WATER CONSERVATION FOR RESTORATION OF WILDLIFE HABITATS

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Abstract: Healthy rangelands are relatively efficient at conserving rainfall, but they may become dysfunctional in this regard as vegetative cover diminishes and aggregation of the surface soil layer is destroyed by overgrazing, drought, and establishment of excessive densities of low-value or noxious brush and weeds. Special water conservation treatments, such as contour ripping, furrowing, pitting, reseeding, or brush and weed control, may be necessary for restoration of rangelands and wildlife habitats that have deteriorated beyond a critical threshold in the downward desertification spiral. This paper describes these technologies and gives details of their utility for restoration of dysfunctional rangelands in arid and semiarid regions. Contour ripping of a degraded clay loam range site near San Angelo, Texas facilitated penetration of water from convectional thunderstorms to a depth of 48 to 54 in. compared to only 4 to 5 in.on adjacent, untreated rangeland. Over a period of 4 to 5 years, total herbage production on ripped rangeland was 1700 lb/acre compared to only 490 lb/acre on adjacent, untreated rangeland. Ripping increased the carrying capacity of the clay loam range site from 8.2 animal unit years (AUY)/section to 28.7 AUY/section.

Water is the trigger factor necessary for plant production in arid or semiarid regions where rainfall is erratic and unpredictable, but it must be effectively transferred deep into the soil reserve in quantities which exceed the minimum threshold necessary to generate pulses of plant growth (Ludwig et al. 1997). Healthy rangelands are efficient in conserving water, soil, and nutrients because the surface soil has good structure (aggregation) and because there is sufficient vegetative cover of perennial grass plants or grass colonies. Good soil structure facilitates rapid infiltration of rainfall while vegetative cover protects the surface soil aggregates from the energy of raindrop impact and provides resistance to runoff. Rangelands become dysfunctional, relative to the hydrologic cycle, mineral cycles, and energy flow, because of droughts, excessive grazing, and persistent infestations of low-value or noxious plants. Ecologically sound rangeland and wildlife habitat management involves working with the natural ecological processes of energy flow, the hydrological cycle, and mineral cycles (Whisenant 1999). Proper grazing management is the basic tool for restoration of degraded rangelands, but recovery of the resources often does not occur within a time frame acceptable to meet the objectives of resource managers. Ecologically sound practices that can expedite the restoration of dysfunctional rangelands and wildlife habitats include ripping, contour furrowing, pitting, reseeding, and control of undesirable weeds and woody plants.

HYDROLOGICALLY FUNCTIONAL RANGELANDS

Healthy rangelands have high rainfall infiltration rates because the soil surface has good structure, meaning that the soil particles are held together in water-stable clusters (aggregates) by roots, fungal hyphae, byproducts of organic matter decay and microbial synthesis, and resistant humus components (Boyle et al. 1989). These water-stable aggregates do not readily disperse during rainfall events; thus the silt and clay particles are not released to plug up the soil macropores as they move into the soil with water. Soil porosity (pore space) increases as the degree of aggregation increases, and rainfall infiltration increases as soil porosity increases. Healthy rangelands support a sufficient amount of vegetative cover, primarily perennial grass plants or colonies, mulch, and desirable shrubs or trees, to protect the soil surface aggregates from being dispersed by the energy of raindrop impact and to provide resistance to surface runoff. Vegetative cover also ameliorates the extremes of soil temperature, reduces evaporation of soil water, and provides a microenvironment favorable for decomposition of organic matter, which in turn contributes to the formation of water-stable soil aggregates (Thurow 1991).

HYDROLOGICALLY DYSFUNCTIONAL RANGELANDS

The direct and indirect effects of drought, excessive grazing, and/or excessive densities or cover of noxious or low-value plants can render rangelands dysfunctional relative to conserving water and nutrients and yielding the products and services needed by society (Thurow 1991). These effects seriously diminish the annual production of foliage and deposition of litter, the depth and branching of plant root systems, soil aggregation, and rainfall infiltration rates while increasing the losses of water, soil and nutrients from the landscape as surface runoff. As vegetative cover and the mulch layer decline, the kinetic energy of raindrops hitting bare soil causes the dispersion of soil aggregates and releases silt and clay particles which move with water into the large soil pore spaces. The clay and silt particles plug the pore spaces, thus reducing the capacity of the soil to absorb and store water. The result is drought-like conditions, even in years when rainfall amounts are normal. Over time the vegetative composition changes as the palatable, productive deep-rooted grasses die out and are replaced by smaller, less palatable, shallow-rooted plants (Archer and Smeins 1991, Briske 1991). These plants are less efficient in capturing the energy of sunlight, retrieving nutrients from deep in the soil, resisting runoff, and transferring rainfall into the soil reserve. The result is less microorganism activity, less aggregate formation, a harsher environment for seed germination and seedling establishment, more soil exposed to raindrop impact, fewer roots to exploit soil water and nutrients, decreased rainfall infiltration, and accelerated surface runoff and erosion. Weeds, woody plants and succulents (e.g., cactus) often increase or invade deteriorated rangelands and compete with the remaining desirable plants for space, sunlight, and the diminished supply of soil water and nutrients.

MANAGEMENT TO ENHANCE WATER CONSERVATION

Resource managers must learn to work with, rather than against, the natural ecological processes of energy flow, the hydrological cycle, and mineral cycles to manage vegetation and soils in order to achieve and maintain high infiltration rates and minimize losses of water, soil, and nutrients in surface runoff (Ludwig et al. 1997, Whisenant 1999). Proper grazing management is the basic tool for achieving efficiency in water and nutrient conservation and utilization on rangelands. Control of excessive densities of low-value or noxious weeds or woody plants can increase the amount of water entering mineral soil and the availability of soil water for desirable plants. Mechanical water-conservation treatments, such as ripping, contour furrowing or pitting, may be necessary to reverse the downward spiral toward desertification on severely deteriorated rangelands, and reseeding may be necessary to re-introduce plants that can efficiently utilize the available soil water and nutrients.

