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Effects of Livestock Grazing on Infiltration and Erosion Rates Measured on Chained and Unchained Pinyon-Juniper Sites in Southeastern Utah

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EFFECTS OF LIVESTOCK GRAZING ON INFILTRATION
AND EROSION RATES MEASURED ON CHAINED
AND UNCHAINED PINYON-JUNIPER SITES
IN SOUTHEASTERN UTAH

by

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ABSTRACT

Effects of Livestock Grazing on Infiltration
and Erosion Rates Measured on Chained
and Unchained Pinyon-Juniper Sites
In Southeastern Utah

by

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Utah State University, 1977

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The objectives of this study were to 1) determine the effects of livestock grazing and periods of rest from grazing on infiltration and erosion rates of unchained woodland; chained, debris-in-place; and chained, debris-windrowed pinyon-juniper sites; and 2) utilize these measurements in developing guidelines for grazing management of pinyon-juniper rangelands that protect or improve the hydrologic condition of the watershed. The study was conducted on sandy loam soils in southeastern Utah during the summers of 1971 and 1972.

Runoff and erosion were artificially induced from small plots by simulating rainfall with the Rocky Mountain infiltrometer. Infiltration rates, erosion rates, and selected vegetative and edaphic parameters were measured on each plot. Forage removal by clipping and soil compaction subtreatments were applied to randomly selected plots in an effort to simulate the forage removal and trampling activities of livestock.

Analysis of variance techniques were used to determine the effect on infiltration and erosion rates of forage removal and soil compaction subtreatment, grazing and varying periods of rest from grazing, and chaining treatments with similar grazing histories. Multiple regression techniques were used to evaluate the influence of vegetative and edaphic factors on infiltration and erosion.

Forage removal and soil compaction subtreatments had no consistent effect on infiltration rates. However, the clipping and compaction subtreatments were an instantaneous application of forage removal and soil pressure and thus may not adequately represent long term, accumulative conditions imposed by actual grazing.

Areas rested from livestock grazing since 1967 had significantly higher infiltration rates than grazed areas on unchained woodland and chained, debris-in-place sites. Grazed plots consistently had the lowest infiltration rates although this lower rate was not significantly different from infiltration rates measured on areas protected from grazing since 1969 or 1971. Grazing did not consistently affect infiltration measured on chained, debris-windrowed sites. Infiltration rates increased on all three vegetative conditions as the period of rest from grazing increased.

None of the 21 soil and vegetative variables included in this study were identified by multiple regression models as consistently explaining significant amounts of variation in infiltration rates. Results of this study indicate that the primary value of multiple regression models is not to predict changes that will occur in infiltration because one management alternative is selected over another, but to help explain significant differences measured between treatments.

Erosion rates were not significantly affected by forage removal subtreatments, but a trend indicates that erosion increases on plots when above ground vegetation is removed by clipping. No consistent relationship between erosion rates and soil compaction subtreatments was found.

A trend toward increased erosion rates on grazed areas was found. No consistent relationship between erosion rates and the various periods of rest from grazing was recorded. Thus, any rest from grazing appears to reduce the erosion potential from pinyon-juniper sites.

In summary, pinyon-juniper rangelands can be improved for livestock by chaining and seeding without causing a deterioration in watershed condition. However, to achieve these objectives, the sites to be treated must be carefully evaluated and the appropriate chaining, plant debris disposal, and seeding techniques identified. And following vegetative conversion, the areas must be properly grazed.

(139 pages)

INTRODUCTION

Domestic livestock grazing has historically been a major use of the pinyon-juniper (Pinus edulis-Juniperus osteosperma) vegetation type in Arizona, Colorado, New Mexico, Nevada, and Utah. Past overgrazing, suppression of wildfires, and other factors have resulted in reduced forage production, increased density and extent of the tree species, and reduced the value of pinyon-juniper dominated lands for livestock grazing. Because of the historical low market demand for pinyon-juniper tree products and a relatively high demand for forage products, various vegetation modification projects have been applied in an effort to convert these woodlands to more productive grazing land (Dortignac 1960; Arnold, Jameson, and Reid 1964; and Aro 1971).

Chaining has been the most widely used plant conversion technique. This technique involves dragging by large track-type tractors a heavy chain through the tree stands thus knocking down or pulling the trees from the soil. Resultant soil disturbance covers grass seed that has been broadcast onto the site. This condition is usually referred to as "chained, debris-in-place"; hereafter referred to as DIP. Sometimes the downed trees are pushed into piles or long ridges (windrows) leaving cleared ground over most of the treated area. Desired forage species are drill-planted into these sites. Areas receiving this supplementary treatment are described as "chained, debris-windrowed" or simply windrowed. Windrowing usually increases the percentage of trees killed by the chaining treatment but also results in more soil disturbance than DIP treatments because the upper soil profile is mixed as the trees are pushed into piles by the bulldozers.

Objectives

Objectives of this study were to determine on sandy loam soils the effects of grazing and varying periods of rest from grazing on infiltration and erosion rates of unchained woodland, DIP, and windrowed pinyon-juniper sites; and utilize these measurements in developing guidelines for grazing management of pinyon-juniper rangeland that protect and improve the hydrologic condition of the watershed. Of particular interest were the following items:

1. Influence of grazing on infiltration and erosion rates, especially as related to surface soil changes and vegetative modification,
2. Separation of the grazing impact into forage removal and trampling effects,
3. Changes in infiltration and erosion rates as a function of time since grazing has been excluded from an area, and
4. Development of multiple regression models for predicting infiltration and erosion rates of unchained, DIP, and windrowed pinyon-juniper rangeland subjected to various grazing situations.

REVIEW OF LITERATURE

Impact of Chaining on Watershed Values of Pinyon-Juniper Woodlands

Gifford (1975b and 1976) has extensively reviewed watershed research that has been conducted on management practices in the pinyon-juniper vegetation type. Following are conclusions that he has proposed in these two reviews:

1. Interception of precipitation by vegetation is often discounted as an important hydrologic factor. However, in areas where short duration, high intensity thunderstorms are common, interception may be important. Skau (1964) reported that average interception in the Utah juniper type during a single year of measurement was about 17.2 percent of the annual average precipitation. This research was conducted at the Beaver Creek watershed in central Arizona.

Chaining of pinyon-juniper can reduce the amount of precipitation intercepted. Gifford (1975a) calculated (no actual measurements) interception rates on unchained woodland, DIP, and windrowed sites in southern Utah. Depending on the year, annual interception rates on DIP and windrowed areas were estimated to be 30 to 90 percent the rate calculated for unchained woodland.

2. Infiltration rates were not affected by chaining on two sites in Nevada (Blackburn and Skau 1974). A slight reduction in infiltration rates was found on windrowed areas in southern Utah

(Williams, Gifford, and Coltharp 1969, and Gifford, Williams and Coltharp 1970). It should be noted, that a reduction in infiltration rates was found on only a few windrowed sites and only during certain time periods within an infiltration test. The reduction in infiltration was not consistent for all areas or time intervals within an infiltration test.

Site factors found by Williams, Gifford, and Coltharp (1972) to influence infiltration rates were total porosity in the 0-7.5 cm layer of soil, percent bare soil surface, soil texture in the 0-7.5 cm layer of soil, and percent vegetative cover. The importance of these factors in predicting infiltration varied from one study area and sample period to another. No multiple regression equations have been developed which satisfactorily or consistently predict infiltration rates on chained or unchained pinyon-juniper sites.

3. Overland runoff probably increases following chaining until new plants become established. Myrick (1971) reported that runoff increased for two years following chaining at Cibecue Ridge, Arizona. Gifford (personal communication) reported that newly installed runoff plots were washed away by thunderstorms the first year following chaining. Similar damage did not occur after seeded species became established on the watersheds.

Gifford (1973) reported no difference in overland flow between DIP and unchained sites in Utah. However, overland flow, during a runoff event, on windrowed sites was 1.2 to 5 times greater than unchained areas. Combining these results with the infiltration results discussed above, Gifford concluded that one major watershed consideration in pinyon-juniper conversion projects was not the change in dominant vegetation type or soil disturbance, but the method of debris disposal. Debris left on DIP plots acted like thousands of small check dams which held the water on the land until it had time to infiltrate. No debris remained on the windrowed areas and overland flow quickly occurred.

4. Most recorded instances of increased stream flow following chaining are flash floods associated with high intensity thunderstorms (Baker, Brown, and Champagne 1970). The only consistent increase in stream flow reported followed pinyon-juniper conversion at Beaver Creek, Arizona, on a watershed sprayed with the herbicide picloram (Clary _et al_. 1974). The dead, standing trees seem to provide protection from evaporative forces such as solar radiation and wind releasing some water for stream flow.

5. Sediment is the most important water quality parameter associated with pinyon-juniper woodlands. Studies in Utah (Williams _et al_. 1969 and Gifford _et al_. 1970), indicate that chaining does not increase sediment production on DIP sites. However, erosion was increased on windrowed sites. The concept of debris creating thousands of small check dams as discussed above for overland runoff appears to apply to sediment production. Less soil disturbance associated with the DIP and broadcast seeding

treatment may also account for erosion being less on DIP sites. This soil disturbance concept has not been adequately studied.

Summary. Research in Arizona, Nevada, and Utah indicates that debris disposal techniques influence watershed values--particularly overland runoff and erosion--more than the actual chaining operation. Chaining has had little effect on stream flow measured at the mouth of a watershed. Therefore, Gifford's (1975b) statement seems appropriate for the pinyon-juniper type:

> Though the guise for much of the research effort has been the potential for water yield improvement, the concept of onsite increased water use efficiency is a more realistic approach.

Impact of Livestock Grazing on Infiltration and Erosion Rates

There is little doubt that grazing has an impact on the hydrologic behavior of range ecosystems. Grazing, whether by domestic or wild animals, may alter the potential infiltration and erosion rate of an area by reducing the protection afforded by vegetation, by reducing or scattering litter, and by compacting the soil. The magnitude of these changes is determined by the intensity of grazing, range condition, soil type, climate, topography, livestock managment, and vegetation type (Stoddart, Smith, and Box 1975).

Gifford and Hawkins (personal communication) summarized much of the literature available on the relation of livestock grazing intensity to infiltration. Included in this summary were results from studies from all regions of the United States, most having been conducted during the past 25 years. In almost all of 61 comparisons reported as 21 separate studies, heavy grazing by livestock reduced infiltration rates below rates measured for ungrazed, lightly grazed, and moderately grazed conditions. No differences in infiltration were consistently measured between these latter three grazing intensities. These results are difficult to interpret because each study involved different lengths of time that the various grazing intensities had been applied, each study was conducted under different soil and climate conditions, and no standard quantitative definition for light, moderate, and heavy grazing intensity suitable for all range sites is possible. However, the results are so consistent that the conclusion that increased grazing pressure--number of animals per unit area per unit of time--leads to reduced infiltration rates cannot be ignored.

One situation reported where heavy grazing did not reduce infiltration rates below those measured on areas receiving less grazing use occurred on slick or semi-slick soils (clay texture) in Montana (Branson, Miller, and McQueen 1962) and on soils derived from Mancos shale in Colorado (Thompson 1968). Both authors indicated that infiltration rates were very low (less than 2.5 cm hr^{-1}) on ungrazed areas and that grazing created micro-depressions in the soil surface which improved the ability of the soil to absorb water.

The increase in water intake attributable to grazing was less than .5 cm hr^{-1}.

The second situation where infiltration was greater on heavily grazed pastures than on lightly or moderately grazed areas was described by Sharp et al. (1964) and attributed to a unique sequence of precipitation events. Two storms occurred within one week and the lightly grazed area, initially having a high infiltration rate, absorbed water until the soil profile became saturated. The heavily grazed area--initially having a low infiltration rate--did not become saturated during the first two storms. A third storm, occurring one week after the second, did not deliver precipitation at a rate great enough to exceed the infiltration rate of the heavily grazed area and no runoff was generated. However, heavy runoff was measured from the lightly grazed area with saturated soils. A fourth storm occurred six weeks later and the lightly grazed area again had significantly higher infiltration rate than the heavily grazed area.

Most studies which have evaluated the relationships between grazing, and infiltration and erosion rates conclude that one or more of the following situations occur (Meeuwig and Packer 1976):

1. Through forage consumption and trampling action, grazing removes vegetative cover which protects the soil surface from raindrop splash. Without the protection afforded by vegetation, raindrops detach soil particles upon impact with the soil surface. Detached clay and other fine particles may settle to the soil

surface and clog pores. Compaction of the soil by raindrops speeds sealing of the soil surface and decreases infiltration.

2. As infiltration decreases, excess water collects on the surface. At some depth, largely dependent on percent slope, this excess water begins to move across the soil surface. The greater the slope, the greater the velocity of the water. Also, the fewer obstacles available to detain flow (such as plants, mulch, debris) the greater the velocity. Generally, erosion potential increases as flow velocities increase.

3. Surface flow alone does not lead to accelerated erosion. Intensive thunderstorms that occur on areas completely--or nearly so--covered with vegetation may produce considerable overland flow, but the runoff water will be clear. The difference is usually attributed to the vegetative cover intercepting the raindrops and preventing soil detachment. Without continuous vegetative cover raindrop splash occurs and detached soil particles are transported off-site by overland flow. Continued rain keeps the water aggitated and prevents soil particles from settling to the soil surface.

4. Grazing animals also compact the soil surface through trampling activity. Compaction increases the bulk density (soil particles per volume of soil), decreases porosity, and breaks down soil aggregates (fine particles cemented together to form large particles). All of these effects reduce the rate at which water can infiltrate the soil and increase surface runoff and erosion potential.

These conclusions are generally true, but more detailed analysis of the studies from which Meeuwig and Packer (1976) base their conclusions improves our understanding of the impact of grazing on infiltration and erosion.

For instance, Packer (1951), Marston (1952), and Packer (1963), and Meeuwig (1970) reported that vegetative cover was the most important variable in explaining variation in infiltration and erosion rates measured on areas receiving different uses--particularly different grazing intensities. These results support the general conclusions listed above. However, all of these studies were conducted on mid- to high elevation range areas with a climate capable of supporting a continuous cover of protective vegetation. The influence of these climatic conditions may be seen in the authors' unanimous recommendation that a plant cover in excess of 65 - 75 percent is needed to maintain high infiltration rates and control erosion. This recommendation is probably applicable to areas receiving more than 400 mm of annual precipitation, but how does this recommendation apply to desert and semi-desert areas ($<$ 300 mm annual precipitation) which are not climatically capable of supporting more than 40-50 percent cover?

Rich and Reynolds (1963), studying chapparal range in Arizona, reported non-significant differences in erosion rates measured on ungrazed areas, sites with 40 percent of the vegetation removed by livestock, and areas with 80 percent of the vegetation removed. Eighty percent utilization did alter plant cover, production and composition. The authors concluded that cover (approximately 40 percent) on ungrazed sites was not sufficient to prevent splash erosion by raindrops and the two grazing intensities--applied for 20 years--did not alter cover in such a way as to change hydrologic processes; i.e., vegetation was not the environmental factor controlling infiltration and erosion as was the case on more mesic areas. Similar results were reported for infiltration rates on Shingle sandy loam sampled at the Central Plains Experimental Range in Colorado by Rauzi and Smith (1973). Cover on lightly, moderately, and heavily grazed sites did not exceed 50 percent. The authors concluded that splash erosion and soil sealing occurred at an equal rate on all grazing intensities and therefore all grazing conditions exhibited similar infiltration characteristics. The grazing treatments had been in effect for 23 years.

Most studies indicate that dead vegetation, litter or mulch, is as effective in preventing raindrop splash and associated hydrologic effects as live vegetation. Knoll and Hopkins (1959) studying in central Kansas; Rauzi and Hanson (1966) in southwest South Dakota; and Johnston, Dormaar, and Smoliak (1971) in southern Alberta, Canada all report that heavy grazing (compared to various lighter grazing intensities) resulted in significantly lower infiltration and higher erosion rates. However, none of the studies indicated significant changes attributable to grazing in the amount of live vegetation. Heavy grazing did in all cases significantly reduce (one author says "eliminated") mulch and litter. Thus, the impact of livestock grazing on infiltration in these studies was partially due to the animals reducing the ability of the plants to produce or the communities to maintain litter or mulch.

Smoliak, Dormaar, and Johnston (1972) add additional insight into the impact of grazing on infiltration. They report that below ground plant biomass at the 45-60 cm soil depth was significantly lower on heavily grazed areas, and associated this below ground biomass with a change in plant composition from mid-grasses to shortgrasses and a decreased infiltration rate on heavily grazed soil. Their argument was that on heavily grazed areas, infiltrating water did not have the advantage of plant roots to "speed" water to the deep soil layers. Similar changes in plant composition (from deep to shallow rooted plants) have been reported for heavily grazed areas by Rauzi and Hanson (1966), Rhoades et al. (1964), Johnston et al. (1971), Packer (1963), and Rauzi (1963). All of these authors also report lower infiltration and higher erosion rates being associated with the heavily grazed treatment.

These studies provide considerable information needed to analyze the relationship of grazing intensity to infiltration and erosion rates and the modifying affect of vegetation on this relationship. Vegetation probably is an important factor influencing infiltration and erosion on most sites, but the influence is much more complicated than the relation between percent total cover and infiltration rates.

