HYDROLOGIC IMPACTS OF MECHANICAL SHEARING OF ASHE JUNIPER IN CORYELL COUNTY, TEXAS

A Thesis

by

COURTNEY HALE GREER

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

August 2005

Major Subject: Rangeland Ecology and Management

HYDROLOGIC IMPACTS OF MECHANICAL SHEARING OF ASHE JUNIPER IN

CORYELL COUNTY, TEXAS

A Thesis

by

COURTNEY HALE GREER

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

Approved by:

Chair of Committee,	Robert W. Knight
Committee Members,	Fred E. Smeins
	Edward C.A. Runge
Head of Department,	Steve Whisenant

August 2005

Major Subject: Rangeland Ecology and Management

ABSTRACT

Hydrologic Impacts of Mechanical Shearing of Ashe Juniper in

Coryell County, Texas. (August 2005)

Courtney Hale Greer, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Robert W. Knight

Several studies have been conducted to research the effectiveness of brush removal on hydrologic properties such as increased water yields and water quality. The Leon River Restoration Project (LRRP) is a large scale brush management program aimed at assessing the impacts of the mechanical removal of Ashe juniper (*Juniperus ashei*) on the quantity and quality of water, as well as wildlife habitat and livestock forage production.

The objectives of this particular study are to assess the short and long term impacts of mechanical rangeland management techniques on runoff water yield and sediment loss from rainfall simulator plots. Two ecological sites were used to conduct rainfall simulation in 3 stages. Rainfall simulations were completed on Redland and Low Stony Hill sites in June 2003 prior to treatment, July 2003 after Ashe juniper was sheared from treated areas of both sites and 11 months after treatment in June 2004.

Infiltration rates on both the Redland and Low Stony Hill sites increased after juniper was removed except for the treated brush plots on the Redland site, which experienced a 33% decrease. During the third simulation, infiltration rates

decreased on all plots. Grass and litter biomass, as well as bare ground were influential on both sites. Percent bare ground affected infiltration rates the most on the Redland site where bare ground on the treated brush site was 23% in July 2003 and 42% in June 2004. The grass plots on the Low Stony Hill site had the greatest percentages of bare ground during the second simulation.

Very few significant differences were apparent with sediment production on the Low Stony Hill site; however, the treated brush plots on the Redland site did experience a significant increase in soil loss following treatment. Sediment production increased from 24.6 kg/ha to 1,730 kg/ha in one month on the treated brush site. All other plots on the Redland site decreased in sediment discharge. Sediment production also had minor increases on the grass plots and treated brush of the Low Stony Hill. Once again, standing crop and bare ground seemed to have the greatest influence on sediment production.

ACKNOWLEDGEMENTS

First I would like to thank Dr. Robert Knight, who has shown great guidance, as well as care and concern for me throughout my undergraduate and graduate studies. I have enjoyed all the moments we have spent on the plant team and in the field. I would like to thank Dr. Fred Smeins and Dr. Ed Runge, my graduate committee members, for their support and direction throughout this study.

I also would like to thank all of the graduate students who braved the exhausting heat and helped with the rainfall simulations; Frank Holland, Lisa James, Edwin Juarez and Jenny C. Sanders. A special thanks to Frank who was literally the muscle behind the project. I would like to thank Andrew Weichert and Tim Brown for their assistance with my data collection. Thank you to all of the others associated with the project. I was very lucky to be involved with such a wonderful project and great people.

Thank you to my wonderful husband Collin whose love and strength has made me a better person. I would especially like to thank my parents for their love and support, without which none of this would have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

Table Page

Table | Page

CHAPTER I

INTRODUCTION

European expansion and settlement in the eighteenth and nineteenth centuries coincided with the replacement of savannahs and grasslands with woodlands (Scholes and Archer 1997). Research has indicated a major transformation occurred in the Cross Timbers region of Texas from an oak savannah to juniper dominated rangelands (Dkysterhuis 1948). Following the introduction of domesticated livestock and the control of wildfires, the landscape became infested with mesquite (*Prosopis glandulosa*) and Ashe juniper (*Juniperus asheii*). Native grasses were greatly reduced as overgrazing and the elimination of naturally occurring fires increased in the Cross Timbers (TPWD 2001). The shift from grassland savannahs to woody dominated rangelands has extensive implications for water availability and quality (Archer 1994, Thurow 1998).

Due to rapid population growth in Texas during the past 20 years, water usage has increased (Griffin and McCarl 1989). The increasing encroachment of Ashe juniper has been blamed for the decline of spring and stream flow, as well as a reduction in runoff and infiltration. All of these factors may be contributing to the reduction in the recharge of the Edwards Aquifer that provides water to the San Antonio and Austin areas. Annual interception losses for juniper have been measured to be approximately 70-80 percent, while

---

This thesis follows the style of the Journal of Range Management.

herbaceous vegetation interception losses range from 11-18 percent (Eddleman 1983, Hester 1996). Studies also indicate that woody vegetation has much higher transpiration rates than those of herbaceous vegetation (Davis and Pase 1977, West 1992).

Control of woody vegetation on rangelands is generally employed to reduce canopy cover, thereby increasing forage production, as well as maintaining and improving wildlife habitat (Hester et al. 1997, Newman 1998). Research, from plot and catchment scale studies, has shown a reduction of woody cover, through brush management, significantly increases water yields (Richardson et al. 1979, Dugas et al. 1996, Thurow and Hester 1997). The alteration of soil and vegetation characteristics, in relation to brush management treatments, may have a substantial impact on the hydrological processes. Factors influencing hydrology, such as organic matter, ground and canopy cover, bulk density and litter, may shift as vegetation composition changes (Thurow et al. 1986).

The effect of brush management techniques on hydrologic properties such as water quality, water yield, infiltration, sediment production and nutrient transport has been researched in North, South, Central and West Texas (Brock et al. 1982, Carlson et al. 1990, Hester 1996, Reilly 1983, Weltz and Blackburn 1995, Wu et al. 2001, Richardson et al. 1979, Wright et al. 1976), however, there is an insufficient amount of information of the effect of brush management has on water yield and quality in the Cross Timbers area. Large-scale brush management techniques such as mechanical treatments and prescribed fire have been developed to control the invasion of Ashe juniper in the Cross Timbers region. The Leon River Restoration Project (LRRP) is a brush management program that was developed in response to a concern for endangered species habitat on Ft. Hood. This large scale project was developed to measure the effects of Ashe juniper removal on increased water yields on rangelands, while improving wildlife habitat and forage production for livestock. Several stakeholders became involved with LRRP, including private landowners in Coryell and Hamilton counties, as well as federal, state, local and non-governmental agencies.

The Leon River Restoration Project serves as a model for future brush management programs throughout the state, as well as nationwide. The goal of the LRRP is to assess the impacts of the mechanical treatment of Ashe juniper on wildlife habitat, livestock forage production, and the quality and quantity of water. Additional objectives of the LRRP include restoring the productivity of native rangelands, habitat for native wildlife and ultimately to improve water quality and quantity within the Leon River watershed (Hoffman and Wolfe 2003).

CHAPTER II

LITERATURE REVIEW

In several areas, invading brushy vegetation continually competes with beneficial grasses and forbs for moisture (Richardson et al. 1979). Many techniques have been used to control brush species, including various mechanical treatments, prescribed fires, herbicide applications, biological controls, as well as combinations of the above treatments. Numerous studies researching the effectiveness of brush removal and control on increased water yields and water quality have been conducted on a wide range of ecological sites and landscapes.

In the early 1930's, Rocky Creek in San Angelo, Texas dried up and came back to life in the 1960's after extensive brush removal along the 29,946 hectares of watershed (Kelton 1975). Mechanical treatments are commonly used for the control of many types of brush species. In areas where annual precipitation exceeds 450 mm (18 inches) there is potential for increasing streamflow by replacing deep rooted brush species with shallow rooted grasses (Hibbert 1983). Hibbert (1983) states that water yield will increase approximately 1 mm for each 4 mm increase in precipitation over the 400 mm "threshold" value. In humid regions of Australia, the widespread replacement of *Eucalyptus* by pasture and crop species has raised the water table, leading to salinization problems (Greenwood 1992, Walker et al. 1993). In 1982 it was estimated that 42.7 million hectares of Texas rangelands was infested with brush species (Johnson 1986). Brush control in Texas warrants serious consideration due to the large tracts of rangelands in relatively high precipitation areas, receiving between 600 to 1,000 mm of rain per year (Wilcox 2002).

Studies in Arizona, California and Texas have indicated that brush management can increase surface water flows and ground water recharge by reducing evapotranspiration and interception (Griffin and McCarl 1989). A reduction in leaf surface area is a main factor when attempting to increase streamflow through brush management. Brush species have a much larger leaf area than grasses, thereby increasing transpiration rates and interception losses, as well as reducing the amount of water that actually reaches the ground. Transpiration rates are also decreased when brush is replaced with grass due to their shallow roots and dormancy during part of the year (Hibbert 1983).

Dugas and Hicks (1998) located two watersheds, dominated by *Juniperus ashei*, in northeast Uvalde County, Texas to research the effect of individual plant removal on runoff and evapotranspiration. Over a three year period, evapotranspiration on the treated watershed decreased by 0.07 mm/day in response to the removal of the juniper. However, the ratio of total precipitation to total evapotranspiration during the period of March through October each year immediately changed after treatment (Dugas and Hicks 1998). The ratio varied from approximately 55 to 75% during the full 5 years of the study in Uvalde County, increasing as precipitation decreased (Dugas and Hicks 1998).

Interception is also a concern with the large biomass of mature shrubs (Hamilton and Rowe 1949). Rainfall that is intercepted by plant canopies or litter is evaporated back into the atmosphere and cannot contribute to the local water budget (Owens et al. 2001). By reducing shrub cover, water that may have been previously intercepted by the canopy can quickly move into the soil beyond the root zone and potentially increase streamflow (Wilcox 2002). Annual precipitation has been estimated to have interception rates of 18.1% by midgrasses, 10.8% by shortgrasses, 17.1% by oak mottes and litter, while 54% reaches the soil by throughfall and stemflow of oak trees (Thurow et al. 1987). The greatest infiltration rates were found under oak mottes, followed by midgrasses and shortgrasses (Thurow et al. 1986). Hester et al. (1997) found similar results with infiltration rates on juniper plots falling between oak and midgrass plots. In a study directed at determining the impact of juniper trees in areas of low to moderate annual rainfall, Owens et al. (2001) found high interception rates by juniper canopies. In Uvalde County on the Annandale Ranch during the month of August, they found that 43% of the total rainfall was intercepted and evaporated back into the atmosphere before it had a chance to reach the ground. In lower rainfall areas (<18 in), it has been reported that as much as 75% of total rainfall has been intercepted by juniper canopies during low intensity storms (Owens et al. 2001).

Treatment responses vary considerably between different vegetation types (Hibbert 1983). Responses tend to be highest in chaparral sites, decreasing in other dense brush areas and aspen. Slight increases have been seen in thinning ponderosa pine (*Pinus ponderosa*). Hibbert (1983) stated that little response would be seen from pinyon-juniper and sagebrush lands except on extremely favorable sites. Experiments in the chaparral watersheds of Arizona and California have demonstrated an increase in mean annual streamflow by as much as 150 mm through the conversion of brush to grass dominated rangelands (Hibbert et al.1974). The Wagon Wheel Gap study in Colorado also exhibited an increase in streamflow when aspen, spruce and fir trees were cut on a pair of watersheds during controversy over the impact of forests on the water balance (Bates and Henry 1928).

Surface roughness, created by rootplowing, has proven to be an important characteristic for increased infiltration rates and decreased runoff rates. Richardson et al. (1979) reported a decrease in runoff following the mechanical treatment of live oak (*Quercus virginiana*), Vasey shin oak (*Q. pungens var. vaseyana*), Ashe and redberry juniper (*Juniperus ashei and J. pinchotii*), and honey mesquite (*Prosopis glandulosa*) in the Edwards Plateau region of central Texas. Rootplowing creates soil depressions allowing for increased water storage and percolation to groundwater (Richardson et al. 1979). A similar study was conducted in the desert shrublands of southeastern Arizona (Tromble 1976). During one hour rainfall simulations on previously rootplowed and pitted plots, a strong correlation was identified between the soil structure of the first horizon and water intake (Rauzi and Fly 1968). Richardson et al. (1979) also found that rootplowing juniper in the Edwards Plateau region increased depression storage, and was able to reduce runoff by 20 percent. Depression storage should decrease with time and create higher runoff rates like those prior to rootplowing (Richardson et al. 1979).

Runoff is highly dependent on antecedent moisture and increases as moisture in the ground increases (Dugas and Hicks 1998). Schreiber and Kincaid (1967) showed that average runoff for any location would increase as antecedent moisture increased. Studying two watersheds in the Edwards Plateau region, Richardson et al. (1979) showed that the shallow soils and fractured limestone had little water holding capacity. Antecedent rainfall had little effect on the amount of runoff following a given rainfall event. The results did vary on the heavy clay soils of the Blackland Prairie where runoff production is much more sensitive to antecedent moisture. In areas of higher moisture content where mesquite had been killed, there was a 10 percent increase in runoff (Richardson et al. 1979).

Sediment production is greatly influenced by protective cover. Kincaid et al. (1964) indicated a strong relationship between infiltration and vegetation cover, thereby reducing sediment loads. As infiltration increases, the amount of sediment leaving the area decreases. On approximately 30,000 acres of rangeland in the Rio Puerco drainage in New Mexico, surface runoff was reduced 97 and 83% during the first and third years of treatment, while soil erosion was also reduced 86 and 30% for the first and third years following ripping and seeding (Dortignac and Hickey 1963). Two similar watersheds in the Edwards Aquifer recharge zone were observed to have an increase in runoff following the removal of juniper. Dugas and Hicks (1998) believed the increase in runoff was due to the lack of vegetation present in the area immediately following treatment. Two years later runoff decreased significantly as bunch grasses increased. Similar results have been found in riparian areas where vegetation has been clipped to near ground level to study the movement of sediment. Pearce et al. (1998) conducted a two-year rainfall simulation study in a riparian area near Fort Collins, Colorado and noticed a significant difference in sand movement when vegetation was removed. An increase in sediment deposition can negatively affect water quality and habitat.

CHAPTER III

INFILTRATION RATE RESPONSE TO MECHANICAL REMOVAL OF ASHE JUNIPER

Introduction

Following European exploration and settlement in the eighteenth and nineteenth centuries, vegetation composition has changed considerably in the Cross Timbers region of Texas. Early travelers found large areas of tall and mid grasses with very few scattered trees (Taylor and Smeins 1994). Trees and brush species currently dominate this region today. Two major factors influencing the increase in brush species were the introduction of domesticated livestock and the suppression of naturally occurring fires. Intensive grazing with fenced pastures replaced the moderate grazing of scattered buffalo, causing severe overgrazing. The suppression of fire led to decreased seedling mortality, allowing several woody plants to invade and dominate the region (Taylor and Smeins 1994). Mesquite (*Prosopis glandulosa*) and Ashe juniper (*Juniperus ashei*) infested the landscape, shifting grassland savannahs to woody dominated rangelands. Ashe juniper is often blamed for the reduction in spring and stream flow, runoff and infiltration. Research has indicated that a reduction in woody cover through brush management can significantly increase water yields (Richardson et al. 1979), Dugas et al. 1996, Thurow and Hester 1997). As the population and agricultural activities in Texas continues to grow, the competition for water resources increases.

In response to the growing concern for Texas' water resources, large scale brush management techniques have been developed to control the encroachment of Ashe juniper. Several mechanical brush management techniques have been used to reduce densities of Ashe juniper in the Cross Timbers region, such as chaining, rootplowing and shearing. By reducing the shrub canopy more precipitation can reach the ground, thereby reducing interception rates and increasing infiltration rates. It has been documented that the canopies of juniper trees typically intercept and lose between 13 and 18 % of rainfall (Thurow et al. 1987). Juniper has been known to intercept as much as 43 percent of annual precipitation (Owens et al. 2001). Therefore, an understanding of the relationship between plant removal and infiltration rates is important to the future of Texas water resources.