Grazing Management

Excessive grazing affects plants directly by altering their physiology and morphology and indirectly by altering microclimate, soil properties, and the competitive interactions among plants (Archer and Smeins 1991). Without sufficient leaf surface area, plants cannot efficiently capture the energy from sunlight via photosynthesis, root growth is reduced, energy reserves are depleted, plant vigor and seed production decline, and plant mortality occurs. Over time, the composition of the vegetation changes; vegetative cover, plant production and rainfall infiltration decline (Figure 1); and surface runoff increases. Grazing management involves balancing the number of animals with the forage supply, selecting the appropriate kinds and classes of animals to be grazed, controlling the timing of grazing, and distributing grazing evenly across the landscape (Briske and Heitschmidt 1991).

Achieving the proper level of utilization of forage plants and maintaining an acceptable minimum amount of litter is the most important management decision, regardless of whether rangeland is grazed continuously or in a complex grazing system. The minimum amounts of litter needed to sustain productivity of shortgrass, mid-grass, and tall-grass rangelands are 300 - 500, 750 – 1,000, and 1,200 - 1,500 lb/acre, respectively (White and McGinty 1992). "Take half and leave half" is the guiding principle for determining stocking rates. Under most management systems, 50% of the forage produced during the year should remain ungrazed. Twenty-five percent of the year's forage growth will be lost to trampling, insects and other animals, or rendered ungrazable due to livestock dung or urine. The remaining 25% of plant growth can be utilized by livestock (White and McGinty 1992). Rangeland vegetation and precipitation records should be continually monitored, and livestock and wildlife numbers should be adjusted annually or even seasonally to achieve proper use.

Proper grazing management is the "natural" and least-cost method for restoration of degraded rangelands and wildlife habitats. However, severely deteriorated rangelands, especially in arid and semiarid regions, often recover slowly or not at all after initiation of proper grazing management or the total removal of livestock because of the lack of vegetative cover, poor soil aggregation, low infiltration rates, and the resultant harsh environment for plant establishment and growth. The potential for range recovery is poor on many southwestern rangelands, even with the exclusion of livestock for 20 to 30 years (Dregne 1978). The rate of recovery following implementation of proper grazing management may be too slow to meet the management objectives of ranchers or resource managers on range sites which have deteriorated beyond a critical threshold in the downward desertification sprial. Mechanical water conservation treatments, reseeding, and/or management of persistent infestations of low-value or noxious vegetation may be useful to expedite restoration of these sites.

Management of Undesirable Vegetation

Excessive grazing, drought, climatic changes, a reduction in the frequency and intensity of fire, and perhaps the increasing concentration of atmospheric carbon dioxide predispose many rangelands to invasion by weeds, woody plants, and succulents that have little or no value to grazing animals or humans. These plants intercept or transpire large quantities of water that might otherwise be used by plants that have greater values for food and cover for livestock and wildlife. The efficiency of water use on rangelands can be increased by controlling undesirable vegetation (Ueckert 1979, Thurow and Hester 2001). Herbicidal, mechanical, prescribed burning, and biological control methods, or appropriately timed and sequenced combinations of these methods, coupled with proper grazing management can provide effective, cost efficient, and ecologically practical solutions to noxious plant problems (Hamilton et al. *in press*). Rangelands should be monitored annually for noxious plants, and control programs should be initiated before these plants mature, thicken, utilize excessive amounts of water, and cause deterioration of desirable vegetative cover (McGinty and Ueckert 2001).

Mechanical Water Conservation Treatments and Seeding

Mechanical land treatments such as ripping, furrowing, and pitting can expedite natural recovery of desertified rangelands (Valentine 1971, Whisenant 1999) by increasing resistance to surface runoff, shattering compacted soil layers, and thereby increasing rainfall infiltration and retention. To have a lasting effect, mechanical treatments must modify the soil surface sufficiently so that rainfall is detained and stored in the soil (Branson et al. 1966). Mechanical treatments that effectively increase deep infiltration or percolation of precipitation in saline soils can leach soluble salts below the root zone and thus increase the availability of water to plants (Branson et al. 1966). The objective of using these mechanical treatments is to facilitate the establishment of dense patches or bands of vegetative cover that will persist and continue to conserve water and nutrients naturally, long after the soil disturbance has disappeared. The full potential of these practices will only be realized if treated areas are initially protected from grazing to allow the establishment of vegetative cover and afforded proper grazing management thereafter.

Ripping

Ripping (also referred to as subsoiling or deep chiseling) involves pulling one to three heavy shanks equipped with broad lifting tips 16 to 24 in. deep through the soil on the contour (Valentine 1971). Space between rips is variable, and usually depends upon the equipment available, slope of the land, and amount of vegetative cover present. Ripping fractures impervious soil layers (which increases porosity and the rate of infiltration), causes uplifting of the soil (which resists surface runoff), leaves a furrow in the center of the uplift (which will retain water), and the soil disturbance provides a seedbed for new plant establishment.