Soil factors and their relation to infiltration and erosion have not been as thoroughly studied on rangelands as have vegetative factors. However, several studies provide some useful conclusions. Orr (1960 and 1975) studying silt loam soils in the Black Hills of South Dakota reported that bulk density is increased by heavy grazing. Lower infiltration rates and higher erosion rates were also associated with heavy grazing. Infiltration rates were significantly correlated with bulk density measurements. Following protection from heavy grazing, Orr found that bulk density decreased to pre-grazing levels within 2-5 years, depending on soil type. Infiltration and erosion recovered to a level equal to long time ungrazed areas at about the same rate as bulk density. Similar results have been reported by Redd (1957), studying the effect of livestock concentrating on silty clay loam soils in South Dakota shelterbelts; Rauzi and Hanson (1966), studying the effect of livestock grazing intensity on silty clay and silty clay loam soils in south-central South Dakota; and Knoll and Hopkins (1959), studying silt loam soils near Hays, Kansas. These latter three studies also indicate that heavy livestock grazing reduces the total porosity of soils and breaks soil aggregates apart.

Not all studies indicate that soil properties are altered by grazing use. In general, failure of heavy grazing to increase bulk density, reduce total porosity, and break soil aggregates apart is attributed to course textured soils (Smoliak et al. 1972), very dry soils (Meeuwig and Packer 1976), or previous disturbance by vegetative conversion treatments (Meeuwig 1965). Laycock and Conrad (1967) conclude from literature and field studies that a consistent relationship between livestock grazing intensity and soil disturbance should only be reported when similar soils of approximately equal moisture content are studied. This has been accomplished in only a few studies.

Summary. The conclusion that livestock grazing reduces infiltration and increases erosion seems to be valid. But significant responses only occur where grazing intensity has been great enough to 1) reduce the total plant cover below some critical level (70 percent on areas capable of supporting a near continuous plant cover), 2) change the species composition from deep to shallow rooted plants, 3) prevent the plant community from producing and maintaining mulch or litter cover, and 4) significantly alter the structural characteristics of the soil--particularly characteristics related to soil porosity. On arid and semi-arid (< 300 mm annual precipitation) rangeland, all of the above factors (with the possible exception of number 1 because dry rangelands generally do not have the potential to produce a continuous plant cover) are important in controlling infiltration and erosion. However, no single factor or group of factors have been identified that consistently influence infiltration and erosion under all circumstances. Thus no models have been developed that help the range manager predict the impact of various management activities.

METHODS AND PROCEDURES

Study Area

A pinyon-juniper dominated area in southeastern Utah was chosen for study. The area is approximately in the center of the type's distribution range and the availability of the following closely adjacent vegetation and grazing conditions made this a highly desirable study area:

1. Unchained Woodland
   a. Grazing not excluded
   b. Grazing excluded since 1967
   c. Grazing excluded since 1969
   d. Grazing excluded since 1971
2. DIP
   a. Grazing not excluded
   b. Grazing excluded since 1967
   c. Grazing excluded since 1969
   d. Grazing excluded since 1971
3. Windrowed
   a. Grazing not excluded
   b. Grazing excluded since 1967
   c. Grazing excluded since 1971

Table 1 provides a brief description of the study area.

Geology. Hunt (1956) and Meiners (1965) discussed the geologic history and formations of the study area. Five geological formations are:

Table 1. Descriptions of chained study sites near Blanding, Utah.

Chaining Project Title	Location	Treatment Method	Date-of Treatment	Species Seeded	Elevation (m)	Annual Precipitation (mm)	Grazing History
Maverick Point	T.37S	a. Chained	Fall, 1961	Crested	2073	330	Grazed from May 1 to June 15 and October 1 to November 1 each year with cattle. Intensity observed to be moderate to heavy. This grazing management has been used for several years. Grazing exclosures established in 1969 and 1971.
	Same	b. Chained windrowed	Fall, 1964	Crested wheatgrass and four-wing salt-bush.	2073	330	Grazed as above. Grazing exclosure established in 1971.
Cyclone Flat	T.37S. R.19E.	Chained debris-in-place	Fall, 1961	Crested wheatgrass	2073	330	Grazed as above. Grazing exclosures established in 1969 and 1971.
U.S.U. Research Plots	T.39S. R.19E	a. Chained debris-in-place	Fall, 1967	Crested wheatgrass	2042	330	Grazing excluded fall, 1967. Grazed as above prior to 1967.
	Same	b. Chained windrowed	Fall, 1967	Crested wheatgrass	2042	330	Grazing excluded fall, 1967. Grazed as above prior to 1967.

Cutler formation (primarily a cream white sandstone; maximum depth 300 m), Moenkope formation (Triassic age; fine grained sandstone and shale beds; average thickness 91 m), Chinle formation (Upper Triassic; limestone, claystone, siltstone, sandstone, and conglomerate; approximately 182 m thick), Windgate formation (Triassic age; fine grained quartz sandstone; average thickness 91 m), and Kayenta formation and Navajo sandstone (Jurassic age; dark red sandstone; average thickness 307 m).

Soils. Parent materials of the study area are eolian sediments. These materials are dark reddish-brown and contain 40 percent or more of very fine sand and less than 40 percent silt. The sediment mantle ranges from a few cm to 3 m or more in thickness. The material is low in fine lime and is of mixed mineralogical composition (U.S. Department of Agriculture 1962).

Climate. Long term records are not available within the immediate study area. Long term records from Blanding (48 km from study sites, approximately same elevation) indicate a 30 year mean annual precipitation of 305 mm (range of 127 to 560 mm per year). A substantial proportion of the precipitation may occur as snow in winter and early spring. There is a tendency toward drought in late spring, and June is often extremely dry. Another important period of precipitation is in late summer from July to September when short duration, high intensity thunderstorms occur (U.S. Department of Agriculture 1962).

Mean monthly temperatures at Blanding vary from 23°C in July to -3°C in January. Mean annual temperature is 10°C. The area experiences a great diurnal fluctuation in temperature with a range of 10°C not being uncommon (Meiners 1965).

Vegetation. Unchained woodland stands are dominated by pinyon pine and Utah juniper (Figure 1). Understory species observed in the area include big sagebrush (*Artemisia tridentata*), little rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Chrysothamnus nauseosus*), broom snakeweed (*Gutierrezia sarothrae*), Russian thistle (*Salsola kali*), globemallow (*Sphaeralcea coccinea*), galleta grass (*Hilaria jamesii*), cheatgrass (*Bromus tectorum*), Indian ricegrass (*Oryzopsis hymenoides*), and prickley pear cactus (*Opuntia* spp.).

Basically a monoculture of crested wheatgrass (*Agropyron cristatum*) occurred on the windrowed sites (Figure 2). Additional species found in minor amounts on this site were Russian thistle, fourwing saltbush (*Atriplex canescens*), broom snakeweed, Indian ricegrass, bitterbrush (*Purshia tridentata*), globemallow, and rubber rabbitbrush.

DIP sites exhibited a richer variety of species (Figure 3). Plants listed for the windrowed condition were present, plus pinyon pine, Utah juniper, and big sagebrush.

Grazing history. The areas surrounding the grazing exclosures were grazed by cattle from May 1 to June 15 and October 1 to November 1 each year. This spring-fall grazing cycle is typical of livestock

Figure 1. Unchained woodland vegetative condition. This area is dominated by Utah juniper trees. Almost no vegetation grows under the trees. Infiltrometer plots were located in the open spaces between trees.

Figure 2. Windrowed vegetative condition. The area is dominated by crested wheatgrass. Infiltrometer plots were located on parts of the cleared area.

Figure 3. DIP vegetative condition. Crested wheatgrass is the primary forage species. Infiltrometer plots were located in open areas between debris piles.

use in the pinyon-juniper type of southeastern Utah. Management of the livestock did not allow accurate estimation of grazing intensity because chained areas are included in pastures with large, unchained areas. Since the animals used the chainings a disproportionate amount of time, estimating grazing use on the basis of total acreage available to the livestock would greatly underestimate the grazing use of the chained areas. Conversely, assuming the animals did not utilize the unchained areas would overestimate use.

Clipping studies conducted during the study indicated the percent forage utilization ranged from 70 percent in 1971 to 45 percent in 1972. This difference in forage utilization was caused by one year being much drier than normal.

Sampling Periods

Selected hydrologic, vegetative, and edaphic parameters were measured during June-July immediately following the spring grazing period and after two months of rest from grazing (approximately August 20) during the summers of 1971 and 1972. Data from 948 infiltrometer plots were collected during these four sampling periods.

Field Procedures

Dortignac (1951) and Williams (1969) described the design and operation of the Rocky Mountain infiltrometer. Artificial rainfall is applied by the infiltrometer at a rate of 7.5-

12.5 cm hr^{-1}. The rain drops produced by this simulator tend to be larger than those of actual thunderstorms, but have lower impact velocities (Meeuwig 1971). The measurements obtained are valuable, however, because the same rainfall conditions can be applied to all treatments, thus allowing comparisons.

Three infiltrometer plot frames were used for each infiltration test during this study rather than one used by Dortignac (1951) or the two used by Williams (1969). These plots were approximately 0.24 m^2 in size (0.77 m x 0.31 m). The Rocky Mountain infiltrometer sprinkles an area approximately 4 m in diameter; therefore, a control of lateral flow from the plots is provided when three plots are used. This alteration allowed increased efficiency of water use (few water sources existed near the study area).

Plot installation. After a site suitable for three runoff plots (free of large obstructions and having slight to moderate slope) was located, the frames were driven approximately 10 cm into the soil. Trough raingages (.77 m x 2.54 cm in size) were positioned around each runoff plot. Following installation of runoff plots and raingages a data collection area (not sprinkled) was established. A hole large enough to accomodate six 4 liter collections cans (three each for rainfall and runoff) was dug. The area surrounding this hole was cleared of obstructions that would hinder work. Plastic pipes were installed to deliver runoff and rainfall from the plots to the collection cans. To reduce wind effects on raindrop distribution, a canvas wind screen was installed around the plots. The installed equipment is illustrated in Figure 4.

Clipping subtreatments. Following plot installation one-third of the plots inside grazing exclosures were clipped at 7.5 cm stubble height to simulate forage removal occurring on adjacent grazed areas (hereafter referred to as "50% Clipped"). Another one-third of the plots had all above ground plant material removed by clipping at ground level and picking litter from the soil surface ("100% Clipped"). These plots provided information on hydrologic effects associated with forage removal but without soil disturbance associated with livestock grazing. The remaining ungrazed plots and those located on grazed areas did not receive a clipping subtreatment ("0% Clipped").

Soil compaction subtreatments. Lull (1959) discussed the detrimental effect of soil compaction on infiltration and soil stability. He reported that cattle exert static or standing loads (averaged over entire surface area of hooves) of 10.9 kg cm^{-2} (24 lbs in^{-2}); however, two or four times this static load can occur when the animal moves. To determine the hydrologic effect of soil compaction (with no associated forage removal), randomly selected plots in ungrazed exclosures had 0, 30, or 60 percent of their surface area compacted with a force of 13.6 kg cm^{-2} (30 lbs in^{-2}). This force was chosen as a compromise between static and moving loads, but favoring standing conditions. All plots were dry at the time soil compaction subtreatments were applied.

Figure 4. Rocky Mountain Infiltrometer. A wind screen is used when necessary to reduce wind effects on raindrop distribution.

To insure uniform soil compaction subtreatments between plots, the compaction frame (Figure 5) was designed to fit the infiltrometer plot and the same trampling 'feet' were used to compact each plot (one-half used for the 30 percent compaction and all used for the 60 percent). Care was taken in installing and removing the frame to prevent the 'feet' from causing any disturbance other than compaction.

Vegetative cover. Prior to sprinkling, but following the clipping or compaction subtreatments, vegetative cover and soil surface characteristics of each infiltrometer plot were determined with an ocular point quadrat frame (Ibrahim 1971). Intercept of vegetation, litter, rock, or bare soil was recorded for 100 points covering the entire plot.

Slope. Percent slope was calculated by measuring the drop in elevation from the back to the front of the plot frame. Slopes involved in this study ranged from 1 to 10 percent and averaged 6 percent.

Prewetting. Antecedent moisture is one factor controlling infiltration (Neal 1938; Myrick 1971), and it was considered desirable to reduce variation in this factor as much as possible. Therefore, following measurement of plot cover characteristics each plot was prewet with approximately 16 liters of water. This wetting was accomplished by allowing water to slowly trickle onto each plot with little surface disturbance. Infiltration runs were not conducted sooner than one hour after plots were prewet. This was sufficient time for the sandy loam soils of the study area to drain to field

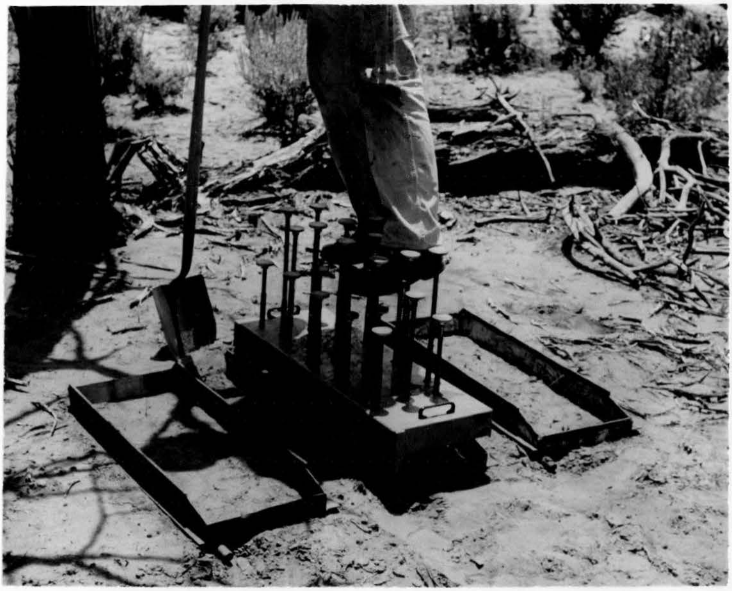


Figure 5. Device used to apply compaction subtreatments.

capacity which should have reduced variation in infiltration due to seasonal moisture conditions.

Infiltration and sediment rate determination. Rainfall simulated by the infiltrometer and runoff were measured at the end of the following time intervals: (1) 0 to 3 minutes, (2) 3 to 8 minutes, (3) 8 to 13 minutes, (4) 13 to 18 minutes, (5) 18 to 23 minutes, and (6) 23 to 28 minutes. The 28 minutes generally provided sufficient time for a relatively constant runoff rate to be reached (when two consecutive five minute measurements are approximately equal). Sampling at these time intervals allowed analysis of infiltration rate changes as the simulated rainfall period increased in time.

The infiltration rate during each time increment was determined by subtracting the runoff collected from the rainfall measured. Infiltration rate (cm hr^{-1}) included water absorbed into the soil, that intercepted by vegetation, that held in surface depressions, and that in transit across the soil surface at the moment runoff and rainfall is measured. These latter three points of water detention are considered minimal after the first few minutes of rainfall.

All runoff collected (usually in excess of 4 liters) during the (1) 0 to 8 minute, (2) 8 to 18 minute, and (3) 18 to 28 minute time periods was thoroughly mixed and a one pint integrated sample taken from each time period. After the sediment settled, excess water was evaporated off, the sediment oven dried, and sample weights converted to kg ha^{-1}. Most sediment collected was observed to be the result of sheet erosion.

Soil samples. Immediately following an infiltration-erosion test, two 7.5 cm diameter aluminum cylinders were pressed into the soil within the plot frame boundaries allowing extraction of 2.5 and 7.5 cm deep soil core samples. These two soil samples were used to determine bulk density, saturated hydraulic conductivity, porosity, texture, and percent water stable aggregates existing at the two depths. Soil cores were collected approximately 24 hours after the cylinders were pressed into the soil.

Vegetative biomass. Above ground plant biomass present within each plot during the infiltration test was clipped at ground level after foliage had dried. The material was oven dried and weights converted to kg ha^{-1} of forage or standing crop production. This measure was used as an additional indication of vegetation's affect on infiltration and erosion.

Air permeameter. After the soil profile had drained to field capacity following the infiltration - erosion test (approximately 2 hrs.), an air permeameter (Faust 1969) was used to determine the resistance of the moist soil to airflow. The air permeameter consists of an air cylinder, regulator, air valve, pressure guage, air hose, and metal cup. The cup has an inside diameter of 4.3 cm and penetrates the soil until a flange around the cup is in contact with the soil surface. Air is released from the tank by the valve and flows through the soil cup into the soil. The resistance of the soil to the air causes a build up of pressure which is reported on the pressure guage. Faust (1969) reported that the resistance of soil to air flow is directly related to the resistance of soil to water flow.

Lab Procedures

Saturated hydraulic conductivity, capillary and total porosity, and bulk density were determined for the 2.5 and 7.5 cm deep soil cores following each field sampling period. Texture and percent water stable aggregates were determined for the August-September, 1971, sampling period.