Study Area

This study was conducted in Gatesville, Texas in Coryell County, which is located within the Grand Prairie and the Western Cross Timbers (Figure 1). The county encompasses approximately 2,737 km^2, or 676,249 acres of grasslands and plateaus ("CORYELL COUNTY." Texas State Historical Association. [Accessed Thurs Dec 16 2:37:14 US/Central 2004]). Approximately 756.8 km^2 are used for the Ft. Hood Military Reservation, while 2,021 km^2 are used for farming, producing crops and livestock. Approximately 68% of the county was rangeland in 1983, while 18% was used for farmland and only 2% of the county was urban. Leon

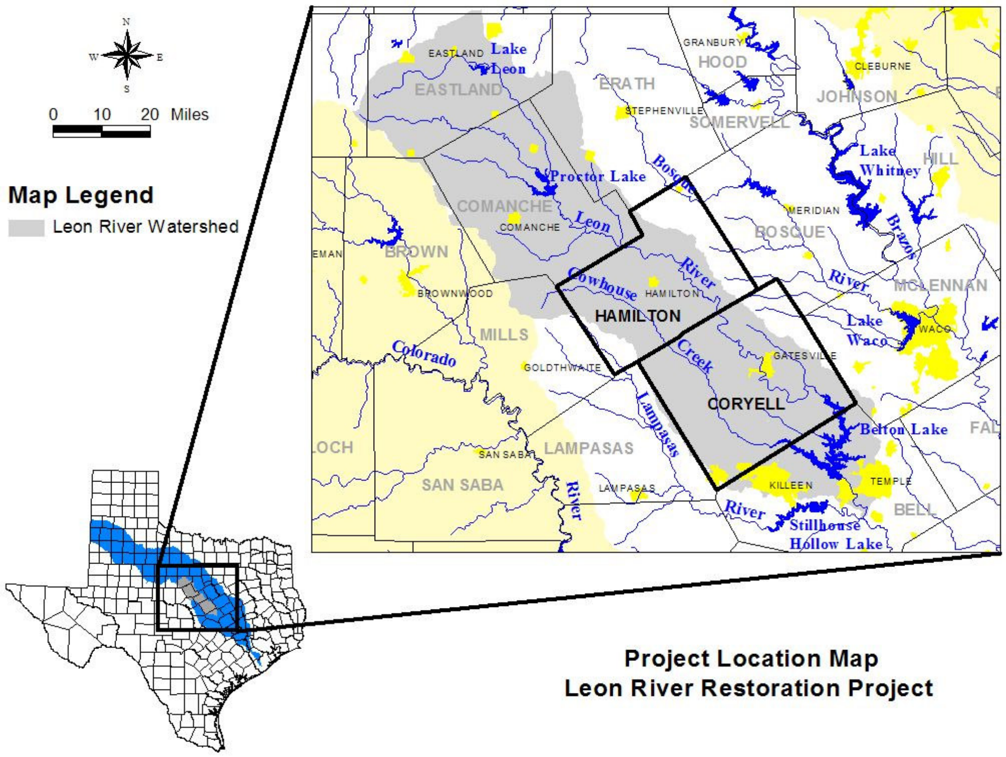

Figure 1. Map of the Leon River watershed within Coryell and Hamilton counties.

River and Cowhouse Creek are the two main streams in Coryell County. The Leon River runs northwest to southeast, flowing through the center of the county. Topographically, Coryell County is underlain with hard limestone on the ridges and softer limestone and marly clay on the rolling hills and plateaus (McCaleb 1985).

Seasonal temperatures are generally warm in the summer with temperatures commonly exceeding 28°C and peaking at 35°C. Wintertime temperatures are commonly mild with an average of 9°C. The annual precipitation is adequately distributed throughout the year with peaks in springtime (McCaleb 1985). The average rainfall for the region is 75 centimeters with 55% falling between April and September (Figure 2). Thunderstorms are a common occurrence during the summertime months.

Coryell County was historically considered to be a farming community (McCaleb 1985). Following the Great Depression of the 1930's more and more farmers began to dedicate their resources to forage crops and livestock. Over the past twenty years approximately 88 percent of the land has been used for farming and ranching operations (Holland 2004). The study areas included two range sites, Low Stony Hill and Redland. The Low Stony Hill site is located at approximately 31° 23' N and 97° 43' W at an elevation of 231.6 m (NOAA 2005). The climax plant community of the Low Stony Hill range site included a live oak savannah with less than 20 percent tree canopy. Live oak mottes are commonly found along water basins, where elm (*Ulmus spp.*) and hackberry (*Celtis*

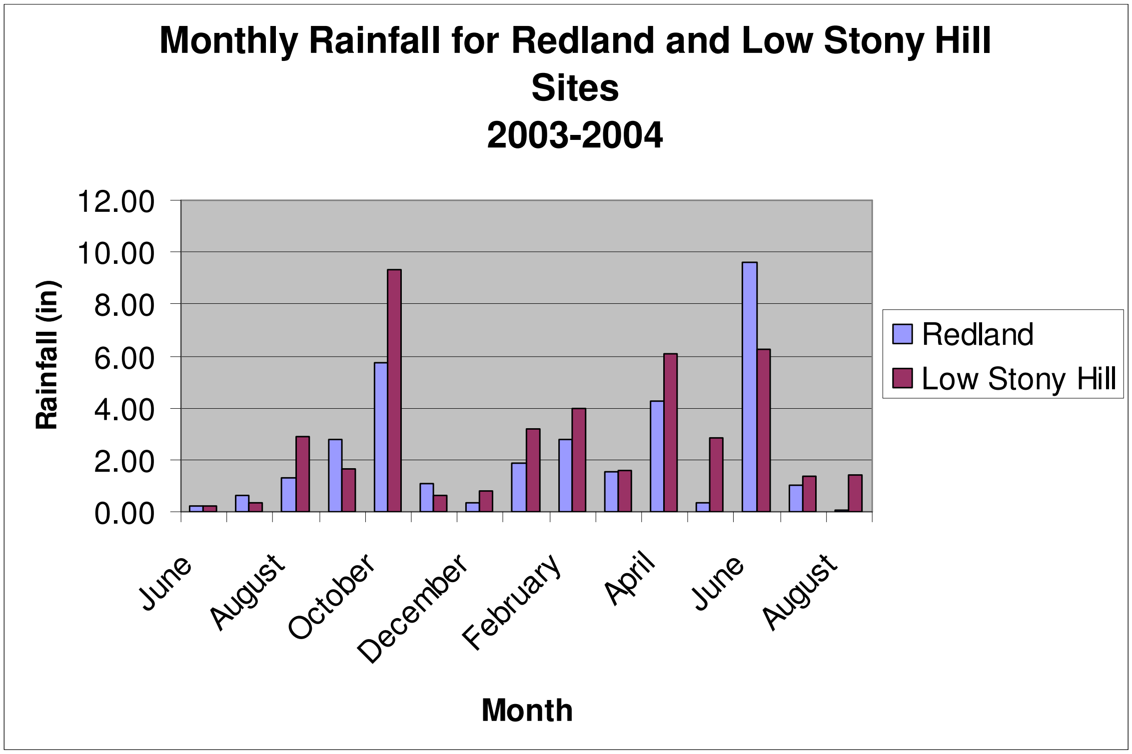

Figure 2. Long-term monthly precipitation received on the Redland and Low Stony Hill sites from June 2003 to August 2004.

occidentalis) can also be found (McCaleb 1985). Vegetation in the Low Stony Hill site consisted of 85% herbaceous vegetation with 10 percent woody vegetation and 5 percent forbs. Little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardi*) and Indiangrass (*Sorghastrum nutans*) make up the majority of the herbaceous vegetation. Approximately 25% of the herbaceous vegetation is composed of sideoats grama (*Bouteloua curtipendula*), silver bluestem (*Bothriochloa laguroides*), vine-mesquite (*Panicum obtusum*), Texas wintergrass (*Stipa leucotricha*) and Canada and Virginia wildrye (*Elymus canadensis and E. virginicus*). Forbs include a variety of species, making the vegetation composition of Low Stony Hill sites quite diverse. With increasing grazing pressure, the more palatable grasses and forbs decrease, yielding to less palatable brush species such as Ashe juniper and mesquite (McCaleb 1985). The Low Stony Hill site consisted of Eckrant cobbly silty clay (EcB) soils (clayey-skeletal,montmorillonitic, thermic lithic haplustolls) with 1-3 percent slopes. The soils ranged from shallow to very shallow. This soil is well drained with moderately slow permeability and rapid surface runoff. Mainly used for rangelands, this Eckrant soil is limited by low water capacity, low depth to rock and limestone fragments located on the soil surface.

The Redland site is located outside Gatesville in a community called Evant at approximately 31° 28' N and 98° 10' W at an elevation of 379.5 m (NOAA 2005). The climax plant community of the Redland site is composed of mid and tall grasses with scattered live oak, blackjack oak (*Quercus* *marilandica*), post oak (*Q. stellata*), hackberry, elm and shinnery oak (*Quercus pungens*). Grasses encompassed 85 percent of the vegetation, while there are 5 percent forbs and 10 percent woody plants (McCaleb 1985). The species composition and richness of the Redland site is similar to that of the Low Stony Hill site. Many of the same species can be found on both sites. The Redland site is primarily composed of Evant silty clay (EvB) soils (clayey, montmorillonitic, thermic, shallow petrocalcic paleustolls) with 1-3 percent slopes. This soil is also shallow and well drained. Again, the permeability of the Evant soil is slow with available water capacity being very low. However, surface runoff is less than that of the Eckrant cobbly silty clay soil. This soil is also primarily used for rangelands (McCaleb 1985).

Methods

Research was conducted in Coryell County on two range sites, Low Stony Hill and Redland, in the Grand Prairie and Cross Timbers region. Rainfall simulation measurements were collected in 3 separate runs. Run 1 was completed in June 2003 prior to treatment. Run 2 was completed in July 2003, approximately 1 month following the shearing of juniper on both sites. Run 3 was completed June 2004, 11 months following treatment.

Infiltration rates and runoff were determined by using a drip-type infiltrometer at 15.2 cm per hour to simulate a high intensity rainfall event, insuring that plots reach their terminal infiltration rate (Thurow et al. 1986). An initial rainfall simulation was conducted on 16 randomly selected microplots ($0.35\ m^2$) dominated by grass and 16 randomly selected microplots dominated by brush on each range site prior treatment. Rainfall simulation was conducted on brush plots beneath the juniper canopies. Branches were cut away to allow placement of the simulators. Following the removal of Ashe juniper with hydraulic shears, 32 additional plots were run on grass and brush dominated areas. Approximately, one year from the start date, the final rainfall simulation was conducted to test the long term impacts of the mechanical removal of Ashe juniper on 32 more plots per range site.

Prior to each simulation a series (16 treated and untreated) of plots were pre-wet with 110 liters of water through a mist type nozzle in order for the soils to reach their matric potential. The plots were then covered with plastic for 24 hours and allowed to drain to field capacity (Thurow et al. 1986). Using this technique limited the influence of antecedent moisture (Blackburn et al. 1974). Simulations ran for 30 to 45 minutes depending on the initial time of runoff. Runoff was collected in a trough at the base of the $0.35\ m^2$ plots and deposited in a 20 liter bottle. Runoff was weighed every 5 minutes and recorded along with initial runoff time, and total lbs of runoff. Preceding the rainfall simulations, each plot was visually evaluated for percent cover of grass, forbs, litter, bare ground, and brush. Using the core method, bulk density and soil moisture samples were taken prior to each simulation at 0 to 3 cm in depth adjacent to each plot (Black 1965). The microrelief of each plot was obtained by using a microrelief board with 10 pens, each measuring the change in microrelief in centimeters along three sections of the plot (Kincaid and Williams 1966). Microrelief is a significant small watershed feature especially in shallow soils such as Low Stony Hill and Redland sites where microrelief increases temporary water storage (Richards 1996). The area of each plot was recorded using a grid sketch and later digitized for a more precise measurement of individual plot size.

Following each simulation, standing grasses, forbs and woody plants were clipped at ground level from each plot. Standing crop samples were dried in an oven at 60° C for 48 hours, weighed and converted to kg ha^{-1}. Additionally, soil from the plot was removed to approximately 8 cm below the soil surface and placed into a large standard soil bag. The soil sample was dried, ground and placed through a #10 seive to remove gravel and rocks. The texture of the soil sample was determined by the hydrometer method (Bouyoucos 1962) and organic matter by use of a carbon/nitrogen analyzer (Pitt et al. 2003).

Treatments

Chaining, rootplowing, and grubbing have been the traditional methods of juniper removal (Scifres 1980, Ueckert 1997). Hydraulic shears have been used more recently in the control of juniper with extremely effective results. Shearing creates fewer disturbances to the soil surface and surrounding areas, whereas alternate mechanical methods cause extensive disturbance to the landscape.

Mechanical shearing was conducted on both the Low Stony Hill and Redland range sites following the first simulation in June 2003. At each site, juniper was removed with a hydraulic shear at ground level in the treated section of the site. During treatment, the ground was "swept" with the tops of the juniper to spread the litter out across the site. This slightly changes the post-treatment effect of removing the juniper. The juniper was put into windrows, which will be burned in later years. Treatments were completed by July 2003. The sites were allowed to re-establish themselves and recover from the disturbance.

Analysis

Statistical analysis, using a within treatment variation, was used to determine significant differences in vegetation and soil characteristics that may influence infiltration in the simulation plots. Data normality was assessed by testing for skewness and kurtosis. Variances due to treatment were determined by using data analysis techniques and means were separated when appropriate using Duncan's multiple range test. Significance levels will be assessed at a 95% probability level.

Results and Discussion

Redland Site

Average infiltration rates on the Redland site were significantly different between grass and brush plots on both treated and untreated sites during the first rainfall simulation (Table 1). Infiltration rates are typically higher under tree canopies and shrubs due to the breakdown of raindrop impact and the improved soil structure from the litter, allowing water to enter the soil more easily (Lyons et al. 2005). The mean infiltration rates for treated and untreated brush plots at 14.8 cm/hr were higher than the grass plots, which averaged 10.8 cm/hr. During the second run in July 2003, infiltration rates were significantly lower on treated brush plots than the treated grass and the untreated brush. The treated brush plots had an average infiltration rate of 9.9 cm/hr, while the untreated brush averaged 15.0 cm/hr. The means on treated and untreated plots were significantly different from one another as well. Infiltration rates on the untreated plots were approximately 25% higher than the treated plots. Although there was a 20% increase on treated grass sites and a 19% increase on untreated sites during the second simulation. The grass plots had no significant differences in infiltration rates between any of the simulations (Table 2). However, the treated brush plots differed significantly from run 1 to run 2 in that there was a 30% decrease in infiltration rates post-treatment. The untreated brush plots had only a slight increase during run 2.

The infiltration rates for the Redland site decreased across all plots during the third simulation (Table 1). The grass treated plots decreased between 13 and 16% from run 1 to run 2. Brush plots increased somewhat less than the grass plots from the previous year. The treated brush plots increased 10%, while the untreated plots only decreased infiltration rates 3%. Treated and

Table 1. Mean infiltration rates (cm/hr) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	10.6 a[1](y[2])	14.8 a(x)	12.7 a
Untreated	11.1 a(y)	14.8 a(x)	12.9 a
Mean	10.8 (y)	14.8 (x)	12.8[3]
	July 2003		
Treated	12.7 a(x)	9.9 b(x)	11.3 b
Untreated	13.2 a(x)	15.0 a(x)	14.1 a
Mean	13.0 (x)	12.5 (x)	12.8
	June 2004		
Treated	10.7 a(x)	8.9 b(x)	9.8 b
Untreated	11.5 a(y)	14.5 a(x)	13.0 a
Mean	11.1 (x)	11.7 (x)	11.4

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean infiltration rate for grass and brush plots within date.

Table 2. Mean infiltration rates (cm/hr) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	11.6 a[1]	15.5 a	10.7 a
Untreated	12.1 a	13.8 a	11.5 a
		Brush Plots	
Treated	14.9 a	10.4 b	8.9 b
Untreated	14.9 a	15.1 a	14.5 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

untreated brush demonstrated significance as untreated brush had a 63% higher infiltration rate than the treated plots. Means for treated and untreated were also significant during the third simulation. Untreated brush plots were significantly higher than the untreated grass plots with 14.5 cm/hr as compared to 11.5 cm/hr. Although the treated brush plots had the only significant change between the first and the third runs, the majority of the infiltration rates decreased from the rates in the first simulation (Table 2). Treated brush had the lowest infiltration rate at 8.9 cm/hr, while untreated brush had the highest infiltration rate at 14.5 cm/hr.