Forage production was 1405 lb/acre 10 years after ripper furrows were installed in a desert grassland in southern Arizona compared to 563 lb/acre on adjacent, unripped areas (Brown and Everson 1952). These rips were installed with construction-type rippers pulled by a crawler tractor. The ripper shanks were broad and the flat cutting tips were 3 to 4 in. wide. The rips were 18 to 24 in. deep and installed in pairs on 30-ft horizontal spacings. The treatment produced a furrow as deep, and ridges as high as an average lister furrow. Forage production on these ripped areas was 1.6 times greater than that on adjacent untreated rangeland after 24 years (Branson et al. 1966). Rips installed with narrow shanks and cutting tips have little lasting effect (Branson et al. 1966). In South Texas, subsoiling increased the production of coastal bermudagrass and buffelgrass by 2026 and 1167 lb/acre, respectively, compared to untreated areas; chiseling increased the production of coastal bermudagrass, kleingrass, and buffelgrass by

1412, 3539, and 1275 lb/acre, respectively, compared to untreated areas (Hanselka et al. 1993). Vibratilling to a depth of 18 in. with rippers spaced 39 in. apart near Post, Texas increased total herbage production to 1700 lb/acre compared to 1125 lb/acre on untreated rangeland (Bedunah and Sosebee 1986).

We initiated a study on rangeland ripping in late April 1995 on a very poor condition, clay loam range site northwest of San Angelo, near Carlsbad, Texas (Ueckert et al. 2001). The soil was a Tulia loam with 3 to 5% slope. Long-term average annual rainfall at the study site is about 20 in. The site appeared abused and overgrazed (90% bare ground) even though it had not been grazed by livestock during 1969-1985 and was grazed lightly with long periods of rest from 1985 until 1995. Visible evidence of a soil crust (platy structure at the surface) and excessive runoff led to the hypothesis that poor rainfall infiltration and the soil crust, which provided a very poor seedbed for grass seed germination and establishment, were the factors limiting herbage production and recovery of the site. A preliminary, small-plot experiment on ripping was installed in late April 1995. Rips were installed 15 in. deep on 22-ft horizontal spacings with a single-shank ripper mounted on the 3-point hitch of a 55-horsepower farm tractor in late April 1995 (Figure 2). At the end of the first growing season, the yield of grasses and forbs was 1760 lb/acre immediately adjacent to rips, compared to only 380 lb/acre on untreated areas. These promising results prompted us to install a larger experiment on the clay loam range site in the spring of 1996, in which similar rips were installed on 30-ft horizontal spacings. Additional treatments installed in 1996 included seeding Haskell sideoats grama, Lometa Indiangrass, little bluestem, and WW-Spar oldworld bluestem and transplanting fourwing saltbush seedlings in the rips.

Rainfall from 1.5- to 2.0-in. spring and summer convection thunderstorms at the Carlsbad study site often penetrates to a depth of 48 to 54 in. along the rips, compared to only 4 to 5 in. on adjacent, unripped rangeland (Figure 3). However, this difference is not as great following gentle, soaking winter rainfall events. The total standing crop of grasses and forbs immediately upslope from the 1995 rips increased gradually through 2000, reaching about 5800 lb/acre by August 2000 (Figure 4). Dense stands of cane bluestem, a highly productive, warm-season midgrass, established naturally on the rips installed in 1995 and the production of buffalograss and three-awns increased substantially. The major change observed on the 1996 rips was a substantial increase in abundance of Texas wintergrass and increased production of buffalograss and threeawns. Seeding was of limited success in the 1996 experiments because of drought and below-normal growing season rainfall for several years. The only seeded grasses which established along the 1996 rips were Haskell sideoats grama and WW-Spar oldworld bluestem, and the number of live grass plants/100 ft of seeded row in mid August 2000 were only 39 and 28 for these two species, respectively. Survival of fourwing saltbush transplants in the rips averaged 25% and these plants averaged 20 in. in height and 14 in. in diameter after 5 growing seasons. By August 2000, the bands of perennial grasses visibly enhanced by ripping were 9.3 ft wide on the 1995 rips and 7.8 ft wide on the 1996 rips. Profiles of native plant yields in August 2000 across 1995 and 1996 rips that were not seeded are shown in Figures 5 and 6, respectively.

The rangeland ripped in 1995 and 1996 were substantially improved within 4 to 5 years in spite of the drought. Averaged over the two experimental areas, clipping data collected in 2000 showed that ripped landscapes that were not seeded yielded 1700 lb/acre of herbage, compared to 490 lb/acre on unripped areas. Assuming proper use, i.e., grazing only 25% of the standing herbage, rangeland that had been ripped on 22- to 30-ft horizontal spacings had a carrying capacity of almost 29 animal unit years (AUY) of grazing/section compared to only about 8 AUY/section for unripped rangeland (Table 1).

Table 1. Effect of ripping in 1995 and 1996 on total herbage production, grazeable herbage, and carrying capacity of a clay loam range site near Carlsbad, Texas. (From data collected in mid August 2000).

Range Site Characteristics	**Untreated**	**Ripped**
Total herbage yield (lb/acre)	490	1700
Grazeable herbage (25% of total lb/acre for proper use)	122	425
Animal unit days of grazing/acre	4.7	16.4
Animal unit years of grazing/section	8.2	28.7

Above-normal cool-season precipitation during the fall-winter of 2000 - 2001 at the Carlsbad study site produced luxuriant growth of cool-season annual forbs. However, there was no effective precipitation on the Carlsbad study site during the growing season of 2001, and the cool-season forbs apparently utilized all of the deep soil moisture. Consequently, a high percentage of the perennial grasses currently appear to have died out. The loss of our perennial grasses has been extremely disappointing, but the presence of perennial grasses along the rips for a few years has improved the structure of the surface soil and some of the dead grass plants and mulch remain to resist runoff and to protect the surface soil from the energy of raindrop impact. We expect the perennial grasses to return whenever some effective growing season precipitation is received.

