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by

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Introduction

Pinyon-juniper (*Pinus* spp. and *Juniperus* spp.) vegetative type conversions have been made on millions of acres and semiarid rangeland. Chaining, which involves mechanically uprooting the trees with a large anchor chain suspended between two crawler tractors, is a frequently employed technique. In Arizona alone, almost a million acres of woodland have received some vegetation treatment between 1950 and 1960 (Dortignac, 1960). Yet many of the hydrological aspects of vegetation conversion are poorly understood. The secondary treatment effects of grazing and burning these treated areas are understood even less.

Our population is continuing to grow. Recreational demands on public lands are accelerating. Arid land use planning and zoning ordinances may well be one the horizon. Natural resource managers are faced with decisions of extreme importance, and in many cases they are hampered by an incomplete knowledge of the physical factors which are taking place on the lands under their control.

For instance, is debris burning to control pinyon-juniper regrowth hydrologically sound? Ecologically sound? Economically sound? Should cattle be allowed on public lands? What effects will grazing have on land that has been chained and then seeded? Are there public health implications that need to be considered in conjunction with grazing?

Obviously the need to be able to answer such questions is paramount to the resource manager's ability to make equitable and intelligent land use decisions.

With such problems in mind, a study designed to answer some questions about secondary treatment of pinyon-juniper chainings was undertaken.

Objectives of the Study

Objectives of the study were as follows:

1. To determine the hydrologic impact of grazing by domestic livestock on runoff, water quality, soil moisture patterns, sediment production, soil percolation rates, and infiltration rates on a pinyon-juniper site which has been chained with debris-windrowed.

2. To determine the hydrologic impact of burning of pinyon-juniper debris on runoff, water quality, soil moisture patterns, sediment production, soil percolation rates, and infiltration rates on a site which has been chained with debris-left-in-place.

Historical Background

During the period 1967-1973 the Bureau of Land Management (BLM) supported a study at Utah State University entitled "Influence of Chaining Pinyon-Juniper on Watershed Values in Utah." However, BLM support for field work terminated on June 30, 1973. Efforts during that period concentrated on defining hydrologic values (runoff and sedimentation characteristics, soil moisture patterns, etc.) on sites chained with debris windrowed, chained with debris-in-place, and natural woodland. Major study areas were located near Milford and Blanding, Utah, and studies were concerned only with the impact of the chaining itself on certain hydrologic parameters. The present study provided support for maintaining the Blanding site and for expanding the study to include influence of grazing on windrowed sites and influence of burning on debris-in-place sites. The study site was therefore already located, fencing was complete, and 20 .04-hectare (0.11 acre) runoff plots at the Blanding site had 5 years of rainfall-runoff calibration data. In addition, data were available from several hundred infiltrometer plots, from 2½ years of soil moisture measurements (to a depth of 150 centimeters (5 feet) on each treatment), and from several other supplementary studies on the site. The following published papers summarize much of the work accomplished during the initial 1967-1973 study period.

1.) Gifford, G. F., and R. K. Tew. 1969. Evaluating rangeland water quality with small-plot infiltrometers. J. Soil & Water Conservation 24:65-67.

2.) Williams, G., G. F. Gifford, and G. B. Coltharp. 1969. Infiltrometer studies on treated vs. untreated pinyon-juniper sites in central Utah. J. Range Manage. 22:110-114.

3.) Gifford, G. F., and R. K. Tew. 1969. Influences of pinyon-juniper conversions and water quality on permeability of surface soils. Water Resour. Res. 5:895-899.

4.) Gifford, G. F. 1970. Some water movement patterns over and through pinyon-juniper litter. J. Range Manage. 23:365-366.

5.) Gifford, G. F., G. Williams, and G. B. Coltharp. 1970. Infiltration and erosion studies on pinyon-juniper conversion sites in southern Utah. J. Range Manage. 23:402-406.

6.) Williams, G., G. F. Gifford, and G. B. Coltharp. 1972. Factors influencing infiltration and erosion on chained pinyon-juniper sites in Utah. J. Range Manage. 25:201-205.

7.) Loope, W. L., and G. F. Gifford. 1972. Influence of a soil microfloral crust on select properties of soil under pinyon-juniper in southeastern Utah. J. Soil & Water Conserv. 27:164-167.

8.) Gifford, G. F. 1973. Influence of chaining pinyon-juniper on net radiation, solar radiation, and wind. J. Range Manage. 26:130-133.

9.) Gifford, G. F., and C. B. Shaw. 1973. Soil moisture patterns on two chained pinyon-juniper sites in Utah. J. Range Manage. 26: 436-440.

10.) Gifford, G. F. 1973. Runoff and sediment production from runoff plots on two chained pinyon-juniper sites in Utah. J. Range Manage. 26:440-443.

11.) Gifford, G. F. 1975. Approximate annual water budgets of two chained pinyon-juniper sites. J. Range Manage. 28:73-74.

12.) Gifford, G. F. 1975. Impacts of pinyon-juniper manipulation on watershed values. In: Proc., Pinyon-Juniper Ecosystem— A Symposium, Utah State Univ., Logan, May 1-2:127-140.

13.) Shaw, C. B., and G. F. Gifford. 1976. Sap velocity studies in natural stands of pinyon and juniper trees. J. Range Manage. 28: 377-379.

14.) Gifford, G. F. 1976. Applicability of some infiltration formulae to rangeland infiltrometer data. J. Hydrol. 28:1-11.

Site Description

Location

The study site is located near Coyote Flat, approximately 1 kilometer west of Utah Highway 621, between Natural Bridges National Monument and Mexican Hat, Utah, and approximately 70 kilometers west of Blanding, Utah. The study area is located at an elevation of 2150 meters and is within the confines of the Colorado Plateau.

Soils

Soils at the study site are derived from a sandstone parent material, and extend to a depth of approximately 1.5 meters. The pH of the soil is slightly basic, averaging about 8.0. Organic matter content is low, slightly less than 2.0 percent. Soil texture is a sandy loam, with few rocks present.

Description of area

Initial chaining treatments. Initial chaining treatments were applied to the site in the fall of 1967. These original treatments included chaining with windrowing of debris and double chaining with debris-left-in-place. The windrowed treatments were drill seeded to crested wheatgrass *(Agropyron cristatum)* at 9.1 kilograms/hectare (8 pounds/acre) and the debris-in-place treatments were broadcast seeded at the same rate to crested wheatgrass. Treatments were applied to from 12 to 16 hectares. The entire study area was then fenced to exclude livestock.

Secondary treatment (burning). Secondary treatment using controlled burning was attempted on September 20, 1973, in the chained with debris-left-in-place site. However, antecedent rainfall conditions were such that the fuel was damp and the fire did not carry well.

It was not until September 5, 1974, at the conclusion of the 1974 field season, that the debris-in-place area was successfully burned (Figure 1). The area had received no rain for over a month and generally westwardly winds were blowing at a constant 10-15 miles per hour. The fire was started about 1:00 p.m. and burned rapidly over the eight hectares in question. A clean burn was produced with most of the fuel being consumed within 2-3 hours. Smoke did persist at isolated spots for approximately 36 hours, however. Table 1 shows the mean maximum temperatures associated with the burn.

Secondary treatment (grazing). During late May and early June, 1974, cattle were stocked in the chained with debris windrowed treatment at the rate of 2 hectares/AUM (Figure 2). This stocking rate parallels the stocking rates which the local Bureau of Land Management officials attempt to attain on well established crested wheatgrass seedings. Utilization of the crested wheatgrass was about 55 percent. Grazing during late May of 1975 followed a similar pattern, but utilization of the crested wheatgrass averaged about 78 percent. Utilization was calculated based on clipping both grazed and ungrazed plots on the study area.

Vegetation

Under undisturbed conditions mature juniper trees *(Juniperus osteosperma)* make up 24 percent of canopy cover (500 trees per hectare) while pinyon pine *(Pinus edulis)* composes about 8 percent of the cover (200 trees per hectare). Shrub cover, consisting primarily of big sagebrush *(Artemisia tridentata)* is less than 1 percent. Bare ground, including some cryptogam species, and litter compose the balance.

During 1973, prior to burning, the chained with debris-in-place site had a total ground cover of 1-81 percent ($\bar{x}$ = 36.23 percent) of which 0-47 percent was litter ($\bar{x}$ = 16.48 percent), and 0-65 percent ($\bar{x}$ = 17.54 percent) was crested wheatgrass.

The chained with debris windrowed treatment had from 13-73 percent ($\bar{x}$ = 40.94 percent) and total cover of which 4-45 percent ($\bar{x}$ = 23.09 percent) was litter and 1-35 percent ($\bar{x}$ = 17.24 percent) was crested wheatgrass cover. Total yield of crested wheatgrass averaged 324 kg/ha (285 lbs/acre) in 1974 and 656 kg/ha (557 lbs/acre) in 1975.

Table 1. Mean temperatures, debris-in-place controlled burn (as defined by the use of Tempils with defined melting points from 52°C to 927°C).

	Open, grassy site	Debris pile
4 in. above soil surface	187°C	>777°C
1 in. below soil surface	<55°C	288°C

Ground cover measurements are based on small plot (0.23 m^2) data.

During the burn in the fall of 1974, the litter and vegetative cover on test plots were consumed by fire. Subsequent regrowth on the grassy openings during 1975 restored the cover to an average of about 16 percent, of which about 2 percent was litter, and about 14 percent was crested wheatgrass. Areas which had been previously occupied by large debris piles remained essentially bare throughout 1975.

Methods

Field procedures

Infiltrometer studies. A Rocky Mountain infiltrometer (Dortignac, 1951) was used to generate runoff from small, movable plots (Figures 3 and 4). Plot frames were constructed from 1/8 inch steel. They are 76.2 cm x 30 cm giving .23 square meters of soil surface coverage. The plots were installed by driving the edges into the soil surface about 9 cm with a specially constructed hammer.

The plot frames were equipped with a metal rainfall trough which fitted over the plot and provided a catchment trough along either side of the plot frame.

Rainfall and runoff water was transported away from the plot frames and rainfall troughs through 3/4 inch plastic hoses and deposited in clean one-gallon containers located in an entrenched collection basin.

An adjustable canvas wind shield was used to minimize wind disturbance and raindrop drift. All plots were pre-wet prior to application of simulated rainfall in order to eliminate confounding effects of antecedent moisture. Artificial rainfall was then applied to the plots at a rate of approximately 7 cm per hour for 28 minutes. Both runoff and rainfall were collected initially, after three minutes, and subsequently at five minute intervals during the rainfall period.