Infiltration rates are highly dependent on a variety of vegetation factors, such as amount and type of vegetation present, as well as soil characteristics (Thurow and Hester 1997). Standing crop aids in breaking down the erosive force of raindrop impact and adding organic matter to the soil, thereby maintaining the integrity of the soil structure and sustaining higher infiltration rates (Weltz and Blackburn 1995, Thurow and Hester 1997). In June 2003, pre-treatment grass and litter production volumes were significantly different between grass and brush plots in both treated and untreated areas (Tables 3, 4 and 5). Grass production was significantly higher on the grass plots than the brush plots, while litter biomass was significantly higher on the brush plots during the first simulation. Due to the accumulation of litter under juniper trees and the lack of sunlight, grass and forb production is severely reduced. By intercepting and absorbing moisture, the tree canopy and litter create less soil moisture availability under the canopy for grasses and forbs (Lyons et al. 2005). Both grass and litter biomasses protect against raindrop impact and lower runoff rates. The grass plots exhibited no significant differences between run 1 and run 2; however, grass biomass decreased 52% on treated grass sites and 11% on untreated grass sites during run 2 (Table 4). Treated and untreated brush plots were significantly different prior to treatment. Grass biomass on the untreated plots was more than double the production on the treated plots. The

Table 3. Mean grass production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	1754.8 a[1](x[2])	103.6 b(y)	929.2 a
Untreated	1394.4 a(x)	393.3 a(y)	893.8 a
Mean	1574.6 (x)	248.5 (y)	911.6[3]
	July 2003		
Treated	838.0 a(x)	747.1 a(x)	792.5 a
Untreated	1241.4 a(x)	458.1 a(y)	849.8 a
Mean	1039.7 (x)	602.6 (x)	821.2
	June 2004		
Treated	1470.6 a(x)	235.1 a(y)	852.8 a
Untreated	1619.2 a(x)	420.8 a(y)	1020.0 a
Mean	1544.9 (x)	327.9 (y)	936.4

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean grass production for grass and brush plots within date.

Table 4. Mean grass production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	1754.8 a[1]	838.0 a	1470.6 a
Untreated	1394.4 a	1241.4 a	1619.2 a
		Brush Plots	
Treated	103.6 b	747.1 a	235.1 ab
Untreated	393.3 a	458.1 a	420.8 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table 5. Mean litter accumulation (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	2027 b[1](y[2])	13736 a(x)	7881 a
Untreated	6622 a(y)	11226 a(x)	8924 a
Mean	4325 (y)	12481 (x)	8403[3]
	July 2003		
Treated	21531 a(x)	16144 a(x)	18838 a
Untreated	7228 a(y)	20624 a(x)	13926 a
Mean	14379 (x)	18384 (x)	16382
	June 2004		
Treated	2996 a(x)	725 b(y)	1861 b
Untreated	4011 a(y)	32507 a(x)	18259 a
Mean	3504 (y)	16616 (x)	10060

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean litter accumulation for grass and brush plots within date.

treated and untreated brush plots also differed significantly between the first and second simulation as the grass production on the treated plots was 104 kg/ha in June 2003 and 747 kg/ha in July 2003. The untreated brush sites only displayed a small increase in grass production during the second simulation.

During the third simulation, grass production was significantly different between grass and brush plots, as well as the mean (Table 3). Being significantly greater than brush plots, the grass plots averaged 1,545 kg/ha on treated and untreated plots during the third run. Grass production changed dramatically on the grass plots, increasing 75% on treated plots and 30% on untreated plots. Brush plots actually decreased in grass biomass during the third simulation. While grass production increased on the grass plots, litter production significantly decreased by 86% on treated grass and 45% on untreated grass plots (Table 6). Treated brush plots also decreased litter biomass significantly by 96%, as the untreated brush plots experienced the only increase in litter production with 58%.

Overland flow is reduced by increasing vegetation and litter, which act as a storage point for water until it is infiltrated into the soil. Following the removal of Ashe juniper from both sites, the litter layer under the canopies was swept with the tops of the trees over the entire area of grass and brush plots. By sweeping the ground, the plots were disturbed and an increase in bare soil resulted. There was also an increase or decrease in litter in certain areas due to the disturbance. Litter accumulation was significantly higher on the brush plots

Table 6. Mean litter accumulation (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates: June 2003	July 2003	June 2004
	Grass Plots		
Treated	2027 b[1]	21531 a	2996 b
Untreated	6622 a	7228 a	4011 a
	Brush Plots		
Treated	13736 a	16144 a	725 b
Untreated	11226 b	20624 ab	32507 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

than the grass plots during the first rainfall simulation (Table 5). In run 1, the grass plots showed a significant difference between litter production on treated and untreated plots. This difference comes as result of natural variability within the site, as the plots had not yet been altered due to treatment. The untreated grass plots had more than 3 times the amount of litter biomass than the treated plots. There were no significant differences in litter production between run 1 and run 2 on the brush plots; however, litter biomass for the grass plots was significant between June and July 2003 (Table 6). Litter accumulation dramatically increased on the grass plots during the second simulation, increasing from 2027 kg/ha to 21,531 kg/ha. This substantial increase in litter production could be attributed to the litter on the treated brush plots being spread across the entire area following treatment. Both grass and brush plots increased in litter biomass on treated and untreated plots from run 1 to run 2 (Table 3). The untreated brush plots also had a large increase in litter production, increasing 84%.

Additionally, litter biomass was significantly different between grass and brush plots, as well as across treated and untreated plots during the third simulation (Table 5). The brush plots had a greater amount of litter at 16,616 kg/ha than the grass plots with 3,504 kg/ha. Rainfall simulators were set up under the tree canopies on brush plots. Branches were cut in order for the simulators to fit properly next to the juniper trees. Once again, plots with the greatest amount of litter exhibited higher infiltration rates.

While forb production was not quite as prominent as grass and litter production, there were several significant differences between plots (Table 7). During the first rainfall simulation, the brush plots exhibited a significant difference in forb biomass between treated and untreated plots. The untreated plots had a much greater standing crop of forbs than the treated plots. Grass and brush plots also differed significantly with greater forb biomass being on the brush plots, while the untreated plots were significantly different from the treated

Table 7. Mean forb production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	3.2 a[1](x[2])	2.4 b (x)	2.8 b
Untreated	13.6 a(x)	73.1 a(x)	43.4 a
Mean	8.4 (x)	37.7 (y)	23.1[3]
	July 2003		
Treated	1.4 a(x)	0.7 a(x)	1.1 a
Untreated	86.3 a(x)	21.8 a(y)	54.1 a
Mean	43.8 (x)	13.1 (y)	28.5
	June 2004		
Treated	76.2 a(y)	278.8 a(x)	177.5 a
Untreated	3.5 b(x)	2.0 b(x)	2.7 b
Mean	39.8 (y)	140.4 (x)	90.1

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean forb production for grass and brush plots within date.

Table 8. Mean forb production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	3.2 b[1]	1.4 b	76.2 a
Untreated	13.6 a	86.3 a	3.5 a
	Brush Plots		
Treated	2.4 b	0.7 b	278.8 a
Untreated	73.1 a	21.8 ab	2.0 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

plots. The second rainfall simulation also included some significant differences between grass and brush plots. The untreated grass plots had a significantly higher standing crop of forbs than the untreated brush plots. The means for both treated and untreated plots on grass and brush resulted in a significant difference with grass plots having the higher forb production at 44 kg/ha. Although there were quite a few differences within simulations, there were no significant differences between the first and second simulations (Table 8).

Forb production also increased significantly on treated grass and brush plots during run 3 (Table 8). The 11 months between the second and third simulations allowed the forbs a full growing season to respond to the juniper removal, accounting for the large increase in forb biomass from July 2003 to June 2004. This is also apparent between run 1 and run 2 where the forbs on the treated plots did not have time to react to the decrease in juniper. Significant relationships were established between treated and untreated grass, as well as treated and untreated brush (Table 7). The treated plots had greater forb biomass, while treated brush had significantly higher production than grass. Due to the low standing crop, forbs most likely did not have a great impact on the infiltration rates.

Bare ground is also a factor closely related to infiltration rates. A decrease in bare ground greatly contributes to higher infiltration rates by reducing overland flow (Wilcox 2002). During the first rainfall simulation, only the untreated plots had a significant difference in bare ground percent (Table 9). The untreated grass plots had 5.5% bare ground, while the brush plots only had 0.5% bare ground. Percent bare ground on all plots was relatively low during the first simulation and probably had very little impact on infiltration. Although there were very few significant differences in the first simulation, the second simulation had several areas of significance. Both the treated and untreated plots for grass and brush were significantly different. Within both vegetation types the treated plots had much higher bare ground

Table 9. Mean percent bare ground (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	4.9 a[1](x[2])	10.8 a(x)	7.8 a
Untreated	5.5 a(x)	0.5 a(y)	3.0 a
Mean	5.2 (x)	5.6 (x)	5.4[3]
	July 2003		
Treated	5.3 a(y)	22.9 a(x)	14.1 a
Untreated	0.8 a(x)	0.0 b(x)	0.4 b
Mean	3.0 (y)	11.4 (x)	7.2
	June 2004		
Treated	9.5 a(y)	41.5 a(x)	25.5 a
Untreated	4.4 a(x)	0.0 b(x)	2.2 b
Mean	6.9 (y)	20.8 (x)	13.9

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent bare ground for grass and brush plots within date.

Table 10. Mean percent bare ground (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates: June 2003	July 2003	June 2004
	Grass Plots		
Treated	4.9 a1	5.3 a	9.5 a
Untreated	5.5 a	0.8 a	4.4 a
	Brush Plots		
Treated	10.8 b	22.9 ab	41.5 a
Untreated	0.5 a	0.0 a	0.0a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

percentages than the untreated plots. The greatest significance occurred between the brush plots. Treated brush had 22.9% bare ground, while the untreated plots did not have any bare ground. The increase in bare ground was due to the movement of the litter layer following treatment. The means for bare ground percent on treated and untreated, as well as grass and brush were also significantly different from one another. The treated plots had a greater percent bare ground, while the brush plots exceeded the grass plots with 74% more bare ground. Infiltration rates during the second simulation for the brush plots correlate with the percent bare ground. The highest percent of bare ground on the brush plots had the lowest infiltration rate, while the lowest bare ground percent had the highest infiltration rate. Although there were major differences in percent bare ground from run 1 to run 2, there were no significant differences between the two simulations (Table 10).

Bare ground percent continued to increase on the treated plots and increased on the untreated grass during run 3 (Table 10). Treated brush increased to 42% bare ground in the third simulation, making it significant when compared to treated grass and untreated brush. Bare ground may have continued to increase due to the movement of the litter layer under the juniper trees following treatment. After the litter was spread over all the plots, it was no longer in the mats that kept it bound to the ground, making the litter more susceptible to movement between simulation 2 and 3. This can also be seen in the significant decrease in litter biomass on the treated grass plots from run 1 to run 2 (Table 6). The increase in bare ground on treated brush was significant between the means of grass and brush, as well as treated and untreated. Infiltration rates were comparable to the bare ground percent in that as bare ground increased, infiltration rate decreased.

Soil characteristics that also influence infiltration rates include micro-topography, soil moisture, bulk density, organic matter, as well as clay and sand content. The microrelief on the brush plots during the first simulation showed a

Table 11. Mean microrelief in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.8 a[1](x[2])	0.8 a(x)	0.8 a
Untreated	0.9 a(x)	0.7 b(x)	0.8 a
Mean	0.8 (x)	0.8 (x)	0.8[3]
	July 2003		
Treated	1.0 a(x)	0.7 a(x)	0.8 a
Untreated	0.7 a(x)	0.7 a(x)	0.7 a
Mean	0.8 (x)	0.7 (x)	0.8
	June 2004		
Treated	0.7 a(x)	0.6 b(x)	0.6 b
Untreated	1.1 a(x)	0.8 a(x)	1.0 a
Mean	0.9 (x)	0.7 (x)	0.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean microrelief for grass and brush plots within date.

Table 12. Mean microrelief in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.8 ab[1]	1.0 a	0.7 b
Untreated	0.9 a	0.7 a	1.1 a
	Brush Plots		
Treated	0.8 a	0.7 a	0.6 a
Untreated	0.7 a	0.7 a	0.8 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

significant difference between treated and untreated plots (Table 11). The brush plots did not exhibit a change in infiltration rates on treated and untreated plots in the first run, demonstrating that the significant difference in microrelief did not affect the infiltration rate. The plots did not exhibit significant differences during the second simulation or between simulations (Table 12). Typically, the disturbance caused during treatment may have also created a greater number of depressions in the soil surface, causing water retention on the plot. Many studies have been conducted with removing brush by rootplowing, which creates a rough surface area. Richardson et al. (1979) conducted a watershed study in Sonora, Texas on the Edwards Plateau to evaluate the hydrologic effects of clearing brush by rootplowing. The study concluded that there was a consistent reduction in runoff due to increased depression storage on the watersheds. However, depression storage does decrease with time and infiltration rates will decrease to those prior to treatment (Richardson et al. 1979). Microrelief did not seem to be related to an increase or decrease in infiltration rates during the first and second rainfall simulations on the Redland site. When the plots were swept post-treatment, the surface was leveled, decreasing surface roughness; therefore, very little change was seen after the juniper was removed.

Infiltration rates were also influenced by soil properties during the third rainfall simulation. Microrelief had little significant differences during run 3 except between treated and untreated brush (Table 11). Untreated brush had a significantly greater microrelief than treated, which possibly contributed to greater depression storage and higher infiltration rates on these plots.

Soil moisture also appears to have not had a major influence on infiltration rates due in part to the lack of significance between plots and between simulations during runs 1 and 2 (Tables 13 and 14). Only the untreated plots during the second simulation exhibited a significant difference between plots. The untreated grass plots had significantly higher soil moisture content than the untreated brush plots. The untreated brush plots did demonstrate higher infiltration rates than the untreated grass in run 2; however, it is unlikely the soil

Table 13. Mean soil moisture (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	32.0 a[1](x[2])	29.8 a(x)	30.9 a
Untreated	32.7 a(x)	31.0 a(x)	31.8 a
Mean	32.3 (x)	30.4 (x)	31.4[3]
	July 2003		
Treated	30.1 a(x)	29.7 a(x)	29.9 a
Untreated	31.4 a(x)	28.7 a(y)	30.0 a
Mean	30.7 (x)	29.2 (x)	30.0
	June 2004		
Treated	43.5 a(x)	48.8 a(x)	46.2 a
Untreated	29.4 b(x)	26.4 b(x)	32.9 b
Mean	36.5 (y)	42.6 (x)	39.6

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean soil moisture for grass and brush plots within date.

Table 14. Mean soil moisture (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	32.0 b[1]	30.1 b	43.5 a
Untreated	32.7 a	31.4 a	29.4 a
	Brush Plots		
Treated	29.8 b	29.7 b	48.8 a
Untreated	31.0 b	28.7 b	36.4 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

moisture influenced infiltration when none of the other plots displayed a significant difference.

Antecedent moisture was significantly greater on both grass and brush treated plots for the third simulation (Table 13). Mean soil moisture was also significantly greater on the brush plots with an average of 43%, while grass plots had a mean of 37%. Soil moisture was significantly higher percentages in the third simulation when compared to the first two simulations (Table 14). Soil moisture increases may be due to the increase in rainfall during the month of

June, while simulations were being conducted (Figure 2). Alternately, infiltration rates decreased during the third simulation, which may be due in part to the increase in soil moisture.