Saturated hydraulic conductivity. Water flow through relatively undisturbed, previously saturated soil cores was measured by maintaining 1 cm head above the core, allowing a constant percolation rate (ml min^{-1}) to be reached during a preliminary 30 minute period, and recording the water flow through the soil core during the next 10 minute period. Water temperature and exact depth of soil in each core was measured and used in the following formula to convert measured percolation rates to comparable values (Hoover, Olson, and Metz 1954):

$$SHC = (P/t)\ (h/H)\ (V_T/V_s)$$

where SHC = Saturated hydraulic conductivity (ml min^{-1})

P = volume of water (ml) transmitted through soil core

t = time of test in minutes

h = height of soil core in cm

H = total height of water column (height of core plus head of water) in cm

V_T = viscosity of water at temperature 'T'

V_s = viscosity of water at standard temperature (15.5°C)

Saturated weight of the soil was determined immediately after conclusion of the saturated hydraulic conductivity test.

Porosity and bulk density. Moisture was drained from the soil cores under 30 cm tension (1/32 atmosphere) using a blotter-tension table (Hoover *et al.* 1954). Tension was applied for 24 hrs and then core weights determined. Soil cores were oven dried at 105°C for 24 hrs and reweighed. Saturated weight, weight after draining at 30 cm tension, oven dry weight, and soil core volume was used in the following formulas to compute capillary porosity (CP), total porosity (TP), and bulk density (BD):

$$CP = \frac{S-T}{V}$$

$$TP = \frac{S-D}{V}$$

$$BD = \frac{D}{V}$$

where S = weight of saturated soil

T = weight of soil dried at 30 cm tension for 24 hrs

D = weight of soil oven dried at 105°C for 24 hrs

V = volume of soil mass

Texture and water stable aggregates. Soil texture was determined with the hydrometer method of Bouyoucos (1962). Percentage of water stable aggregates was measured by omitting the Calgon in the hydrometer method.

Analysis of Data

Differences in infiltration and erosion rates between treatments were analyzed using analysis of variance techniques. Three series of analyses were conducted for each sampling period: 1) clipping and compaction sub-treatments within each vegetation-grazing condition combination were analyzed to determine the effect of instantaneous forage removal or soil compaction on infiltration or erosion, 2) data gathered from areas with similar grazing histories within unchained, DIP, and windrowed sites were analyzed to determine the impact of livestock grazing on infiltration and erosion, and 3) grazing conditions among vegetative conditions were analyzed to determine the impact of chaining treatments on sites with similar grazing history.

When analysis of variance indicated that significant differences ($P \leq 0.10$) existed between clipping subtreatments, compaction subtreatments, or grazing conditions Duncan's New Multiple Range Test was used to evaluate treatment means (Duncan 1955).

Stepwise multiple regression analyses were used to determine the relationship between soil and vegetative factors and infiltration and erosion rates. Variables explaining significant ($P \leq .10$) amounts of variation in infiltration and erosion rates were identified by regression analysis techniques. The relationship between significant variables and infiltration and erosion rates were further interpreted by evaluation of correlation coefficients.

All statistical analyses were accomplished through use of the STATPAC statistical package available at the Utah State University Computer Center (Hurst n.d.).

RESULTS AND DISCUSSION

Infiltration Results

The following tabulation indicates the organization of the infiltration results section:

Unchained Woodland

Sampled June-July, 1971

Sampled August-September, 1971

Sampled June-July, 1972
compaction subtreatments
compaction subtreatments pooled

Sampled August-September, 1972
compaction subtreatments
compaction subtreatments pooled

Summary of infiltration results measured on unchained woodland sites.

DIP Condition

Sampled June-July, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled August-September, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled June-July, 1972
clipping subtreatments
clipping subtreatments pooled
compaction subtreatments
compaction subtreatments pooled

Sampled August-September, 1972
compaction subtreatments
compaction subtreatments pooled

Summary of infiltration results measured on DIP sites

Windrowed Condition

Sampled June-July, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled August-September, 1971

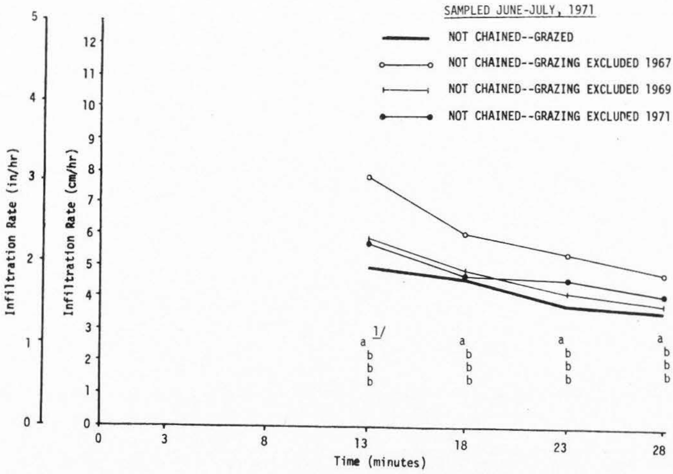
Sampled June-July, 1972
clipping subtreatments
clipping subtreatments pooled
compaction subtreatments
compaction subtreatments pooled

Summary of infiltration results measured on
windrowed sites

Unchained woodland

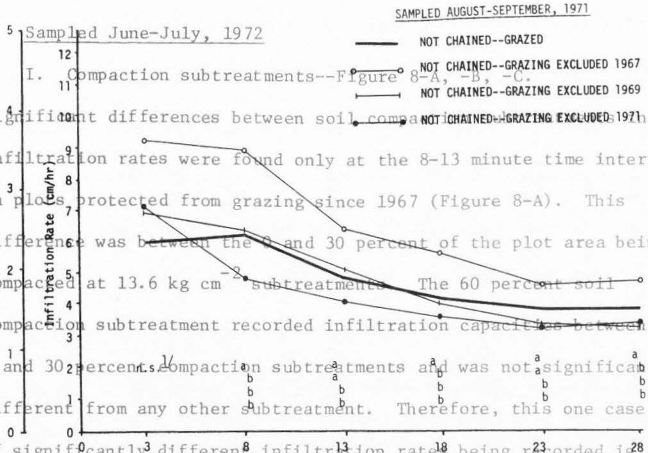
Sampled June-July, 1971--Figure 6. During the time intervals for which the infiltration capacity was defined, areas protected from grazing since 1967 recorded significantly higher infiltration rates than areas protected since 1969, 1971, or grazed from May 1 to June 15, 1971. Infiltration rates measured on grazed plots were statistically equal to rates on plots protected since 1969 and 1971.

Sampled August-September, 1971--Figure 7. Infiltration measured on plots protected from grazing since 1967 had consistently and usually significantly higher infiltration rates than plots protected from grazing since 1969, 1971, or grazed from May 1 to June 15, 1971. Also, as was found during the June-July, 1971, sampling period; infiltration rates as measured on grazed plots were (with the exception of the 18-23 minute time interval) statistically equivalent to rates measured on plots protected since 1969 and 1971.



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 6 . Infiltration rates measured on unchained woodland sites sampled June-July, 1971.



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 7. Infiltration rates measured on unchained woodland sites sampled August-September, 1971.

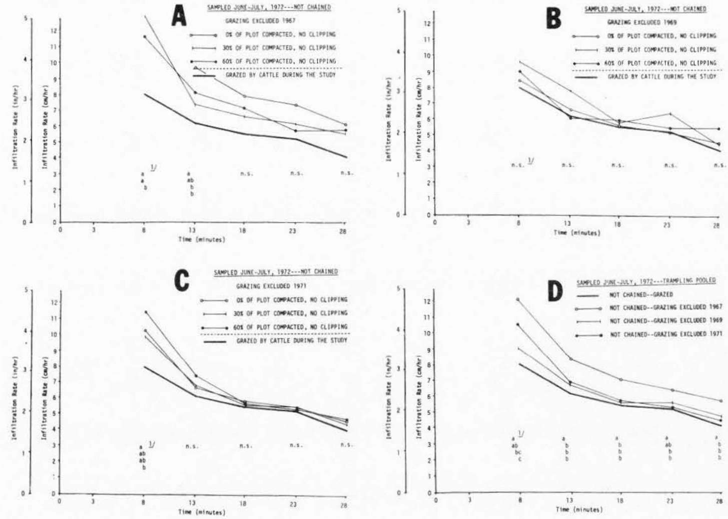
Sampled June-July, 1972

I. Compaction subtreatments--Figure 8-A, -B, -C. Significant differences between soil compaction subtreatments in infiltration rates were found only at the 8-13 minute time interval on plots protected from grazing since 1967 (Figure 8-A). This difference was between the 0 and 30 percent of the plot area being compacted at 13.6 kg cm^{-2} subtreatments. The 60 percent soil compaction subtreatment recorded infiltration capacities between the 0 and 30 percent compaction subtreatments and was not significantly different from any other subtreatment. Therefore, this one case of significantly different infiltration rates being recorded is probably due to random variation, rather than being attributable to the compaction subtreatments.

II. Subtreatments pooled--Figure 8-D. Because infiltration rates measured on soil compaction subtreatments were for the most part not significantly different, all trampling data within years of protection from grazing were pooled. Infiltration capacity measured on plots protected since 1967 were consistently and generally significantly higher than rates measured on other treatments. Plots grazed from May 1 to June 15, 1971, consistently recorded the lowest infiltration capacities, but these rates were not significantly different from areas protected from grazing since 1969 or 1971.

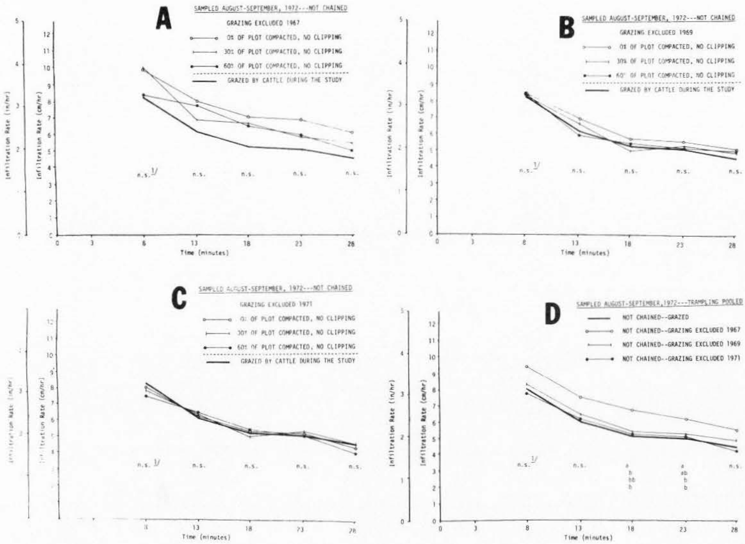
Sampled August-September, 1972.

I. Compaction subtreatments--Figure 9-A, -B, -C. No significant differences were measured in infiltration rates between



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 8. Infiltration rates measured on unchained woodland sites sampled June-July, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1969; C = compaction subtreatments applied to area protected from grazing since 1971; and D = comparison of grazing conditions (compaction subtreatments for all years pooled).



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 9. Infiltration rates measured on unchained woodland sites sampled August-September, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1969; C = compaction subtreatments applied to area protected from grazing since 1971; and D = comparison of grazing conditions (compaction subtreatments for all years pooled).

plots with 0, 20, and 60 percent of the soil surface area compacted at 13.6 kg cm^{-2}.

II. Subtreatments pooled--Figure 9-D. Plots protected from grazing since 1967 recorded significantly higher infiltration rates during the 13-18 and 18-23 minute time intervals than any other treatment. Grazed plots recorded consistently but not significantly lower infiltration rates than areas protected from grazing since 1969 or 1971.

Summary of infiltration results measured on unchained woodland sites

1. The only consistent and significant difference was a higher infiltration capacity measured on plots protected from grazing since 1967. Plots protected since 1969 or 1971 did not have infiltration rates different from plots grazed from May 1 to June 15 during 1971 and 1972.

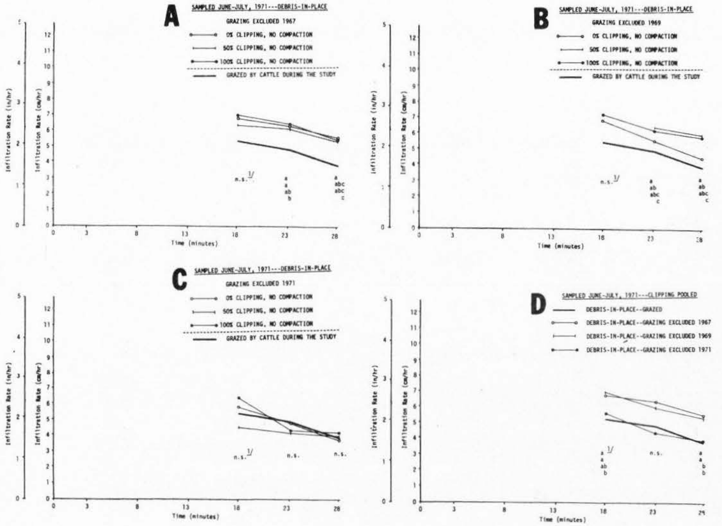
2. Except for the August-September, 1971, sampling period, plots grazed from May 1 to June 15 each year recorded lower infiltration rates than plots protected from grazing since 1967, 1969, or 1971.

3. Infiltration rates were not altered by soil compaction subtreatments applied on unchained woodland sites.

DIP Condition

Sampled June-July, 1971.

I. Clipping subtreatments--Figure 10-A, -B, -C. No significant differences in infiltration rates were recorded between



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 10. Infiltration rates measured on DIP sites sampled June-July, 1971. A = clipping subtreatments applied to areas protected from grazing since 1967; B = clipping subtreatments applied to areas protected from grazing since 1969; C = clipping subtreatments applied to areas protected from grazing since 1971; and D = comparison of grazing conditions (clipping subtreatments for all years pooled).

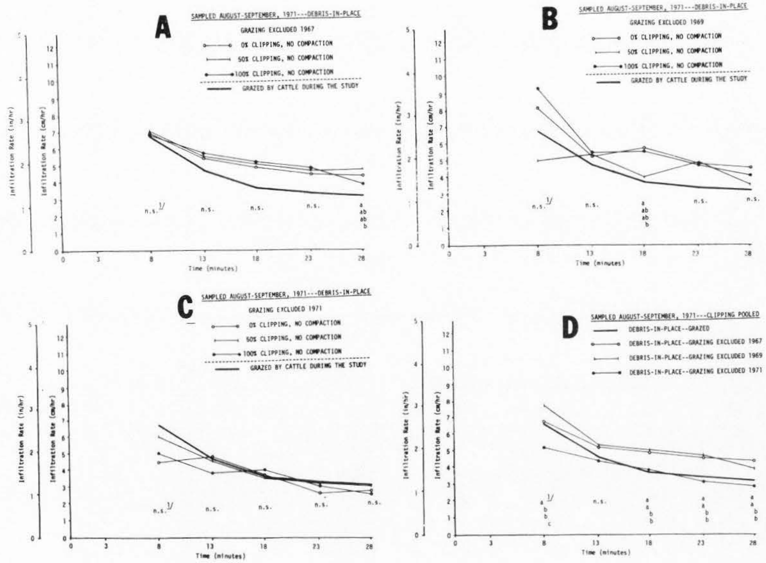
plots with approximately 0, 50, and 100 percent of the vegetation removed prior to infiltration tests. Infiltration rates on the area protected from grazing in 1971 seemed to have less variability between clipping subtreatments than plots protected from grazing in 1967 and 1969.

II. Clipping subtreatments--Figure 10-D. Infiltration rates measured on areas protected from grazing since 1967 and 1969 were consistently and generally significantly higher than rates recorded on plots protected from grazing since 1971 and on plots grazed from May 1 to June 15, 1971.

Sampled August-September, 1971.

I. Clipping subtreatments--Figure 11-A, -B, and -C. No statistical differences were observed in infiltration rates measured on plots with 0, 50, and 100 percent of the vegetation removed. Infiltration rates measured on plots protected from grazing in 1971 seem to have less variability between clipping subtreatments and grazed plots than areas protected in 1967 or 1969.

II. Clipping subtreatments pooled--Figure 11-D. Plots grazed from May 1 to June 15, 1971, and plots protected from grazing in 1971 recorded consistently and generally significantly lower infiltration rates than areas protected from grazing in 1967 and 1969.



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 11. Infiltration rates measured on DIP sites sampled August-September, 1971. A = clipping subtreatments applied to areas protected from grazing since 1967; B = clipping subtreatments applied to areas protected from grazing since 1969; C = clipping subtreatments applied to areas protected from grazing since 1971; D = comparison of grazing conditions (clipping subtreatments for all years pooled).

