New Mexico State University

Corona Range and Livestock Research Center

Half Day of College
July 17, 2009

Ranch-Scale
Alternative Energy
Wind and Solar

Rangeland Carbon
Sequestration
Carbon Credits

Hydrology of Pinyon-
Juniper Rangelands
Facts vs Fiction

Southwest Grazing Land Innovations
CORONA
Range and Livestock Research Center

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Half Day of College

July 17, 2009 — "Year of Sustainability" — 8:30a-2:00p

8:30 am	Registration	Shop
9:00 am	Welcome Introductions Update: SWCRS Construction	Shop
	Concurrent Sessions	
10:00—10:55	Rangeland Carbon Sequestration Meet with Dr. Joel Brown	Shop
	Hydrology of P-J Rangelands Meet with Dr. Sam Fernald	N. Barn
11:00—11:55	Rangeland Carbon Sequestration Meet with Dr. Joel Brown	Shop
	Ranch Scale Alternative Energy Meet with Corey Asbill and Luis Estrada	N. Barn
12:00—12:55	Lunch Prepared by Crown Cowbelles and assisted by Corona FFA Chapter	Shop
1:00— 1:55	Ranch Scale Alternative Energy Meet with Corey Asbill and Luis Estrada	Shop
	Hydrology of P-J Rangelands Meet with Dr. Sam Fernald	N. Barn

Instructors

Rangeland Carbon Sequestration	Dr. Joel Brown	Ecologist, USDA NRCS, Jornada Exp. Range
Hydrology of Piñon-Juniper Rangelands	Dr. Sam Fernald	Hydrologist, NMSU, Animal and Range Sci.
Ranch Scale Alternative Energy	Mr. Corey Asbill Mr. Luis Estrada	Engineer, NMSU, SW Tech Development Inst. Engineer, NMSU, SW Tech Development Inst.

Southwest Grazing Land Innovations
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Thank You!

Corona FFA
Corona Public Schools
Corona Trading Company
Crown Cowbelles

Your help in facilitating this event is greatly appreciated!

Rangeland Carbon Sequestration

Carbon Credits

The current status of rangeland soil carbon sequestration offset programs

Joel Brown, USDA NRCS, Jornada Experimental Range

In general, rangeland soil carbon dynamics reflect three primary driving factors: 1) the climate, 2) inherent soil fertility and 3) management. Climate, and in the short term weather, govern the input of carbon into the soil system. Plants fix carbon dioxide and transfer the carbon below ground—the more favorable the conditions for plant growth, the more carbon input. Soil carbon levels at a regional scale generally reflect rainfall. Consecutive years of above average rainfall result in increased soil carbon, while extended droughts usually result in loss of soil carbon across climatic, soil and management regimes. In addition, the ability of soil to store moisture and vegetation to access that water controls plant productivity and soil carbon dynamics.

Inherent soil fertility is also an important driver of soil carbon levels. Soils with relatively high levels of available nutrients have higher levels of plant productivity, when soil water is available. Few, if any, rangelands receive regular additions of fertilizer, so inherent fertility, along with moisture availability, is a key factor in plant productivity and carbon dynamics.

Finally, management is an important contributor to carbon dynamics on rangelands. Ranchers rely on domestic herbivores to harvest and convert plant material to useable products to support society. It is important to recognize that good management, however intensive, will not overcome the importance of climate and inherent soil fertility in controlling plant productivity and soil carbon. On the other hand, poor management (the excessive harvest of plant growth) can reduce productivity. Typically, soils gain carbon during periods of plant growth, while soils lose carbon during periods of dormancy. The length and severity (air temperatures) of drought can have an inordinate influence on soil carbon levels, regardless of management.

Thus, the challenge is to balance the harvest of plant growth (stocking rate) with plant production to optimize sustainability for a given climate:soil combination. Ranchers have known and practiced this balancing act for hundreds, if not thousands, of years.

While the basic processes associated with the uptake, fixation and transfer of carbon in rangelands are relatively well-known, the rates and magnitudes of particular pastures, ranches and groups of ranches and sites remain difficult (and very expensive) to predict and measure. The primary group that is attempting to make a carbon market work for rangelands is the Chicago Climate Exchange. CCX attempted to hold down costs by using regional default rates credited to proven rangeland management practices (moderate stocking rate, proper distribution, drought response). Verification at the ranch level requires an independent third-party to visit the ranch and verify that agreed to management practices are in place and records support the management decisions. This approach sacrifices the precision of site-specific measurement for keeping the overhead costs low.

Ranch-Scale Alternative Energy

Wind and Solar

Photovoltaic Energy Resources

- Home Power Magazine
www.homepower.com

- New Mexico Energy and Minerals
www.cleanenergynm.org

- Federal/State Incentives
www.dsireusa.org

- PV Water Pumping Resources
www.builditsolar.com/Projects/WaterPumping/waterpumping.htm

- RE Equipment Source/Reference - Solar Living Source Book
www.realgoods.com

- Solar Pricing Information
www.solarbuzz.com

- Solar Energy International
www.solarenergy.org

- Positive Energy (NM PV Installer)
www.positivenergy.com

- NABCEP Certified Solar Installers List
www.nabcep.org

- Geothermal Ground Loop Description
www.groundloop.com/geothermal.htm

- Presenter Contact: Corey Asbill
casbill@nmsu.edu

Hydrology
Of
Piñon-Juniper
Rangelands

Facts vs Fiction

UNDERSTORY VEGETATION AND WATER AVAILABILITY EFFECTS OF TREATING JUNIPER WITH HERBICIDE IN CENTRAL NEW MEXICO

Hector R. Garduño[1], Alexander G. Fernald[2], Andres F. Cibils[3], and Dawn M. VanLeeuwen[4]

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ABSTARCT

In semi-arid regions of the western U.S. there is heightened interest in tree removal to promote forage growth and groundwater recharge. We conducted a study in central New Mexico to determine the effect of treating one-seed juniper (*Juniperus monosperma*) dominated woodlands with herbicide on herbaceous biomass production and basal cover, and soil water availability. Undestory vegetation and soil water were measured in plots under dead juniper snags, live juniper trees, and in woodland interspaces. In addition, soil temperature regimes were characterized by installing soil temperature sensors in juniper stands. Plots under both live and dead tree stands in three livestock grazing exclosures were instrumented with recording soil moisture probes under trees and between juniper stands. We hypothesized that herbicide treatment would not have a detrimental effect on herbaceous basal cover and above-ground biomass production and would increase superficial soil water content. Exclosures had similar precipitation patterns during the study with average weekly total rainfall of 7.99 mm. Basal cover of total herbaceous vegetation and perennial grasses was higher under dead than live trees. Herbaceous biomass production was higher under dead trees than under live trees. In interspaces between juniper dead and live trees, perennial grass basal cover was the only variable measured which exhibited significantly higher values between dead vs. live trees. Biomass production, on

the other hand, was not significantly affected by tree status (dead and live trees). Soil temperature regimes, mean daily maximum surface soil temperature was highest (17.19 ºC) between juniper stands, intermediate (16.13 ºC) under dead trees and lowest (14.90 ºC) under live trees. Tree status (live or dead) affected surface soil moisture. Such effects were found in August and October, 2006, when soil was drier under dead than under live juniper trees and when excess soil moisture wet deeper soil layers beyond the grass root zone. There was less soil moisture in interspaces vs. under trees. It is likely that the use chemical thinning may have different effects on vegetation and soil moisture such as 1) increase of native grass basal cover under juniper trees, 2) increase in biomass production under trees and between juniper stands, and 3) increase in soil moisture availability for herbaceous biomass production.

