of the experiment limits the observation of treatment effect. If the plant communities were allowed to establish for five or ten years, treatment differentiation might be more prominent.

From the data collected in this experiment, no basis for decision making in mechanical juniper removal method can be made based on differential seedbed preparation or seedling establishment. Findings from this research would support the decision of the EQIP program to cost share reseeding for landowners who chose to clear juniper with shearers as there is seemingly no difference in re-vegetation between the two clearing methods.

One aspect of these two clearing methods that is clearly differentiated is the cost of brush management. In this case, the cost of shearing was only 80% of the cost of dozing. The actual cost of clearing was inflated beyond normal prices due to the fact that clearing had to be done within very small, specific areas to make research plots. However, based on what has been found so far, cost was the most prominent variable between these two clearing methods, and in this case, shearing was preferable to dozing.

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APPENDIX I

SOIL CHEMICAL PROPERTIES

Treatment	pH (H₂O)	Ph (CaCl₂)	CEC *	Exchangeable Acid *	Base Saturation (%)	Soluble Salts (uS)	K *	Ca *	Mg *	Na *	P (ppm)	Organic Matter (%)	Organic C (%)	C (%)	N (%)	SAND (%)	SILT (%)	CLAY (%)	Texture Class (abr.)
C - 1	7.6	7.2	82.9	0.7	99.2	290	0.36	75.9	5.9	0.04	0.0	8.8	2.6	5.1	0.25	14.8	49.6	35.6	Scl
C - 2	7.4	6.9	55.5	4.1	92.5	220	0.32	48.6	2.4	0.05	0.2	11.2	6.4	6.5	0.47	18.7	45.6	35.7	Scl
C - 3	7.5	7.0	71.7	3.4	95.3	260	0.83	64.6	2.9	0.05	0.2	20.4	11.4	11.8	0.75	21.6	42.7	35.7	Cl
C - 4	7.5	7.0	33.4	1.3	96.0	260	0.24	30.2	1.5	0.05	0.1	11.4	6.1	6.6	0.46	21.0	54.2	24.8	Sl
C - 5	7.5	7.2	85.2	3.1	96.3	220	0.44	79.5	2.1	0.04	0.1	16.2	7.8	9.4	0.50	21.0	42.5	36.5	Cl
D - 1	7.4	7.2	64.0	4.4	93.1	330	0.87	56.0	2.7	0.04	0.1	12.9	7.2	7.5	0.44	12.0	36.7	51.3	C
D - 2	7.6	7.3	80.2	3.6	95.5	295	0.29	73.1	3.2	0.05	0.1	17.1	9.4	9.9	0.59	26.7	42.8	30.6	Cl
D - 3	7.5	7.2	67.0	3.1	95.3	290	0.43	61.1	2.3	0.05	0.1	13.8	7.8	8.0	0.46	18.2	49.5	32.3	Scl
D - 4	7.4	7.1	70.9	3.6	94.9	280	0.33	64.9	2.0	0.04	0.1	14.3	7.9	8.3	0.46	19.7	46.3	34.0	Scl
D - 5	7.1	6.7	26.9	6.1	77.5	140	0.42	18.4	2.0	0.03	1.0	8.7	5.0	5.1	0.29	39.8	33.8	26.5	L
D - 6	7.1	6.6	29.7	5.9	80.0	160	0.35	21.9	1.4	0.04	0.2	10.1	5.8	5.9	0.32	15.0	61.1	23.9	Sl
S - 1	7.5	7.2	92.0	3.8	95.9	320	0.66	84.8	2.8	0.04	0.1	10.7	5.2	6.2	0.39	15.2	37.3	47.5	C
S - 2	7.5	7.2	88.3	3.0	96.6	340	0.60	79.6	5.0	0.04	0.0	9.8	4.3	5.7	0.33	21.7	55.9	22.4	Sl
S - 3	7.6	7.3	83.0	3.1	96.2	260	0.38	77.0	2.5	0.04	0.1	11.0	5.3	6.4	0.38	21.9	43.3	34.8	Cl
S - 4	7.6	7.2	71.7	4.1	94.2	260	0.36	65.7	1.4	0.05	0.1	10.6	5.7	6.2	0.42	21.2	43.2	35.6	Cl
S - 5	7.5	7.2	77.7	3.9	95.0	270	0.32	71.7	1.8	0.04	0.1	17.2	9.5	10.0	0.61	22.3	51.3	26.5	Sl
S - 6	7.3	6.9	21.1	2.9	86.1	170	0.26	15.9	1.9	0.04	0.2	9.2	5.3	5.3	0.30	12.7	65.8	21.5	Sl

* indicates that the measurement unit is milliequivalents · 100g of soil.