A minimum of six replications per treatment area per treatment date were run. Two randomly located clusters of three plots were located within each of the three treatment areas (undisturbed woodland, chained with debris windrowed, and chained with debris-left-in-place). Each of the six observations were considered independent samples, and were treated as such in all data manipulations.

Runoff plots. Paired runoff plots .04 hectare (0.11 acre) in size were used during the period of

Figure 1. Burning on the chained-with-debris-in-place treatment at Blanding. Burning date was September 5, 1974.

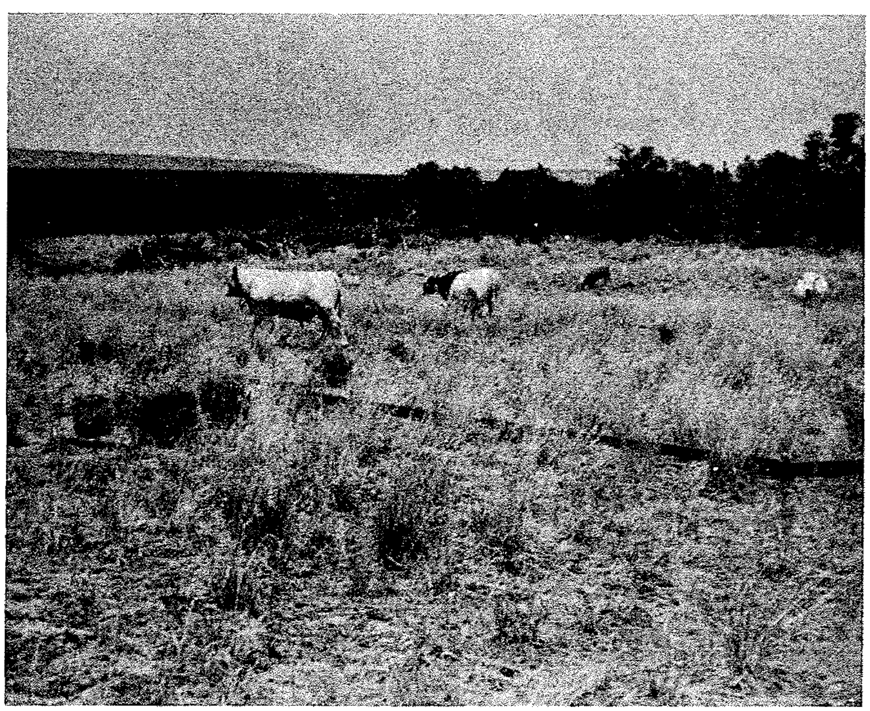


Figure 2. Cattle grazing on windrowed treatment at Blanding.

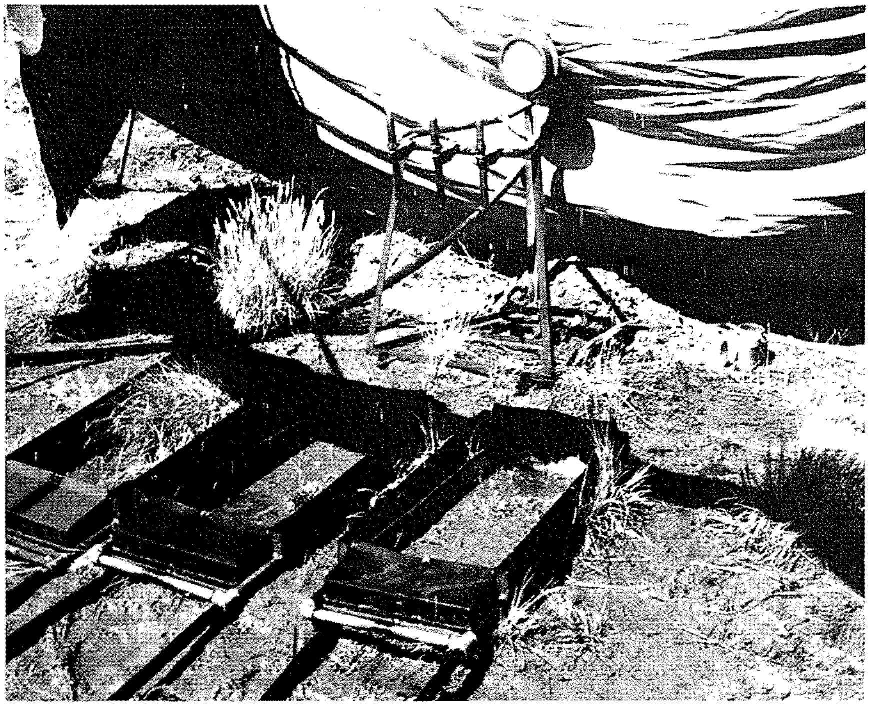


Figure 3. Physical setup of infiltrometer and equipment.

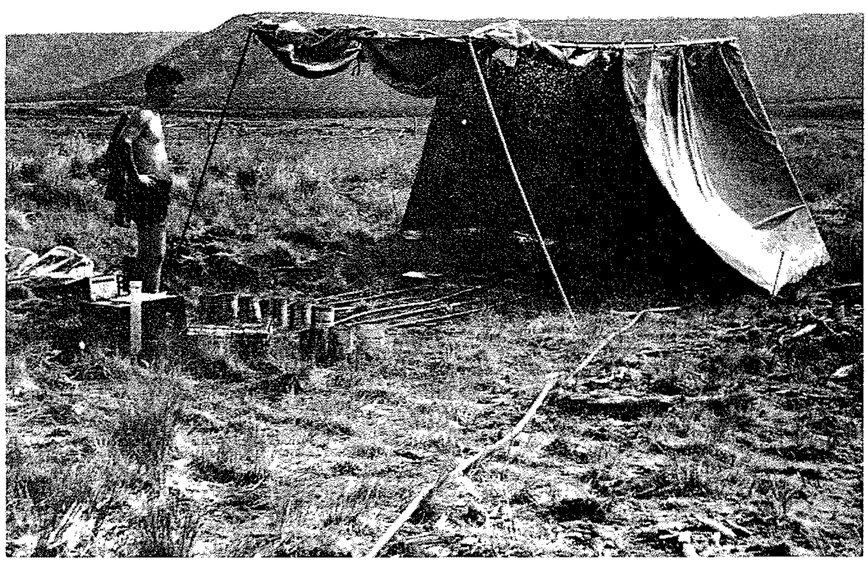


Figure 4. General view of Rocky Mountain infiltrometer with wind screen. The infiltrometer sprinkles an area approximately 3.5 meters in diameter with three type F nozzles. Three runoff collection plots, each 0.26 m^2, and three rainfall trough gages (positioned around each runoff plot in such a way that each plot has a rainfall trough along each side) are sprinkled during each run. The infiltrometer is positioned to deliver approximately equal amounts of water to each plot. A canvas screen reduces wind effects on raindrop distribution.

approximately June 6 to October 1 of each year to study runoff under natural summertime convectional rainfall (Figure 5). The runoff plots were all located prior to chaining in the fall of 1967 and were installed followed the chaining treatments. There were separate controls for each treatment (chaining with windrowing and chaining with debris-in-place) and five paired runoff plots per treatment, for a total of 20 plots. Plot borders were defined by redwood boards carefully buried in the ground. The collection trench at the bottom of each plot was lined with 30-cm half-round corrugated 16-gage steel. The area immediately below each collection trench was sloped and drained to prohibit flow back into the trench. Each collection trench conveyed runoff water to a 30-centimeter Type HS flume with a Stevens Type F water level recorder. The runoff water then dropped into one end of a 2.1 x 0.6 x 0.3-m aluminum sediment tank with 2.5-cm baffles spaced at about 30-cm intervals on the bottom. When the tank filled, water ran out the opposite end. The tank simply provided a sediment index for each plot, since there was no attempt to collect all the runoff water. Sediment records are probably biased, therefore, toward the fraction of materials which would settle to the bottom of the tank before being carried out.

Soil moisture studies

Soil moisture measurements at the Blanding site were taken with a Troxler depth moisture probe (Model 56A, Model 105A) and scaler (Model 399C). Moisture measurements were taken

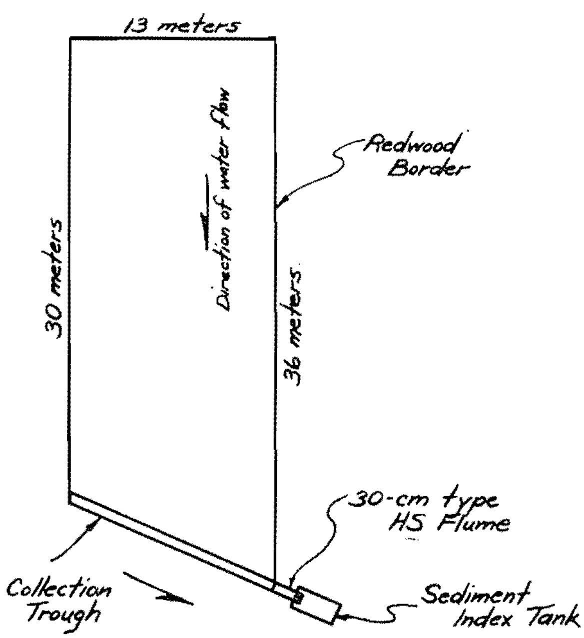


Figure 5. General layout of .04 hectare (0.11-acre) runoff plots.

at 30 cm increments, starting 15 cm below the soil surface to a depth of 150 cm. Compaction of soil around access tubes was minimized by using a small platform for support while taking neutron readings at each tube. From June through September soil moisture was measured approximately once every 2 to 3 weeks. Measurements were less frequent other parts of the year (Figure 6).

Fifteen access tubes were installed in each of the three treatments (natural woodland, chained-with debris-in-place, and chained-with-debris-windrowed).

Access tubes were located throughout each 12- to 16-ha woodland and chain-with-debris-in-place treatment, the final exact location of each tube being determined by the required soil profile depth. On the debris-windrowed treatment, access tubes were generally installed between each set of windrows in the pattern shown in Figure 7. Given two windrows, access tube X1 would be 5 to 7 m from the first (uppermost) windrow, X2 would be one-third to one-half the distance between the two windrows, and X3 would be approximately two-thirds the distance from the first windrow. On the next set of windrows, this pattern would be reversed, etc. Data were analyzed using standard analysis of variance techniques for a completely randomized design.

Parameters analyzed

Sediment. Sediment from infiltrometer plots was measured by collecting total runoff plus sediment from each plot, mixing thoroughly, and finally obtaining a 0.95-liter sample. The water was then evaporated, the sediment oven-dried, and sample weights converted to kilograms/hectare.