Bulk density defines the amount of pore space in the soil. Higher bulk density results in less pore space, slowing water movement into the soil. Although bulk density was not exceptionally high on any of the plots, it indicated a significant difference between grass and brush plots in the first simulation (Table 15). The treated grass and brush plots were significantly different from one another, as well as the means for both treated and untreated plots. Bulk density on the grass plots was 1 g/cm^3, while the brush plots had a lower bulk density at 0.8 g/cm^3. As discussed earlier, the accumulation of litter under juniper canopies contributes to greater soil structure and lowers bulk density. Bulk density was similar during the second rainfall simulation as grass plots were higher than brush plots. Grass and brush plots were significantly different for treated plots and untreated plots. The mean bulk density for the grass plots was 1.1 g/cm^3, which was approximately 9% greater than bulk density for the brush plots. Bulk density was significantly different between simulations on both grass and brush plots (Table 16). Grass and brush plots had an increase in bulk density between run 1 and run 2. The grass plots increased from 1.0 g/cm^3 to 1.1 g/cm^3 during the second simulation. The treated brush plots increased from 0.8 g/cm^3 to 0.9 g/cm^3, while the untreated plots increased from 0.9 g/cm^3 to 1.0 g/cm^3. All plots had low bulk densities; therefore, they had little to no influence

Table 15. Mean bulk density (g/cm^3) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	1.0 a[1](x[2])	0.8 a(y)	0.9 a
Untreated	1.0 a(x)	0.9 a(x)	0.9 a
Mean	1.0 (x)	0.8 (y)	0.9[3]
	July 2003		
Treated	1.1 a(x)	0.9 a(y)	1.0 a
Untreated	1.1 a(x)	1.0 a(y)	1.0 a
Mean	1.1 (x)	1.0 (y)	1.1
	June 2004		
Treated	0.8 a(x)	0.8 a(x)	0.8 a
Untreated	0.9 a(x)	0.8 a(x)	0.8 a
Mean	0.9 (x)	0.8 (x)	0.9

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean bulk density for grass and brush plots within date.

Table 16. Mean bulk density (g/cm^3) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	June 2003	July 2003	June 2004
		Grass Plots	
Treated	1.0 b[1]	1.1 a	0.8 c
Untreated	1.0 ab	1.1 a	0.9 b
		Brush Plots	
Treated	0.8 b	0.9 a	0.8 b
Untreated	0.9 a	1.0 a	0.8 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

on infiltration.

Bulk density was significantly different during the third simulation on grass and brush plots (Table 16). On all plots bulk density decreased between 11 and 27% from the second simulation. Bulk densities were already so low that the decrease in soil compaction would not affect infiltration rates.

Low Stony Hill Site

The Low Stony Hill site was quite similar to the Redland site in regards to the increases and decreases of average infiltration rates from run 1 to run 2. During the first simulation in June 2003, infiltration rates for the brush plots were significantly higher than the infiltration rates on the grass plots (Table 17). Treated and untreated brush plots were approximately 15 cm/hr, while the treated grass plots had 6.6 cm/hr and the untreated grass 8.4 cm/hr. Infiltration rates had a similar response during the second simulation. Following treatment, infiltration rates on the treated grass plots significantly increased 77% (Table 18). The untreated grass plots also had an increase in infiltration rates with a 23% increase. Infiltration rates are often observed to be much higher on woody dominated sites due to higher cover values and the obstruction of runoff by the litter layer (Thurow and Hester 1997). Although infiltration rates for the grass plots increased, the brush plots were still significantly higher. Infiltration rates on the brush plots did not vary much from run 1 to run 2, but the rates dropped by the third simulation date.

All of the infiltration rates decreased between July 2003 and June 2004 on the Low Stony Hill site (Table 18). The treated sites had a significant decrease in infiltration rates with grass plots falling 20% and brush plots 10%. The untreated grass and brush plots continued to be significantly different, as well as the means for both vegetation types (Table 17). The mean infiltration rate for the brush plots was 14 cm/hr, while the grass plots exhibited 10 cm/hr.

Table 17. Mean infiltration rates in (cm/hr) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	6.6 a[1](y[2])	15.1 a(x)	10.8 a
Untreated	8.4 a(y)	15.0 a(x)	11.7 a
Mean	7.5 (y)	15.1 (y)	11.3[3]
	July 2003		
Treated	11.7 a(y)	15.1 a(x)	13.4 a
Untreated	10.3 a(y)	15.1 a(x)	12.7 a
Mean	11.0 (y)	15.1 (x)	13.1
	June 2004		
Treated	9.9 a(x)	13.4 a(x)	11.6 a
Untreated	9.5 a(y)	14.2 a(x)	11.9 a
Mean	9.7 (y)	13.9 (x)	11.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.

[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.

[3]Mean infiltration rate for grass and brush plots within date.

Table 18. Mean infiltration rates (cm/hr) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	7.0 c[1]	12.4 a	9.9 b
Untreated	9.1 a	10.8 a	9.5 a
	Brush Plots		
Treated	15.1 a	15.1 a	13.6 b
Untreated	15.0 a	15.1 a	14.2 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Kincaid et al. (1964) indicated that there was a strong relationship between infiltration and plot cover, reporting that average runoff would decrease as vegetation crown cover increased (Schreiber and Kincaid 1967). A rainfall study conducted in southeastern Arizona also stated that total crown cover significantly reduced runoff (r = 0.80). Additionally, the research determined that the percent bare soil was strongly correlated with runoff at the 1% level (Tromble 1976). Grass production exhibited few significant differences between grass and brush plots during the first and second simulations (Table 19). Only the treated and untreated brush plots during the first run were significantly different, where the untreated brush plots had 71% more grass biomass than the treated plots. The treated brush plots had a significant increase in grass production during the second run (Table 20). Grass production actually decreased on all plots except for the treated brush, which increased 86% from the first simulation to the second. The treated grass plots decreased grass production by 57%, as the untreated grass plots experienced only a slight decrease in grass biomass.

Grass production was significantly different between brush and grass plots during the third simulation (Table 19). Similar to the second simulation, production rates were significantly higher on the grass plots than the brush. Grass production increased significantly on all plots except for the treated brush, which exhibited a significant decrease from the second run (Table 20).

Forb production was significantly different between grass and brush plots during both simulations (Table 21). During the first simulation, forb production was greater on the grass plots with an average of 236 kg/ha, while brush plots had a mean of 86 kg/ha. Following treatment on the brush plots, forb production significantly increased on the treated sites. The average forb biomass increased to 177 kg/ha on brush plots, while the grass plots experienced a decrease in production. The treated grass plots demonstrated a significant decrease in forb production from simulation 1 to simulation 2 as production dropped 78% (Table 22). The brush plots did not display a significant difference between simulations.

Table 19. Mean grass production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	789.5 a[1](x[2])	241.2 b(x)	515.4 a
Untreated	411.2 a(x)	412.0 a(x)	411.6 a
Mean	600.3 (x)	326.6 (x)	463.5[3]
	July 2003		
Treated	341.9 a(x)	448.1 a(x)	395.0 a
Untreated	390.0 a(x)	279.1 a(x)	284.5 a
Mean	316.0 (x)	363.6 (x)	339.8
	June 2004		
Treated	1294.0 a(x)	221.7 b(y)	757.8 a
Untreated	921.0 a(x)	528.0 a(y)	724.5 a
Mean	1107.5 (x)	374.8 (y)	741.2

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean grass production for grass and brush plots within date.

Table 20. Mean grass production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	June 2003	July 2003	June 2004
		Grass Plots	
Treated	789.5 ab[1]	341.9 b	1294.0 a
Untreated	411.2 b	290.0 b	921.0 a
		Brush Plots	
Treated	241.2 b	448.1 a	221.7 b
Untreated	412.0 ab	279.1 b	528.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table 21. Mean forb production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	301.2 a[1](x[2])	100.6 a(y)	200.9 a
Untreated	170.4 a(x)	71.0 a(x)	120.7 a
Mean	235.8 (x)	85.8 (y)	160.8[3]
	July 2003		
Treated	67.2 b(y)	279.4 a(x)	173.3 a
Untreated	197.44 a(x)	73.5 b(y)	135.4 a
Mean	132.3 (x)	176.5 (y)	154.4
	June 2004		
Treated	398.4 a(x)	665.7 a(x)	532.1 a
Untreated	317.0 a(x)	14.0 b(y)	165.5 b
Mean	357.7 (x)	339.9 (x)	348.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean forb production for grass and brush plots within date.

Table 22. Mean forb production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	301.2 a[1]	67.2 b	398.4 a
Untreated	170.4 a	197.4 a	317.0 a
	Brush Plots		
Treated	100.6 b	279.4 b	665.7 a
Untreated	71.0 a	73.5 a	14.0 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table 23. Mean litter accumulation (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	1055 b[1](y[2])	21077 a(x)	11066 a
Untreated	8528 a(y)	24257 a(x)	16392 a
Mean	4792 (x)	22667 (y)	13730[3]
	July 2003		
Treated	44736 a(x)	2309 b(y)	23523 a
Untreated	4272 b(y)	49740 a(x)	27006 a
Mean	24504 (x)	26024 (x)	25264
	June 2004		
Treated	5408 a(x)	21618 a(x)	13513 a
Untreated	3193 a(y)	25248 a(x)	14220 a
Mean	4300 (y)	23433 (x)	13867

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean litter accumulation for grass and brush plots within date.

Forbs had similar production as all the plots increased in production except the untreated brush in the third simulation. The untreated brush plots significantly decreased forb production by 81% in run 3 (Table 22). Significantly greater forb biomass occurred on the treated areas with the greatest increase being on the grass plots.

Litter also contributes greatly to reducing runoff. Grass and brush plots were significantly different in regards to litter biomass during the first two rainfall simulations (Table 23). During the first run, litter biomass was significantly greater on brush plots than grass plots. The brush plots averaged 22,667 kg/ha, while the grass plots had an average of 4,792 kg/ha of litter. Treated and untreated grass plots also exhibited a significant difference with treated plots having greater litter production. Simulation 2 had significant differences between brush and grass plots, as well as between treated and untreated plots. A significant increase in litter biomass on the treated grass plots led to significant relationships with untreated grass plots and treated brush plots. Untreated brush also had a significant increase in litter biomass, which had significant differences between untreated grass and brush, and between treated and untreated brush. Significant differences between simulations occurred on the brush plots and the treated grass plots (Table 24). Litter biomasses doubled on the untreated brush plots, while the untreated grass and treated brush plots decreased in litter production. Although grasses and forbs decreased on the treated grass plots during the second simulation, litter production increased

Table 24. Mean litter accumulation (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	1055 b[1]	44736 a	5408 b
Untreated	8528 a	4272 a	3193 a
		Brush Plots	
Treated	21077 a	2309 b	21618 a
Untreated	24257 b	49740 a	25248 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

exponentially. Litter biomass increased from 1,055 kg/ha to 44,736 kg/ha during the second simulation. The untreated brush plots more than doubled in litter production, while the treated brush decreased significantly by 89% during the second run. The outstanding litter accumulation on both the treated grass and untreated brush plots may be due to the litter being spread across the area following treatment or some error in measurement when the litter was being weighed in the laboratory. The percentages of litter and bare ground cover do not account for such high numbers of litter biomass (Tables 25 and 26).

On average, litter accumulation was significantly different between grass and brush plots during the third simulation (Table 23). Brush plots had a significantly greater amount of litter biomass with 24,433 kg/ha, while the grass plots only had 4,300 kg/ha. Litter biomass for the treated plots, as well as the untreated brush plots experienced significant differences in run 3; however, none were significantly different from the first simulation (Table 24). While the treated grass and untreated brush decreased in production, the treated brush plots had a significant increase in litter biomass. As the infiltration rates decreased across all plots, decreases in vegetative cover may have had a minor affect on infiltration.

Bare ground is an additional factor to consider when observing infiltration rates. Simulations 1 and 2 had significant differences between grass and brush plots on all plots (Table 26). During both simulations, percent bare ground was significantly greater on grass plots than brush plots. This may account for the low infiltration rates on grass plots. The mean percent bare ground for grass plots in run 1 was 13%, while brush plots had only 1% bare ground. Although there were no significant differences between simulations, bare ground increased 26% during the second simulation on grass plots (Table 27).

Bare ground quite possibly contributed to the change in infiltration rates as it increased significantly on the treated brush plots from 0% in run 2 to almost

Table 25. Mean percent litter cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	15.6 b[1](y[2])	58.8 a(x)	37.2 a
Untreated	32.5 a(x)	47.5 a(x)	40.0 a
Mean	24.1 (y)	53.1 (x)	38.6[3]
	July 2003		
Treated	24.4 a(y)	89.9 a(x)	57.1 a
Untreated	14.3 b(y)	56.8 b(x)	35.5 b
Mean	9.3 (y)	73.3 (x)	41.3
	June 2004		
Treated	19.8 a(y)	40.8 a(x)	30.3 a
Untreated	21.5 a(y)	36.1 a(x)	28.8 a
Mean	20.6 (y)	38.4 (x)	29.5

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent litter cover for grass and brush plots within date.

Table 26. Mean percent bare ground (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	14.9 a[1](x[2])	1.4 a(y)	8.1 a
Untreated	10.9 a(x)	0.6 a(y)	5.8 a
Mean	12.9 (x)	1.0 (y)	7.0[3]
	July 2003		
Treated	16.8 a(x)	0.0 a(y)	8.4 a
Untreated	15.8 a(x)	0.0 a(y)	7.9 a
Mean	16.3 (x)	0.0 (y)	8.2
	June 2004		
Treated	5.6 b(x)	9.6 a(x)	7.6 a
Untreated	11.5 a(x)	5.0 a(x)	8.3 a
Mean	8.6 (x)	7.3 (x)	8.0

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent bare ground for grass and brush plots within date.

Table 27. Mean percent bare ground (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	14.9 a[1]	16.8 a	5.6 b
Untreated	10.9 a	15.8 a	11.5 a
	Brush Plots		
Treated	1.4 b	0.0 b	9.6 a
Untreated	0.6 a	0.0 a	5.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

10% in run 3 (Table 27). Untreated brush plots also increased in bare ground, while the grass plots decreased on both treated and untreated. The decrease in percent bare ground on treated grass was significantly different from both pre and post-treatment simulations. The grass plots also had a significant difference between treated and untreated grass in the third simulation in which the untreated plots had a greater percent bare ground (Table 26). With approximately 12% bare ground on the untreated grass plots infiltration rates were lower than any of the other plots.

When discussing infiltration rates, soil conditions are also important to take into account. Microrelief measures the topography of the soil surface inside the plot boundary. Depressions in the soil act as water storage areas, allowing the water more time to infiltrate the soil. Although significant differences were observed during the three simulations, microrelief on the Low Stony Hill site indicated that there were very few changes in the topography of the plots. The most significant difference in microrelief occurred during the July 2003 simulation on the treated brush plots (Table 28). The treated brush plots had a 1.1 surface roughness, while the other plots were below 0.5. The micro-topography on these plots was also significantly different from the first and third simulations (Table 29). An increase in microrelief results in a rougher soil surface with more water storage. Mechanical treatments such as chaining and rootplowing cause greater soil disturbance, thereby increasing depressions in the soil and reducing runoff. The Low Stony Hill site was sheared with machines that had large rubber tires, which decreased the disturbance to the site. The increase in microrelief on the treated brush plots was not enough to severely alter infiltration rates as they did not experience any change post-treatment.

Soil moisture is an additional characteristic associated with infiltration rates. During the first simulation soil moisture was significantly higher on the brush plots than the grass plots (Table 30). Greater antecedent moisture is commonly linked to lower infiltration rates; however in this case, the brush plots had greater infiltration rates than the grass plots. During pre-wetting, water may

Table 28. Mean microrelief in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.4 a[1](y[2])	0.6 a(x)	0.5 a
Untreated	0.4 a(y)	0.5 a(x)	0.5 a
Mean	0.4 (y)	0.6 (x)	0.5[3]
	July 2003		
Treated	0.4 a(y)	1.1 a(x)	0.8 a
Untreated	0.4 a(x)	0.5 b(x)	0.4 b
Mean	0.4 (y)	0.8 (x)	0.6
	June 2004		
Treated	0.7 a(x)	0.6 a(x)	0.6 a
Untreated	0.4 b(y)	0.6 a(x)	0.5 b
Mean	0.5 (x)	0.6 (x)	0.6

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean microrelief for grass and brush plots within date.

Table 29. Mean microrelief in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	0.4 b[1]	0.4 b	0.7 a
Untreated	0.4 a	0.4 a	0.4 a
		Brush Plots	
Treated	0.6 b	1.1 a	0.6 b
Untreated	0.5 a	0.5 a	0.6 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

have run off the grass plots, while the brush plots retained more of the water. Generally, a mist nozzle is used to prevent runoff during the pre-wetting phase; however, the range condition was not optimal, which is evident by the low infiltration rates observed during all three simulations. Although soil moisture was slightly greater on the grass plots in run 2, there were no significant differences between plots.

Soil moisture may have had a small influence in the reduction of infiltration rates as it increased in the third simulation (Table 31). Antecedent moisture was significantly greater on the treated and untreated grass plots, as well as the treated brush during Run 3. The great increase in rainfall during June 2004 had an impact on the soil moisture on both grass and brush plots as all plots increased in antecedent moisture.