Variation in Herbaceous Vegetation and Soil Moisture Under Treated and Untreated Oneseed Juniper Trees

Hector Ramirez[1], Alexander Fernald[1], Andres Cibils[1], Michelle Morris[1], Shad Cox[2], and Michael Rubio[2]

***Abstract**—Clearing oneseed juniper* (Juniperus monosperma) *may make more water available for aquifer recharge or herbaceous vegetation growth, but the effects of tree treatment on soil moisture dynamics are not fully understood. This study investigated juniper treatment effects on understory herbaceous vegetation concurrently with soil moisture dynamics using vegetation sampling, soil sampling, and automated precipitation and soil moisture data collection. The study was conducted at New Mexico State University's Corona Range and Livestock Research Center Corona, NM. We created plots under dead and live juniper trees in three cattle-grazing exclosures (CD, FG, and KI). We applied heavy defoliation clipping treatment and no defoliation in the winter months. This study reports on soil moisture from volumetric water content probes installed at 0-25 cm depth at the drip line or the outside of each plot. Understory herbaceous cover and biomass were significantly higher under dead than under living trees, while volumetric water content was lower under dead than under living trees. Water content was higher on clipped than on unclipped plots for dead and living trees. At this site, water made available by treating oneseed juniper appears to be consumed by additional herbaceous vegetation under dead trees.*

***Keywords:** volumetric water content, P-J control, understory defoliation, soil moisture dynamics.*

Introduction

Effects of clearing oneseed juniper woodlands on forage for cattle and big game have been extensively studied (Pieper 1990). However, less is known about the effects of such tree clearing treatments on soil water dynamics. In some locations, juniper clearing may be associated with groundwater recharge, while in others the water not used by trees may simply be consumed by herbaceous vegetation. According to Walter's model cited by Breshears and Barnes (1999), two soil layers may be distinguished on the basis of the rooting depths of plants (herbaceous and woody). Herbaceous plants have a denser root distribution than woody plants and are much more efficient obtaining water from the upper layer. Woody plants have sole access to the lower soil layer. Yet, some studies have shown that root depth to extract water depends on woody species (Montaña and others 1995) and competition for resources with herbaceous plants (Young and Evans 1981), although the distribution of plants varies with plant cover (Joffre and Rambal 1988) and depends on available soil moisture and nutrients (Breshears and Barnes 1999). Extensive research has been conducted on methods to remove piñon-juniper woodlands, yet much less is known about the sustainable management of cleared areas. Where juniper treatment increases understory herbaceous

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vegetation growth, prescribed grazing by goats and sheep may suppress juniper regrowth and improve ongoing recovery of herbaceous vegetation.

A straightforward approach to assessing juniper treatment effects on soil water dynamics is to identify understory herbaceous response and soil moisture content under treated dead and untreated live trees. To improve understanding of how juniper treatments affect understory herbaceous vegetation concurrently with soil moisture dynamics, this study investigated four aspects of vegetation and soil moisture response to juniper treatment: 1) the effect of juniper treatment on understory herbaceous vegetation cover and biomass; 2) the effect of juniper treatment on soil moisture under dead and live trees; 3) the soil moisture response to rainfall under dead and live trees; and 4) the soil moisture response to rainfall under dead and live trees where understory herbaceous vegetation had been subjected to a single high intensity defoliation event during the dormant season.

Materials and Methods

This study was conducted at New Mexico State University's Corona Range and Livestock Research Center also known as the Corona Ranch. Of the Corona Ranch, about half (5797 ha) has been classified as actual or potential piñon-juniper woodland. The herbicide Tebuthiuron was applied aerially to 959 ha in 1995, and tree mortality from the herbicide treatment was readily identifiable by the time of this study ten years later. Three cattle-grazing exclosures (C_t/D_u, F_u/G_t, and K_t/I_u) were selected for this study, with the subscript "t" indicating herbicide treatment and the subscript "u" indicating the untreated half of each exclosure. We created six plots under dead juniper snags and six plots under live juniper trees. Crown dimensions were used to delineate each rectangular plot with a long axis stretching under the largest axis of the crown and a short axis perpendicular to the long axis. All six plots per dead or live treatment were marked within a relatively small (~60 m diameter) area to reduce potential impacts of soil variation and to facilitate installation of an automated soil moisture sensor system.

We applied heavy defoliation (clipping treatment) and no defoliation (unclipped treatment) to aboveground biomass in February 2005. The purpose of the defoliation treatment was to imitate high intensity (>70% utilization) grazing by sheep and goats during the winter months. Six trees were defoliated in each exclosure: three were in the herbicide treated part of the exclosure and three were in untreated part of the exclosure. The remaining six trees were not clipped and left untreated. An additional defoliation treatment will be applied in winter 2006. Basal cover by species was determined prior to the beginning of this study with ten separate ten pin frames in each plot, including percent cover of bare ground, litter, and rock. Aboveground biomass by species was determined at the time of the basal cover measurements in plots that received defoliation. Superficial soil moisture content was determined in spring 2005 from 4x10 cm core samples taken at 1/3, 2/3, and 3/3 of the distance from the tree to the drip line along the short and the long axis of each plot. Each soil sample was stored in sealed plastic bags, weighed, oven dried at 105 °C for 48 hrs, and weighed again to determine water mass. With porosity from soil bulk density measured with a separate core sample, gravimetric water content was converted to volumetric water content (volume water/volume soil). Data were analyzed statistically in SAS using a completely randomized block design, with significant differences determined at $P \leq 0.05$.

For continuous soil moisture measurement, a nest of three CS616 (all Campbell Scientific Inc. equipment) volumetric water content reflectometer soil moisture probes was installed in each plot at the drip line on the outside of each plot at depths of 0 to 25 cm, 25 to 50 cm, and 50 to 75 cm. This paper reports on results from the surface layer, which corresponds to the herbaceous understory rooting depth. The CS616 probes were connected by cable to AM16/32 multiplexers, which in turn were connected to CR10X-2M data loggers powered by SP5-L five watt solar panels and PS100 batteries. In each exclosure, a TE525WS-L tipping bucket rain gage was installed and connected to the data logger to measure precipitation. Soil volumetric water content (volume water/volume soil) data were collected hourly from all locations beginning in September 2005. This study reports on continuous soil moisture in the period from September until November 2005, comparing time series of soil moisture averaged by dead, live, clipped, and unclipped treatments.

Results and Discussion

Juniper treatment significantly affected herbaceous understory vegetation. Basal cover of herbaceous understory was significantly different under live and dead trees ($P \leq 0.05$); it was about three times higher under dead trees (14.60%) than under live trees (4.64%) (table 1). There were also significant differences in vegetation basal cover between exclosures (table 1). Biomass was significantly different under dead and live trees, with much greater vegetation biomass under dead trees (59.52 $g \cdot m^{-2}$) than under live trees (17.91 $g \cdot m^{-2}$) (table 2).