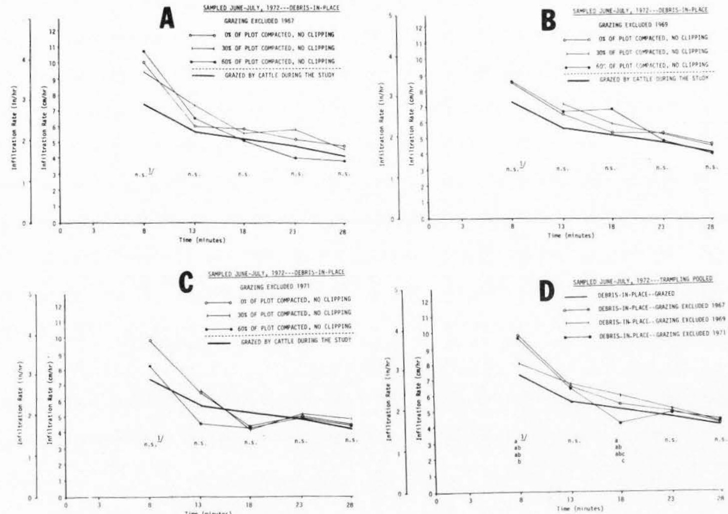
Sampled June-July, 1972.

I. Clipping subtreatments--Figure 12-A, -B, -C. Only two instances of significant differences were measured between plots with 0, 50, and 100 percent of the vegetation removed prior to infiltration test. The first occurred on plots protected from grazing in 1969 during the 8-13 minute time interval (Figure 12-B). In this instance, the 50 percent clipped plots were significantly higher than all other treatments. The second instance was measured on plots protected from grazing in 1971 during the 3-8 minute time interval (Figure 12-C) when plots with 0 percent of the vegetation removed recorded significantly higher infiltration rates than plots with 50 percent of the vegetation removed. These differences are probably due to random variation rather than due to the true relationship between clipping subtreatments and infiltration rates.

II. Clipping subtreatments pooled--Figure 12-D. Plots protected from grazing in 1967 and 1969 generally had significantly higher infiltration rates than plots protected from grazing in 1971 and plots grazed from May 1 to June 15, 1972.

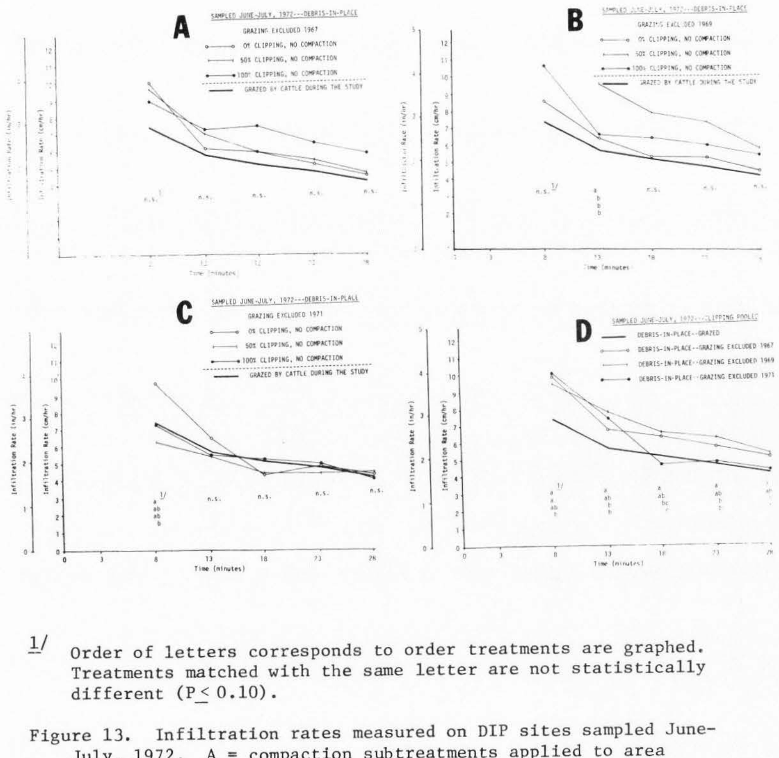
III. Compaction subtreatments--Figure 13-A, -B, -C. No significant differences in infiltration rates were measured between plots with 0, 30, and 60 percent of the soil surface area compacted at 13.6 kg cm^{-2}.

IV. Compaction subtreatments pooled--Figure 13-D. Only in two instances were significant differences in infiltration rates observed. First, during the 3-8 minute time interval, infiltration



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 12. Infiltration rates measured on DIP sites sampled June-July, 1972. A = clipping subtreatments applied to areas protected from grazing since 1967; B = clipping subtreatments applied to areas protected from grazing since 1969; C = clipping subtreatments applied to areas protected from grazing since 1971; D = comparison of grazing conditions (clipping subtreatments for all years pooled).



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 13. Infiltration rates measured on DIP sites sampled June-July, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1969; C = compaction subtreatments applied to area protected from grazing since 1971; and D = comparison of grazing conditions (compaction subtreatments for all years pooled).

rates measured on plots protected from grazing in 1967 were found to be significantly higher than plots grazed from May 1 to June 15, of 1972. Second, at the 13-18 minute time interval infiltration rates measured on plots protected from grazing in 1969 were found to be significantly higher than on plots protected in 1971.

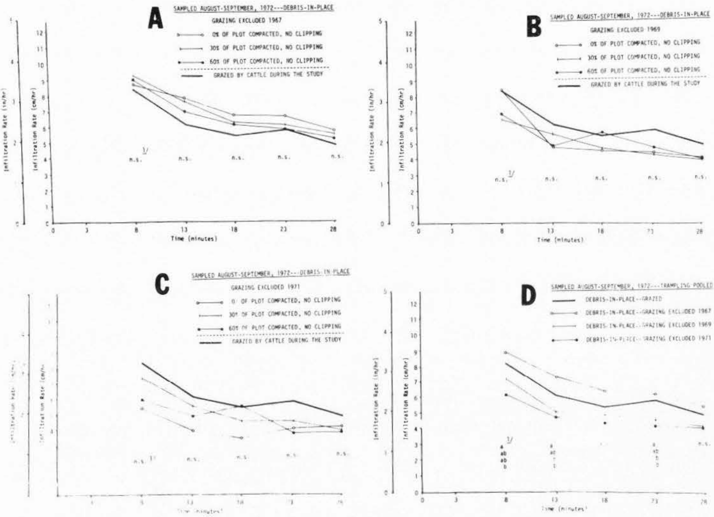
Sampled August-September, 1972.

I. Compaction subtreatments--Figure 14-A, -B, and -C. No significant differences were found in infiltration rates between plots with 0, 30, and 60 percent of their soil surface area compacted at 13.6 kg cm^{-2}.

II. Compaction subtreatments pooled--Figure 14-D. The 3-8, 8-13, and 18-23 minute time intervals revealed significant differences in infiltration rates. At the 3-8 minute interval, plots protected from grazing in 1967 recorded significantly higher infiltration rates than plots protected from grazing in 1971. At the 8-13 and 18-23 minute time intervals, plots protected from grazing since 1967 recorded a higher infiltration rate than plots protected since 1969 or 1971. Infiltration rates measured on grazed plots were not significantly different from any other treatment.

Summary of infiltration results measured on DIP sites

1. Plots protected from grazing since 1967 and 1969 had consistently and generally significantly higher infiltration rates



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 14. Infiltration rates measured on DIP sites sampled August-September, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1969 ; C = compaction subtreatments applied to area protected from grazing since 1971; and D = comparison of grazing conditions (compaction subtreatments for all years pooled).

than plots protected from grazing in 1971 or plots grazed during the study.

2. Contrary to results observed on the woodland sites where grazed areas had consistently lower infiltration rates, rates measured on grazed plots in the DIP area were not generally lower than other treatments.

3. Clipping and soil compaction subtreatments did not affect infiltration rates on DIP plots.

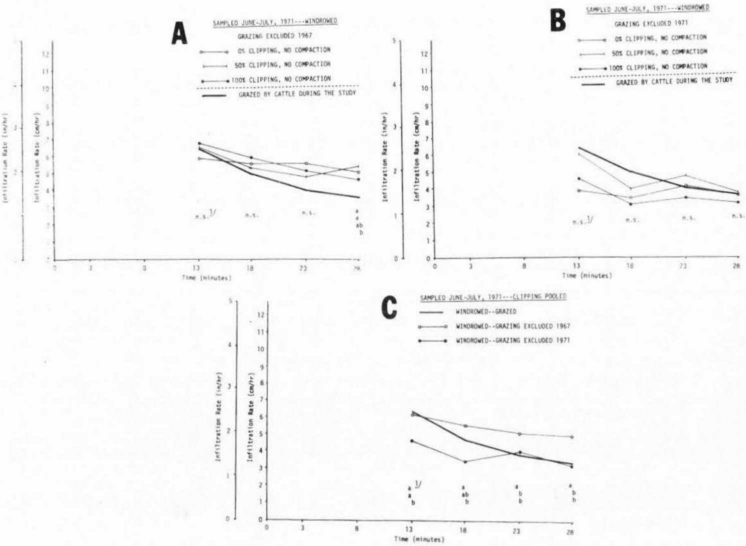
Windrowed condition

Sampled June-July, 1971.

I. Clipping subtreatments--Figure 15-A, and -B. No significant differences in infiltration rates were measured among plots with 0, 50, and 100 percent of the vegetation removed prior to infiltration test.

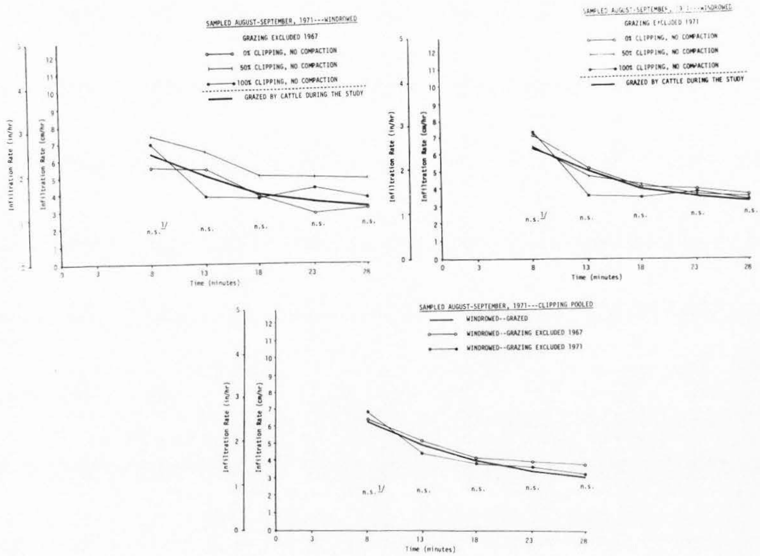
II. Clipping subtreatments pooled--Figure 15-C. Plots grazed from May 1 to June 13, 1971 had the highest infiltration rate during the 8-13 minute time interval, but these rates steadily declined until infiltration rates on grazed plots and plots protected from grazing in 1971 were almost equal at the 23-28 minute time interval. Plots protected from grazing since 1971 had consistently and significantly lower infiltration rates than plots protected since 1967.

Sampled August-September, 1971--Figure 16-A, -B, and -C. No significant differences in infiltration rates were recorded for



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 15. Infiltration rates measured on windrowed sites sampled June-July, 1971. A = clipping subtreatments applied to area protected from grazing since 1967; B = clipping subtreatments applied to area protected from grazing since 1971; and C = comparison of grazing conditions (clipping subtreatments pooled over all years).



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 16. Infiltration rates measured on windrowed sites sampled August-September, 1971. A = clipping subtreatments applied to area protected from grazing since 1967; B = clipping subtreatments applied to area protected from grazing since 1971; and C = comparison of grazing conditions (clipping subtreatments pooled over all years).

any of the comparisons between clipping subtreatments (Figure 16 -A and -B) and clipping subtreatments pooled (Figure 16-C).

Sampled June-July, 1972.

I. Clipping subtreatments--Figure 17-A and -B. No significant differences were measured between plots with 0, 50, and 100 percent of the vegetation removed prior to infiltration test.

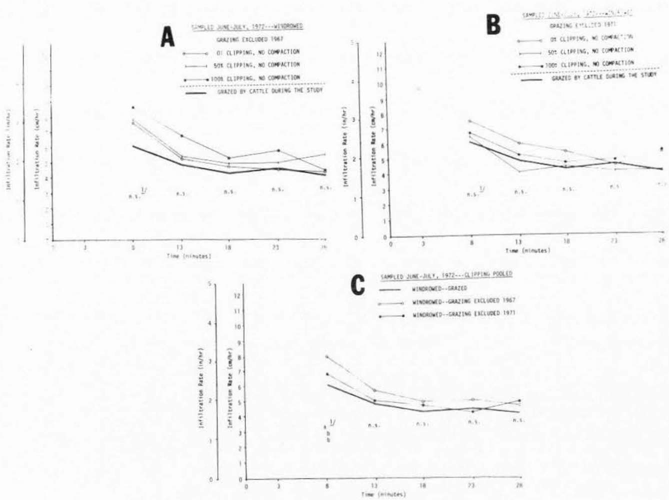
II. Clipping subtreatments pooled--Figure 17-C. Significant differences were observed only at the 3-8 minute time interval when plots protected from grazing since 1967 recorded a higher infiltration rate than plots protected since 1971 and plots grazed from May 1 to June 15, 1972.

III. Compaction subtreatments and compaction subtreatments pooled--Figure 18-A, -B, and -C. No significant differences in infiltration rates were measured for any soil compaction subtreatment or vegetation-grazing condition.

Sampled August-September, 1972.

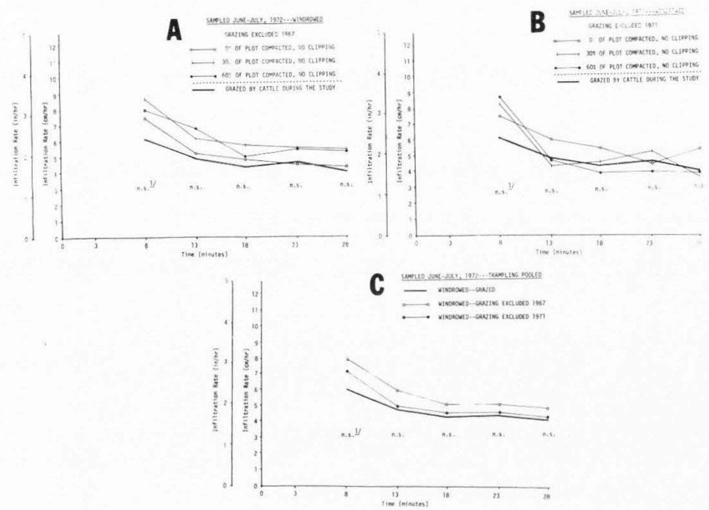
I. Compaction subtreatment--Figure 19-A, and -B. No significant differences were measured between plots with 0, 30, and 60 percent of the soil surface compacted at 13.6 kg cm^{-2}.

II. Compaction subtreatment pooled--Figure 19-C. Significant differences were observed only at the 8-13 minute time interval when plots protected since 1967 recorded a higher infiltration rate than plots protected since 1971 and plots grazed from May 1 to June 15, 1972.



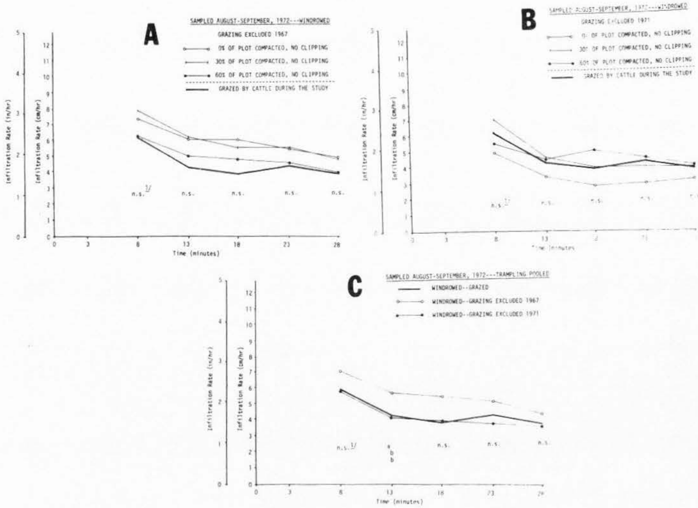
1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 17. Infiltration rates measured on windrowed sites sampled June-July, 1972. A = clipping subtreatments applied to area protected from grazing since 1967; B = clipping subtreatments applied to area protected from grazing since 1971; and C = comparison of grazing conditions (clipping subtreatments pooled over all years).



1/ Order of letters corresponds to order treatments are graphed. Treatmenst matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 18. Infiltration rates measured on windrowed sites sampled June-July, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1971; C = comparison of grazing conditions (compaction subtreatments pooled over all years).



1/ Order of letters corresponds to order treatments are graphed. Treatments matched with the same letter are not statistically different ($P \leq 0.10$).

Figure 19. Infiltration rates measured on windrowed sites sampled August-September, 1972. A = compaction subtreatments applied to area protected from grazing since 1967; B = compaction subtreatments applied to area protected from grazing since 1971; and C = comparison of grazing conditions (compaction subtreatments pooled over all years).

Summary of infiltration results measured on windrowed plots

1. Grazing and protection from grazing did not consistently influence the rate of infiltration on windrowed sites, although a tendency for plots protected since 1967 to record higher infiltration rate was observed.