The Low Stony Hill site was overstocked with cattle during the simulations which affected the bulk density. Bulk density measures the compaction of the soil, which can be affected by use and treatments conducted on the land. The grass plots had significantly higher bulk densities than the brush plots (Table 32). As discussed previously, litter aids in reducing bulk density by introducing more organic matter to the soil profile and litter was greatest under thee juniper canopies. Due to overstocking, bulk density may be higher on the Low Stony Hill site than if it were moderately grazed. Bulk densities on the grass plots averaged 1.2 g/cm^3 during the first run and 1.1 g/cm^3 in the second run. Bulk density also increased on the brush plots during the second run from 0.9 g/cm^3 to 1.0 g/cm^3, displaying a significant difference (Table 33).

Soil conditions did not seem to be as influential during the third simulation on the Low Stony Hill site. Bulk density had some significant differences between plots; however, the changes did not appear to be significant enough to affect infiltration rates in the third run (Table 32). Treated brush had significantly lower bulk density at 0.7 g/cm^3 than it had in either of the first simulations (Table 33). The greatest bulk density occurred on the untreated plots, which were significantly different than the treated plots.

Table 30. Mean soil moisture in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	26.1 a[1](y[2])	34.8 a(x)	30.5 a
Untreated	26.6 a(y)	32.6 a(x)	29.6 a
Mean	26.4 (y)	33.7 (x)	30.1[3]
	July 2003		
Treated	31.6 a(x)	28.6 a(x)	30.1 a
Untreated	31.0 a(x)	30.5 a(x)	30.8 a
Mean	31.3 (x)	29.6 (x)	30.5
	June 2004		
Treated	39.1 a(x)	47.9 a(x)	43.5 a
Untreated	33.6 a(x)	34.2 b(x)	33.9 b
Mean	36.4 (x)	41.0 (x)	38.7

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.

[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.

[3]Mean soil moisture for grass and brush plots within date.

Table 31. Mean soil moisture in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	26.1 b[1]	31.6 b	39.1 a
Untreated	26.6 b	31.0 ab	33.6 a
	Brush Plots		
Treated	34.8 b	28.6 b	47.9 a
Untreated	32.6 a	30.5 a	34.2 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table 32. Mean bulk density (g/cm^3) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	1.2 a[1](x[2])	0.9 a(y)	1.0 a
Untreated	1.2 a(x)	1.0 a(y)	1.1 a
Mean	1.2 (x)	0.9 (y)	1.1[3]
	July 2003		
Treated	1.2 a(x)	1.0 a(y)	1.1 a
Untreated	1.1 b(x)	1.0 a(y)	1.0 b
Mean	1.1 (x)	1.0 (y)	1.3
	June 2004		
Treated	0.9 b(x)	0.7 b(x)	0.8 b
Untreated	1.0 a(x)	1.0 a(x)	1.0 a
Mean	0.9 (x)	0.8 (y)	0.9

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean bulk density for grass and brush plots within date.

Table 33. Mean bulk density (g/cm^3) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	1.2 a[1]	1.2 a	0.9 a
Untreated	1.2 a	1.1 ab	1.0 b
		Brush Plots	
Treated	0.9 b	1.0 a	0.7 c
Untreated	1.0 a	1.0 a	1.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Summary and Conclusions

Results from this study indicate that shearing Ashe juniper increased infiltration rates one month following treatment. Infiltration rates decreased 11 months following treatment to similar levels as before treatment (Figures 3 and 4).

A combination of vegetation and soil properties had the strongest influence on infiltration on the grass and brush plots for both the Redland and Low Stony Hill Sites. Grass production and percent bare ground were the factors found to be closely related to the terminal infiltration rate on the Low Stony Hill site brush plots during all three simulations. Bare ground did not seem to influence the grass plots quite as much. Plots on the Redland site seemed to be influenced most by grass and litter production, as well as bare ground. Percent bare ground had its greatest affect on the treated brush plots as it increased from 11% in June 2003 to 42% in June 2004.

Overall, the two sites, Redland and Low Stony Hill had increased infiltration rates on all grass plots between the first and third simulations. Infiltration rates decreased slightly on untreated brush plots from June 2003 to June 2004. Treated brush remained the same on the Low Stony Hill site, while the Redland site exhibited a significant decrease in infiltration rate. Both sites also had a reduction in infiltration rates across all plots between the second and third rainfall simulations. Infiltration rates on both sites seemed to decline as bare ground increased and litter accumulation decreased. Infiltration rates on

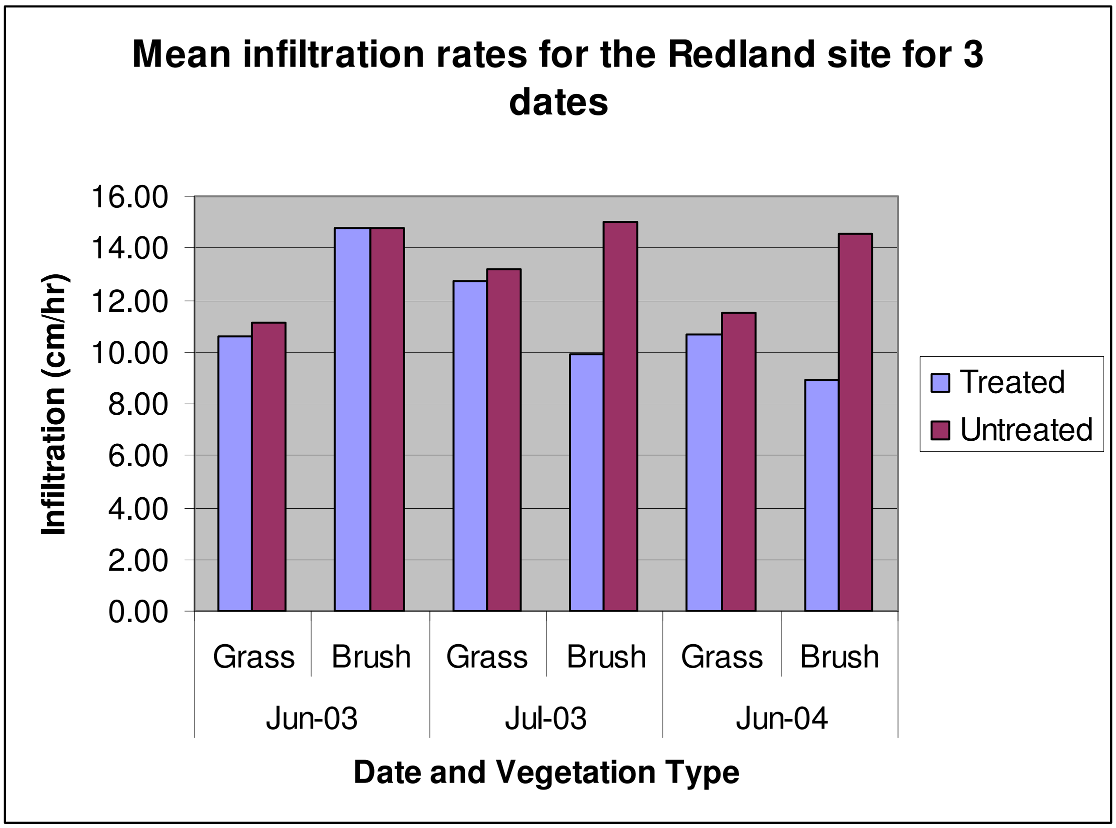

Figure 3: Mean infiltration rates for the Redland site for 3 dates on treated and untreated grass and brush plots.

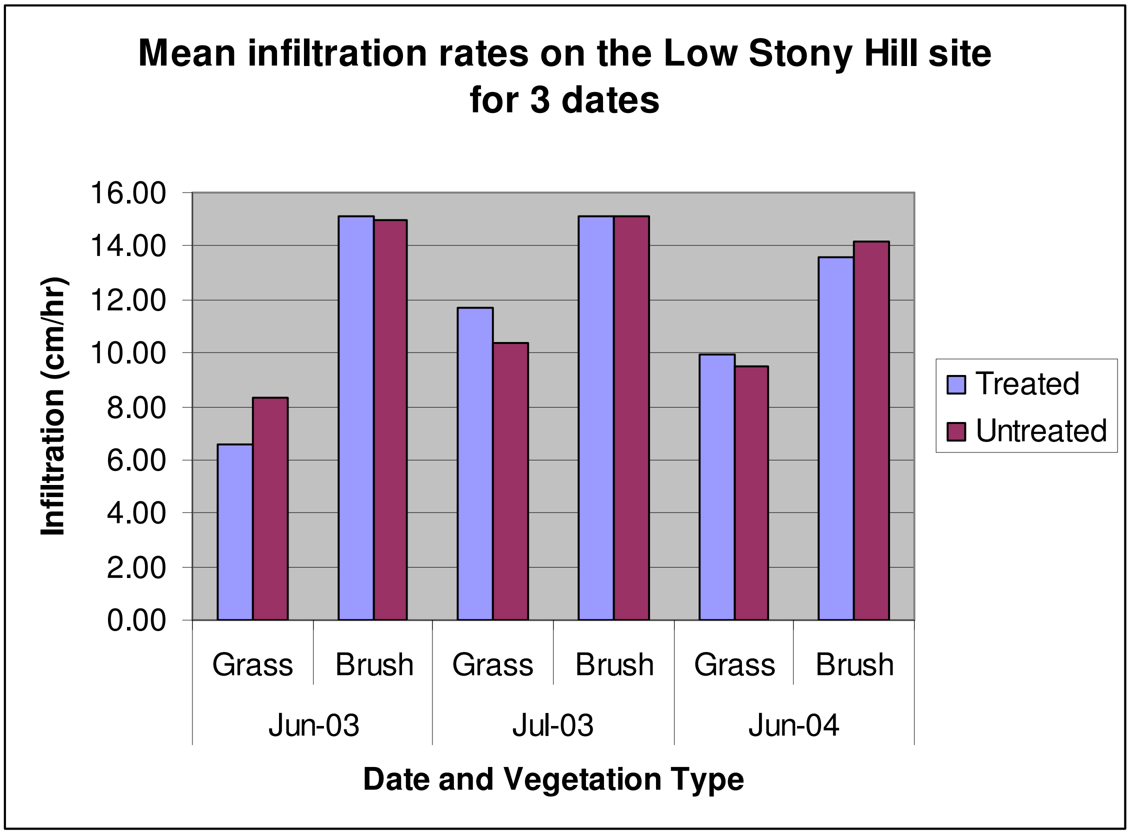

Figure 4: Mean infiltration rates for the Low Stony Hill site for 3 dates on treated and untreated grass and brush plots.

the grass plots during run 3 continued to be higher than they were during the first simulation on the Low Stony Hill and Redland sites. However, brush plots on both sites experienced a decrease in infiltration rates when comparing run 1 to run 3. Infiltration rates on the Redland site were higher than the Low Stony Hill site on grass plots, which may be due to the better range condition on the Redland site. Infiltration rates on the Redland site seemed to be affected more than the Low Stony Hill site by the reduction in juniper densities. The Redland site experienced a 40% reduction in infiltration from run 1 to run 3, while the Low Stony Hill site only reduced infiltration rates by 11%.

CHAPTER IV

SEDIMENT PRODUCTION

Introduction

Prior to European expansion Central Texas was covered in lush grassland ecosystems growing in a deep soil profile (Hoffman and Wolfe 2003). However, lack of proper management has resulted in the replacement of tall deep rooted native vegetation, such as big bluestem, little bluestem, Indiangrass, eastern gamagrass (*Tripsacum dactyloides*) and switch grass (*Panicum virgatum*) with undesirable plant species and loss of the soil profile. Woody invaders, such as Ashe juniper, have negatively impacted the native vegetation, soils, as well as water quality and quantity.

The vegetation shift came with the absence of fire in Central Texas. Historically, fire was able to shift the hierarchy away from junipers toward oaks as junipers cannot withstand fire without the protection of other species surrounding them (Amos and Gehlbach 1988). With fire kept at a minimum Ashe juniper is able to rapidly invade open woodlands and grasslands. Grazing impacts and drought has also shifted the once tall grasslands to short grasslands, which provide less fuel for fires, promoting woody invasion (Amos and Gehlbach 1988).

An increased dominance of juniper on former grasslands and savannahs has a substantial impact on the fate of precipitation on rangelands with broad implications for availability and quality of water (Thurow and Hester 1997, Wu et al. 2001). Being a direct or indirect limiting factor to all production in semi-arid regions, it is important to understand how juniper affects the movement of water through ecosystems (Thurow and Hester 1997). Since rangeland watersheds are a primary source of water for the state of Texas, it is crucial to understand and consider the impact of encroaching juniper on the recharge of aquifers and streams (TWDB 1990). There is an increasing concern among policymakers that believe vegetation management on rangelands might be responsive to regional water yield objectives (Thurow et al. 2000). Theoretically, the replacement of deep rooted woody species with more desirable shallow rooted herbaceous vegetation would consume and intercept less water, increasing spring and stream flow. Sites with shallow soils that drain rapidly and are underlain with fractured limestone, such as the Edwards Plateau region, are more likely to increase groundwater recharge when brush management practices are implemented (Ball and Taylor 2003). The development of large-scale brush management techniques such as mechanical treatments and prescribed fire have been used to control the invasion of Ashe juniper in the Central Texas region.

The Leon River Restoration Project (LRRP) is a large-scale brush management program that has been incorporated in Coryell and Hamilton counties in the Cross Timbers and Grand Prairie region of Texas to reduce densities of Ashe juniper through mechanical treatments. The goal of the project is to assess the impacts of shearing juniper on water quality and quantity, as well as livestock forage production and wildlife habitat. The LRRP hopes to provide a model for future large-scale brush management programs throughout the nation, while they restore native grasslands, habitat for wildlife and improve water quality and quantity within the Leon River watershed (Hoffman and Wolfe 2003).

Study Area

See Chapter III for site description.

Methods

Research was conducted in Coryell County on two range sites, Low Stony Hill and Redland, in the Grand Prairie and Cross Timbers region. Measurements were collected by rainfall simulation during 3 separate runs. Rainfall simulations conducted in the field enable researchers to present a rapid assessment of infiltration under a variety of conditions (Byars et al. 1996). Run 1 was completed in June 2003 prior to treatment. Approximately 1 month following the shearing of juniper on both sites, Run 2 was completed in July 2003. Ashe juniper was removed using shears to reduce soil disturbance. Run 3 was completed June 2004, 11 months following treatment.

Infiltration rates and runoff were determined by using a drip-type infiltrometer at 15.2 cm per hour to simulate a high intensity rainfall event, insuring that plots reach their terminal infiltration rate (Thurow et al. 1986). An initial rainfall simulation was conducted on 16 randomly selected microplots (0.35 m^2) dominated by grass and 16 randomly selected microplots dominated by brush on each range site prior treatment. After Ashe juniper was removed with hydraulic shears from the treated areas, 32 additional plots were run on grass and brush dominated areas. Approximately, one year from the start date, the final rainfall simulation was conducted to test the long term impacts of the mechanical removal of Ashe juniper on 32 more plots per range site.

Prior to each simulation a series (16 treated and untreated) of plots were pre-wet in order for the soils to reach their matric potential. The plots were then covered with plastic for 24 hours and allowed to drain to field capacity (Thurow et al. 1986). Simulations ran for 30 to 45 minutes depending on the initial time of runoff. Runoff was collected and deposited in a 20 liter bottle. The runoff was weighed every 5 minutes and recorded along with initial runoff time, and total pounds of runoff. The total runoff was then agitated to obtain a 1-liter sample for determining sediment load of the runoff. The suspended sediment was extracted with a tared #1 Whatman filter. The sediment on the filter was then oven dried at 105° C, weighed in grams and converted to sediment production (kg ha^{-1}) based on area and total runoff from each plot (Blackburn et al. 1974, Thurow et al. 1986). Using small plots prevents the full expression of overland flow; therefore, sediment yields should be interpreted accordingly (Williams et al. 1968).

Preceding the rainfall simulations, each plot was visually evaluated for percent cover of grass, forbs, litter, bare ground, and brush. The area of each plot was recorded using a grid sketch and later digitized for a more precise measurement of individual plot size. Following each simulation, standing grasses, forbs and woody plants were clipped at ground level from each plot. Standing crop samples were dried, weighed and converted to kg ha^{-1}.