Bacterial pollution indicators. Each sample of the runoff water from infiltrometer plots was tested for indicator bacteria (fecal and total coliform) using the multiple tube and elevated temperature tests as outlined in *Standard Methods* (American Public Health Association, 1971) and *A Laboratory Manual for Aquatic Microbiology* (Post, 1971).

Since it was difficult to use distilled water as the artificial rainfall source, local water from Natural Bridges National Monument was used. This water was drawn from one of the two deep wells located at the monument and stored in a large 50,000-gallon metal tank. The artificial rainfall water was transported from the Natural Bridges storage tank to the plots in three 55-gallon drums and a 300 gallon water tank mounted on a trailer. Runoff water samples were collected for analysis after they had passed over the soil surface and into containers at the base of the plot.

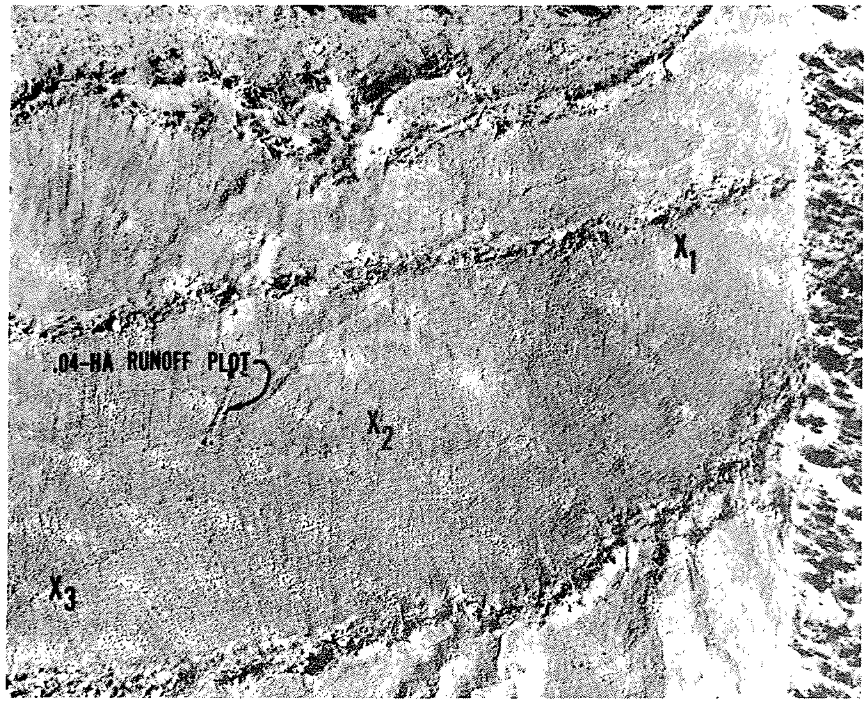


Figure 6. General view of soil moisture instrumentation. Included in this photo is the soil access tube, scaler, neutron probe, platform to stand on, and point frame for reading vegetation density around each access tube.

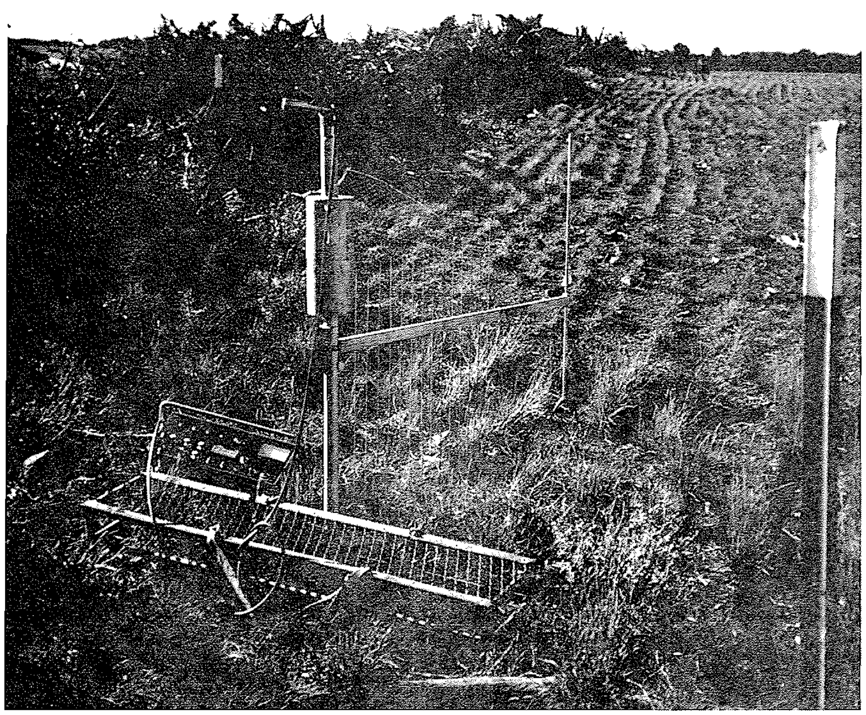


Figure 7. Aerial view of chain-with-windrowing treatment at Blanding study site showing location of soil moisture access tubes (see text) between windrows. Barely visible is one of several .04-hectare run-off plots used to measure runoff from natural storms. Photo scale 1 cm = 21 meters.

Samples of rainfall were collected concurrently by placing a 1000 ml beaker on an elevated stand and catching drops of water as they fell. The rainfall water was then analyzed in the same fashion as the runoff water.

Bacterial analyses were performed using a Most Probable Number (MPN) (American Public Health Association, 1971). The principle involved in this technique is that coliform bacteria will produce gas from the fermentation of lactose in a broth medium within a given time at a specific incubation temperature. Presumptive and confirmed tests for coliform were performed routinely at the field laboratory. The presumptive test involved the use of a volume of water sample innoculated into Lange Sulfate Lactose broth (Difco) (LST) medium incubated for 48 hours at 35°C. Positive tubes (those demonstrating gas production at 24 or 48 hours) are presumed to contain coliform bacteria. Confirmation was made by transferring a loopful of medium from the positive LST tubes to test tubes containing Brilliant Green Lactose Bile broth (Difco) (BGB) medium. The BGB tubes were then incubated for 48 hours at 35°C. Positive tubes at 24 or 48 hours are taken as confirmed evidence of the presence of coliform bacteria.

An elevated temperature test for fecal coliform was also conducted. This test involves the subculture of gas positive LST presumptive tubes to EC medium (Difco) with incubation for 24 hours at a temperature of 44.5°C. Presence of gas in the inverted vials within the test tube is indicative of fecal coliform bacteria.

The multiple tube MPN technique is a statistical procedure which has evolved over decades of water quality analysis. It involves the innoculation of replicated, serial dilutions of the presumptive medium. Probability statistics have been worked out based upon the number of bacteria required to initiate growth (or reaction) in a tube with one sample size and not in a tube with a smaller volume of sample (Post, 1971).

The multiple tube technique was chosen over the membrane filter technique due to the heavy sediment load present in the water samples which interfered with filtration or suppressed bacterial growth on the filters. Pre-filtration to remove the sediment was unacceptable since that would also remove any bacteria adhering to the sediment particles (Post, 1973, personal communication). Kitrell and Furfari (1963) noted a similar situation when they observed that bacteria may be effectively removed from water if they are absorbed on soil particles which subsequently settle out of suspension.

Nitrate-nitrogen (field laboratory analysis). Field laboratory analysis of the runoff and rainfall water from infiltrometer plots was conducted on site to determine levels of nitrate-nitrogen by means of a Hach Chemical Company portable laboratory. This process employs a cadmium reduction method and an electronic photometer. It was used to give an estimate of the nitrate-nitrogen levels present. Certified laboratory techniques were impossible due to the extreme distances and elapsed time between sample collection and earliest possible delivery to a certified laboratory.

Calcium, sodium, potassium, and phosphorus (certified laboratory analysis). Further water analysis of the runoff and rainfall water was made by standard laboratory analysis (Utah State University, Soils and Biometeorology Department, Soil and Water Testing Laboratory). The water samples collected in the field were refrigerated and transported on ice between collection and delivery. At the laboratory the waters were examined to determine the concentrations of selected chemical elements. The laboratory analysis involved testing, by means of atomic absorption techniques, for sodium (Na), calcium (Ca), potassium (K), and phosphorus (P).

The values obtained for the rainfall waters were subtracted from the nutrient values determined from the runoff water. Thus a net change due to soil nutrient losses can be detected in the runoff water.

Results and Discussion

Water quality studies

Bacterial pollution indicators. A graphic representation of averages of fecal indicator bacteria is shown in Figure 8. There are no significant differences between treatments, time, or years; and only the year/time interaction of the related interactions showed significance at the .05 level. Figure 9 is a representation of the total coliform values for the first time period. No significance at the .05 level was demonstrated between treatments, time, or years for the total coliform numbers.

Both the total and fecal coliform counts per 100 mls are relatively low in the runoff water produced by a simulated rainstorm from the Rocky Mountain infiltrometer. However, increased variability was noted on the area grazed by cattle (Figures 8 and 9).

The bacteria numbers were fairly low, though they do not necessarily meet the Public Health

Service standard of <1 coliform/100 ml for drinking water (Public Health Service, 1962).

Why is an area subjected to cattle grazing registering such low coliform counts? Do the bacteria die rapidly after being deposited on hot soil surfaces and subjected to intense sunlight?

Apparently coliform bacteria are able to survive intense sunlight and heat for at least one summer. A bacterial longevity experiment was conducted concurrently with the other research to determine if the bacteria would remain viable under local conditions throughout the entire grazing season. A fresh fecal deposit was marked and periodic samples were taken from it to determine bacterial viability. A sample of approximately 16 cc of fecal material was suspended in 100 mls of distilled water for 1 hour. At the end of the hour the supernatant was withdrawn and processed according to the standard method for the multiple tube coliform bacterial test. The results of the experiment are delineated in Table 2. The coliforms within this study are able to persist in numbers in excess of 1100/ml of slurry for at least seven weeks. At approximately nine weeks under ambient conditions, some variation in bacterial die-off was noticed. Fecal coliforms, which are present in lower numbers than total coliforms, began to show a decline in population several weeks earlier than the total coliforms. The atypical pattern expressed during the eleventh week is attributed to natural variation in bacteria numbers within the feces itself as the bacteria numbers begin to decline.