APPENDIX II

PERCENT FREQUENCIES OF ALL SPECIES IDENTIFIED WITHIN THE SCOPE OF EITHER SURVEY

Common name	Latin name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
Seeded Species							
Green sprangletop	*Leptochloa dubia*	23	22	0	9	20	0
Illinois bundleflower	*Desmanthus illinoensis*	5	2	0	3	9	<1
Indiangrass	*Sorghastrum nutans*	0	0	0	1	2	0
Little bluestem	*Shizachyrium scoparium* var. *scoparium*	2	<1	0	5	5	0
Sideoats grama	*Bouteloua curtipendula*	45	54	4	72	77	7
Sorghum almum	*Sorghum almum*	73	80	0	32	38	0
Volunteer Grasses							
Annual							
Japanese brome	*Bromus japonicas*	0	0	0	5	0	0
Oldfield threeawn	*Aristida oligantha*	3	0	0	6	4	2
Ozarkgrass	*Limnodea arkansana*	0	0	0	10	7	0
Rye grass	*Lolium perenne*	0	0	0	0	<1	0
Perennial							
Bermudagrass	*Cynodon dactylon*	<1	0	0	<1	<1	0
Cedar sedge	*Carex planostachys*	28	10	40	16	15	48
Fall witchgrass	*Digitaria cognate*	3	0	0	<1	<1	0
Hairy erioneuron	*Erioneuron pilosum*	4	3	8	1	0	0
Hairy grama	*Bouteloua hirsute*	0	0	1	0	<1	0
Hall panicum	*Panicum hallii*	0	0	0	4	3	<1
King Ranch bluestem	*Bothriochloa ischaemum* var. *songarica*	36	17	28	45	45	18
Ozark dropseed	*Sporobolus vaginiflorus* var. *ozarkanus*	0	0	0	43	11	8

APPENDIX II continued

Common name	Latin name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
Paspalum sp.	*Paspalum sp.*	4	0	0	<1	3	1
Perennial threeawn	*Aristida pupurea*	<1	<1	0	9	3	1
Purpletop	*Tridens flavus*	0	0	0	<1	0	0
Red grama	*Bouteloua trifida*	2	0	0	0	0	0
Sand dropseed	*Sporobolus cryptandrus*	0	0	0	2	3	<1
Scribner rosettegrass	*Dichanthelium oligosanthes var. scribnerianum*	10	4	11	28	10	9
Silver bluestem	*Bothriochloa laguroides* var. *torreyana*	<1	<1	2	5	2	0
Slim tridens	*Tridens muticus* var. *muticus*	0	0	2	0	0	0
Switchgrass	*Panicum virgatum*	0	0	0	<1	<1	0
Tall dropseed	*Sporobolus asper* var. *asper*	28	15	1	26	16	28
Texas grama	*Bouteloua rigidiseta*	3	0	41	4	1	6
Texas wintergrass	*Stipa leucotricha*	8	9	0	9	13	6
Tumble windmillgrass	*Chloris verticillata*	4	3	0	0	0	0
Tumblegrass	*Schedonnardus paniculatus*	0	0	0	<1	0	0
White tridens	*Tridens albescens*	3	0	0	0	0	0
Volunteer Forbs							
Annual							
Annual marshelder	*Iva annua* var. *annua*	0	0	0	3	5	1
Beebalm	*Monarda citriodora*	<1	0	0	0	0	0
Bur-clover	*Medicago polymorpha*	0	0	0	14	8	1
Buttonweed sp.	*Diodia sp.*	0	0	0	0	0	<1
Chervil	*Chaerophyllum tainturieri* var. *dasycarpum*	0	0	0	0	<1	0