Treatments

Traditional methods of juniper removal have included chaining, rootplowing, and grubbing (Scifres 1980, Ueckert 1997). In more recent years, hydraulic shears have been used to control juniper, producing extremely effective results. Shearing creates fewer disturbances to the soil surface and surrounding areas, whereas the alternate mechanical methods cause extensive disturbance to the landscape. Greater soil disturbance often leads to a greater amount of soil loss during rainfall events.

Following the first rainfall simulation in June 2003, shearing was conducted on both the Low Stony Hill and Redland range sites. At each site, juniper was removed with a hydraulic shear at ground level in the treated section of the site. After the trees were sheared, the ground was “swept” with the tops of the juniper to spread the litter out across the site. This slightly changes the post-treatment effect of removing the juniper, which can potentially increase runoff and sediment removal from the plots. The juniper was put into windrows, which will be burned in later years. Treatments were completed by July 2003. The sites were allowed to re-establish themselves and recover from the disturbance prior to the final simulation in June 2004.

Analysis

Statistical analysis using a within treatment variation was used to determine significant differences in vegetation and soil characteristics that may influence sediment production in the simulation plots. Data normality was assessed by testing for skewness and kurtosis. Variances due to treatment were determined by using data analysis techniques and means were separated when appropriate using Duncan's multiple range test. Significance levels will be assessed at a 95% probability level.

Results and Discussion

Redland Site

Prior to treatment, sediment production was significantly different between grass and brush plots in both treated and untreated areas on the Redland site (Table 34). The grass plots yielded about 92% more sediment on treated plots than the brush plots prior to treatment. Following juniper removal, the treated brush plots exhibited a significant increase in sediment production with 1,730 kg/ha (Table 35). The treated brush plots were the only plots to

Table 34. Mean sediment production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	235.4 a[1](x[2])	24.6 a(y)	130.0 a
Untreated	200.7 a(x)	14.3 a(y)	107.5 a
Mean	218.0 (x)	19.5 (y)	118.8[3]
	July 2003		
Treated	210.4 a(y)	1730.6 a(x)	970.5 a
Untreated	103.7 a(x)	9.3 b(x)	56.5 b
Mean	157.0 (y)	869.9 (x)	513.5
	June 2004		
Treated	451.6 a(x)	1207.0 a(x)	829.3 a
Untreated	127.8 a(x)	44.1 b(x)	85.9 b
Mean	289.7 (x)	625.6 (x)	457.7

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean sediment production for grass and brush plots within date.

Table 35. Mean sediment production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates June 2003	July 2003	June 2004
		Grass Plots	
Treated	235.4 a[1]	210.4 a	451.6 a
Untreated	200.7 a	103.7 a	127.8 a
		Brush Plots	
Treated	24.6 b	1730.6 a	1207.0 a
Untreated	14.3 a	9.3 a	44.1 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

increase sediment production during the second simulation. Infiltration rates on these plots also had a corresponding decrease during the second run. Infiltration on the treated brush descended from 15 cm/hr in run 1 to 10 cm/hr in run 2 (Table 1). Sediment production decreased somewhat on the grass plots from the first simulation. The untreated plots for both brush and grass decreased the most as brush decreased 35% and grass 48%. Sediment production rates on the treated brush plots during runs 2 and 3 were high enough to be of concern for water quality. The increase in sediment production from run1 to run 2 on the treated brush plots is due to the decrease in litter biomass and bare ground percent.

Kincaid and Williams (1966) discovered a high negative correlation between runoff and crown cover, which indicated that an increase in runoff was related to a decrease in crown cover. As discussed in Chapter III, grass production decreased on the grass plots during the second run (Table 4); however, litter biomass increased (Table 6). The brush plots experienced an increase in grass production as well as litter production following treatment; however, percent bare ground was greatest on the treated brush in run 2, yielding the greatest sediment production (Table 9). Although grass and litter production increased, there was still an average of 23% bare ground exposed on the treated brush plots, resulting from the juniper litter being spread out over the area. This increase in bare ground was definitely an influential factor in increasing sediment production in run 2 on the treated brush plots. A research study conducted north of Throckmorton, Texas indicated a similar relationship between sediment production and standing crop (Pluhar et al. 1987). As infiltration rates increased, sediment production did not increase due to an increase in vegetative standing crop and cover.

The Redland site had significant differences in sediment production between the treated and untreated brush sites during the third rainfall simulation (Table 34). Although sediment production decreased, percent bare ground continued to increase on the treated brush plots (Table 10). Sediment production increased on the grass plots and untreated brush as well. Bare ground percentages seem to account for the increases on the grass plots; however, the increase in sediment on the untreated brush may be due in part to decreased infiltration (Table 1). Infiltration rates decreased from run 2 to run 3, increasing overland flow. As overland flow increases, so do sediment losses. The high losses of sediment during the second and third simulations may be a concern for water quality standards.

Low Stony Hill Site

Sediment production on the Low Stony Hill site was much lower and not quite as reactive to treatment as the Redland site. The grass and brush plots had significant differences on treated and untreated plots during the first and second simulations (Table 36). Grass plots had significantly greater sediment loss than the brush plots on both treated and untreated sites. Higher sediment rates occurred in the second rainfall simulation on all grass plots. The treated brush plots only slightly increased from 0 kg/ha to 0.2 kg/ha in run 2. Sediment production on the Low Stony Hill site was not great enough to affect water quality measurements before or after treatment. One might expect higher sediment production rates following the removal of Ashe juniper; however, the Low Stony Hill site was in a degraded condition due to overstocking with cattle. Typically, infiltration rates, standing crop, and bare ground influence sediment

Table 36. Mean sediment production (kg/ha) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	107.3 a[1](x[2])	0.0 a(y)	53.7 a
Untreated	72.3 a(x)	9.4 a(y)	40.8 a
Mean	89.8 (x)	4.7 (y)	47.3[3]
	July 2003		
Treated	132.5 a(x)	0.2 a(y)	66.3 a
Untreated	121.1 a(x)	0.0 a(y)	60.5 a
Mean	126.8 (x)	0.1 (y)	63.5
	June 2004		
Treated	88.2 a(x)	114.0 a(x)	101.1 a
Untreated	76.7 a(x)	36.4 a(x)	56.5 a
Mean	82.4 (x)	75.2 (x)	78.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean sediment production for grass and brush plots within date.

Table 37. Mean sediment production (kg/ha) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	June 2003	July 2003	June 2004
		Grass Plots	
Treated	72.3 a[1]	121.1 a	76.7 a
Untreated	107.3 a	132.5 a	88.2 a
		Brush Plots	
Treated	0.0 a	0.2 a	114.0 a
Untreated	9.4 a	0.0 a	36.4 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

production rates. The low sediment production on the brush plots seemed to be due in part to the high infiltration rates. Grass production did not seem to influence sediment production as plots with less standing crop had lower sediment production (Table 19). Litter reduced raindrop impact and soil loss from the plots (Table 23). Litter biomass was significantly greater on the brush plots during the first simulation. The brush plots also had less sediment loss when compared to the grass plots in run 1. The treated grass plots in the second simulation increased sediment production from 107 kg/ha to 133 kg/ha, while litter production increased significantly. This increase in litter could be due to the treatment in which the litter under the juniper trees was spread over the entire area. The litter that was moved from the brush plots would not have been stabilized during the second simulation and greatly susceptible to movement. Grass production increased somewhat on the treated grass plots and may have helped stabilize some of the area, which is why there was not a significant increase in sediment loss from the first simulation to the second (Table 37).

Bare ground also played an important role in the significant difference in sediment loss between grass and brush plots during both simulations (Table 26). Grass plots had a much greater percent of bare ground than brush plots, which accounts for the higher sediment production rates on the grass plots.

The Low Stony Hill site had no significant differences between plots during the third simulation (Table 36). Sediment production decreased on the grass plots, but increased on the brush plots. Although there were no significant differences in sediment production between simulations, the brush plots lost substantially more soil during the third run (Table 37). The treated brush plots, which had a slight loss in sediment production during run 2, lost 114 kg/ha of sediment in run 3. The untreated brush plots did not lose quite as much sediment as the treated plots. Percent bare ground also seems to be the most influential factor in increased sediment losses on the Low Stony Hill site. Percent bare ground increased significantly on the treated brush plots, which also had a significant increase in sediment production. Infiltration rates had dropped from run 2 to run 3, thereby increasing overland flow (Table 18). Grass production was also less on the treated brush plot during the third simulation than during previous simulations (Table 20). With a reduction in standing crop, there is less cover on the plots to reduce raindrop impact as well as filter the sediment out of the runoff. Once again, sediment loss was not enough to adversely affect water quality within the watershed.

Summary and Conclusions

Results of this study indicate that shearing Ashe juniper results in increased sediment production on grass plots within the Redland site, while the Low Stony Hill site was barely affected within 1 month of treatment (Figures 5 and 6). Treated brush plots increased soil loss on both the Redland and Low Stony Hill sites immediately following treatment, while the untreated brush plots decreased in sediment production. Results vary 11 months following treatment. Along with the grass plots on the Redland site, the untreated brush plots had increased sediment loss. The brush plots on the Low Stony Hill site also increased sediment loss. The Low Stony Hill grass plots decreased in sediment production 11 months after treatment, as well as the treated brush plots on the Redland site.

Control of overland flow and soil erosion is a requirement when discussing the protection of watersheds (Meeuwig 1970). As cited in several

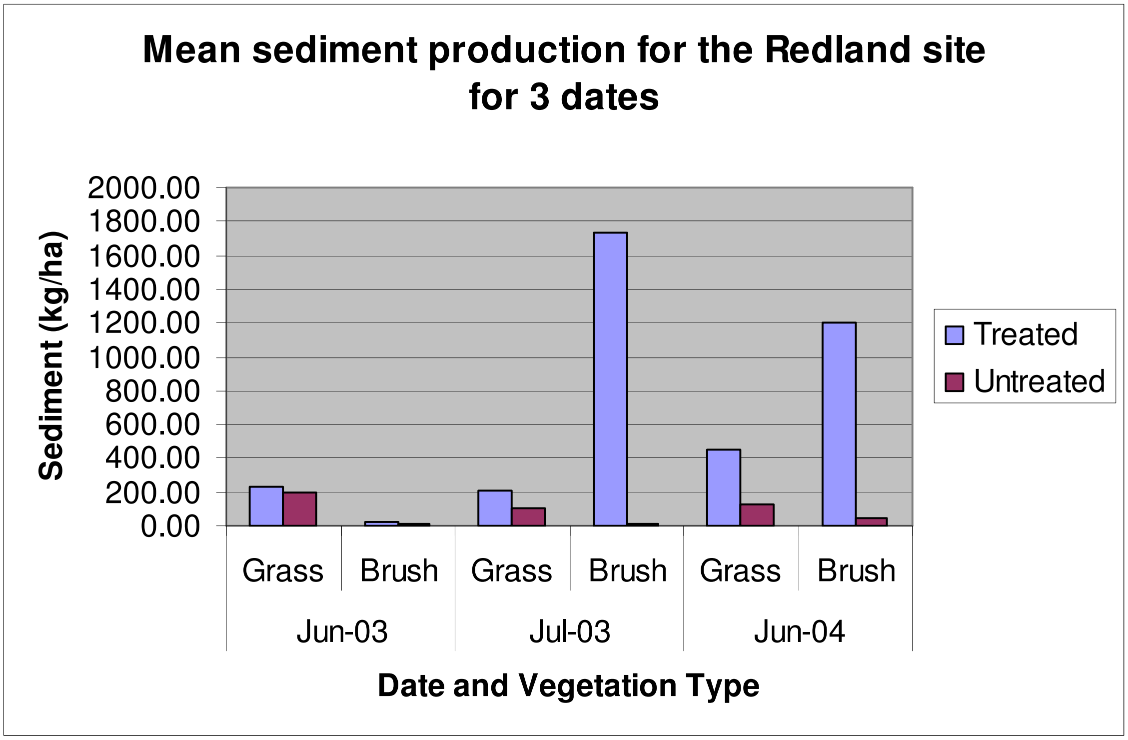

Figure 5. Mean sediment production on the Redland site for 3 dates on treated and untreated grass and brush plots.

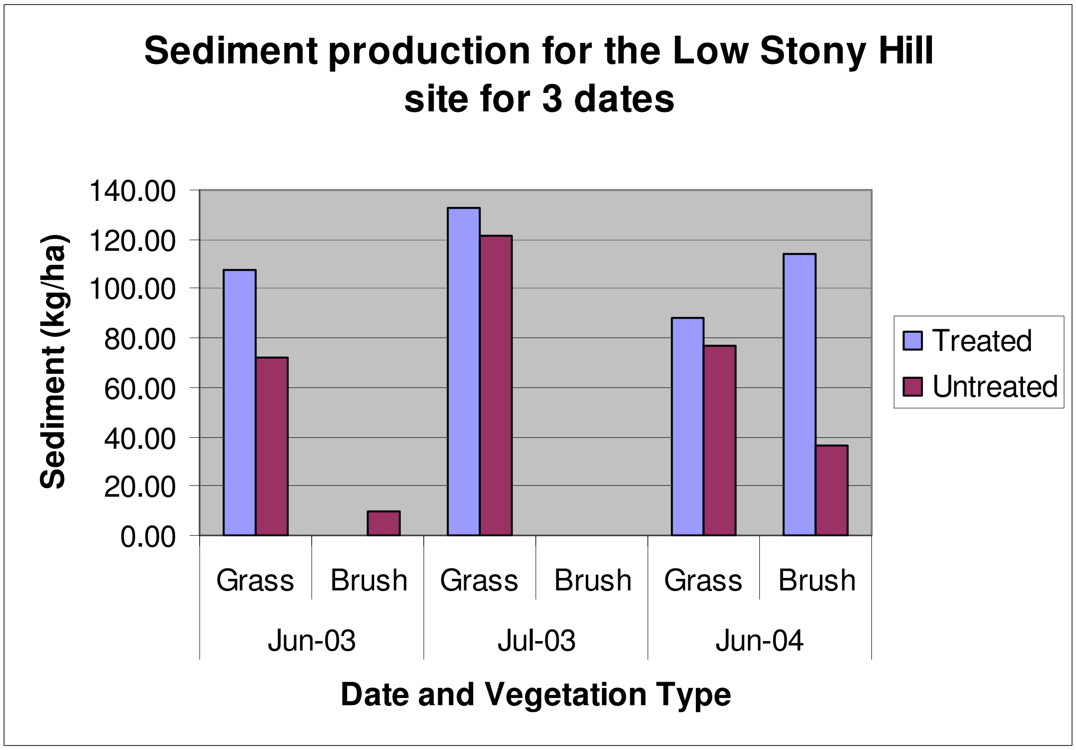

Figure 6. Mean sediment production on the Low Stony Hill site for 3 dates on treated and untreated grass and brush plots.

additional studies, standing crop and soil cover are important factors in reducing sediment loss (Pluhar et al. 1987, Pearce et al. 1998, Meeuwig 1970 and Wood et al. 1986). Percent bare ground seemed to have the greatest influence on increasing sediment production on both the Redland site and the Low Stony Hill site. Grass production, as well as decreased infiltration rates, possibly contributed to the increase in sediment loss on both sites.

CHAPTER V

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Results from this study indicate the removal of juniper with hydraulic shears increased infiltration rates within 1 month of treatment on grass plots and untreated brush plots. Infiltration rates on the treated brush plots of the Low Stony Hill site remained the same, while treated brush plots on the Redland site had decreased infiltration by 33%. Eleven months following treatment infiltration rates continued to be greater than the first simulation on the grass plots of both sites; however, infiltration rates had decreased from the second simulation. Infiltration rates on brush plots of the Low Stony Hill and Redland sites both decreased with the treated plots having lower infiltration rates than untreated brush. Infiltration rates on both sites were lower on the brush plots during run 3 than the previous simulations. Juniper removal was an effective short-term method for increasing infiltration rates on grass plots; however, infiltration rates began to decrease 11 months later.

As a result of the juniper removal, grass production and litter accumulation increased on the Redland and Low Stony Hill sites. Due to the increased production of grasses and forbs, soil conditions were not degraded throughout the duration of the study. Litter accumulation was difficult to assess due to the treatment on both sites. After tree removal, the litter was spread over both grass and brush plots within the immediate area. This contributed litter to plots that would normally have much less.