Post (1974, personal communication) has speculated that the bacterial life span under such conditions could be as long as several seasons since the bacteria are able to maintain life for several years if they are desiccated quickly, while at the same time held within a protective media. This may

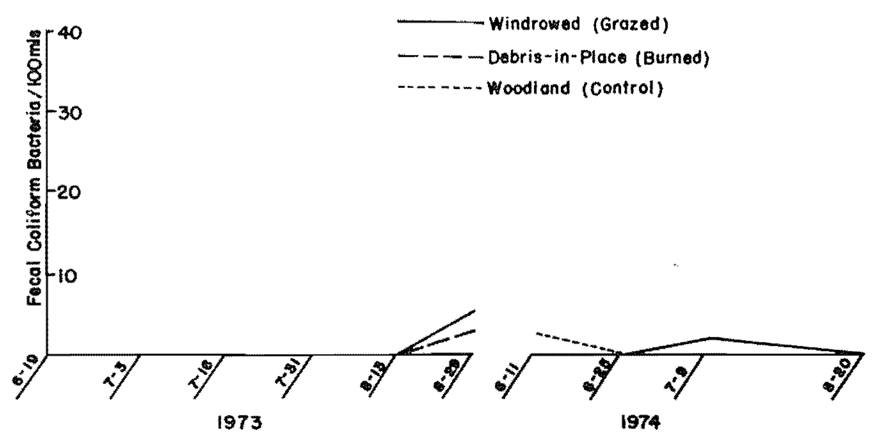


Figure 8. Averages of fecal coliform indicator bacteria under several treatment conditions.

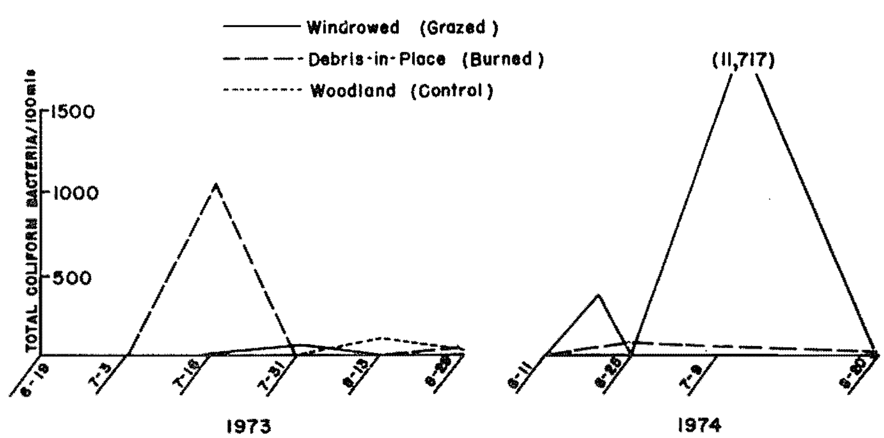


Figure 9. Average of total coliform indicator bacteria under several treatment conditions.

have been the case on the study site, since the cow manure containing the bacteria dries within three or four days under the summer sun and subsequently remains intact for several months or even years.

Apparently then, the low bacterial counts must be associated with a low density of bacterial sources. In this study, 102 plots, each 0.89 m^2 in size, were analyzed for percentage of feces coverage on the debris windrowed watershed. This survey indicated that only 0.2 percent of the area was covered by manure at this level (2 hectares/AUM) of grazing per season. If the manure itself is taken as a point source for pollution, then it is apparent that only a very small percentage of any given watershed area is contributing indicator bacteria.

Figure 10 shows the results of another experiment testing the bacterial relationship from one month-old manure and increasing distances from it. A series of three infiltrometer plots were located so that one plot was centered on the fecal deposit. The next two were centered 0.5 and 1.0 meters away from the feces, respectively. A high intensity simulated storm was created above the plots with the Rocky Mountain infiltrometer. The resultant runoff was collected and analyzed for total and fecal coliform bacteria.

At a distance of one meter from the feces very few fecal coliforms were present (average of approximately 23 organisms/100 mls) and relatively few (average of approximately 4300 organisms/100 mls) total coliforms were observed. Apparently only the feces themselves and an area within perhaps a meter radius of soil surrounding them, are subjected to any degree of fecal bacteria pollution from grazing livestock. Even including the adjacent area associated with pollution sources, only about 4.90 percent of this particular grazed area could be considered as a source area.

Table 2. Longevity study of coliform bacteria existing in bovine feces exposed to ambient weather conditions.

Week	Total coliform/ml *	Fecal coliform/ml *	Date
0	>1100	>1100	6/19/74
1	>1100	>1100	6/26/74
3	>1100	>1100	7/09/74
7	>1100	>1100	8/04/74
9	>1100	290	8/20/74
11	9.3	9.3	9/03/74
18	>1100	53	10/22/74

*Based on 16 cc of bovine fecal material suspended in 100 ml distilled water.

It seems, therefore, that unless the feces are deposited in or adjacent to a streambed there is little danger of significant bacterial contamination resulting from livestock grazing on semiarid watersheds similar to those included in this study. Even those feces deposited in the streambeds and gullies of these dry, ephermeral watersheds may not constitute a problem, since Gifford (1973) has noted that little, if any, water runs off from similar areas during any given year, particularly in debris-in-place chainings. (Gifford's studies have, however, been confined to areas of less than 20 percent slope and fairly deep soils. His findings do not refer to steep slopes, shallow soils, or slick rock areas. They are applicable, however, since livestock tend to favor the flatter, better vegetated sites, rather than the steeper, rough areas.)

Phosphorus. Runoff waters showed a significant increase of about 0.2 ppm phosphorus (P) following burning in the debris-in-place treatment. While 0.2 ppm seems to be a small amount, this represents about 400 percent increase in measured phosphorus levels. No significant change, however, was noted following the grazing treatments on the debris windrowed site.

Maximum permissible quantities of phosphorus and potassium are not listed by the Public Health Service (1962). Apparently there is no particular human health hazard directly associated with these two elements. However, they are both essential elements for plant growth and are frequently included as an integral part of commercial fertilizers. Herein lies the problem.

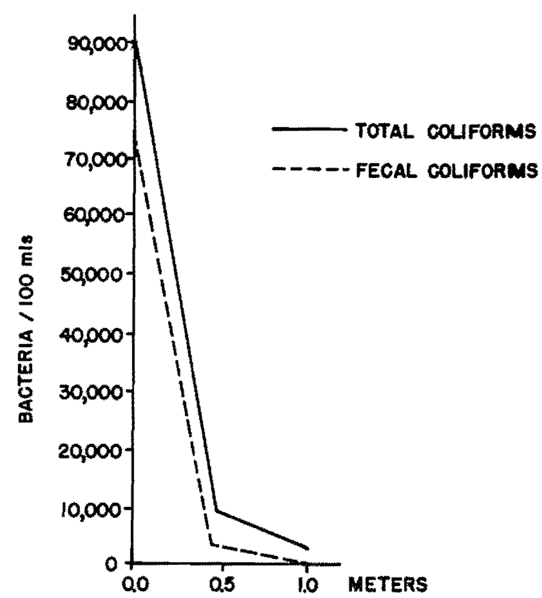


Figure 10. Spatial relationship between coliform bacteria and distance from month-old bovine feces.

Fertilizer elements become undesirable in water supplies due to eutrophication. Eutrophication has rendered many reservoirs and streams unproductive (in terms of game fish) and unattractive.

The increase in phosphorus is significant at the .05 level in terms of treatment and year. Apparently this 0.2 ppm increase is due to a "release" of the nutrient by burning. The large (two-three tree) P-J debris piles, particularly, represent a large store of "tied-up" nutrients. Following the burning, the release of nutrient was apparently sufficient to cause a detectable increase of the element at the soil surface where it could be picked up by runoff waters.

Potassium. A pattern of nutrient release similar to phosphorus was noted when analyzing measured potassium (K) values (Figure 11). A 4 ppm increase of potassium was observed following burning within the debris-in-place site. This is significant, as it is approximately a fourfold increase of this element. Again, no significant changes in K content of runoff were detected under the secondary treatment of grazing in the debris windrowed site. The significant increase in potassium in the debris-in-place site was observed to persist throughout the entire 1974 field season (a full year after the burn). Apparently potassium, as well as phosphorus, is released from the biomass as a result of burning.

Sodium. A picture different from that of potassium and phosphorus is presented by the measured sodium (Na) values (Figure 12). In this instance a significant yearly fluctuation was observed, but no differences between treatment, primary or secondary, were demonstrated.

In terms of climatic parameters, 1973 and 1974 were rather different years. Precipitation was particularly different; 1973 was a "wet" year in terms of vegetation production, while 1974 was a "dry" year. Below average amounts of precipitation fell during the winter, spring, and summer. As a consequence vegetation yields as well as many other vegetative/soil interactions were affected. Significant interactions between years can thus be explained.

Calcium. The least definitive picture of the several elements observed was presented by the measured calcium values (Figure 13). As was the case with the measured sodium values, calcium

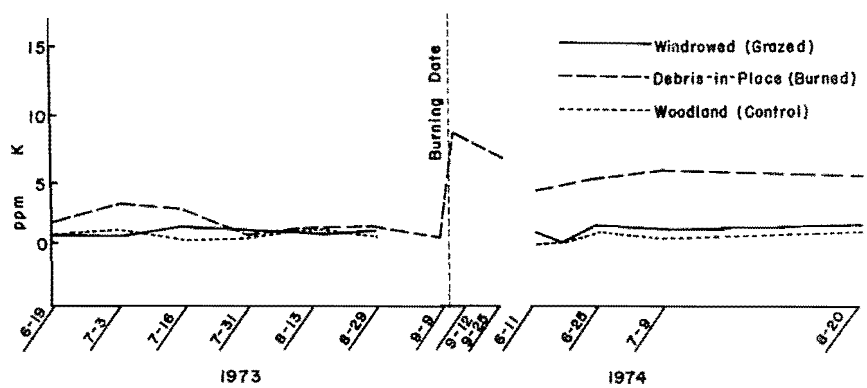


Figure 11. Net changes in ppm potassium. Samples collected from small plot infiltrometer runoff under several treatment conditions.

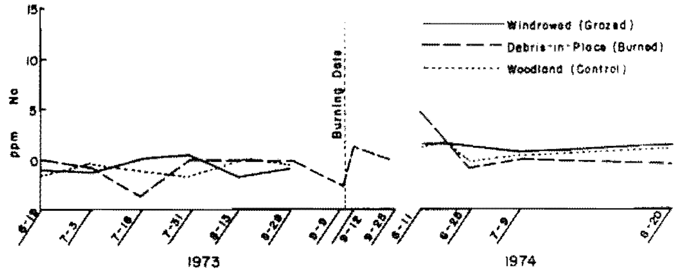


Figure 12. Net changes in ppm sodium. Samples collected from small plot infiltrometer runoff under several treatment conditions.

values showed significance in terms of yearly variations. However, no significant differences were noted between primary or secondary treatments. Extremely high natural variability among sites apparently accounts for the confusing pattern of calcium removed by runoff.