Ripping with the 55-horsepower farm tractor is relatively inexpensive. About 6.7 acres can be ripped/hr using the single-shank ripper on 20-ft horizontal spacings in 3rd gear and about 9.9 acres can be ripped/hr when rips are installed on 30-ft horizontal spacings. Assuming a labor cost of $10/hr and a cost of $ll.67/hr for the tractor, the cost for ripping on 20- and 30-ft spacings is $3.28 and $2.18/hr, respectively. Costs are somewhat higher than those shown in Table 2 for ripping in extremely dry and compacted soils because lower gears must be used. Rippers that can be mounted on the 3-point hitch of farm tractors can be purchased with one to several ripper shanks. We recently purchased a single-shank ripper (Bison SVH-1, Bison Equipment Co., Waco, TX) for $374. Ripping on 30-ft horizontal spacings with a small crawler tractor (Caterpillar D3C XL) equipped with a single-shank, construction-type ripper at a contract price of $45/hr cost about $6.75/acre. Performance of the crawler tractor was about 6.7 acres/hr.

Wing ripping is accomplished by attaching shop-made wings or a furrow opener to the shank of ripping implements (Branson et al. 1966). The attached wings or furrow openers remove soil from the trench created by the ripper shank and flattened tip, resulting in a larger furrow for greater water retention capacity and larger ridges of soil for increased resistance to surface runoff. While installing water conservation treatments at 10 locations in western Texas during 2002, we found that ripping alone did not create sufficient uplifting or soil ridges or furrows on soils with a low clay content. Wing ripping was accomplished by attaching 18.5-in.-wide wings made in the shop from 1/4-in. steel plate (Figure 7) or a standard furrow opener onto the leading edge of the the ripper shank. Brackets welded onto the back sides of the wings or furrow opener facilitate attaching these to the ripper shank with 5/8-in. bolts. The brackets and bolts also facilitate the vertical positioning of wings or furrow openers at the proper height to effectively create a clean furrow and shove the soil aside to create effective soil ridges. We found that the properly positioned furrow opener created a furrow with a depth of about 5 in. below the undisturbed soil surface, 24 in. wide at the top, and soil ridges about 5 to 6 in. in height on a sandy soil in Ector County. The overall depth from the top of soil ridges to the furrow bottom was about 10 in. Furrows made when the shop-built wings are attached to the ripper shank are slightly narrower and shallower.

Contour furrowing

Contour furrowing involves pulling disk plows or other tillage implements, such as lister bottoms, to create depressions or grooves in the soil surface 4 to 8 in. deep, 6 to 30 in. wide, and 2 to 10 ft apart (Valentine 1971). These soil depressions increase on-site water retention and the ridges of soil adjacent to the furrow provide resistance to surface runoff. Furrowing implements can be designed with rippers in front of the disks and dikers that dam up the furrows at selected intervals. Diking of the furrows makes furrowing on an exact contour less critical than for furrowing without dikes (Branson et al. 1966). Seeders can also be attached that deposit seed on or into the disturbed soil during the furrowing process to establish plant species that can make beneficial use of the water retained in the furrows. Broadbase furrows are built with a road grader by pushing soil from a 6- to 8-ft-wide area downslope to form low dikes 1.5 to 2 ft in height. We bolt shop-built wings made from 1/4-in. steel plate or a lister bottom onto the shank of our single-shank ripper to create furrows (Figure 7) and attach a 1-row grass seeder to the ripper frame to facilitate seeding. The seeder, made by the Truax Company (Minneapolis, Minnesota), which has separate seed boxes for slick and chaffy seeds and is powered by a hydraulic motor, was fitted with a flexible seed tube that can be moved right or left by the tractor operator to strategically deposit grass seeds immediately upslope from the ridge of soil along rips or furrows (Figure 8). Log chains, pulled in a loop behind the seed tube, cover the seeds with soil.

Contour furrowing with the Arcadia Model B contour furrowing machine increased perennial grass production by over 500 lb/acre and broadbase furrowing increased perennial grass by almost 1500 lb/acre (Branson et al. 1966). Listing of rangeland near Spur, Texas increased perennial grass production 2.1 to 4.1 times compared to that produced on untreated rangeland (Dickenson et al. 1940).

Pitting

The most effective rangeland pitting has been done with disk plows equipped with eccentric or deeply notched disks or disk plows with eccentric furrow wheels that alternatively raise and lower the disks. The pitting implements create thousands of small basins or pits across the landscape, which function similarly to contour furrows (Valentine 1971).   Perennial grass production has been increased by about 200 lb/acre by eccentric disk pitting (Branson et al. 1966). Seeders can also be attached to pitting implements. Pits installed with implements that utilize spike teeth tend to fill in with soil within about a year. It is questionable whether spike-tooth or rotary pitters are of value as a land-treatment practice (Branson et al. 1966).

Seeding

Seeding of rangeland is an expensive and high-risk venture in arid and semiarid regions due to the erratic and unpredictable nature of rainfall. Seeding should be preceeded by seedbed preparation. Root plowing is normally used for seedbed preparation on rangelands infested with woody plants. Root plowing alone costs about $100/acre while a native grass seed mixture may cost $40 to $50/acre and roller chopping to cover the seeds and compact the seedbed may cost an additional $20 - $25/acre. Due to the high costs and risk and the low potential for recovery of costs, we have seen little root plowing and reseeding in arid and semiarid regions in several decades.