The superficial volumetric water content exhibited significant differences between live and dead trees, being greater under live trees (10.36) than under dead trees (8.84) (table 3). There were also significant differences between exclosures

Table 1—Basal cover (%) under dead and live trees in three cattle grazing exclosures at the Corona Ranch. Values in each group with the same superscript letter are not significantly different ($P \leq 0.05$).

	Dead				Live				
Exclosure	Bare ground	Litter	Rock	Veg	Bare ground	Litter	Rock	Veg	Dead+Live Veg
CD	16.50	70.00	0.83	12.60	36.60	61.60	0.83	0.83	6.70[b]
FG	10.50	70.50	0.00	19.00	9.50	80.10	0.00	10.30	14.60[a]
KI	17.80	69.30	0.50	12.30	26.50	70.30	0.33	2.80	7.50[b]
All exclosures	14.93	69.93	0.44	14.60[a]	24.20	70.67	0.39	4.64[b]	

Table 2—Biomass $g \cdot m^{-2}$ under dead and live trees in three cattle grazing exclosures at the Corona Ranch. Values in each group with the same superscript letter are not significantly different ($P \leq 0.05$).

	Tree treatment		Average by exclosure
Exclosure	Dead	Live	Average
CD	55.54	7.82	31.68[b]
FG	83.99	32.82	58.40[a]
KI	39.06	13.09	26.07[b]
All exclosures	59.52[a]	17.91[b]	

Table 3—Volumetric water content (volume water/volume soil) under dead and live trees in three cattle grazing exclosures at the Corona Ranch.Values in each group with the same superscript letter are not significantly different (P ≤ 0.05).

	Axis of tree canopy		Distance from tree to drip line			Tree treatment		Average by exclosure
Exclosure	**Long**	**Short**	**1/3**	**2/3**	**3/3**	**Dead**	**Live**	**Average**
CD	10.82	12.21	11.79	11.76	11.00	10.90	12.13	11.50[a]
FG	6.84	8.19	7.35	7.97	7.37	7.19	7.89	7.0[c]
KI	10.96	8.52	9.69	9.98	9.54	8.43	11.05	9.70[b]
All exclosures	9.54[a]	9.64[a]	9.61[a]	9.90[a]	9.30[a]	8.84a	10.36[b]	

(table 3). There were not significant differences in soil moisture by long or short plot axis or by distance (1/3, 2/3, or 3/3) from tree to drip line (table 3). Since these preliminary data showed no significant differences in soil moisture content at different locations under the tree canopies, recording soil moisture probes were located under the drip line to be representative of the tree to interspace continuum and to avoid interference with vegetation in each plot under each tree.

The September to November time period was opportune for characterizing soil moisture response to rainfall, because it came after at least four weeks without rain, allowing the herbaceous water consumption to be exhibited, and it included precipitation events then a period of drying into November. Comparing volumetric water content averaged for dead and live trees, the surface soil under dead trees was drier at the start of the period, rose higher than under live trees in response to rainfall, and dried faster than under live trees after rainfall (fig. 1). Comparing volumetric water content under dead trees that were clipped or unclipped, there was a muted response to rainfall, with slightly more wetting and faster drying seen on the clipped plots (fig. 2). Comparing volumetric water content under live trees that were clipped or unclipped, there was visibly greater soil moisture and slightly faster drying under clipped plots (fig. 3).

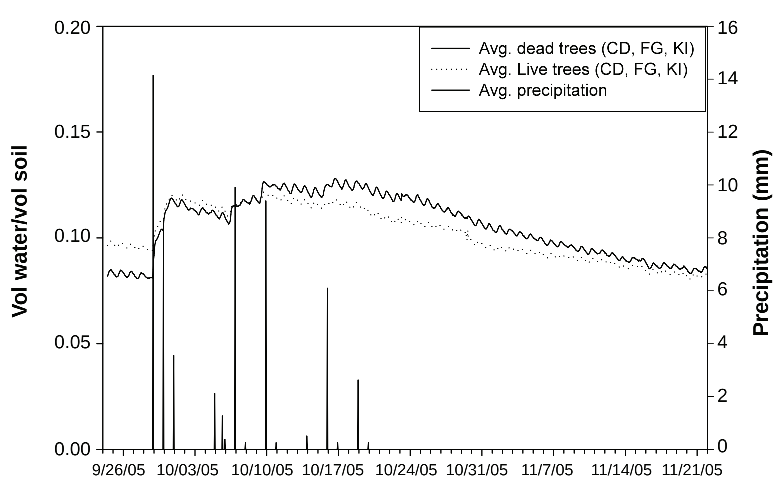

Figure 1—Soil volumetric water content response to rainfall beneath dead and living trees in CD, FG, and KI exclosures at the Corona Ranch.

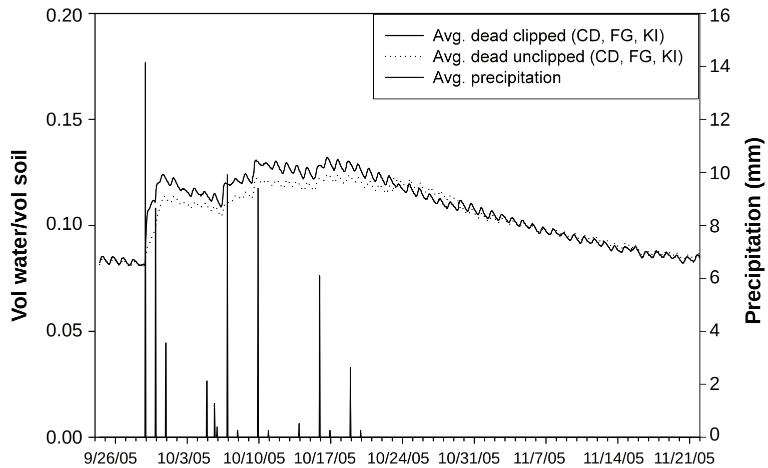

Figure 2—Soil volumetric water content response to rainfall under clipped and unclipped herbaceous vegetation beneath dead trees in CD, FG, and KI exclosures at the Corona Ranch.

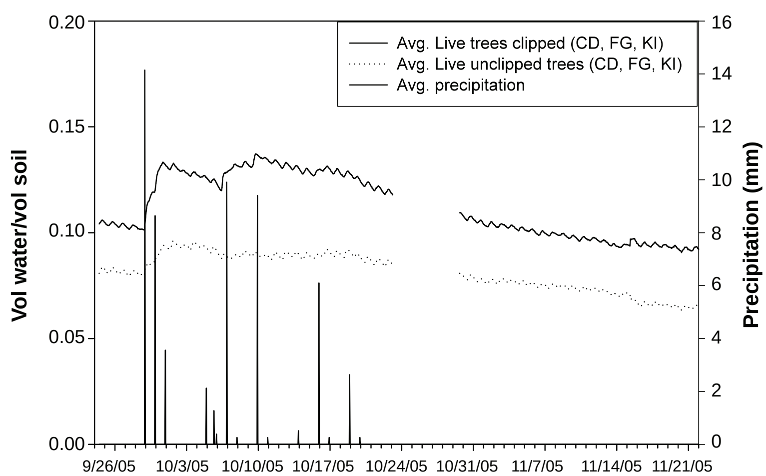

Figure 3—Soil volumetric water content response to rainfall under clipped and unclipped herbaceous vegetation beneath living trees on CD, FG, and KI exclosures at the Corona Ranch.