Nitrate-nitrogen. Nitrate-nitrogen presented a difficult sampling challenge. Since the values of nitrate-nitrogen are subject to rapid changes following collection due to aerobic and anaerobic bacterial synthesis, it was impossible to return water samples to the laboratory in Logan for analysis. Therefore, a field technique was employed in order to obtain an estimate of the nitrogen interactions and relationships present on site.

Figure 14 is a graphic representation of the measured nitrate-nitrogen values that were obtained. No significant differences between treatments were detected at the .05 level. It appears, therefore, that the primary chaining treatments and the secondary treatments of grazing or burning produced no significant changes toward the "release" of this element.

Sediment. Figure 15 is a graphic representation of the potential sediment production values which were measured following the first burning attempt in September, 1973, and the first year of grazing during summer, 1974. Potential sediment production varied considerably, but generally was less than 5,000 kg/ha and frequently was less than 2,000 kg/ha. No significant treatment differences were observed. However, immediately following the fire in September, 1973, a large, 19,500 kg/ha increase was noted on the debris-left-in-place area. This increase in potential sediment and ash production apparently declined rapidly, however, by early June, 1974, the debris-in-place site had the potential for contributing about the same amount of sediment as the other sites.

Natural variability among sites seems to be the theme for sediment production within the debris windrowed site also. The area was grazed by cattle during June, 1974. However, no predictable increase in potential sediment production was observed at this particular level of grazing (2 ha/AUM). Apparently, any increase in potential sediment production caused by a single instance of

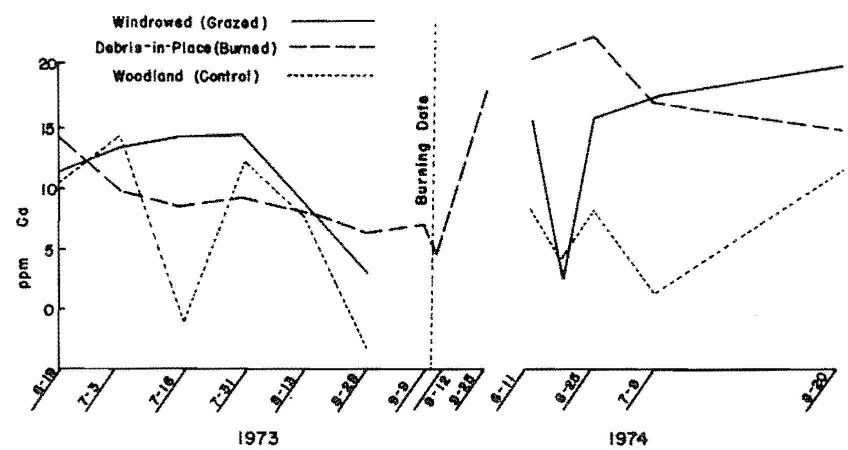


Figure 13. Net changes in ppm calcium. Samples collected from small plot infiltrometer runoff under several treatment conditions.

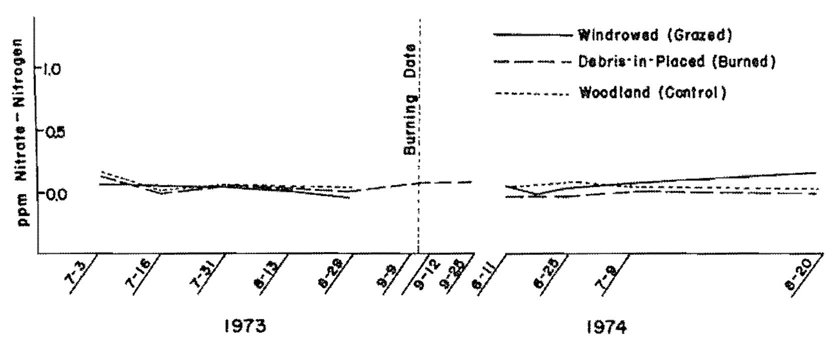


Figure 14. Net changes in ppm nitrate-nitrogen. Samples collected from small plot infiltrometer runoff under several treatment conditions.

grazing use or fire disturbance had been masked by the high natural variability which seems to exist within these locations.

Potential sediment production values were also measured during the summer of 1975. These sediment values represent the first year following the more general burn during September, 1974, and the second year of grazing on the windrowed site. Mean sediment production values for a June and August sampling period are given in Table 3. Despite the wide range of the respective means there are no significant differences (at .05 level) within sampling dates. There is, however, a strong indication that the potential for sediment discharge during a runoff event has definitely increased on those portions of the debris-in-place area where debris piles were burned. Otherwise, few trends can be pinpointed at this time.

Infiltration rates

Several interesting patterns emerged when infiltration rates were examined. Figure 16 is a graphic representation of the average infiltration rates observed prior to secondary treatment (1973) and following the initial grazing treatment in 1974. Average values are given in Table 4. Differences among means were calculated using the Newman-Keuls technique.

During 1973, prior to secondary treatment, no statistical differences were observed among the primary treatment means. Apparently the significantly depressed infiltration rates in the chained with debris windrowed location which were observed following chaining by Gifford et al. (1970) and Gifford and Busby (unpublished data) have been restored to a pre-treatment condition in terms of infiltration rates. Six years of complete protection has been provided on these sites following the initial chaining treatments, therefore,

Table 3. Potential sediment production from various treatments at the Blanding study site during June and August 1975.

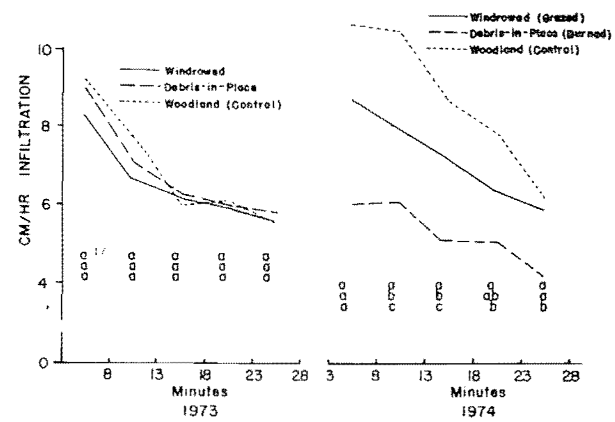
Treatment	Potential Sediment Yield (kg/ha) June 13	Potential Sediment Yield (kg/ha) August 25
1. Burned debris piles[a]	2,858	2,306
2. Burned interspace between debris piles[a]	3,885	361
3. Unburned, debris-in-place[b]	717	385
4. Grazed[c]	779	2,281
5. Ungrazed[d]	952	1,173

[a]Burned in fall, 1974; no grazing since chaining treatments installed in 1967.

[b]No grazing since chaining treatments installed in 1967.

[c]Crested wheatgrass utilized 55 percent during spring of 1974 and 78 percent during spring of 1975.

[d]No grazing since chaining treatments installed in 1967.



1/ Infiltration means not matched by the same letter are statistically different (.05 level).

Figure 16. Mean infiltration rates per treatment for each of several time intervals during a 28-minute simulated rainstorm. Data pooled over several sampling dates within a year.

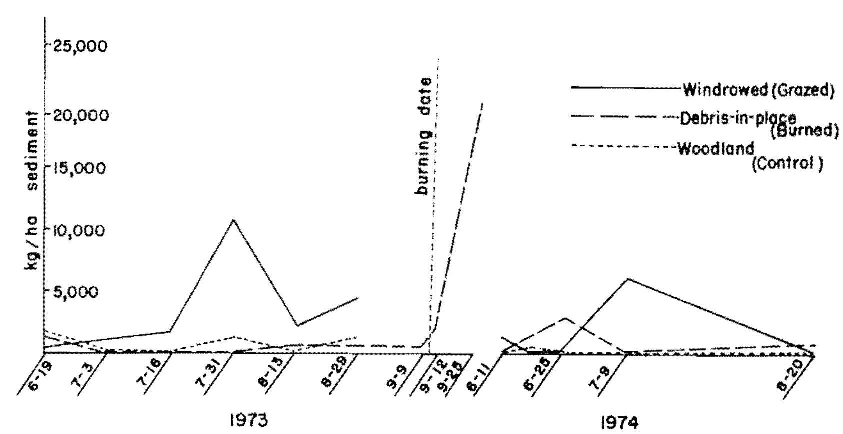


Figure 15. Potential sediment production in kilograms/hectare under several treatment conditions.

it is probably reasonable to expect a restoration of hydrologic conditions at the area.

Secondary treatments were applied during 1974. As previously described, the chained with debris-left-in-place location was burned and the windrowed location was grazed. At certain time intervals within the 28-minute simulation rainstorm, significantly decreased infiltration rates were noted when compared to the control location (several sampling dates within 1974 pooled).

Grazing prompted a decrease in infiltration rates when compared to the woodland (control) location. Apparently the trampling effect of the grazing animals was sufficient to cause statistical differences to appear during certain periods of the high-intensity simulated storm.

The burning treatment resulted in a further depression of the infiltration rates. It seems that a problem with hydrophobic soils may be an important consideration in burning. It has been commonly observed that coarse-textured soils seem to be particularly susceptible to this hydrophobic phenomenon, even under "undisturbed" conditions. Burning seems to increase this susceptibility. This, or course, may be reflected by decreased infiltration rates following fire.

Infiltration measures continued during 1975. As with the sediment production values these infiltration measures represent the first year following the more general burn during September, 1974, and the second year of grazing on the windrowed site. Figures 17 and 18 show infiltration rates as measured on five treatments during June and August of 1975. Most striking is the general overall downward shift in infiltration rates between the June and August sampling dates. Second, infiltration rates on soils beneath the burned debris-piles were consistently low, regardless of sampling season. Highest infiltration rates were associated with the unburned debris-in-place area. Differences between grazed vs. ungrazed on the windrowed treatment were not significant at the .05 level of probability, though the differences were greater during the August sampling period than during the June sampling period. Mean infiltration rates for each treatment on the two sampling dates are given in Tables 5 and 6.

Though infiltration takes place at the soil-air interface, infiltration rates are often related to soil permeability. However, intrinsic permeabilities as determined on 7.6 cm x 7.6 cm undisturbed soil cores did not show a strong relationship to measured infiltration rates. In fact, soil on which debris piles had been burned had the lowest infiltration rates but the highest intrinsic permeabilities (Figure 19). The importance of knowing exactly what is happening with the upper 2 mm or so of soil profile is therefore emphasized for understanding hydrologic behavior under short-term high-intensity rainfall. Answers derived by integrating over a 7.6 cm depth are not satisfactory.