Seeding only within a 1-ft-wide band on the upslope side of the ridge of soil created by contour ripping or furrowing reduces the risks and the costs substantially. First, the amount of seed that would be necessary to broadcast or drill seed 1 acre will seed about 8.3 miles of rips or furrows. If rips or furrows are spaced 20 or 30 ft apart, the amount of seed necessary to drill or broadcast seed one acre will extend over 20 to 30 acres of rips or furrows. Because of this, our seeding costs have generally been less than $2/acre, averaged over the entire treated pasture or research plot. Strategically placing the seed immediately upslope from the ridge of soil created by rips or furrows reduces the risk of a seeding failure because this is the region where water will stand the deepest and most often following rainfall events of sufficient intensity to cause runoff. This seed placement strategy and leaving 20 to 30 ft between rips or furrows increases the probability that the soil immediately upslope from soil ridges will stay sufficiently moist for a sufficient duration to facilitate seed germination, seedling emergence, and seedling establishment. Seeding only on the upslope side of rips or furrows has its own inherent risks for two reasons. First, a good seedbed has not been prepared and often is not present. In some cases the surface soil may be too compacted for the drag chain to cover the seeds with soil, or the presence of dense stands of weeds may prevent seed coverage by the chain. Secondly, following effective rainfall events the seeded band may be rapidly colonized by annual weeds or low-value grasses which may out compete seedlings of the seeded species.

We do not feel that grass seed should be placed in the furrows created by ripping or contour furrowing because of the high probability that the small seeds will be covered too deeply as this extremely porous band of soil settles and as soil sloughs off the soil ridges into the furrow bottom during intense rainfall events. Grass seeds should generally be planted only about 1/8 to 1/4 in. deep and the soil should be firmed up so that there is intimate contact between the grass seed and the soil particles.

The plant species and varieties to be used in reseeding along rips or furrows should be carefully selected from among those known to be adapted to the climate and soils of the treated area. Local Texas Cooperative Extension or U.S.D.A. Natural Resources Conservation Service personnel are good sources of information on adapted species for use in rangeland reseeding projects.

CONCLUSION

Maintaining good vegetative cover, litter, and soil aggregation is critical for the efficient utilization of water on rangelands. Proper grazing management budgets about half of the annual plant production to be left to maintain healthy hydrological and mineral cycles and an acceptable level of energy capture via photosynthesis. Control of excessive densities of undesirable plants can decrease wasteful interception and transpiration of water and increase availability of water for beneficial plants. Mechanical water conservation treatments, such as contour ripping, furrowing or pitting, can effectively reduce surface runoff and increase infiltration of rainfall into the soil reserve, thus increasing the potential for plant production. Seeding, even in conjunction with mechanical water conservation treatments, is risky but can result in the establishment of plant species which have greater genetic potential than the resident plant species for effectively utilizing the available soil water. The long-term effectiveness of these mechanical water conservation treatments hinges upon the use of proper grazing management and periodic pasture rest to facilitate the establishment and maintenance of dense patches or bands of vegetative cover.

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FIGURE CAPTIONS

Fig. 1. Mean infiltration rates for four grazing treatments six years after they were initiated on the Edwards Plateau, Texas. LEX = livestock exclosure; MCG = continuously grazed at moderate intensity; SDG = short duration rotation (14-pasture, 1-herd; 4 days on, 50 days rest) stocked at 1.75 times the moderate intensity; HCG = continuously grazed, stocked at 1.75 times the moderate intensity. Means within a time period with different letters are significantly different at P _ 0.05. [from (2)]. Reprinted from *Grazing Management: An Ecological Perspective* with permission from R.K. Heitschmidt and J.W. Stuth.

Fig. 2. Single-shank ripper used for restoration of a clay loam range site near Carlsbad, Texas in 1995 and 1996.

Fig. 3. Depth of penetration of water from a 2-in. convection thunderstorm along rips and on untreated rangeland near Carlsbad, Texas.

Fig. 4. Herbage production during 1995 - 2000 immediately upslope from rips installed on a clay loam range site near Carlsbad, Texas in April 1995 and on adjacent untreated areas. Means within a year with different lower case letters are significantly different at the 5% probability level.

Fig. 5. Profile of herbage production in mid August 2000 across rips installed in 1995 on a clay loam range site near Carlsbad, Texas. Values with different lower case letters are significantly different at the 5% probability level.

Fig. 6. Profile of herbage production in mid August 2000 across rips installed in 1996 on a clay loam range site near Carlsbad, Texas. Values with different lower case letters are significantly different at the 5% probability level.

Fig. 7. A single-shank ripper (Bison SVH-1, Bison Equipment Co., Waco, TX) with shop-made wings.

Fig. 8. A single-row grass seeder (Truax Company, Minneapolis, MN) attached to a single-shank ripper for strategic placement of seeds immediately upslope from the ridge of soil created by contour ripping or furrowing.