Understory herbaceous vegetation response to juniper treatment shows more vegetation under dead trees. At the same time, volumetric water content is greater under live trees, likely because there is less vegetative consumptive demand. In the time series comparing soil moisture, there was more rapid drying under dead trees, likely again because of the higher vegetative water consumption. Increased soil moisture after rainfall under dead compared to live trees may be from reduced rainfall interception under dead tree snags. At this site, water made available by treating oneseed juniper appears to be consumed, at least in part, by additional herbaceous vegetation under dead trees.

Clipping treatments in the dormant season did not seem to negatively impact vegetation vigor. Soil moisture time series were consistent with the interpretation that clipped vegetation grows back and consumes water as readily as or more readily than unclipped vegetation. The combination of herbicide treated trees and high intensity dormant season defoliation appeared to result in the most water consumption by herbaceous vegetation.

Conclusion

This study found that herbicide treatment of oneseed juniper resulted in greater understory herbaceous vegetation cover and biomass. While there were no significant differences in soil moisture under the area of the tree canopy, there were soil moisture differences between dead and live trees. Under dead trees, soil moisture increased more after rainfall, dried more quickly, and became drier than under live trees. Intense defoliation of the herbaceous vegetation seemed to follow a muted, but similar pattern as under tree treatment. Removing trees apparently makes more water available for herbaceous vegetation, that in turn consumes more water and with vigor unreduced by intense defoliation. While aquifer recharge may not be increased by juniper control at the Corona Ranch, tree treatment and intense dormant season grazing may result in ongoing improvements in the understory herbaceous vegetation as seen through the window of soil moisture dynamics shown in this study.

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Rainfall, Soil Moisture, and Runoff Dynamics in New Mexico Piñón-Juniper Woodland Watersheds

Carlos Ochoa[1], Alexander Fernald[1], and Vincent Tidwell[2]

Abstract—*Clearing trees in piñón-juniper woodlands may increase grass cover and infiltration, leading to reduced surface runoff and erosion. This study was conducted to evaluate piñón-juniper hydrology conditions during baseline data collection in a paired watershed study. We instrumented six 1.0 to 1.3 ha experimental watersheds near Santa Fe, NM to collect rainfall, soil moisture, and runoff data. Volumetric water content reflectometers (VWCRs) were used to measure soil moisture on wooded hillslopes, on grass hillslopes, and in valley bottoms. Time domain reflectometry (TDR) probes were installed in two watersheds to measure soil wetting at hillslope, gully headcut and channel locations. Spatial dynamics of rainfall and runoff interactions were evaluated for 9 rainfall events. Runoff was present at all watersheds in 3 of the 9 rainfall events. Rainfall intensity of 5mm/15min was generally the minimum precipitation required to generate channel runoff. During high intensity rain storms, greater soil moisture was observed at valley bottoms when compared to grass hillslopes and wooded hillslopes. At the watershed scale, total runoff as a proportion of precipitation was relatively low. Wetting depth measured with TDR probes was consistent with increases in soil moisture measured with VWCRs. In general, the wetting depth was greater at the channel, followed by the gully headcut and then by the hillslope. Results to date from the baseline data collection period suggest that larger storms that wet the entire watersheds produce most annual runoff, so clearing trees may increase grass cover, but may have little effect on annual runoff.*

Keywords: *New Mexico, piñón-juniper, baseline data, rainfall, soil moisture, runoff, wetting depth, TDR*

Introduction

Piñón-juniper (PJ) woodlands cover a large portion of semi-desert U.S. ecosystems, extending from Texas to California and occupying an area of approximately 24.7 million ha (Burns and Honkala 1990). In New Mexico, PJ woodlands are the most abundant type of forest and cover nearly 53 percent of the total forested area of the state (O'Brien 2003). Temporal variations in precipitation are important for runoff generation in piñón-juniper woodlands of northern New Mexico. Wilcox (1994) reported two typical precipitation seasons that produce runoff in a steep mountainous area of this region: a mid-summer season, with convective storms generating most of the runoff; and a mid-to-late winter season, with snow melt producing some runoff. Amount and intensity of precipitation is also important for the generation of runoff. Reid and others (1999) reported that convective storms characterized by high-intensity short-duration precipitation events generated most of the runoff and that frontal storms also produced considerable runoff in a 26-month study done in north-central New Mexico. Soil moisture dynamics in piñón-juniper woodlands, especially in the shallow soil layer, are important in

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[2] Sandia National Laboratories.

determining water availability for different plant species. Breshears and others (1997) found that both piñón and juniper trees can extract water from the top 30 cm of intercanopy locations and compete with forage species for water.

Piñón-juniper tree control by mechanical removal, treatment with fire, or herbicide, may increase forage response and soil water infiltration and consequently reduce surface runoff and erosion. In order to characterize hydrology effects of PJ control, it is important to understand and evaluate watershed conditions prior to treatment. This study is part of a research effort to evaluate watershed response to piñón-juniper control in northern New Mexico. This study was conducted to collect baseline data and evaluate hydrology conditions before tree clearing planned in 2009. We formulated two study questions:

1. How does channel runoff respond to different precipitation amounts and intensities?
2. What is the soil moisture response to rainfall on wooded hillslopes, on grass hillslopes, and in valley bottoms of the watersheds?

Study Site

The research site is located at the New Mexico State University-Santa Fe Ranch (NMSU-SFR), 16 km northwest of Santa Fe, NM. The vegetation of the area is represented by piñón-juniper woodland on the hillslopes and grassland in the valleys. Oneseed juniper (*Juniperus monosperma* Engelm.) is the dominant tree species, followed by piñón pine (*Pinus edulis* Engelm.). The dominant species in the understory is blue grama (*Bouteloua gracilis*. Willd. ex Kunth), followed by New Mexico feathergrass (*Stipa neomexicana*), sideoats grama (*Bouteloua curtipendula*. Michx), and purple threeawn (*Aristida purpurea*. Nutt). Piñón-juniper woodlands are generally between 1370 and 2440 m. In New Mexico, these woodlands are found in elevation that range from 1520 m to 2130 m (Burns and Honkala 1990). Elevation of the watersheds at the NMSU-SFR study site ranges from 1939 m in the valley bottoms to 1977 m on the ridge tops. Slopes range from 2% to 5% in the valley bottoms and 20% to 50% on the hillslopes. Average annual precipitation is 387 mm. Most of this precipitation falls during the monsoon season from May to October. The average low annual temperature is 4.4 °C and the average high annual temperature is 26.7 °C. The soil type is classified as part of The Santa Fe Group (Tsf) and is mostly characterized by sediments from fluvial deposits of sand, silt, clay and pebbles with basaltic and sedimentary inclusions (Scholle 2003, Till and others 2003).

Methods

Six watersheds (WS-1, WS-2, WS-3, WS-4, WS-5, and WS-6) of 1.0 to 1.3 ha were instrumented to collect precipitation, runoff, and soil moisture data starting in April of 2003 (fig. 1). WS-2 and WS-3 were equipped with Time Domain Reflectometry (TDR) technology to measure soil wetting depth.

Precipitation measurements were taken with four tipping-bucket rain gauges with datalogger enclosed (HOBO rain gauge, manufactured by Onsetcomp). These rain gauges were installed at mid-slope elevation in four watersheds (WS-2, WS-3, WS-5, and WS-6) to collect precipitation data. The rain gauge at WS-2 was installed in April of 2003 and the remaining three were installed between June and July of the same year. The WS-2 rain gauge was used to represent adjacent WS-1, and the WS-3 rain gauge was used to represent adjacent WS-4 (fig. 1).