Additionally, bare ground increased for the majority of the treated plots at both sites. The hydraulic shears were mounted on skid stear tractors with rubber tires so as not to disturb the soil surface; however, when the litter was distributed over the plots bare ground increased. The most significant increase in bare ground occurred on the treated brush plots on the Redland site between the first and third simulations. Percent bare ground increased from 11% to 42%, while infiltration rates decreased 40% from run 1 to run 3.

Increased precipitation during the month of June 2004 significantly increased soil moisture on the grass plots and treated brush plots of the Low Stony Hill and the plots during the third simulation. Soil moisture also increased significantly on the brush plots, as well as the treated grass plots at the Redland site. Soil moisture may have influenced infiltration rates slightly during run 3 as infiltration rates on both sites decreased from the second simulation.

Standing crop, litter production, percent bare ground and soil moisture had the strongest influence on infiltration rates on both grass and brush plots on the Redland and Low Stony Hill sites. Due to overgrazing on the Low Stony Hill site, infiltration rates were lower than they were on the Redland site for all three rainfall simulations.

The removal of Ashe juniper from the Low Stony Hill site did not significantly affect sediment production. The treated brush plots at the Redland site had significant increases in sediment loss due to increased runoff rates. Sediment increased from 25 kg/ha to 1,731 kg/ha in run 2 and 1,207 kg/ha in run

3. Most plots had an increase in sediment loss from run 1 to run 3; however, losses were not significant at the 95% level according to Duncan's multiple test. Sediment production rates on the treated brush of the Redland site increased to levels that would cause concern for water quality during run 2 and 3.

Percent bare ground was related to sediment production. Fluctuations in bare ground were mirrored by fluctuations in sediment production on the Low Stony Hill site during the three simulations. The Redland site varied a little more with changes in bare ground percent. For example, sediment production actually decreased on the treated brush plots during the June 2004 simulation as percent bare ground increased to 42%. Vegetative cover and litter production also influenced sediment production.

Maintaining the health of rangeland watersheds through the use of brush management techniques is important for the future of Texas' water resources. It was demonstrated that mechanical treatments improve infiltration rates and decrease sediment production by increasing herbaceous standing crop. Herbaceous plant production is increased when brush and tree canopies are reduced. Negative short-term effects from mechanical treatments such as increased bare ground, decreased infiltration rates and increased sediment losses can result. Long-term brush management will have to be conducted on much larger scales across the state of Texas to increase streamflow and aquifer recharge. However, this study has identified brush management techniques that will improve range condition by increasing forage production for livestock and improving wildlife habitat with concurrent improvement In water infiltrations and reduced sediment loss.

LITERATURE CITED

Amos, B.B. and F.R. Gehlbach. 1988. Edwards Plateau vegetation: Plant ecological studies in Central Texas. Baylor Univ. Press. Waco, TX. 117-118.

Archer, S. 1994. Woody plant encroachment into southwestern grasslands and savannahs: rates, patterns and proximate causes. pp.13-68. *In:* M. Vavra, W.A. Laylock and R.D. Pieper (eds.), Ecological implications of livestock herbivory in the west. Society for Range Management, Denver, CO.

Ball, L. and M. Taylor. 2003. Brush management myths and facts. Environmental Defense. http://www.environmentaldefense.org.

Bates, C.G. and A.J. Henry. 1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. U.S. Monthly Review Supplement 30:79.

Black, C.A. (ed.). 1965. Methods of soil analysis. Amer. Soc. Agron. Series No. 9. 1572 Madison, Wis.

Blackburn,W.H., R.O. Meeuwig, and C.M. Skau. 1974. A mobile infiltrometer for use on rangeland. Journal of Range Management. 27:322-323.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. Agronomy Journal. 54:464-465.

Brock, J.H., W.H. Blackburn and R.H. Haas. 1982. Infiltration and sediment production on a deep hardland range site in North Central Texas. Journal of Range Management. 35:195-198.

Byars, B.W., P.M. Allen and N.L. Bingham. 1996. A portable rainfall simulator for assessing infiltration. Journal of Soil and Water Conservation. 51:508-510.

Carlson, D.H., T.L. Thurow, R.W. Knight and R.K. Heitschmidt. 1990. Effects of honey mesquite on the water balance of Texas Rolling Plains. Journal of Range Management. 43:491-496.

Davis, E.A. and C.P. Pase. 1977. Root systems of shrub live oak: implications for water in Arizona chaparral. Journal of Soil and Water Conservation. 32:174-180.

Dortignac, E.J. and W.C. Hickey. 1963. Surface runoff and erosion as affected by soil ripping. Proc. Of the Federal Inter-Agency Sedimentation Conference. U.S. Dep. Agr. Misc. Pub. 970:156-165.

Dugas, W.A., R.A. Hicks, P. Wright, and G. Lindemann. 1996. Effect of removal of *Juniperus ashei* on evapotranspiration and runoff in the Seco Creek watershed. *In:* Seco Creek Water Quality Demonstration Project. 1996 Ann. Proj. Rep. Hondo, Tex.

Dugas, W.A., R.A. Hickas and P. Wright. 1998. Effect of removal of Juniperus ashei on evapotranspiration and runoff in the Seco Creek watershed. Water Resour. Res. 34:1499-1506.

Dykstrerhuis, E.J. 1948. The vegetation of the western Cross Timbers. Ecol. Monogr. 18:327-376.

Eddleman, L.E. 1983. Some ecological attributes of western juniper. pp. 32-34. *In:* Research in range management, USDA ARS, SR-682, Washington, D.C.

Greenwood, E.A.N. 1992. Deforestation, revegetation, water balance, and climate: an optimistic path through the plausible, impractible, and controversial. Advances in Bioclimatology. 1:89-154.

Griffin, R.C. and B.A. McCarl. 1989. Brushland management for increased water yields in Texas. Water Resources Bulletin. 25(1):175-186.

Hamilton, E.L. and P.B. Rowe. 1949. Rainfall interception by chapparal in California. USDA Forest Service with California Dept. of Natural Resources, Forestry. 43 p.

Hester, J.W. 1996. Influence of woody dominated rangelands on site hydrology and herbaceous production, Edwards Plateau, Texas. M.S. Thesis Texas A&M University, College Station, TX.

Hibbert, A.R., E.A. Davis, and D. G. Scholl. 1974. Chaparral conversion potential in Arizona. Part I: Water yield response and effect on other resources. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado. USDA Forest Service Research Paper. 36 p.

Hibbert, A.R. 1983. Water yield improvement potential by vegetation management on western rangelands. Water Resources Bulletin. 19:375-381.

Hicks, R.A. and W.A. Dugas. 1998. Estimating ashe juniper leaf area from tree and stem characteristics. Journal of Range Management. 51:633-637.

Holland, F.D. 2004. Natural resource assessment of the Leon River restoration project with an emphasis on vegetation (range) evaluation. M.S. Professional Paper Texas A&M University, College Station, TX.

Hoffman, D. and J. Wolfe. 2003. Monitoring program to evaluate water quality impacts of vegetation restoration in the Leon River watershed. Blackland Res. and Ext. Center. Temple, TX.

Johnson, R.H. 1986. Personal communication via Griffin and McCarl. Soil Conservation Service. U.S. Dep. of Agriculture. Temple, TX.

Kelton, E. 1975. The story of Rocky Creek. The Practicing Nutritionist. 9:1-5.

Kincaid, D.R., J.L. Gardener, and H.A. Schreiber. 1964. Soil and vegetation parameters affecting infiltration under semiarid conditions. Int. Assoc. of Scientific Hydrology Bulletin. 65:440-453.

Kincaid, D.R. and G. Williams. 1966. Rainfall effects on soil surface characteristics following range improvements. Journal of Range Mangement. 19:346-351.

Lyons, R.K., M.K. Owens and R.V. Machen. 2005. Juniper biology and management. Texas Agricultural Extension Service. Texas A&M Univ. Sys. www.texasextension.tamu.edu.

McCaleb, N. L. 1985. Soil survey of Coryell County, Texas. U.S. Department of Agriculture, Soil Conservation Service.

Meeuwig, R.O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. Journal of Range Management. 23:185-188.

National Oceanic and Atmospheric Administration (NOAA). 2005. National weather service. http://www.nws.noaa.gov/

Newman, W.L. 1998. Water quality following application of picloram, triclopyr and tebuthiuron on South Texas rangeland. M.S. Thesis Texas A&M University, College Station, TX.

Owens, M.K., R. Lyons, and C. Kneuper. 2001. Evaporation and interception water loss from juniper communities on the Edwards Aquifer recharge area. Uvalde Research and Extension Center. Uvalde, TX.

Pearce, R.A., M.J. Trlica, W.C. Leininger, D.E. Mergen, and G. Frasier. 1998. Sediment movement through riparian vegetation under simulated rainfall and overland flow. Journal of Range Management. 51:301-308.

Pitt, J.L., T.L. Provin, F.M. Hons, F. Dou, J.S. Waskom. 2003. Use of a total carbon/nitrogen analyzer for the determination of soil organic and inorganic carbon in soil, manure and composts. Amer. Soc. of Agron. Annual Meetings. Denver, CO.

Pluhar, J.J., R.W. Knight and R.K. Heitschmidt. 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas Rolling Plains. Journal of Range Management. 40:240-243.

Rauzi, F. and C.L. Fly. 1968. Rainfall effects on soil surface characteristics following range improvement treatments. Journal of Range Management. 19:346-351.

Reilly, J.J. 1983. Hydrologic impacts of a herbicide/fire brush management system on post oak savannah soils. M.S. Thesis Texas A&M University, College Station, TX.

Richards, N.A. 1996. Forest windthrow microrelief as a non-restorable watershed feature. Amer. Water Resources Assoc. 254-263.

Richardson, C.W., E. Burnett, and R.W. Bovey. 1979. Hydrologic effects of brush control on Texas rangelands. Transactions ASAE. 22(2):315-319.

Scholes, R.J. and S.R. Archer. 1997. Tree-grass interactions in savannas. Annu. Rev. Ecol. Syst. 28:517-544.

Schreiber, H.A. and D.R. Kincaid. 1967. Regression models for predicting on-site runoff from short-duration convection storms. Water Resources. 3(2): 389-395.

Scifres, C.J. 1980. Brush management, principles and practices for Texas and the southwest. Texas A&M University Press, College Station, TX.

Taylor, C.A. and F.E. Smeins. 1994. A history of land use of the Edwards Plateau and its effect on the native vegetation. pp. 1-8. *In:* Juniper Symposium Proceedings at Texas A&M Univ. Research Station. Sonora, TX. Tech. Rep. 94-2. College Station, TX.

Texas Parks and Wildlife (TPWD). 2001. Cross Timbers and prairies ecological region. Austin, Texas, USA. http://www.tpwd.state.tx.us/conserve/wildlifemanagement/crosstimbers/ecoregions/crosstimbers.html.

Texas State Historical Association. 2004. The handbook of Texas online. http://www.tsha.utexas.edu/handbook/online/index.html

Thurow, T.L., W.H. Blackburn, and C.A. Taylor, Jr. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. J. Range Manage. 39:505-509.

Thurow, T.L. W.H. Blackburn, S.D. Warren, and C.A. Taylor, Jr. 1987. Rainfall interception by midgrass, shortgrass and live oak mottes. J. Range Manage. 40:455-459.

Thurow, T.L., and J.W. Hester. 1997. How an increase or reduction in juniper cover alters rangeland hydrology. *In:* Juniper Symposium Proceedings at Texas A&M Univ. Research Station. San Angelo, TX. Tech. Rep. 97-1, College Station, TX.

Thurow, T.L. 1998. Assessment of brush management as a strategy for enhancing water yield. pp. 191-198. *In*: R. Jensen (ed.) Proc. of the Water for Texas Conference. Texas Water Resources Institute, Texas Water Conservation Association, College Station, TX.

Thurow, T.L., A.P. Thurow and M.D. Garriga. 2000. Policy prospects for brush control to increase off-site water yield. Journal of Range Management. 53:23-31.

Tromble, J.M. 1976. Semiarid rangeland treatment and surface runoff. Journal of Range Management. 29:251-255.

Ueckert, D.N. 1997. Juniper control and management. pp. 5:23-34. *In:* Juniper Symposium proceedings at Texas Agricultural Experiment Station, San Angelo, TX. Texas Agr. Exp. Sta. Tech. Rep. 97-1, College Station, TX.

Walker, J., F. Bullen, and B.G. Williams. 1993. Ecohydrological changes in the Murray-Darling Basin. I. The number of trees cleared over two centuries. J. Appl. Ecol. 30:265-273.

Weltz, M.A. and W.H. Blackburn. 1995. Water budget for South Texas rangelands. Journal of Range Management. 48:45-52.

West, N.E. 1992. Shrubs: adaptations and functions. *In:* Encyclopedia of Earth System Science, Volume 4. Academic Press, San Diego, Calif.

Wilcox, B.P. 2002. Shrub control and streamflow on rangelands: a process based viewpoint. Journal of Range Management. 55:318-326.

Williams, G., G.F. Gifford and G.B. Coltharp. 1968. Infiltrometer studies on treated vs. untreated pinon-juniper sites in central Utah. Agricultural Experiment Station. Logan, Utah.

Wood, M.K., G.B. Donart and M. Weltz. 1986. Comparative infiltration rates and sediment production on fertilized and grazed blue grama rangeland. Journal of Range Management. 39(4):371-374.

Wright, H.A., F.M. Churchill and W.c. Stevens. 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in Central Texas. Journal of Range Management. 29:294-298.

Wu, B.X., E.J. Redeker and T.L. Thurow. 2001. Vegetation and water yield dynamics in an Edwards Plateau watershed. Journal of Range Management. 54:98-105.

APPENDIX A

Table A1. Mean percent grass cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	78.0 a[1](x[2])	21.8 a(y)	49.9 a
Untreated	69.1 a(x)	26.6 a(y)	47.9 a
Mean	73.6 (x)	24.2 (y)	48.9[3]
	July 2003		
Treated	62.1 a(x)	3.5 b(y)	32.8 b
Untreated	72.5 a(x)	22.6 a(y)	47.6 a
Mean	67.3 (x)	13.1 (y)	40.2
	June 2004		
Treated	60.0 b(x)	23.3 b(y)	41.6 b
Untreated	81.6 a(x)	56.8 a(y)	69.2 a
Mean	70.8 (x)	40.0 (y)	55.4

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent grass cover for grass and brush plots within date.

Table A2. Mean percent grass cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	June 2003	July 2003	June 2004
		Grass Plots	
Treated	78 a[1]	62.1 b	60.0 b
Untreated	69.1 a	72.5 a	81.6 a
		Brush Plots	
Treated	21.8 a	3.5 a	23.3 a
Untreated	26.6 b	22.6 b	56.8 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A3. Mean percent forb cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	0.3 a[1](x[2])	1.5 a(x)	0.9 a
Untreated	0.4 a(x)	1.4 a(x)	0.9 a
Mean	0.3 (y)	1.4 (x)	0.9[3]
	July 2003		
Treated	0.0 a(x)	1.6 a(x)	0.8 a
Untreated	3.9 a(x)	0.4 a(x)	2.1 a
Mean	1.9 (x)	1.0 (x)	1.5
	June 2004		
Treated	9.0 a(x)	14.6 a(x)	11.8 a
Untreated	2.1 a(x)	1.0 b(x)	1.6 b
Mean	5.6 (x)	7.8 (x)	6.7

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent forb cover for grass and brush plots within date.

Table A4. Mean percent forb cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.3 b[1]	0.0 b	9.0 a
Untreated	0.4 a	3.9 a	2.1 a
	Brush Plots		
Treated	1.5 b	1.6 b	14.6 a
Untreated	1.4 a	0.4 a	1.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A5. Mean percent litter cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	15.9 a[1](y[2])	65.1 a(x)	40.5 a
Untreated	20.9 a(y)	68.1 a(x)	44.5 a
Mean	18.4 (y)	66.6 (x)	42.5[3]
	July 2003		
Treated	25.1 a(y)	65.9 a(x)	45.5 a
Untreated	17.3 a(y)	73.3 a(x)	45.3 a
Mean	21.2 (y)	69.6 (x)	45.4
	June 2004		
Treated	21.0 a(x)	11.0 b(x)	16.0 b
Untreated	12.3 a(y)	36.5 a(x)	24.4 a
Mean	16.6 (x)	23.8 (x)	20.2

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent litter cover for grass and brush plots within date.