2. Clipping and soil compaction subtreatments did not affect infiltration rates on windrowed plots.

Discussion of Infiltration Results

Influence of clipping subtreatments

Because forage removal by the clipping subtreatments was an instantaneous effect (rather than an accumulated effect as occurs with long-term, continuous grazing), the clipping subtreatments did not simulate actual livestock grazing other than simply removing protective vegetative material. Their primary benefit was, therefore, to provide three conditions of vegetative cover on the plots during the infiltration-erosion test.

The clipping subtreatments had no consistent or statistically measurable affect on infiltration rates on DIP or windrowed sites. This is surprising because most literature concludes that vegetative cover is a major factor influencing infiltration (summarized by Meeuwig and Packer 1976). The reasoning is that cover reduces the amount of surface sealing by fine soil particles; and increases hydraulic roughness allowing water to be held on the soil surface until infiltration can take place (Pearse and Woolley 1936; Rauzi and Kuhlman 1961; Rauzi, Fly and Dyksterhuis 1968; Meeuwig 1970). Extensive literature reviews by Wolff (1970) and Branson, Gifford, and Owens (1972) all support this conclusion. However, careful evaluation of this literature reveals that most of these studies were concluded in more humid areas with a cover potential of 50 to 100 percent. The influence of vegetative cover on infiltration was much less consistent when vegetative cover dropped below 50 percent.

Rauzi and Smith (1973) studied the relationship between grazing intensity and infiltration rates on three soils at the Central Plains Experimental Range in eastern Colorado. The Ascalon Sandy Loam and the Nunn Loam had significantly lower infiltration rates for heavily grazed areas than for lightly or moderately grazed sites. There was also a strong positive correlation between vegetative cover and infiltration rates on these two soils. However, no differences in infiltration rates were found between grazing treatments on Shingle Sandy Loam. On this site the light, moderate, and heavy grazing treatments all had less than 40 percent total cover. The authors concluded that infiltration rates on Shingle Sandy Loam did not respond to grazing treatments because equal splash erosion and soil sealing occurred on all three grazing treatments.

It would appear that when vegetative cover is less than 40 or 50 percent, the positive influence of cover on infiltration rates is overshadowed by other factors. Kincaid, Gartner, and Schreiber

(1964), working on semiarid range in Arizona, found a high correlation between the amount of gravel in the surface one-fourth inch of soil and the infiltration rate. This correlation only held for sites with less than 40 percent vegetative cover. As the vegetative cover increased, the influence of gravel decreased until it was entirely overshadowed by that of vegetative cover.

Thompson (1968) also reported that vegetation was not a controlling factor in the relationship between grazing and infiltration of Badger Wash in western Colorado, where percent cover is less than 35 percent. He indicated that a higher correlation existed between infiltartion rates and the sampling season than between infiltration and any vegetative or soil factors studied.

Grazing has reduced infiltration rates on many areas. This reduction is usually partially attributed to forage being removed by livestock, but studies by Rauzi and Smika (1963) indicate that forage removal causes an accumulative effect rather than an instantaneous effect. Their study compared areas where vegetation was clipped throughout the season, areas clipped only in the fall with none of the clipped material left as litter, and plots clipped in the fall with one-half of the material returned to the plot as litter. Both of the plots clipped in the fall had significantly higher infiltration rates than the plots clipped throughout the season. No differences attributable to litter being returned to the plots were found between the two fall clipped plots. A season of clipping reduced infiltration while instantaneous forage removal immediately prior to infiltration tests had no effect.

Results of my study on sandy loam soils in southeastern Utah indicate that when vegetative cover is less than 50 percent, factors other than vegetation begin to control infiltration. Also instantaneous removal of vegetation does not seem to alter infiltration. Otherwise, a decrease in infiltration rate would have occurred on plots where all vegetative cover was removed (100 percent clipped). This latter conclusion may be somewhat explained by the growth characteristics of crested wheatgrass. This plant grows as a bunchgrass and there is not much difference between basal cover and foliage cover. The "100 percent clipped" subtreatment removed all the foliage cover, but did not affect the proportion of the soil protected by the basal cover.

Influence of soil compaction subtreatments

The soil compaction subtreatments (0, 30, and 60 percent of the dry soil surface compacted at 13.6 kg cm^{-2} prior to infiltration test) had no consistent or statistically measurable effect on infiltration rates recorded on unchained woodland, DIP, or windrowed sites. Soil compaction (or related measurements such as bulk density or porosity) has been reported as a factor influencing infiltration, but most studies indicated that soil compaction is primarily a problem on fine textured soils (Lull 1959, and Reynolds and Packer 1962). Apparently, the sandy loam soil occurring on the southeastern Utah study site did not contain enough clay and silt particles to be affected by the compaction subtreatments. It must be noted, however, that these subtreatments were an instantaneous, short-term (less than one minute) application of pressure. Also, the compaction subtreatments represented the static pressure exerted by a mature cow. Considerably more pressure occurs when the animals walk. A long-term history of compaction, as might result from a season or repeated seasons of grazing, could have a different effect.

Influence of grazing and varying periods of rest from grazing

Rest from livestock grazing since 1967 significantly increased infiltration rates on unchained woodland and DIP plots. Unchained woodland plots grazed during 1971 and 1972 from May 1 to June 15, consistently had the lowest infiltration rate. This lower rate was not significantly lower than plots protected from grazing since 1969 or 1971. Grazed plots did not consistently have the lowest infiltration rate on DIP or windrowed sites.

It seems that an unchained woodland area with no prior history of site disturbances is impacted by grazing more severely than DIP areas with a history of some disturbance (two-way chaining and aerial seeding) and windrowed areas with a history of considerable disturbance (one-way chaining, debris disposal, drill seeding). Conversely, it might be concluded that maximum disturbance of the factors influencing infiltration occurred on the windrowed sites during the vegetative conversion treatments. Therefore, livestock grazing did not further reduce infiltration on the windrowed site. In addition, rest from grazing since 1967 was not enough to allow windrowed sites to completely recover from the disturbance associated with vegetative conversion.

DIP sites were previously disturbed by chaining treatments to the point that livestock grazing did not consistently further reduce infiltration rates. However, the disturbance associated with chaining was not permanent, and some recovery of infiltration capacity was made on DIP sites protected since 1967 and 1969.

Infiltration rates on woodland sites were consistently reduced by livestock grazing. Disturbance by livestock was not permanent and recovery of infiltration capacity was recorded on plots protected from grazing since 1967.

Evaluation of the relationship between vegetative condition having the same grazing history and infiltration rates supports the conclusion that on sandy loam soils in southeastern Utah chaining and windrowing consistently reduced infiltration rates below the rates measured on unchained woodland and DIP sites (Table 2). This trend toward lower infiltration rates on windrowed sites was consistent for all grazing conditions indicating that protection from grazing for 4-5 years does not allow infiltration rates on windrowed sites to recover or increase to a level equal to rates measured on closely adjacent unchained woodland sites.

The following tabulation represents the average increase in infiltration rates (cm hr^{-1}) per plot as determined by subtracting mean infiltration rates measured on grazed plots from mean rates measured on areas protected from grazing since 1967 or 1971:

Table 2 . Infiltration rates measured on unchained woodland, DIP, and windrowed sites during four sampling periods.

Sampling Period	Vegetative Condition	Protected from Grazing Since 1967 13-18 Minute Time Interval ($cm\ hr^{-1}$)	Protected from Grazing Since 1967 23-28 Minute Time Interval ($cm\ hr^{-1}$)	Protected from Grazing Since 1971 13-18 Minute Time Interval ($cm\ hr^{-1}$)	Protected from Grazing Since 1971 23-28 Minute Time Interval ($cm\ hr^{-1}$)	Grazed 13-18 Minute Time Interval ($cm\ hr^{-1}$)	Grazed 23-28 Minute Time Interval ($cm\ hr^{-1}$)
June-July, 1971	Unchained woodland	6.1 a[1/]	4.6 b	4.8 a	4.2 a	4.7 b	3.7 a
	DIP	6.7 a	5.6 a	5.6 a	3.8 a	6.1 a	4.3 a
	Windrowed	5.6 a	4.6 b	3.5 b	3.1 b	4.7 b	3.5 a
August-September, 1971	Unchained woodland	3.1 a	3.4 a	5.7 a	4.7 a	4.2 a	4.0 a
	DIP	3.9 a	2.8 a	5.0 a b	4.4 a b	3.7 a	3.3 a b
	Windrowed	3.9 a	3.3 a	4.2 b	3.6 b	3.9 a	3.0 b
June-July, 1972	Unchained woodland	7.0 a	5.7 a	5.6 a	4.4 a	5.1 a	4.2 a
	DIP	6.0 a b	5.0 a	4.6 b	4.4 a	4.9 a	3.8 a
	Windrowed	5.0 b	4.7 a	4.6 b	4.8 a	4.2 a	4.2 a
August-September, 1972	Unchained Woodland	6.6 a	5.4 a	5.3 a	4.5 a	5.1 a	4.6 a
	DIP	6.3 a b	5.3 a	4.3 a	3.7 a	5.3 a	4.8 a
	Windrowed	5.2 b	4.3 b	4.0 a	3.8 a	3.8 b	3.8 a

1/ Means within sampling periods followed by the same letter are not statistically significant ($P \leq 0.10$).

Grazing and Vegetative Condition	13-18 Minute Time Interval	23-28 Minute Time Interval
Grazing Excluded in 1967		
Unchained woodland	+ .93 cm hr^{-1}	+ .65 cm hr^{-1}
DIP	+ .73 cm hr^{-1}	+ .63 cm hr^{-1}
Windrowed	+ .70 cm hr^{-1}	+ .60 cm hr^{-1}
Grazing Excluded in 1971		
Unchained woodland	+ .58 cm hr^{-1}	+ .33 cm hr^{-1}
DIP	+ .10 cm hr^{-1}	+ .15 cm hr^{-1}
Windrowed	- .08 cm hr^{-1}	+ .10 cm hr^{-1}

Apparently infiltration rates on woodland sites quickly increase when protected from grazing for only 1-2 years. Additional increases in infiltraiton rates on woodland sites occur for at least 4-5 years. Windrowed and DIP sites recover more slowly. However, infiltration rates did increase on all three vegetative conditions as the period of rest from grazing increased. The number of years rest from grazing that is needed to obtain the maximum increase in infiltration rates is not known.

Results of this study generally agree with studies by Williams (1969) who reported significantly higher infiltration rates on unchained woodland than windrowed sites.

Factors Influencing Infiltration Rates

Unchained woodland

The following tabulation (summarized from Table 3) lists the variables explaining significant amounts of variation in infiltration rates measured on unchained woodland sites (numbers indicate the frequency (percent) variables were found significant):

Table 3. Variables explaining significant ($P \leq 0.10$) amounts of variation in infiltration rates measured on unchained woodland sites. Variables are listed in order of importance as identified by the stepwise multiple regression analysis.

Sampling Period	13-18 Minute Time Interval	23-28 Minute Time Interval
June-July, 1971	Orthogonal Comparison Representing Grazing Condition 2.5 cm Total Porosity 7.5 cm Saturated Hydraulic Conductivity 2.5 cm Capillary Porosity	Orthogonal Comparison Representing Grazing Condition Percent Slope
Accumulated R^2	26%	22%
August-September, 1971	Percent Slope 7.5 cm Bulk Density 2.5 cm Percent Silt 7.5 cm Saturated Hydraulic Conductivity 7.5 cm Capillary Porosity	Orthogonal Comparison Representing Grazing Condition 7.5 cm Saturated Hydraulic Conductivity Percent Slope 7.5 Capillary Porosity
Accumulated R^2	35%	21%
June-July, 1972--Compaction Subtreatments	None	7.5 Capillary Porosity
Accumulated R^2		13%
August-September, 1972--Compaction Subtreatments	2.5 cm Capillary Porosity 2.5 Bulk Density Air Permeameter Reading 2.5 cm Total Porosity 2.5 cm Saturated Hydraulic Conductivity	2.5 cm Saturated Hydraulic Conductivity 2.5 cm Bulk Density 2.5 cm Total Porosity 2.5 cm Capillary Porosity
Accumulated R^2	22%	17%

Variables	18-18 Minute Time Interval	23-28 Minute Time Interval
Percent Slope	33%	66%
Saturated Hydraulic Conductivity		
2.5 cm deep soil cores	33%	33%
7.5 cm deep soil cores	50%	25%
Capillary Porosity		
2.5 cm deep soil cores	66%	100%
7.5 cm deep soil cores	25%	
Total Porosity		
2.5 cm deep soil cores	66%	33%
Bulk Density		
2.5 cm deep soil cores	33%	33%
7.5 cm deep soil cores	25%	
Orthogoanl Comparison Representing Grazing Condition	25%	50%
Air Permeameter Reading	50%	
Percent Silt (2.5 cm deep soil cores)	100%	

Percent silt was only sampled during the August-September, 1971, sampling period; therefore, the reported 100 percent frequency of significance in explaining variation in infiltration during the 13-18 minute time interval may be overestimating the value of textural parameters. Percent silt did not explain a significant amount of variation in infiltration during the 23-28 minute time interval.

The 100 percent frequency of significance listed for capillary porosity of 2.5 cm deep soil cores measured during the 23-28 minute time interval is probably a true representation of its value because this variable explained significant amounts of infiltration variation during all sampling periods except June-July, 1972, when the 2.5 cm deep soil cores were damaged and soil characteristics were not measured. Capillary porosity measured from 2.5 cm deep soil cores was also valuable in explaining variation in infiltration during the 13-18 minute time interval.

Evaluation of correlation coefficients between infiltration rates and capillary porosity in 2.5 cm deep soil cores indicate a non-significant, but consistently negative relationship; i.e., as capillary porosity (small pores) increases infiltration rates become lower. Grazed sites consistently had lower capillary porosity in the 2.5 cm deep soil cores than plots protected from grazing for varying periods of time. It appears that grazing is compacting the surface soil and/or breaking up sand size soil aggregates, thus causing a reduction in infiltration rates. Capillary porosity seems to be a more sensitive soil parameter to indicate grazing impact on infiltration than bulk density or total porosity.

Total porosity (2.5 cm deep soil cores), saturated hydraulic conductivity (7.5 cm deep soil cores), percent slope, and the orthogonal comparison representing grazing condition were additional variables that were significantly useful in explaining variation in infiltration rates measured on unchained woodland sites.

The regression equations developed with the stepwise multiple regression programs were not successful in explaining variation in infiltration rates (Table 3). Significant variables explained (R^2) from 0 to 35 percent of the variation in infiltration during particular time intervals and sampling periods. Addition of non-significant variables increases the amount of variation explained by the multiple regression model, but the increase is as likely due to chance as to true variable relationships.

Variables	13-18 Minute Time Interval	23-28 Minute Time Interval
Total Porosity		
2.5 cm deep soil cores	66%	33%
Bulk Density		
2.5 cm deep soil cores	33%	33%
7.5 cm deep soil cores	25%	
Orthogonal Comparison Representing Grazing Condition	25%	50%
Air Permeameter Reading	50%	
Percent Silt (2.5 cm deep soil cores)	100%	

Percent silt was only sampled during the August-September, 1971, sampling period; therefore, the reported 100 percent frequency of significance in explaining variation in infiltration during the 13-18 minute time interval may be overestimating the value of textural parameters. Percent silt did not explain a significant amount of variation in infiltration during the 23-28 minute time interval.

The 100 percent frequency of significance listed for 2.5 cm capillary porosity measured during the 23-28 minute time interval is probably a true representation of its value because this variable explained significant amounts of infiltration variation during all sampling periods except June-July, 1972, when the 2.5 cm deep soil cores were damaged and soil characteristics were not measured. Capillary porosity measured from 2.5 cm soil cores was also valuable in explaining variation in infiltration during the 13-18 minute time interval.

Evaluation of correlation coefficients between infiltration rates and 2.5 cm capillary porosity indicate a non-significant, but consistently negative relationship; i.e., as capillary porosity (small pores) increases infiltration rates become lower. Grazed sites consistently recorded lower 2.5 cm capillary porosity than plots protected from grazing for varying periods of time. It appears that grazing is compacting the surface soil and/or breaking up sand size soil aggregates, thus causing a reduction in infiltration rates. Capillary porosity seems to be a more sensitive soil parameter to indicate grazing impact on infiltration than bulk density or total porosity.

Total porosity (2.5 cm soil cores), saturated hydraulic conductivity (7.5 cm soil cores), percent slope, and the orthogonal comparison representing grazing condition were additional variables that were consistently and significantly useful in explaining variation in infiltration rates measured on unchained woodland sites.

The regression equations developed with the stepwise multiple regression programs were not successful in explaining variation in infiltration rates (Table 3). Significant variables explained (R^2) from 0 to 35 percent of the variation in infiltration during particular time intervals and sampling periods. Addition of non-significant variables increases the amount of variation explained by the multiple regression model, but the increase is as likely due to chance as to true variable relationships.