APPENDIX II continued

	Common name	Latin name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
	Common broomweed	*Amphiachyris amoena*	0	0	0	9	3	3
	Common mullein	*Verbascum thapsus*	0	0	0	3	<1	0
	Common vetch	*Vicia sativa*	0	0	0	3	<1	0
	Hedeoma	*Hedeoma sp.*	0	0	0	44	34	7
	Lesser chickweed	*Stellaria pallida*	0	0	0	53	63	5
	Mountain pink	*Centaurium beyrichii*	0	0	0	11	5	3
	Pink verbena	*Verbena pumila*	0	0	0	0	<1	0
	Rabbit tobacco	*Gnaphalium obtusifolium*	0	0	0	11	8	4
	Red seed plantain	*Plantago rhodosperma*	0	0	0	22	9	3
	Red-stemmed leafflower	*Phylanthus urinaria*	0	0	0	<1	0	0
	Sandmat sp.	*Euphorbia sp.*	0	0	0	16	15	<1
	Slender-leaf hymenoxys	*Hymenoxys linearifolia*	0	0	0	2	2	5
	Texas bluebonnet	*Lupinus subcarnosus*	0	0	0	1	0	0
	Texas croton	*Croton texensis*	26	9	20	68	55	20
	Texas dandelion	*Pyrrhoppappus carolinianus*	0	0	0	0	<1	0
	Texas thistle	*Cirsium texanum var. texanum*	0	0	0	2	2	0
	Venus looking glass	*Triodanis sp.*	0	0	0	15	10	2
	White heliotrope	*Heliotropium tenellum*	2	0	0	16	9	1
Perennial								
	Antelope horn	*Asclepias virdiflora*	<1	0	0	1	2	0
	Beggars lice	*Hackelia virginiana*	0	0	0	52	43	9
	Blackfoot daisy	*Melampodium leucanthus*	3	0	0	14	11	9
	Crow poison	*Nothoscordum bivalve*	0	0	0	0	<1	0