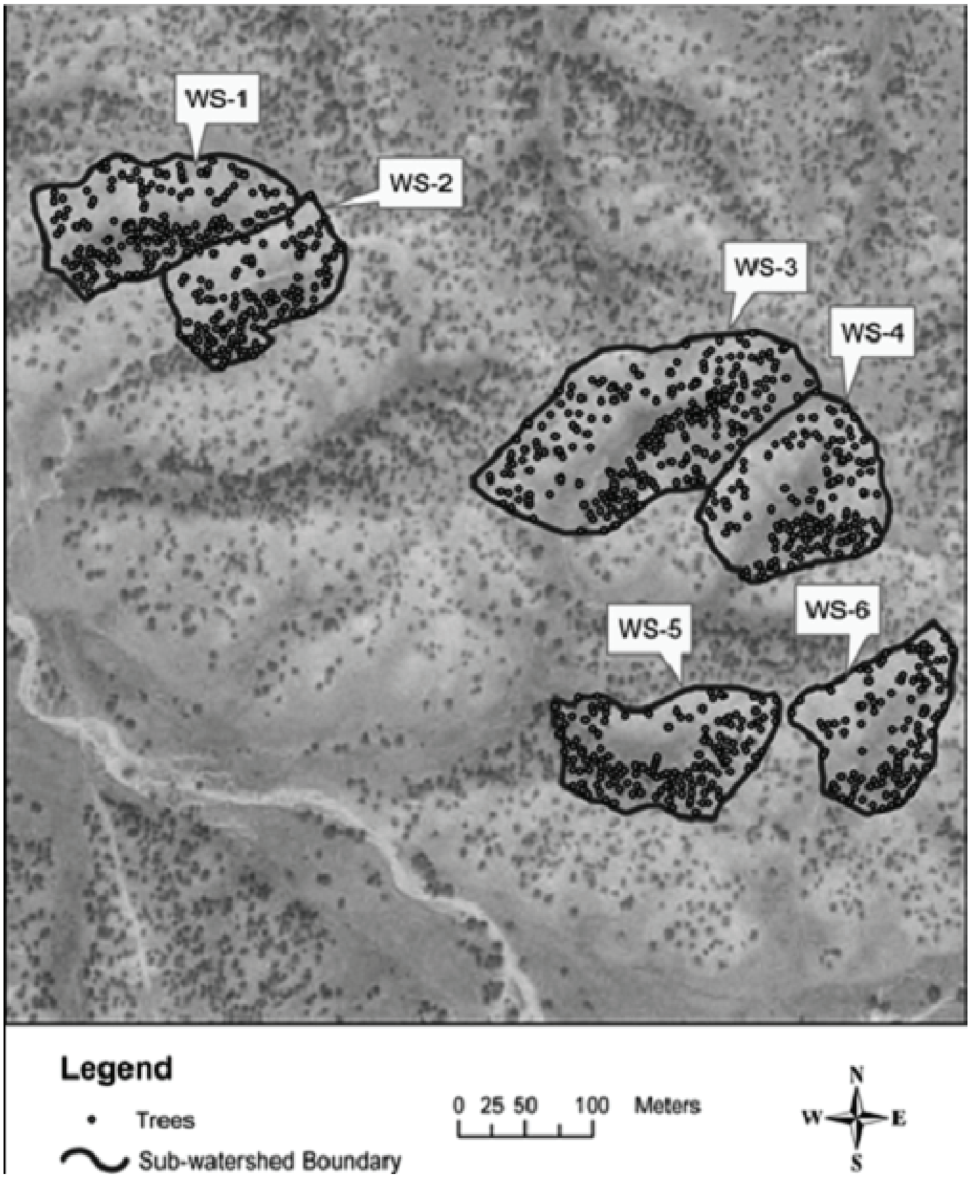

Figure 1—Watersheds of the NMSU-Santa Fe Ranch.

Runoff data were collected at the outlets of the watersheds. Type H flumes equipped with pressure transducers were installed at the outlets to measure water stage. Total amount of runoff per rainfall event was calculated with the low flow discharge equation for type H flumes with floor sloping of 0.003 to 0.03 (Brakensiek and others 1979).

Soil moisture data were collected using six volumetric water content reflectometers (VWCRs) in each watershed. The VWCRs were installed under canopy and in the intercanopy of wooded hillslopes, grass hillslopes, and valley bottoms. The VWCRs were inserted horizontally at 10 cm depth and attached to dataloggers. Soil volumetric water content data were collected every hour. Maximum values of increase in soil moisture measured by all six VWCRs after precipitation events that produced runoff in each watershed were added and divided by the total number of precipitation events to obtain average increase in soil water content for the two-year study period.

Soil wetting depth was calculated using data collected with TDR sensors. A total of sixteen 15 cm-long experimental sensors were installed at WS-2 and WS-3 to collect the TDR trace signals. The TDR sensors were installed vertically, with the tip exposed, at gully headcut, channel bed, channel bank, ridge, and hillslope. Two rain gauges attached to dataloggers were installed in the valley bottoms of WS-2 and WS-3 to activate the TDR systems. During rainfall events, the TDR systems were triggered by the automated rain gauges and data were continuously collected during the precipitation event and until 15 minutes after rainfall stopped in order to capture the total expected time needed for rainfall to either infiltrate or run off. Under dry conditions, TDR data were collected twice a day, at noon and at midnight. TDR data were entered into a physically based multisection model developed by Tidwell and Brainard (2005) to calculate the soil wetting depth. The model uses the S_{11} scatter function and Debeye parameters for dielectric dispersion and loss is used to analyze the TDR traces.

Results

Precipitation

We present precipitation data for nine rainfall events that generated runoff. Two occurred in 2003 and the remaining seven happened in 2004 (table 1). Rainfall was temporally and spatially variable among watersheds. During the two-year study, we observed that precipitation at the study site was characterized by scattered convective storms during the months of May to September and by frontal storms during October and November. Also, it is noteworthy that precipitation varied considerably from one watershed to the other, with differences up to 3.4 mm inter-watershed differences measured in one single rain storm. The year of 2003 was drier than 2004. For example, precipitation recorded at WS-2 from April to December of 2003 was 215.6 mm, and for the same period in 2004 it was 308.6 mm.

Table 1—Runoff response to precipitation events during a two-year study period at the NMSU-Santa Fe Ranch, NM.