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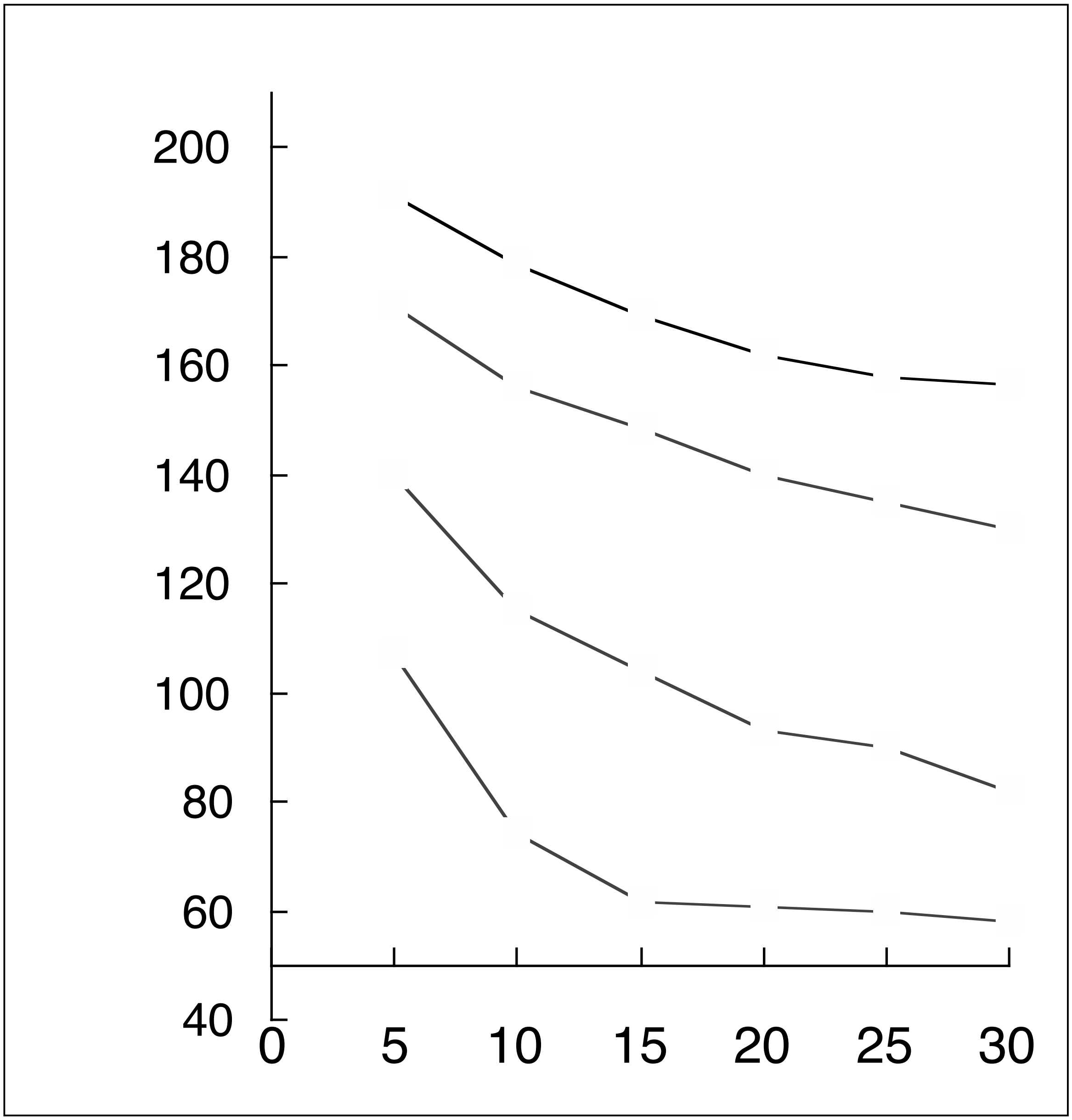
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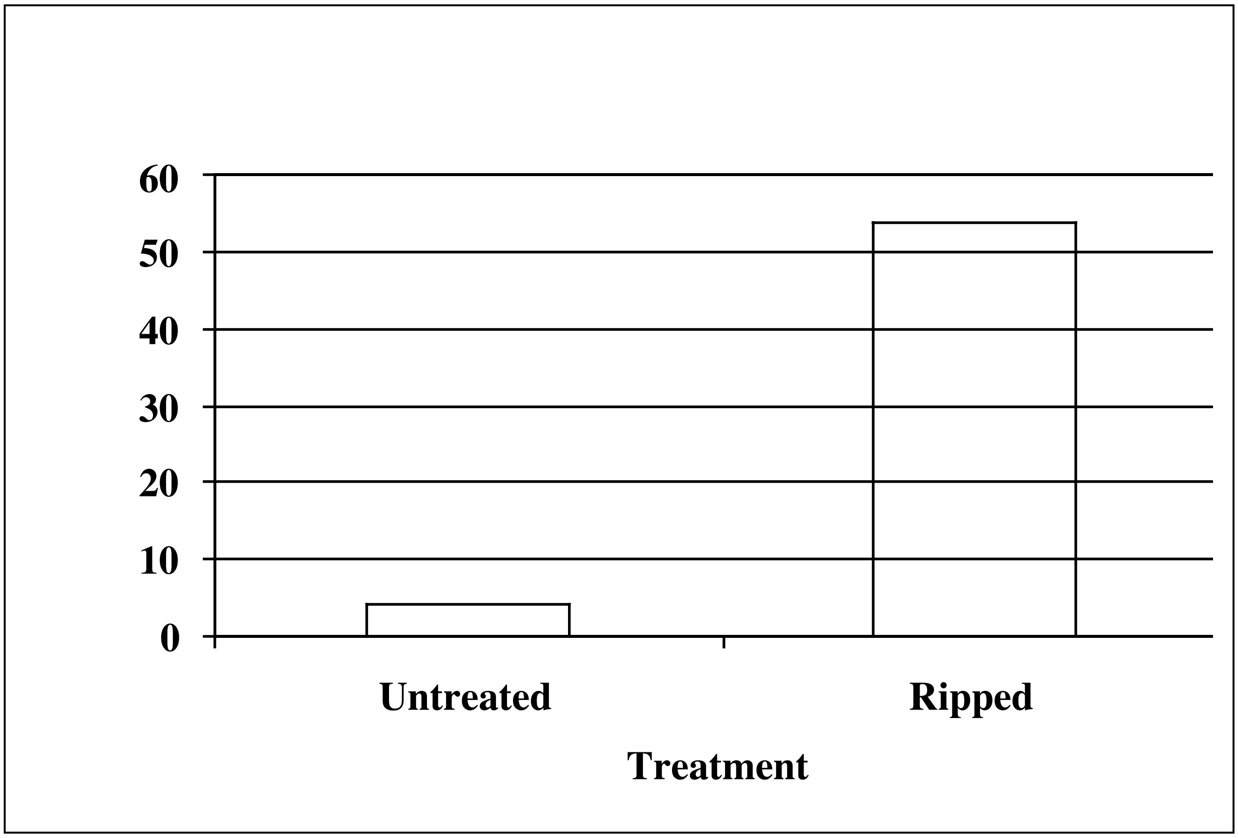
5
10
15
20
25
30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