Soil moisture studies

Figure 20 shows the trends in soil mositure under various treatments as a function of time. Table 7 gives actual values in terms of centimeters of water per 30 centimeters of soil profile. Prior to the initiation of the grazing and burning aspects, the soil moisture patterns followed a trend similar to that previously reported by Gifford and Shaw (1973). They state the following:

> Results. . .indicate the greatest moisture accumulation occurred under the debris-in-place treatment (as compared to woodland controls), . . . regardless of season. . .. The woodland had the least soil moisture throughout most of each year. Most moisture flux took place in the upper 60- to 90-cm of

Table 4. Average infiltration rates (cm/hr) treatment for each of several time intervals during a 20-minute simulated rainstorm. Data pooled over several sampling dates within a year.

	Time interval 3-8 minutes	Statistical code[1]	Time interval 8-13 minutes	Statistical code	Time interval 13-18 minutes	Statistical code	Time interval 18-23 minutes	Statistical code	Time interval 23-28 minutes	Statistical code
Woodland (1973)[2]	9.3	a	7.7	ab	6.1	ab	6.2	a	5.6	a
Debris-in-place (1973)[2]	9.0	a	7.1	ab	6.4	ab	6.1	a	5.9	a
Windrowed (1973)[2]	8.4	a	6.8	ab	6.2	ab	5.6	a	5.7	a
Woodland (1974)[2]	10.6	a	10.4	c	8.7	c	7.8	c	6.3	a
Windrowed (1974)[3]	8.8	a	7.9	a	7.2	a	6.4	ac	5.8	a
Debris-in-place (1974)[4]	6.1	a	6.1	b	5.2	b	5.2	a	4.2	b

[1] Infiltration means not matched to the same letter are statistically different (.05 level).
[2] No grazing since fall of 1967.
[3] Crested wheatgrass utilized 55 percent during this first year of grazing.
[4] No grazing since fall of 1967. Data represents pooled infiltration rates from both burned debris-pile sites and burned interspaces (mostly crested wheatgrass) between piles.

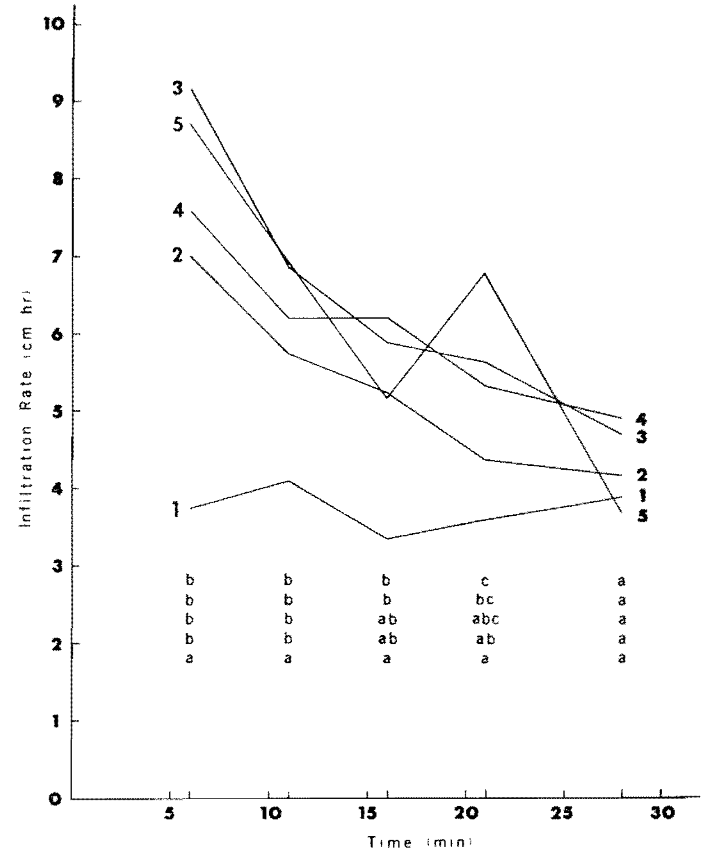


Figure 17. Mean infiltration rates per treatment for each of several time intervals during a 28-minute simulated rainstorm in June 1975. Treatment 1 is soil beneath burned debris-piles; treatment 2 is the burned interspace areas between debris-piles; treatment 3 is unburned debris-in-place; treatment 4 is the grazed windrow area; and treatment 5 is the ungrazed windrow area.

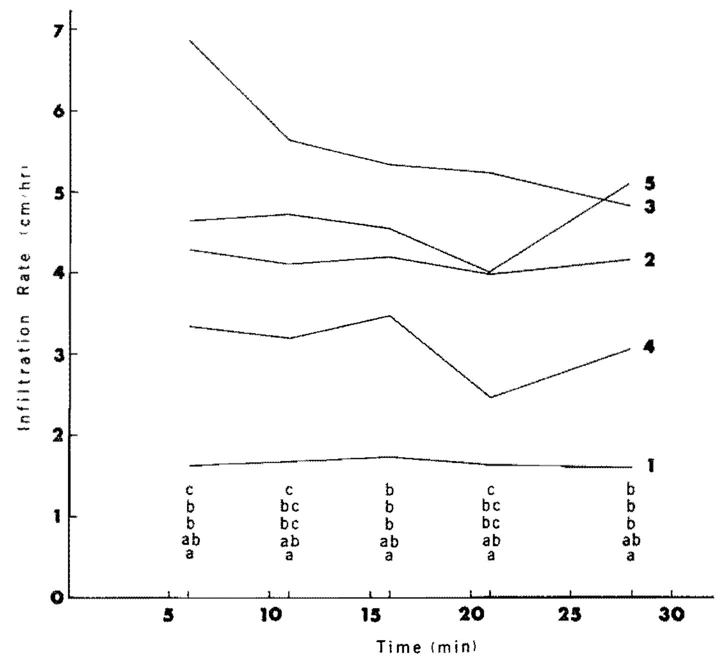


Figure 18. Mean infiltration rates per treatment for each of several time intervals during a 28-minute simulated rainstorm in August 1975. Treatment 1 is soil beneath burned debris-piles; treatment 2 is the burned interspace area between debris-piles; treatment 3 is unburned debris-in-place; treatment 4 is the grazed windrow area; and treatment 5 is the ungrazed windrow area.

Table 5. Average infiltration rates (cm/hr) during specific time intervals for various treatments at the Blanding study site, June 13, 1975.

Treatment	Time Interval (minutes)[5] 3-8	8-13	13-18	18-23	23-28
Burned debris piles[1]	3.75^{a}	4.12^{a}	3.37^{a}	3.62^{a}	3.90^{a}
Burned interspace between debris piles[1]	7.02^{b}	5.75^{b}	5.25^{ab}	4.38^{ab}	4.18^{a}
Unburned, debris-in-place[2]	9.18^{b}	6.87^{b}	5.90^{b}	5.65^{bc}	4.71^{a}
Grazed[3]	7.59^{b}	6.21^{b}	6.22^{b}	5.34^{abc}	4.93^{a}
Ungrazed[4]	8.72^{b}	6.93^{b}	5.18^{ab}	6.80^{c}	3.68^{a}

[1] Burned in fall, 1974; no grazing since chaining treatments installed in 1967.
[2] No grazing since chaining treatments installed in 1967.
[3] Crested wheatgrass utilized 55 percent during spring of 1974 and 78 percent during spring of 1975.
[4] No grazing since chaining treatments installed in 1967.
[5] Any means in the same column with the same subscript are not significantly different at the .05 level of probability (Duncan's Multiple Range Test).

Table 6. Average infiltration rates (cm/hr) during specific time intervals for various treatments at the Blanding study site, August 25, 1975.

Treatment	Time Interval (minutes)[5] 3-8	8-13	13-18	18-23	23-28
Burned debris piles[1]	1.62^{a}	1.67^{a}	1.73^{a}	1.63^{a}	1.60^{a}
Burned interspace between debris piles[1]	4.28^{b}	4.10^{bc}	4.18^{b}	3.97^{bc}	4.15^{b}
Unburned, debris-in-place[2]	6.88^{c}	5.63^{c}	5.33^{b}	5.23^{c}	4.82^{b}
Grazed[3]	3.34^{ab}	3.19^{ab}	3.47^{ab}	2.46^{ab}	3.06^{ab}
Ungrazed[4]	4.63^{b}	4.72^{bc}	4.53^{b}	4.00^{bc}	5.08^{b}

[1] Burned in fall, 1974; no grazing since chaining treatments installed in 1967.
[2] No grazing since chaining treatments installed in 1967.
[3] Crested wheatgrass utilized 55 percent during spring of 1974 and 78 percent during spring of 1975.
[4] No grazing since chaining treatments installed in 1967.
[5] Any means in the same column with the same subscript are not significantly different at the .05 level of probability (Ducan's Multiple Range Test).

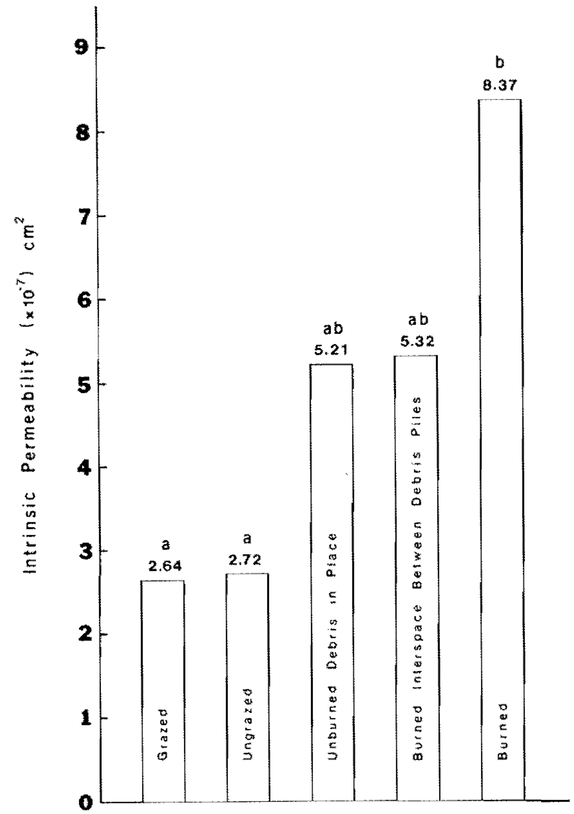


Figure 19. Mean intrinsic permeabilities as determined on 7.6 cm x 7.6 cm undisturbed surface soil cores for various treatments at Blanding. Any bar with the same subscript is not significantly different at the .05 level of probability. Cores were collected in June 1975.