Table A6. Mean percent litter cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	15.9 a[1]	25.1 a	21.0 a
Untreated	20.9 a	17.3 a	12.3 a
	Brush Plots		
Treated	65.1 a	65.9 a	11.0 b
Untreated	68.1 a	73.3 a	36.5 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A7. Mean percent rock cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.8 a[1](x[2])	0.1 a(x)	0.4 b
Untreated	2.9 a(x)	1.8 a(x)	2.3 a
Mean	1.2 (x)	0.9 (x)	1.1[3]
	July 2003		
Treated	3.8 a(x)	4.8 a(x)	4.3 a
Untreated	3.6 a(x)	1.6 a(x)	2.6 a
Mean	3.7 (x)	3.2 (x)	3.5
	June 2004		
Treated	0.5 a(y)	3.4 a(x)	1.9 a
Untreated	1.5 a(x)	1.6 a(x)	1.6 a
Mean	1.0 (x)	2.5 (x)	1.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent rock cover for grass and brush plots within date.

Table A8. Mean percent rock cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.8 b[1]	3.8 a	0.5 b
Untreated	2.9 a	3.6 a	1.5 a
	Brush Plots		
Treated	0.1 b	4.8 a	3.4 ab
Untreated	1.8 a	1.6 a	1.6 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A9. Mean percent woody cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.0 a[1](x[2])	0.6 a(x)	0.3 a
Untreated	0.0 a(y)	1.8 a(x)	0.9 a
Mean	0.0 (y)	1.2 (x)	0.6[3]
	July 2003		
Treated	0.0 a(x)	0.0 a(x)	0.0 a
Untreated	0.0 a(x)	0.9 a(x)	0.4 a
Mean	0.0 (x)	0.4 (x)	0.2
	June 2004		
Treated	0.0 a(x)	0.0 a(x)	0.0 a
Untreated	0.0 a(x)	4.0 a(x)	2.0 a
Mean	0.0 (x)	2.0 (x)	1.0

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent woody cover for grass and brush plots within date.

Table A10. Mean percent woody cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.0 a[1]	0.0 a	0.0 a
Untreated	0.0 a	0.0 a	0.0 a
	Brush Plots		
Treated	0.6 a	0.0 a	0.0 a
Untreated	1.8 a	0.9 a	4.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A11. Mean time of runoff (min.) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	13.0 a[1](y[2])	37.5 a(x)	25.3 a
Untreated	10.4 a(y)	28.5 a(x)	19.4 a
Mean	11.7 (y)	33.0 (x)	22.4[3]
	July 2003		
Treated	11.3 b(x)	8.9 b(x)	10.1 b
Untreated	31.9 a(x)	39.4 a(x)	35.6 a
Mean	21.6 (x)	24.1 (x)	22.9
	June 2004		
Treated	13.3 a(x)	3.3 b(x)	8.3 b
Untreated	12.1 a(x)	22.4 a(x)	17.3 a
Mean	12.7 (x)	12.8 (x)	12.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean time of runoff for grass and brush plots within date.

Table A12. Mean time of runoff (min.) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	13.0 a[1]	11.3 a	12.3 a
Untreated	10.4 b	31.9 a	12.1 b
	Brush Plots		
Treated	37.5 a	8.9 b	3.3 b
Untreated	28.5 ab	29.4 a	22.4 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A13. Mean percent clay content (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type		Mean
	Grass	Brush	
	June 2003		
Treated	38.1 a[1](x[2])	37.2 a(x)	37.6 a
Untreated	34.1 a(x)	34.3 a(x)	34.21 b
Mean	36.1 (x)	35.7 (x)	35.9[3]
	July 2003		
Treated	35.0 a(x)	39.3 a(x)	37.1 a
Untreated	34.6 a(y)	40.0 a(x)	37.3 a
Mean	34.8 (y)	39.6 (x)	37.2
	June 2004		
Treated	37.8 a(x)	38.1 a(x)	37.9 a
Untreated	36.2 a(x)	26.8 b(y)	31.5 b
Mean	37.0 (x)	32.5 (y)	34.8

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent clay content for grass and brush plots within date.

Table A14. Mean percent clay content (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	June 2003	July 2003	June 2004
		Grass Plots	
Treated	38.1 a[1]	35.0 a	37.8 a
Untreated	34.1 a	34.6 a	36.2 a
		Brush Plots	
Treated	37.2 a	39.3 a	38.1 a
Untreated	34.3 b	40.0 a	26.8 c

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A15. Mean percent sand content (%) in grass and brush plots for the treated and untreated plots 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	15.8 a[1](x[2])	16.6 a(x)	16.2 a
Untreated	15.7 a(x)	19.5 a(x)	17.6 a
Mean	15.7 (x)	18.1 (x)	16.9[3]
	July 2003		
Treated	17.5 a(x)	15.6 b(x)	16.4 a
Untreated	15.1 a(y)	18.4 a(x)	16.7 a
Mean	16.1 (x)	17.0 (x)	16.6
	June 2004		
Treated	25.4 a(x)	22.8 b(x)	24.1 a
Untreated	19.3 b(y)	27.2 a(x)	23.3 a
Mean	22.3 (x)	25.0 (x)	23.7

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent sand content for grass and brush plots within date.

Table A16. Mean percent sand content (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	15.8 b[1]	17.2 b	25.4 a
Untreated	15.7 b	15.1 b	19.3 a
		Brush Plots	
Treated	16.6 b	15.6 b	22.8 a
Untreated	19.5 b	18.4 b	27.2 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A17. Mean organic matter in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	9.2 a[1](y[2])	12.2 a(x)	10.7 a
Untreated	9.1 a(y)	14.0 a(x)	11.6 a
Mean	9.2 (y)	13.1 (x)	11.2[3]
	July 2003		
Treated	9.8 a(x)	10.5 a(x)	10.2 a
Untreated	7.8 a(y)	9.7 a(x)	8.7 a
Mean	8.8 (x)	10.1 (x)	9.5
	June 2004		
Treated	10.3 b(x)	12.0 a(x)	11.1 a
Untreated	16.8 a(x)	8.3 b(y)	12.6 a
Mean	13.5 (x)	10.2 (y)	11.9

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean organic matter for grass and brush plots within date.

Table A18. Mean organic matter content in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates: June 2003	July 2003	June 2004
		Grass Plots	
Treated	9.2 a[1]	9.8 a	10.3 a
Untreated	9.1 b	7.7 b	16.8 a
		Brush Plots	
Treated	12.2 a	10.5 a	12.0 a
Untreated	14.0 a	9.6 b	8.3 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A19. Mean sediment concentration (g/L) in grass and brush plots for the treated and untreated plots for 3 dates on the Redland site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.1 a[1](x[2])	0.1 a(x)	0.1 a
Untreated	0.1 a(x)	0.0 a(y)	0.1 a
Mean	0.1 (x)	0.1 (x)	0.1[3]
	July 2003		
Treated	0.4 a(y)	3.4 a(x)	1.9 a
Untreated	0.1 a(x)	0.3 b(x)	0.2 b
Mean	0.2 (y)	1.8 (x)	1.0
	June 2004		
Treated	1.0 a(y)	3.2 a(x)	2.1 a
Untreated	0.2 a(x)	0.3 b(x)	0.2 b
Mean	0.6 (y)	1.8 (x)	1.2

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean sediment concentration for grass and brush plots within date.

Table A20. Mean sediment concentration (g/L) in grass and brush plots for the treated and untreated plots across 3 dates on the Redland site.

Treatment	Dates: June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.1 b[1]	0.3 ab	1.0 a
Untreated	0.1 a	0.1 a	0.1 a
	Brush Plots		
Treated	0.1 b	3.4 a	3.2 a
Untreated	0.3 a	0.3 a	0.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A21. Mean percent grass cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	38.1 a[1](x[2])	25.0 b(y)	31.6 a
Untreated	35.9 a(x)	43.1 a(x)	39.5 a
Mean	37.0 (x)	34.1 (x)	35.6[3]
	July 2003		
Treated	39.1 a(x)	2.8 b(y)	20.9 b
Untreated	43.5 a(x)	40.8 a(x)	42.1 a
Mean	41.3 (x)	21.8 (y)	31.6
	June 2004		
Treated	49.3 a(x)	17.3 b(y)	33.3 b
Untreated	46.5 a(x)	53.8 a(x)	50.1 a
Mean	47.9 (x)	35.5 (y)	41.7

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent grass cover for grass and brush plots within date.

Table A22. Mean percent grass cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	38.1 a[1]	29.1 a	49.3 a
Untreated	35.9 a	43.5 a	46.5 a
	Brush Plots		
Treated	25.0 a	2.8 b	17.3 a
Untreated	43.1 a	40.8 a	53.8 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A23. Mean percent forb cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	29.4 a[1](x[2])	10.9 a(y)	20.1 a
Untreated	20.6 a(x)	11.3 a(y)	15.9 a
Mean	25.0 (x)	11.1 (y)	18.1[3]
	July 2003		
Treated	19.8 a(x)	0.5 a(y)	10.1 b
Untreated	27.3 a(x)	3.1 a(y)	15.2 a
Mean	23.5 (x)	1.8 (y)	12.7
	June 2004		
Treated	25.6 a(x)	28.5 a(x)	27.1 a
Untreated	20.5 a(x)	4.8 b(y)	12.6 b
Mean	23.1 (x)	16.6 (y)	19.9

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent forb cover for grass and brush plots within date.

Table A24. Mean percent forb cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	29.4 a[1]	19.8 b	25.6 ab
Untreated	20.6 a	27.3 a	20.5 a
		Brush Plots	
Treated	10.9 b	0.5 c	28.5 a
Untreated	11.3 a	3.1 b	4.8 b

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A25. Mean percent rock cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.8 a[1](x[2])	0.9 a(x)	0.8 a
Untreated	0.1 a(x)	0.0 a(x)	0.1 a
Mean	0.4 (x)	0.4 (x)	0.4[3]
	July 2003		
Treated	0.0 a(x)	5.4 a(x)	2.7 a
Untreated	0.5 a(x)	0.6 a(x)	0.6 a
Mean	0.3 (y)	3.0 (x)	1.7
	June 2004		
Treated	1.0 a(y)	3.3 a(x)	2.1 a
Untreated	0.6 a(x)	0.0 b(x)	0.3 b
Mean	0.8 (y)	1.6 (x)	1.2

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent rock cover for grass and brush plots within date.

Table A26. Mean percent rock cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.8 a[1]	0.0 a	1.0 a
Untreated	0.1 a	0.5 a	0.6 a
	Brush Plots		
Treated	0.9 a	5.4 a	3.3 a
Untreated	0.0 a	0.6 a	0.0 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A27. Mean percent woody cover (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	0.0 a[1](x[2])	3.1 a(x)	1.6 a
Untreated	0.0 a(x)	0.0 a(x)	0.0 a
Mean	0.0 (x)	1.6 (x)	0.8[3]
	July 2003		
Treated	0.0 a(x)	0.3 a(x)	0.1 a
Untreated	0.0 a(x)	0.0 a(x)	0.0 a
Mean	0.0 (x)	0.1 (x)	0.1
	June 2004		
Treated	0.0 a(x)	0.0 a(x)	0.0 a
Untreated	0.0 a(x)	0.4 a(x)	0.2 a
Mean	0.0 (x)	0.2 (x)	0.1

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent woody cover for grass and brush plots within date.

Table A28. Mean percent woody cover (%) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	0.0 a[1]	0.0 a	0.0 a
Untreated	0.0 a	0.0 a	0.0 a
	Brush Plots		
Treated	3.1 a	0.3 a	0.0 a
Untreated	0.0 a	0.0 a	0.4 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A29. Mean time of runoff (min.) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	2.8 a[1](y[2])	45.0 a(x)	23.9 a
Untreated	5.0 a(y)	40.4 a(x)	22.7 a
Mean	3.9 (y)	42.7 (x)	23.3[3]
	July 2003		
Treated	11.3 a(y)	40.1 a(x)	25.7 a
Untreated	8.6 a(y)	45.0 a(x)	26.8 a
Mean	9.9 (y)	42.6 (x)	26.3
	June 2004		
Treated	5.6 a(y)	26.8 a(x)	16.2 a
Untreated	5.6 a(y)	39.8 a(x)	22.7 a
Mean	5.6 (y)	33.3 (x)	19.5

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean time of runoff for grass and brush plots within date.

Table A30. Mean time of runoff (min.) in grass and brush plots for the treated and untreated plots across 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	2.8 a[1]	11.3 a	5.6 a
Untreated	5.0 a	8.6 a	5.6 a
	Brush Plots		
Treated	45.0 a	40.1 ab	26.8 b
Untreated	40.4 a	45.0 a	39.8 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A31. Mean percent clay content (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	27.9 b[1](x[2])	29.5 a(x)	28.7 b
Untreated	32.3 a(x)	32.0 a(x)	32.1 a
Mean	30.1 (x)	30.8 (x)	30.5
	July 2003		
Treated	29.9 a(y)	33.8 a(x)	31.9 a
Untreated	30.4 a(y)	32.7 a(x)	31.6 a
Mean	30.2 (y)	33.2 (x)	31.7
	June 2004		
Treated	32.9 a(x)	33.4 a(x)	33.1 a
Untreated	34.5 a(x)	32.4 a(x)	33.1 a
Mean	33.7 (x)	32.9 (x)	33.3

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent clay content for grass and brush plots within date

Table A32. Mean percent clay content (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	27.9 b[1]	29.9 ab	32.9 a
Untreated	32.3 b	30.4 b	34.5 a
	Brush Plots		
Treated	29.5 b	33.8 a	33.4 ab
Untreated	32.0 a	32.7 a	32.4 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A33. Mean percent sand content (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	28.1 a[1](x[2])	31.3 a(x)	29.7 a
Untreated	26.6 a(x)	28.2 a(x)	27.4 a
Mean	27.3 (y)	29.7 (x)	28.5
	July 2003		
Treated	28.9 a(x)	29.5 a(x)	29.2 a
Untreated	27.5 a(x)	27.4 a(x)	27.4 b
Mean	28.2 (x)	28.4 (x)	28.3
	June 2004		
Treated	29.1 a(x)	29.6 a(x)	29.4 a
Untreated	26.1 a(y)	29.4 a(x)	27.7 a
Mean	27.6 (x)	29.5 (x)	28.6

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean percent sand content for grass and brush plots within date

Table A34. Mean percent sand content (%) in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
	Grass Plots		
Treated	28.1 a[1]	28.9 a	29.1 a
Untreated	26.6 a	27.5 a	26.1 a
	Brush Plots		
Treated	31.3 a	29.5 a	29.6 a
Untreated	28.2 a	27.4 a	29.4 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

Table A35. Mean organic matter in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Vegetation Type: Grass	Vegetation Type: Brush	Mean
	June 2003		
Treated	13.5 a[1](x[2])	8.5 a(y)	11.0 a
Untreated	7.9 b(x)	8.0 a(x)	7.9 b
Mean	10.7 (x)	8.3 (y)	9.5
	July 2003		
Treated	7.6 b(y)	18.8 a(x)	13.2 a
Untreated	11.7 a(x)	14.2 a(x)	13.0 a
Mean	9.7 (y)	15.5 x	12.6
	June 2004		
Treated	10.3 a(y)	15.5 a(x)	12.9 a
Untreated	7.9 b(y)	11.9 b(x)	9.9 b
Mean	9.1 (y)	13.7 (x)	11.4

[1]Means followed by the same letter in a column within date are not significantly different at the 95% level according to Duncan's multiple range test.
[2]Means followed by the same letter in a row within parentheses and vegetation type within each row are not significantly different at the 95% level according to Duncan's multiple range test.
[3]Mean organic matter for grass and brush plots within date

Table A36. Mean organic matter content in grass and brush plots for the treated and untreated plots for 3 dates on the Low Stony Hill site.

Treatment	Dates		
	June 2003	July 2003	June 2004
		Grass Plots	
Treated	13.4 a[1]	7.6 b	10.3 b
Untreated	7.9 b	11.7 a	7.9 b
		Brush Plots	
Treated	8.5 b	18.8 a	15.5 a
Untreated	8.0 b	14.2 a	11.9 a

[1]Means followed by the same letter within each row are not significantly different at the 95% level according to Duncan's multiple range test.

VITA

Name: Courtney Hale Greer

Born: November 7, 1979

Address: P.O. Box 140
Center, TX 75935

Education: B.S. Rangeland Ecology and Management, 2002
Texas A&M University

M.S. Rangeland Ecology and Management, 2005
Texas A&M University