DIP condition

Vegetation and soil parameters measured from DIP plots were about equal in importance in explaining variation of infiltration rates during the 23-28 minute time interval. Soil characteristics were more important than vegetative parameters during the 13-18 minute time interval. The following tabulation (summarized from Table 4) list all variables explaining significant amounts of variation in infiltration rates on DIP sites (numbers indicate the frequency (percent) variables were identified as significant):

Variables	13-18 Minute Time Interval	23-28 Minute Time Interval
Percent Slope	25%	
Forage on Plot at End of Infiltration Test	20%	60%
Percent Cover		
Bare Ground		20%
Crested Wheatgrass		20%
Litter		20%
Total Cover	20%	20%
Saturated Hydraulic Conductivity		
7.5 cm deep soil cores		20%
Capillary Porosity		
2.5 cm deep soil cores	66%	66%
7.5 cm deep soil cores		20%
Total Porosity		
2.5 cm deep soil cores	33%	33%
7.5 cm deep soil cores	40%	
Bulk Density		
7.5 cm deep soil cores	20%	20%
Orthogonal Comparison Representing Grazing Conditions	20%	20%
Percent Sand plus Sand Sized Aggregates (2.5 cm deep soil cores)		100%
Sand Sized Aggregates (2.5 cm deep soil cores)		100%
Percent Silt (2.5 cm deep soil cores)		100%
Percent Clay (7.5 cm deep soil cores)		100%

Table 4. Variables explaining significant ($P \leq 0.10$) amounts of variation in infiltration rates measured on DIP sites. Variables are listed in order of importance as identified by the stepwise multiple regression analysis.

Sampling Period	13-18 Minute Time Interval	23-28 Minute Time Interval
June-July, 1971-- Clipping Subtreatments	None	Orthogonal Comparison Representing Grazing Condition Percent Cover--litter Percent Cover--Crested Wheatgrass Percent Cover--Bare Ground
Accumulated R^2		28%
August-September, 1971-- Clipping Subtreatments	Orthogonal Comparison Representing Grazing Condition 2.5 cm Capillary Porosity Percent Slope 7.5 cm Bulk Density 7.5 cm Total Porosity	2.5 cm Capillary Porosity 7.5 Bulk Density Forage on Plot at End of Infiltration Test 7.5 cm Saturated Hydraulic Conductivity 2.5 cm Percent Sand plus Sand Sized Aggregates 7.5 cm Percent Clay 2.5 cm Silt 2.5 cm Sand Sized Aggregates
Accumulated R^2	27%	38%
June-July, 1972-- Clipping Subtreatments	Forage on Plot at End of Infiltration Test Percent Total Cover 7.5 cm Total Porosity	Forage on Plot at End of Infiltration Test Percent Total Cover 7.5 cm Capillary Porosity
Accumulated R^2	27%	29%
June-July, 1972 Compaction Subtreatments	None	Forage on Plot at End of Infiltration Test
Accumulated R^2		9%

Table 4. (cont'd)

Sampling Period	13-28 Minute Time Interval	13-28 Minute Time Interval
August-September, 1972--Compaction Subtreatments	2.5 cm Total Porosity	2.5 cm Total Porosity
	2.5 cm Capillary Porosity	2.5 cm Capillary Porosity
Accumulated R^2	28%	25%

The last four soil textural characteristics were only sampled during August-September, 1971; thus the 100 percent frequency of importance in explaining variation in infiltration rates for the 23-28 minute time interval may be overestimating the true value of these variables.

Capillary porosity measured in 2.5 cm deep soil cores was the most useful variable in explaining infiltration rates during the 13-18 and 23-28 minute time interval. Percent slope and total porosity in 2.5 cm deep soil cores were the only other variables that were consistently identified as explaining significant amounts of variation in infiltration rates.

Significant variables explained (R^2) from 0 to 38 percent of the variation in infiltration rates measured on DIP sites (Table 4). No multiple regreasion equation was developed that successfully explained infiltration variation for sampling periods.

Windrowed condition

Neither vegetative or soil parameters proved particularly important in explaining variation in infiltration rates measured on windrowed sites. Percent cover provided by crested wheatgrass was the only variable that consistently explained infiltration variation during the 13-18 and 23-28 minute time intervals.

The following tabulation (summarized from Table 5) list all variables that explained significant amounts of variation in infiltration on windrowed areas (numbers indicate the frequency (percent) variables were identified as significant):

Table 5. Variables explaining siginificant ($P \leq 0.10$) amounts of variation in infiltration rates measured on windrowed sites. Variables are listed in order of importance as identified by the stepwise multiple regression analysis.

Sampling Period	13-18 Minute Time Interval	23-28 Minute Time Interval
June-July, 1971-- Clipping Subtreatments	Orthogonal Comparison Representing Grazing Condition 2.5 cm Total Porosity	None
Accumulated R^2	31%	
August-September, 1971-- Clipping Subtreatments	2.5 cm Percent Clay 2.5 cm Percent Sand Plus Sand Sized Aggregates 2.5 cm Sand Sized Aggregates 2.5 cm Percent Silt 2.5 cm Bulk Density Percent Cover--Crested Wheatgrass Forage on Plot at End of Infiltration Test	Forage on Plot at End of Infiltration Test Percent Cover--Crested Wheatgrass
Accumulated R^2	20%	14%
June-July, 1972-- Clipping Subtreatments	None	Orthogonal Comparison Representing Grazing Condition Percent Cover--Crested Wheatgrass Percent Slope 7.5 cm Saturated Hydraulic Conductivity 7.5 cm Capillary Porosity
Accumulated R^2		29%
June-July, 1972 Compaction Subtreatments	7.5 cm Saturated Hydraulic Conductivity Percent Cover--Crested Wheatgrass 7.5 Bulk Density	Percent Total Cover Forage on Plot at End of Infiltration Test 7.5 cm Total Porosity
Accumulated R^2	25%	20%

Table 5. (cont'd)

Sampling Period	13-18 Minute Time Interval	23-28 Minute Time Interval
June-July, 1972 Compaction Subtreatment	7.5 Saturated Hydraulic Conductivity Percent Cover--Crested Wheatgrass 7.5 cm Bulk Density	Percent Total Cover Forage on Plot at End of Infiltration Test 7.5 cm Total Porosity
Accumulated R^2	25%	20%
August-September, 1972--Compaction Subtreatments	Orthogonal Comparison Representing Grazing Condition 2.5 cm Bulk Density	2.5 cm Saturated Hydraulic Conductivity 7.5 cm Bulk Density Percent Total Cover 7.5 Saturated Hydraulic Conductivity
Accumulated R^2	13	39

Variable	3-18 Minute Time Interval	23-28 Minute Time Interval
Percent Slope	-	25%
Forage on Plot at End of Infiltration Test	20%	40%
Crested Wheatgrass	40%	40%
Total Cover	-	40%
Saturated Hydraulic Conductivity		
2.5 cm deep soil cores	-	33%
7.5 cm deep soil cores	20%	40%
Capillary Porosity		
7.5 cm deep soil cores	-	20%
Total Porosity		
2.5 cm deep soil cores	33%	-
7.5 cm deep soil cores	-	20%
Bulk Density		
2.5 cm deep soil cores	66%	-
7.5 cm deep soil cores	20%	20%
Orthogonal Comparison Representing Grazing Condition	40%	20%
Percent Sand plus Sand Sized Aggregates (2.5 cm deep soil cores)	100%	-
Sand Sized Aggregates (2.5 cm deep soil cores)	100%	-
Percent Clay (2.5 cm deep soil cores)	100%	-

The 100 percent frequency of importance in explaining variation measured in infiltration for the last three soil textural characteristics may overestimate their true value because these textural parameters were only sampled during August-September, 1971.

Significant variables explained (R^2) 0 to 39 percent of the variation in infiltration rates measured on windrowed sites (Table 5). Multiple regression models were not successful in explaining variation in infiltration rates.

Discussion of Factors Influencing
Infiltration Rates

A total of 21 different variables were identified by multiple regression models as explaining significant amounts of variation in infiltration rates measured on unchained woodland, DIP, and windrowed sites during one or more sampling periods. However, none of these variables proved consistently useful for explaining variation in infiltration during all vegetative conversion--grazing condition combinations studied. This result probably represents the true complex nature of hydrologic systems and expresses the frustration of other researchers (Williams, 1969 and Gifford, P.C.) who have tried to develop models to successfully predict infiltration rates on pinyon-juniper areas. Despite this frustration and inability to develop these models, several results from this study deserve additional investigation.

First, although some useful information was provided by both soil core depths, data from 0-2.5 cm deep soil cores seems more useful in explaining variation in infiltration than data from the 0-7.5 cm deep soil cores. This result was particularly true for measurement of capillary porosity which was the most consistent variable in explaining significant amounts of variation in infiltration measured on unchained and DIP sites.

Alderfer and Robinson (1947) reported that grazing effects on soils are most apparent in the upper 2.5 cm of soil. Other studies indicate the critical depth may be slightly deeper (Robinson and

Alderfer 1952, Keen and Casheen 1932, and Kucera 1958), but little change in soil characteristics attributable to grazing seem to occur below 8 cm. A reduction in plant rooting depth and below ground biomass at depths greater than 20 cm appear to be the major exception (Smoliak et al. 1972).

Second, soil textural characteristics were identified as explaining significant amounts of variation on all vegetative conditions during the August-September, 1972, sampling period. No significany differences in textural characteristics existed between vegetative--grazing conditions among data collected during August-September, 1972; therefore textural data were not collected during other sampling periods. Multiple regression analysis indicates that some relationship existed between infiltration rates and various textural characteristics. Additional study needs to be directed toward further explaining this relationship. Percent sand plus sand sized aggregates seem to be the most important variable to study.

Third, a knowledge of site history (vegetative conversion, grazing, and environmental situations) is probably necessary to successfully explain variation in infiltration. Results of this study indicate that unchained woodland, DIP, and windrowed sites react differently to grazing or different periods of rest from grazing. In addition, different variables were identified by the stepwise multiple regression program as being valuable in explaining variation in infiltration rates for each vegetative conversion--grazing condition combination. And the same variables used in regression equations for unchained, DIP and windrowed sites were not consistent in their ability to explain (R^2) variation in infiltration measured on the different areas.

The value of knowing grazing history is indicated by the number of times that the orthogonal comparison representing grazing condition was identified as explaining significant amounts of variation in infiltration rates. This comparison was found significant at least once on all three vegetative conditions and during all time intervals of the infiltration test. Separating multiple regression analysis into grazing conditions within vegetative conditions also supports the idea that grazing history helps in evaluating variation measured in infiltration rates. Table 6 indicates that the amount of variation explained by significant variables in multiple regression models is increased when grazing conditions are analyzed separately. A unique example is the 80 percent of variation in infiltration that is explained by significant variables on DIP plots protected from grazing since 1969 (Table 6). Additional value of knowing the grazing history is indicated by the different order of importance variables were selected for each grazing condition by the multiple regression programs.

Grazing history information that would be valuable includes the 1) intensity of use (number of animals per unit of area per unit of time; 2) change in vegetation composition, cover, and production that

Table 6. Variables explaining significant ($P \leq 0.10$) amounts of variation in infiltration rates measured on unchained woodland, DIP, and windrowed sites--grazing conditions separated--during the 23-28 minute time interval (June-July, 1971 sampling period). Varialbes are listed in order of importance as identified by the stepwise multiple regression analyses.

Vegetative Condition	Grazing Excluded 1967	Grazing Excluded 1969	Grazing Excluded 1971	Grazed During Study
Unchained woodland	None	2.5 cm Bulk Density	None	2.5 cm Saturated Hydraulic Conductivity
Accumulated R^2		16%		19%
DIP	None	7.5 cm Saturated Hydraulic Conductivity	2.5 cm Capillary Porosity	Forage on Plot at End of Infiltration Test
		2.5 cm Total Porosity	Forage on Plot at End of of Infiltration Test	Percent Cover—Bare Ground
		Forage on Plot at End of Infiltration Test	2.5 cm Bulk Density	7.5 cm Capillary Porosity
		2.5 cm Bulk Density	7.5 cm Total Porosity	2.5 cm Total Porosity
				7.5 cm Total Porosity
Accumulated R^2		80%	61%	56%
Windrowed	None	Not applicable	None	2.5 cm Capillary Porosity
Accumulated R^2				31%

may have occurred as a result of this grazing use; 3) number of years that the present grazing program has been applied, and 4) grazing use prior to the present program.

Environmental data might also be useful for interpreting infiltration results. Examples include information on the past winter's freezing and thawing cycle which helps fluff-up the soil and increase infiltration capacity, the timing (in relationship to sampling period) and intensity of recent precipitation events that may have altered soil surface or vegetative characteristics, or severe wind storms that may have altered surface characteristics. Any of these events could influence soil or vegetative parameters in such a way that a variable explaining significant amounts of variation in infiltration during one sampling period may be unimportant during another sampling period. And these environmental situations might well affect different vegetative conditions (woodland vs. windrowed) in different ways.

In summary, results of this study indicate that generalized equations to predict infiltration rates on unchained woodland, DIP, and windrowed pinyon-juniper sites will probably not be consistently accurate and therefore probably not universally useful. The primary value of multiple regression analysis is probably to help explain significant differences between treatments that are identified by analysis of variance and Duncan's New Multiple Range Test (Duncan 1955) techniques.

Erosion Results

The following tabulation indicates the organization of the erosion results section:

Unchained Woodland

Sampled June-July, 1971

Sampled August-September, 1971

Sampled June-July, 1972
compaction subtreatments
compaction subtreatments pooled

Sampled August-September, 1972
compaction subtreatments
compaction subtreatments pooled

Summary of erosion data measured on
unchained woodland sites.

DIP Condition

Sampled June-July, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled August-September, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled June-July, 1972
clipping subtreatments and clipping subtreatments pooled
compaction subtreatments
compaction subtreatments pooled

Sampled August-September, 1972

Summary of erosion rate data measured on
DIP sites.

Windrowed Condition

Sampled June-July, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled August-September, 1971
clipping subtreatments
clipping subtreatments pooled

Sampled June-July, 1972

Sampled August-September, 1972
compaction subtreatments
compaction subtreatments pooled

Summary of erosion rate data measured on windrowed plots.

Unchained woodland

Sampled June-July, 1971--Table 7. No significant differences were measured in erosion rates during the 8-18 minute time interval although grazed plots and those protected from grazing in 1971 recorded higher erosion rates than plots protected from grazing since 1967 and 1969. During the 18-38 minute time interval, plots protected from grazing in 1971 produced significantly more sediment than grazed plots and plots protected from grazing since 1967. Grazed plots and plots protected from grazing since 1967 produced significantly more sediment than plots protected from grazing in 1969.

Sampled August-September, 1971--Table 7. During the 8-18 minute time interval, grazed plots and plots protected since 1971 had significantly higher erosion rates than plots protected from grazing since 1969. No differences were measured in erosion rates during the 18-28 minute time interval.

Table 7. Erosion rates measured on unchained woodland sites sampled June-July, 1971, and August-September, 1971.

Sampling Period	Grazing Condition	Erosion Rates: 8-18 Minute Time Interval ($kg\ ha^{-1}$)	Erosion Rates: 18-28 Minute Time Interval ($kg\ ha^{-1}$)
June-July, 1971	Grazed	777 a[1/]	315 b[1/]
	Grazing excluded in 1967	234 a	335 b
	Grazing excluded in 1969	161 a	175 c
	Grazing excluded in 1971	623 a	1092 a
August-September, 1971	Grazed	1357 a	978 a
	Grazing excluded in 1967	878 ab	1182 a
	Grazing excluded in 1969	456 b	645 a
	Grazing excluded in 1971	1514 a	1721 a

1/ Means of grazing conditions within a sampling period are not statistically different ($P \leq 0.10$) if followed by the same letter.

Sampled June-July, 1972--Table 8.

I. Compaction subtreatments. No significant differences in erosion rates attributable to soil compaction subtreatments were measured for any grazing condition during the 8-18 or the 18-28 minute time interval.

II. Subtreatments pooled. No significant differences in erosion rates were recorded for any grazing condition during the 8-18 or 18-28 minute time interval.

Sampled August-September, 1972--Table 9.

I. Compaction subtreatments. The 30 and 60 percent soil compaction subtreatments significantly increased erosion rates above the 0 percent soil compaction subtreatment on plots protected from grazing since 1967 during the 8-18 minute time interval. No other differences in erosion rates attributable to soil compaction subtreatments were measured during this sampling period.

II. Subtreatments pooled. No significant differences in erosion rates attributabel to grazing conditions were measured during this sampling period.

Summary of erosion data measured on unchained woodland sites.

No consistent relationships between grazing conditions or compaction subtreatments and erosion rates were measured on woodland sites. Trends indicated soil compaction increased erosion and plots protected since 1969 produced less than grazed plots or plots protected in 1967 or 1971.

Table 8. Erosion rates measured on unchained woodland sites sampled June-July, 1972.