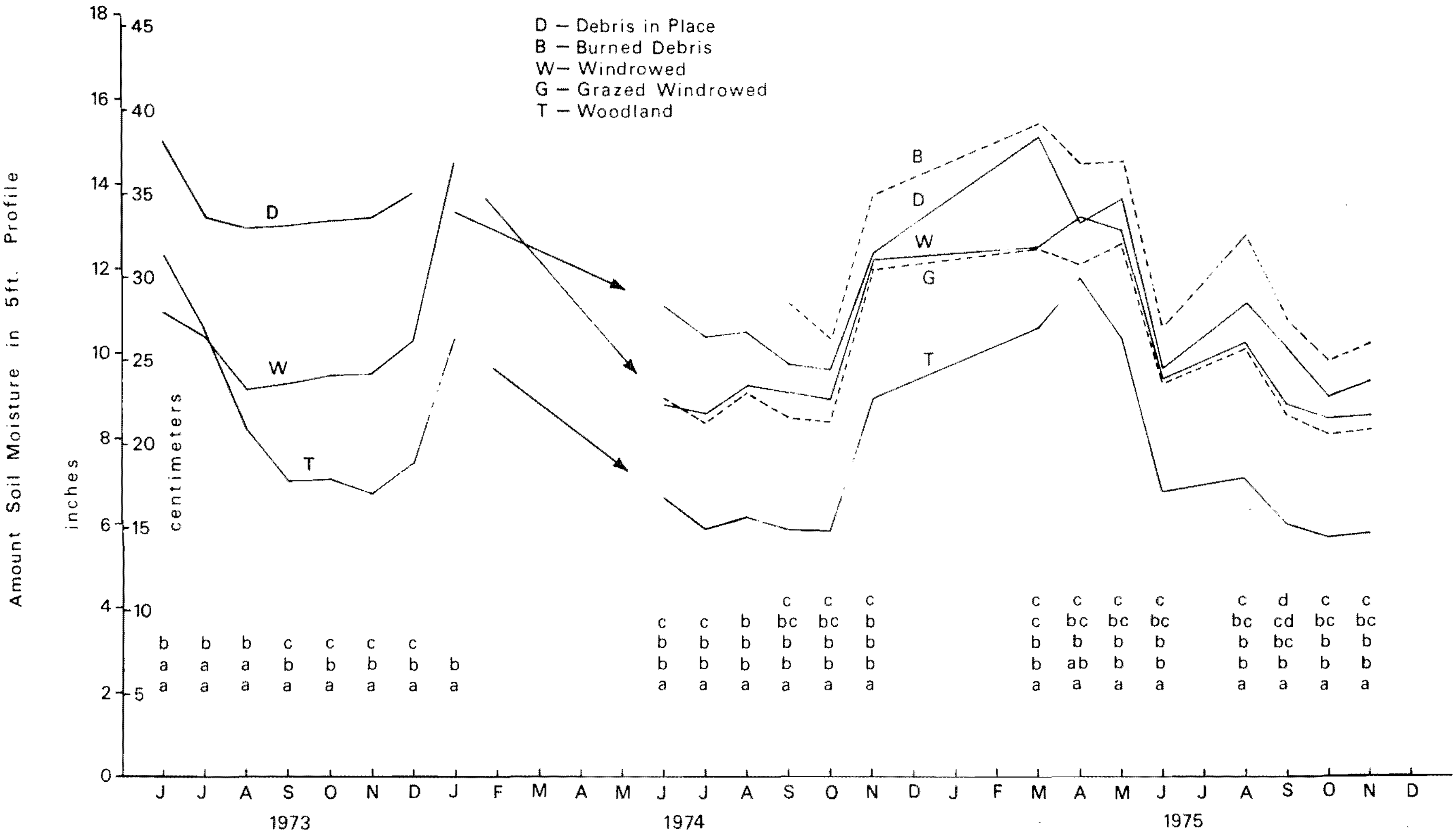


Figure 20. Soil moisture trends under various treatments as a function of time.

soil profile, with only minor changes occurring at greater depths. Differences in soil moisture patterns have been attributed to changes in microclimates due to chaining, different rooting depths and length of growing season, mulching effect of litter on the debris-in-place treatment, and possible differences in snow accumulation.

Trends during the 1974-1975 sampling period are similar to those previously mentioned, though gross differences between the sites with debris-in-place (unburned) and sites windrowed (ungrazed) are less. The burning treatment and grazing treatment influenced soil moisture patterns slightly, though neither curve is significantly different (at .05 level) from either the unburned or ungrazed curve. These trends may change with time, and therefore the studies will be continued.

Runoff studies

Runoff data from the .04-hectare runoff plots were indeed scarce during the study period. Precipitation patterns for the study period are shown in Figure 21, and Table 8 gives average runoff values from the various treatments during 1975, the only year in which summer storms of sufficient magnitude were received to generate any runoff whatsoever.

Previous studies by Gifford (1973) had established that runoff from debris-in-place sites was equal to or less than that measured from the natural woodland for all summer storms measured over a 5-year period. This trend obviously continued for 1973 and 1974, but changed during

Table 7. Average centimeters of water per 30 cm of soil profile on various dates at Blanding study site.[1]

		Chain-Windrow		Chain-Debris-in-Place	
Date	Woodland[2]	Grazed[3]	Ungrazed[4]	Burned[5]	Unburned[4]
6-21-73	6.26[a]		5.57[a]		7.60[b]
7-06-73	5.20[a]		4.99[a]		6.42[b]
7-19-73	5.49[a]		5.55[a]		7.01[b]
8-01-73	4.45[a]		4.67[a]		6.70[b]
8-16-73	3.90[a]		4.66[a]		6.45[b]
9-13-73	3.73[a]		4.91[b]		6.77[c]
9-24-73	3.37[a]		4.55[b]		6.45[c]
10-19-73	3.57[a]		4.82[b]		6.66[c]
11-24-73	3.41[a]		4.83[b]		6.69[c]
12-18-73	3.79[a]		5.23[b]		6.99[c]
1-26-74	5.32[a]		7.38[b]		----
6-16-74	3.24[a]	4.78[bc]	4.54[b]		5.75[c]
6-28-74	3.09[a]	4.33[b]	4.39[b]		5.54[c]
7-11-74	3.02[a]	4.27[b]	4.36[b]		5.35[c]
7-24-74	2.98[a]	----	----		5.44[b]
8-05-74	3.11[a]	4.61[b]	4.71[b]		5.39[b]
8-22-74	3.13[a]	4.63[b]	4.66[b]		5.29[b]
9-18-74	3.03[a]	4.32[b]	4.61[b]	5.69[c]	4.97[bc]
10-20-74	2.96[a]	4.27[b]	4.54[b]	5.51[c]	4.89[bc]
11-30-74	4.53[a]	5.98[b]	6.22[b]	7.23[c]	6.28[b]
3-03-75	5.40[a]	6.34[b]	6.38[b]	7.84[c]	7.66[c]
4-12-75	6.01[a]	6.14[ab]	6.74[bc]	7.36[c]	6.64[b]
5-10-75	5.28[a]	6.41[b]	6.58[b]	7.39[c]	6.93[bc]
6-24-75	3.43[a]	4.72[b]	4.79[b]	5.41[c]	4.91[bc]
8-24-75	3.59[a]	5.13[b]	5.22[b]	6.52[c]	5.72[b]
9-27-75	3.06[a]	4.37[b]	4.49[bc]	5.50[d]	5.15[cd]
10-11-75	2.89[a]	4.14[b]	4.32[b]	5.01[c]	4.58[bc]
11-22-75	2.95[a]	4.20[b]	4.35[b]	5.23[c]	4.77[bc]

[1] All values in same row with some superscript are not significantly different at .05 level of probability

[2] No grazing since 1967.

[3] Crested wheatgrass utilized 55 percent during spring of 1974 and 78 percent during spring of 1975.

[4] No grazing since treatments installed in 1967.

[5] Burned in fall, 1974; no grazing since chaining treatments installed in 1967.

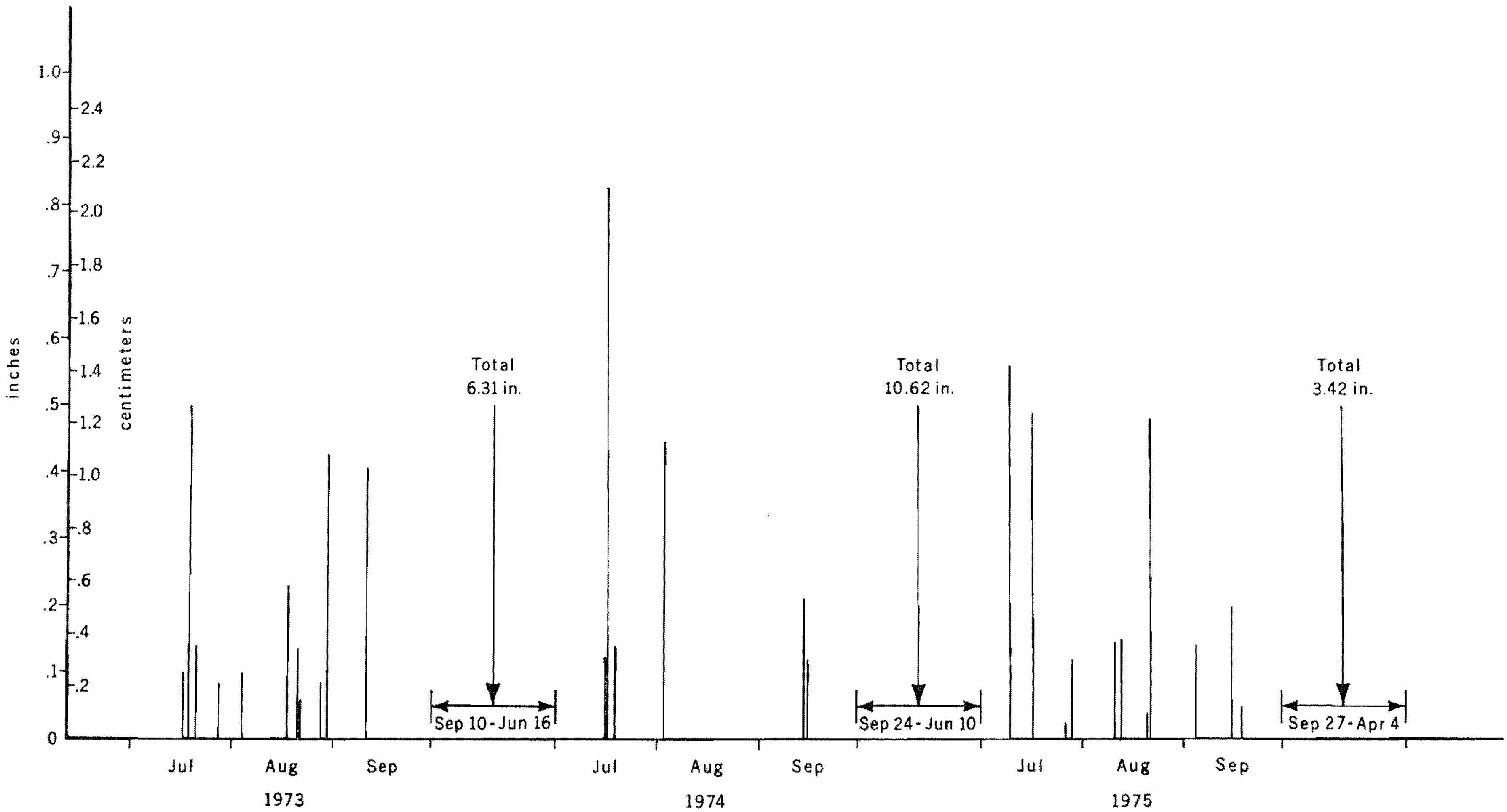


Figure 21. Precipitation patterns at the Blanding site during the study period.