	Watersheds and Areas											
	WS-1 1.35 ha		WS-2 1.00 ha		WS-3 1.14 ha		WS-4 1.34 ha		WS-5 1.21 ha		WS-6 1.06 ha	
Date	Rain	Runoff	Rain	Runoff	Rain	Runoff	Rain	Runoff	Rain	Runoff	Rain	Runoff
	(mm)											
5/26/03	14.0	0.175	14.0	0.172	14.0	-	14.0	-	14.0	-	14.0	-
10/4/03	6.0	0.051	6.0	*	5.8	*	5.8	*	5.2	0.025	5.6	*
6/19/04	11.8	-	11.8	0.007	12.4	0.041	12.4	0.004	13.6	-	12.4	0.005
7/12/04	24.6	0.180	24.6	0.019	22.2	0.010	22.2	0.044	24.2	0.977	23.6	0.010
8/18/04	6.6	-	6.6	0.036	5.8	-	5.8	0.005	5.6	-	5.6	0.00002
8/21/04	6.2	-	6.2	0.020	6.8	0.013	6.8	-	6.0	-	6.0	-
10/5/04	12.4	0.953	12.4	0.022	11.3	0.136	10.3	0.229	9.3	0.136	9.0	0.006
10/11/04a	7.6	0.372	7.6	0.027	8.4	0.127	7.6	0.056	7.6	0.184	7.0	*
10/11/04b	17.2	1.534	17.2	0.016	14.2	0.145	13.0	0.402	11.0	0.088	9.0	0.006
Total	**106.4**	**3.3**	**106.4**	**0.3**	**100.9**	**0.5**	**97.9**	**0.7**	**96.5**	**1.4**	**92.2**	**0.03**

- No data
* No runoff

Runoff

The difference in precipitation between years was also reflected in the amount of runoff generated. In 2003, runoff data were collected at two watersheds during a convective, high-intensity short-duration rain storm on 26 May. Also in 2003, runoff data were collected at two watersheds during a low-intensity long-duration frontal storm on 4 October. In 2004 there was more precipitation and runoff than in 2003. A total of seven storms produced runoff in at least two of the watersheds. The highest runoff value of 1.534 mm was calculated from a frontal storm at WS-1 in 11 October 2004, and the lowest runoff value of 0.00002 mm was calculated from a low-intensity rain storm at WS-6 in 18 August 2004. The total amount of single event runoff produced per watershed during the two-year study was relatively low. WS-6 presented the lowest amount of total runoff with 0.03 mm and WS-6 had the highest value with 3.3 mm (table 1).

Soil Moisture

Average increase in soil volumetric water content (VWC) ranged widely depending on the point of measurement, which was dictated by the soil moisture sensor location in the watershed. Calculations of average soil VWC were based on soil moisture increases measured after precipitation events that produced some runoff in the two-year study period. The lowest average value of 0.01 (one percent) was observed in the intercanopy of grass hillslope at WS-6. The highest average value of 0.18 (eighteen percent) was observed in the intercanopy of the valley bottom at WS-4 (table 2).

Table 2—Average soil moisture increase after precipitation events during a two-year study period at the NMSU-Santa Fe Ranch, NM.

	Valley bottom Vol water content (cm^3/cm^3)		Grass hillslope Vol water content (cm^3/cm^3)		Wooded hillslope Vol water content (cm^3/cm^3)	
Watershed	**Under canopy**	**Interspace**	**Under canopy**	**Interspace**	**Under canopy**	**Interspace**
WS-1	0.03	0.06	0.06	0.04	0.02	0.05
WS-2	0.10	0.02	0.12	0.08	0.04	0.09
WS-3	0.07	0.04	0.03	0.03	0.06	0.04
WS-4	0.16	0.18	0.05	0.10	0.04	0.02
WS-5	0.05	0.07	0.05	0.05	0.08	0.08
WS-6	0.01	0.06	0.04	0.01	0.04	0.04
Average	**0.07**	**0.07**	**0.06**	**0.05**	**0.05**	**0.05**

Depth to Wetting Front

Data from TDR sensors in WS-3 were used to calculate soil-wetting depth. Figure 2 shows soil wetting depth calculated using data collected with one TDR sensor and soil volumetric water content data from one VWCR. Both, the TDR sensor and the VWCR are installed within 3 m distance of each other in WS-3. In general, the soil wetting depth measured with the TDR sensor followed the same wetting-drying pattern than soil moisture content measured with the VWCR.

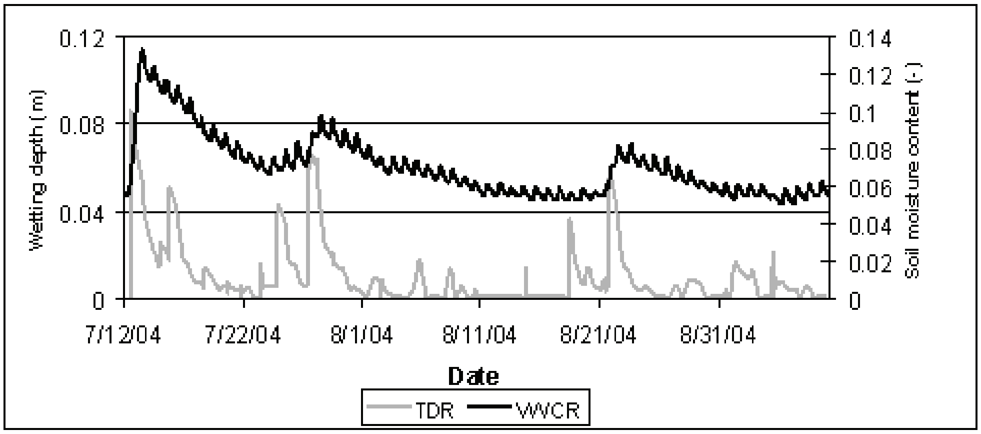

Figure 2—Volumetric water content reflectometer (VWCR) soil moisture and site-adjacent time domain reflectometry sensor (TDR) wetting depth response during the summer of 2004.

Discussion

Precipitation data collected during the two-year study indicated a clear pattern, which showed differences in the spatial distribution of precipitation at the watersheds. The lowest cumulative precipitation occurred in WS-6 and the highest cumulative precipitation occurred in WS-2. Precipitation amount and intensity play an important role in the generation of runoff. We were able to identify the temporal distribution of precipitation that produced runoff in the watersheds. In contrast to results reported by Wilcox (1994) where he stated that runoff in PJ woodlands in northern New Mexico is typically present in mid summer (intense thunderstorms) and mid to late winter (snow melting), we found that runoff at the NMSU-SFR watersheds was present during the summer season when runoff was generated by high intensity convective storms. Runoff was also produced during early to mid fall, when runoff was produced by frontal storms. Rainfall intensity greater than 5 mm/15 min appears to be the minimum amount of precipitation needed before runoff occurred at the watersheds outlet.

It was observed that frontal storms with low-intensity precipitation events, which occurred in the month of October in 2003 and 2004, lasted longer than convective storms with high-intensity precipitation events in May to August of both years. These precipitation events during frontal storms lasted several hours until the soil got wetted and overland flow started to occur. Thus, antecedent soil moisture was important for runoff response at the watersheds. Also, it was noted that sediment movement was greater during these frontal storms than during convective precipitation events, probably due to the moisture regime of the soil.

In general, across all watersheds, greater average soil moisture was observed in the valley bottoms than on the grass hillslopes and wooded hillslopes. However, there were small differences in soil moisture increases between under canopy and intercanopy locations. At the single watershed level, WS-4 presented higher soil moisture in the valley bottom, followed by grass hillslope, and then by wooded hillslope. This difference by location was probably due to the topography of the watershed that includes a greater valley area and less steep hillslopes.

The new application of TDR technology worked well and seems to be a promising tool to accurately calculate soil-wetting depth in real time. In contrast to data obtained with the VWCR, where an average water content value of the soil in contact with the probe waveguides is obtained, the use of this model allowed us to calculate to 1 mm precision the soil water flux in the upper 15 cm of the soil. Also, it was noted that in general the wetting depth was greater at the channel, followed by the gully headcut and then by the hillslope.