Grazing Condition	Subtreatments	Erosion Rates			
		Subtreatments Separate		Subtreatments Pooled	
		8-18 Minute Time Interval	18-28 Minute Time Interval	8-18 Minute Time Interval	18-28 Minute Time Interval
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Grazed	None			973 a[2/]	1523 a[2/]
Grazing Excluded in 1967				1572 a	1614 a
	0% compacted	1540 a[1/]	2168 a[1/]		
	30% compacted	1407 a	1211 a		
	60% compacted	1776 a	1348 a		
Grazing Excluded in 1969				542 a	561 a
	0% compacted	536 a	646 a		
	30% compacted	566 a	746 a		
	60% compacted	521 a	320 a		
Grazing Excluded in 1971				1033 a	1709 a
	0% compacted	1301 a	2244 a		
	30% compacted	1266 a	718 a		
	60% compacted	896 a	1835 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 9. Erosion rates measured on unchained woodland sites sampled August-September, 1972.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed				724 a[2/]	701 a[2/]
Grazing Excluded in 1967				1056 a	889 a
	0% Compacted	402 b[1/]	596 a[1/]		
	30% Compacted	1538 a	1594 a		
	60% Compacted	1011 a	380 a		
Grazing Excluded in 1969				906 a	990 a
	0% Compacted	652 a	937 a		
	30% Compacted	1286 a	1151 a		
	60% Compacted	780 a	881 a		
Grazing Excluded in 1971				1624 a	1491 a
	0% Compacted	2505 a	1949 a		
	30% Compacted	1577 a	1835 a		
	60% Compacted	589 a	402 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

DIP condition

Sampled June-July, 1971--Table 10.

I. Clipping subtreatments. The 100 percent clipped plots recorded significantly higher erosion rates than the 0 to 50 percent clipped plots protected from grazing in 1971 during the 18-28 minute time interval. No other differences in sediment production attributable to clipping subtreatments were measured.

II. Subtreatments pooled. No significant differences in erosion rates attributabel to grazing or varying periods of rest from grazing were recorded during this period.

Sampled August-September, 1971--Table 11.

I. Clipping subtreatments. The 50 and 100 percent clipped plots on the area protected from grazing since 1967 recorded a higher erosion rate than the 0 percent clipped plots during the 8-18 minute time interval. No other instances of significant differences in sediment production attributable to clipping subtreatments were measured during this sampling period.

II. Clipping subtreatments pooled. No differences between grazing conditions in erosion rates were recorded during the 8-18 minute time interval. During the 18-28 minute time interval, plots protected from grazing since 1967 produced significantly more sediment than any other grazing condition.

Sampled June-July, 1972.

I. Clipping subtreatments and clipping subtreatments pooled--Table 12. No significant difference in erosion rates attributable to

Table 10. Erosion rates measured on DIP sites sampled June-July, 1971.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Grazed	None			112 a[2/]	136 a[2/]
Grazing Excluded in 1967				63 a	463 a
	0% Clipped	58 a[1/]	460 a[1/]		
	50% Clipped	65 a	475 a		
	100% Clipped	64 a	430 a		
Grazing Excluded in 1969				53 a	162 a
	0% Clipped	35 a	162 a		
	50% Clipped	57 a	59 a		
	100% Clipped	64 a	265 a		
Grazing Excluded in 1971				113 a	189 a
	0% Clipped	100 a	109 b		
	50% Clipped	157 a	111 b		
	100% Clipped	83 a	348 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 11. Erosion rates measured on DIP sites sampled August-September, 1971

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed	None			436 a[2]	261 b[2]
Grazing Excluded in 1967				554 a	1004 a
	0% Clipped	208 b[1]	992 a[1]		
	50% Clipped	675 a	868 a		
	100% Clipped	816 a	1174 a		
Grazing Excluded in 1969				221 a	141 b
	0% Clipped	93 a	84 a		
	50% Clipped	330 a	190 a		
	100% Clipped[3]				
Grazing Excluded in 1971				315 a	342 b
	0% Clipped	430 a	354 a		
	50% Clipped	259 a	262 a		
	100% Clipped	245 a	449 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

3/ Erosion data from 100% clipped plots lost when sample bottles were broken.

Table 12. Erosion rates measured on DIP sites sampled June-July, 1972 (clipping subtreatments).

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Grazed	None			977 a[2/]	711 a[2/]
Grazing Excluded in 1967				756 a	1135 a
	0% Clipped	328 a[1/]	287 a[1/]		
	50% Clipped	452 a	1099 a		
	100% Clipped	1345 a	1735 a		
Grazing Excluded in 1969				661 a	478 a
	0% Clipped	541 a	470 a		
	50% Clipped	549 a	361 a		
	100% Clipped	941 a	613 a		
Grazing Excluded in 1971				371 a	418 a
	0% Clipped	424 a	277 a		
	50% Clipped	363 a	86 a		
	100% Clipped	324 a	836 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

clipping subtreatments or grazing condition were measured during this sampling period.

II. Compaction subtreatments--Table 13. Erosion rates measured on the 0 and 60 percent soil compacted plots in the area protected from grazing since 1971 were significantly higher than the 30 percent soil compacted plots during the 18-28 minute time interval. No other differences in erosion rates attributable to soil compaction activity were measured during this sampling period.

III. Compaction subtreatments pooled. No differences in erosion rates attributable to grazing or varying periods of rest from grazing were measured during the 8-18 minute time interval. During the 18-28 minute time interval, however, grazed plots recorded a significantly higher erosion rate than any other grazing condition. Also during the 18-28 minute time interval the area protected from grazing since 1969 produced significantly more sediment than areas protected since 1967 or 1971.

Sampled August-September, 1972--Table 14.

I. Compaction subtreatments. No differences in erosion rate attributable to soil compaction subtreatments were measured.

II. Subtreatments pooled. Erosion rates measured on grazed plots were significantly higher than those measured for any other grazing condition and the areas protected from grazing since 1967 and 1971 produced more sediment than areas protected in 1969 during the 8-18 minute time interval. No differences in erosion rates attributable to grazing condition were measured during the 18-28 minute time interval.

Table 13. Erosion rates measured in DIP sites sampled June-July, 1972 (compaction subtreatments).

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed				977 a[2/]	711 a[2/]
Grazing Excluded in 1967				652 a	212 c
	0% Compacted	328 a[1/]	287 a[1/]		
	30% Compacted	241 a	116 a		
	60% Compacted	1073 a	209 a		
Grazing Excluded in 1969				486 a	587 b
	0% Compacted	542 a	470 a		
	30% Compacted	475 a	634 a		
	60% Compacted	433 a	670 a		
Grazing Excluded in 1971				342 a	199 c
	0% Compacted	424 a	276 a		
	30% Compacted	171 a	77 b		
	60% Compacted	405 a	221 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 14. Erosion rates measured on DIP sites sampled August-September, 1972.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed	None			1992 a[2/]	1065 a[2/]
Grazing Excluded in 1967				963 b	669 a
	0% Compacted	786 a[1/]	400 a[1/]		
	30% Compacted	730 a	632 a		
	60% Compacted	1313 a	884 a		
Grazing Excluded in 1969				359 c	264 a
	0% Compacted	319 a	246 a		
	30% Compacted	424 a	265 a		
	60% Compacted	321 a	280 a		
Grazing Excluded in 1971				762 b	1034 a
	0% Compacted	719 a	1604 a		
	30% Compacted	792 a	783 a		
	60% Compacted	775 a	717 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Summary of erosion rate data measured on DIP sites.

No consistently significant differences in erosion rates attributable to clipping or soil compaction subtreatments and grazing conditions were measured. A non-significant trend toward higher erosion on plots clipped at the 50 and 100 percent level and compacted at the 30 and 60 percent level was observed.

Windrowed condition

Sampled June-July, 1971--Table 15.

I. Clipping subtreatments. The plots receiving the 100 percent clipping subtreatments sampled on the area protected from grazing in 1971 produced significantly more erosion during the 18-28 minute time interval than the 0 or 50 percent clipped plots. No other differences attributable to clipping subtreatments were measured.

II. Subtreatments pooled. During the 8-18 minute time interval, plots protected from grazing in 1971 produced significantly more sediment than grazed plots or plots protected since 1967. No significant differences in erosion rates were measured during the 18-28 minute time interval.

Sampled August-September, 1971--Table 16.

I. Clipping subtreatments. The 0 percent clipped plots protected from grazing since 1967 recorded a significantly higher sediment production rate during the 18-23 minute time interval. The opposite result--significantly lower erosion rates on the 0 percent clipped plots--were measured during the 18-28 minute time intervals.

Table 15. Erosion rates measured on windrowed sites sampled June-July, 1971.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed	None			265 b[2/]	341 a[2/]
Grazing Excluded in 1967				239 b	374 a
	0% Clipped	174 a[1/]	539 a[1/]		
	50% Clipped	358 a	365 a		
	100% Clipped	190 a	240 a		
Grazing Excluded in 1971				586 a	682 a
	0% Clipped	513 a	439 a		
	50% Clipped	373 a	233 a		
	100% Clipped	869 a	1589 b		

1/ Means of clipping subtreatments within the grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 16. Erosion rates measured on windrowed sites sampled August-September, 1971.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Grazed	None			1253 a[2/]	2013 a[2/]
Grazing Excluded in 1967				570 b	489 b
	0% Clipped	793 a[1/]	823 a[1/]		
	50% Clipped	432 a	229 b		
	100% Clipped	473 a	402 b		
Grazing Excluded in 1971				577 b	557 b
	0% Clipped	289 a	316 b		
	50% Clipped	766 a	736 a		
	100% Clipped	659 a	609 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

II. Subtreatments pooled. Plots protected from grazing in 1971 produced more sediment than plots on grazed areas or plots on areas protected from grazing since 1967 during both the 8-18 and 18-28 minute time interval.

Sampled June-July, 1972. No significant differences in erosion rates attributable to clipping subtreatments (Table 17), soil compaction subtreatments (Table 18), or grazing condition (Tables 17 and 18) were recorded during this sampling period.

Sampled August-September, 1972--Table 19.

I. Compaction subtreatments. No significant differences in erosion rates attributable to soil compaction subtreatments were measured.

II. Compaction subtreatments pooled. During the 8-18 minute time interval, plots protected since 1967 recorded a higher erosion rate than plots protected since 1971. During the 18-28 minute time interval, grazed plots protected from grazing since 1967 recorded a higher erosion rate than plots protected since 1971.

Summary of erosion rate data measured on windrowed plots.

No consistent trends in erosion rates attributable to clipping subtreatments, soil compaction subtreatments, or grazing condition were measured on windrowed areas.

Table 17. Erosion rates measured on windrowed sites sampled June-July, 1972 (clipping subtreatments).

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed	None			938 a 2/	1786 a 2/
Grazing Excluded in 1967				728 a	1242 a
	0% Clipped	946 a 1/	1224 a 1/		
	50% Clipped	628 a	511 a		
	100% Clipped	683 a	1986 a		
Grazing Excluded in 1971				815 a	893 a
	0% Clipped	694 a	1396 a		
	50% Clipped	762 a	416 a		
	100% Clipped	1016 a	862 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 18. Erosion rates measured on windrowed sites sampled June-July, 1972 (compaction subtreatments).

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed				939 a[2/]	1786 a[2/]
Grazing Excluded in 1967				1243 a	1194 a
	0% Compacted	946 a[1/]	1224 a[1/]		
	30% Compacted	1799 a	1663 a		
	60% Compacted	887 a	707 a		
Grazing Excluded in 1971				1191 a	1595 a
	0% Compacted	694 a	694 a		
	30% Compacted	1600 a	2672 a		
	60% Compacted	1326 a	717 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Table 19. Erosion rates measured on windrowed sites sampled August-September, 1972.

Grazing Condition	Subtreatments	Erosion Rates: Subtreatments Separate, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Separate, 18-28 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 8-18 Minute Time Interval	Erosion Rates: Subtreatments Pooled, 18-28 Minute Time Interval
		($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Grazed				780 ab[2/]	1186 a[2/]
Grazing Excluded in 1967				1201 a	1170 a
	0% Compacted	750 a[1/]	788 a[1/]		
	30% Compacted	1587 a	1420 a		
	60% Compacted	1205 a	1236 a		
Grazing Excluded in 1971				380 b	343 b
	0% Compacted	459 a	456 a		
	30% Compacted	409 a	337 a		
	60% Compacted	269 a	234 a		

1/ Means of clipping subtreatments within grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

2/ Means of grazing conditions are not statistically different ($P \leq 0.10$) if followed by the same letter.

Discussion of Erosion Results

Influence of clipping subtreatments

Few instances of erosion rates being significantly affected by clipping subtreatments were recorded. However, some trends seem to be evident. The following tabulation indicates the number of times each clipping subtreatment was associated with the highest or lowest erosion rate measured (all vegetative--grazing conditions, sampling seasons and the 8-18 and 18-28 minute time intervals combined):

Subtreatment	Lowest Erosion Rate	Highest Erosion Rate
0% clipped	11	7
50% clipped	12	6
100% clipped	5	15

Both the 0 and 50 percent clipped plots indicate that vegetation--in this case crested wheatgrass--helps reduce erosion, while the 100 percent clipped plots favor higher erosion rates. This apparent trend deserves additional research to verify if the indicated trend really exists or if the trend is a chance happening. Meeuwig (1970), Marston (1952), and Packer (1951) have reported that 65-70 percent cover is needed to control erosion on range capable of producing a near continuous plant cover. This recommendation is not very useful for arid and semi arid ranges (< 300 mm annual precipitation). The "threshold level" where vegetative cover begins to reduce erosion needs to be identified (or documented if such a level does not exist).

Influence of compaction subtreatments

The following tabulation lists the number of times each compaction subtreatment recorded the lowest or highest erosion rate (vegetative--grazing conditions, sampling seasons, and the 8-18 and 18-28 minute time intervals combined):

Subtreatment	Occurrence of Lowest Erosion Rate	Occurrence of Highest Erosion Rate
0% of Soil Compacted	11	12
30% of Soil Compacted	8	14
60% of Soil Compacted	13	6

Literature indicates that 0 percent compacted plots should have resulted in low erosion rates with higher erosion rates being associated with plots receiving the 60 percent compacted subtreatment (Meeuwig and Packer 1976). However, the 0 percent compacted subtreatment recorded approximately an equal number of low and high erosion rates, while the 60 percent compaction subtreatment favored lower erosion rates, and the 30 percent compaction subtreatment favored high erosion rates. It is believed that these trends are a chance variation rather than true relationships between compaction subtreatments and erosion rates.

Influence of grazing and varying periods of rest from grazing

The effect of livestock grazing and varying periods of rest from grazing on erosion rates are summarized in the following tabulation (vegetative conditions, sampling periods, and the 8-18 and the 18-28 minute time intervals combined):

Grazing Condition	Occurrences of Lowest Erosion Rate	Occurrences of Highest Erosion Rate
Grazed	5	11
Grazing Excluded 1967	5	7
Grazing Excluded 1969	11	0
Grazing Excluded 1971	7	10

Although statistical analysis rarely indicated that grazing increased erosion, a trend toward increased erosion rates on grazed plots is evident. No strong trends of increased or decreased erosion rates related to protection from grazing since 1967 or 1971 occur. A definite trend toward low erosion rates on plots protected from grazing since 1969 does occur. This latter trend may be due to the fact that a 1969 grazing exclosure was not available for the windrowed vegetative condition. A 1969 grazing exclosure on a windrowed area might have recorded some instances of a high erosion rate. Regardless, however, of the trend indicated by the 1969 exclosure, it can be concluded that grazing tends to increase the erosion potential (but not necessarily a significant increase) and any rest from grazing reduces this increased erosion trend.

Factors Influencing Erosion Rates

Unchained woodland

Multiple regression models were generally not successful in explaining variation in erosion rates measured on unchained woodland sites during June-July, 1971. However, significant variables (total porosity in 7.5 cm deep soil cores, capillary porosity in 7.5 cm deep soil cores, percent slope, and capillary porosity in 2.5 cm deep soil cores) explained (R^2) 73 percent of the variation in erosion rates measured during the 18-28 minute time interval (Table 20). This one instance of a high R^2 value was the exception as models developed for the other sampling periods explained no more than 17 percent of the variation measured in erosion rates.

The following tabulation indicates the frequency variables were identified as explaining significant amounts of variation in erosion rates:

Variable	8-18 Minute Time Interval	18-28 Minute Time Interval
Percent Slope	33%	33%
Saturated Hydraulic Conductivity		
2.5 cm deep soil cores	-	33%
Capillary Porosity		
2.5 cm deep soil cores	-	33%
7.5 cm deep soil cores	-	25%
Total Porosity		
2.5 cm deep soil cores	33%	-
7.5 cm deep soil cores	-	25%
Orthogonal Comparison Representing Grazing Condition	50%	-
2.5 cm Percent Sand Plus Sand Sized Aggregates	100%	-
2.5 cm Percent Clay	-	100%

Table 20. Variables explaining significant ($P \leq 0.10$) amounts of variation in erosion rates measured on unchained woodland sites. Variables are listed in order of importance as identified by the stepwise multiple regression analysis.

Sampling Period	8-18 Minute Time Interval	18-28 Minute Time Interval
June-July, 1971	2.5 cm Total Porosity	7.5 cm Total Porosity 7.5 cm Capillary Porosity Percent Slope 2.5 cm Capillary Porosity
Accumulated R^2	10%	73%
August-September, 1971	Orthogonal Comparison Representing Grazing Condition Percent Slope 2.5 cm Percent Sand plus Sand Sized Aggregates	2.5 cm Percent Clay 2.5 cm Saturated Hydraulic Conductivity
Accumulated R^2	17%	6%
June-July, 1972-- Compaction Subtreatments	Orthogonal Comparison Representing Grazing Condition	None
Accumulated R^2	14	0
August-September, 1972--	None	7.5 cm Total Porosity
Accumulated R^2	0	4%

The 100 percent frequency of importance listed for the latter two textural characteristics may overestimate the true value of these variables. They were only sampled during the Augusy-September 1971, sampling period.