1975, the first summer following the debris burning. Since ground cover was relatively sparse the first year following burning (<20 percent), the abrupt change in cover due to burning probably accounts in part for the unexpected runoff during the storms of 7-16-75 and 7-29-75. Possible soil wettability problems associated with soils originally beneath debris piles (as defined by the infiltrometer studies) may also account for part of the change. Based on these results it might be concluded that a large storm, if it had occurred, might have caused serious on-site damages in terms of erosion and loss of soil nutrients. These studies will continue in hopes of defining some of the long-term impacts of burning. No runoff was measured during either 1974 or 1975 from the windrow area which was grazed.

Summary and Conclusions

Obviously it is difficult to make sweeping conclusions based on data from a short segment of a much longer-term study. However, some of the results do warrant additional attention at this time.

Bacterial analysis

Results of the study indicate, first of all, that it is indeed possible to record levels of bacteria (which would seemingly have the potential to wash from upland watershed areas into streams) through use of the Rocky Mountain infiltrometer. Secondly, it appears the potential public health hazard of livestock grazing on semiarid open range on gentle slopes is minimal. While the bacteria present in the livestock fecal material remains viable for at least one grazing season, they are apparently confined primarily within the fecal material itself. Therefore, only the feces and the area immediately adjacent to it, which may be contaminated by raindrop splash from the feces, seem to be sources for bacterial pollutants. The actual watershed area which is occupied by fecal material may only be in the order of 0.2 percent during the year's grazing season, based upon a grazing use rates of 2 hectares/AUM, though approximately 4.9 percent of the area may be within a one meter radius of the feces.

Table 8. Average runoff values (area centimeters) and sediment index records (kilograms) from paired runoff plots at Blanding study site. Each value is an average of five runoff plots.

Date	Total Rain-fall	Chain-with windrow		Chain-with debris-in-place	
		Woodland[1] Control	Treated[2]	Woodland[1] Control	Treated[3]
1973	----	No runoff	No runoff	No runoff	No runoff
1974			No runoff	No runoff	No runoff
7-16-75	1.47	No runoff	Trace	No runoff	0.37
7-29-75	1.52	No runoff	Trace	No runoff	0.41
	Sediment Index Records				
7-16-75	1.47	0	0	0	4.5
7-29-75	1.52	0	0	0	2.7

[1]No grazing since 1967.

[2]No grazing during period 1967-1973. Crested wheatgrass utilized 55 percent during spring of 1974 and 78 percent during spring of 1975.

[3]Burned in fall, 1974; no grazing since chaining treatments installed in 1967.

Under dry rangeland conditions, such as experienced in much of the southwest, permanent flowing streams are rare. More frequently, the area is perennially dry, with an occasional flash flood providing a short lived, ephemeral water flow. Cattle are maintained in these locations by hauling water to established watering troughs or by developing water catchment ponds at local springs. Therefore, there is little or no effective stream bank area from which the bacteria can be flushed into a water course. Moreover, on most chainings and in particular on debris-on-place chainings, it is doubtful that runoff water ever flows any distance overland. Due to high water retention and detention storage potentials, very little rainfall coming into these debris-in-place areas ever runs off. Apparently, therefore, few bacteria would ever leave the site, even if they were dislodged and therefore available for water transport.

It is difficult to extrapolate from the results observed under small plot measurements to an entire watershed. The reactions of the whole, integrated system may well be different from those observed as components of this system. Nevertheless, with these risks and hazards in mind, one must at least attempt to draw some practical conclusions. In terms of livestock grazing, no apparent negative public health hazards were demonstrated through observation of the small runoff plots established on an area grazed at the rate of 2 hectares/AUM. While additional factors may cause significant alteration of this pattern on the watershed as a whole, there is no evidence based on this study to indicate any significant public health problems presented by cattle grazing on open range similar, at least, to the sites and grazing rates included in these observations.

Nutrient release

Season long, significantly increased amounts of phosphorus and potassium were measured in overland flow following burning on chained with debris-left-in-place sites. No significant (0.5 level) changes were detected in calcium, sodium or nitrate-nitrogen contents in the runoff due to differences in land treatment.

It seems, therefore, that burning of debris may have varying effects on chained pinyon-juniper areas. Burning may result in several positive attributes. First, some stored nutrients locked into the debris piles may be released for uptake by forbs and grasses which have been seeded onto the area (not actually measured in this study). Second, debris-in-place chainings may be "cleaned up," presenting a more aesthetically pleasing view following burning. Randomly scattered skeletons of chained pinyon-juniper trees present a dismal vista in many people's opinions. Burning destroys these "snags" and presents the visitor with a more park-like appearance. Third, access on these sites is vastly improved. Debris are cleared and livestock, as well as humans, are able to penetrate the areas much easier.

However, some hazards may also be present: (1) Erosion and runoff on the burned sites may be more severe than on unburned sites for the first few years until seeded vegetation becomes well established. This is probably particularly important on steep slopes (Wright et al., 1973). (2) The ability of the soil to accept water (soil wettability) may be adversely affected. (3) Short term, negative effects on site aesthetics may be prevalent. Smoke and particulate matter present in the air may be increased during and immediately following the burn. The blackened landscape, and partially burned areas, may present an eyesore for several years.

Sediment production and infiltration rates

No significant changes were recorded in terms of potential sediment production during the study (as measured with the Rocky Mountain infiltrometer). High natural variability exists among these locations, and any changes in potential sediment production due to grazing or burning was masked by this natural variability. Second-year trends would seem to indicate an increase in potential sediment production following both burning and grazing. Limited data from .04-hectare runoff plots would tend to support this apparent trend, especially with respect to burning.

Earlier studies at the Blanding site indicated that mechanical disturbance following chaining could have a significant impact on infiltration rates. During 1973 (prior to either grazing or burning), however, no statistical differences among treatments were noted for any of the initial land treatments. The area had been afforded complete protection during the six years since original treatments had been implemented, therefore, it is reasonable to expect that infiltration differences due to treatment might be minimized.

The grazing treatment was in effect on the windrowed area during 1974 and 1975. Statistical differences in infiltration rates between grazed and ungrazed treatment were apparent during 1974 but not during 1975, though infiltration rates were consistently lower on grazed plots during both years. The impact of the grazing animal was apparently sufficient to depress the infiltration process. A further decline in infiltration rates was observed on the burned watershed, and especially on soils which were beneath debris piles. Soil wettability is frequently a problem on coarse textured soils. Apparently burning increased the problem by contributing to this hydrophobic soil phenomenon. This, of course, may contribute to lower infiltration rates.

Mass loading rates were calculated in order to express this data in a form that could be applied to watershed impact analyses (Table 9). The mass loading rates were calculated based on data from the small .23 square meter runoff plots. There is some risk involved in extrapolating from small sample plots to the watershed as a whole, for the factors affecting the entire integrated system may be different from that of the components. The mass loading rates further assume a 7-10 cm/hr rainstorm which is probably a rainfall event in excess of a hundred year return period. The final assumption made in calculating these rates is that this rainstorm does produce a runoff event, and that the water leaves the site rather than being merely redistributed within it.

Soil moisture patterns

Soil moisture patterns were not significantly altered during the course of this study as a result of either the grazing or burning treatment. The woodland had the least soil moisture throughout most of each year and, as before, most moisture flux took place in the upper 60- to 90-cm of soil profile, regardless of treatment. Where greater soil moisture accumulations on the debris-in-place area have been attributed in the past to changes in microclimates due to chaining, mulching effect of litter, and also possible differences in snow accumulation, it will be of interest to follow the trends over a greater period of time now that burning has eliminated most of the mulch and has, in effect, greatly reduced the total cover on this treatment. As for the grazed vs. ungrazed sites within the windrow treatment, it may be that grazing under conditions of relatively low plant cover has little impact on soil moisture changes.

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Table 9. Potential mass loading rates for several water quality parameters based upon a 7-10 cm/hr rainstorm (<100 year event) and assuming a runoff event occurred.

	Total Coliform[1]	Fecal Coliform[1]	Phosphorus[2]	Potassium[2]	Sodium[2]	Calcium[2]	Nitrate-Nitrogen[2]	Sediment[3]
Chained debris windrowed (ungrazed)	$3x10^5$	$1x10^4$	$7x10^{-5}$	$1x10^{-3}$	0	$1.1x10^{-2}$	$1x10^{-5}$	2.13
Chained debris windrowed (grazed)	$2.9x10^7$	$5x10^3$	$1x10^{-5}$	$8x10^4$	$7x10^{-4}$	$1.1x10^{-2}$	$1x10^{-5}$	2.11
Chained debris-left-in-place (unburned)	$2.08x10^6$	$5x10^3$	$7x10^{-5}$	$1.7x10^{-3}$	0	$9.2x10^{-3}$	$2x10^{-5}$	.80
Chained debris-left-in place (burned)	$6x10^5$	$1x10^3$	$1.3x10^{-4}$*	$3.3x10^{-3}$*	$5x10^{-4}$	$1.2x10^{-2}$	0	.60
Undisturbed natural woodland	$2.9x10^5$	$3x10^3$	$4x10^{-5}$	$6x10^{-4}$	$2x10^{-4}$	$5.4x10^{-3}$	$3x10^{-5}$	.94

[1]Bacteria per cubic meter of runoff.

[2]Element expressed as kilograms of element per cubic meter of runoff.

[3]Sediment expressed as kilograms of sediment per cubic meter of runoff.

*Significantly different from other treatments as .05 level.