Some obstacles and limitations of the study and study site in particular are worth noting. The study site is located on federal land, and it is exposed to the inherent risks of open public access. To protect from vandalism, most of the equipment is inside solid material enclosures. This is the case of the type H flumes that are enclosed in cages built with concrete and steel screen. In some high intensity rain storms, the screen starts accumulating debris, and if not cleaned right after the storm, chances are that accumulated debris will trap sediment, creating a dam and restricting free water flow. For example, it was observed that after a high intensity rainfall in 11 October 2004, the screen that protects the flume got clogged and acted as a dam, accumulating sediment in the upstream arroyo and impeding free water flow through the flume. Thus, for a rain storm that occurred at the same location two days later, data collected was not considered reliable and it was discarded.

Dealing with electronic equipment in remote locations to measure real time natural phenomena is always a challenge. The study site is located 480 km from the investigator offices, and there is to date no remote communication with the sensors installed in the watersheds. Thus, the long distance between the study site and the headquarters and the lack of a telecommunication system that would alert us in real time to precipitation events, made it difficult to perform maintenance needed after each precipitation event. Also, TDR data collected from WS-2 were not considered reliable due to high variability in the TDR signal, probably due to a faulty multiplexer rely or a poor connection that introduced some noise in the signal.

Conclusions

Channel runoff responded differently to different precipitation amount and intensities. Runoff was produced by rainfall events with intensities greater than 5 mm/15 min. Runoff is affected by antecedent soil moisture. Most of the runoff was produced by convective storms during the summer. Some runoff was produced by frontal storms during the fall. Total amount of runoff produced per watershed during the two-year study was relatively low. Soil moisture response to rainfall was higher in the watershed valley bottoms than in grass hillslopes, and wooded hillslopes. The use of TDR technology to measure wetting depth is a potential tool to determine threshold precipitation for runoff generation.

Management Implications

Based on analysis of rainfall, runoff, soil moisture, and channel flow, we feel confident that the main runoff generating mechanism at the NMSU-SFR study site is infiltration excess runoff. This is similar to that observed by Wilcox (2002), who states that overland flow is important and may be the dominant mechanism of runoff in the majority of juniper woodlands. This infiltration excess runoff appeared to occur even during longer-duration frontal storms. Results to date from the baseline data collection period suggest that larger storms that wet the entire watersheds produce most annual runoff, so clearing trees may increase grass cover, but may have little effect on annual runoff. Detailed characterization of actual effects of tree clearing will be improved with continued measurements during baseline data collection and after planned tree clearing in 2009.

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Impacts of Pinyon-Juniper Treatments on Water Yields: A Historical Perspective

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***Abstract**—Pinyon-juniper woodlands are not normally considered a high water-yielding type largely because of the low precipitation amounts and high evapotranspiration rates encountered. Nevertheless, a recommendation was made in the 1950s to evaluate the effectiveness of increasing water yields by converting pinyon-juniper overstories to herbaceous covers. A series of process and plot studies and watershed-level experiments were carried out in acting upon this recommendation. It was concluded, however, that the potentials for increasing water yields through conversion treatments is "poor" in the region. A summary of these research findings is presented in this paper.*

Introduction

Pinyon-juniper woodlands, the largest "forest type" in the southwestern United States, lie adjacent to and surround the montane forests in the region. Occurring at lower elevation and generally with less annual precipitation than the forests, these woodlands possess a lower water-yield improvement potential compared to these forests. Because of their extensive distribution, however, early investigators felt that water-yield improvement practices in pinyon-juniper woodlands could conceivably affect the availability of water supplies (Barr 1956, Dortignac 1960). The water-yield improvement practices to be implemented were conversions of comparatively high water-demanding pinyon-juniper overstories to lower water-demanding herbaceous covers by mechanical, chemical, and burning treatments. It was anticipated that the reductions in water consumption by plants might become recoverable water. A historical summary of the effects of these treatments on water yields is presented in this paper.

Hydrologic Characteristics

Pinyon-juniper woodlands are not normally considered a high water-yielding type largely because of the low precipitation amounts and high evapotranspiration rates encountered. Streamflow is largely ephemeral, with no permanent streams originating in the area. While runoff events can coincide with the two seasonal precipitation patterns encountered, most of the annual water flows are associated with the winter period, primarily the result of heavy rainfall, rapid snowmelt-runoff, or rain-on-snow events. Over 70 percent of the annual streamflow originating in the pinyon-juniper woodlands on the Beaver Creek watersheds in north-central Arizona occurs in this winter period (Clary and others 1974, Baker 1984). When they occur, runoff events in the summer are low, variable, and short-lived events following torrential summer thunderstorms.

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Water Yield Improvement Potentials

While there was some evidence in the literature (prior to 1956) that removal of pinyon-juniper overstories with the replacement of a herbaceous cover might not produce additional water, a recommendation of Barr (1956) and others was that evaluations of alternative conversion treatments to achieve water-yield improvement in the type should be made by watershed-level experiments. Before this recommendations could be implemented, however, a justification for considering water-yield improvement in pinyon-juniper woodlands was deemed necessary. This justification was largely attained through process and plot studies.

Process and Plot Studies

In a study of interception, throughfall, and stemflow, Skau (1964a) reported that between 10 to 20 percent of the precipitation falling on pinyon-juniper woodlands on the Beaver Creek watersheds was intercepted by the tree crowns. He felt that these interception losses might be (at least partially) reduced by conversion treatments. A somewhat similar conclusion was also reached by Collings (1966) on the Fort Apache Indian Reservation.

Researchers believed that an increase in soil moisture storage might occur following the removal of pinyon-juniper overstories, reducing infiltration losses and (possibly) increasing water yields. Skau (1964b), in another study, found two percent more soil moisture in the upper two feet of the soil on sites cleared of pinyon-juniper overstories than on uncleared sites at the beginning of the summer and winter precipitation seasons. He implied that this difference might have been greater if it was not for the dense herbaceous vegetation that had invaded the cleared sites.

Decker and Skau (1964) measured transpiration rates of Utah and alligator juniper trees by enclosing sample trees in a ventilated tent of transparent plastic film. Increased humidity of the ventilation stream was a direct index of vapor production and, therefore, transpiration rates through conversion. They observed transpiration rates increasing through the morning, peaking at noon, and remaining at this high rate until the middle of the afternoon when transpiration rapidly decreased into early night. By coupling their results with knowledge of the frequencies of occurrences of trees similar to those sampled, the researchers were able to estimate water losses to the hydrologic cycle by transpiration in woodland communities where juniper trees tend to dominate.

The results of these and earlier process and plot studies formed a basis for subsequent experiments to evaluate the effectiveness of converting pinyon-juniper overstories to herbaceous covers to increase water yields on a watershed-level.

Treatment Methods

A variety of treatments had been used into the early 1960s to increase herbage (forage) production by clearing pinyon-juniper overstories. Researchers suggested that these treatment methods might also be implemented for water-yield improvement purposes. Extensive areas of pinyon-juniper woodlands had been cleared by chaining or cabling, in which a heavy anchor chain or cable was dragged between two tractors (Cotner 1963, Arnold and others 1964). Pushing (bulldozing) had been widely used to remove individual trees. These mechanical treatment methods of conversion pulled trees from the ground, leaving pits or depressions where the trees formerly stood. Parenthetically, Skau (1961) had determined that these pits reduced overland flow on the cleared landscapes. Nevertheless, at the time, these mechanical methods of conversion were considered to be a viable approach to implementing water-yield improvement treatments.