DIP condition

The following tabulation indicates the frequency that variables were identified as explaining significant amounts of variation in erosion rates measured on DIP sites (Table 21):

Variable	8-18 Minute Time Interval	18-28 Minute Time Interval
Percent Slope	66%	33%
Forage on Plot at End of Erosion Test	33%	33%
Percent total Cover	33%	66%
Saturated Hydraulic Conductivity		
2.5 cm deep soil cores	33%	-
7.5 cm deep soil cores	-	25%
Capillary Porosity		
2.5 cm deep soil cores	-	33%
7.5 cm deep soil cores	25%	75%
Total Porosity		
2.5 cm deep soil cores	33%	-
7.5 cm deep soil cores	-	50%
Bulk Density		
2.5 cm deep soil cores	33%	33%
7.5 cm deep soil cores	-	25%
Orthogonal comparison Representing Grazing Condition	75%	50%
Air Permeameter Reading	-	50%
Percent Sand Plus Sand Sized Aggregates		
2.5 cm deep soil cores	-	100%
7.5 cm deep soil cores	-	100%
2.5 cm Sand Sized Aggregates	100%	-

Table 21. Variables explaining significant ($P \leq 0.10$) amounts of variation in erosion rates measured on DIP sites. Variables are listed in order of importance as identified by the stepwise multiple regression analysis.

Sampling Period	8-18 Minute Time Interval	18-28 Minute Time Interval
June-July, 1971-- Clipping Subtreatments	2.5 cm Total Porosity Orthogonal Comparison Representing Grazing Condition Percent Slope	7.5 cm Capillary Porosity
Accumulated R^2	13%	11%
August-September, 1971-- Clipping Subtreatments	Orthogonal Comparison Representing Grazing Condition 2.5 cm Saturated Hydraulic Conductivity Forage on Plot at End of Erosion Test 2.5 cm Sand Sized Aggregates	Percent Total Cover 2.5 cm Percent Sand Sand Sized Aggregates 7.5 cm Percent Sand plus Sand Sized Aggregates
Accumulated R^2	26%	9%
June-July, 1972-- Clipping Subtreatments	None	Orthogonal Comparison Representing Grazing Condition 7.5 cm Total Porosity Forage on Plot at End of Erosion Test
Accumulated R^2	0	31%
June-July, 1972-- Compaction Subtreatments	Percent Slope	Orthogonal Comparison Representing Grazing Condition Percent Slope 7.5 cm Total Porosity 7.5 cm Bulk Density Air Permeameter Reading 7.5 cm Capillary Porosity
Accumulated R^2	7%	34%

Table 21. (cont'd)

Sampling Period	8-18 Minute Time Interval	18-28 Minute Time Interval
August-September, 1972--	7.5 cm Capillary Porosity	7.5 cm Capillary Porosity
Compaction Subtreatments	Orthogonal Comparison Representing Grazing Condition Percent Total Cover 2.5 cm Bulk Density	7.5 cm Saturated Hydraulic Conductivity Percent Total Cover 2.5 cm Bulk Density 2.5 cm Capillary Porosity
Accumulated R^2	34%	38%

The 100 percent frequency of importance indicated for the latter three textural characteristics may overestimate their true value for explaining variation in erosion rates. These variables were only sampled during the August-September, 1971, sampling period.

Percent slope, percent total cover, capillary porosity measured in 7.5 cm deep soil cores, and the orthogonal comparison representing grazing condition all consistently explained significant amounts of variation in erosion measured on DIP sites (Table 21). Significant variables explained (R^2) from 0 to 38 percent of variation in erosion rates measured on DIP plots.

Windrowed condition

Percent total cover and bulk density in 2.5 cm deep soil cores consistently explained significant amounts of variation in erosion rates during both the 8-18 and 18-28 minute time interval, while percent cover of crested wheatgrass, total porosity, and saturated hydraulic conductivity measured in 2.5 cm deep soil cores explained significant amounts of variation in erosion during the 18-28 minute time interval. The following tabulation list the frequency with which variables were identified as explaining significant amounts of variation measured in erosion rates on windrowed sites:

Variable	8-18 Minute Time Interval	18-28 Minute Time Interval
Percent Cover--Crested Wheatgrass	-	75%
Percent Total Cover	33%	66%
Saturated Hydraulic Conductivity		
2.5 cm deep soil cores	-	66%

Variable	8-18 Minute Time Interval	18-28 Minute Time Interval
Capillary Porosity		
2.5 cm deep soil cores	33%	-
7.5 cm deep soil cores	25%	-
Total Porosity		
2.5 cm deep soil cores	-	33%
7.5 cm deep soil cores	-	75%
Bulk Density		
2.5 cm deep soil cores	66%	66%
7.5 cm deep soil cores	25%	-
Orthogonal Comparison Representing Grazing Condition	25%	25%
Percent Sand Plus Sand Sized Aggregates		
2.5 cm deep soil cores	100%	100%
7.5 cm deep soil cores	100%	100%
2.5 cm Sand Sized Aggregates	-	100%
2.5 cm Percent Silt	-	100%
2.5 cm Percent Clay	-	100%

The 100 percent frequency of importance indicated for the soil textural characteristics may overestimate their true value in explaining variation in erosion rates because these variables were only sampled during the August-September, 1971, sampling period. However, it appears that these soil textural variables are important in explaining variation in erosion rates because they were identified as significant in several regression models. Future research should evaluate these variables--particularly the percent sand plus sand sized aggregates and percent sand sized aggregates--in several sampling periods.

Multiple regression analyses were not successful in consistently explaining variation measured in erosion rates on windrowed sites (Table 22). The amount of variation explained (R^2) by regression models developed for each sampling period ranged from 0 to 48 percent. The success of these models in explaining erosion varied between the

Table 22. Variables explaining significant ($P \leq 0.10$) amounts of variation in erosion rates measured on windrowed sites. Variables are listed in order of importance as identified by the stepwise multiple regression program.

Sampling Period	8-18 Minute Time Interval	18-28 Minute Time Interval
June-July, 1971-- Clipping Subtreatments	7.5 cm Bulk Density Orthogonal Comparison Representing Grazing Condition Percent Total Cover 2.5 cm Bulk Density 2.5 cm Capillary Porosity 7.5 cm Capillary Porosity	Percent Total Cover Percent Cover--Crested Wheatgrass 2.5 cm saturated Hydrolic Conductivity Orthogonal Comparison Representing Grazing condition 2.5 cm Bulk Density 7.5 cm Total Porosity
Accumulated R^2	48%	36%
August-September, 1971-- Clipping Subtreatments	7.5 cm Percent Sand plus Sand Sized Aggregates 2.5 cm Sand Sized Aggregates 2.5 cm Percent Sand plus Sand Sized Aggregates 2.5 cm Bulk Density	2.5 cm Saturated Hydraulic Conductivity 2.5 cm Bulk Density 7.5 cm Percent Sand plus Sand Sized Aggregates 2.5 cm Total Porosity Percent Cover--Crested Wheatgrass 2.5 cm Percent Clay 2.5 cm Percent Silt 2.5 cm Sand Sized Aggregates 2.5 cm Percent Sand plus Sand Sized Aggregates 7.5 cm Total Porosity
Accumulated R^2	39%	47%
June-July, 1972-- Clipping Subtreatments	None	7.5 cm Total Porosity
	0	15%
Accumulated R^2	0	15%

Table 22. (cont'd)

Sampling Perion	8-18 Minute Time Interval	18-28 Minute Time Interval
June-July, 1972-- Compaction Subtreatments	Percent Total Cover Percent Cover--Crested Wheatgrass	None
Accumulated R^2	9%	0
August-September, 1972-- Compaction Subtreatments	None	None

plots sampled in 1971 and 1972. Variation in erosion rates explained (R^2) by significant variables during June-July and August-September, 1971, ranged from 36 to 48 percent while variation explained during these two sampling periods in 1972 did not exceed 15 percent.

Discussion of Factors Influencing Erosion Rates

The orthogonal comparison representing grazing condition was the variable most consistently identified by multiple regression models as explaining significant variation in erosion rates. This result is consistent with the trend that grazing increases erosion and rest from grazing reduces erosion (page 103).

Percent total cover also explained significant amounts of variation measured in erosion rates. Evaluation of correlation coefficients (r) provided by the multiple regression program indicates that the relationships are not strong (as would be indicated by a coefficient near 1.0), but are consistently negative. This means that a consistent relationship exists between a high percent total cover and a low erosion rate. This result also is consistent with trends indicated by erosion data (page 102). This non-significant trend indicated that the 100 percent clipped plots (with 0 percent cover) produced more erosion than the 0 or 50 percent clipped plots (with up to 40 percent total cover). Additional research is needed to verify the trend that vegetation--expressed as percent total cover--reduces erosion on DIP and windrowed areas. Such research might also answer some of the questions relating to the watershed value of converting pinyon-juniper woodland--with no understory vegetative cover--to areas dominated by shrub or herbaceous plants.

In summary, grazing and the associated effects on vegetation had a greater influence on erosion than on infiltration. Splash erosion and soil sealing probably occurred at an equal rate on all study sites. This is indicated by infiltration data. However, the additional amount of vegetation (both alive and dead plant material) on plots protected from grazing and on plots receiving the 0 and 50 percent clipped subtreatments detains overland flow and allows sediment to settle to the soil surface. Thus, vegetation influences erosion but not infiltration on DIP and windrowed sites.

SUMMARY, CONCLUSIONS, AND MANAGEMENT IMPLICATIONS

The objectives of this study were to 1) determine the effects of livestock grazing, and varying periods of rest from grazing on infiltration and erosion rates of unchained, DIP, and windrowed pinyon-juniper sites; and 2) utilize these measurements in developing guidelines for grazing management of pinyon-juniper rangelands that protect or improve the hydrologic condition of the watershed. Of particular interest were the following items:

1. Influence of grazing on infiltration and erosion rates, especially as related to surface soil changes and vegetative modification,
2. Separation of the grazing impact into forage removal and trampling effects,
3. Changes in infiltration and erosion rates as a function of time since grazing has been excluded, and
4. Development of multiple regression models for predicting infiltration and erosion rates of unchained, DIP, windrowed, and pinyon-juniper rangeland subjected to various grazing situations.

The study was conducted in southeastern Utah during the summers of 1971 and 1972. The following closely adjacent vegetation--grazing conditions were studied:

1. Unchained Woodland

    a. Grazing not excluded

    b. Grazing excluded since 1967

    c. Grazing excluded since 1969

    d. Grazing excluded since 1971

2. DIP

    a. Grazing not excluded

    b. Grazing excluded since 1967

    c. Grazing excluded since 1969

    d. Grazing excluded since 1971

3. Windrowed

    a. Grazing not excluded

    b. Grazing excluded since 1967

    c. Grazing excluded since 1971

Runoff and erosion were artificially induced from small plots by simulating rainfall with the Rocky Mountain Infiltrometer. Infiltration rates, erosion rates, and selected vegetative and edaphic parameters were measured on each plot. Clipping and compaction subtreatments were applied to randomly selected plots in an effort to evaluate the forage removal and trampling activities of livestock. Analysis of variance techniques were used to determine the effect on infiltration and erosion rates of 1) clipping and compaction subtreatments, 2) grazing and varying periods of rest from grazing, and 3) chaining treatments with similar grazing histories. Multiple regression techniques were used to evaluate the influence of vegetative and edaphic factors on infiltration and erosion.

The clipping subtreatments had no consistent effect on infiltration rates measured on DIP or windrowed sites, indicating that when vegetative cover is less than 40-50 percent factors other than vegetation control infiltration.

The compaction subtreatments had no consistent or statistically measurable affect on infiltration rates recorded on unchained woodland, DIP, or windrowed sites. Apparently, the sandy loam soil occurring on the study site did not contain enough fine soil particles to be affected by the compaction subtreatments.

It must be noted, that the clipping and compaction subtreatments were an instantaneous application of forage removal and pressure respectively. A long-term history of forage removal and soil compaction, as might result from a season or repeated seasons of grazing, could have an accumulative effect that would eventually influence infiltration. Applying these subtreatments during the regular spring grazing season (May 1-June 15) might also result in the clipping and compaction subtreatments affecting infiltration and erosion rates.

Areas rested from livestock grazing since 1967 had significantly higher infiltration rates than currently grazed areas on unchained woodland and DIP sites. Grazed plots consistently recorded the lowest infiltration rates although this rate was not significantly lower than infiltration rates measured on areas protected from grazing since 1969 or 1971. Grazing did not consistently affect infiltration measured on windrowed sites.

It seems that an unchained woodland area with no prior history of treatments or site disturbance is impacted more by grazing than DIP areas with a history of some disturbance (two-way chaining and aerial seeding) and windrowed areas with a history of considerable disturbance (one-way chaining, debris disposal, drill seeding). Conversely, maximum disturbance of the factors influencing infiltration may have occurred on the windrowed sites during the vegetative conversion treatments. Therefore, livestock grazing was unable to further disturb the windrowed site. In addition, rest from grazing since 1967 did not allow windrowed sites or on DIP to fully recover from the disturbance associated with vegetative conversion.

Infiltration rates on woodland sites increase when protected from grazing for only 1-2 years. Additional increases in infiltration rates occur on woodland sites for at least 4-5 years. Windrowed and DIP sites recover more slowly. However, infiltration rates did increase on all three vegetative conditions as the period of rest from grazing increased. Additional research is needed to determine the number of years of rest from grazing that is needed to obtain the maximum increase in infiltration rates.

None of the 21 soil and vegetative variables included in this study were identified by multiple regression models as consistently explaining significant amounts of variation in infiltration rates measured on unchained woodland, DIP, or windrowed sites. However, the following information was provided by the regression analyses: 1) data obtained from 2.5 cm deep soil seems more useful in explaining variation in infiltration rates than 7.5 cm deep cores, and 2) knowledge of site history (vegetative conversion, grazing and environmental situations) is necessary to better explain the effect of treatments on infiltration rates.

Results of this study indicate that the primary value of multiple regression models is not to predict changes that will occur in infiltration because one management alternative is selected over another, but to help explain significant differences measured between treatments.

Erosion rates were not significantly affected by clipping subtreatments, but a definite trend indicates that erosion increases on DIP and windrowed plots with all vegetation removed by clipping. No consistent relationship between erosion rates and compaction subtreatments was found.

A trend toward increased erosion rates on grazed areas was found. No consistent relationship between erosion rates and the various periods of rest from grazing was recorded. Thus, any rest from grazing seems to reduce the erosion potential of pinyon-juniper sites.

The orthogonal comparison representing grazing conditions and the variable percent total cover were the only variables that consistently explained significant amounts of variation recorded in erosion rates.

This result was consistent with results indicated for the comparison between grazing and varying periods of rest from grazing, and the clipping subtreatments analyses.

Results of this study combined with relevant literature indicate that the following management guidelines should be followed to maintain or improve watershed conditions on pinyon-juniper rangelands similar to those evaluated in this study:

1. Areas with sandy loam soils with less than 5 percent slope can be converted from woodland to grassland by chaining and seeding without appreciable change in watershed characteristics if debris is left scattered on the soil surface rather than pushed into piles or windrows.

2. Spring-fall grazing (when compared to areas protected from grazing for 4-5 years) significantly reduced infiltration rates on unchained woodland and DIP sites, but generally did not alter infiltration rates on windrowed sites. Similar, but non-significant, results were found for erosion rates. These results are interpreted to mean that site disturbance by the chaining debris disposal, and drill seeding treatments was so great on windrowed sites that grazing caused no additional hydrologic impact on windrowed sites. Because of this initial site disturbance, and considering the hydrologic value of debris being scattered over the soil surface, windrowing is not recommended as a management technique unless site analysis indicates it is appropriate for specific management objectives.

3. No specific grazing management recommendations are suggested by the results of this study. Long-term spring-fall livestock grazing that removed 45 to 70 percent of the current year's forage production did significantly reduce infiltration and tended to increase erosion from study sites in southeastern Utah. Based on data from protected exclosures, recovery of infiltration and erosion rates on grazed sites occurs for at least 4-5 years, although some recovery is apparent after an area has been protected for only 1-2 years. It is not known whether this improvement in infiltration and erosion characteristics (attributable to rest from grazing) is eliminated with one season of grazing or if the improvement would persist for several grazing seasons. However, it is evident that one or more seasons of grazing followed by one or more seasons of rest is not sufficient for full recovery of infiltration rates.

If a grazing system that periodically provides rest from grazing is established, trends from this study indicate that grazing intensity should be regulated so that litter built up during the period of rest is not destroyed by forage removal and trampling activities during the period of grazing. This accumulation of litter may not greatly increase the total cover of an area, but litter should decrease the velocity of water moving across the soil surface, allow additional time for infiltration to occur, and allow sediment to be deposited on-site rather than downstream. This level of "proper" grazing will have to be determined for each site.

In summary, pinyon-juniper rangelands can be improved for livestock by chaining and seeding without causing a deterioration in watershed condition. However, to achieve these objectives, the sites to be treated must be carefully evaluated and the appropriate chaining, debris disposal, and grazing management practices applied.

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