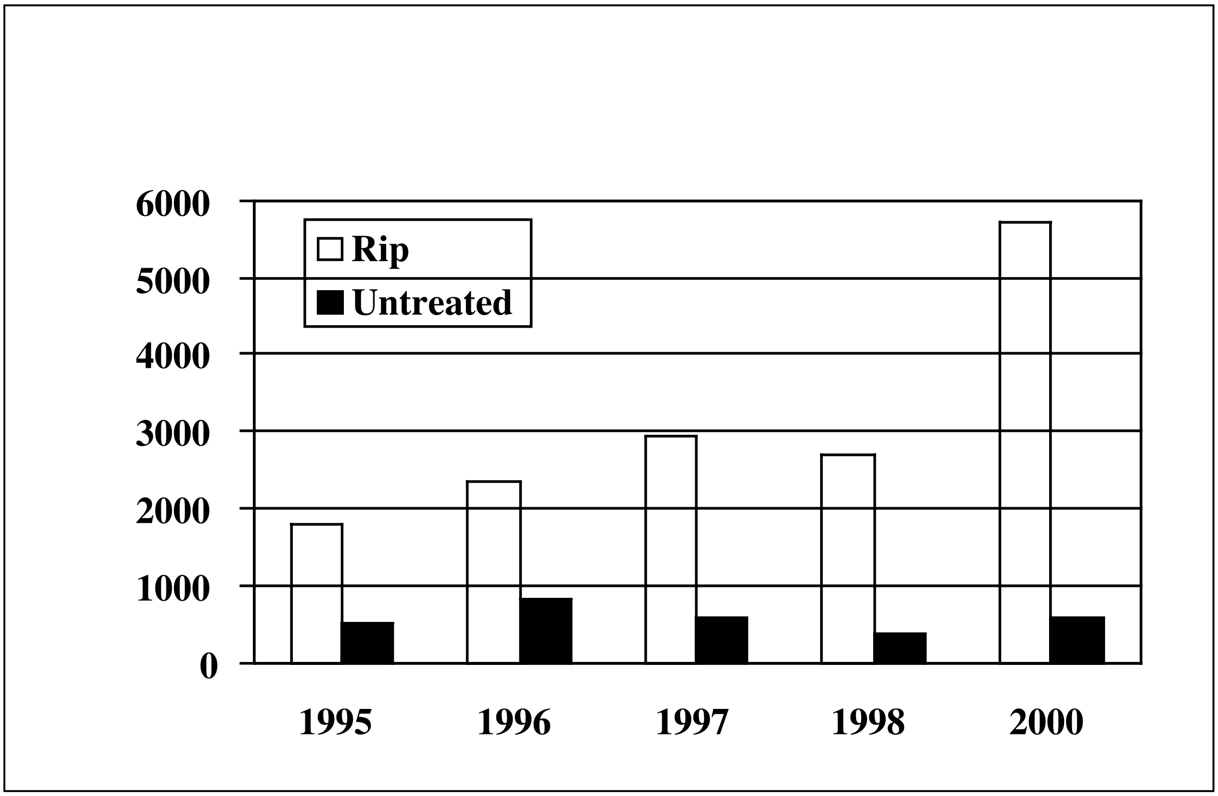
10
0
Untreated
Ripped
Treatment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4000
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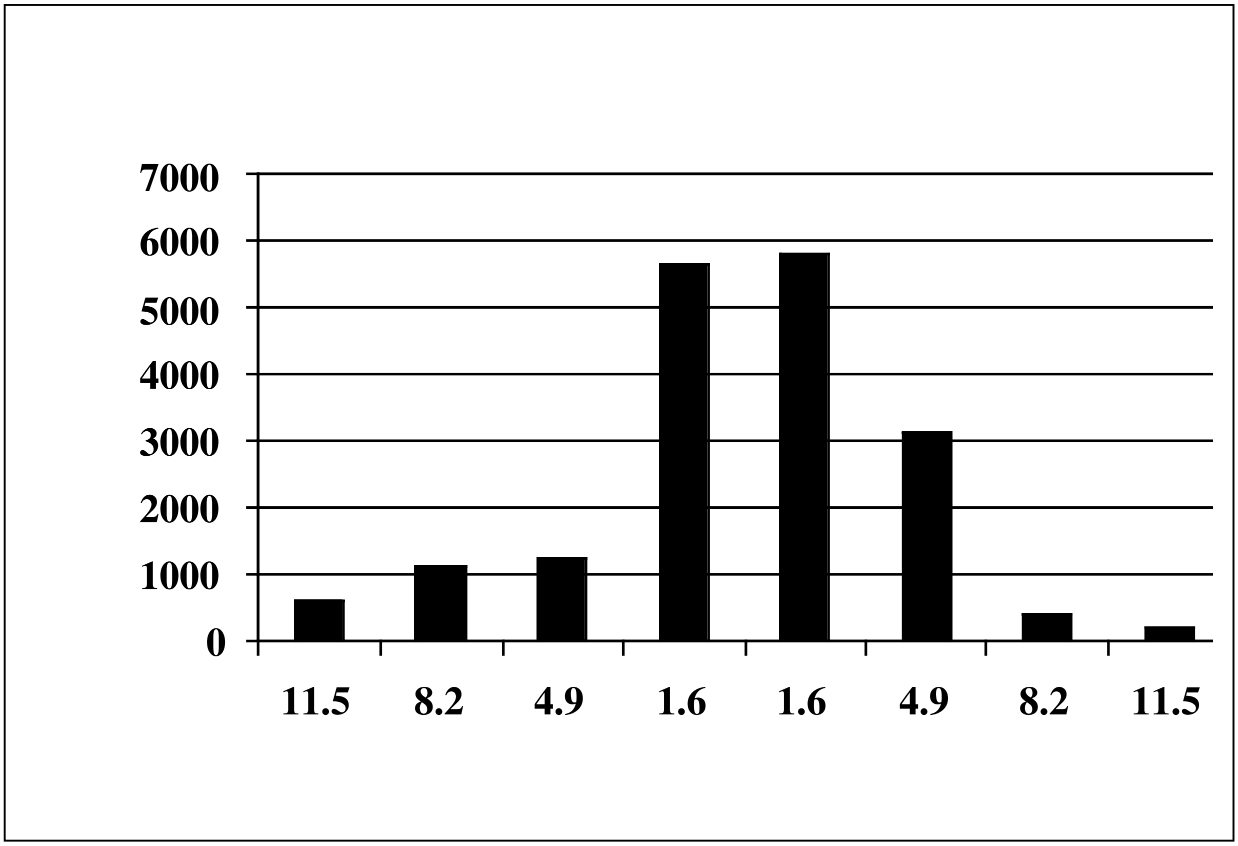
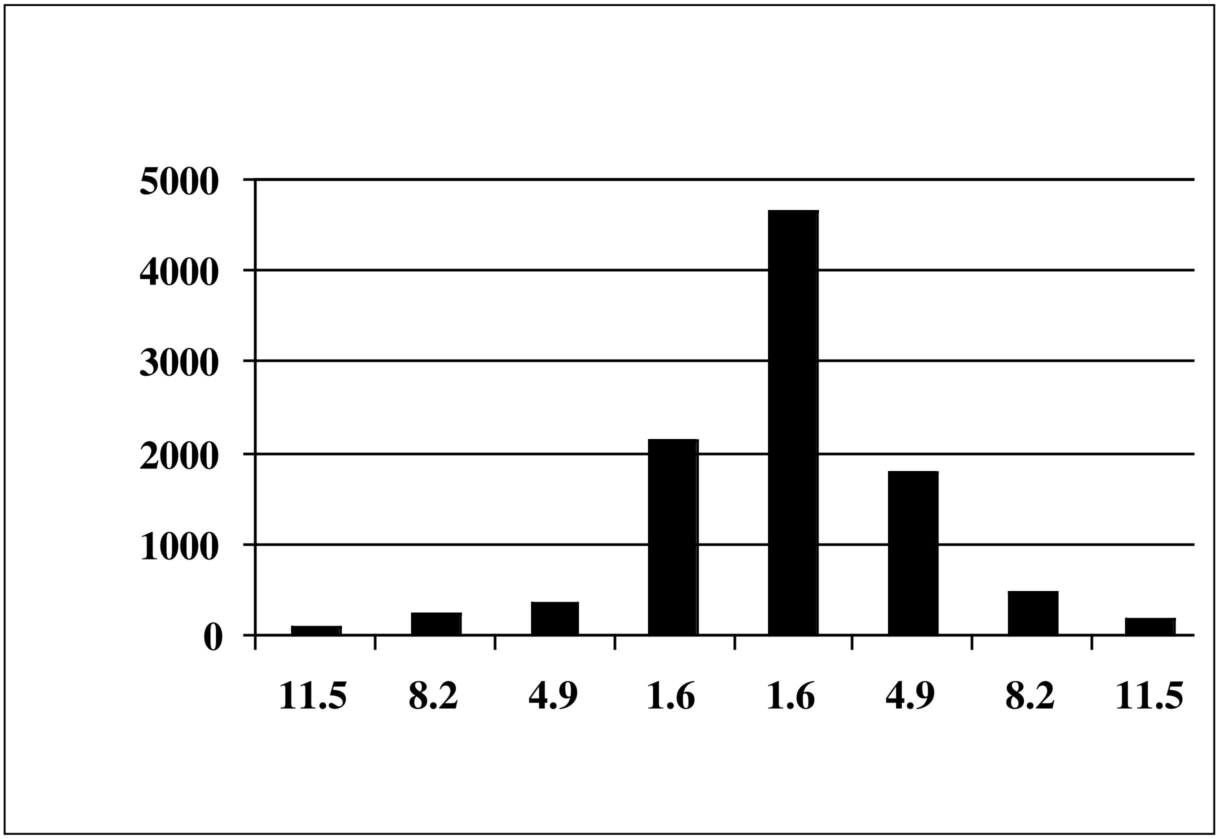
2000
1000
0
Rip
Untreated
1995
1996
1997
1998
2000



7000
6000
5000
4000
3000
2000
1000
0
11.5
8.2
4.9
1.6
1.6
4.9
8.2
11.5


5000
4000
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2000
1000
0
11.5
8.2
4.9
1.6
1.6
4.9
8.2
11.5