Another approach to clearing pinyon-juniper woodlands was hand-clearing with ax and (or) saw. This treatment method had been used to a lesser extent than chaining, cabling, or pushing treatments, however. Hydrologically speaking, this method of tree removal had a "minimal impact" on overland flow because pitting was eliminated. Recurring problems of increased soil erosion that occurred with chaining, cabling, or pushing were also minimized with hand-clearing treatments.

Broadcast burning was successful where the pinyon-juniper overstory was dense enough to carry a fire (Arnold and others 1964). Once again, pits were not created by this method and increased soil erosion was minimal when the burning treatment was properly prescribed and carefully implemented. Individual-tree burning was carried out on a mostly limited scale (Jameson 1966).

Killing trees with herbicides was also a possible option, but this kind of treatment had not been operationally applied at the time. Herbicidal treatments left the dead trees standing on the landscape, and the trees influenced less surface-area than if they were uprooted or felled by cutting and left on the ground.

Watershed-Level Experiments

An early test of the effects of pinyon-juniper conversion treatments on water yields was conducted on a large (operational) scale in the basin of the adjacent Corduroy and Carrizo Creeks in east-central Arizona in 1957-59. The pinyon-juniper overstory on Corduroy Creek was cleared on 34,000 acres (25 percent of the basin) by chaining, while the shrubs, litter, and duff beneath ponderosa pine stands on 18,000 acres (13 percent of the basin) were burned. Carrizo Creek was left undisturbed to serve as a control. Because the evaluation of these two treatments considered only their "total composite effect" on water yields (Collings and Myrick 1966), conversion of the pinyon-juniper overstory to a herbaceous cover on Corduroy Creek could not be isolated as the "sole influence" on subsequent water yields. Nevertheless, these differences were not important because it was concluded that this pinyon-juniper conversion treatment produced no significant changes in water yields in the post-treatment evaluation period.

Two small watersheds less than 100 acres in size were selected to investigate the effects converting pinyon-juniper overstories to herbaceous plants on a smaller-scale on Cibecue Ridge, in the same general area as Corduroy and Carrizo Creeks. Following a calibration period, the overstory on one of the watersheds was cleared by chaining in 1967, with the resulting slash burned and the watershed seeded with a mixture of perennial grasses and fenced to exclude livestock. The other watershed was the control. A "parameter model" to predict how components of the hydrologic cycle changed as a result of the treatment was used to evaluate this experiment (Robinson 1965, Myrick 1971). It was determined that water yields increased on the converted watershed in the initial two post-treatment years, but it then dropped below the expected water yields on the untreated watershed in the following two years. One reason for the subsequent decrease in water yields was the increase in transpiration by the perennial grasses seeded as part of the treatment prescription.

The effectiveness of converting pinyon-juniper overstories to herbaceous covers to increase water yields was also evaluated on three "experimental watersheds" as part of the Beaver Creek watershed program in north-central Arizona (Worley 1965, Price 1967). Varying conversion methods were imposed on the watersheds.

A cabling treatment similar to that extensively used for rangeland improvement was applied to a 323-acre Beaver Creek watershed in 1963. The larger pinyon and juniper trees were uprooted by a cable pulled between two bulldozers and the smaller trees missed by the cable were felled by ax. These larger trees were then burned and the watershed was then seeded with a mixture of forage species.

A hand-clearing treatment with the trees felled by power saw was applied to a second Beaver Creek watershed 104 acres in size in 1965. It was hoped that the problems of pitting and other soil disturbances associated with uprooting trees would be eliminated with this method. Stumps of alligator juniper, the principal overstory species on the watershed, were treated with polychlorinated-benoic acid to reduce subsequent sprouting. Shrub live oak clumps were initially treated with fenuron and later with picloram and Gambel oak sprouts were sprayed with 2,4,5-T in the dormant season to control the occurrence of these species. No seeding of forage species was done.

A herbicidal treatment of a mixture of two and one-half pounds of picloram and five pounds of 2,4-D was applied to a third Beaver Creek watershed of 363 acres. An aerial application of the herbicide was sprayed on 281 acres of the watershed in 1968. The remaining 82 acres were either untreated or individual trees treated with the same herbicide using a backpack mist-blower. This treatment was intended to reduce transpiration losses by killing the trees, while leaving the dead trees standing to reduce windspeeds and solar radiation to control evaporation losses. The treatment also avoided trapping overland flow in pits formed by uprooting trees. A firewood sale removed all of the merchantable wood from the watershed in 1976, eight years after the herbicidal treatment. The resulting slash was piled and burned the following year.

Results of Watershed-Level Experiments

The results of the watershed-level experiments in the basin of Corduroy and Carrizo Creeks, at Cibecue Ridge, and on Beaver Creek indicated that conversions of pinyon-juniper woodlands to herbaceous covers by mechanical treatments has little effect on water yields for varying reasons. Reduced overland flows caused by pitting on the watersheds where chaining or cabling conversion methods were imposed likely compensated for any changes in water yields brought about by reductions in transpiration rates by the tree removals. Elimination of the trees in the largely open stands on the watershed converted to a herbaceous cover by hand-clearing was probably too little to significantly impact on the loss of water to the transpiration process.

Only killing trees with herbicide and leaving them in place to reduce evapotranspiration losses increased water yields on one of the Beaver Creek watersheds. While the increase averaged nearly 160 percent in the 8-year post-treatment period to the time that the dead trees were removed, it amounted to less than an inch in absolute terms (Baker 1984). Furthermore, the increase could only be expected about 1 out of every 2 years, when winter precipitation equals or exceeds the average. That landscapes treated with herbicides might not be aesthetically pleasing to much of the public was also a possible limitation to its widespread application. More importantly, the use of chemicals for natural resources management purposes is opposed by many people and their use limited by environmental regulations.

Conclusion

Overall, the potentials for increasing water yields through conversions of pinyon-juniper woodlands to herbaceous covers is considered "poor" in the region. While this general conclusion contradicted the earlier recommendation of Barr (1956) and others, it should not necessarily be surprising. Water-yield improvements in any vegetative type are largely based on the premise that streamflow and (or) groundwater regimes are increased by an amount that is equal to the net reduction in evapotranspiration (Hibbert 1979). However, there is little opportunity to reduce evapotranspiration on watersheds where precipitation is less than 18 inches and its total is exceeded by potential evapotranspiration (Thornthwaite and Mather 1957), because this amount of precipitation will not penetrate far enough into the soil to influence the storage of moisture in the soil. This latter situation exists throughout much of the pinyon-juniper woodlands in the region.

A similar conclusion that little, if any, increase in recoverable water should be expected through manipulations of pinyon-juniper overstories has also been reported by Ffolliott and Brooks (1988) in their summary of opportunities for enhancing water yields in the Mountain West, by Roundy and Vernon (1999) in their assessment of watershed values in pinyon-juniper woodlands of the Interior West, and by Baker and Ffolliott (2000) in their analysis of opportunities for increasing water yields through vegetative management in the Colorado River Basin.

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