APPENDIX II continued

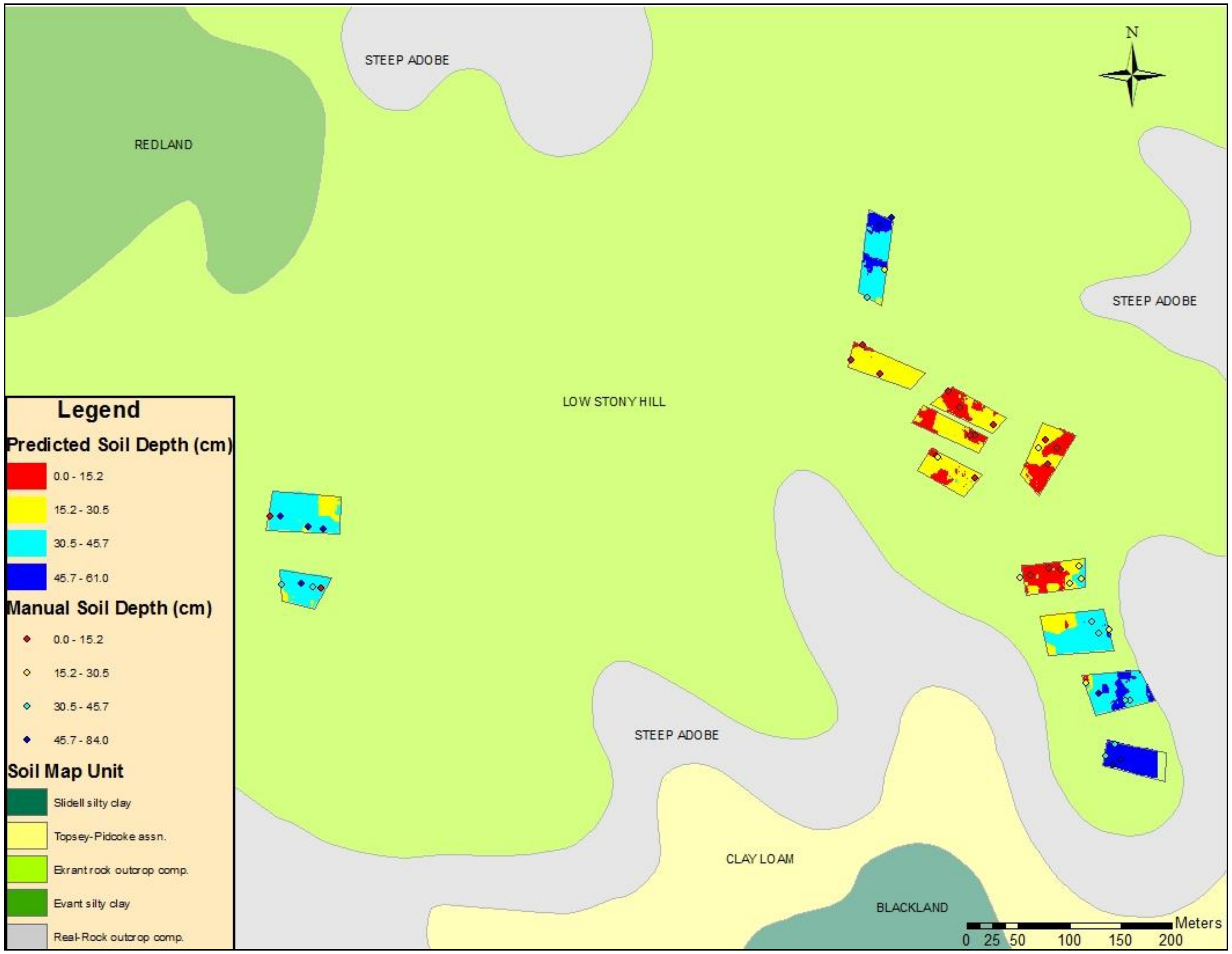
Common name	Latin name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
Dakota verbena	*Verbena bipinnatifida* var. *bipinnatifida*	3	<1	0	38	33	7
False dandelion	*Krigia biflora*	0	0	0	0	2	5
Fleabane sp.	*Erigeron sp.*	0	0	0	13	11	8
Greenbriar	*Smilax bona-nox*	2	0	2	<1	0	6
Grey goldaster	*Heterotheca canescens*	<1	<1	0	3	3	3
Heath aster	*Aster ericoides*	0	0	0	7	22	<1
Indian mallow sp.	*Abutilon incanum*	0	0	0	0	<1	<1
Knotweed leafflower	*Phyllanthus polygonoides*	0	0	0	21	24	8
Liatris	*Liatris sp.*	0	0	0	<1	1	0
Morning-glory	*Evolvulus sp.*	0	0	1	0	0	0
Narrowleaf milkweed	*Asclepias stenophylla*	0	<1	0	<1	<1	<1
New Mexico verbena	*Verbena neomexicana* var. *neomexicana*	0	0	0	4	3	0
Noseburn sp.	*Tragia sp.*	14	15	10	24	29	22
Orange zexmenia	*Wedelia hispida*	0	0	0	0	0	2
Oval-leaf milkweed	*Asclepias ovalifolia*	0	0	0	<1	0	0
Peppergrass	*Lepidium sp.*	0	0	0	6	11	2
Poison ivy	*Rhus radicans*	0	0	0	2	1	2
Queen Anne's lace	*Daucus carota*	0	0	0	11	1	0
Queensdelight	*Stillingia sylvatica*	0	0	2	0	0	1
Range ratany	*Krameria glandulosa*	0	0	0	<1	1	0
Scurfpea	*Psoralea tenuiflora*	0	0	0	5	5	1
Sida sp.	*Sida sp.*	4	3	0	10	5	4
Skullcap sp.	*Scuttellaria sp.*	0	0	0	2	8	1
Snowbrush Ceanothus	*Ceanothus velutinus*	0	0	0	0	<1	0
Velvet bundleflower	*Desmanthus velutinus*	0	0	0	3	5	<1

APPENDIX II continued

Common name	Latin name	06 Sheared	06 Dozed	06 Control	07 Sheared	07 Dozed	07 Control
Western ragweed	*Ambrosia psilostachya*	0	0	15	0	2	0
Wild mercury	*Argythamnia sp.*	0	0	0	0	<1	0
Wild onion	*Allium canadense* var. *canadense*	0	0	0	1	<1	2
Yellow neptunia	*Neptunia lutea*	4	4	0	0	0	0
Yellow oxalis	*Oxalis dillenii* var. *dillenii*	0	0	0	30	29	4

APPENDIX III

MAP OF MANUAL DEPTH MEASUREMENTS AND PREDICTED SOIL DEPTH VARIATION IN CLEARED PLOTS



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